CPV Valley Energy Center
50 Braintree Hill Office Park
Suite 300
Braintree, MA 02184

March 13, 2023

VIA US AND ELECTRONIC MAIL

Mr. Daniel Whitehead
Division Director
Department of Environmental Conservation
Division of Environmental Permits
625 Broadway, 4th Floor
Albany, NY 12233-1750
(daniel.whitehead@dec.ny.gov)

RE: CPV Valley, LLC – CPV Valley Energy Center Title V and Title IV Permit Applications DEC ID 3-3356-00136/000010 & 00009— Supplemental Response to August 24, 2022 Second Request for Additional Information ("Second RFI")

Dear Director Whitehead,

Thank you for coordinating the February 24, 2023 telephone conference between Department Staff and CPV Valley, LLC ("Valley"). This letter serves to supplement Valley's January 9, 2023 response to the Second RFI.

In Valley's January 6, 2023 submission, Valley provided an analysis under DAR-21 § V (E) of immediately employable mitigation, as well as longer-term options to achieve economy-wide greenhouse gas ("GHG") reductions consistent with the CLCPA. This supplement focuses on alternative or additional mitigation measures that prioritize reductions of GHG emissions and co-pollutants within Census Tract 36071011801 where the facility is located which has been identified as a potential disadvantaged community ("DAC") under subdivision 5 of section 75-0101 of the environmental conservation law.[1]

A. Immediately Employable GHG and Co-Pollutant Mitigation Measures Prioritizing DACs

In furtherance of prioritizing mitigation that benefits the potential DAC where the Facility is located, Valley has considered the following: (1) school bus / municipal fleet electrification (transit buses, garbage trucks); and (2) tree plantings at the Facility site.

Transportation sector emissions are usually concentrated at the ground level, often in densely populated areas, resulting in a tendency toward higher levels of exposure for more people

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[1] CJWG Draft List of Disadvantaged Communities, *available at:* https://climate.ny.gov/-/media/project/climate/files/Draft-List-of-Disadvantaged-Communities.pdf (last accessed January 6, 2023).

than emissions associated with other energy use sectors. Some of the co-pollutants emitted are associated with an increased risk of respiratory and cardiovascular effects, among others.

The New York State Climate Action Council's Draft Scoping Plan has identified climate policy opportunities for GHG emission reductions and health co-benefits associated with transportation sector vehicle electrification. In addition to GHG and co-pollutant reductions, vehicle electrification can also contribute to reduced traffic noise, especially at slower and medium speeds where tire and wind noises are low. Particularly in areas with high volumes of traffic, noise reduction is an important health co-benefit for the deployment of electric vehicles.

In accordance with DAR-21 § V (E), Valley undertook a good-faith accounting of potential vehicle electrification options to identify quantifiable benefits and any technical or economic barriers to implementation.

1. Fleet Electrification - Feasibility and Implementation

Diesel-fueled school buses produce harmful GHG co-pollutants that have the potential to harm both passersby and expose school children to diesel exhaust which often leaks into the cabin of buses posing a larger health threat than outdoor idling emissions. School bus electrification would reduce or eliminate these harmful pollutants and protect the health of school children and others exposed to this type of air pollution.

Similarly, electrification of heavy-duty municipal construction / utility vehicles and transit buses that are typically diesel-powered, will protect the health and reduce emissions (and noise) in rural and urban areas where they are often near residents and pedestrians.

As per the US EPA's Diesel Emissions Quantifier[2] ("DEQ"), replacement of one diesel-fueled school bus with an average cost of $350,000[3] would result in an 0.022-ton reduction in NOx and 15.3-ton reduction in CO2 emissions on an annual basis. A DEQ Report for School Bus Electrification and vehicle specifications is attached hereto as **Attachment 2**.

With an average cost of approximately $950,000, replacement of one diesel-fueled transit bus would result in an annual reduction of 0.123 tons of NOx and 69 tons of CO2 emissions. A DEQ Report Bus for Transit Bus Electrification and vehicle specifications is attached hereto as **Attachment 3**.

The cost of an electric garbage truck ranges from approximately $300,000 to $500,000 and replacing a similar diesel counterpart would result in an 0.074 ton reduction in NOx and 44.9 ton

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[2] *See* US EPA DEQ, *available at* https://cfpub.epa.gov/quantifier/index.cfm?action=main.home.

[3] *See* ROCKEFELLER INSTITUTE OF GOVERNMENT, *Meeting New York's Electric School Bus Mandate: Takeaways from the 2022 School Finance Symposium* (Nov. 22, 2022) *available at* https://rockinst.org (*last accessed* March 6, 2023); EMPIRE CENTER, *Charging Forward* (Nov. 4, 2022) attached hereto as **Attachment 1**.

reduction in CO2 emissions on an annual basis. A DEQ Report for Garbage Truck Electrification and vehicle specifications is attached hereto as **Attachment 4**.

Technical and economic barriers to implementing the above electrification measures are fully discussed in **Attachment 1** but generally include additional funding and resources to install charging stations, overhaul electrical infrastructure, increased maintenance costs, and reconfigure transportation routes to support new electric fleets. These costs, however, may be offset by state and federal clean energy vehicle funding programs that are available to municipalities, and when accounting for the social cost of carbon.

Valley offers to accept permit condition(s) that require one or more of the above electrification measures which prioritizes reductions of GHG emissions and co-pollutants within Census Tract 36071011801 or surrounding DACs. The exact financial commitment would, however, depend on several factors including: (1) the Department's determination as to whether Valley's Title V application is inconsistent with or interferes with the attainment of the Statewide GHG emission limits; (2) the Department's consideration of the currently implemented mitigation measures[4] at the Facility which exceed regulatory requirements; and (3) the level of Valley's commitment to use more costly certified gas[5] as a fuel input which would result in quantifiable reductions of upstream and economy-wide GHG emissions but may not have the same local impacts as the measures discussed above.

Once Valley's application is complete and the public has had the opportunity to provide input, Valley is committed to coordinating with its local municipal partners, interested stakeholders, and Department Staff to identify a reasonable and appropriate level of financial support in furtherance of GHG reductions within the surrounding DACs. In terms of implementation, Valley is open to working with local economic development organizations like the Orange County Partnership and Center for Economic Development, local municipalities and elected leaders to fund and recruit additional business partners to establish a regional decarbonization fund. The fund will provide financial assistance focused on the electrification of public transportation, electric vehicle charging infrastructure, buildings, local decarbonization efforts, and green spaces that would benefit the surrounding DACs. Valley anticipates that the specific details regarding the amount of financial support, recipients, and the types of programs to be funded will be negotiated with the relevant stakeholders and after public input.

2. Tree Plantings and Additional Vegetative Landscaping

Tree planting can have a number of positive climate impacts, including carbon sequestration, biodiversity conservation, soil conservation, water conservation, and an important tool to mitigate noise and visual impacts.[6] According to sources cited by the US. Department of

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[4] *See* Valley's January 9, 2023 Response to NYDEC's 2d RFI.

[5] *Id.*

[6] *See* NYS Department of Environmental Conservation, *New York State Forest Action Plan*, (December 2020) *available at* https://www.dec.ny.gov/docs/lands_forests_pdf/nysfap.pdf.

Agriculture, a single tree can sequester an average 48 pounds (22 kg) of carbon dioxide per year.[7] Moreover, on average, an acre of forest can sequester around 2.5 to 10 tons of carbon per year, according to the US Forest Service.[8] This estimate assumes a mature forest with trees that have an average DBH of 16 inches (40.6 cm) and a density of 135 trees per acre. If the forest is managed for conservation and carbon sequestration, the carbon sequestration value may be higher because the trees are allowed to grow to their full potential and store more carbon over time.

Valley's 122-acre Facility site contains approximately 14 acres of vacant land adjacent to U.S. Route 6 that is unaffected by state or federal wetlands restrictions (**Attachment 7**). If managed properly, this land could have a carbon sequestration potential of 35-140 or more tons of carbon per year. When compared to the vehicle electrification metrics discussed above, 14 acres of properly managed forest land is equivalent to replacing nine school buses with electric vehicle counterparts in terms of net carbon reduction.

Valley offers to accept permit condition(s) that require plantings along the perimeter of its property along Route 6 for additional visual / noise mitigation, or use some or all of the available 14 acres to be reforested in accordance with a forest management plan provided that Valley is able to use that property in the future for other GHG reduction projects as described in Valley's January 9, 2023 submission. Valley anticipates that the specific details regarding green-scaping and plantings will be negotiated with the relevant stakeholders after public comment is received.

B. SEQRA Environmental Assessment Form

Due to changes in SEQRA regulations, Valley submits a new long form environmental assessment form ("EAF") Part 1 for its applications under Title IV and Title V (**Attachment 8**). Where appropriate, citations to relevant sections in Valley's draft environmental impact statement ("DEIS") are referenced in the EAF.

Very truly yours,

Donald G. Atwood
Asset Manager Representative

cc. M. Sanza, Esq. (mark.sanza@dec.ny.gov)
J. Afzali, Esq. (JAfzali@HarrisBeach.com)

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[7] USDA, *The Power of One Tree*, *available at* https://www.usda.gov/media/blog/2015/03/17/power-one-tree-very-air-we-breathe (*last accessed* March 6, 2023).

[8] See USDA, *Methods of Calculating Forest Ecosystem and Harvested Carbon with standard Estimates for Forest Types of the United States* (April 2006) *available on* USDA Publications (**Attachment 5**); AGRICULTURAL AND RESOURCE ECONOMICS REVIEW, Estimating the Present Value of Carbon Sequestration in U.S. Forests, 2015–2050, for Evaluating Federal Climate Change Mitigation *Policies* (April 2020) *available on* USDA Publications (**Attachment 6**).

Attachment 1

CHARGING FORWARD

New York's Costly Rush to Electrify School Buses

by Gillian K. Perry

and James E. Hanley

November 2022

EMPIRE CENTER

Charging Forward

New York's Costly Rush to Electrify School Buses

by Gillian K. Perry
and James E. Hanley

A new law requires New York State's school bus fleet be entirely zero-emission by 2035. But the higher price of electric school buses relative to diesel buses, the cost of necessary new infrastructure to support electric buses, and the limited funding available for the transition make it unlikely that the state can achieve full electrification by that deadline.

Replacing all of the state's diesel-fuel school buses with electric buses will cost between $8 and $15.25 billion more than the cost of replacing them with new diesel buses. Of that amount, less than $800 million - less than 10 percent of the transition cost - may be available from a combination of state and federal sources to help school districts and private fleet operators make the transition.

The extra cost of electric buses, their limited range compared to diesel buses, and their more rapid battery depletion in cold weather and hilly terrain will create substantial challenges for local school districts.

Given the state's goal of achieving cleaner school buses, most of the benefits that electric buses would bring can be achieved more cost-effectively by purchasing newer diesel models, retrofitting bus equipment or using alternative fuels.

INTRODUCTION

In her January 2022 State of the State agenda, New York Governor Kathy Hochul established a goal of making all new school bus purchases zero-emission vehicles by 2027, with all school buses being zero emission by 2035.[i] The stated purpose was to "improve air quality for New York State's children while also working toward [the state's] Climate Act goals."[ii] The proposal became a statutory mandate in April when it was enacted as part of the state's 2023 budget.

Hochul announced on January 5th, 2022 that the state would provide aid for installing electric bus infrastructure, including the purchase and lease of buses and their charging equipment. Funding for this transition will come from the American Rescue Plan, the Diesel Emissions Reduction Act, the Infrastructure, Investment and Jobs Act, the Inflation Reduction Act, the Volkswagen Clean Air Act Settlement, and the New York Truck Voucher Incentive Program (NYTVIP).[iii] An additional $500 million would be available from New York's proposed Clean Water, Clean Air, and Green Jobs Environmental Bond Act of 2022, if approved on November 8th. All of these funds are distributed through annual competitive programs, and in certain cases cannot be combined.

With more than 50,000 school buses,[iv] New York has ten percent of the national fleet.[v]

With purchase prices of $150,000 to $275,000 more than diesel buses, plus infrastructure upgrade costs of $10,000 to $30,000 per bus, the upfront cost to electrify New York's entire school bus fleet will be between $8 billion and $15.25 billion more than replacing them all with new diesel buses. At that price even the combined outside funding sources — which add up to less than $800 million — won't go far toward helping New York school districts pay for the switch to zero-emission buses.

A COSTLY TRANSITION

Currently, 95 percent of the nation's school buses run on diesel.[vi] Only 5,000 out of the estimated 500,000 buses are electric, as of November 2021. Electric school buses have upfront costs more than double that of diesel buses. The electric buses cost around $300,000 to $400,000[vii] with similarly sized diesel buses going for around $125,000 to $150,000.[viii]

The price of electric buses is projected to decrease over time as higher demand promotes innovation and more fully developed supply chains.[ix] But this suggests that the first school districts to acquire electric buses will be at an economic disadvantage, as they will purchase the least-advanced models at the highest prices. School districts would be wise to wait until electric bus technology is more advanced.

The anticipated future lower cost of electric school buses also depends on a projected decline in battery costs and the achievement of efficiencies of scale in component markets and manufacturing.[x] But the CEO of electric vehicle automaker Rivian recently noted that, "all the world's [battery] cell production combined represents well under 10 percent of what we will need in ten years . . . meaning 90 to 95 percent of the battery supply chain does not exist."[xi] Given the increased demand for critical materials for batteries for both electric vehicles and electricity storage, the limited mining of battery minerals worldwide, and China's current domination of refining of these critical materials, the future cost of batteries is highly unpredictable.

An advantage of electric buses is that their maintenance costs may be less than or equal to the lifetime cost of diesel buses. Because electric school buses have fewer moving parts than diesel buses, they are expected to need less maintenance over their operating lives.[xii] Electric buses do not require oil and brake fluid changes, engine tune-ups, spark plugs, drive belts, or fuel filter replacements. In addition, systems such as regenerative braking technology enhance energy efficiency and decrease the wear on brakes and tires, further reducing maintenance costs.

Electric buses are in some cases also cheaper to power than diesel buses. The state of Vermont places charging costs at around $0.14 to $0.22 per mile when vehicles are plugged in at non-peak times.[xiii] One study that assumed diesel fuel costs of $0.36 per mile ($2.50 per gallon in these calculations) yielded projected annual fuel cost savings of around $1,700 to $2,600, for a bus traveling 12,000 miles.[xiv] At the current average price of roughly $5 per gallon, those fuel savings would be as much as $5,000 per year. Of course, this calculation will vary based on the changes in both diesel fuel costs and the costs of the source of electricity, which can be highly variable.

Other factors, however, complicate the lifetime cost calculation. Batteries for electric school buses are more expensive to replace than engines and require more frequent replacement. They are expected to lose 30 percent of their range after 10 years and to need replacement every 12 to 15 years.[xv] Diesel bus engines are typically replaced every 12 to 20 years.[xvi] And while diesel engine costs range from $4,500 to $13,500,[xvii] lithium-ion batteries can run as high as $50,000, if replacement costs are not covered under warranty.[xviii]

Terrain and climate also help determine the operating cost of an electric bus.[xix] Inconsistent vehicle range and variability in cold weather create potential additional expenses and decreased performance.[xx] While lithium-ion batteries hold their charge in the cold and are not damaged by freezing temperatures, less energy can be pulled from the battery, decreasing the range up to 30 percent.[xxi] This could be a problem particularly in New York's North Country.

Heating, ventilation and air conditioning on a bus create more load on the battery, causing driving range to drop, as shown in an Alternative Fuels Data Center study.[xxii] The study used a transit bus rather than a school bus, but both are medium-heavy duty, zero-emission vehicles. Studies carried out by other transit agencies in colder climates found heating and cooling consume as much as 50 percent of total battery power usage.[xxiii]

Even using the most generous estimates, the federal and state assistance would pay for only around 5,000 electric buses, or about 10 percent of the state's total school bus fleet.

To power more than 50,000 electric school buses in the state,[xxiv] will require a massive charging and energy storage infrastructure. Existing bus storage facilities will need to be expanded and rehabbed — or new ones will need to be built — to accommodate adequate charging operations. This can be costly and time-consuming, with each electric bus requiring up to $10,000 to $30,000 in additional infrastructure.[xxv]

Infrastructure requirements are substantial and go beyond the bus and charger.[xxvi] It is not only the electrical capacity of the site that matters, but the capacity of the local electric utility. Some municipal utilities may not have the necessary transmission capacity and will need to upgrade. Overall, installing the proper infrastructure can take years.[xxvii]

Electric buses also require four to eight hours to recharge, depending on the bus model and its usage; some fast-charging models may require less than two hours.[xxviii] En route charging — charging somewhere other than at the bus storage facility — is generally more expensive than depot charging.[xxix] Unless school districts are given flat rates for electricity, charging during peak times — or any time between 6 am and 10 pm — incurs extra costs not typically factored into calculations of reduced fuel costs.[xxx] Recharging buses midday - which could be needed to run after-school routes - could add about $3,000 per year in peak demand costs, offsetting much of the annual fuel savings.[xxxi]

Electric grid capacity considerations further complicate the issue of bus charging. Full deployment of electric school buses will greatly hike demand on the grid, with an impact that remains unclear.

Overall, purchasing and operating a single electric school bus for 10 to 12 years costs roughly $506,010[xxxii] — a conservative, low-end, estimate. The lifetime cost of a diesel bus is approximately $324,500,[xxxiii] assuming higher bus price estimates and engine replacement.

The higher costs of electric school buses are projected to be offset by the reduced environmental costs from their use. Unfortunately, there is no standard formula for assessing environmental costs. A Nepalese case study attempted to account for the benefit of reduced environmental damage, by calculating a "lifecycle cost" that considers both the cost paid to purchase and operate buses, and the estimated cost of environmental damage from carbon dioxide (CO2) emissions. It found that the life cycle cost of an electric bus over 10 years was $166,387.25 USD.[xxxiv] The life cycle cost of a diesel bus over a 10-year period was estimated at $159,866.57 USD.[xxxv] That said, when the usage of an electric bus exceeded 10.7 years, then the environmental cost of diesel buses ($6,520.68 USD) made the electric buses cheaper in comparison.[xxxvi]

The calculation for environmental costs in that study focused primarily on the cost of CO2 per ton, which was set at $4 per ton.[xxxvii] Substituting a higher cost of CO2 damage — the U.S. government currently sets it at $51 per ton — yields a greater environmental cost of diesel buses and enhances the comparative value of electric buses. Unfortunately, there is no widespread agreement on how to estimate the social cost of CO2.

Crucially, however, this does not make zero-emission buses any more affordable — or more operationally effective in unfavorable conditions - for school districts. They do not directly capture the value of CO2 emissions reductions, no matter how that value is calculated.

THE CHALLENGE OF MEETING THE STATE'S 2035 DEADLINE

Funding allocated to pay the considerably higher cost of electric buses is a fraction of what is required to make the state's school bus fleet zero emission by 2035. That makes the timeline a daunting challenge for school districts.

Funding Challenges

Of the federal funding set aside for clean school buses in the Infrastructure, Investment and Jobs Act, only $2.5 billion of the full $5 billion is to be used solely for electric school buses.[xxxviii] The other $2.5 billion is split between electric buses and other types of clean school buses, including hydrogen fuel-cell buses or buses that utilize clean fuels in diesel engines. These sums are the totals to be allocated nationally over a 5-year period. For each fiscal year from 2022 to 2026, there is only $500 million for clean and zero emission school buses, and $500 million for solely zero emission school buses. Grants are to be awarded on a competitive basis for clean or zero-emission school buses.[xxxix]

The goal of the federal funding is nationwide deployment, and each state would receive about $10 million in funding annually if divided equally among the states. With electric school buses costing at least an estimated $150,000 more than their diesel counterparts, that would help each state purchase about 67 school buses per year. That would allow New York to purchase around 335 buses before 2027, converting less than one percent of the New York fleet. If the state managed to gain a share of funding equal to its proportion of the U.S. population, it could get as much as $30 million per year - or $150 million over five years - enough to buy perhaps 1,000 buses by 2027 (based solely on the premium over diesel bus costs, because schools will eventually have to replace their buses anyway). This equals two percent of the state's needs.

The Inflation Reduction Act sets aside $1 billion over 10 years[xl] to fund heavy-duty electric vehicle replacement – including other vehicles besides school buses – throughout the country. Eligible recipients of funding include states, municipalities, Native American tribes, and nonprofit school transportation associations.[xli] With a diverse and broad group of recipients eligible to receive the annually distributed $100 million, New York will reap nominal benefits from this source of funding for heavy-duty electric vehicles. If the entire amount went to school buses, it would buy about 667 electric school buses nationwide. If New York got a population-proportionate share, it would get $60 million over the next decade, enough to purchase up to 400 buses.

Other federal funding comes from the Volkswagen Clean Air Act Settlement, which stems from VW's sale of diesel motor vehicles with "defeat devices,"[xlii] (computer software designed to cheat on federal emissions tests).[xliii] The settlement required Volkswagen to fund a $2.7 billion mitigation trust fund, with an additional $225 million added to the fund after a supplementary settlement.[xliv] Out of the $48.3 million in funding set aside for New York, approximately $6 million is dedicated to electric school buses,[xlv] enough to purchase around 40 buses.

Through the Diesel Emissions Reduction Act (DERA) the EPA offers rebates in addition to grants to reduce harmful emissions from older, dirtier diesel vehicles.[xlvi] In addition to electric buses, DERA funds retrofits for buses using alternative fuels such as propane, natural gas, clean diesel, or gasoline. Since the DERA program was started in 2012, there have been 2,000 bus replacements, or about 200 per year, or an average of four per state annually. Assuming that New York received rebates for four electric buses per year until 2035, that would come to approximately $15.6 million.

The EPA also offers separate rebates for electric school bus replacements through the American Rescue Plan of 2021 (ARP). $7 million is set aside for eligible school districts to replace their current fleet with electric school buses, with a $300,000 rebate per bus. This allotment of funding will cover around 23 buses nationwide.[xlvii] As that would cover potentially the full amount of an electric bus, it would free up the school's normal bus funding to purchase other buses, so roughly speaking it might double the number of buses schools can afford. At 46 buses nationwide, this is still less than one bus per state. New York's population proportionate share is $420,000, or less than three buses.

While schools and other bus fleet operators can apply to both the DERA and ARP programs, they cannot combine the funds towards one bus purchase. Each pot of money must be applied to a different bus purchase.[xlviii]

Finally, $500 million is set aside in New York's Clean Water, Clean Air, and Green Jobs Environmental Bond Act of 2022 (EBA) for the costs associated with purchasing and converting to a zero-emission bus fleet.[xlix] That half-billion will become available if the bond referendum is approved by voters on November 8, 2022. A few guidelines in the EBA describe how these funds are to be allocated throughout the state. These include ensuring that 40 percent of the funds in the EBA be used to benefit disadvantaged communities and that such communities receive at least 35 percent of the benefits of the funds. Considering again just the premium over diesel buses, these funds would purchase up to 3,333 electric buses.

Table 1 compiles these estimated numbers and shows how limited the funding is, with the rest falling on fleet operators (school districts and private transit firms, who will necessarily pass the costs on to school districts).

In sum, even using the most generous estimates, the federal and state assistance sources outlined above would pay for only around 5,000 electric buses, or about 10 percent of the state's total school bus fleet. The rest of the cost will fall on school districts, either directly (for those that operate their own bus fleets) or indirectly (for those who contract with private school bus operators).

Issues with the flexibility of funding are a concern. For instance, funding from the New York Truck Voucher Incentive Program (NYTVIP) cannot be combined with funds from the US EPA's Diesel Emissions Reduction Act

School Bus Rebate Program or from the New York State Energy Research and Development Authority (NYSERDA) Clean Green School funding.[l] NYSERDA's Clean Green Schools Initiative is broadly used for projects revolving around clean heating or cooling and capital projects which move toward decarbonization. NYTVIP funding also cannot be used for more than five buses within a given school district, and no more than 20 buses within New York City.[li] No more than two school buses will be funded for a given private school, and no more than 12 school buses will be funded for a single contractor that is upstate-based and under exclusive contract with four school districts. Any electric school bus replacement must be within 0.5 miles of a disadvantaged community.[lii]

Issues Stemming from Current Production Levels

Securing the funds to purchase electric buses is just one step in the process school districts must go through to meet the 2035 mandate. The acquisition process poses further challenges. "Committing" is an umbrella term that summarizes the four key steps in acquiring an electric school bus: awarding of funding; ordering; delivery; and operation.[liii] The World Resource Institute (WRI) notes that school districts and fleet operators across the U.S. have committed to 12,275 school buses, but only five percent of these buses are currently delivered or operational.[liv] According to the WRI, once funds have been awarded, it takes up to another 16 months for an electric school bus to be delivered.

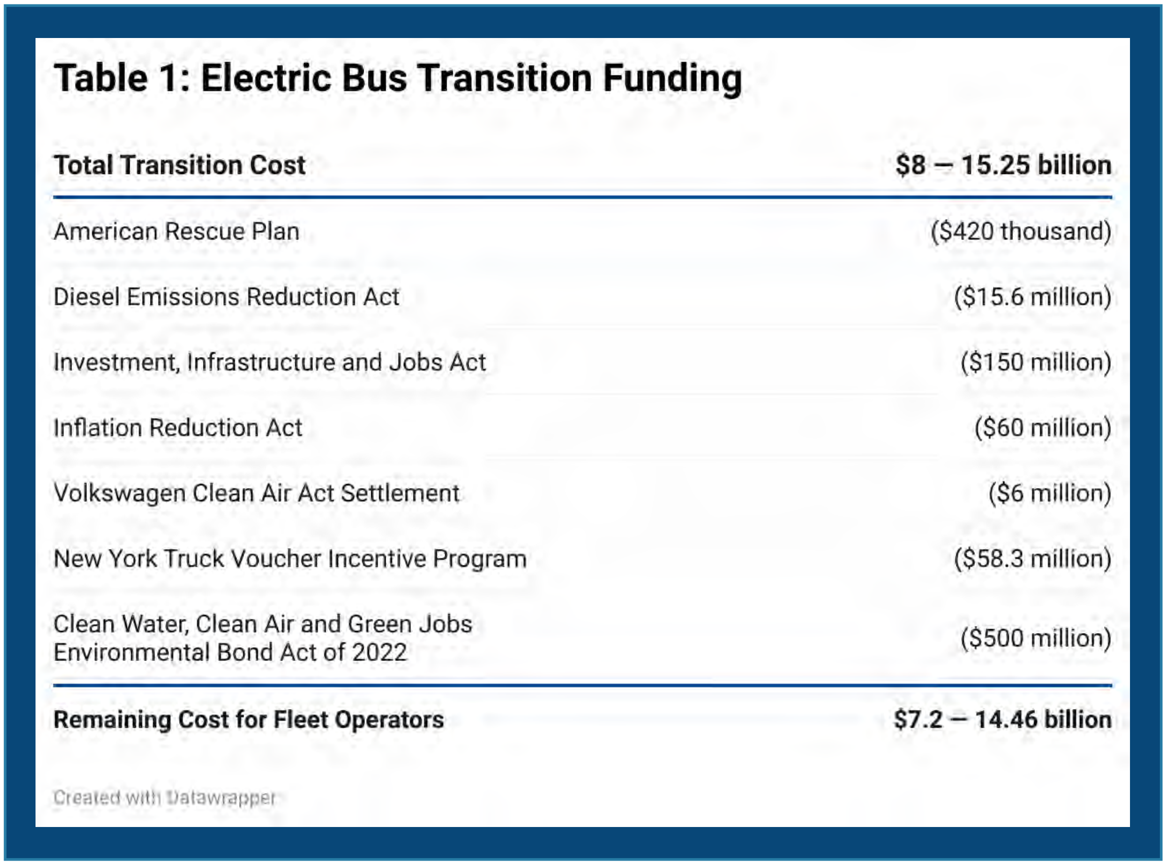

Table 1: Electric Bus Transition Funding

Total Transition Cost	**$8 — 15.25 billion**
American Rescue Plan	($420 thousand)
Diesel Emissions Reduction Act	($15.6 million)
Investment, Infrastructure and Jobs Act	($150 million)
Inflation Reduction Act	($60 million)
Volkswagen Clean Air Act Settlement	($6 million)
New York Truck Voucher Incentive Program	($58.3 million)
Clean Water, Clean Air and Green Jobs Environmental Bond Act of 2022	($500 million)
Remaining Cost for Fleet Operators	**$7.2 — 14.46 billion**

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Production levels will have to increase substantially to meet demand not only from New York but from California — the leader in school bus electrification — and other states that are moving in the same direction. But the supply chain constraints referenced above may limit how rapidly manufacturers can ramp up production.

IMPACT ON SCHOOL ACTIVITIES, EDUCATIONAL EXPERIENCE AND STUDENT HEALTH

Further complications are evident when listening to education leaders and school officials. These individuals warn that the implementation of this plan will be both financially and logistically challenging.[lv] Districts will have to install charging stations, overhaul electrical infrastructure and reconfigure bus routes to support new electric fleets.[lvi] The Association of School Business Officials is lobbying for more funding and more flexibility in the mandate.[lvii]

Because of schools' budget constraints, increasing the amount spent on transportation could also harm academic achievement. Schools may have less to spend on teachers and academic programming.[lviii]

School districts would also have to plan field trips and extracurricular activities around bus range and the availability of charging stations, which is not the case when using diesel buses.[lix] Limited range will be a problem particularly for schools located in rural districts, potentially putting some field trips out of reach, thus limiting students' educational opportunities.

Electric buses are tied to lower levels of asthma and pneumonia, particularly in elementary-aged children as they are exposed to lower levels of nitrogen oxide emissions and particulate matter than from buses using diesel fuel.[lx]

However, the main method of reducing negative health effects stemming from diesel school buses is to replace older models with newer buses that have emission controls and idle reduction technologies.[lxi] The buses that are identified as being most imperative to replace are those built between 1998 and 2010.[lxii] The EPA also recommends the use of cleaner fuels such as biodiesel or compressed natural gas which work to reduce emissions from school buses.[lxiii] Cleaner biodiesel fuel is quickly becoming more readily available.

While electric school buses are cleaner than modern diesel bus retrofits, the cost of retrofitting a bus is much lower than replacing that vehicle with an electric model, and both retrofitting and shifting to cleaner fuels can be done in a shorter timeframe.

Moreover, funding for retrofitting buses already exists through the federal Diesel Emissions Reduction Act (DERA) and through the Congestion Mitigation and Air Quality Improvement Program (CMAQ).[lxiv]

These more cost-effective shifts bring positive changes in student health and academic performance, as shown by a study from the state of Georgia. The installation of emission reduction retrofit devices, reduction of bus idling, and increased use of ultra-low sulfur diesel were used together to produce noticeable benefits. These benefits included significant positive effects on students' aerobic capacity, respiratory health, and English test scores.[lxv]

In Georgia, the total amount spent on engine retrofits was $12.6 million at an average cost of roughly $8,110 per bus.[lxvi] Retrofitting 10 percent of the bus fleet cost the average district around $90,000, while replacing 10 percent of a fleet with new diesel or hybrid buses would cost anywhere from $1.4 million to $4 million.[lxvii]

Assuming all 50,000 New York school buses were retrofitted (although many, of course, will be replaced as they wear out), they could be upgraded for under $500 million — the amount set aside in the Environmental Bond Act — rather than the billions required for electrification.

RECOMMENDATIONS

Allow for newer or retrofitted diesel buses

Newer diesel buses burn more cleanly and produce less particulate matter than older diesel buses. Significant improvements in student health can be achieved at much lower cost through this approach. And as fleet operators find their buses coming to the end of their operational lives, they can be expected, and if necessary required, to buy the cleanest diesel buses available.

Funding in New York State specifically allocated for electric school buses should be used alternatively for retrofitting. There is $6 million dedicated to funding electric school buses in New York State alone through NYTVIP and $500 million available if the Clean Water, Clean Air, and Green Jobs Environmental Bond Act of 2022 passes. When using figures from a study of Georgia's retrofits, there is enough funding for over 60,000 retrofits in the state. That is more than enough funding to retrofit every bus in the state with additional funds left over.

Consider the use of renewable hydrocarbon biofuels[lxviii]

Biofuels are produced from biomass sources through a variety of biological, thermal, and chemical processes. These fuels are chemically identical to petroleum gasoline, diesel or jet fuels. They also meet the same ASTM International fuel quality standards as the petroleum fuels that they replace, meaning that they can be used in existing engines and infrastructure. While production is limited currently to a capacity of over 590 million gallons per year, it is expected to rise soon to 2 billion gallons.[lxix] Commercial facilities are increasingly focused on renewable diesel production, and these production plants may stand alone or be co-located at petroleum refineries. Flexibility to consider other technologies could also allow for hydrogen fuel cells to be implemented into existing compressed natural gas fleets

Push for funding to be diverted to the DERA and CMAQ

Funding set aside for electric bus initiatives will have a minuscule effect on the state's air quality and reduction in fossil fuel emissions. But if the $500 million of funding distributed annually from the $2.5 billion set aside for electric school buses in the Infrastructure, Investment and Jobs Act were to be diverted to DERA ($46 million)[lxx] and Congestion Mitigation and Air Quality Improvement Program (CMAQ) ($11.2 million)[lxxi] the effect of the programs would greatly increase. Combined, these programs have retrofitted only 2,072 buses since 2009.[lxxii] With proper placement of funding, these programs could be highly effective in reducing negative environmental and health impacts of school buses in the United States without imposing unneeded and unfunded mandates on school districts.

Extend the Deadline

If the zero-emission bus mandate is kept in place, the deadline should be extended so that no fleet operator has to replace their current buses before the end of their normal operational life. Because diesel buses last up to 20 years, any recently purchased buses will have to be replaced prematurely, imposing extra costs on fleet operators, including school districts. And the later in time zero-emission buses can be purchased, the more affordable they are likely to be.

CONCLUSION

Electric school buses are substantially more expensive to purchase than diesel school buses. Although they are cheaper to maintain, the upfront costs pose a barrier to school districts trying to comply with the state mandate. Future lower prices for electric school buses depend on uncertain projections of lower battery costs.

Electric buses themselves are problematic as their range is substantially shorter than their fuel-using counterparts, and they experience shorter ranges from heating and cooling the vehicles. Local terrain and weather also negatively impact battery range. The batteries on electric buses deplete over time, and they are considerably more expensive to replace than typical diesel engines.

Charging during peak times of the day may increase the cost of charging and decrease estimated fuel savings if school districts are not awarded flat rates for electricity. Additionally, the capacity of the electric grid to handle the surge in demand from full school bus fleet electrification is unclear.

The substantial delay between the awarding of funding, the ordering of the vehicles, and their actual delivery complicates the goal of achieving a zero-emission school bus fleet by 2035. Funding itself is a major concern as the federal and state aid sources identified to date fall well short of the cost of replacing 50,000 school buses in 13 years. Even the federal and state funding sources that are available carry restrictions that limit their likely utility to school districts.

The estimated net cost of replacing the state's entire school bus fleet with electric battery buses is $8 to $15.25 billion, 16 to 30 times the $500 million cost of retrofitting the current

fleet. Even with generous funding and conservative cost estimates, each electric school bus will cost $150,000 to $275,000 more than a diesel bus, with an additional $10,000 to $30,000 in infrastructure costs per bus.

Ultimately, there are more cost-effective solutions to making New York's school bus fleet more environmentally friendly, such as using biofuels or diverting funding to historically successful and established programs.

Of course, some school districts are choosing on their own to transition to electric buses, and this discussion is no critique of that. Allowing each district to make its own decisions on the relative costs and benefits is the most appropriate public policy model to follow, as local school officials are electorally accountable to their constituents.

But while electric school buses can improve the health of students, the negative health impacts of diesel buses are more cost-effectively mitigated by purchasing newer models or retrofitting older buses with more advanced technology.

Gillian K. Perry is a student fellow at the Empire Center.
James E. Hanley is a fellow at the Empire Center.

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Attachment 2

DEQ Summary and Detailed Reports

Project Name: Electric School Bus Replacement (1 Unit) **Run Date:** 03/06/2023

Total Project Funding: $ 350,000

Summary Emission Results[1] for Project:

Annual Results (short tons)[2]	**NO_x**	**PM2.5**	**HC**	**CO**	**CO_2**	**Fuel**[3]
Baseline for Project	0.022	0.000	0.000	0.011	15.3	1,360
Amount Reduced After Upgrades	0.022	0.000	0.000	0.011	15.3	1,360
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline for Project	0.111	0.001	0.002	0.056	76.5	6,800
Amount Reduced After Upgrades	0.111	0.001	0.002	0.056	76.5	6,800
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$3,166,978	$390,337,262	$156,910,727	$6,202,000	$4,575	
Total Cost Effectiveness[4] (includes all project costs)	$3,166,978	$390,337,262	$156,910,727	$6,202,000	$4,575	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Detailed Emission Results[1] for School Transportation:

Annual Results (short tons)[2]	**NO_x**	**PM2.5**	**HC**	**CO**	**CO_2**	**Fuel**[3]
Baseline of Group	0.022	0.000	0.000	0.011	15.3	1,360
Amount Reduced After Upgrades	0.022	0.000	0.000	0.011	15.3	1,360
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline of Group	0.111	0.001	0.002	0.056	76.5	6,800
Amount Reduced After Upgrades	0.111	0.001	0.002	0.056	76.5	6,800
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$3,166,978	$390,337,262	$156,910,727	$6,202,000	$4,575	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Inputs:

School Transportation:

Type: Onroad
Target Fleet: School Bus
Quantity: 1
Engine Model Year: 2018
Upgrade Year: 2024
Remaining Life: 5

Fuel Type: ULSD (diesel)
Annual Fuel Gallons: 1,360
Diesel-equivalent Gallons: 1,360
Annual Miles Traveled: 14,084
Annual Idling Hours: 107

Vehicle Replacement:

Upgrade: Vehicle Replacement - All-Electric
Upgrade Cost per Unit: $350,000 **Labor Cost per Unit:** $0
Percent Reduction: **NOx:** 100% **PM2.5:** 100% **HC:** 100% **CO:** 100% **CO_2:** 100%

BEAST

BATTERY ELECTRIC AUTOMOTIVE SCHOOL TRANSPORTATION

A Purpose-Built Type D School Bus

PURPOSE BUILT

RANGE
140 MILES

BATTERY SIZE
194 KWH

CHARGING
J1772, 19 KW AC
CCS-1, 85 KW DCFC
WIRELESS, 60 KW

SEATING CAPACITY
Up to 90 passengers
Lift Equipped *optional

GreenPower
MOTOR COMPANY

BEAST

USA 909-308-0960
CANADA 604-563-4144
GREENPOWERMOTOR.COM
SALES@GREENPOWERMOTOR.COM

TECHNICAL DATA

CLASSIFICATION
Heavy-duty class 8, Type D

GVWR
42,990 lbs.

PAYLOAD CAPACITY *
13,790 lbs.

AXLE WEIGHT LOAD RATING
Front: 14,330 lbs., Rear: 24,250 lbs.

LENGTH ③
40 ft.

WHEELBASE ④
240.15 inches

OVERHANG ⑤
104.5 (front), 128 inches (rear)

APPROACH & DEPARTURE ANGLES ⑥
8 (front), 9 degrees (rear)

WIDTH ②
102 inches, widest in the industry

HEIGHT * ①
138.5 inches

TIRES
295 / 80R / 22.5 (qty. 6)

TURNING RADIUS
37.7 +/- 1.6 ft (outside body)

SUSPENSION
Air ride suspension

PASSENGER DOOR
Electric, 36in wide, 34 in opening

EMERGENCY EXITS
Hatch, window, door

ADA
Wheelchair accessibility optional

HVAC
75,000 BTU/h, front, rear, electric

ECU COMMUNICATION
CAN BUS, J1939

CHP CERTIFIED

CARB CERTIFIED

GreenPower
MOTOR COMPANY

BEAST

SEATING CONFIGURATION * ⑦
Front facing bench seating, 15 rows,
2 benches per row, 3 seats per bench

MAX SEATING CAPACITY (w/driver)
Up to 90 Passengers

STORAGE
Full pass-through storage compartment

BATTERY
Voltage: 614 V, Chemistry: LiFePo4

BATTERY CAPACITY
194 kWh, 6 total packs

RANGE *
140 miles

FUEL ECONOMY *
23 mpge, 1.5 kWh/mi, 0.67 mi/kWh

TOP SPEED
68 mph

MOTOR POWER
350 kW max

TRANSMISSION
Direct drive, No transmission

BRAKES
Full ABS disc brakes

FRAME / BODY / ROOF
Steel, Monocoque

DESIGN LIFE
10 years

LCFS EER VALUE * †
HDV, 5.0 EER, 1 credit every 740 kWh

CHARGING * (AC/DC)

LEVEL-2, J1772
19 kW, 220v, 10.5 hrs

DCFC, CCS-1
85 kW, 3 hrs

WIRELESS DC * (optional)
85 kW, 3 hrs

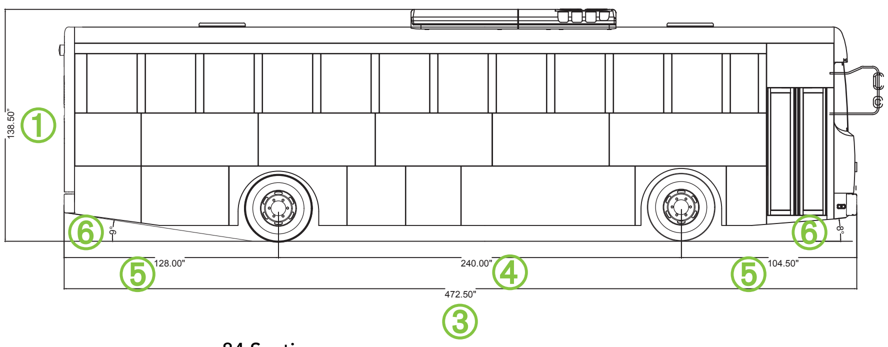
VEHICLE VOUCHER REBATES *
Email: grants@greenpowermotor.com

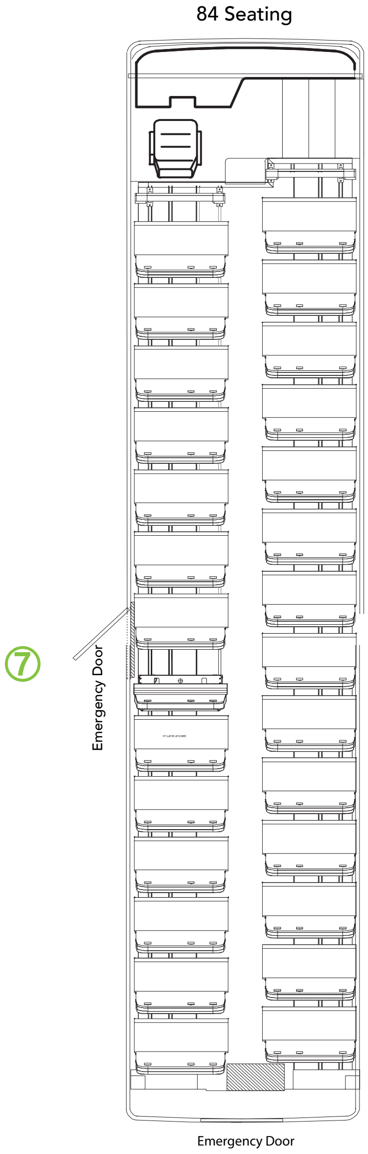
HVIP BASE VOUCHER †
$120K, DAC+15%, School+65%

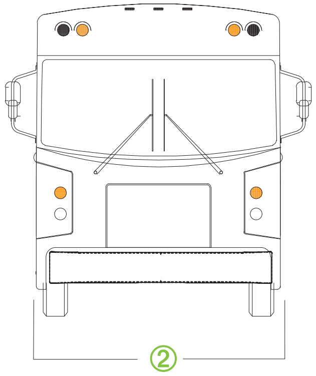
VW MITIGATION *
75% - 100%

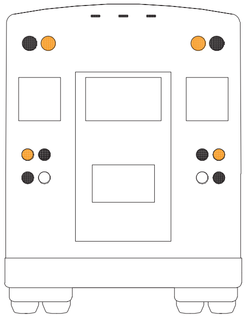
† California region only
* Specification can vary
by region, application, availabilty

LAYOUT DIMENSIONS & SEATING









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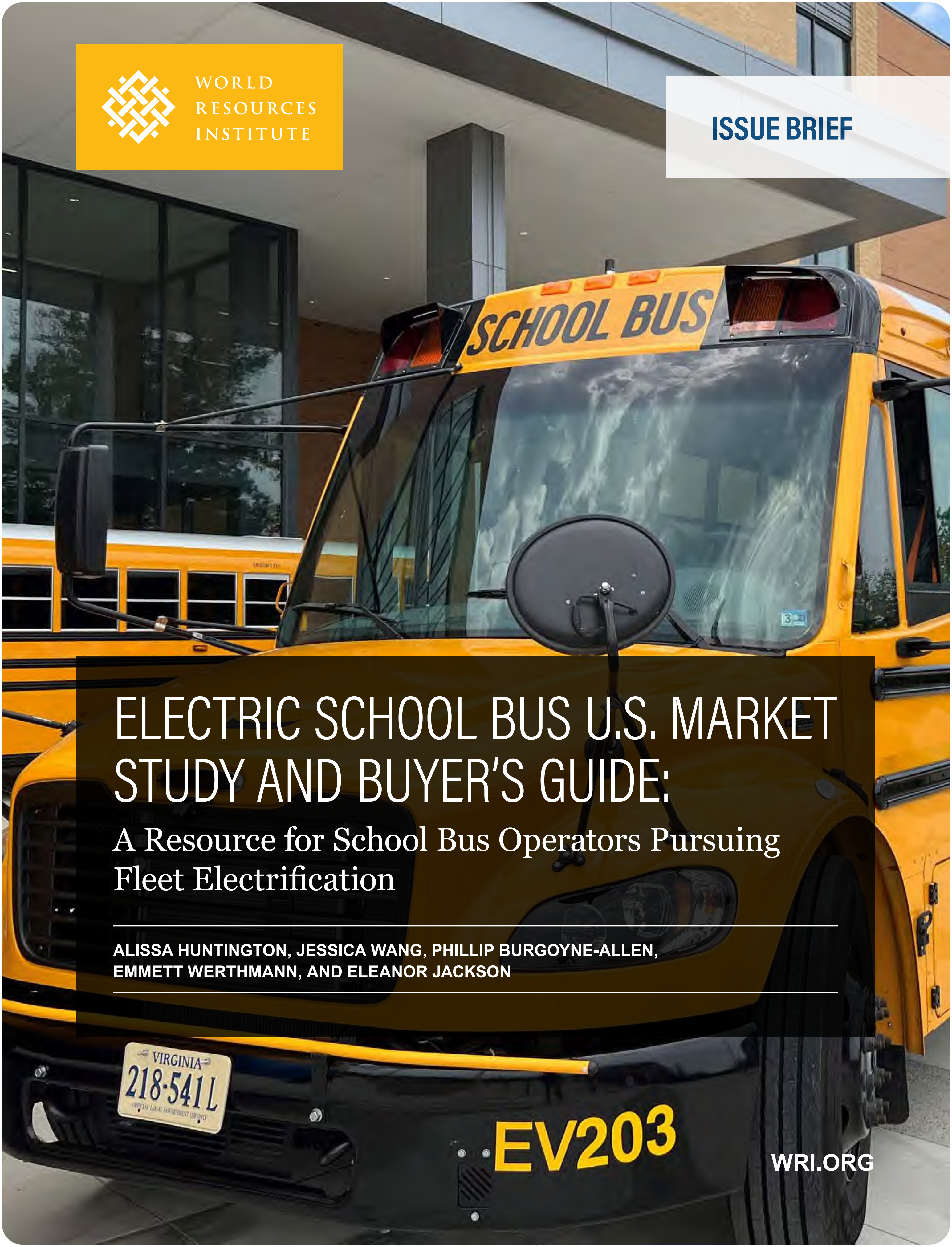

ELECTRIC SCHOOL BUS U.S. MARKET STUDY AND BUYER'S GUIDE:

A Resource for School Bus Operators Pursuing Fleet Electrification

ALISSA HUNTINGTON, JESSICA WANG, PHILLIP BURGOYNE-ALLEN, EMMETT WERTHMANN, AND ELEANOR JACKSON

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CONTENTS

EXECUTIVE SUMMARY

Highlights

- School districts across the United States have started transitioning to electric school buses (ESBs). As of March 2022, 415 districts (or private fleet operators) had committed[1] to procuring 12,275 ESBs across 38 states and a range of operating conditions. States and municipalities are setting electrification goals while manufacturers scale production.
- Compared with the typical school bus that runs on diesel fuel, ESBs have the potential to lower operations and maintenance costs for fleets and have zero tailpipe emissions. Their large batteries can store and deliver energy using "vehicle-to-everything" technology, to power buildings and other devices, which can support greater resiliency, including through the integration of renewable energy. ESBs also have the potential to generate revenue by discharging energy from their batteries back onto the grid, lowering utility costs and emissions. Though this is a nascent market, technological advancements should make this widely available in the near future.
- As of January 2022, 22 ESB models were available from 12 manufacturers for Type A, C, and D buses: 14 newly manufactured vehicle models and 8 repowered vehicle models.[2] There is the largest selection of Type A models. Type C models are the most commercially ready.
- Each generation of buses is more advanced than the previous: Many manufacturers are on their second or third iteration, some even further along. According to industry experts, electric school buses can reliably cover more than 99 percent of routes in operation (STN 2021a).

Context

Momentum around electric school buses (ESBs) is growing in the United States as school districts across the country transition to this cleaner and healthier technology, bolstered by an infusion of new funding from the federal government. The ESB transition will require a coordinated effort among numerous entities, including school district leadership and staff, school bus manufacturers and contractors, utilities, policymakers, regulators, local advocacy organizations, and community members.

This publication is intended to serve as a resource primarily for school districts, transportation directors, and other school bus operators exploring school bus electrification to provide a better understanding of the state of the ESB market and available offerings. It aims to present the growing interest and investment in this sector along with key aspects of the current technology. In Section 1, we explore the growing demand for these buses and how manufacturers are positioning themselves to meet that demand through a scan of the market. Next, in Section 2, we explain key components of an ESB and discuss the charging and related infrastructure that is needed to support these buses. The core element of the publication, Section 3, presents a catalog of the 22 ESB models available as of early 2022 with detailed vehicle specifications allowing readers to compare various models and weigh important considerations. We conclude by summarizing the status of school bus electrification to date.

Approach and Methodology

The content of this publication has been gathered from a variety of sources, with information on models available in the United States from publicly available vehicle specifications sheets confirmed through discussions with bus manufacturers when possible.

We explored school district experiences with ESBs representing a variety of use cases in the United States—rural, suburban, and urban; warm and cold weather, including extreme temperatures; and early adopters further along in the process, as well as those in earlier stages of procurement. We compiled recent research and reporting on school district commitments and experiences and supplemented public information with conversations with school districts and other partners. We plan to update this publication annually as new vehicles come to market and existing models are altered.

This resource is one of many from World Resources Institute's Electric School Bus Initiative and is intended to be updated to expand upon topics like funding and financing, alternative service models, and utility engagement.[3]

1. STATUS OF THE ELECTRIC SCHOOL BUS MARKET

There are nearly half a million school buses in the United States that transport more than 20 million children to and from school (FHA 2019; SBF 2021a). More than 90 percent of school buses on the road today are diesel powered, but interest in ESBs has grown in recent years (APP 2022). There are 12,275 ESB commitments, representing around 2.5 percent of the current fleet size (Lazer and Freehafer 2022). The ESB market was established in 2014, when two California school districts, Kings Canyon School District and Escondido Union High School District, became the first school districts to operate ESBs. Kings Canyon's four early Trans Tech models carried 25 students each and were able to travel between 80 and 100 miles on a charge while Escondido's TransPower bus had a range of approximately 60 miles (MPS 2014; Edelstein 2014; Adams 2014).

Since 2014, hundreds of other school districts across the United States have begun to embrace fleet electrification, manufacturers have positioned themselves to meet growing demand, and school bus electrification has gained traction (Figure 1).

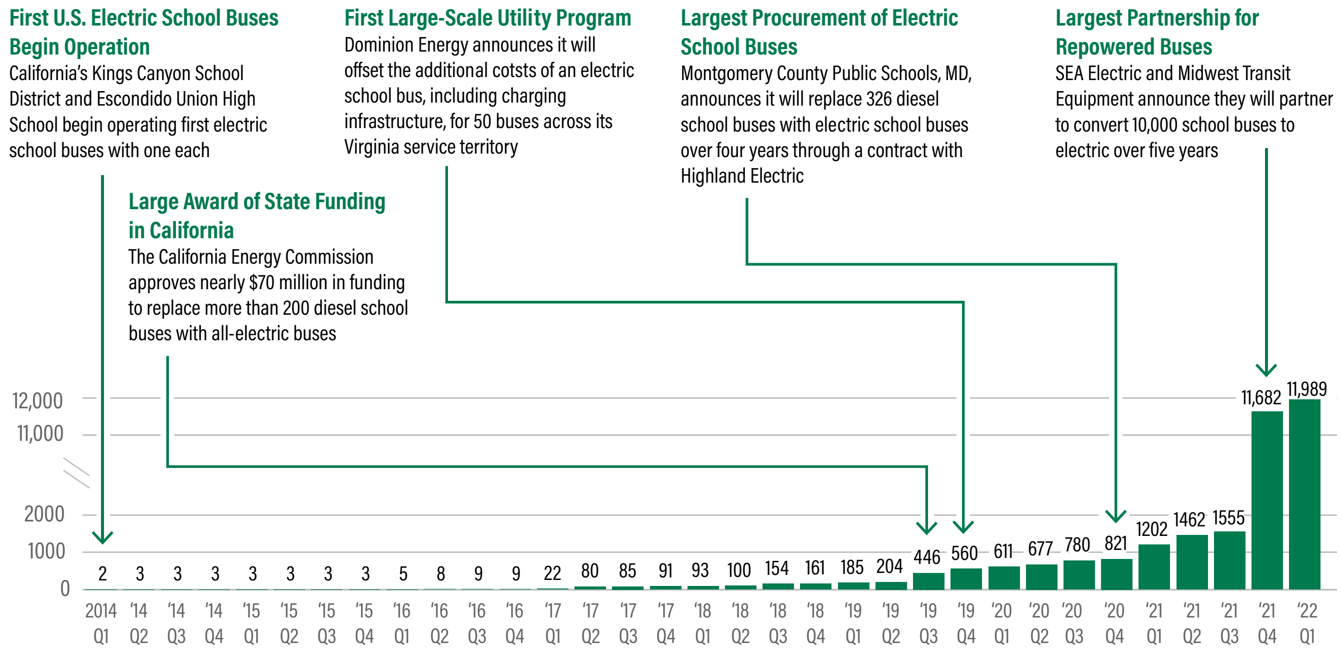
1.1 Rising Demand

A combination of factors is priming the market for ESB adoption. Compared with the typical school bus that runs on diesel fuel, ESBs have the potential to lower operations and maintenance costs for fleets and have zero tailpipe emissions (Figure 2). If equipped with bidirectional charging technology, ESBs can provide additional benefits, such as potentially acting as mobile generators in an emergency.

Influenced by these benefits, communities and policymakers are advocating for ESBs, which has resulted in commitments to electrification. Implementation of these commitments is aided by grants and incentives to bring down the upfront price of the buses (Box 6).

FIGURE 1

CUMULATIVE NUMBER OF ELECTRIC SCHOOL BUSES COMMITTED BY QUARTER IN THE UNITED STATES (2014–2022)


First U.S. Electric School Buses Begin Operation
California's Kings Canyon School District and Escondido Union High School begin operating first electric school buses with one each

Large Award of State Funding in California
The California Energy Commission approves nearly $70 million in funding to replace more than 200 diesel school buses with all-electric buses

First Large-Scale Utility Program
Dominion Energy announces it will offset the additional cotsts of an electric school bus, including charging infrastructure, for 50 buses across its Virginia service territory

Largest Procurement of Electric School Buses
Montgomery County Public Schools, MD, announces it will replace 326 diesel school buses with electric school buses over four years through a contract with Highland Electric

Largest Partnership for Repowered Buses
SEA Electric and Midwest Transit Equipment announce they will partner to convert 10,000 school buses to electric over five years

Notes: This graph depicts electric school bus (ESB) commitments at the earliest confirmed phase in the commitment process (awarded, ordered, delivered, or first operating)—286 ESBs were excluded due to unknown dates of their commitment stages. Abbreviation: Q = quarter.

Source: Based on Lazer and Freehafer 2022.

FIGURE 2

SAMPLE OF ELECTRIC SCHOOL BUS BENEFITS AND CONSIDERATIONS

Lower Operations and Maintenance Costs

Research suggests that after the upfront cost, electric school buses could save districts an estimated $4,000–$11,000 per school bus every year on operational expenditures like fueling and maintenance and repair costs (depending on labor costs, local electric utility rates, and the price of petroleum fuels).[a] Today, these savings alone are insufficient to cover the vehicle price differential without additional grant funding or subsidies.[b]

Health Benefits

There is increasing evidence that children are particularly susceptible to the negative health impacts of diesel exhaust, which has been linked to increased risk for asthma and pneumonia (Box 1).[c] There is also evidence that reducing this exposure can improve not just respiratory health but also standardized test scores, especially for elementary-age students.[d] While there has been little research measuring the air quality benefits of electric school buses specifically, these results strongly suggest that adopting these vehicles— which have zero tailpipe emissions— would have positive effects on students' health and academic outcomes, particularly for low-income students and Black students, who are more likely to ride the school bus than their peers.[e]

Climate Benefits

For school buses, electricity emits half as many greenhouse gas emissions annually as the next-best fuel. Electricity is the only viable fuel that will reduce greenhouse gas emissions over time and as buses age as the grid integrates more renewables.[f] Buses can also be paired with on-site renewable energy projects.

Resilience and Grid Potential

Electric school buses have the potential to serve as mobile generators for buildings during outages (vehicle-to-building; V2B), for the grid during high energy demand (vehicle-to-grid; V2G), or for another load (vehicle-to-another-load; V2L).[g] This technology is constantly being improved upon, and manufacturers are working actively to understand the impacts of higher charge and discharge cycles on battery life. Charging electric school buses off-peak and under managed charging offers grid benefits today by not charging when energy demand is highest or by charging when renewable energy is abundant.

Sources: [a.] Levinson 2022; Energetics Incorporated et al. 2021; Ercan et al. 2016; [b.] EDF 2021; [c.] Liu and Grigg 2018; Espinoza and Vemireddi 2018; Vieira et al. 2012; [d.] Austin et al. 2019; [e.] BTS 2021; FHA 2019; [f.] ANL 2020, comparing five fuels for school buses: electric, compressed natural gas, propane, diesel, and biodiesel. Utilizing various electricity mixes for electric school buses and North American natural gas for compressed natural gas. Based on 15,000 miles per bus per year; [g.] U.S. PIRG n.d.; [h.] Hutchinson and Kresge 2022.

BOX 1

HEALTHIER AIR FOR STUDENTS IN STOCKTON, CALIFORNIA

The residents of Stockton Unified School District (SUSD) experience some of the highest asthma rates in California, with the state ranking Stockton in the 96th percentile for pollution burden and the 100th percentile for asthma. SUSD saw the conversion to ESBs as a way to help improve air quality and protect student health.

With a host of partners, SUSD applied for the California Air Resources Board's (CARB's) Clean Mobility in Schools Project and was ultimately awarded $4.8 million from the state program. SUSD leveraged the CARB grant to secure additional sources of funding from utility, local, and state programs. In total, SUSD secured $8.3 million for 11 ESBs and charging infrastructure (a mixture of direct current fast and level 2 chargers; see Table 1 for distinction) for 24 buses in phase one of the pilot.

SUSD's pilot moved quickly despite COVID-19 budget cuts and constraints. SUSD received the initial CARB grant on January 7, 2020, had funds approved by April, broke ground on the bus charging infrastructure in September 2020, and had the charging infrastructure operational in December 2020. The district aims to eventually convert all 96 of the school district's buses.

In addition to focusing on the air quality benefits of ESBs, SUSD engages students in clean energy projects to demonstrate that the green jobs of the future are for them. "Zero-emission buses are a symbol of hope and a means of change for communities like Stockton," says Gil Rosas who was SUSD's energy education specialist during its ESB transition. "Stockton has shown how a disadvantaged community can go from design to construction to electric school buses in less than a year."

Source: Rosas 2021. Learn more about Stockton's experience by visiting Kaplan, L., and A. Huntington. 2021. "The Electric School Bus Series: Healthier Air for Students in Stockton, California." Washington, DC: World Resources Institute. https://www.wri.org/update/electric-school-bus-series-stockton-california.

Community Support

Community members can drive demand for school bus electrification. Grassroots organizations and advocacy groups, often made up of parents and other caregivers, have been effective at pushing school district commitments and creating policy changes. At the national level, Chispa LCV has been driving the ESB conversation since 2016 by creating the "Clean Buses for Healthy Niños" campaign to ask decision-makers to prioritize ESBs when spending the Volkswagen settlement funds,[4] forming the Alliance for Electric School Buses, and championing the numerous benefits ESBs bring to communities (Chispa n.d.). Its volunteers have supported legislation in Nevada and helped hold school districts to their commitments in Arizona (Schlosser 2021). In Virginia, Mothers Out Front helped get Virginia Delegate Mark Keam's ESB bill passed (MOF n.d., 2021; FCPS 2021a). In New York, advocacy from groups helped push both New York City's and New York State's commitments to transition the fleet by 2035 (News 12 Staff 2022; EarthJustice 2022; Kaye 2022; CNY 2021). Students have also been effective changemakers, especially at the school district level. For example, in Miami, student pressure at school board meetings helped convince the district to pursue a grant for 50 ESBs (Casey 2021).

These are just a few examples of how communities have driven demand for ESBs by advocating for their children's health and safety.

Policy Commitments

Policy commitments can influence speed of adoption. The New York State budget for fiscal year 2023 includes a new, nation-leading requirement for all new school bus purchases in New York State to be zero emission starting in July 2027 (Lewis 2022). All school buses in service statewide must be zero emission by 2035. The new law also requires the New York State Energy Research & Development Authority to offer technical assistance to school districts and publish an implementation roadmap. The legislation further allocates $500 million in potential state funding for school bus electrification. This new funding, part of a larger environmental bond act, is subject to voter approval in November 2022. In California, the governor's budget proposal, currently being considered in the state legislature, would allocate $1.5 billion in one-time funding, available over three years, to support school transportation programs, with a focus on greening school bus fleets (Gray 2022).

At the local level, Fairfax County Public Schools in Virginia, with 1,625 school buses, one of the largest fleets in the country, adopted a goal for full fleet electrification by 2035 (FCPS 2021b; Schlosser 2019). In addition, after receiving North Carolina's first ESB earlier this year, the Eastern Band of Cherokee Indians set a goal of becoming the first school system in the state to electrify its full fleet and has already ordered four additional ESBs that are expected to be delivered this summer (WLOS Staff 2022; Kays 2022).

Grants and Incentives

As of April 2022, about 80 percent of school districts or fleet operators with committed ESBs had only one batch of ESBs so far—20 percent (83 school districts or fleet operators) had between two and four batches.[5] Funding at the utility, local, state, and federal levels has catalyzed adoption, with school districts leveraging dozens of funding sources across the country to offset the high upfront prices of the buses, which can be three to four times more than a diesel model (Levinson 2022; Tables 2, 3, and 4).

States are an important source of funding for school bus electrification. California has awarded over $116 million for ESBs through its California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (California HVIP 2022). New York State's Truck Voucher Incentive Program and Massachusetts' Vehicle-to-Grid Electric School Bus Pilot Program are other early examples of states providing funding for ESBs (NYSERDA 2022; MDER 2022). Across the board, the state funding landscape has evolved due to the Volkswagen settlement funds, which make up over one-third of state public funding for ESBs allocated to date and are the primary source of state funding for ESBs in most states (McLaughlin and Balik 2022; Box 2).

BOX 2

A RURAL COUNTY'S EXPERIENCE WITH ELECTRIC SCHOOL BUSES—KNOX COUNTY, MISSOURI

After success with on-site solar, Knox County R-I School District—the second largest geographically in Missouri—began looking for other ways to reduce expenditures, increase revenues, and expose students to a growing field that could offer well-paying clean energy jobs within their own community. At the suggestion of Lewis County REC, the district's electric cooperative, Knox County Superintendent Andy Turgeon and his team turned their sights to an ESB.

In 2020, the district began searching for funding, ultimately securing four grants—one state, one federal, and two from utilities: Department of Natural Resources Volkswagen settlement funding ($169,126); U.S. Department of Agriculture's Community Facilities program ($116,626); Associated Electric Cooperative Inc. ($30,000); and Lewis County REC ($15,000).

The district received its ESB six months after placing an order. The school district had slight challenges with regenerative braking and the direct current to direct current (DC-DC) converter. When installing USB (universal serial bus) ports in the bus, one of the relay switches that operates the regenerative braking was knocked loose. Turgeon and his team quickly identified and fixed the issue after plugging in a laptop for remote communication and diagnostics. For the DC-DC converter, the cameras Knox County School District installed on the bus were not shutting off and were draining the onboard 12-volt battery. Once identified, the manufacturer sent a new onboard battery and the bus mechanic installed it within an hour.

Overall, Turgeon and the drivers have enjoyed the bus, noting how quiet and smooth the rides are. Looking ahead, Knox County schools believe that full electrification of their 14-bus fleet is in their future and have already applied for grants for two more buses through the state's Department of Natural Resources.

Source: Turgeon, A. 2021. Learn more about Knox's experience at Huntington, A., and L. Kaplan. 2021. "The Electric School Bus Series: Wiring Up in Knox County." Washington, DC: World Resources Institute. https://www.wri.org/update/electric-school-bus-series-knox-county.

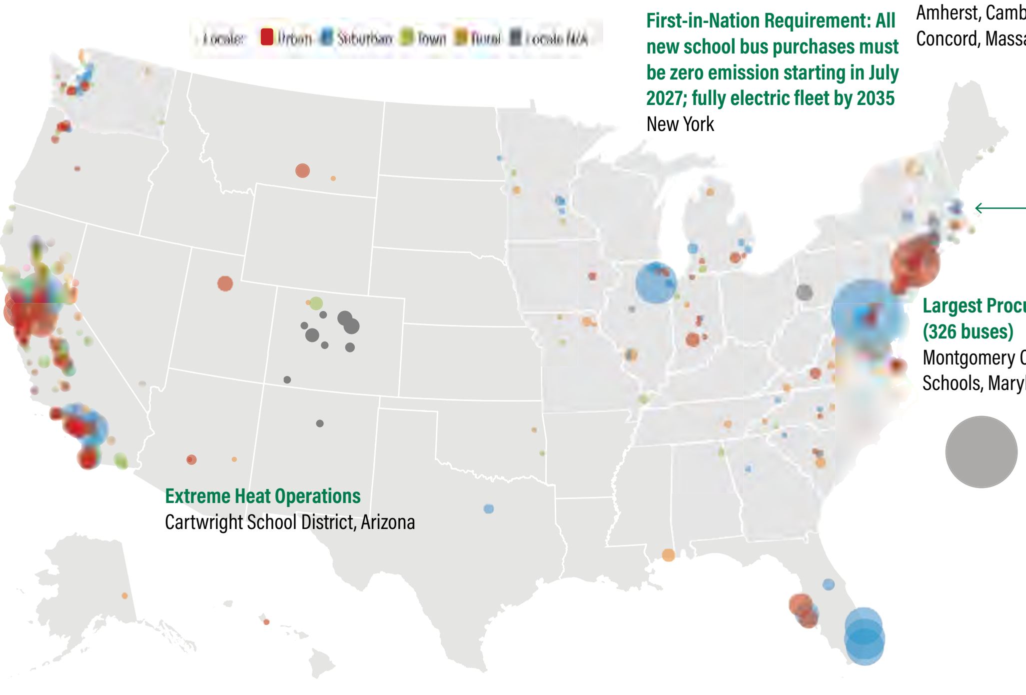
In addition to state and local funding, the bipartisan Infrastructure Investment and Jobs Act, signed into law in November 2021, will provide an unprecedented amount of funding—$5 billion over five years to the U.S. Environmental Protection Agency to establish the Clean School Bus Program—to school districts and other eligible contractors or entities starting in mid-2022. The program will offer both rebate and grant programs to support the replacement of existing school buses with cleaner zero- or low-emission school buses, which should help bring down the upfront price school districts pay for electric models. This funding includes $2.5 billion in dedicated funding for ESBs and another $2.5 billion for zero- and low-emission school buses, including both electric and alternative fuel buses. These programs will prioritize projects that align with the Justice40 initiative, which aims to deliver at least 40 percent of overall benefits from federal climate and clean energy investments to underserved communities.

Current Market Status

School districts and cities across the country are becoming part of the transition to ESBs, driving up demand nationwide. As of March 2022, 415 districts (or, in some cases, private fleet operators) had committed to procuring 12,275 ESBs (Lazer and Freehafer 2022; Figure 3). ESBs are committed in 38 states, the Cherokee Nation, and the White Mountain Apache Tribe. Most are located in California, which features robust and long-standing state funding programs (Box 3).

FIGURE 3

ELECTRIC SCHOOL BUSES IN THE UNITED STATES



Largest Electric School Bus Fleet (50 buses)
Twin Rivers Unified School District, California (Box 3)

Oldest Electric School Bus Fleets (Est. 2014)
Kings Canyon Unified School District and Escondido Union High School District, California

Extreme Heat Operations
Cartwright School District, Arizona

Extreme Cold Operations
Alaska Gateway School District, Alaska

First-in-Nation Requirement: All new school bus purchases must be zero emission starting in July 2027; fully electric fleet by 2035
New York

First Cold Weather Pilot (2016–18)
Amherst, Cambridge, and Concord, Massachusetts

Largest Procurement (326 buses)
Montgomery County Public Schools, Maryland

Notes: Data as of March 2022. Midwest Transit Equipment and SEA Electric have not yet announced the location of their 10,000 repowered electric school buses (grey circle).

Sources: Lazer and Freehafer 2022; NCES 2018, 2020; examples gathered by authors.

BOX 3

BUILDING INTERNAL CAPACITY WITH ELECTRIC SCHOOL BUSES IN TWIN RIVERS, CALIFORNIA

Twin Rivers Unified School District began operating its first ESBs in 2017. Currently, the school district operates the largest ESB fleet in the nation with 50 electric Type A, C, and D buses from a variety of manufacturers (Lion, Trans Tech, Blue Bird, and Collins with orders placed for Micro Bird and Thomas Built Buses). All are newly manufactured models; none are repowered models.

Reflecting on his district's journey, Twin Rivers Transportation Director Tim Shannon encourages fleets to "think big" at the outset, as doing multiple upgrades for infrastructure can be burdensome and costly. Depot upgrades include underground work, trenching, and laying pipe. Fleets can minimize facility disruption by planning early on to accommodate a larger electric fleet. While total infrastructure costs depend on several factors, the size of the fleet and the available power source are two of the greatest. To make nationwide electrification possible, Twin Rivers highlighted the need for broader investments in public infrastructure so that school districts can use their electric buses for longer field trips or activities, which has proved difficult to date.

Twin Rivers has experienced some operational issues, primarily problems with converters/inverters and battery replacements in three of its eight first-generation buses. These replacements were covered by the eight-year warranties offered by the manufacturer. Twin Rivers has not experienced this challenge in later-generation buses and has found that manufacturers and dealers have been responsive regarding both immediate needs and longer-term modifications to their offerings. While Raymond Manalo, Twin Rivers' vehicle maintenance manager, emphasizes that forging strong partnerships with manufacturers and dealers is essential, he also cautions against relying too heavily on those parties: Effectively training technicians to resolve issues internally can address simpler issues and reduce downtime. A school district can build internal capacity for its maintenance technicians by receiving manufacturer or dealer training, which can be built into purchase contracts or requests for proposals. Twin Rivers has also leveraged its network of local school districts operating electric buses as a form of mutual aid when schools encounter issues or need parts.

Source: Shannon and Manalo 2021.

Electric school buses have successfully been deployed in a variety of climates. For example, Tok Transportation began operating Alaska's only ESB, a Type C with a 138-mile range, in October 2020 and has since been able to operate in temperatures as low as -38 degrees Fahrenheit (°F) (O'Hare 2021). In such extreme conditions, the bus's efficiency is halved—a more substantial decrease in efficiency than that of buses operating in areas with less severe winters regardless of fuel type (Henning et al. 2019). However, Tok Transportation can manage this drop in efficiency as its average route length is just 30 miles. Buses have also been deployed in hot weather climates. Cartwright School District 83 outside of Phoenix, Arizona, received the state's first ESB in July 2021. The bus has an upgraded air conditioning system that is appropriate for the Arizona heat and has successfully operated in summer temperatures without major battery impacts (Hannon 2021).

1.2 Scaling Supply

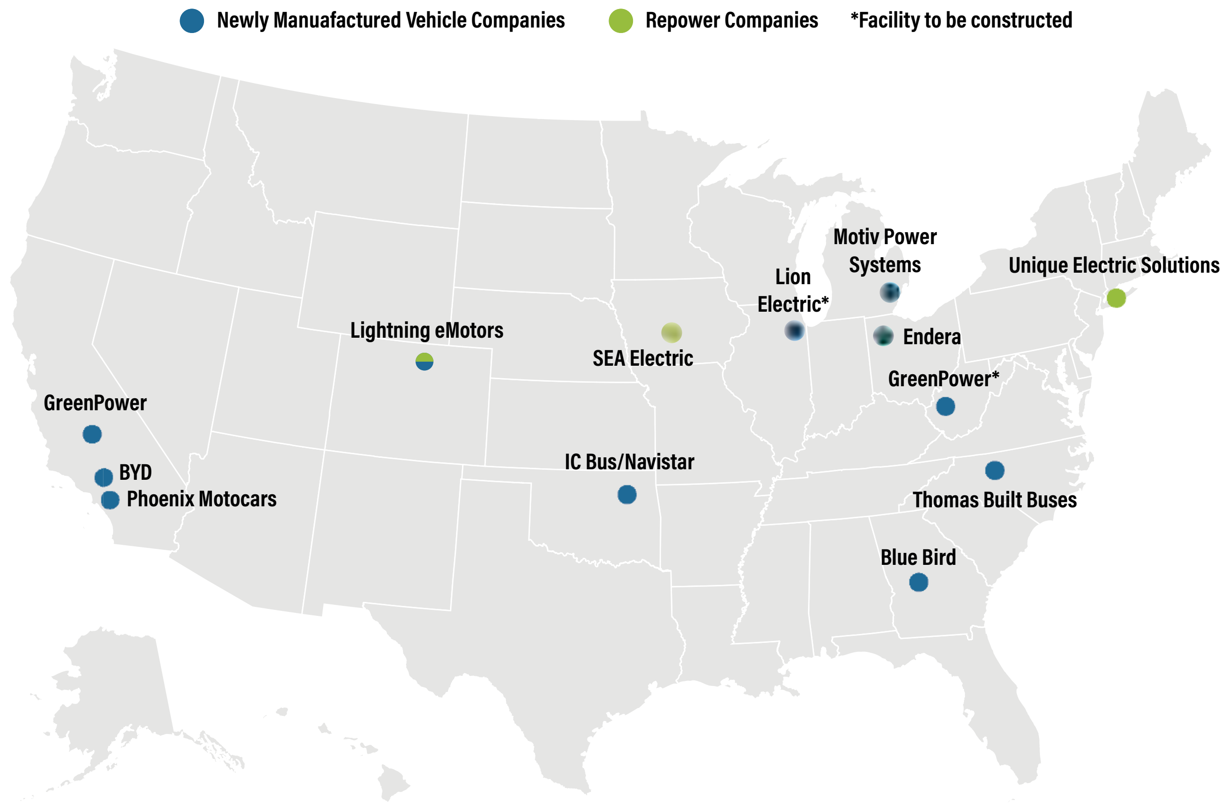
To meet the growing demand for ESBs, existing manufacturers are ramping up production, and new manufacturers continue to enter the field (Figure 4). While initial offerings were limited, today many manufacturers are on their second or third ESB model iteration, some more, and are expanding their production capacity to meet demand. For example, after expanding its production capacity sixfold in late 2020 due to a sales increase of 250 percent compared with the previous year, Blue Bird became the first manufacturer to achieve 800 electric-powered school buses either delivered or on order (Blue Bird 2020; STN 2021c). The company reported a backlog of over 380 buses on order last year and will again increase production capacity in 2022 (Blue Bird 2021a, 2021b). Lion Electric, a Canada-based group, announced it would expand its footprint by constructing a U.S. manufacturing facility in Joliet, Illinois, that will have an annual production capacity of up to 20,000 all-electric buses and trucks (Lion Electric 2021). In response to the favorable market outlook due to the federal government's Infrastructure Investment and Jobs Act, GreenPower announced it would double its ESB production capacity in 2021; the manufacturer said it would lease or purchase a manufacturing facility in West Virginia (GreenPower 2021; Justice 2022). Providers are also forging partnerships: Lightning eMotors, an all-electric powertrain manufacturer, and Collins Bus, a school bus body upfitter, have partnered to deliver more than 100 electric Type A buses by 2023 (Lightning eMotors 2021).

School bus manufacturing is concentrated in the United States, supported by federal Buy America regulations, and in Canada. However, ESBs are still dependent on a global supply of lithium-ion batteries, electric motors, and other electric vehicle components that have less domestic manufacturing capacity (FTA n.d.). The cost of these components, particularly batteries, will directly impact ESB capital cost and the industry's ability to see rapid ESB adoption. Despite these challenges, even as the COVID-19 pandemic has presented unprecedented hardships for the education sector, ESBs have persisted as the only fuel type to see growth in new bus sales during the pandemic with sales increasing 61 percent (STN 2021b). As ESBs continue to gain market share, it will be crucial to also manage diesel bus scrappage in a way that limits used vehicle flows to international markets, permits repowering by not cutting frame rails, and allows fleet managers to hold on to buses long enough to become acclimated to ESB replacements in their fleets.

To meet demand, existing contractors and emerging third-party services are looking for ways to support school districts in this transition. Contractors, who represent around 40 percent of the school bus market,

FIGURE 4

MAP OF ELECTRIC SCHOOL BUS MANUFACTURING FACILITIES IN THE UNITED STATES



Notes: This map does not include electric school bus manufacturing facilities in Canada. Lion Electric and Micro Bird both have facilities in Quebec.

Source: WRI authors based on publicly available information.

are beginning to explore pathways to electrification to meet customer demand (Gissendaner 2021). For example, Student Transportation of America, a private fleet operator servicing school districts across the United States and Canada, launched an Electric School Bus Pilot Program in 2021, and Midwest Transit Equipment is partnering with SEA Electric to repower 10,000 school buses to electric through 2026 (SBF 2021b; SEA Electric 2021). New service providers are employing alternative business models to lower the upfront cost barrier and reduce new technology risks for school districts (Box 4).

BOX 4

TURNKEY ASSET MANAGEMENT AND OTHER AS-A-SERVICE MODELS

Structured as service contracts, districts can benefit from expert project management, procurement support, and ongoing operations and maintenance services. Services can span from bus ownership to site energy management, with different combinations of service solutions depending on the specific needs and context of each customer.

Two examples are Highland Electric and Levo Mobility, firms that leverage private finance, potential vehicle-to-grid revenues, public funds, and the purchasing power of multiple clients to provide bundled packages of services that enable electrification. Montgomery County Public Schools in Maryland is partnering with Highland Electric on the largest procurement of ESBs in North America. The school district announced in 2021 it would convert 326 buses to electric by 2025 on a path to full electrification of its 1,400-bus fleet.[a] Building on this progress, Highland signed a letter of intent with school bus manufacturer Thomas Built Buses in March 2022, which will allow Highland to provide ESB subscriptions through 2025 at prices that put them at cost parity with diesel.[b] In Illinois, Levo Mobility will use its turnkey electrification solution to help Troy Community Consolidated School District 30-C convert its 64-school bus fleet to zero emission within five years.[c]

Notes: [a] Proterra 2021; [b] DTNA 2022; [c] Levo Mobility LLC 2022.

2. ELECTRIC SCHOOL BUS BASICS

In preparing for ESB adoption, project developers need to understand considerations for both the buses themselves as well as the charging infrastructure to power them. This section outlines components of the ESB and its charging infrastructure (Tables A1 and A2 in Appendix A provide additional terms and units, respectively) and offers considerations for implementation.

2.1 Electric School Bus

As school districts embrace electric buses, fleet managers, bus drivers, and maintenance technicians will need to familiarize themselves with elements that vary between diesel and electric (Figures 5 and 6). While many elements of the body and inside the cabin remain similar, two key differences are present in electric models:

1. The presence of high-voltage electrical systems
2. The absence of internal combustion–related components

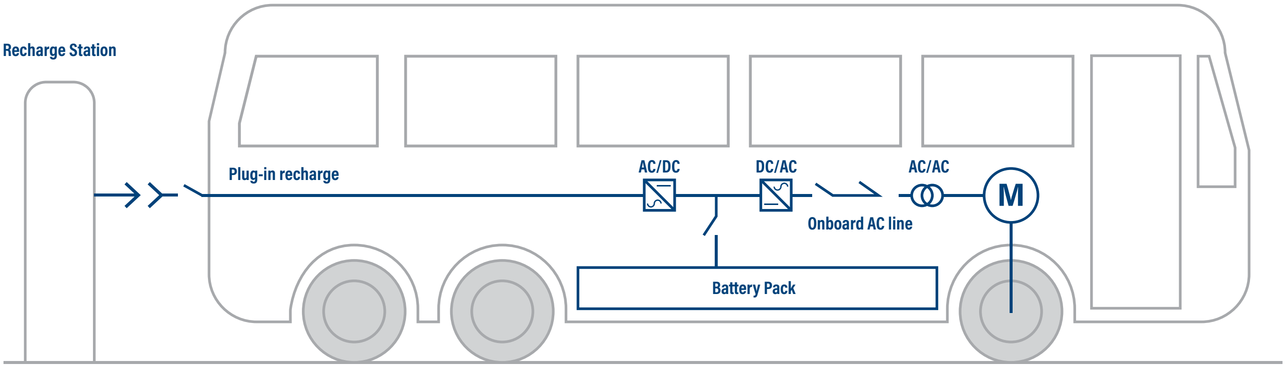
ESBs contain high-voltage systems powered by a large lithium-ion battery pack mounted to the chassis. Power from the high-voltage battery is distributed to the electric motor and other systems using high-voltage cables (colored bright orange), direct current/alternating current (DC/AC or AC/DC) inverters, and AC/AC transformers. The high-voltage battery pack is supported by a thermal management system that maintains battery health and longevity by keeping the batteries within an optimal temperature range regardless of external temperature (vital to ESBs operating in cold and hot climates).

With the inclusion of an electric powertrain, ESBs do not contain internal combustion engine components and systems (see components highlighted in red in Figure 6). Electric buses utilize motors comprising only around 20 parts (compared with 2,000 in a diesel engine); require fewer fluid changes (including elimination of engine oil); and commonly use a direct drive system, eliminating the need for a transmission.

With respect to vehicle servicing, technicians have fewer parts to maintain for electric buses when compared with their diesel counterparts. Moreover, many auxiliary systems in ESBs, such as braking and steering, remain similar to those of diesel buses, making them relatively easy to keep up and service (see components highlighted

FIGURE 5

ELECTRIC SCHOOL BUS DIAGRAM



Note: Abbreviations: AC = alternating current; DC = direct current; M = motor.

Source: Ainsalu et al. 2018.

in blue in Figure 6). Additionally, like diesel buses, ESBs also have low-voltage auxiliary systems that use a lead-acid battery to support components like the dashboard, lights, and windshield wipers. However, to operate on high-voltage systems, maintenance technicians do need specialized training. For on-site depot maintenance staff, completing this training can be both costly and time consuming.

If qualified technicians are not readily available where the bus operates, any issues that arise with the high-voltage system must be resolved by the closest dealer or manufacturer that has trained staff. Depending on the proximity of the bus to these services, there can be delays and challenges with bus uptime. To address this, it is imperative that manufacturers and dealers work closely with transportation managers, technicians, and their teams to provide training to properly manage these systems and related safety considerations and to decentralize where the ability and knowledge to operate on high-voltage systems is concentrated.

2.2 Charging Infrastructure

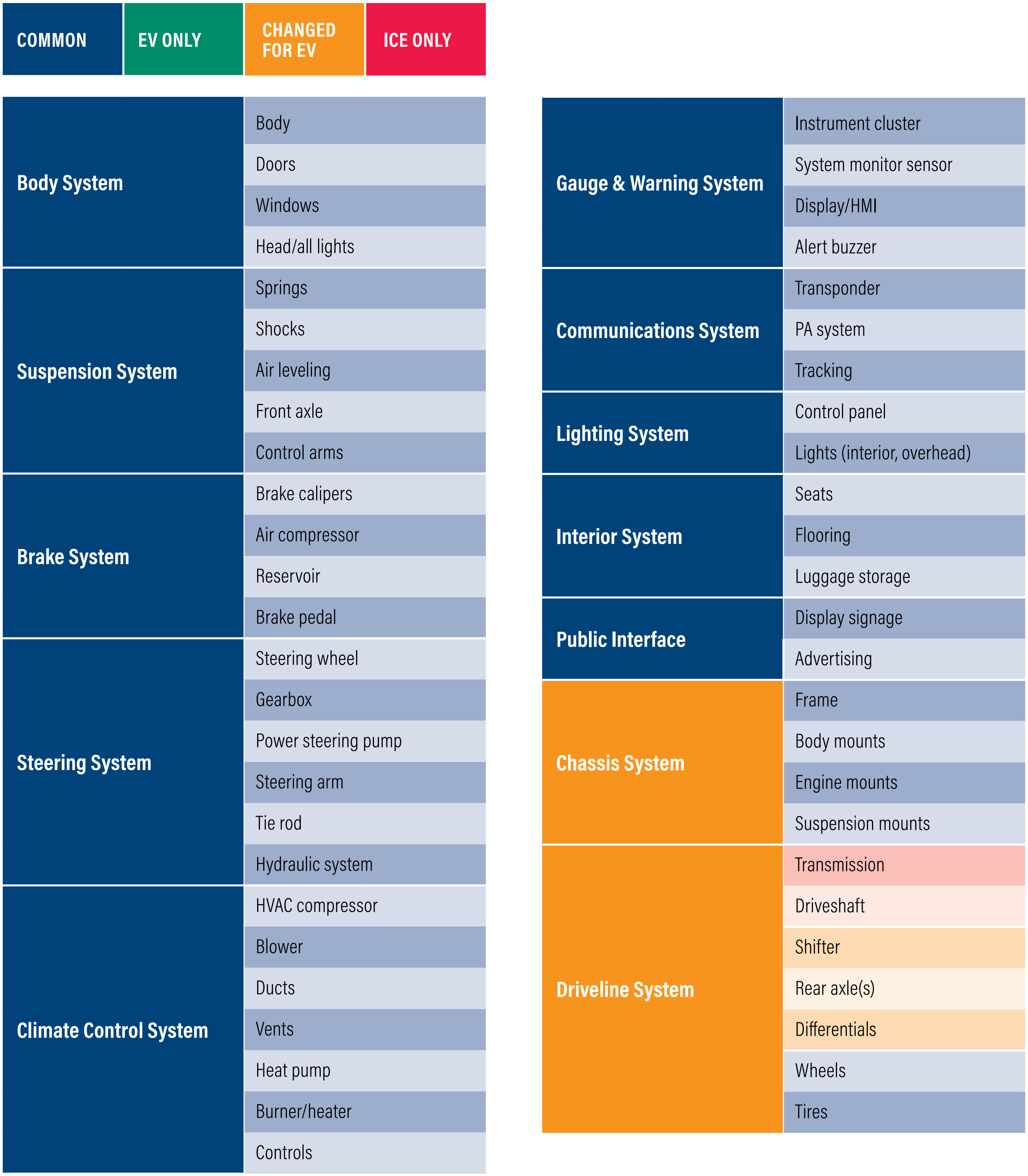
As school districts consider procuring ESBs, they must also think about the corresponding infrastructure needed to charge these buses. Infrastructure can be broken down into hardware and software components. For charging hardware or electric vehicle supply equipment, there are three levels available today (Table 1).

Bus depots can and often do have a mix of level 2 (L2) chargers and direct current fast chargers (DCFCs). With lower power demand, several buses can typically charge at the same time with multiple L2 chargers that can have two ports per charger. For DCFCs, higher power demands may restrict charging to fewer buses and only one per DCFC charger.

Early and frequent engagement with a school district's electric utility is crucial. This is necessary to evaluate the existing power supply and identify required system upgrades and charging configurations to support fleet turnover. Once charging infrastructure is in place, which can take approximately 12 to 24 months, bus operators can take advantage of time-of-use rates (if available) and managed smart charging to help realize greater energy savings. For example, a 2015–18 ESB pilot at three Massachusetts school districts found that unmanaged bus charging and high parasitic loads during charging (e.g.,

FIGURE 6

COMPARISON OF ELECTRIC AND INTERNAL COMBUSTION ENGINE VEHICLE COMPONENTS

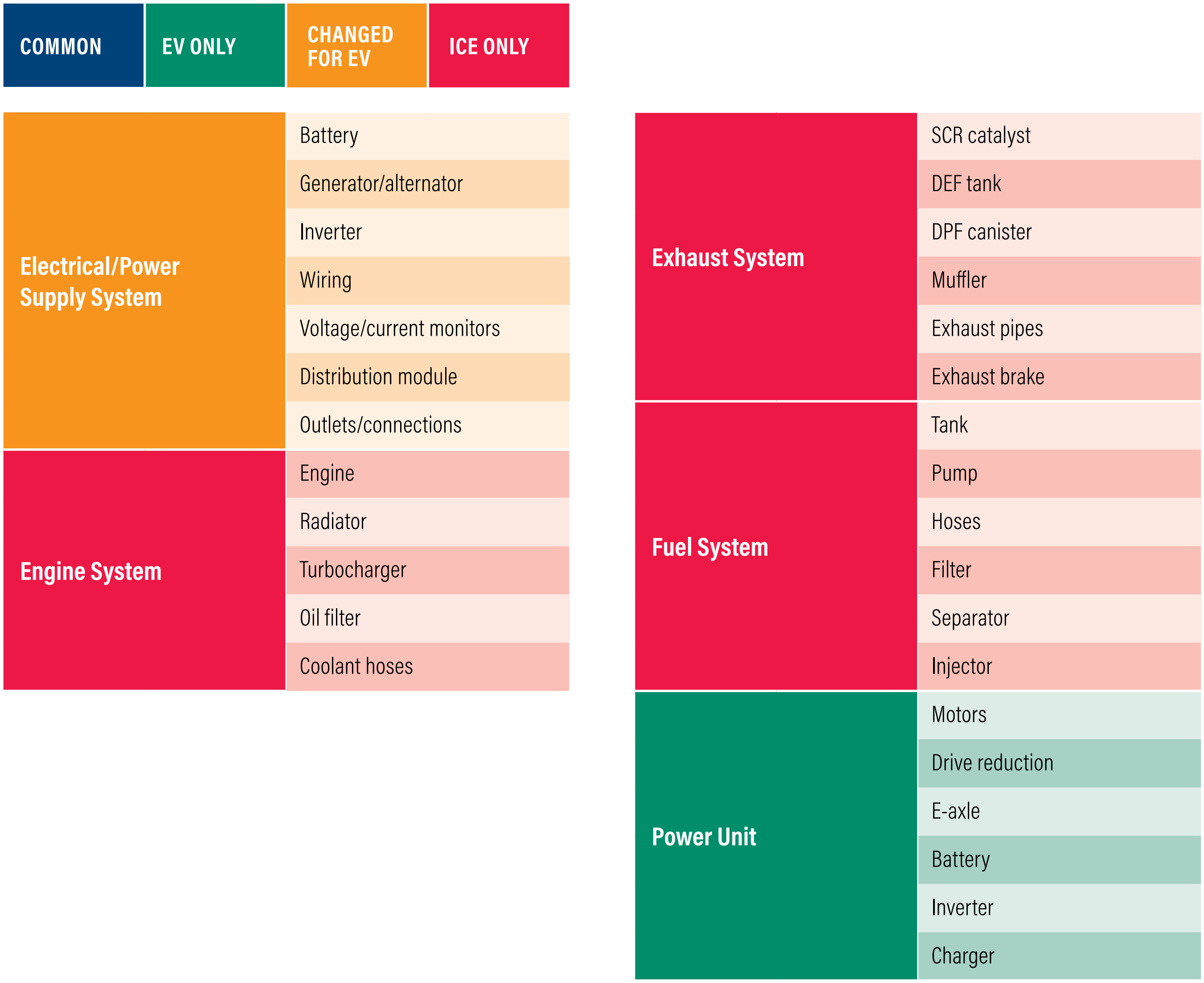


🟦 COMMON	🟩 EV ONLY	🟧 CHANGED FOR EV	🟥 ICE ONLY

System	Component
🟦 **Body System**	🟦 Body
	🟦 Doors
	🟦 Windows
	🟦 Head/all lights
🟦 **Suspension System**	🟦 Springs
	🟦 Shocks
	🟦 Air leveling
	🟦 Front axle
	🟦 Control arms
🟦 **Brake System**	🟦 Brake calipers
	🟦 Air compressor
	🟦 Reservoir
	🟦 Brake pedal
🟦 **Steering System**	🟦 Steering wheel
	🟦 Gearbox
	🟦 Power steering pump
	🟦 Steering arm
	🟦 Tie rod
	🟦 Hydraulic system
🟦 **Climate Control System**	🟦 HVAC compressor
	🟦 Blower
	🟦 Ducts
	🟦 Vents
	🟦 Heat pump
	🟦 Burner/heater
	🟦 Controls
🟦 **Gauge & Warning System**	🟦 Instrument cluster
	🟦 System monitor sensor
	🟦 Display/HMI
	🟦 Alert buzzer
🟦 **Communications System**	🟦 Transponder
	🟦 PA system
	🟦 Tracking
🟦 **Lighting System**	🟦 Control panel
	🟦 Lights (interior, overhead)
🟦 **Interior System**	🟦 Seats
	🟦 Flooring
	🟦 Luggage storage
🟦 **Public Interface**	🟦 Display signage
	🟦 Advertising
🟧 **Chassis System**	🟦 Frame
	🟦 Body mounts
	🟦 Engine mounts
	🟦 Suspension mounts
🟧 **Driveline System**	🟥 Transmission
	🟥 Driveshaft
	🟧 Shifter
	🟧 Rear axle(s)
	🟧 Differentials
	🟦 Wheels
	🟦 Tires

FIGURE 6

COMPARISON OF ELECTRIC AND INTERNAL COMBUSTION ENGINE VEHICLE COMPONENTS (CONT.)



🟦 COMMON
🟩 EV ONLY
🟧 CHANGED FOR EV
🟥 ICE ONLY

System	Component
🟧 **Electrical/Power Supply System**	Battery
	Generator/alternator
	Inverter
	Wiring
	Voltage/current monitors
	Distribution module
	Outlets/connections
🟥 **Engine System**	Engine
	Radiator
	Turbocharger
	Oil filter
	Coolant hoses

System	Component
🟥 **Exhaust System**	SCR catalyst
	DEF tank
	DPF canister
	Muffler
	Exhaust pipes
	Exhaust brake
🟥 **Fuel System**	Tank
	Pump
	Hoses
	Filter
	Separator
	Injector
🟩 **Power Unit**	Motors
	Drive reduction
	E-axle
	Battery
	Inverter
	Charger

Note: Abbreviations: ICE = internal combustion engine; EV = electric vehicle; HVAC = heating, ventilation, and air conditioning; HMI = human-machine interface; PA = public address; SCR = selective catalytic reduction; DEF = diesel exhaust fluid; DPF = diesel particulate filter.

Source: Nair et al. 2022.

TABLE 1

CHARGING LEVELS

	Level 1 (L1)	Level 2 (L2) Single Port[a]	Direct Current Fast Charger (DCFC) Single Port
Type of current	Typically for residential, personal vehicle charging; not suitable for ESBs due to low rate of charge relative to the time it takes to charge a battery	Alternating Current	Direct Current
Voltage (V)		208/240	200–600
Power level (kW)		~7–20	~24–150
ESB recharge time		5.5–13 hours[b]	1–4.5 hours[b]
Charger equipment cost[c]		$400–$6,500[d]	$10,000–$40,000[d]
Installation cost[e]		$600–$12,700[d]	$4,000–$51,000[d]

Notes: Abbreviations: V = volt; kW = kilowatt; ESB = electric school bus; [a] Potential for dual port offering; [b] See Tables 2, 3, and 4; [c] Costs are largely dependent on the power output (kilowatts) of the charger, the degree of control over charging, and other advanced features; [d] Smith and Castellano 2015; ITSJPO 2019; [e] Installation costs will be site and geography dependent. Estimates do not include potential grid upgrade costs.

bus heaters, fans, lights) contributed to ESB electricity costs being 63 percent higher than necessary (VEIC 2018). To avoid the excess energy consumption, the report authors recommended utilizing managed charging.

Beyond the hardware, managed charging uses software designed to help fleet operators optimize charging schedules, costs, and bus performance. This software, often provided by charging software developers, can allow for scheduling charging times for when electricity prices are lowest or for turning off charging to preserve battery life without manual adjustments, even if the bus is plugged in continuously (Box 5). Chargers equipped with this software will likely be somewhat more expensive upfront and incur ongoing subscription or service fees. Managed charging software can be customized for a fleet, and operators can leverage tools through mobile apps or online platforms.

With the right hardware and software, school districts can take advantage of bidirectional charging, where the vehicle can receive electricity to charge as well as discharge back to a different load or onto the grid. If equipped with this functionality, a bus can serve as a backup battery for a building by providing power during emergencies (vehicle-to-building; V2B) or for another load (vehicle-to-another-load; V2L). Buses can also store electricity in their batteries and later discharge it onto the grid to reduce districts' utility costs (vehicle-to-grid; V2G). Since the first vehicle-to-grid deployment in 2014 at three California school districts, at least 15 utilities across 14 states have committed to pilot ESB V2G programs (PCA 2014; Hutchinson and Kresge 2022). Through V2G programs, buses also have the potential to generate revenue by discharging energy from their batteries back to the grid to be used elsewhere—this is a nascent market but technological advancements should make this widely available in the near future. While these bidirectional concepts have been deployed by only a handful of school districts to date, they offer potential to increase resilience, generate revenue, and reduce costs (Proterra 2019).

Electric bus adoption can also be paired with new or existing on-site solar installation as an energy storage solution (ENGIE Impact 2021; Soneji et al. 2020; Ellis 2020; Riley 2021). This approach could further decrease energy costs while providing a power source for charging during service disruptions. Installing on-site solar also helps districts contribute to wider school district, city, or state emissions reduction or sustainability goals.

BOX 5

ENERGY-AS-A-SERVICE SOLUTIONS

Just as transportation-as-a-service offerings on the bus side have emerged, as-a-service offerings that handle the intersecting charging elements have also proliferated. As-a-service arrangements can help school districts reduce charging costs, finance necessary infrastructure upgrades, and manage their energy needs within the grid capacity of their depots. The robust market extends much beyond services exclusive to the school bus industry, ranging from fleet energy management firms like eIQ Mobility and Olivine to charging- and infrastructure-as-a-service firms like The Mobility House, Amply, and NextEra Energy's Mobility Team. Other entrants in this space include electric utilities and energy services companies, which are experimenting with energy performance contract offerings. This topic requires more detail than covered in this report and is a dynamic space. More information can be found in Cleary and Palmer (2020).

2.3 Considerations for Implementation

School districts that choose to adopt ESBs without contractors or transportation-as-a-service providers generally follow a similar roadmap to adopting ESBs, laid out in Figure 7. Many of these stages overlap and are executed concurrently.

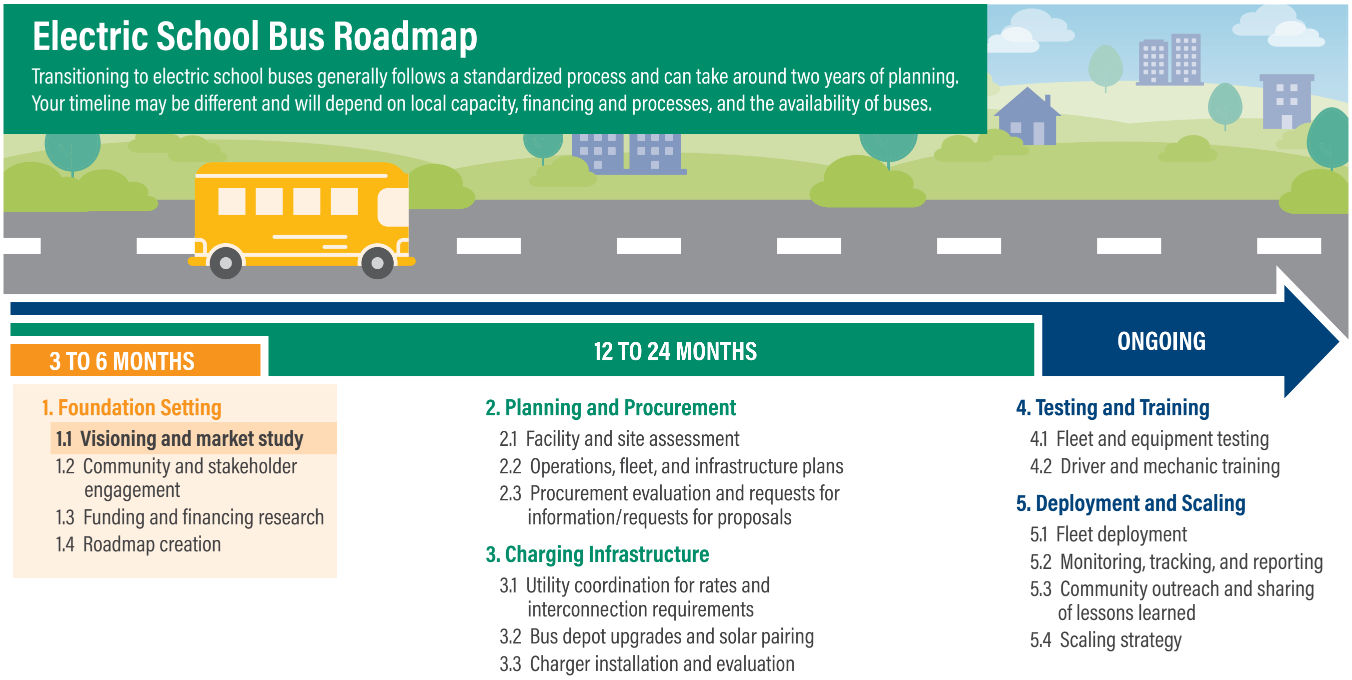
While this publication predominantly focuses on information that can support school districts in the foundation-setting stage (Stage 1.1 in Figure 7), some potential considerations and guiding questions for all five stages are listed below. This list is not exhaustive and will be explored in more detail in future publications.

Stage 1. Foundation Setting

- What are your ultimate electrification goals?
- How are local community-based organizations, students, parents, and other stakeholders being brought into the process?
- Would a school district benefit from leveraging an "as-a-service" model (Boxes 4 and 5)?

FIGURE 7

FIVE STAGES AND CORRESPONDING STEPS OF ELECTRIC SCHOOL BUS ADOPTION



Electric School Bus Roadmap

Transitioning to electric school buses generally follows a standardized process and can take around two years of planning. Your timeline may be different and will depend on local capacity, financing and processes, and the availability of buses.

3 TO 6 MONTHS

1. Foundation Setting
- **1.1 Visioning and market study**
- 1.2 Community and stakeholder engagement
- 1.3 Funding and financing research
- 1.4 Roadmap creation

12 TO 24 MONTHS

2. Planning and Procurement
- 2.1 Facility and site assessment
- 2.2 Operations, fleet, and infrastructure plans
- 2.3 Procurement evaluation and requests for information/requests for proposals

3. Charging Infrastructure
- 3.1 Utility coordination for rates and interconnection requirements
- 3.2 Bus depot upgrades and solar pairing
- 3.3 Charger installation and evaluation

ONGOING

4. Testing and Training
- 4.1 Fleet and equipment testing
- 4.2 Driver and mechanic training

5. Deployment and Scaling
- 5.1 Fleet deployment
- 5.2 Monitoring, tracking, and reporting
- 5.3 Community outreach and sharing of lessons learned
- 5.4 Scaling strategy

Sources: WRI authors, based on technical assistance from the Electric School Bus Initiative.

- What types of funding are available (e.g., voucher, rebate, grant) to reduce the upfront price (Box 6)? Can incentives be stacked?
- How can electrification help increase access to school and after-school activities?
- What are your plans for retiring old diesel school buses?
- Who will be responsible for recycling bus batteries?
- Are you considering newly manufactured or repowered ESBs, or both?

Stage 2. Planning and Procurement

- Which models meet local restrictions and requirements (e.g., street width restrictions, heating and air conditioning requirements)?
- Which models meet your range needs?
- Which models best serve students with disabilities?
- Are there other features, such as Wi-Fi, that could benefit students and communities?

BOX 6

THE REAL COST OF ELECTRIC SCHOOL BUSES (IS LOWER THAN YOU THINK)

While the upfront price of ESBs is substantial, experts anticipate significant price declines over the next decade as battery costs decrease and the electric vehicle industry achieves efficiencies of scale in component markets and manufacturing. In fact, the real lifetime cost of ESBs can be much closer to that of their diesel counterparts due to significant savings on operational expenditures—such as fueling and maintenance—that build up over the years a vehicle is in use. These savings can range from an estimated $4,000 to $11,000 per school bus every year (depending on labor costs, local electric utility rates, and the price of petroleum fuels).[a] Market experts predict that the lifetime costs of ESBs will be around the same as diesel buses for new purchases starting between 2025 and 2030.[b] This total cost parity will be driven mainly by continuation of the precipitous decline in battery prices over the past decade and further development of new battery chemistries.[c]

Notes: [a] Levinson 2022.; [b] Smith 2019; Watson et al. 2020.; [c] BloombergNEF 2021.

Stage 3. Charging Infrastructure

- Questions for utilities:
  - ☐ Are you currently subject to “demand charges?”
  - ☐ Does your electric utility have an electric vehicle–specific time-of-use (TOU) rate?
  - ☐ Have you considered ongoing operations and maintenance of the charger and associated equipment through a service-level agreement with the charger network provider?
  - ☐ Does your electric utility offer bidirectional charging programs?
- What stakeholders will be important to engage beyond utilities (e.g., landlords if facility is leased, city agencies if building or electrical permits are required)?
- How might driver behavioral patterns, like park outs (drivers taking buses home at night), affect charging planning?
- How will charging infrastructure impact your school and surrounding community? Can charging be paired with renewables? Can infrastructure be installed near drivers’ homes in rural areas?
- Do you plan to use your buses as part of disaster response strategies?

Stage 4. Testing and Training

- How are employees being trained to work with this infrastructure (Box 7)? Who has access to training programs and new jobs?

Stage 5. Deployment and Scaling

- How is route electrification executed? Can routes that serve disadvantaged riders or drive through underserved communities be prioritized when electrifying?
- How can fleet electrification positively impact other energy- or sustainability-related goals?
- Can regional collaboration and support networks be formed among schools converting their fleets to electric to support field trips or sporting events (e.g., creating mutual aid networks for charging based on existing or new partnerships; see Box 3)?

BOX 7

LESSONS LEARNED ON THE ROAD TO ELECTRIFICATION IN CARMEL CLAY, INDIANA

Carmel Clay Schools received Indiana's first ESB in the summer of 2020. The school district is keen on finding new technologies to improve air quality and reduce emissions and has pursued alternative-fuel school buses for several years. After being awarded Volkswagen settlement funding, the school district paid the equivalent price of a diesel bus for a first-generation Type D electric bus.

In its year and a half of electric school bus operations, Carmel Clay has learned from several challenges, mostly operational issues affecting range and reliability. For example, in winter months, the bus's 12-volt onboard electric heater drained the battery faster than anticipated and it was a struggle to maintain temperatures above 40°F inside the cabin. To resolve the issue, the manufacturer performed several modifications, including rewiring the bus so the onboard battery did not draw as much power, but this adjustment did not fully resolve the issue.

Despite some challenges, Gary Clevenger, the assistant director of transportation and facilities for the school district, remains optimistic about the potential of ESBs. He believes that the predictability of school bus routes makes them particularly conducive to electrification if reliability issues can be addressed. However, he would like to see additional efforts to improve not just the technology itself but also the training provided to maintenance technicians, as much of the down time resulted from waiting for technicians trained to work with high-voltage equipment.

Source: Clevenger and Decker 2022.

3. SUMMARY OF AVAILABLE ELECTRIC BUS MODELS

As of January 2022, there were 22 models of ESBs available for purchase in the United States, and established manufacturers were expanding their offerings based on the potential growth of the ESB market. Electric models are available for Types A, C, and D school buses.[6] Among the available electric models, the Type C offerings are the most mature, or commercially ready. Manufacturers gauge commercial maturity as they move from pre-production assembly to full production, a process that achieves modest volumes and means a vehicle model is available for retail sale. Moreover, electric bus models that enter commercial production will have undergone multiple testing iterations prior to factory line assembly and are more mature as a later-generation product. Finally, a test of maturity can be applied to a supportive supply chain where manufacturers and their dealers establish formal maintenance networks to service ESBs after delivery. In today's market there are a mixture of early-stage ESB models that have not yet been deployed and mature models that are sold like conventional school bus models.

3.1 Newly Manufactured Electric School Buses

A newly manufactured bus is one that has been designed and built to operate with an electric powertrain from the ground up, with one exception being some electric Type A cutaway buses (see Type A). Although the purchase price of newly manufactured buses is currently around three to four times that of diesel buses—as batteries are more expensive than internal combustion engines and the market has yet to achieve economies of scale—the costs associated with operations and maintenance are substantially lower. According to one analysis, fueling and maintaining electric models could be less than half the cost of diesel over an expected lifetime of 12 years (Tables 2, 3 and 4; EDF 2021). When considering models, school districts should keep in mind the difference between a newly manufactured ESB and a repowered bus (see Section 3.2).

Type A

Type A buses are small, typically accommodating fewer than 36 passengers. There can be multiple entities involved in the construction of a Type A bus with different manufacturers responsible for different elements (e.g., the chassis, the powertrain, the body). Available electric models are presented in Table 2.

Type A buses are constructed using three distinct approaches:

- New repower cutaway: The diesel or gasoline powertrain is removed from a new internal combustion engine cutaway (usually produced by

Ford or General Motors) and replaced with an electric powertrain. A school bus body is attached to the new repowered cutaway.

- E-cutaway: The school bus body is attached to a new purpose-built, electric cutaway.
- Non-cutaway: The bus chassis, powertrain, and body are all assembled as a single integrated unit. The bus is not built on a cutaway platform. This model is comparable to Type C and D manufacturing.

Type C

Type C buses, with passenger capacities between 40 and 83 and a curved hood that increases front visibility, make up 70 percent of the overall school bus fleet (Matthews 2021). Type C offerings are the most mature for the ESB market and are listed in Table 3.

Type D

Type D, the largest of school buses seating up to 90 students, make up approximately 20 percent of the market (Matthews 2021). Electric offerings are presented in Table 4.

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A)

	Lightning eMotors[a]	Lion Electric	Micro Bird	Motiv[b]	Phoenix Motorcars[c]	COMING SOON	
						Endera	GreenPower
MODEL	ELECTRIC E-450	LIONA	MICRO BIRD G5	EPIC E-450	ZEUS 600	O-SERIES	NANO BEAST
BUILD TYPE	NEW REPOWER CUTAWAY	NON-CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	NEW REPOWER CUTAWAY	E-CUTAWAY
Price range[d]	*Not available*	$340,162–$343,162[e]	$236,390–$251,425[f]	Collins Bus: $300,784 Trans Tech: $322,015[g]	*Not available*	TBD	TBD
Length (L)/ width (W)/ height (H)[h]	L: 290″ W: 96″ Height not available	L: 313″ W: 96″ H: 111″	L: 283″ W: 96″ H: 113–118″	L: 288″ Width and height not available	L: 277″/288″ W: 96″ H: 120″	L: 288″ W: 98″ H: 108″	L: 300″ W: 91″ H: 124″
Passenger capacity	24	24	30	24	23	24	20
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CC1S	L2: J1772 DCFC: CCS1 or CHAdeMO	DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Coming 2022	Yes	Yes	*Not available*	Optional	Yes	Yes
Battery size (kWh)	120	84/168	88	127	94/125/156	151	118.2
Range (miles)	100	75/150	100	105	100/130/160	135	150

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A) (CONT.)

						COMING SOON	
	Lightning eMotors[a]	**Lion Electric**	**Micro Bird**	**Motiv**[b]	**Phoenix Motorcars**[c]	**Endera**	**GreenPower**
MODEL	**ELECTRIC E-450**	**LIONA**	**MICRO BIRD G5**	**EPIC E-450**	**ZEUS 600**	**O-SERIES**	**NANO BEAST**
BUILD TYPE	**NEW REPOWER CUTAWAY**	**NON-CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**NEW REPOWER CUTAWAY**	**E-CUTAWAY**
Battery thermal management	Dynamic liquid cooled system	Liquid cooled	Liquid cooled	*Not available*	Liquid cooled	Liquid cooled	PTC heating, liquid cooled
Recharge time	L2 (13.2 kW): 5.5–7.5 hours DCFC (80 kW max): 1.5 hours–2 hours	L2 (19.2 kW): 6.5–11 hours DCFC (24 kW): 5–9 hours or (50 kW) 2.5–4.25 hours	L2 (19.2 kW): 7 hours DCFC (50 kW): 2 hours	L2 (19.2 kW): 8 hours DCFC (60 kW): Charge time not available	L2 (13 kW): Depends on battery pack size DCFC (50 kW): Depends on battery pack size	Onboard AC charger (6.6 kW): 7 hours DCFC: (~50 kW) 2.5 hours or (~125 kW) 1 hour	L2 (11 kW): 11 hours DCFC (60 kW): 2 hours
Charge port location options	Front driver's side fender	Rear driver	Front nose	*Not available*	Front driver's side fender	Front grille	Front driver's side
Electric drivetrain (Mfr.)	Cascadia Motion	DANA TM4 SUMO-MD	EcoTuned	Motiv	Phoenix/TM4	Endera	TM4
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	2-speed	*Not available*	None (direct drive)	2-speed	None (direct drive)
Brakes (air/hydraulic)	Hydraulic	Hydraulic	Hydraulic	*Not available*	Hydraulic	Hydraulic	Hydraulic (front—disc; rear—drum)
Heat type (electric/diesel)	Electric	Auxiliary diesel or electric	Electric	*Not available*	Electric	Electric	Electric
Delivery time	2 months (dependent on chassis availability)	7–9 months	Up to 8 months	*Not available*	6 months	Expected production 2023	6 months (production TBD)
WARRANTY INFORMATION							
Battery	5 years/ 60,000 miles	8 years	8 years/ 100,000 miles	*Not available*	5 years/ 150,000 miles	5 years/ 100,000 miles	5 years/ 100,000 miles
Drivetrain	5 years/ 60,000 miles	5 years/ 160,000 miles	5 years/ 100,000 miles	*Not available*	5 years/ 60,000 miles	5 years/ 60,000 miles	3 years/ 150,000 miles

TABLE 2

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE A) (CONT.)

	Lightning eMotors[a]	Lion Electric	Micro Bird	Motiv[b]	Phoenix Motorcars[c]	COMING SOON	
						Endera	**GreenPower**
MODEL	**ELECTRIC E-450**	**LIONA**	**MICRO BIRD G5**	**EPIC E-450**	**ZEUS 600**	**O-SERIES**	**NANO BEAST**
BUILD TYPE	**NEW** **REPOWER** **CUTAWAY**	**NON-CUTAWAY**	**NEW** **REPOWER** **CUTAWAY**	**NEW** **REPOWER** **CUTAWAY**	**NEW** **REPOWER** **CUTAWAY**	**NEW** **REPOWER** **CUTAWAY**	**E-CUTAWAY**
WARRANTY INFORMATION							
Chassis	*Not available*	5 years	Body (1 year/12,000 miles) and structure (5 years)	*Not available*	3 years/36,000 miles	3 years/36,000 miles	3 years/250,000 miles
Additional	Bumper to bumper 3 years/36,000 miles	Up to 12 years	*Not applicable*	*Not available*	Bumper to bumper 3 years/36,000 miles	For the earlier of 2 years/75,000 miles, Endera warrants that all vehicle components will be free from defects	Additional warranties offered for various parts Extended warranties available case by case

Notes: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; PTC = positive temperature coefficient; DCFC = direct current fast charger; AC = alternating current; L2 = level 2 charger; Mfr. = manufacturer. [a] As of April 2022, WRI was aware of an established public relationship between Lightning eMotors and bus body manufacturer Collins Bus; [b] As of April 2022, WRI was aware of established public relationships between Motiv Power Systems and bus body manufacturers Collins Bus and Trans Tech; [c] As of April 2022, WRI was aware of an established public relationship between Phoenix Motorcars and bus body builder Pegasus Bus; [d] Based on lowest price authors found announced publicly to date. Prices are meant to be illustrative. School districts or contractors will need to work with a local dealer for an accurate price quote. Prices vary from state to state and depend on bus specification needs; [e] Lion: STBC 2020; DTS 2020; [f] Micro Bird: NYOGS 2022; KDE 2022.; [g] Motiv: NYOGS 2022; [h] State and city requirements and needs will influence a school district's dimension needs. For example, some geographies have a width maximum for school buses.

Sources: WRI author collaboration with Micro Bird, Lion, Phoenix Motorcars, Lightning eMotors, Endera, and GreenPower. Other information gathered from public specifications.

TABLE 3

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE C)

	Blue Bird	Lion	Thomas	IC Bus/Navistar	BYD
MODEL	**BLUE BIRD VISION**	**LIONC**	**SAF-T-LINER C2 JOULEY**	**IC CE SERIES ELECTRIC BUS/ PB10E**	**TYPE C**
Price range	$326,810–$365,000[a]	$338,253–$422,302[b]	$335,287–$437,000[c]	$347,870–$364,123[d]	Not available
Length (L)/width (W)/height (H)	L: Max 477″ W: 96″ H: 123″	L: 473″ W: 96–102″ H: 122″	L: 396″ W: 96″ H: 144″	L: 303.9″/474.9″ W: 96″ H: 123″	L: 435″/462″ W: 102″ H: 132.9″
Passenger capacity	77	77	81	29–72	78
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Optional	Yes	Optional
Battery size (kWh)	155	126/168	226	210/315	255.5
Range (miles)	120	100/125	138	135/210	155
Battery thermal management	Liquid cooled	Liquid cooled	Set to maintain 70°F battery temp	Set to maintain 70°F battery temp	Water cooling
Recharge time	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (19.2 kW): 6.5–11 hours DCFC: (24 kW) 5–9 hours or (50 kW) 2.5–4.25 hours	DCFC: (25 kW) 8.25 hours or (60 kW) 3.4 hours	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (20 kW max): 12.5–13 hours DCFC (150 kW): 1.5–2 hours
Charge port location options	Rear or front passenger side/front passenger side	Rear passenger, front nose, or both	Front passenger side—optional rear charge port curbside	Front right side—optional rear right side	Curbside rear
Electric drivetrain (Mfr.)	DANA TM4	DANA TM4 SUMO-MD	Proterra	DANA TM4 SUMO-MD	BYD
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	2-speed	None (direct drive)	None (direct drive)
Brakes (air/hydraulic)	Air disc or drum (hydraulic in 2022)	Hydraulic (air available)	Air	Air disc	Front/rear air disc, ABS
Heat type (electric/ diesel)	Electric (diesel supplemental heat option)	Auxiliary diesel or electric	Electric	Electric (optional diesel)	Electric or diesel
Delivery time	8 months	6–8 months	6–8 months	7–11 months	*Not available*

TABLE 3

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE C) (CONT.)

	Blue Bird	**Lion**	**Thomas**	**IC Bus/Navistar**	**BYD**
MODEL	**BLUE BIRD VISION**	**LIONC**	**SAF-T-LINER C2 JOULEY**	**IC CE SERIES ELECTRIC BUS/ PB10E**	**TYPE C**
WARRANTY INFORMATION					
Battery	8 years/125,000 miles/160,000 kWh discharge	8 years/160,000 kWh discharge (12-year extend available)	8 years/175,000 miles/200,000 kWh discharge	8 years/ 175,000 miles	15 years
Drive	5 years/ 100,000 miles	5 years/ 100,000 miles	5 years/ 100,000 miles (motor, transmission, inverter)	5 years/ 100,000 miles	5 years/ 250,000 miles
Chassis	Standard Blue Bird chassis warranty (5 years or more)	Standard warranty bumper to bumper (8 years)	3 years/ 50,000 miles	Standard IC Bus chassis warranty (5 years or more); basic chassis warranty is 1 year	12 years/ 500,000 miles
Additional	*Not applicable*	Extended warranties up to 12 years available	Extended warranties up to 12 years available	1 year/unlimited mileage for high-voltage steering pump, air compressor	*Not applicable*

Note: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; °F = degrees Fahrenheit; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Sources: WRI author collaboration with manufacturers listed in table. [a.] Blue Bird: Farquer 2021; NYOGS 2022; [b.] Lion: KCRISD 2020; HPS 2020; [c.] Thomas: Farquer 2021; Lydersen 2021; [d.] IC Bus/Navistar: NYOGS 2022; KDE 2022.

TABLE 4

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE D)

	Blue Bird	**Lion**	**GreenPower**	**BYD**
MODEL	**ALL-AMERICAN**	**LIOND**	**BEAST 90**	**TYPE D**
Price range	\$340,445–\$373,239[a]	Not available	\$371,900[b]	Not available
Length (L)/width (W)/height (H)	L: Max 489″ W: 96″ H: 123″	L: 473″ W: 102″ H: 122″	L: 480″ W: 102″ H: 138″	L: 435″/462″/486″ W: 102″ H: 132.9″
Passenger capacity	84	83	90	84
Charger connector	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1	L2: J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Yes	Optional
Battery size (kWh)	155	126/168	193.5	255.5
Range (miles)	120	100/125	150	155
Battery thermal management	Liquid cooled	Liquid cooled	PTC for heating, liquid cooled	Water cooling
Recharge time	L2 (19.2 kW): 8 hours DCFC (60 kW): 3 hours	L2 (19.2 kW): 6.5–11 hours DCFC: (24 kW) 5–9 hours or (50 kW) 2.5–4.25 hours	L2 (19.2 kW): 10.5 hours DCFC (60 kW): 3.5 hours	L2 (20 kW max): 12.5–13 hours DCFC (150 kW): 1.5–2 hours
Charge port location options	Rear of bus/front driver's side	Rear passenger	Rear driver's side	Rear curbside
Electric drivetrain (Mfr.)	DANA TM4	DANA TM4 SUMO-MD	TM4	BYD
Transmission (direct drive/2-speed)	None (direct drive)	None (direct drive)	None (direct drive)	None (direct drive)
Brakes (air/hydraulic)	Air (disc or drum)	Air	Air disk brakes, ABS	Front/rear air disc brakes, ABS
Heat type (electric/diesel)	Electric	Auxiliary diesel or electric	Electric	Electric or diesel
Delivery time	8 months	7–9 months	6 months	Not available
WARRANTY INFORMATION				
Battery	8 years/125,000 miles/160,000 kWh discharge	8 years/160,000 kWh discharge (12-year extend available)	5 years/100,000 miles	15 years
Drive	5 years/100,000 miles	5 years/100,000 miles	5 years/100,000 miles	5 years/250,000 miles

TABLE 4

AVAILABLE NEWLY MANUFACTURED ELECTRIC SCHOOL BUSES (TYPE D) (CONT.)

	Blue Bird	Lion	GreenPower	BYD
MODEL	**ALL-AMERICAN**	**LIOND**	**BEAST 90**	**TYPE D**
WARRANTY INFORMATION				
Chassis	Standard Blue Bird chassis warranty (5 years or more)	Standard warranty bumper to bumper (8 years)	3 years	12 years/500,000 miles
Additional	*Not applicable*	Up to 12 years	Additional warranties offered for various parts Extended warranties available case by case	*Not applicable*

Note: Abbreviations: TBD = to be determined; kWh = kilowatt-hour; PTC = positive temperature coefficient; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Sources: WRI author collaboration with manufacturers listed in table. [a.] Blue Bird: KDE 2022; NYOGS 2022; [b.] GreenPower: Walker 2020.

3.2 Repowered Electric School Buses (Types A, C, and D)

Electric repowering is the process of taking an existing school bus, removing the internal combustion engine components, and replacing them with a new electric powertrain and high-voltage battery (Kelly and Gonzales 2017).[7] Repowered buses can be half the price of a newly manufactured electric bus, be assembled in a shorter timeframe, and work within an existing fleet by extending the useful life of the bus body (Wachunas 2022). Additionally, repowered buses present an opportunity to reduce scrappage and waste—and with fewer components required to complete a build, repowers can limit susceptibility to supply chain delays. A fleet can consist of both repowered and newly manufactured buses as both use the same charging infrastructure.

As of April 2022, there were three companies offering repower solutions—SEA Electric, Unique Electric Solutions, and Lightning eMotors. Table 5 shows currently available options for repowered ESBs from these three manufacturers. As this approach grows in popularity and availability, repower kits, produced by these types of companies, could be used by entities such as dealers and post-production service providers to repower buses nationwide. A repower kit would include all the necessary components and software to fully integrate a new electric powertrain into an existing bus.

Even with this range of benefits, ESB repowering is not without its own set of challenges. On the regulatory side, some states have regulations capping school bus age. In those states, the potential for repowering is limited because buses generally retain their vehicle identification number and therefore their age is not reset after being repowered. Additionally, not all federal funding streams for ESBs can currently be applied to repowers. As of April 2022, repowers remained an emerging solution that could bring dramatic cost savings but had not yet experienced scaled deployment. As this solution matures, it is expected that repowers will play an important role in supporting the full electrification of school bus fleets. Notable commitments include Unique Electric Solutions' deployment of five repowered Type C buses in New York City and SEA Electric's deal with Midwest Transit Equipment to repower 10,000 school buses through 2026.

TABLE 5

AVAILABLE REPOWERED ELECTRIC SCHOOL BUSES (TYPES A, C, AND D)

	SEA Electric				Unique Electric Solutions			Lightning eMotors
MODEL	**SEA DRIVE 70A/SEA DRIVE 100A/ SEA DRIVE 100B**	**SEA DRIVE 120A/SEA DRIVE 120B/ SEA DRIVE 120C**	**SEA DRIVE 180A**	**SEA DRIVE 180B**	**UNIQUEEV PLATFORM—TYPE A**	**UNIQUEEV PLATFORM—TYPE C**	**UNIQUEEV PLATFORM—TYPE D**	**ELECTRIC E450**
BUS TYPE (A, C, D)	**A**	**C**	**C AND D**	**D**	**A**	**C**	**D**	**A**
Manufacturer list price	Work with local dealer				$85,000	$125,000	$150,000	$119,900 (powertrain only)
Charger model	SAE J1772 compliant				Compatible with all major brands			Compatible with all major brands
Charger connector	L2: Type 1, Single Phase (208/240 VAC) up to 19.2 kW DCFC (optional): provided through standard CCS1 (Type A, up to 100 kW)				L2: SAE J1772 DCFC: CCS1			L2: SAE J1772 DCFC: CCS1
Capable of bidirectional charging	Yes	Yes	Yes	Yes	Yes			Yes
Battery size (kWh)	88–100	138	220	220	Up to 100	Up to 200	Up to 200	120
Range (miles)	Not available	170–200	Not available	Not available	Up to 180			100
Battery thermal management	Engineered out the need for thermal management				Yes			Dynamic liquid cooled system
Charge port location options	Flexible charge port location				Front, back, left, right	Front, back, right	Front, back, right	Front driver fender
Electric drive-train (Mfr.)	JJE/Dana/provider agnostic				Unique Electric Solutions			Cascadia Motion
Transmission (direct drive/2-speed)	None (direct drive)				None (direct drive)	Direct drive or 2-speed	Direct drive or 2-speed	None (direct drive)
Brakes (air/ hydraulic)	Hydraulic	Hydraulic/air	Air	Air	Hydraulic	Air	Air	Hydraulic
Heat type (electric/ diesel)	Electric				Either electric or fuel fired			Electric driver and cabin heat

TABLE 5

AVAILABLE REPOWERED ELECTRIC SCHOOL BUSES (TYPES A, C, AND D) (CONT.)

	SEA Electric				**Unique Electric Solutions**			**Lightning eMotors**
MODEL	**SEA DRIVE 70A/SEA DRIVE 100A/ SEA DRIVE 100B**	**SEA DRIVE 120A/SEA DRIVE 120B/ SEA DRIVE 120C**	**SEA DRIVE 180A**	**SEA DRIVE 180B**	**UNIQUEEV PLATFORM—TYPE A**	**UNIQUEEV PLATFORM—TYPE C**	**UNIQUEEV PLATFORM—TYPE D**	**ELECTRIC E450**
BUS TYPE (A, C, D)	**A**	**C**	**C AND D**	**D**	**A**	**C**	**D**	**A**
Delivery timeline	Electrify in less than 1 month				1–1.5 months			2 months (dependent on chassis availability)
WARRANTY INFORMATION								
Battery	8 years (optional extension up to 12 years)				Up to 8 years			5 years/ 60,000 miles
Drive	3 years/50,000 miles				Up to 8 years			5 years/ 60,000 miles

Note: Abbreviations: kWh = kilowatt-hour; DCFC = direct current fast charger; L2 = level 2 charger; Mfr. = manufacturer; ABS = antilock braking system.

Source: WRI author collaboration with manufacturers listed in table.

4. CONCLUSION

Although school bus electrification is still in its early stages, the school transportation industry has made considerable progress since the first ESBs were deployed in 2014. In particular, the ESB model range has grown—from 60 to 100 miles during Kings Canyon's and Escondido's 2014 deployments to models today that offer between 75 and 210 miles in range—enough to cover 99 percent of routes in the United States (STN 2021a). These vehicles were once limited to a handful of pilot programs, but by March 2022, the number of school districts procuring electric models and integrating them into their fleets had grown to 415. At the same time, the number and production capacity of ESB manufacturers has grown substantially, and vehicle features, such as range and bidirectional charging, have improved considerably. As of January 2022, manufacturers offered 22 models of ESBs across Type A, C, and D school buses with more expected to enter the market. Like any new technology, there are still barriers to adopting these buses, such as high upfront bus prices and new infrastructure needs, reliability issues with earlier bus models, and insufficient access to specialized maintenance and technical support. However, ESBs could provide a number of benefits, such as lowering operations and maintenance costs, reducing pollution and emissions, improving students' health and academic outcomes, and bolstering resilience. As school districts navigate this growing market, we hope this publication and its future updates will serve as a valuable resource for school transportation providers interested in adopting electric school buses.

APPENDIX A.
KEY TERMS AND DEFINITIONS: COMPARING DIESEL AND ELECTRIC SCHOOL BUSES

The following tables provide key terms, units, definitions, and parallels to diesel operations, where applicable, for ESBs. Table A1 defines terms, and Table A2 defines units.

TABLE A1

ELECTRIC SCHOOL BUS KEY TERMS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS

Term	Definition	Parallel to Diesel (if applicable)	Reference or Example
state of charge (SOC)	For buses: The charge level of the battery	Fuel tank level (full/half/empty)	SOC refers to the level of charge left in the battery, which ranges from 0 to 100% or empty to full on the dashboard.
state of health (SOH)	For buses: Battery health and useful life	No exact diesel parallel; however, general wear and tear has similarities	SOH refers to the maximum charge or capacity of the battery over time and use. Repeated complete discharge or use of a full battery charge (i.e., running until empty) can accelerate battery degradation. Degradation is a normal part of the battery life cycle and will decrease gradually over time.
alternating current (AC)	For chargers: A type of electrical current associated with the charger	Refueling—a diesel pump and hose equate to a charger and connector cable	AC is used to describe the electrical current coming from the grid into a charger. It typically takes longer to charge a bus (8 hours) using AC and likely requires overnight charging but is cheaper than fast chargers with regard to hardware, installation, and utility upgrades.
direct current (DC)	For chargers: A type of electrical current associated with the charger	Refueling—a diesel pump and hose equate to a charger and connector cable	DC is used to describe the electrical current coming from a charger into the bus. Unlike AC chargers, DCFCs deliver DC current directly to the battery so they can charge school buses at faster rates (1.5–4 hours). Fast charging is approximately 8–10 times the cost of L2 charging for the hardware and may incur additional demand charges for electricity. Fast charging may have more of a detrimental effect on battery life and longevity.
bidirectional charging capacity	For buses and chargers: Allows vehicles to both receive and deliver energy externally (V2G, V2B, V2L—collectively V2X)	Unique to electric vehicles	Vehicle-to-grid (V2G): Stored energy is delivered back through facility infrastructure (reverse power flow) to the grid. Vehicle-to-building (V2B): Stored energy in the vehicle is delivered to a facility/building, enabling the bus to serve as an emergency power source. Vehicle-to-another-load (V2L): V2L allows the bus to serve as a mobile charging source to power another load.

Note: Abbreviations: AC = alternating current; DCFC = direct current fast charger; L2 = level 2.

Sources: WRI authors; CTE 2020; KCM 2020; Aamodt et al. 2021.

TABLE A2

ELECTRIC SCHOOL BUS KEY UNITS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS

Unit	Definition	Parallel to Diesel (if applicable)	Reference or Example
kilowatt (kW)	For buses: Measure of power	Horsepower (HP)	Manufacturers specify a bus motor's power in kW. For example, a typical electric motor can provide 230 kW (308 HP).
	For chargers: Measure of power	No diesel parallel	Different vehicle chargers can deliver electricity at different power levels.
kilowatt-hour (kWh)	For buses: Measure of battery pack energy capacity either as rated (advertised total battery capacity for vehicle), usable (actual accessible battery capacity for operating), or passively consumed (while bus is not driving but still powered on) Unit can be used to measure range in miles	Fuel tank capacity (gallons)	Manufacturers specify an electric bus's range in kWh. For example, a typical ESB uses a 150 kWh battery pack with an 80-to-120-mile range (depending on conditions) and a typical diesel bus has a 60-gallon diesel tank with a 450-mile range. This equates to approximately 1.3 kWh/mile for an ESB and 7.5 miles/gallon for a diesel bus. Today's ESB models have the range to serve more than 90% of routes in the United States.
	For chargers: Kilowatts multiplied by total hours, which is a measure of energy	Gallon or liter of fuel	kWh are measured by a utility and charged to customers on their electricity bills.
kWh per mile (kWh/mi)	For buses: The battery capacity (kWh) used for every mile driven Unit can be used to measure efficiency	Miles per gallon	Efficiency can be calculated by dividing the battery pack size by the range. For a typical 150 kWh battery pack with a stated range of 100 miles, the bus would have an efficiency of 1.5 kWh per mile (150 kWh/100 miles = 1.5 kWh/mile). Models described in this report range between 0.78 and 1.61 kWh per mile. However, efficiency is route and climate dependent and impacted by use of air conditioning, heat, or other factors. The greater the efficiency, the lower the energy cost per mile—efficiency can be further improved by efficient driving.
amperes (amps)	For buses and chargers: Measure of electrical current	Both diesel and electric buses have components that are measured in amps—some applications vary	Amps are an important unit for measuring utility capacity to support chargers. For example, each L2 charger requires approximately 40–60 amps while each DC fast charger requires a minimum of 120 amps.
volts (V)	For buses and chargers: Measure of electric potential or electromotive force	Both diesel and electric buses have components that are measured in volts—some applications vary	Voltage varies by battery size and state of charge. For example, both diesel and electric buses have a 12 V battery to power low-voltage components like the radio, clocks, and lights—this battery also provides the starter motor and spark plugs with the energy needed to start an internal combustion engine. With regard to charging, L2 chargers typically use a 208 or 240 V AC power and DC fast chargers can use 200–600 V DC power.

TABLE A2

ELECTRIC SCHOOL BUS KEY UNITS, DEFINITIONS, AND PARALLELS TO DIESEL OPERATIONS (CONT.)

Unit	Definition	Parallel to Diesel (if applicable)	Reference or Example
acceptance rate	For buses: The power the bus can receive from the charger	No diesel parallel	For example, if the acceptance rate is 9.6 kW, the maximum power the vehicle can draw is 9.6 kW.
delivery rate	For chargers: The power the charging station can deliver to the vehicle	No diesel parallel	For example, if the delivery rate is 9.6 kW, the maximum power the charging station can deliver is 9.6 kW even though the vehicle might be able to accommodate higher-level charging.

Note: Abbreviations: ESB = electric school bus; L2 = level 2; DC = direct current; AC = alternating current.

Sources: WRI authors; CTE 2020; KCM 2020; Aamodt et al. 2021.

APPENDIX B. ADDITIONAL RESOURCES

Additional resources that can provide information on ESBs include the following:

World Resources Institute Resources

- Homepage, Electric School Bus Initiative: https://www.wri.org/insights/where-electric-school-buses-us
- Blog Post: "The State of Electric School Bus Adoption in the US" with accompanying dataset—dataset and visualization of ESB adoption nationwide (blog: https://www.wri.org/insights/where-electric-school-buses-us; dataset: https://datasets.wri.org/dataset/electric_school_bus_adoption)
- Highlight Stories—school district experiences with deployment of ESBs including in Stockton, California (https://www.wri.org/update/electric-school-bus-series-stockton-california), Knox County, Missouri (https://www.wri.org/update/electric-school-bus-series-knox-county), and Fairfax County, Virginia (https://www.wri.org/update/electric-school-bus-series-electrifying-partnership-fairfax-county-virginia)

Webinar Recordings and Presentations

- CTE. 2020. "Electric School Bus Webinar Series." https://cte.tv/ctes-electric-school-bus-webinar-series/—Three parts: buses, charging, and costs and funding
- Vermont Energy Investment Corporation. 2019. "Electric School Bus Planning and Lessons Learned." https://www.veic.org/clients-results/reports/electric-school-bus-resources—Webinar
- Dallas Fort Worth Clean Cities. 2022. "EV School Bus." https://www.dfwcleancities.org/events—Three-part webinar series

Electric School Bus Reports and Resources

- Alliance for Electric School Buses. 2022. Washington, DC: electricschoolbuses4kids.org—Resources for advocates and other members of the community.
- Bellwether Education Partners. 2019. From Yellow to Green: Reducing School Transportation's Impact on the Environment. Sudbury, MA: Bellwether Education Partners. https://bellwethereducation.org/sites/default/files/Bellwether_WVPM-YellowToGreen_FINAL.pdf—Examines cases of ESB pilots, pros and cons of impact reduction strategies, funding streams, and recommended next steps for states and districts
- CALSTART. 2021. Zeroing In on Electric School Buses—The Advanced Technology School Bus Index: A U.S. ESB Inventory Report. Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2022/01/ZIO-Electric-School-Buses-2021-Edition.pdf—Inventory of the number of ESBs currently present within the United States
- CALSTART. 2021. Electric School Bus Market Report. Pasadena, CA: CALSTART. https://calstart.org/wp-content/uploads/2021/12/Electric-School-Bus-Market-Report-2021.pdf—Includes vehicle design and model availability, cost considerations, demonstration case studies, and funding opportunities
- Electrification Coalition. 2021. "Dashboard for Rapid Vehicle Electrification (DRVE Tool)." Washington, DC: Electrification Coalition. https://www.electrificationcoalition.org/resource/drve/—Microsoft Excel–based tool that can evaluate a variety of procurement ownership structures, vehicle types, electric vehicle charging configurations, and other scenarios

- Jobs to Move America. 2022. Driving the Future: How to Electrify Our School Buses and Center Kids, Communities, and Workers in the Transition. Los Angeles, CA: Jobs to Move America. https://jobstomoveamerica.org/resource/driving-the-future-how-to-electrify-our-school-buses-and-center-kids-communities-and-workers-in-the-transition/—Insights from conversations with school districts, private fleet operators, utilities, worker organizations, and others; provides an overview of the state of ESB technology, workforce impacts, and opportunities and policy implications
- Oregon Department of Energy. 2022. Guide to School Bus Electrification. Salem, OR: Oregon Department of Energy. https://www.oregon.gov/energy/energy-oregon/Documents/2022-Jan-14-School-Bus-Electrification-Guidebook.pdf—Guide to school districts on the benefits and challenges of electric buses, how to get started, selecting a manufacturer, and more
- School Transportation News. 2022. 2022 Buyers Guide. https://content.yudu.com/web/1qiu9/0A1rp8i/bg22/html/index.html?origin=reader—School—Bus buyer's guide including but not limited to electric variants, with contact information for manufacturers and dealers
- U.S. PIRG and Environment America. 2021. Accelerating the Transition to Electric School Buses. https://environmentamericacenter.org/sites/environment/files/reports/US_EL%20buses%202021%20Final.pdf—How schools, lawmakers, and utilities can work together to speed the transition to zero-emission buses
- Vermont Energy Investment Corporation. 2019. "Electric School Bus Resources." https://www.veic.org/clients-results/reports/electric-school-bus-resources—Resources include bus model comparisons, utility bill considerations, a charging guide, funding tips, and fuel comparisons
- Vermont Energy Investment Corporation. 2018. Electric School Bus Pilot Evaluation. Winooski, VT: VEIC. https://www.veic.org/clients-results/reports/electric-school-bus-pilot-project-evaluation—Pilot project was a first-of-its-kind deployment of ESB technologies in cold weather environments in the United States

Electric School Bus Manufacturer Websites

- Blue Bird (https://www.blue-bird.com/buses/electric-school-buses)
- BYD (https://en.byd.com/bus/school-bus/)
- Endera (https://enderamotors.com/)
- GreenPower (https://greenpowermotor.com/gp-products/beast-school-bus/)
- IC Bus/Navistar (https://www.icbus.com/electric)
- Lightning eMotors (https://lightningemotors.com/e-450-school-bus/)
- Lion (https://thelionelectric.com/en/products/electric)
- Micro Bird (https://www.microbird.com/our-buses/G5-Electric)
- Motiv (https://www.motivps.com/application/electric-school-bus/)
- Phoenix Motorcars (https://www.phoenixmotorcars.com/products/)
- SEA Electric (https://www.sea-electric.com/products/industries-applications/)
- Thomas Built Buses (https://thomasbuiltbuses.com/electric-school-buses/electric-bus/)
- Unique Electric Solutions (https://www.uesmfg.com/electric-school-bus-conversions/)

GLOSSARY

alternating current/direct current (AC/DC) charging: Buses that use level 2 chargers powered by AC input require an onboard charger built into the bus. This converts the AC current to DC before reaching the battery. Buses using DC fast chargers do not require an onboard charger as the external charger can charge the battery directly.

battery thermal management: Vehicles have a cooling and heating system to maintain a specific battery pack temperature range during operation and charging based on the manufacturer's design. This helps the batteries operate safely and maintain peak performance.

brakes (air/hydraulic): The vehicle braking system uses either air or brake fluid (hydraulic) to compress the brakes. This impacts the required skills needed to maintain the vehicles. Air brakes require the use of an air compressor, which draws from the battery and may impact advertised range. Vehicles with air brakes require a specialized license to operate.

capable of bidirectional charging: Buses that are capable of vehicle-to-grid (V2G), vehicle-to-building (V2B), and vehicle-to-another-load (V2L) are also referred to as being capable of bidirectional charging because of the two-way flow. A vehicle capable of V2G/V2B/V2L (collectively V2X) can serve as a clean energy asset through energy storage, which can produce energy cost savings depending on time of charge and discharge.

charger port: The charger port delivers electric current from the charging hardware to the battery. The charger cable connection type is specific to the vehicle. It is best for fleets to use the same charger connector, but adaptors are available. SAE J1772 is the industry standard for level 2 (L2) charger connectors. Direct current fast chargers can use either a CHAdeMo or CCS connector. While the CCS plug allows for alternating current and direct current charging on the same port (i.e., L2 or direct current fast charging) as ports come with both CCS and J1772 plugs, CHAdeMo would require an additional J1772 connector to charge with L2.

heat type (electric/diesel): The heating of the vehicle can be either electric powered or fuel (diesel) powered for driver and/or cabin heat. The manufacturer should be consulted on whether heat pumps should be used to achieve the desired results.

managed charging: Managed charging refers to any form of control over when vehicles are charging, integrated either into the charger itself or through some outside switch, which allows the site owner to remotely control activation and deactivation of the charger. Proper application of managed charging not only enables the site owner to take advantage of potential cheaper energy but may also allow for planned fleet management where higher-priority vehicles are charged first. Networked and controlled charging may also offer the ability to distribute charging across the chargers in use so that higher energy is provided to a smaller number of vehicles: As more vehicles plug in, the total available energy can be distributed at a lower level to more vehicles. This scenario can work well for overnight charging where vehicles sit for long periods without use. Overall, managed charging offers site owners and fleet managers many more options to optimize fleets than chargers without controls.

park out: In some circumstances, for operational efficiency or convenience, some school bus operators allow buses to be parked in remote locations between shifts or overnight. This could include being parked at or near a driver's home. These operating conditions need to be considered when planning for charging infrastructure. Solutions could include utilizing public charging or installing chargers at other sites such as schools or drivers' homes.

range: Battery capacity, which influences range, can be broken into two components: rated capacity and usable capacity. The rated capacity captures the advertised total capacity of the vehicle while the usable capacity is the actual accessible battery capacity for operating (i.e., some manufacturers may reserve 10 percent of the battery for critical loads). For example, if a school bus is advertised as having 150 kilowatt-hours (kWh) of battery capacity, only 90 percent (135 kW) may be accessible for driving. Range can also be impacted by idling—there are significant potential cost and emission savings for vehicles that idle often, like school buses. Rated and usable capacity and energy used idling are all measured in kWh.

regenerative braking: Regenerative braking is a braking system unique to vehicles with electric motors that converts the vehicle's kinetic energy during braking directly into electrical energy that can be used to recharge the battery pack. It allows electric vehicles to recoup some of the energy that would otherwise be wasted as the vehicle decelerates. This improves overall efficiency and range.

time-of-use (TOU) rates: Through TOU rates, utilities charge a customer on total energy consumed based on the time of day the energy is used. Utilities send price signals to customers to shift consumption from when electricity demand is high to times of day when energy supply is the least expensive to produce or most abundant from specific resources. Customers can save money if they align consumption with off-peak times. Often, TOU rates are designed specifically to support programs like electric vehicle charging or to encourage use of abundant renewable energy. TOU rates vary by region and utility, and not all utilities offer TOU rates.

transmission (direct drive/2-speed): Transmission refers to the transmission of power from the motor to the wheels. Options include direct drive (short drive shaft) and multi-speed transmission.

ENDNOTES

1. An ESB is considered “committed” starting from the point when a school district or fleet operator has been awarded funding to purchase it or has made formal agreement to purchase it from a manufacturer or dealer. We would not consider an ESB committed if a school district or other fleet operator only expressed interest in ESBs or stated that they plan to acquire ESBs, without awarded funding or an agreement with a third party. More information can be found in L. Lazer and L. Freehafer, *Technical Note for a Dataset of Electric School Bus Adoption in the United States* (Washington, DC: World Resources Institute, 2022), https://www.wri.org/research/technical-note-dataset-electric-school-bus-adoption-united-states.

2. Compared with newly manufactured school buses that are built as electric from the start, a repowered bus removes a vehicle’s existing engine and replaces it with a new engine or power source (e.g., an electric drive system). See Section 3.2 for greater detail on repowered buses.

3. More resources from the Electric School Bus Initiative can be found at https://www.wri.org/initiatives/electric-school-bus-initiative.

4. As part of the settlement between Volkswagen and the federal government following allegations that Volkswagen violated the Clean Air Act by selling vehicles equipped with “defeat devices” (i.e., computer software designed to cheat on federal emissions tests), Volkswagen will contribute to an Environmental Mitigation Trust to provide states, territories, and tribes funding to mitigate sources of nitrogen oxides. Each state designated a lead implementing agency, conducted stakeholder meetings, and submitted a state action plan (also known as a Beneficiary Mitigation Plan, or BMP) for use of the funds. One of the eligible mitigation actions was the replacement of school buses. To date, Volkswagen settlement funds have been a critical source of state funding for transportation electrification. More information can be found in K. McLaughlin and J. Balik, *5 Ways US States Can Get More Electric School Buses on the Road* (Washington, DC: World Resources Institute, 2022), https://www.wri.org/insights/how-states-can-transition-electric-school-buses, and Environmental Protection Agency, *Volkswagen Clean Air Act Civil Settlement* (Washington, DC: Environmental Protection Agency, n.d.), https://www.epa.gov/enforcement/volkswagen-clean-air-act-civil-settlement.

5. Electric school buses were considered part of the same batch if any of their time-series data (when they were first awarded, ordered, delivered, or operating) occurred in the same quarter or in adjacent quarters. Batches can consist of ESBs in any phase of the adoption process, meaning that not all are currently in operation. Original analysis was conducted by the Electric School Bus Initiative based on WRI’s Dataset of Electric School Bus Adoption in the United States: https://datasets.wri.org/dataset/electric_school_bus_adoption.

6. There are currently no electric models available for Type B school buses as the United States no longer produces Type B school buses for any fuel type.

7. Certain specifications for repowers depend on the vehicle being used, which is why we have removed certain specifications such as passenger capacity, length/width/height, and recharge time.

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ABOUT THE AUTHORS

Alissa Huntington is a research analyst for the Electric School Bus Initiative at the WRI Ross Center for Sustainable Cities.

Jessica Wang is a technical associate for WRI's Electric School Bus Initiative.

Phillip Burgoyne-Allen is a technical associate with the Electric School Bus Initiative.

Emmett Werthmann is a research and engagement analyst with the Electric School Bus Initiative.

Eleanor Jackson is the electric mobility research and communications analyst for the WRI Ross Center for Sustainable Cities.

ABOUT WRI ELECTRIC SCHOOL BUS INITIATIVE

In collaboration with partners and communities, the Electric School Bus Initiative aims to build unstoppable momentum toward an equitable transition of the U.S. school bus fleet to electric by 2030, bringing health, climate, and economic benefits to children and families across the country and normalizing electric mobility for an entire generation. We are working with key stakeholders at all levels and across areas, including school districts, private fleet operators, electric utilities, public and private lenders, manufacturing organizations, policymakers, program administrators, and community members and groups.

ABOUT WRI

World Resources Institute (WRI) is a global research organization that spans more than 60 countries, with international offices in Brazil, China, India, Indonesia, Mexico, and the United States, regional offices in Ethiopia (for Africa) and the Netherlands (for Europe), and program offices in the Democratic Republic of Congo, Turkey, and the United Kingdom. Our more than 1,000 experts and staff turn big ideas into action at the nexus of environment, economic opportunity, and human well-being. More information at www.wri.org.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

PHOTO CREDITS

COVER
Sue Gander

PAGE 2
FatCamera/iStock

WORLD
RESOURCES
INSTITUTE

10 G STREET NE
SUITE 800
WASHINGTON, DC 20002, USA
+1 (202) 729-7600
WWW.WRI.ORG

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Attachment 3

DEQ Summary and Detailed Reports

Project Name: Transit Bus Electrification **Run Date:** 03/06/2023

Total Project Funding: $ 800,000

Summary Emission Results[1] for Project:

Annual Results (short tons)[2]	**NO_x**	**PM2.5**	**HC**	**CO**	**CO_2**	**Fuel**[3]
Baseline for Project	0.123	0.000	0.002	0.086	69.0	6,131
Amount Reduced After Upgrades	0.123	0.000	0.002	0.086	69.0	6,131
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline for Project	0.614	0.001	0.011	0.428	344.9	30,655
Amount Reduced After Upgrades	0.614	0.001	0.011	0.428	344.9	30,655
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$1,303,111	$905,352,448	$70,002,749	$1,869,489	$2,320	
Total Cost Effectiveness[4] (includes all project costs)	$1,303,111	$905,352,448	$70,002,749	$1,869,489	$2,320	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Detailed Emission Results[1] for Municipal Bus (1 Unit):

Annual Results (short tons)[2]	**NO_x**	**PM2.5**	**HC**	**CO**	**CO_2**	**Fuel**[3]
Baseline of Group	0.123	0.000	0.002	0.086	69.0	6,131
Amount Reduced After Upgrades	0.123	0.000	0.002	0.086	69.0	6,131
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline of Group	0.614	0.001	0.011	0.428	344.9	30,655
Amount Reduced After Upgrades	0.614	0.001	0.011	0.428	344.9	30,655
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$1,303,111	$905,352,448	$70,002,749	$1,869,489	$2,320	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Inputs:

Municipal Bus (1 Unit):

Type: Onroad	**Fuel Type:** ULSD (diesel)
Target Fleet: Transit Bus	**Annual Fuel Gallons:** 6,131
Class: Class 8	**Diesel-equivalent Gallons:** 6,131
Quantity: 1	**Annual Miles Traveled:** 44,782
Engine Model Year: 2018	**Annual Idling Hours:** 340
Upgrade Year: 2024	
Remaining Life: 5	

Vehicle Replacement:

Upgrade: Vehicle Replacement - All-Electric

Upgrade Cost per Unit: $800,000 **Labor Cost per Unit:** $0

Percent Reduction: **NOx:** 100% **PM2.5:** 100% **HC:** 100% **CO:** 100% **CO_2:** 100%

TRANSIT BUS SPECIFICATION

TECHNICAL INFORMATION TO BE FURNISHED BY CONTRACTOR WITH RESPONSE FOR EACH VEHICLE Enter "N/A" where not applicable

A. Bus Manufacturer New Flyer of America Inc.
B. Bus Model Number 35' Xcelsior CHARGE™ (XE35)
C. Dimensions
1. Overall Length: a. Over Bumpers 36 ft. 3 in. b. Over Body 35 ft. 5 in.
2. Overall Width: a. Over Body excluding Mirrors 8 ft. 6 in., b. Over Body including Mirrors 11 ft. 0 in., c. Over Tires 8 ft. 5 in.
3. a. Over Height (Maximum) 11 ft. 1 in., b. Over Height (Main Roof Line) 10 ft. 8 in.
4. Angle of Approach 9 Deg., 5. Breakover Angle N/A Deg., 6. Angle of Departure 9 Deg.
7. Doorway Clear Opening (including grab handles) a. Front: Width 33.8 in. Height 77.3in. b. Rear: Width 34.8in. Height 77.3 in.
8. Floor Height from Ground: Front Entrance: a. (Kneeled) 10 in., b. Ride Height 14 in.,
Rear Exit: a. (Kneeled) 10 in., b. Ride Height 14 in.
9. Overhand, centerline of Axle Over Bumper: a. Front - ft. 15.5 in., b. Rear - ft. 15.5 in.
10. Floor: a. Interior Length 29 ft. 5.5 in.: b. Interior Width 8 ft. 0 in.
11. Seats: a. No. of Seats (No wheelchairs) 32, b. No. of Seats (With wheelchairs) 26, c. No. of Wheelchairs 2
12. a. Minimum Knee to Hip Room 27.57 in., b. Minimum Foot Room 10 in.
13. Interior Head Room (center of aisle) a. Front Axle Location 79 in., b. Rear Axle Location 79 in.
14. Aisle Width Between Seats (Minimum) 20.88 in. 18. Wheel Base ____ ft. 283.75 in.
15. Floor Height Above Ground (at each door): a. Front Door 15.5 in., b. Rear Door 15.5 in.
16. Minimum Ground Clearance (between bus found with bus unkneeled) 10 in.
17. Turning Envelope: a. Outside Body Turning (including bumper radius) 43 ft. 0 in.,
b. Inside Turning Radius 22 ft. 2 in.

D.	Weight of Bus	Wet Weight	GVWR
1.	Front Axle	11.700	15.873
2.	Rear Axle	22.180	28.660
3.	Total	33.880	44.533

E. Engine
1. Manufacturer Siemens E-Drive
2. Type and weight rating ____
3. Model number 1DB2016
4. Net SAE horsepower 561 V / peak power 190 kW
5. Net SAE torque 1770 ft. lbs

F. Hybrid Drive or Transmission
1. Manufacturer N/A, 2. Type ____
3. Model Number ____, 4. Speeds ____,
5. Gear Ratios: Forward ____ Reverse ____
6. Shift Speeds: a. 1st - 2nd ____, b. 2nd - 3rd ____, c. 3rd - 4th ____, d. 4th - 5th ____
7. Oil Capacity (including Heat Exchanger) ____ gals.,
8. Retarder: Make, Type and Size ____, ____, ____

G. Voltage Regulator
1. Manufacturer N/A
2. Model N/A

H. Voltage Equalizer
1. Manufacturer Vanner Power Group
2. Model P/N 80-80-015-2-LVD Software: A817388-E

I. Alternator
1. Manufacturer Vanner EBA, 2.Type Electric Beltless Motor, 3. Model ____

4. Output at Idle 300 Amps, 5. Output at Maximum Speed 300 Amps
6. Maximum Warranted Speed N/A RPM, 7. Speed at Idle N/A RPM
8. Drive Type N/A , 9. Cooling Type ________

J. Air Compressor
1. Manufacturer Powerex , 2. Type Direct Coupled Scroll Compressor, 3. Capacity, at Idle N/A cfm
4. Capacity, at Maximum Speed N/Acfm, 5. Maximum Warranted Speed 3450 RPM
6. Speed Idle N/A , 7. Drive Type Direct coupled air compressor powered by electric motor

K.A xle, Front
1. Manufacturer MAN , 2.Type Reverse Elliot Cast Beam, Drop Center
3. Model Number VOK-07-F , 4.Gross Axle Weight Rating 15,873 lb.

L. Axle, Rear
1. Manufacturer MAN , 2.Type Single Reduction, Driven
3. Model Number HY-1350-F , 4.Gross Axle Weight Rating 28,660 lb.

M. Drive Axle Ratio
1. Axle Ratio 5.67:1 , 2.Final N/A

N. Suspension System
1. Manufacturer New Flyer of America , 2.Type 2 Pneumatic Firestone (Front), 4 Pneumatic Firestone (Rear)
3. Springs: 2 Koni (Front), 2 Koni (Rear)

O. Wheels
1. Make Alcoa 2. Size 22.5" x 8.25" 3. Capacity 7,824
4. Material Aluminum Buffed

P. Tires
1. Manufacturer Michelin 2. Type X InCity Z 3. Size 305/70R22.5
4. Load Range/Air Pressure L/125 PSI

Q. Steering Power
1. Pump
a. Manufacturer & Model No. Parker Hannifin
b. Type DC 3-Phase Brushless with DC Drive Controller
c. Relief Pressure 2,175 psi

2. Booster
a. Manufacturer & Model No. Sheppard
b. Type Recirculating Ball
c. Ratio 23:1

3. Power Steering Fluid Capacity 6 gals.

4. Effort at Steering Wheel 9 lb.
(Unloaded Stationary Bus on dry asphalt pavement)

R. Brakes
1.Make of Fundamental Brake System
MGM
2.Brake Chamber Vendor's Size & Part No.
a. Front 1627717 & 1627718
b. Rear ________

5. Brake Block Manufacturer Ferodo 4567
7. Brake Blocks Per Shoe
a. Front 2
b. Rear 2

3. Slack Adjusters Vendor's Type & Part No.
a. Front
1. Right MAN N2G
2. Left MAN N2G

b. Rear

1. Right MAN N2G
2. Left MAN N2G
c. Length
1. Front Take-up N/A in.

2. Rear Take-up N/A in.

6. Brake Block Identification

a. Front

1. Forward 4567
2. Reverse 4567
b. Rear
1. Forward 4567
2. Reverse 4567

4. Brake Drums-Disc/Rotors
a. Front (Drum /Rotor)
1. Manufacturer MAN
2. Part Number SN 7000 Disc Lateral Run Out: 0.002" (max) Caliper Guides: 0.079" (max play)
3. Diameter (Drum/Rotor) Pad Clearance: 0.027" Pad Thickness: 0.079" Disc Thickness: 1.457"
4. Thickness/Number of Turns____in./____times
b. Rear (Drum /Rotor)
1. Manufacturer MAN
2. Part Number Pad Length: 7.09" (180 mm) Thickness: 0.827" (21 mm) Total Pad Area per Axle: 121.52 sq in Pad Clearance: 0.027- 0.047 " (0.7 to 1.2 mm)
3. Diameter (Drum/Rotor) Pad Thickness (min) : 0.079" (2 mm) Disc Thickness (min): 1.457" (37mm)
4. Thickness/Number of Turns____in./____times

8. Brake Block Widths
a. Front 3.378 in.
b. Rear 3.378 in.

9. Brake Block Lengths
a. Front 9.5 in.
b. Rear 9.5 in.

10. Brake Block Thickness
0.827 in.

11. Brake Block Area Per Wheel
a. Front 128 sq. in.
b. Rear 128 sq. in.

S. Cooling System
1. Radiator
a. Manufacturer N/A________________, b. Type N/A___________, c. Model Number______________
d. Number of Tubes__ , e. Tubes Outer Diameter__ in., f. Fins Per Inch____Fins, g. Fin Thickness_________in.
2. Total Cooling and Heating System Capacity____gals.,
3. Radiator Fan Speed Control_________Type
4. Surge Tank Capacity________gals.,
5. Engine Thermostat Temperature Setting _______degrees (F)
6. Overheat Alarm Temperature Sending Unit Setting______degrees (F),

7. Condenser Fan
a. Manufacturer & Model _Thermo King EBM Brushless_
b. Fan Diameter 17.7____in.
c. Speed Maximum 2370RPM______
d. Flow Rate Maximum N/A_______CFM

8. Condenser Fan Drive, if Separate Condenser Used - Motor
a. Manufacturer Thermo King_____
b. Model Brushless____________
c. Type Encased axial____
d. Horse Power 0.75_____________
e. Operating Speed 1390 rpm_____________

9. Evaporator(s)/Condenser(s)

Evaporators

Condensers

a. Manufacturer & Model _Thermo King___________
b. Quantity/Bus ____________________
c. Number of Rows/Core _5 rows_______________
d. Number of Fins 9______in. _______in.
e. Outer Diameter of Tube 0.375___in.
f. Fin Thickness 0.008__in.

10. Expansion Valve
Manufacturer and Model N/A________________

11. Filter - Drier
Manufacturer and Model Thermo King Disposable In-line__

a.

12. Heater Blowers

Main Auxiliary

a. Manufacturer & Model _Thermo King__________
b. Horsepower ____________________
c. Speed ______________________________________
d. Capacity_____________________________________
17. Driver's Heater
a. Manufacturer & Model MCC_______________
b. Capacity 56.880_____________BTU

T. Batteries
1. Manufacturer _Odyssey__________________________
2. Model _Group 31____
3. Type _Absorbed Glass Mat (AGM)___

U. Electrical Multiplex System
1. Manufacturer _Vansco__________________________
2. Model _VMM1615___
3. Type _________________

V. Energy Storage
1. Type _Lithium Ion__________________________
2. Cells____________

3. Battery Pack Voltage 388 kWh
4. Weight ________

W. Fire Detection System
1. Manufacturer Amerex
2. Model Number TBD
3. Fire Detectors 1
4. Type Thermal
5. Number of Detectors 4

PROPOSER NAME: ______________________________

Buy America

PRODUCT LEAFLET

Electric Vehicle Infrastructure

HVC-C UL depot charging for electric fleets

HVC Depot Boxes and power cabinets, lined up at a depot site.

ABB HVC-C UL Depot Charging systems offer a highly reliable, intelligent and cost-effective solution to charge large EV fleets such as buses, trucks and other commercial vehicles.

A practical solution for busy depots

ABB Heavy Vehicle Charger (HVC) products enable electric buses and trucks to charge at the depot ensuring flexibility and scale for every fleet operation that is transitioning to zero-emission transportation.

Key Benefits
+ Smart charging
+ Small infrastructure footprint at vehicle interface
+ Flexible design for roof and floor mounting
+ SAE J1772 CCS and OCPP 1.6 compliant
+ Remote diagnostics and management tools

Sequential Charging

Improving total cost of ownership is easy using the sequential charging feature offered by ABB's depot chargers. This feature allows connection of up to three depot charge boxes with a single power cabinet and vehicles are charged sequentially over time. The system can follow an embedded, predefined charging process or remote triggers sent by a fleet management system via OCPP 1.6.

- Vehicles are charged with high power, maximizing vehicle availability
- The required grid connection is smaller, reducing upfront investments and operational costs
- The compact depot box is easy to install at sites with space constraints
- Optimal utilization of installed infrastructure meaning lower investments in charging equipment.

Buy America

ABB can offer the HVC-C Depot Charging Solution with compliance to the Buy America Act Rule 49 CFR Part 661.5.

Future-proof modular design

Power cabinets can be upgraded from 100 or 150 kW in the field, as well as add additional depot charge boxes, allowing operators to scale their operation and to spread investments over time.

Safe and reliable operation

ABB fast chargers are designed to the highest international electrical, safety, and quality standards, and are certified by notified bodies - guaranteeing safe and reliable operation.

Connectivity and remote services

ABB chargers come with an extensive suite of connectivity features including remote services such as monitoring, management, diagnostics and software upgrades. These advanced services provide equipment owners with powerful insights into their charging operations while enabling high uptime.

ABB is your experienced partner

ABB HVC products are based on a decade of high power experience in EV charging solutions. ABB has installed over 13,000 fast charging systems in more than 80 countries – and is the leading EV infrastructure technology supplier globally.

Overnight charging 100 kW - 150 kW

A field upgradeable system with future proof reliability

HVC 100C

Upgrade

HVC 150C

A power upgrade can be done in the field by adding an extra power module. No groundworks, digging and disturbance to the site are required.

HVC 150C*

* 150 kW overnight charging system with three depot charge boxes; shown mounted on pedestal option.

Technical specifications			
Configurations		**HVC 100C**	**HVC 150C**
Maximum output power		100 kW	150 kW
AC Input voltage		UL: 3-phase, 480Y/277 VAC +/- 10 % (60 Hz) CSA: 3-phase, 600Y/347 VAC +/-10% (60 Hz)	
AC Input connection		L1, L2, L3, GND (no neutral)	
Rated input power		117 kVA	170 kVA
Rated input current		UL: 132 A / CSA: 108 A	UL: 198 A / CSA: 168 A
Recommended upstream circuit breaker(s)		UL: 1 x 200 A / CSA: 1 x 150 A	UL: 1 x 250 A / CSA: 1 x 250 A
Output voltage range		150 – 850 VDC	
Maximum DC output current		166 A	200 A
Vehicle connection interface		CCS/Combo Type 1 Connector	
Cable length		3.5 m (11.5 ft) standard; 7 m (23 ft) optional	
DC connection standard		SAE J1772 - IEC 61851-23 / DIN 70121 - ISO 15118	
Environment		Indoor/Outdoor	
Operating temperature		Standard: -10 °C to +50 °C (de-rating characteristic applies) Optional: -35 °C to +50 °C	
Protection		Power Cabinet: IP54 – IK10 (equivalent to NEMA 3R) Depot Charge Box: IP65 - IK10	
Network connection		GSM/3G modem | 10/100 base-T Ethernet	
Compliance and Safety		CSA No. 107.1-16 and UL 2202 certified by TUV BA Rule 49 CFR Part 661.5 (Optional)	
Dimensions			
Power Cabinet	Dimensions (H x W x D)	2030 x 1170 x 770 mm / 79.9 x 46.1 x 30.3 in	
	Weight	1340 kg / 2954 lbs	
Depot Charge Box (without pedestal)	Dimensions (H x W x D)	800 x 600 x 210 mm / 31.5 x 23.6 x 8.3 in	
	Weight	61 kg / 134.5 lbs (with 7 m / 23 ft cable)	
Depot Charge Box (with pedestal)	Dimensions (H x W x D)	1914 x 600 x 400 mm / 75.4 x 23.6 x 16.3 in	
	Weight	181 kg / 398 lbs (with 7 m / 23 ft cable)	

ABB Inc.
4050 E. Cotton Center Blvd
Phoenix, AZ 85040
United States
Phone: 800-435-7365
E-mail: US-evci@us.abb.com

abb.com/evcharging

ABB Inc.
800 Hymus Boulevard
Saint-Laurent, QC H4S 0B5
Canada
Phone: 800-435-7365
E-mail: CA-evci@abb.com

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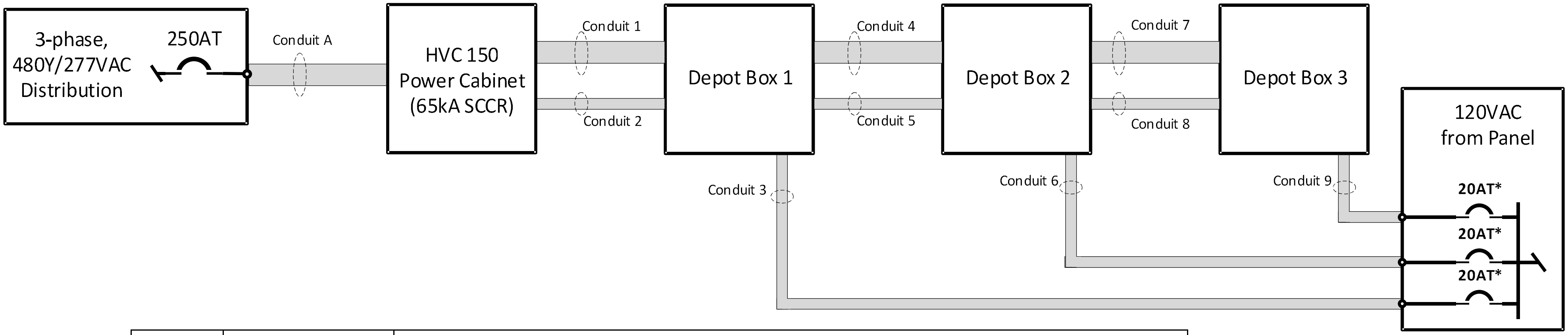

* Control power feeds to depot boxes must have 30mA Ground Fault Circuit Interrupter and support max inrush current of 100A for < 5ms

CONDUIT IDs	FUNCTION OF INTERNAL CABLES	CABLE SELECTION
A	AC PRIMARY POWER	(3) 250 MCM TO 500 MCM (CU, 75°C, 600V) + (1) #4 AWG (CU, 75°C, 600V, EGC)
1	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (3) #2 AWG (CU, 75°C, 600V, EGC)
4	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (2) #2 AWG (CU, 75°C, 600V, EGC)
7	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (1) #2 AWG (CU, 75°C, 600V, EGC)
2	INTERLOCK	(1) CABLE THAT HAS (1) TWISTED PAIR OF #18 AWG (SHIELDED, 600V, 120Ω CHAR. IMPEDANCE)
	FIBER CAN	(1) MULTIMODE FIBER (OM3, 8 STRANDS, PCF OR FIBERGLASS, WITH ST CONNECTORS, SEE MANUAL)
	FIBER ETHERNET	
5, 8	FIBER CAN	(1) MULTIMODE FIBER (OM3, 4 STRANDS, PCF OR FIBERGLASS, WITH ST CONNECTORS, SEE MANUAL)
	ETHERNET	(1) ETHERNET (S/FTP, CAT6/CAT5e, 600V, 100Ω CHAR. IMPEDANCE, WITH RJ45 CONNECTORS)
	INTERLOCK	(1) CABLE THAT HAS (2) TWISTED PAIRS OF #18 AWG (SHIELDED, 600V, 120Ω CHAR. IMPEDANCE); EACH PAIR SHOULD HAVE TWO WIRES AND THE CABLE SHOULD HAVE FOUR TOTAL WIRES
	DC GUARD	
3, 6, 9	120VAC CONTROL POWER	(1) CABLE THAT HAS (2) #12 AWG (CU, 75°C, 600V) + (1) #12 AWG (CU, 75°C, 600V, EGC)

N1. Equipment enclosures must be externally labeled according to local codes by the installing contractor to notify service personnel to verify absence of voltage from more than one power source.

N2. Customer must ensure wire sizes for main AC input (in conduit A), DC power (in conduits 1, 4, & 7), and control power (in conduits 3, 6, & 9) maintain an acceptable voltage drop based on their lengths and account for other application specific requirements. There shall be no greater than 2% voltage drop on the complete DC cabling between the HVC power cabinet and the depot box which has the farthest total DC cable distance from the HVC power cabinet. Voltage drop calculations for the DC cable runs shall be performed using 200ADC and the lowest expected electric vehicle battery voltage from the HVC power cabinet output as assumptions. Typically 300VDC is a sufficient worst case assumption for the lowest expected electric vehicle battery voltage, however, it is the customer's responsibility to ensure this is sufficient for each specific application. Voltage drop assumptions and calculations for the AC cables must be defined by the customer.

N3. Each depot box must have an equipment ground conductor directly connected to the HVC 150 power cabinet. As a result conduit IDs 1 & 4 show more than one equipment ground conductor.

N4. It is recommended to consider installing conduits for the future use case if applicable. For example, if on Day One only one or two depot boxes are installed and there is a possibility the site owner would want two or three depot boxes installed in the future, consider installing the conduits for the future possible depot boxes on Day One also. See ABB's conduit and cable concept for the future use case scenario if applicable.

N5. This concept does not show the presence of ground electrodes. It is the responsibility of the customer to determine if a ground electrode per each HVC power cabinet and depot box is required. See the product installation manual for more details.

TITLE
HVC-C 150kW Charging System - Conduits & Cables for (3) Depot Boxes

REV	DATE	BY	DESCRIPTION	DRAWING	REV
A	28/AUG/20		PRELIMINARY FOR DISCUSSION		A
-	-	-	-		
-	-	-	-		

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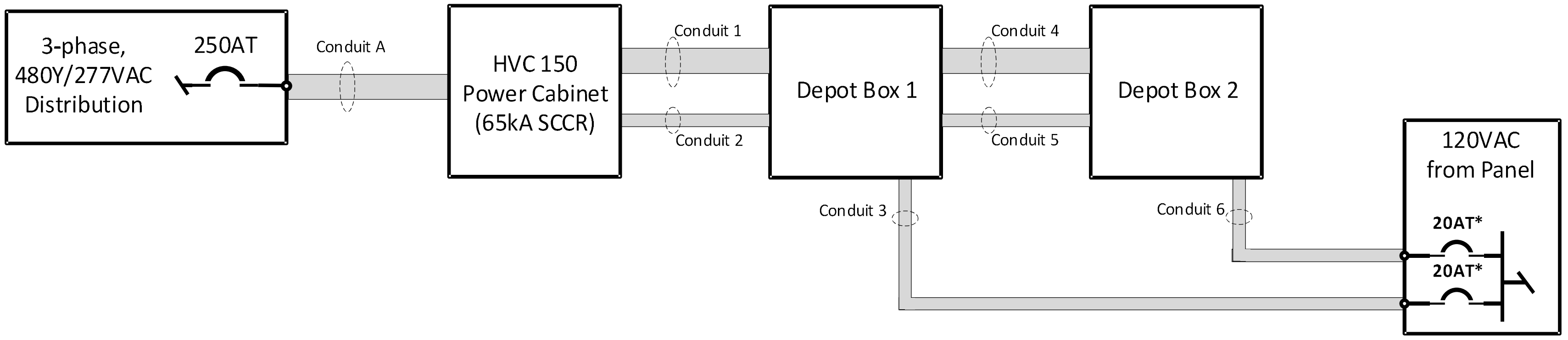

*** Control power feeds to depot boxes must have 30mA Ground Fault Circuit Interrupter and support max inrush current of 100A for < 5ms**

CONDUIT IDs	FUNCTION OF INTERNAL CABLES	CABLE SELECTION
A	AC PRIMARY POWER	(3) 250 MCM TO 500 MCM (CU, 75°C, 600V) + (1) #4 AWG (CU, 75°C, 600V, EGC)
1	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (2) #2 AWG (CU, 75°C, 600V, EGC)
4	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (1) #2 AWG (CU, 75°C, 600V, EGC)
2	INTERLOCK	(1) CABLE THAT HAS (1) TWISTED PAIR OF #18 AWG (SHIELDED, 600V, 120Ω CHAR. IMPEDANCE)
	FIBER CAN	(1) MULTIMODE FIBER (OM3, 8 STRANDS, PCF OR FIBERGLASS, WITH ST CONNECTORS, SEE MANUAL)
	FIBER ETHERNET	
5	FIBER CAN	(1) MULTIMODE FIBER (OM3, 4 STRANDS, PCF OR FIBERGLASS, WITH ST CONNECTORS, SEE MANUAL)
	ETHERNET	(1) ETHERNET (S/FTP, CAT6/CAT5e, 600V, 100Ω CHAR. IMPEDANCE, WITH RJ45 CONNECTORS)
	INTERLOCK	(1) CABLE THAT HAS (2) TWISTED PAIRS OF #18 AWG (SHIELDED, 600V, 120Ω CHAR. IMPEDANCE); EACH PAIR SHOULD HAVE TWO WIRES AND THE CABLE SHOULD HAVE FOUR TOTAL WIRES
	DC GUARD	
3, 6	120VAC CONTROL POWER	(1) CABLE THAT HAS (2) #12 AWG (CU, 75°C, 600V) + (1) #12 AWG (CU, 75°C, 600V, EGC)

N1. Equipment enclosures must be externally labeled according to local codes by the installing contractor to notify service personnel to verify absence of voltage from more than one power source.

N2. Customer must ensure wire sizes for main AC input (in conduit A), DC power (in conduits 1, 4, & 7), and control power (in conduits 3, 6, & 9) maintain an acceptable voltage drop based on their lengths and account for other application specific requirements. There shall be no greater than 2% voltage drop on the complete DC cabling between the HVC power cabinet and the depot box which has the farthest total DC cable distance from the HVC power cabinet. Voltage drop calculations for the DC cable runs shall be performed using 200ADC and the lowest expected electric vehicle battery voltage from the HVC power cabinet output as assumptions. Typically 300VDC is a sufficient worst case assumption for the lowest expected electric vehicle battery voltage, however, it is the customer's responsibility to ensure this is sufficient for each specific application. Voltage drop assumptions and calculations for the AC cables must be defined by the customer.

N3. Each depot box must have an equipment ground conductor directly connected to the HVC 150 power cabinet. As a result conduit IDs 1 & 4 show more than one equipment ground conductor.

N4. It is recommended to consider installing conduits for the future use case if applicable. For example, if on Day One only one or two depot boxes are installed and there is a possibility the site owner would want two or three depot boxes installed in the future, consider installing the conduits for the future possible depot boxes on Day One also. See ABB's conduit and cable concept for the future use case scenario if applicable.

N5. This concept does not show the presence of ground electrodes. It is the responsibility of the customer to determine if a ground electrode per each HVC power cabinet and depot box is required. See the product installation manual for more details.

TITLE
HVC-C 150kW Charging System - Conduits & Cables for (2) Depot Boxes

REV	DATE	BY	DESCRIPTION	DRAWING	REV
A	28/AUG/20	-	PRELIMINARY FOR DISCUSSION		A
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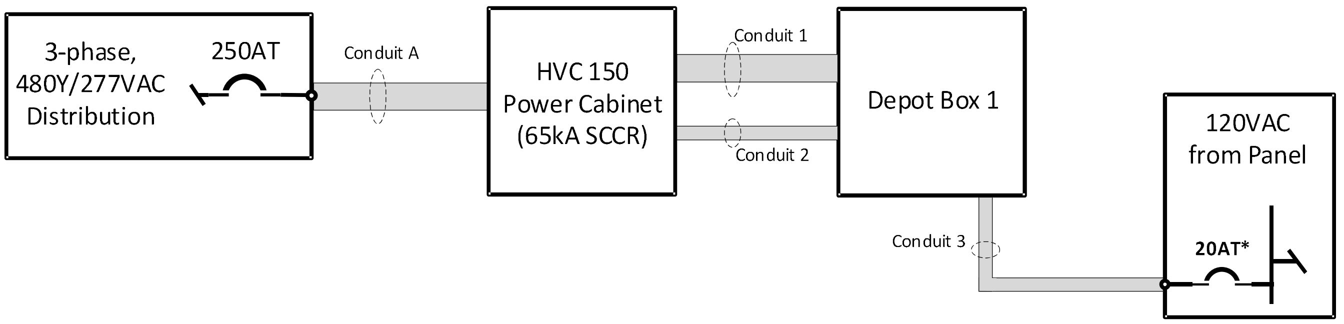

* Control power feeds to depot boxes must have 30mA Ground Fault Circuit Interrupter and support max inrush current of 100A for < 5ms

CONDUIT IDs	FUNCTION OF INTERNAL CABLES	CABLE SELECTION
A	AC PRIMARY POWER	(3) 250 MCM TO 500 MCM (CU, 75°C, 600V) + (1) #4 AWG (CU, 75°C, 600V, EGC)
1	DC POWER (200A)	(2) 3/0 AWG TO 350 MCM (CU, 75°C, 1KV) + (1) #2 AWG (CU, 75°C, 600V, EGC)
2	INTERLOCK	(1) CABLE THAT HAS (1) TWISTED PAIR OF #18 AWG (SHIELDED, 600V, 120Ω CHAR. IMPEDANCE)
	FIBER CAN	(1) MULTIMODE FIBER (OM3, 8 STRANDS, PCF OR FIBERGLASS, WITH ST CONNECTORS, SEE MANUAL)
	FIBER ETHERNET	
3	120VAC CONTROL POWER	(1) CABLE THAT HAS (2) #12 AWG (CU, 75°C, 600V) + (1) #12 AWG (CU, 75°C, 600V, EGC)

N1. Equipment enclosures must be externally labeled according to local codes by the installing contractor to notify service personnel to verify absence of voltage from more than one power source.

N2. Customer must ensure wire sizes for main AC input (in conduit A), DC power (in conduits 1, 4, & 7), and control power (in conduits 3, 6, & 9) maintain an acceptable voltage drop based on their lengths and account for other application specific requirements. There shall be no greater than 2% voltage drop on the complete DC cabling between the HVC power cabinet and the depot box which has the farthest total DC cable distance from the HVC power cabinet. Voltage drop calculations for the DC cable runs shall be performed using 200ADC and the lowest expected electric vehicle battery voltage from the HVC power cabinet output as assumptions. Typically 300VDC is a sufficient worst case assumption for the lowest expected electric vehicle battery voltage, however, it is the customer's responsibility to ensure this is sufficient for each specific application. Voltage drop assumptions and calculations for the AC cables must be defined by the customer.

N3. Each depot box must have an equipment ground conductor directly connected to the HVC 150 power cabinet. As a result conduit IDs 1 & 4 show more than one equipment ground conductor.

N4. It is recommended to consider installing conduits for the future use case if applicable. For example, if on Day One only one or two depot boxes are installed and there is a possibility the site owner would want two or three depot boxes installed in the future, consider installing the conduits for the future possible depot boxes on Day One also. See ABB's conduit and cable concept for the future use case scenario if applicable.

N5. This concept does not show the presence of ground electrodes. It is the responsibility of the customer to determine if a ground electrode per each HVC power cabinet and depot box is required. See the product installation manual for more details.

TITLE
HVC-C 150kW Charging System - Conduits & Cables for (1) Depot Box

REV	DATE	BY	DESCRIPTION	DRAWING	REV
A	28/AUG/20	-	PRELIMINARY FOR DISCUSSION		A
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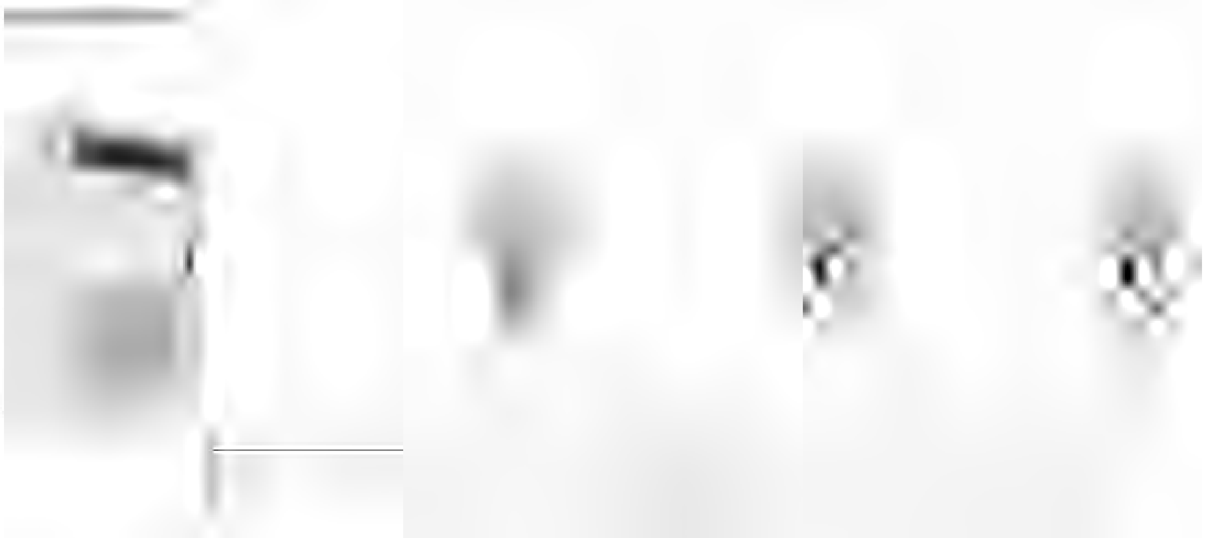


More details on cable entry into the depot box coming soon...

TITLE

HVC-C 150kW Charging System – Misc. Install Considerations

REV	DATE	BY	DESCRIPTION	DRAWING	REV
A	28/AUG/20		PRELIMINARY FOR DISCUSSION		A
-	-	-	-		
-	-	-	-		

Ulster County Area Transit

Fleet Electrification – Final Assumptions and Proposed Action Plan

This document intends to outline a proposed purchase and implementation plan for Ulster County Area Transit (UCAT) bus fleet electrification while considering future and projected capital costs. The goal of this plan is to achieve maximum fleet electrification as quickly as possible while keeping capital spending to a minimum. This document is divided into three sections. Section 1 summarizes market trends and current market trends and projections for BEBs and related infrastructure, Section 2 details a year-by-year fleet replacement schedule, and Section 3 includes projections for annual operating costs.

Section 1: BEB Market Trends and Price Projections

1.1 Current BEB Prices and Market Trends

Current market trends and industry literature suggests that the cost differential between BEBs and conventional diesel-powered buses will decrease over the next decade as battery production becomes cheaper and more efficient. BEBs will still likely have higher up-front costs than diesel buses, including costs of vehicles, costs associated with charging infrastructure, and facility upgrades. However, it likely that state and federal grants will be available to offset some of these costs.

Table 1 (below) summarizes the differences in projected costs of BEBs and conventional buses, the costs of other BEB components and infrastructure, and the projected price trends for these components.

Table 1. *Summary of BEB and conventional bus cost assumptions*

Cost Component	2021 Price (approx.)	2030 Price (assuming +2.5% inflation/yr)	Price Trend Assumption (relative to inflation)
35' BEB	$875,000	$875,000	Price will trend down
40' BEB	$1,000,000	$1,000,000	Price will trend down
35' Diesel bus	$500,000	$625,000	Price will remain constant
35' CNG bus	$520,000	$674,000	Price will remain constant
Depot charging installation (per cabinet)	[redacted]	[redacted]	Price will remain constant
Depot charging equipment (per three dispensers)	$137,000	$171,000	Price will remain constant
On-route charging equipment (per charger)	$500,000	$625,000	Price will remain constant
On-route charging installation (per charger)	$200,000	$250,000	Price will remain constant

Sources: California Air Resources Board, Transit Cooperative Research Program, UCAT provided project costs

Table 2 summarizes recent BEB procurements made by other peer American transit agencies, including price paid, purchase year, bus manufacturer, and bus size. Utilizing these data points provides a baseline from which we can calculate average market prices and begin to observe market trends. *Table 3* provides a summary of the total average procurement cost of both 35- and 40-foot electric buses after adjusting for inflation.

Table 2. Peer Transit Agency Battery Electric Bus Procurements, 2018 - 2021

City/Region	Agency	Purchase Year	Bus Price	Bus Mfg.	Bus Size
Los Angeles, CA	LADOT	2018	$720,000	BYD	35'
Madison, WI	Metro Transit	2018	$667,000	Proterra	35'
Rhode Island	RIPTA	2018	$855,000	Proterra	40'
Dallas, TX	DART	2019	$970,000	Proterra	35'
St. Louis, MO	Metro St. Louis	2019	$950,000	Gillig	40'
Chicago, IL	CTA	2020	$900,000	Proterra	40'
New York, NY	MTA	2020	$1,960,000*	Multiple	Multiple
Seattle, WA	King County Metro	2020	$925,000	New Flyer	40'
Philadelphia, PA	SEPTA	2020	$800,000	Proterra	40'
Marin Co., CA	Marin Transit	2020	$1,000,000	Gillig	40'
Orange Co., CA	OCTA	2020	$1,000,000	New Flyer	40'
Ulster Co.	UCAT	2021	$865,000	New Flyer	35'
Niagara Falls, NY	NFTA	2021	$1,000,000	New Flyer	Unknown, likely 40'
North LA area, CA	Antelope Valley Transit	2021	$545,000	BYD	30'

Sources: see "Sources" section

* Purchase price likely includes charging infrastructure and additional costs

Table 3. Average Battery Electric Buses Prices Adjusted for Inflation

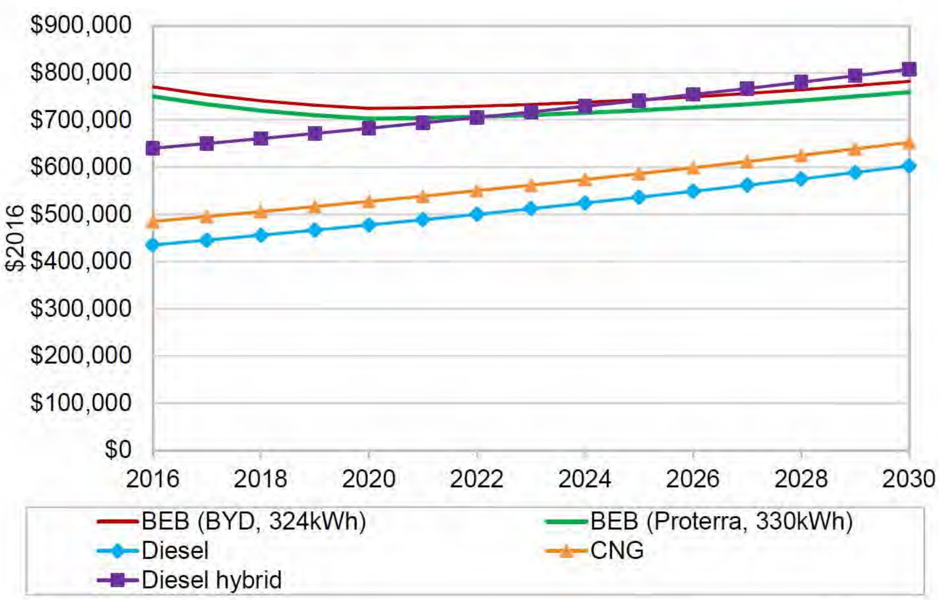
Purchase Year	Bus Size	35’ Bus Cost		40’ Bus Cost	
		Purchase Year Dollars	2021 Dollars	Purchase Year Dollars	2021 Dollars
2018	35’	$693,000	$737,000	$855,000	$909,000
2019	35’	$970,000	$1,001,000	$950,000	$992,000
2020	35’	--	--	$925,000	$954,000
2021	35’	$865,000	$865,000	--	--
		Average 2021 Cost, 35’	$867,000	Average 2021 Cost, 40’	$951,000

1.2 *BEB Price Projections*

The California Air Resources Board (CARB) projects that the price differential between BEBs and conventionally fueled buses will *decrease* over the next decade (*Figure 1*). The price of fossil-fuel powered buses is expected to rise along with inflation year to year while the relative price of BEBs is anticipated to decrease as battery technology advances and current research and development investment levels continue. Adjusting for inflation, the real price of BEBs will decrease each year as the nominal price remains somewhat constant, and the average sticker price of a BEB in 2021 will be the same in 2030.

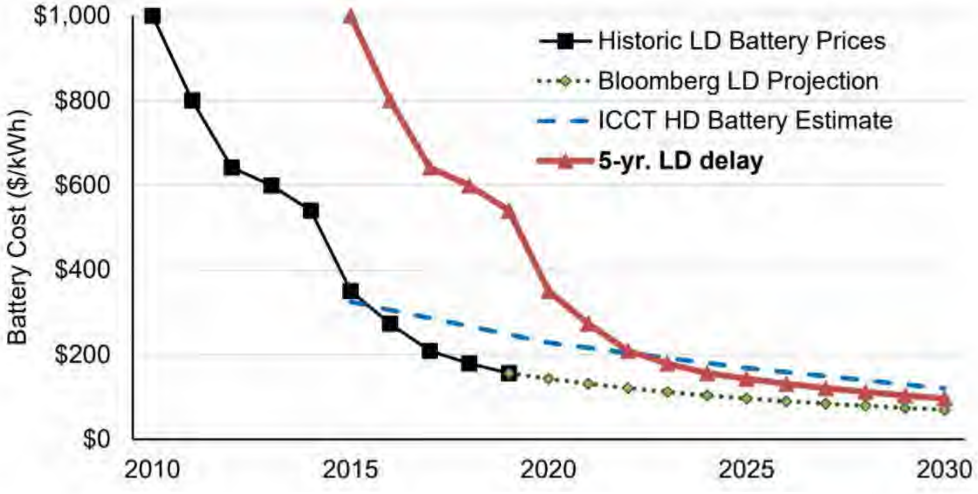
It should be noted that the decreasing production costs and purchase prices of BEBs is largely due to the development of cheaper and more efficient battery technologies. CARB also predicts a continual downward trend in battery prices, thus resulting in lower BEB prices (*Figure 2*).

Figure 1. *Bus price projections for conventional buses and BEBs*



Source: California Air Resources Board

Figure 2. *Lithium battery price projections*



Source: California Air Resources Board

1.3 UCAT Operating Costs of Fossil-Fuel Powered Buses vs. BEBs

The feasibility study found the average annual operating cost of the current UCAT fleet in 2020 to be approximately $59,500 per vehicle. This includes amortized purchase price, annual maintenance, and fuel costs, social costs from GHG and noise emissions. The calculated average considered variations in purchase price, fuel consumptions and maintenance costs of the various vehicles comprising UCAT's fleet and weighted by the quantity of each vehicle type in operation.

Using 2020 prices, annual operating costs for BEBs will be significantly greater than fossil fuel-powered buses due to higher vehicle costs and current electric utility price schedules. Year one annual operating costs for BEBs is projected at approximately $90,500 per vehicle, more than a 50% increase. However, it is likely that this net differential will decrease over time as the purchase cost of BEBs decrease and more favorable electric utility price schedules are introduced. Further detail is provided in Section 3 of this study.

Section 2: Proposed Procurement and Action Plan

2.1 Action Plan Summary

The proposed bus replacement schedule *(Table 4)* considers several factors previously identified by both UCAT and Creighton Manning. These factors are as follows:

- **35' BEB and cutaway vehicle replacements** – While there is no currently FTA-approved zero-emission cutaway vehicle available for purchase, we project that some type of sub-35' electric vehicle will become readily available by 2024. If there is no suitable cutaway replacement available by mid-decade, this plan assumes that all non-paratransit diesel/CNG buses would be replaced by fast-charge capable 35' BEBs, regardless of existing vehicle size and in accordance with their planned replacement date. The capital cost estimate for 35 foot electric buses is used throughout the proposed bus replacement schedule as no reliable pricing for these future vehicles is available. It is reasonable to assume that smaller vehicles would be available at a lower purchase price. As such, using the cost of 35-foot BEBs throughout this exercise provides a conservative capital estimate projection.
- **Staggered installation of on-route charging equipment** – On-route charging equipment presents the challenge of high up-front capital costs. Conceptual cost estimates developed for en-route charging equipment and site work developed previously in study totaled approximately $1.1 million per fast charger. This cost is consistent with cost estimates listed in available literature.

  The cost of this equipment will be staggered through implementation by assuming each layover location will be constructed separately. Following construction of each, BEBs purchased should be assigned to a route that utilizes that layover location until all routes which utilize that charger location are electrified. This continues until all four layover locations are completed and all buses are electrified.
- **Preemptive purchase of depot charging infrastructure** – All BEBs will dock overnight at the existing UCAT depot or the new future facility. Three charge cabinets and three depot-box charging plugs will be installed at the existing facility with the first BEB purchase in FFY 2021.

These cabinets will have the capacity to support up to 9 vehicles with overnight plug-in capability after additional depot box units are procured and installed. This installation of an additional 6 depot boxes at the facility is planned for FFY 2022. A fourth cabinet will be installed in FFY 2024 increasing depot charging capacity to 12 vehicles. It will be assumed that all future depot charging infrastructure investment will be included in the new UCAT depot facility, tentatively slated for completion in 2026. It is assumed that this facility will be designed to be ready to support electric charging equipment.

- **Charging Equipment at New UCAT Facility** – Capital costs associated with the construction of the new facility are not included in this phased implementation plan and it is assumed that the facility will be constructed to be ready to accommodate charging demands. However, this plan does assume that installation of charging equipment at the new facility will be phased over time on an as-needed basis. As such, the capital costs for incremental implementation of BEB charge equipment is included in this plan.
- **Full Electrification** – As discussed in the report, 100% electrification of the UCAT fleet is not feasible with current battery technology and operational structures. Routes with long one-way trips, such as those serving Pine Hill, NY and Bellaire Mountain, would require opportunity chargers at each end of the route and significantly extended layover times between each trip to be electrified with current battery technology. Agencies across the world have begun to assess hydrogen fuel cell powered buses to achieve zero emission fleets with routes that cannot be electrified. Challenges with hydrogen fuel cells include the cost of fuel and the reliability of supply. While outside the scope of this study, UCAT may wish to begin exploring this emerging propulsion technology as a way to reach full electrification in the future.

2.2 *Fleet Replacement and Charger Procurement Schedule*

Table 4 (below) describes a proposed UCAT fleet replacement plan. As stated above, there are several key years that involve both the procurement of buses and the installation of charging equipment. Although financial burden will be higher in these years, the resulting infrastructure will be vital for the subsequent electrification of UCAT's fleet.

Table 4. *BEB and Charger Procurement Plan*

FFY	# of BEBs to be Replaced	Total Vehicle Cost** (millions, USD)	Fast Charger Layover Area	Fast Charger Costs† (millions, USD)	Depot Charger Costs††	# of Depot Plugs Available	Annual CO_2e Reduction (tonnes)	Total BEBs in UCAT Fleet	Total Capital Costs* (millions, USD)	Five Year Running Total (millions, USD)
2021	3	$2.595	--	--	$762,000	3	110	3	$3.357	$18.577
2022	3	$2.595	Kingston	$2.200	$281,000	9	215	6	$5.076	
2023	4	$3.460	--	--	--	9	357	10	$3.460	
2024	3	$2.595	--	--	$280,000	12	461	14	$2.875	
2025	3	$2.595	New Paltz	$1.185	--	12	583	18	$3.809	
2026	3	$2.595	--	--	$575,000	18	679	22	$3.170	$15.934
2027	3	$2.595	--	--	--	18	776	24	$2.595	
2028	3	$2.595	Tech City	$1.276	--	18	890	26	$3.903	
2029	3	$2.595	-	-	$619,000	24	1,004	28	$3.214	
2030	2	$1.712	Poughkeepsie	$1.340	--	24	1,080	30	$3.052	
2031	1	$0.865	--	--	--	24	1,127	31	$0.865	$3.460
2032	3	$2.595	--	--	--	24	1,237***	34	$2.595	
									GRAND TOTAL	$37.971

* Amounts shown **exclude** monies from state and federal grants and reflect full purchase price

** Total vehicle cost remains constant independent of inflation (see Section 1.2, *Figure 4*)

*** Assuming UCAT is able to transition the Z Route to use zero-emissions buses.

† Fast charger costs are adjusted for 2.5% annual inflation

†† Depot charger costs are adjusted for 2.5% annual inflation and include a 20% design and mobilization cost

Table 5 provides a more granular snapshot of year-by-year bus replacement. The only exception to this is Bus #83 which is currently 40'. Depending on ridership demands and route considerations, this bus can be replaced by either a 35' or a 40' BEB. While electric cutaway options are assumed to be available starting in 2024, the cost is unknown. To determine the capital cost estimate in Table 4 above, the 35' BEB replacement cost was used.

Table 5. *Year-by-Year Bus Replacement*

Proposed Replacement Year	Bus #	Life Cycle Year End	Existing Bus Length	Proposed BEB Replacement Length	Bus Route
2021	55	2022	35'	35'	UCAT
	56	2022	35'	35'	UCAT
	58	2022	35'	35'	UCAT
2022	9037	2019	35'	35'	CitiBus
	9161	2021	23'	35'	CitiBus
	9162	2021	23'	35'	CitiBus
2023	59	2022	35'	35'	UCAT
	60	2022	30'	35'	UCAT
	61	2022	30'	35'	UCAT
	80	2022	26'	35'	UCAT
2024	81	2022	26'	Elec. Cutaway	UCAT
	82	2022	26'	Elec. Cutaway	UCAT
	9111	2023	35'	Elec. Cutaway	CitiBus
2025	9112	2023	35'	35'	CitiBus
	62	2024	30'	35'	UCAT
	63	2024	30'	35'	LINK
2026	67	2025	30'	35'	KPL
	84	2025	26'	Elec. Cutaway	UCAT
	85	2025	26'	Elec. Cutaway	UCAT
2027	86	2025	23'	Elec. Cutaway	UCAT
	87	2025	23'	Elec. Cutaway	UCAT
	69	2026	30'	35'	LINK
2028	70	2026	30'	35'	LINK
	71	2026	30'	35'	LINK
	73	2027	30'	35'	UCAT
2029	74	2027	30'	35'	UCAT
	75	2027	30'	35'	UCAT
	76	2027	30'	35'	UCAT
2030	78	2028	30'	35'	UCAT
	79	2028	30'	35'	UCAT
2031	83	2031	40'	35' or 40'	UCAT
2032	88	2032	35'	35'	UCAT
	89	2032	35'	35'	UCAT
	90	2032	35'	35'	UCAT

Section 3: Annual Operating Cost Comparison Details

The following provides some additional detail and context as to how the annual operating costs for both fossil-fueled and BEBs were calculated. The previously submitted final report for the feasibility study included a calculation of the annual operating costs of the current UCAT fleet. These were based on real purchase, maintenance, and fuel costs reported by UCAT, with vehicle purchase costs amortized over the anticipated lifecycle of the vehicles. The annual operating costs (in 2020 dollars) of UCAT's existing fleet is summarized in Table 6.

Table 6. UCAT Operating Annual Operating Costs by Vehicle Type

Vehicle Type	Cost per Mile (2020)			Cost per Year (2020)		
	Purchase cost	Fuel cost	Maintenance cost	Purchase cost	Fuel cost	Maintenance cost
25ft Gas	$0.74	$0.25	$0.20	$23,784	$7,933	$6,312
30ft Diesel	$0.89	$0.25	$0.33	$28,638	$8,094	$10,496
35ft Diesel	$1.05	$0.30	$0.32	$33,809	$9,768	$10,166
40ft Diesel	$1.13	$0.31	$0.31	$36,458	$10,024	$9,836
35ft Hybrid	$1.70	$0.31	$0.43	$54,858	$10,104	$13,981
40ft Hybrid	$1.47	$0.26	$0.51	$47,241	$8,465	$16,307

The social costs for the existing fleet, calculated by assigning a monetary value to the greenhouse gas and noise emissions of the fleet, was also calculated in the final report. The total average operating cost of the existing fleet, including calculated social costs and weighted by the number of each vehicle type currently serving the UCAT service area is summarized in Table 7***:***

Table 7. *Weighted Average Annual Operating Cost of Existing UCAT Fleet*

	Cost per Year (2020)
Purchase Cost	$33,400
Maintenance Cost	$10,400
Fuel Cost	$8,700
Social Cost	$7,100
Total	$59,600

Table 8. *Calculated Annual Operating Cost of Electric Buses*

	Cost per Year (2020)
Purchase Cost	$67,379
Maintenance Cost	$12,753
Fuel Cost	$9,226
Social Cost	$966
Total	$90,324

The projected annual operating costs for BEBs was calculated by amortizing the purchase price over the lifecycle of the bus, projecting maintenance cost savings over current costs based on a review of research and peer agency experience, and estimating electricity costs. The social costs of electric buses is estimated to be less than 14% that of the existing fleet, with only noise contributing to annual costs. The annual operating costs of electric buses, calculated in 2020 dollars and based on 2020 market trends and utility pricing, is summarized in Table 8 (above).

Attachment 4

DEQ Summary and Detailed Reports

Project Name: Municipal Garbage Truck (1 Unit) **Run Date:** 03/06/2023

Total Project Funding: $ 400,000

Summary Emission Results[1] for Project:

Annual Results (short tons)[2]	NO_x	PM2.5	HC	CO	CO_2	Fuel[3]
Baseline for Project	0.074	0.000	0.001	0.048	44.9	3,993
Amount Reduced After Upgrades	0.074	0.000	0.001	0.048	44.9	3,993
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline for Project	0.370	0.001	0.006	0.239	224.6	19,965
Amount Reduced After Upgrades	0.370	0.001	0.006	0.239	224.6	19,965
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$1,080,354	$694,166,975	$62,941,222	$1,670,907	$1,781	
Total Cost Effectiveness[4] (includes all project costs)	$1,080,354	$694,166,975	$62,941,222	$1,670,907	$1,781	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Detailed Emission Results[1] for Municipal Garbage Truck:

Annual Results (short tons)[2]	NO_x	PM2.5	HC	CO	CO_2	Fuel[3]
Baseline of Group	0.074	0.000	0.001	0.048	44.9	3,993
Amount Reduced After Upgrades	0.074	0.000	0.001	0.048	44.9	3,993
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Results (short tons)[2]						
Baseline of Group	0.370	0.001	0.006	0.239	224.6	19,965
Amount Reduced After Upgrades	0.370	0.001	0.006	0.239	224.6	19,965
Percent Reduced After Upgrades	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Lifetime Cost Effectiveness ($/short ton reduced)						
Capital Cost Effectiveness[4] (unit & labor costs only)	$1,080,354	$694,166,975	$62,941,222	$1,670,907	$1,781	

[1] Emissions from the electrical grid are not included in the results.

[2] 1 short ton = 2000 lbs.

[3] In gallons; fuels other than ULSD have been converted to ULSD-equivalent gallons.

[4] Cost effectiveness estimates include only the costs which you have entered.

Inputs:

Municipal Garbage Truck:

Type: Onroad
Target Fleet: Refuse Hauler
Class: Class 8
Sector: Municipal
Quantity: 1
Engine Model Year: 2018
Upgrade Year: 2024
Remaining Life: 5

Fuel Type: ULSD (diesel)
Annual Fuel Gallons: 3,993
Diesel-equivalent Gallons: 3,993
Annual Miles Traveled: 23,646
Annual Idling Hours: 50

Vehicle Replacement:

Upgrade: Vehicle Replacement - All-Electric
Upgrade Cost per Unit: $400,000 **Labor Cost per Unit:** $0
Percent Reduction: **NOx:** 100% **PM2.5:** 100% **HC:** 100% **CO:** 100% **CO_2:** 100%

Technical Review of:

Medium and Heavy-Duty Electrification Costs for MY 2027- 2030

Final Report

Vishnu Nair, Sawyer Stone, Gary Rogers, Sajit Pillai

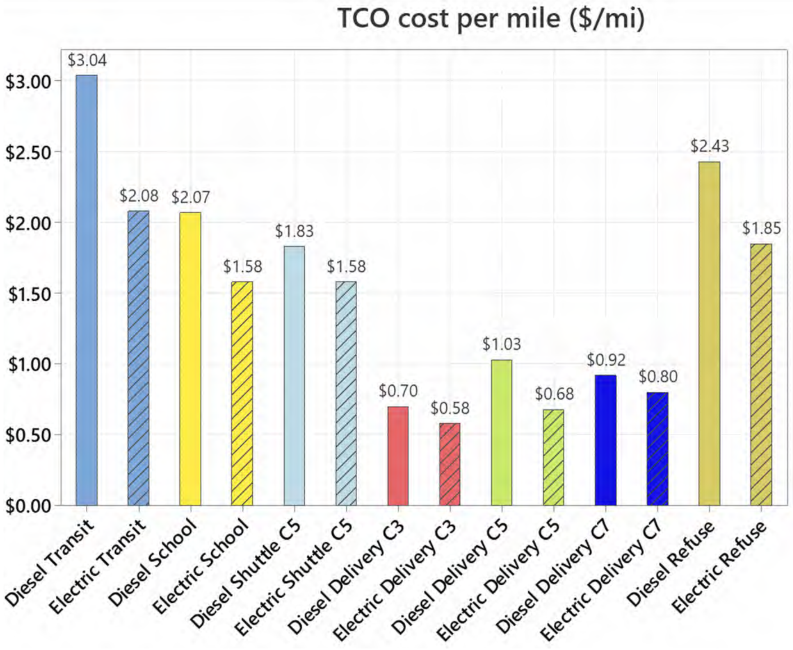
Roush Industries, Inc

2nd February 2022

Abstract: Medium- and Heavy-Duty Electrification Cost Evaluation

This report evaluates the cost of electrifying vehicles in several medium- and heavy-duty market segments such as class 8 transit and class 7 school buses, class 3-7 shuttles & delivery vehicles, and class 8 Refuse haulers, whose use patterns are concentrated in urban areas. Emissions from diesel vehicles in these categories are significant sources of pollutants that are damaging to human health and the environment, including particulate matter, nitrogen oxides, and greenhouse gases. Greenhouse gas and NOx regulations will continue to become stricter, with the next milestones planned to take effect in 2024 and 2027. To accomplish these targets, engine, aftertreatment, and transmission technology will be developed that improves fuel economy and reduces emissions, adding costs to the ICE system. At the same time, battery, motor, and power electronics costs are decreasing more rapidly than predictions made in the past decade. This report evaluates the incremental costs at each of these milestones and compile a comprehensive total cost of ownership for a vehicle purchased in 2027. When considering vehicle purchase price alone (no amortization of costs), EV's are favored in all categories except shuttle buses in 2027 and favored in all categories in TCO when purchased in 2027. The TCO analysis shows that in the cases where EVs have higher upfront costs, total cost parity is achieved within 2 years of vehicle purchase, summarized in the below table. Charging costs were sourced from available literature detailing the installation cost as well as the hardware costs. The average published cost in literature for chargers of each power level were used in the TCO analyses for each class.

Class	Segment	Batt. Size	Purchase	Operating	Total Cost	TCO Parity
		kWh	% Cost Reduction of EV vs ICE			Year
Class 8	Transit Bus	400	0.8	49.5	31.6	2
Class 7	School Bus	60	12.4	26.5	23.7	1
Class 5	Shuttle Bus	200	0.2	15.9	13.7	3
Class 3	Delivery Van	100	0.7	31.2	16.9	3
Class 5	Delivery Truck	150	12.4	52.0	34.0	1
Class 7	Delivery Truck	100	9.4	14.3	12.7	4
Class 8	Refuse Hauler	200	7.3	35.6	23.9	1



EDF - Medium- and Heavy-Duty Electrification Cost Evaluation			
Date:	02/02/2022	Roush Project:	127864
Authors (Roush):	Sawyer D Stone Vishnu Nair Gary Rogers		
Program Manager: (Roush):	Sajit Pillai		
Advanced Engineering V.P.: (Roush):	Matt Van Benschoten		
Customer:	Chet France Rick Rykowski Peter Zalzal Alice Henderson		

Revision Summary

Date	Version	Change Description
11/18/2021	1.0	Preliminary Release - Draft
12/8/2021	1.1	Updated figures, sections, and links
12/14/2021	1.2	Updated TCO figures & calculations
01/13/2022	1.3	Revisions based on EDF comments, updated tables
02/02/2022	1.4	Further revisions based on comments, figures and tables updated

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Glossary

ADAS - Advanced Driver Assistance Systems

AWD - All Wheel Drive

BEV - Battery Electric Vehicle

BISG - Belt Integrated Starter Generator

BNEF - Bloomberg New Energy Finance

CAFE - Corporate Average Fuel Economy

GHG - Green House Gas

DI - Direct Injection

EHC - Electrically Heated Catalyst

EPA - Environmental Protection Agency

GCTP - Gravimetric Cell To Pack ratio (weight of the cells/weight of the battery pack)

HVAC - Heating Ventilation and Air-Conditioning

ICCT - International Council on Clean Transportation

ICE - Internal Combustion Engine

LFP - Lithium Ferro (Iron) Phosphate

NMC - Nickel Manganese Cobalt

NCA - Nickel Cobalt Aluminum

NHTSA - National Highway Traffic Safety Administration

NVH - Noise Vibration Harshness

OEM - Original Equipment Manufacturer

PM - Permanent Magnet

SAFE - Safer Affordable Fuel-Efficient Vehicles Rule

TM - Thermally Modulated

VCTP - Volumetric Cell To Pack ratio (volume of the cells/volume of the battery pack)

VVT - Variable Valve Timing

WLTP - Worldwide Harmonized Light Vehicle Test Procedure

YOY - Year on Year

Executive Summary

Emissions from diesel trucks and buses in all classes, particularly those used in urban areas, contribute to pollution that is damaging to both human health and the environment. Nitrogen oxides (NOx) emissions contribute to smog, and particulate emissions and other pollutants in diesel exhaust contribute to poor health outcomes. Additionally, greenhouse gas emissions contribute to climate change and are the subject of regulatory scrutiny. Delivery, box and stake trucks, and shuttle vehicles in class 3-7 segments, as well as class 8 transit and class 7 school buses, are a significant part of the medium- and heavy-duty market. These vehicles and their use tend to be concentrated in cities where average trip distances are short and the health and pollution effects are of most concern, making these categories logical targets for early electrification deployment.

The goal of this work is to evaluate the electrification of several medium- and heavy-duty market segments to develop projected incremental costs and total cost of ownership (TCO) for electric vehicles (BEV) in 2027-2030 for these vehicles. These costs are compared to equivalent ICE vehicles meeting the EPA Greenhouse Gas Phase 1 and 2 rules, as well as California Low NOx regulations in the California Omnibus HD NOx rule. Through these costing exercises, the approximate timeframe of EV cost parity with their ICE counterparts can be identified, and the viability of electrification in the selected MD/HD market segments can be determined for the 2027-2030 timeframe.

This study focuses on existing fleets with infrastructure (excluding chargers) already owned by the fleet operator, eliminating the need for any major changes. The study assumes EV market penetration levels such that higher costs associated with low production rates do not affect the adoption of EVs, matching predictions of increased EV availability and production. Model year 2027 is chosen to support regulation development and match the timeline of the possible adoption of these regulations in MY2027, including the costs of diesel powertrain advancements required to meet anticipated regulations in that time frame, such as tighter NOx standards.

While many sources point to substantial health and welfare benefits associated with the deployment of EVs, particularly in the HD market segments, these benefits are not considered nor included in the current analysis. This work focuses exclusively on the direct financial costs and savings related to vehicle ownership.

Prior work in the area supported by MJ Bradley and Associates identified the key market segments of the MD/HD market ripe for electrification, as well as the associated battery capacities chosen for this study [1]. The market segments, weight classes, and projected battery capacities used in this study for each class evaluated are summarized in Table 1. Battery capacities listed below are sized to cover an approximately average trip distance for each class and were derived from the MJ Bradley work and others. For example, the school bus segment is significantly lower in this report compared to the MJ Bradley report, owing to the generally short trip distance a majority of school buses travel in a day, as well as their ability to recharge mid-day during school hours.

Table 1: MD/HD market segments included in analysis.

Market Segment	Weight Class	Battery Capacity (kW-h)
Transit Bus	Class 8	400
School Bus	Class 7	60
Shuttle Bus	Class 3-5	100
Delivery and Service Van, Box and Stake Truck	Class 3	100
Short Haul Delivery, Service, Box, and Stake Truck	Class 6-7	150
Short Haul Delivery and Service Van, Box and Stake Truck	Class 4-5	100
Refuse Hauler	Class 8	200

Incremental costs were determined by identifying the major components in a diesel-powered vehicle that would be eliminated in an EV, as well as identifying components that must be added to a vehicle for electrification. Literature reviews of ICE and EV component costs were conducted to determine the current and future projections of costs in the MD/HD vehicle markets, accounting for developments in technology expected in the EV market and improvements to diesel engines, aftertreatment systems, and transmissions to meet increasingly stringent regulations in 2024 and 2027. Figure 1 shows the incremental costs (ICE delete vs. EV add) in 2021, 2024, and 2027.

The general trend across all categories and classes evaluated, point to the decreasing upfront cost of electrification compared to traditional ICE powertrains. Only Class 3 Shuttles show any cost increase of EV's over ICE vehicles in 2027, with an incremental cost of $3,214. Electrification costs drop between 26-30% by 2024, and 42-44% in 2027. Due to the large portion of the EV costs being driven by battery costs, batteries are the primary source of this reduction, projected to fall from $123/kW-h in 2021 to $68/kW-h in 2027. Table 2 shows the battery and other EV component cost decrease in 2027 compared to 2021. Motors, inverters, and other power electronics are projected to decrease in cost as well due to the increased ubiquity of manufacturing, use, and advancements in technology.

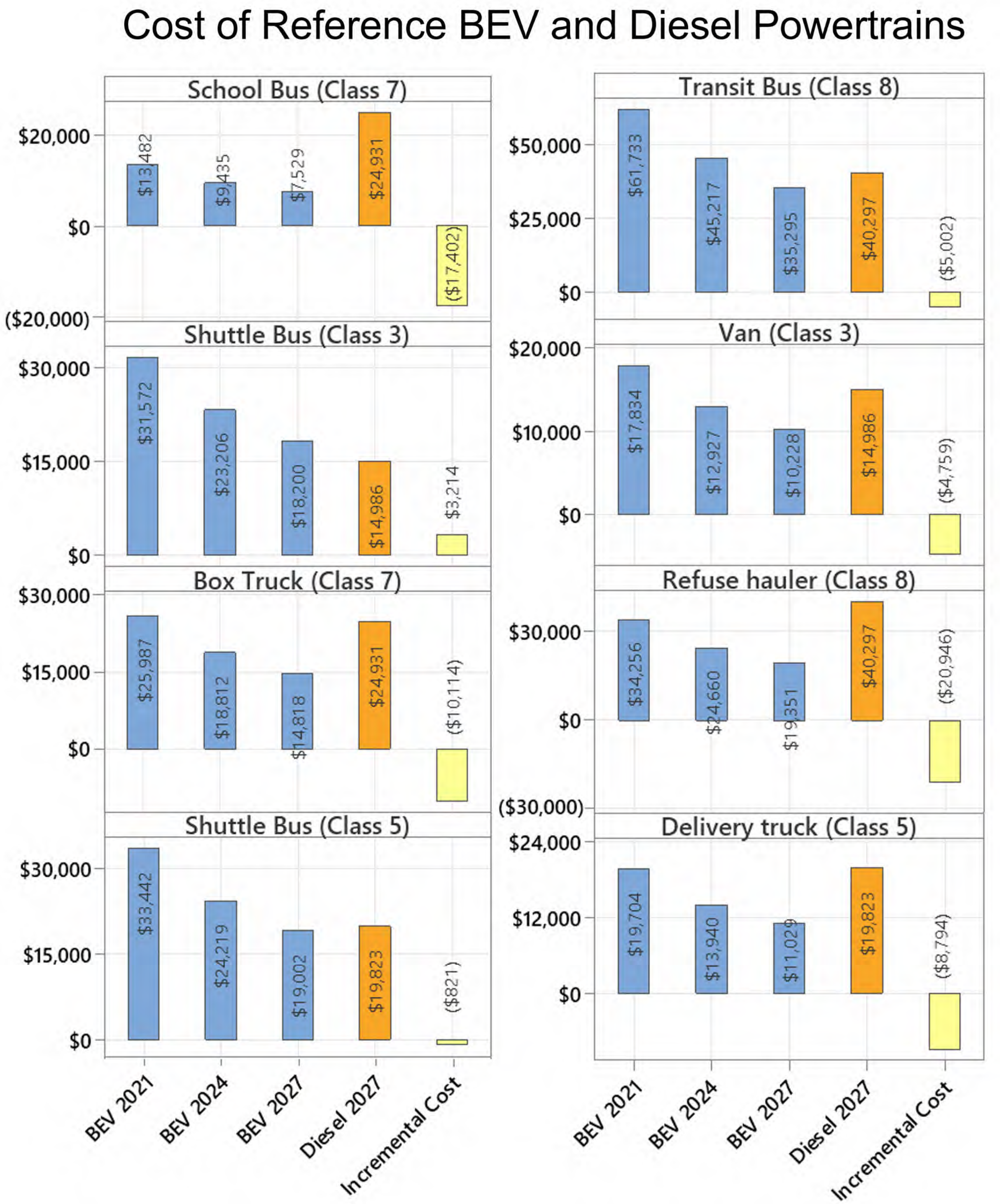


Figure 1: Incremental costs of electrification of MD/HD vehicles. Blue bars are EV powertrain (add) costs in 2021, 2024, and 2027, orange bars are ICE powertrain (delete) costs in 2027, and the yellow bars are incremental costs of the BEV in 2027 (negative value implies that an electric powertrain is cheaper than diesel in 2027)

Table 2: EV Component costs decrease from 2021 to 2027.

EV Component Costs 2027 vs 2021	
Batteries	-45%
Motors	-65%
Power Electronics	-19%

The total cost of ownership was determined for all financial aspects of ownership, including vehicle purchase cost of ICE or EV, fuel, or energy costs, charging or fueling infrastructure costs, maintenance costs, and vehicle mid-life refresh if applicable. Indirect costs or benefits outside of costs directly borne by the vehicle purchaser were not considered in this analysis, including the pollution and climate benefits associated with the deployment of zero-emission vehicles. The incremental costs derived in Figure 1 were used as a basis to determine the difference in the purchase price of a certain class of vehicle, as the study assumes economies of scale in the manufacturing and production of EVs.

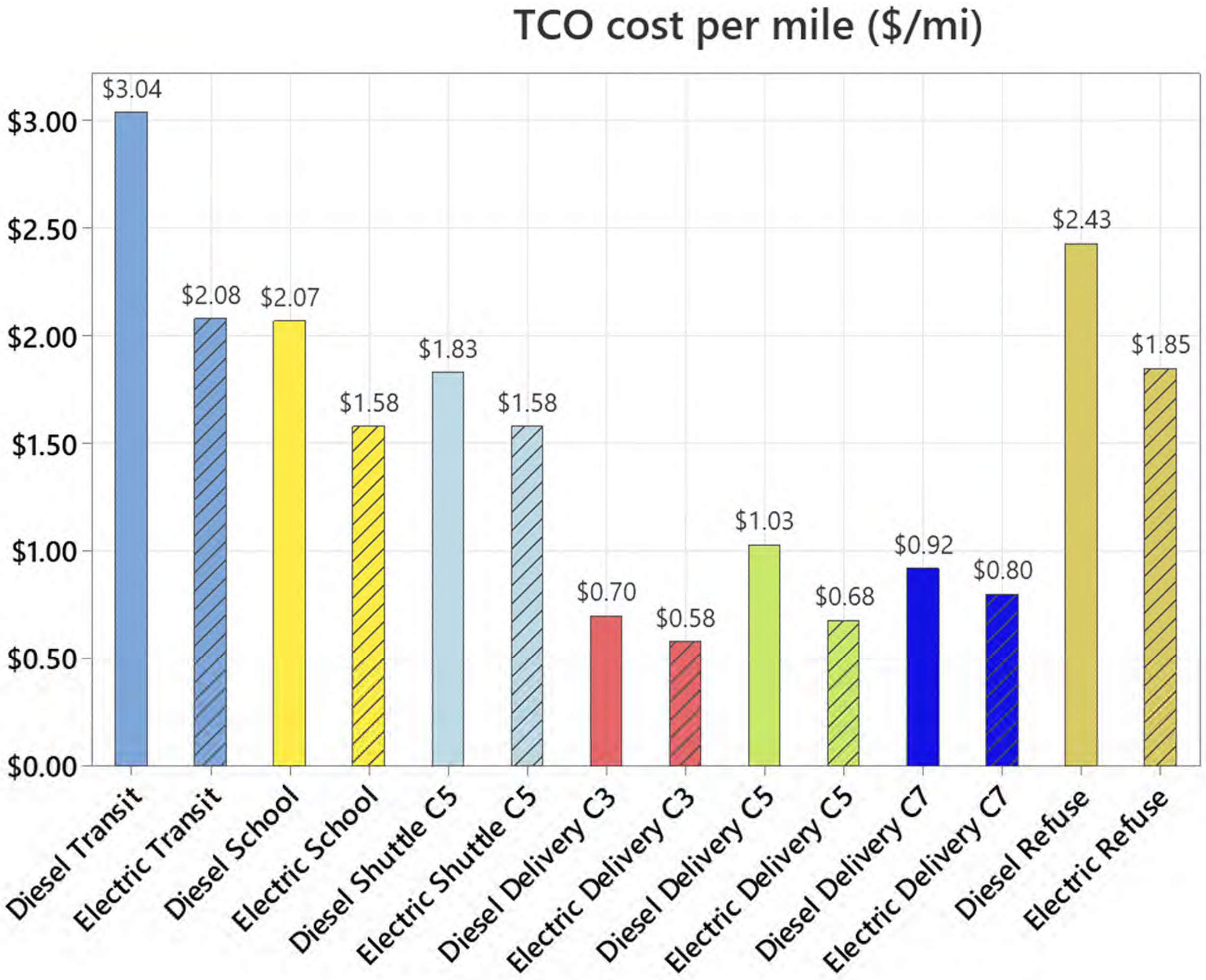
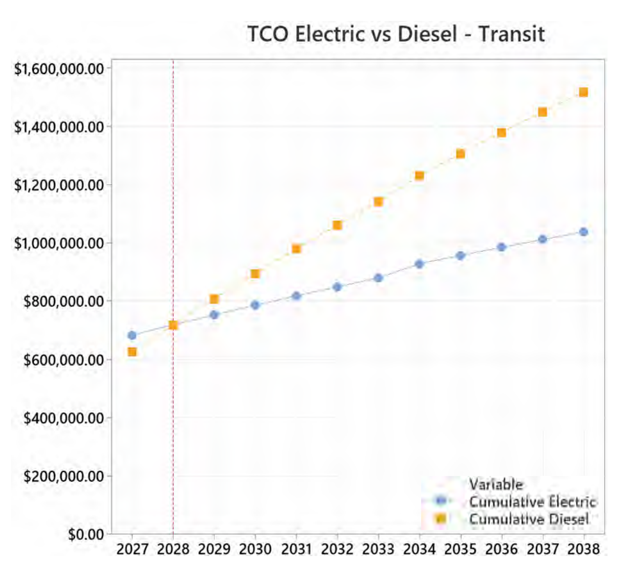
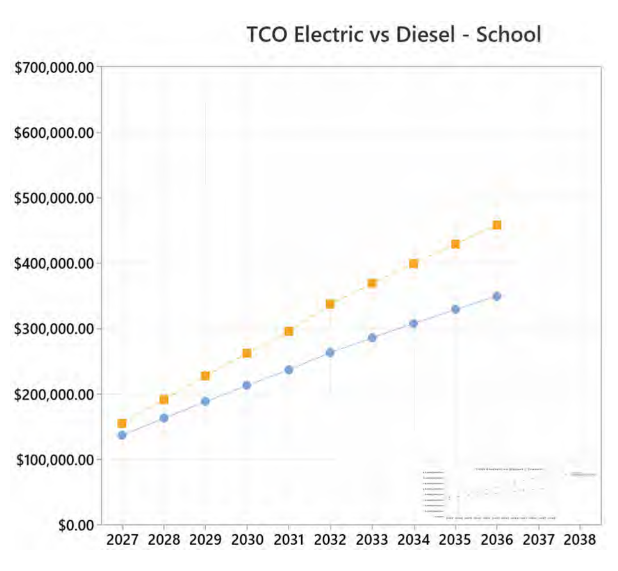
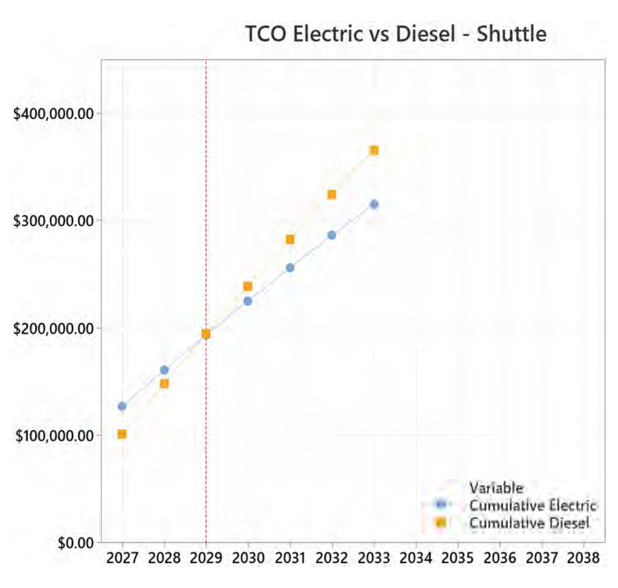


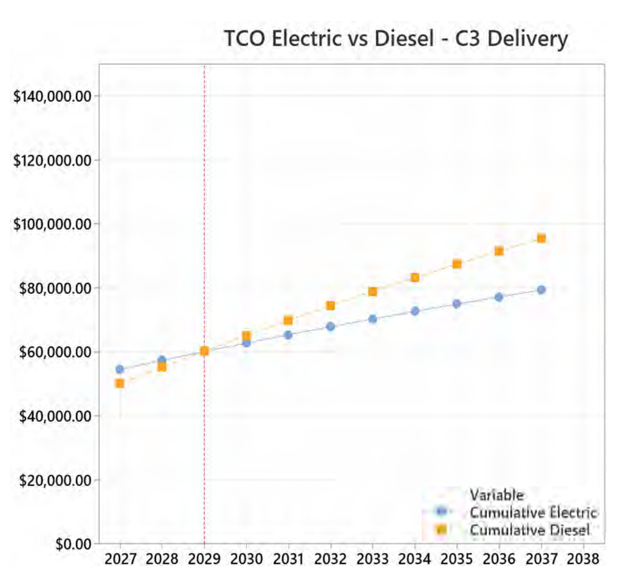
Figure 2: Total cost of ownership per mile in 2027 of all vehicle classes studied.

Figure 2 shows the cost per mile of all financial aspects of ownership of each class for a vehicle purchased in 2027. The striped bars show the electric vehicle costs. In all classes, EV costs are less than ICE costs over the life of the vehicle, as maintenance and energy costs are significantly lower for EVs than ICE vehicles. This overcomes the difference in costs associated with charging infrastructure and vehicle costs that can make initial investment costs of EVs higher than ICE vehicles. Plotting cumulative TCO over time shows the time to parity for each vehicle class.









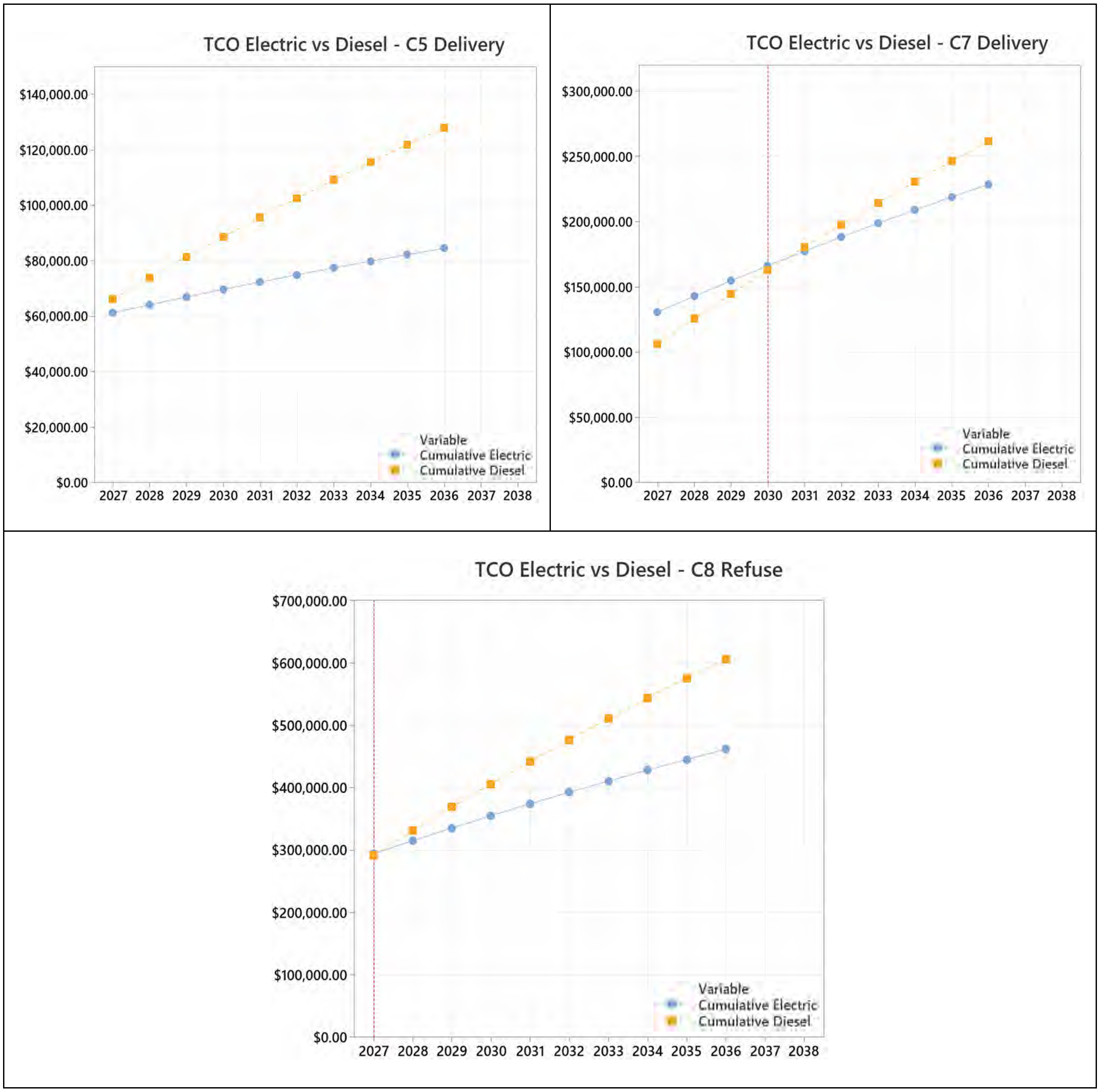


Figure 3: Cumulative TCO for all categories in the study. Vertical lines show the time to parity for classes where initial EV costs are higher than ICE.

Figure 3 shows the cumulative cost of all financial aspects of ownership of each class from 2027 to 2038. In all categories but Transit, Shuttle, and Class 7 delivery, cost parity is immediate given a 2027 purchase date. Transit reaches parity in the second year of operation, while the Shuttle and Class 7 Delivery categories reach parity in the third year of operation. The result is driven by the relatively higher cost of charging infrastructure when compared to the vehicle costs of these categories. A summary of the time to reach parity for each TCO is shown in Table 3.

Table 3: Year to parity for the cumulative cost of ownership for each class studied.

Cumulative TCO Parity Reached – 2027 Purchase	
Market Segment	**Parity Reached**
Class 8 Transit Bus	2028
Class 7 School Bus	Immediate
Class 5 Shuttle Bus	2029
Class 8 Refuse Truck	Immediate
Class 7 Delivery	2030
Class 5 Delivery	Immediate
Class 3 Delivery	2029

Charging infrastructure is a potential significant capital expense when transitioning a fleet to EVs. For the reference case TCO analysis, the depot charger and vehicle on-board charger were sized to charge a vehicle in 4 hours, assuming one charger per vehicle. The costs associated with the chargers examined in the study are shown in Figure 4. Charging costs were taken from literature sources detailing the installation cost as well as the hardware costs. The average published cost in literature for chargers of each power level was used in the TCO analysis. Charger costs are assumed constant in the costing timeframe presented. A detailed study of future charger costs was not conducted and optimizing charger utilization was not considered since they were outside the scope of this study. This results in fairly conservative estimates of charger costs in this study. Increasing charger availability, advancing technology, and optimized charging strategies could all reduce the infrastructure costs in the future, further reducing the TCO for BEVs presented in the report.

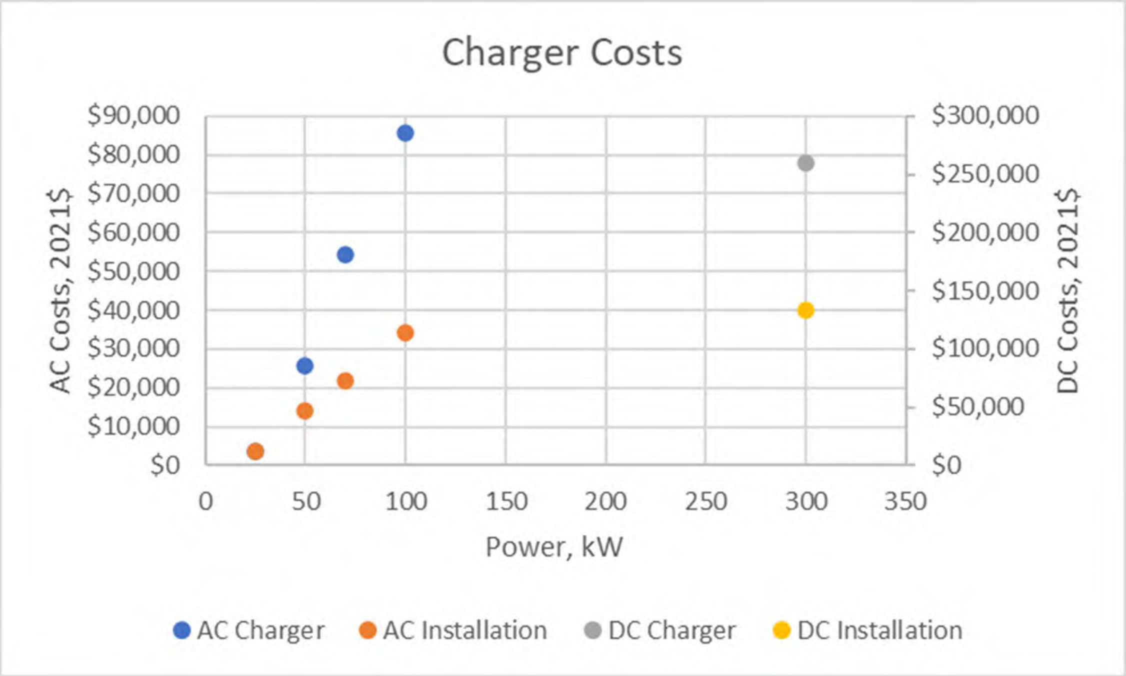


Figure 4: Charger and charger installation costs used in the study.

Sensitivities in the costing analyses are presented for both the incremental and total costs of ownership. For the incremental costs, these sensitivities are based on technology developments and options that may change the costs of both EV and ICE vehicles. The primary sensitivities for ICE vehicles are the possibilities of mild and full hybridization. Mild hybridization increases the hardware costs of diesel vehicles for start-stop functionality. Full hybridization includes the addition of a PMSM drive motor and small battery pack, as well as hardware costs associated with an optimized engine for hybrid functions. For EVs, the base assumption is an NMC battery pack, but lithium iron phosphate packs are cheaper and well suited to the large form factor of heavy-duty vehicles. Additionally, convergence in light- and heavy-duty motor design and production is expected to bring motor costs down, and this provides another sensitivity in the costs analysis of EVs. Once these sensitivities are considered in the incremental costs, all vehicle classes studied show a case where electrification provides a strong cost advantage over the equivalent ICE vehicle, as shown in Figure 5, even considering the conservative estimates of charger costs which ignore future developments in charger technology and adoption.

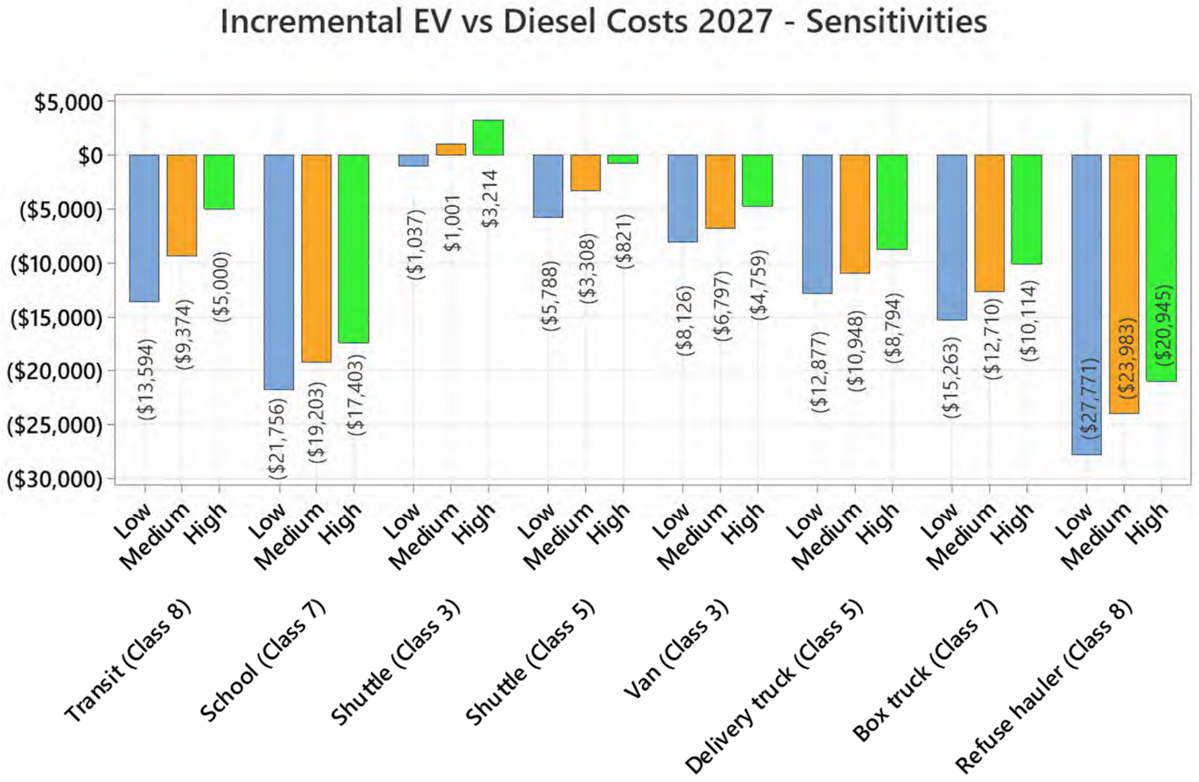


Figure 5: Incremental costs ranges after sensitivities are applied to the costs of an ICE powertrain vs an EV powertrain.

For the TCO analyses, sensitivities are more dependent on costs external to the vehicle such as fuel or energy costs, maintenance, and infrastructure choices. The best and worst-case scenarios of these factors, as well as vehicle costs, were analyzed in addition to a reference case to obtain a more complete picture of the costs associated with electric vehicle ownership. For some factors such as energy prices, a low case assumption for diesel vehicles would likely coincide with low costs for electricity for BEVs. In other cases such as vehicle costs, there is little connection between the two sets of assumptions. The low and high cases are intended to bound the operating costs of each vehicle. Figure 6 shows the results of the TCO sensitivity analysis on a cost-per-mile basis.

In both the upfront incremental costs and total cost of ownership, cost parity is achievable in all of these vehicle classes within the first three years of operation for the reference cases. Incremental costs differences in powertrain, emissions, and transmission equipment for diesel ICE vehicles compared to EVs favor EV adoption between 2024 and 2027 in nearly all cases based on the current trends and available forecasts. Because infrastructure costs are significant relative to the vehicle and operating costs in Class 3-5 shuttles, and lifetimes are shorter than other vehicles, the added expense of fast charging has an outsized effect on these TCO cases.

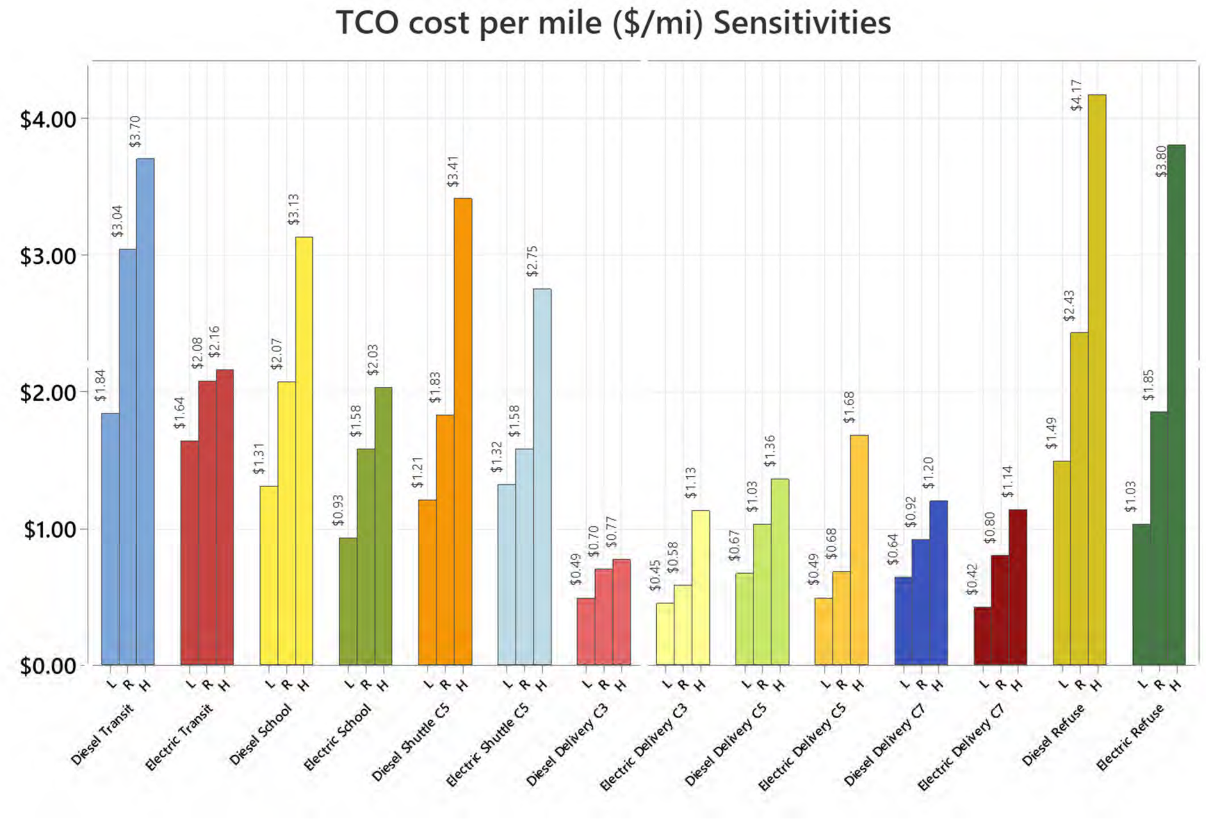


Figure 6: Sensitivities applied to each category costed for TCO per mile.

Vehicle cost is not the only consideration that goes into fleet purchase planning, as charging infrastructure will add upfront costs and operational costs which can be significant over the lifetime of the vehicle, which can be over a decade. In each TCO case studied, EVs show a cost advantage over the life of the vehicle at or near the purchase time, with savings increasing throughout the vehicle's life. Planning and active charging management can increase these savings even more as an investment in charging is optimized across the fleet for its specific needs. The charging infrastructure cost is considered as an upfront cost for this analysis and financing of these costs is not evaluated. The impact of financing is assumed to be the same between the different types of vehicles from a fleet owner's perspective and therefore is not included. Additionally, incentives and tax rebates may also be available for the fleet owner to cover some portion of the upfront costs and weren't considered.

There are many external benefits to EV adoption, including environmental benefits through the reduction of PM and NOx emissions, as well as the reduction in noise in congested environments. While these benefits are not included in this analysis, they may improve the case for EV adoption. Also not considered in this analysis are government-based incentives, subsidies, or policies that can offset or outright reduce the costs of EV adoption. These policies can only further drive investment in EV adoption, increasing the overall market penetration and economies of scale for EV components.

As with any developing technology, there are challenges associated with the widespread adoption of EVs. Batteries and motors currently rely on expensive and volatilely priced rare-earth metals for the permanent magnets and the battery cells. Some have argued that widespread EV adoption could strain these currently fragile supply chains and could offset the cost benefits seen in EV adoption without advancements or changes in technology pathways. Several current, emerging, and future technologies are presented that can alleviate this pressure and minimize reliance on these metals, including battery chemistries that minimize or eliminate the use of lithium, and motors that reduce or eliminate rare-earth permanent magnet use. Further work is underway developing battery production methods that increase the cycles that a battery can experience while maintaining its charge capacity. The analysis timeframe of 2027-2030 mitigates the effect of any near-term supply constraints as well as the effects of disruptive future technologies.

The categories in this study are not the only candidates viable for electrification in 2027 but were chosen as available evidence points to these MD/HD classes being the most viable. The results in this study show that broader adoption across the MD/HD market is possible and should be examined in future work.

Overall, typical worries with electric cars concern supply chains, materials, and price escalations. Assuming current availability continues and no continued development of technologies including cost reduction in EV parts, cost parity is achievable in both purchase costs and TCO. Developing technologies further drive the attractiveness of EV adoption for fleet customers, minimizing the reliance on rare-earth and expensive metals in the EV powertrain. There are no technical impediments to EV adoption in these classes with the technology available in 2021, and this will only continue to improve as technologies and production mature with the increasing adoption of EVs.

1.0 Introduction

Medium and heavy vehicles comprise less than 10% of the US vehicle fleet but account for 23% of the greenhouse gas emissions as shown in Figure 7 [2]. Since a large portion of MDHD vehicles are powered by diesel engines, they account for almost 60% of the total NOx and particulate emissions [2]. Hence electrification of the MDHD fleet will result in not only a significant reduction in greenhouse car emissions but also a marked improvement in air quality. It is important to understand the present and future (2021-2027) trajectory of electrification technologies and costs to have the right regulatory framework to accelerate the transition of the US MDHD fleet to BEVs. The transition to BEVs is not only important to mitigate the effects of climate change and improve air quality to reduce healthcare costs but also maintain the technology leadership and competitiveness of the US economy as many of the world's developed economies have announced deadlines to transition away from using fossil fuel for transportation.

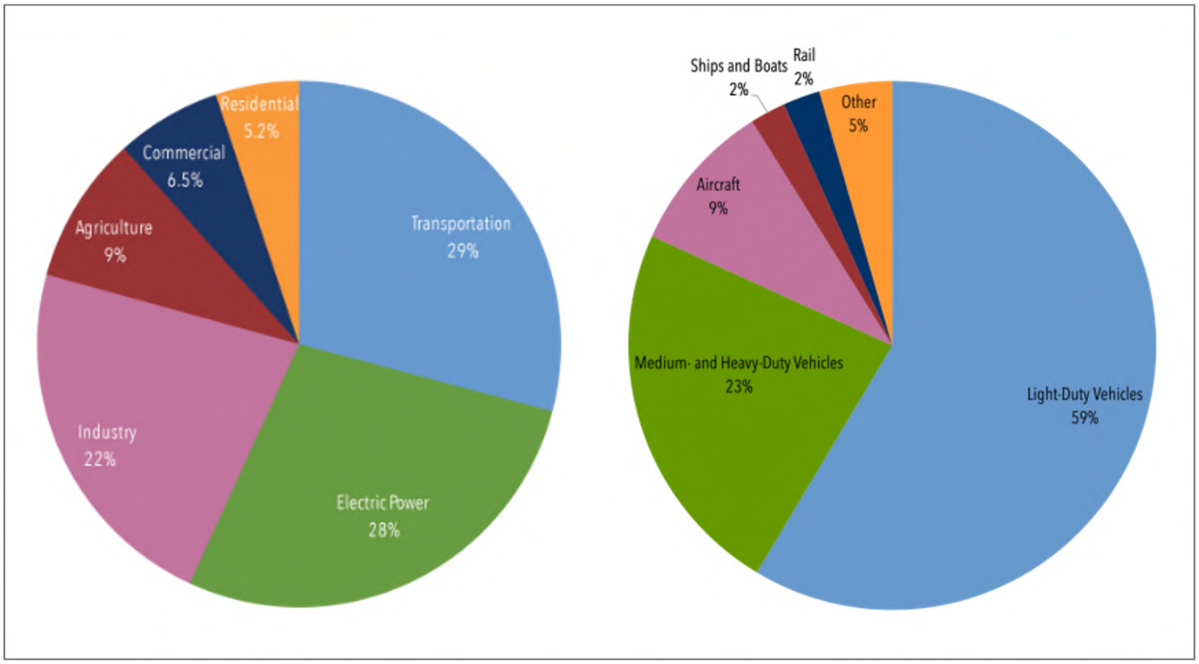


Figure 7: Factors contributing to the US total and US transportation-related CO_2 Emissions (2019 data). Source US EPA [2]

Emissions from the transportation sector contribute significantly to air pollution and the negative health effects that accompany it. More than 20,000 Americans die prematurely every year as a result of pollution from highway vehicles [3]. The health burden from vehicles in the heavy-duty categories such as trucks and buses is substantial, causing adverse health impacts in utero, in infants and children, in adults, and in the elderly. Those that live close to roads, highways, ports, distribution centers, freight depots, and other sources of truck pollution are subject to the greatest harm [4] [5] [6] [7] [8]. Additionally, NOx and PM emissions from the medium- and heavy-duty fleet are currently responsible for up to 4,550 premature deaths, 4,290 hospital visits, and 2.7 million incidents of exacerbated respiratory conditions and lost or restricted workdays annually. The monetized cost of these public health impacts from the medium- and heavy-duty fleet are estimated to exceed $53 billion annually [9] [10].

Battery prices have fallen by 88% in the last decade with cell cost per kWh falling under $100/ kWh for NMC chemistry in 2020 [11]. The increasing energy density, innovative cell form factor, and pack construction of cheaper (more than 20% when compared to NMC) and significantly more durable LFP chemistry has made it suitable for all but the highest range MDHD applications. Several motor technologies that do not use rare earth metals have matured and entered production. With the rapidly increasing manufacturing scale of electrification components (batteries, motors, power electronics) and increased automation of battery pack and motor manufacturing, the cost of electric powertrains is falling rapidly, significantly outpacing projections made as late as 2017. Unlike ICE powertrains, there can be significant sharing of components – cell modules, motors, and inverters between light-duty and MDHD applications giving significantly higher manufacturing scales and cost savings. Some of these cost savings are yet to be realized due to the manufacturing of most current MDHD applications being extremely small-scale, low automation using custom components. Given the state of technology summarized above, most of the MDHD fleet is ready for electrification.

It is also important to understand the contribution of various factors to the cost of owning and operating a BEV for different MDHD applications over the entire life of the vehicle. It is important to provide the right legislative framework and incentives to encourage not only BEV manufacture and purchase but also infrastructure development. This study quantifies the purchase price in 2021, 2024, and 2027, and the total cost of ownership ($/mile over the life of the vehicle) of representative battery electric vehicles from class 3 to 8 (listed in Table 4) purchased in 2027. An effort is made to assess the various factors (sensitivities) which will affect these costs and quantify their effects.

For every major market segment from classes 3 to 8, the paper defines a representative battery electric vehicle (Table 4) whose battery pack is sized based on vehicles usage statistics [12] and power output based on MDHD component sizing presented by Argonne National Labs [13] and specified by EDF for this work. A vehicle is divided into subsystems grouped into four categories (outlined in Figure 8) for calculating vehicle manufacturing cost: components that are only present in an ICE vehicle, components common to ICE and BEV, components that are only present in a BEV, and components that are modified when switching from an ICE to BEV architecture. All cost inputs for the analysis are derived from peer-reviewed journals, industry analysis reports, and teardown studies. Increase in cost of a diesel ICE powertrain from 2021 to 2027 due to fuel economy improvements required to meet the Phase II greenhouse gas rule and the 2027 California ARB low NOx rule are taken from the regulatory impact analyses [14] [15]. For calculation of the TCO, purchase price, fueling infrastructure cost (charger/ fuel depot operation), energy costs (diesel/ electricity), and maintenance are considered. The TCO of a BEV is compared to an ICE purchased in 2027 over the life of the vehicle using a discount rate of 3%.

Table 4: Representative vehicles used for TCO analysis

Market Segment	Weight Class	Battery Capacity (kW-h)
Transit Bus	Class 8	400
School Bus	Class 7	60
Shuttle Bus	Class 3-5	200
Delivery and Service Van, Box and Stake Truck	Class 3	100
Short Haul Delivery, Service, Box, and Stake Truck	Class 6-7	150
Short Haul Delivery and Service Van, Box and Stake Truck	Class 4-5	100
Refuse Hauler	Class 8	200

These categories represent vehicles that are typically operated along fixed routes and return to a home base daily. They are typically operated by fleet owners with the infrastructure to manage maintenance and charging. These features make these categories logical targets for electrification.

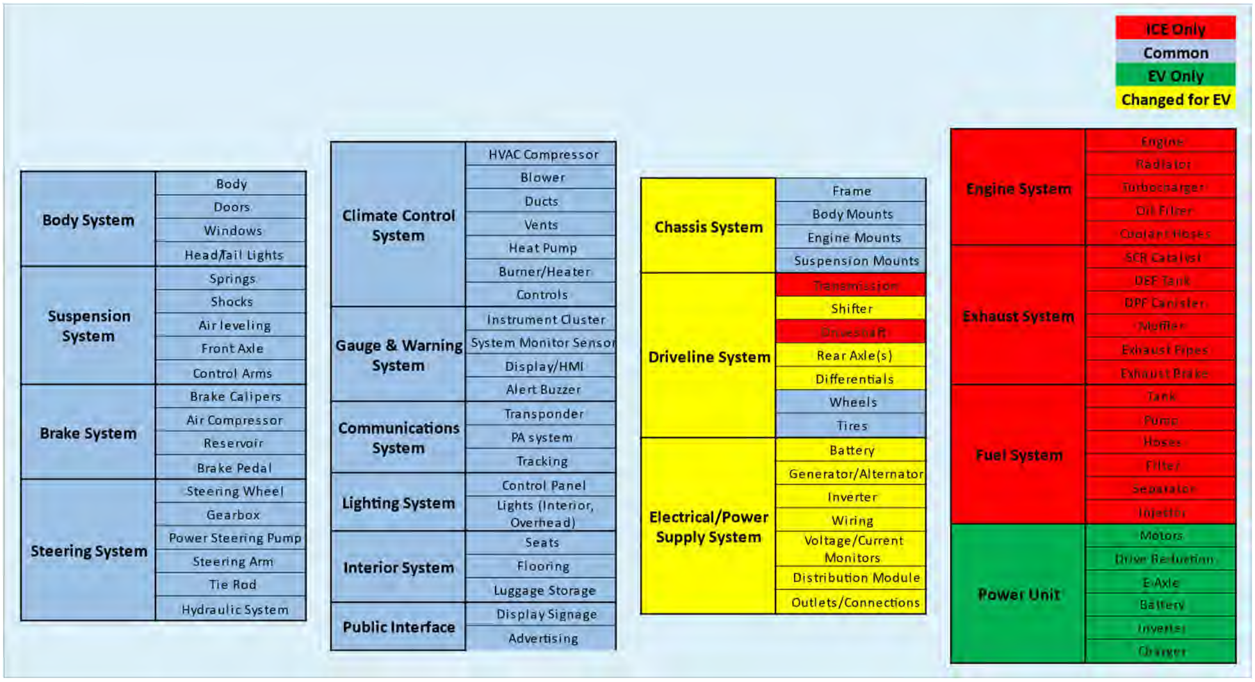


Figure 8: Comparison of the BOM for an ICE vehicle and BEV used for new vehicle cost analysis

The report summarizes the present state of the art and future trajectory of technology in battery, traction motor, and power electronics. The technology review is guided by the following questions – Are there technologies that will:

1) Significantly reduce the direct manufacturing cost and total cost of ownership of battery electric vehicles from 2021 to 2027 and beyond?
2) Mitigate increase in commodity prices or supply chain issues due to geopolitical or other factors of raw materials (like rare earth metals, copper, Cobalt, etc.) that might negatively affect the cost of a BEV derailing electrification of the US MDHD fleet?

The study found that the purchase price parity for almost all classes and vehicle use cases analyzed will be reached between 2024 and 2027. The only exception is class 3 delivery vans and shuttle busses that have low-cost gasoline or diesel engines that are based on light-duty applications. Due to the substantially lower fuel and maintenance cost of BEVs, the TCO advantage of the BEV widens over the life of the vehicle. For battery-electric vehicles, charging infrastructure represents a significant upfront cost that is dependent on fleet size, vehicle use patterns (uptime and charging time available, miles traveled per day), sharing of charging infrastructure between different fleets, etc. There are several technologies in the battery, traction motor, power electronics that can significantly reduce the cost of an electric vehicle from 2021 to 2027. There are also several alternative battery and motor technologies that the industry can take in the event of an increase in the commodity price of raw materials or supply issues due to geopolitical or other factors and continue its trajectory of reducing the cost of electrification.

2.0 Methodology

2.1 ICE Components

To determine the costs of the components that would be replaced or not present on an EV, a list of components related to an ICE vehicle was created and the parts to be eliminated were identified as seen in Figure 8. Of these, the primary drivers of cost were found to be the engine, transmission, and aftertreatment systems. Each of these is costed independently based on the vehicle segment, as well as required improvements for each to meet anticipated regulations in 2027. The engine is the prime mover of the vehicle and is the primary driver of fuel economy, power output, and emissions. Emissions control for the engine may consist of waste heat recovery devices, exhaust gas recirculation (EGR), and various combustion control systems built into the injectors, pistons, turbocharger, or otherwise.

The exhaust stream of the engine is routed to the aftertreatment system where further emissions control or cleanup occurs. This system commonly consists of a diesel particulate filter (DPF), selective catalytic reduction catalyst (SCR), and diesel oxidation catalyst (DOC). The aftertreatment system directly acts on emissions components that can cause pollution, such as PM, NOx, CO, and unburnt hydrocarbons.

The rotational power from the engine is sent to the transmission, which adjusts gear ratios for the required speed and torque of the vehicle. Transmissions may be automatic or manual, or an automated-manual with the number of gear ratios ranging from 6 to 18, depending on the application. Proper calibration and selection of forward ratios can improve fuel mileage in an ICE vehicle. This section examines the base technologies and advancements required to meet emissions regulations for the 2024 and 2027 GHG regulations, as well as the 2027 California Low NOx requirements.

The base costs for the engine portion of the delete package are derived from power levels as shown in Figure 2.2-4 of the 2019 Argonne National Labs report, copied in Figure 9 [16]. This figure, adjusted to reflect the value in 2021 USD, is used as the base engine and aftertreatment costs in the costing exercises. The base engine hardware is considered mostly mature and no significant cost reduction through optimization or improvements are anticipated. Most of the cost increments are for the engines to meet emissions standards put forward by EPA and ARB.

To achieve anticipated emissions standards, various engine systems are expected to change. These include overall engine developments such as downsizing, waste heat reduction, and down speeding. Inside the engine, systems such as injectors, piston shapes, and valves may increase in complexity to achieve higher efficiency. Advanced exhaust gas recirculation systems, turbocharging, and engine control systems will also help achieve lower emissions and higher efficiency. The tables below outline the various parts and systems that will increase cost in a base heavy-duty engine in 2027 [17] [18] [19] [20] [21].

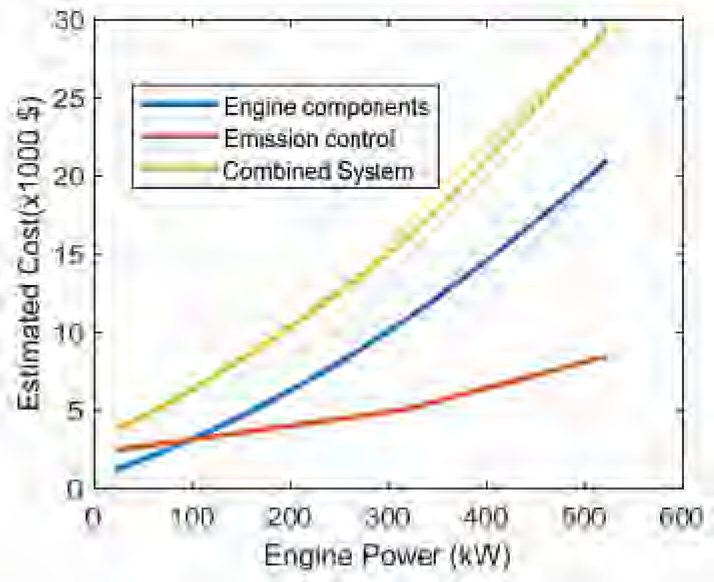


Figure 9: Estimated cost of diesel systems as a function of engine power, Figure 2.2-4 [16]

Table 5, Table 6, and Table 7 show the engine costs incurred for each regulation for the various engines examined.

Table 5: Engine costs incurred to meet 2024 and 2027 GHG rules for diesel engines in classes 3-6

Engine Component	2024 Cost: GHG Phase 1	2027 Cost: GHG Phase 2
	2021$	2021$
Valve Actuation	$188.78	$203.91
Cylinder Head	$11.86	$11.86
Turbocharger	$18.88	$20.15
EGR Cooler	$3.54	$3.54
Water Pump	$95.57	$100.77
Oil Pump	$4.72	$4.72
Fuel Pump	$4.72	$4.72
Fuel Rail	$13.04	$13.04
Fuel Injector	$15.41	$16.60
Piston	$2.36	$3.56
Valve Train	$115.00	$120.92
Model Based Controls	$37.76	$48.61
Incremental Costs per Regulation	**$511.64**	**$40.76**

Table 6: Engine costs incurred to meet 2024 and 2027 GHG rules for diesel engines in classes 7-8

Engine Component	2024 Cost: GHG Phase 1	2027 Cost: GHG Phase 2
	2021$	2021$
Valve Actuation	$188.78	$202.94
Cylinder Head	$7.08	$7.08
Turbocharger	$18.88	$20.06
EGR Cooler	$3.54	$3.54
Water Pump	$95.57	$100.29
Oil Pump	$4.72	$4.72
Fuel Pump	$4.72	$4.72
Fuel Rail	$10.62	$10.62
Fuel Injector	$11.80	$11.80
Piston	$2.36	$3.54
Valve Train	$86.13	$90.85
Model Based Controls	$37.76	$48.37
Incremental Costs per Regulation	**$471.95**	**$36.58**

Table 7: Engine costs incurred to meet 2027 Low NOx rules.

Engine Size	Cost to meet 2027 Low NOx
9L Heavy Duty (Class 8 Engines)	$2,200.97
Up to 7L Heavy Duty (All others)	$1,419.45

These costs were added to the base engine and transmission cost taken from Figure 9 to determine the reference cost of a diesel powertrain in 2021, 2024, and 2027.

2.2 Aftertreatment

Aftertreatment systems serve to remove emissions and pollutants from the engine's exhaust stream. Three primary aftertreatment systems are in use on heavy-duty diesel engines today: diesel particulate filter (DPF), selective catalytic reduction (SCR), and diesel oxidation catalyst (DOC). These serve to remove particulate matter (PM), NOx, CO, and hydrocarbons from the exhaust stream. Aftertreatment systems can effectively reduce emissions of non-CO2 pollutants below regulatory thresholds and will be a source of increased costs on ICE vehicles as emissions standards tighten.

Improvements to these systems may take the form of integration, backpressure reduction by reducing the wall thickness of DPF, reduced NOx emissions by improving SCR cell density, and reduced urea consumption during transients. These improvements, coupled with the engine improvements discussed previously, can help improve efficiency and emissions performance and contribute to the costs listed. For the costing exercise, Figure 9 was used for the base aftertreatment costs, with the additional costs in Table 8 added for the 2024 and 2027 model year costs.

Table 8: Aftertreatment costs incurred to meet each emissions regulation target compared to 2021 base aftertreatment.

Aftertreatment Component	2024 Cost: GHG Phase 1	2027 Cost: GHG Phase 2	2027 Cost: CARB
	2021$	**2021$**	**2021$**
SCR, Dosing, DPF - Vocational HHD	$16.52	$17.70	
Low NOx Aftertreatment Improvements			$2,262.35
Incremental Costs per Regulation	**$16.52**	**$1.18**	**$2,262.35**

2.3 Transmissions

Transmissions help maintain efficiency by keeping the engine in its most efficient operating range at all speeds and loads. Optimization of the number of forward speeds, as well as the drive ratio, can increase transmission cost. Automated manual and fully automatic transmissions can implement advanced controls to optimize efficiency better than a driver can with a manual transmission. Other implementations such as a dual-clutch transmission (DCT) or automated manual transmission can increase shift speed and reduce losses through a torque converter, improving efficiencies. The costs of the base transmission as well as advancements to reduce friction and optimize the transmission system for better efficiency and reduced emissions are shown in Table 9.

Table 9: Transmission costs incurred to meet each emissions regulation target compared to 2021 base transmission [22] [23] [24].

Transmission Component	2024 Cost: GHG Phase 1	2027 Cost: GHG Phase 2	2027 Cost: CARB
	2021$	**2021$**	**2021$**
Base Cost – Class 7-8 Heavy Duty	$15,628.00		
Base Cost – School Bus	$7,676.82		
Base Cost – Shuttle and Class 3-5	$2,600.00		
Improvements for Emissions (Class 7-8)		$2,200.72	

2.4 Hybridization

Hybridization is a form of partial electrification where some energy is provided by a system other than the consumable fuel, such as a rechargeable battery. There are multiple levels of hybridization that can be implemented, from mild to full hybridization. All energy supplementation by hybridization can reduce fuel consumption, directly reducing CO2 emissions from the vehicle. Hybridization is not required to meet more stringent emissions and fuel economy regulations, but it is an option that can save fuel and be attractive to fleet operators. Thus, it is considered as a sensitivity to the base engine costs in this work.

Mild hybridization may take the form of a belt-driven starter-generator that shuts the engine off when not needed, and starts the engine when power is required again. Some engine power may be supplemented by the ISG in this situation, but very minimal power is available from the motor and battery.

Emissions and fuel consumption are fairly low for a diesel engine at idle, but mild hybridization can still offer some improvement.

More expensive and fully hybridized drivetrains contain a larger, more powerful electric motor integrated into the drivetrain, typically as part of the transmission. This motor-generator unit can provide launch assist torque, fully electric operation, or regenerative braking for power generation. These full hybrid systems also require a battery for storing the energy harvested from the system and providing sufficient range for some full-electric operation. To convert the battery power to useable power by the motor, an inverter is required as well. Full hybrid drivetrains are complex and cost-adding systems that can greatly improve fuel economy, reduce carbon dioxide emissions, and improve performance.

Regenerative braking in a hybrid reduces the wear on brakes, by recovering mechanical energy through the motor-generator and converting it to electrical energy for the battery. This process eliminates the mechanical energy waste that turns vehicle kinetic energy into heat and reduces stress on many vehicle components. This in turn increases fuel efficiency and can reduce maintenance expenses to a degree.

Two sensitivities were applied to the base cost of an ICE drivetrain: mild hybridization and full hybridization. These two levels were selected as sensitivities as they represent significant investments in equipment on a vehicle to meet more stringent fuel economy and emissions standards compared to the minor variations of some components of an engine or aftertreatment system. Variations in the full hybridization cost can come from the power level of the motor(s) and the battery capacity selected. For this study, electrification power was set at 50% of ICE power. While this may vary depending on the application, motor costs are a lower contributor than battery costs and have a minor effect on the incremental cost of hybridization. Hybrid battery packs were sized to be 10% of the specified size for the full electric vehicle. Mild hybridization creates a moderate cost ICE package, and full hybridization creates the high-cost ICE package. It is worth noting that the advancement in electrification also reduces the future hybridization costs for ICE-based powertrains. Costs of the motor and battery are the same as used for electrification costs, discussed in the next section.

2.5 Electrification Costs

Figure 10 illustrates the main components of an electric vehicle and Table 10 summarizes the electrification costs used in the study.

The common components required to achieve vehicle electrification include the traction motor, inverter, battery (typically in pack form), and other power electronics such as an on-board charger and the DC-DC converter. In addition, a thermal management system is required to provide cooling to the components, similar to the thermal management system of an ICE vehicle.

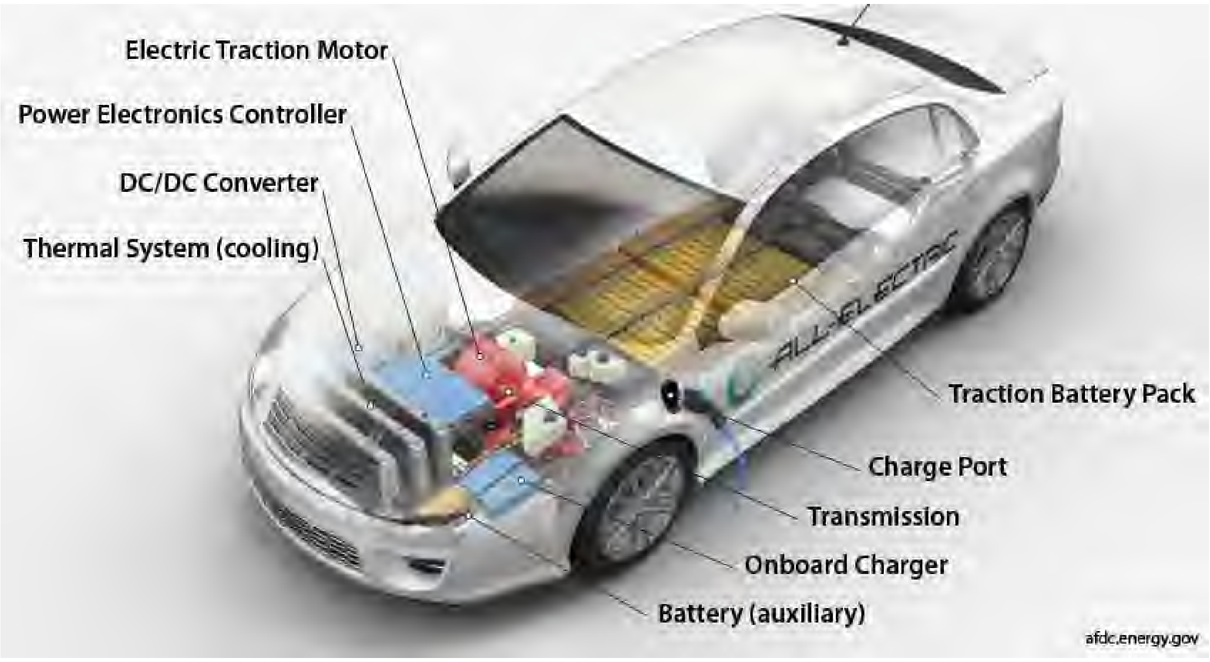


Figure 10: Components of a Battery Electric Vehicle (Source NREL)

The traction motor is typically an induction or permanent-magnet based AC motor operating at high voltages and frequencies for torque and speed control. The motor is the prime mover of the vehicle, and EVs may contain 1-4 of these motors depending on the drivetrain layout. Some vehicles utilize a single motor for driving a single axle, while others may employ one motor per axle or wheel or a combination of layouts.

To store the energy necessary for driving the vehicle, EVs utilize a battery pack. The battery pack consists of many small battery cells connected in both series and parallel to create a battery of the necessary voltage and capacity for the vehicle's requirements. Batteries may use a variety of chemistries but typically rely on Lithium-based formulations, though research is underway on other chemistries. NMC and LFP cathode chemistries are considered for this report. Several advanced battery technologies discussed in Section 3.1 are not used for projected costs, although these advanced battery technologies have the potential to significantly reduce cell and pack costs. Hence the costs used in this study are conservative.

The inverter takes the DC power output from the battery and turns it into AC power for the motor, at a specific frequency and amplitude required for the driver's requested torque and speed. The inverter controls the output of the motor and subsequently the vehicle's behavior. Under regenerative braking, the inverter handles electrical power flow in the opposite direction, taking power from the vehicle's traction motor and sending it back to the battery pack to recover some electrical energy from the vehicle's kinetic energy.

The power electronics of the vehicle provide auxiliary functions, such as a DC-DC converter for converting the high battery voltage to the common 12V used by many auxiliary vehicle systems. The onboard charger takes the AC power from a charger and converts it to usable DC power for charging the battery.

In the incremental “add cost” case, three situations were analyzed for electrification costs. A high-cost electrification package includes an NMC battery chemistry and heavy-duty specific motors. The lowest cost option consists of LFP battery chemistry and light-duty-based motors. A moderate-cost option was created that includes HD motors and LFP batteries. All cases used to create the electrification incremental costs assume an onboard charger sized for a 4-hour depot charge for the battery capacity in each class. The assumptions used in TCO are discussed in Section 2.6.3.

Some production medium and heavy-duty vehicles employ a single ratio reduction gearbox while others employ a two-speed gearbox. Some suppliers like Eaton are working on multispeed (4 speed) transmission for medium and heavy-duty vehicles. Roush believes that in the future most MDHD BEVs will employ a single-speed gearbox in the interest of cost, complexity, and reliability. In this report, only a single-speed gearbox was considered in EV drivetrains.

Table 10 summarizes the higher and lower unit cost of electrification components in 2021, 2024, and 2027.

Table 10: Summary Table of Electrification Component Cost

Component	Decription/ Assumption	Unit Cost ($/kW, $/kWh)		
		2021	2024	2027
Batteries	High – NMC	$123.40	$90.20	$68.40
	Low – Lithium Iron Phosphate (LFP)	$107.45	$78.54	$59.56
Motor	High - Low volume low speed high torque (ANL)	$18.35	$8.64	$6.48
	Low - Mass produced, light duty based Munro and associates teardown study 2020	$4.02	$3.62	$3.25
Inverter	Based on 2020 Model Y (SiC MOSFET) Munro and associates teardown study 2020	$3.65	$3.28	$2.96
DC-DC Converter	Lutsey & Nicholas 2019 [25]	$55.94	$50.35	$45.31
On board Charger	Lustey & Nicholas 2019 [25]	$55.94	$50.35	$45.31

2.6 Total Cost of Ownership

The total cost of ownership analysis in this study was conducted to account for all of the financial aspects of ownership of an ICE or EV. Only tangible financial aspects of ownership related directly to the vehicle were considered: purchase price, maintenance, energy, and infrastructure. Costs not included were staffing and labor, scrap or resale, taxes, grants, subsidies, or intangible benefits such as healthcare costs or environmental costs related to emissions or fuels. Staffing and labor costs, scrappage, and resale are not expected to change significantly between the two types of vehicles. Subsidies were not included to ascertain the costs are derived from a non-supported framework. As a consequence, the results of our analysis show that subsidies are not an essential portion of cost reduction or EV favorability in the 2027-2030 timeframe. The inclusion of subsidies for the consumer may accelerate the adoption and penetration of EVs but is not necessary for achieving cost parity.

Three cases were developed for TCO: Reference, Low, and High. The reference case provides approximately a median prediction for all costs associated with the vehicle with a 2027 purchase timeframe. For the ICE powertrain, this includes mild hybridization on top of the base diesel, while the EV powertrain assumes heavy-duty specific motors and an LFP battery pack. Literature sources were chosen for vehicle mileage, lifespan, energy costs, charger costs, and maintenance. These provide a middle-of-the-road approach to viewing TCO and should approximate expected costs in the future for vehicles.

The Low and High cases attempt to set bounds on the TCO by considering the best-case scenario and worst-case scenario for costs, respectively. The Low scenario assumes the lowest cost of energy, lowest purchase price, lowest vehicle mileage, lowest maintenance costs, highest fuel economy, and low-cost charging infrastructure in the EV cases. The High scenario assumes the opposite: High purchase price, high vehicle mileage, high maintenance, and energy costs, and expensive DC chargers. While it is unlikely that all of these situations combine to meet the high and low-cost scenarios, they do serve as bounds on the TCO analysis.

2.6.1 Common TCO Considerations

Common to both vehicle types are vehicle lifespan, daily mileage, and annual mileage. These were held constant between ICE and EV calculations to provide a direct comparison of the overall costs as well as costs per mile. The reference, low, and high lifespans and mileages used in the analysis are shown in Table 11 [26] [27] [28] [29] [15] [30] [31] [32] [33].

Table 11: Vehicle lifespans used in the TCO analysis.

Vehicle Lifetimes						
Vehicle Type	**Low Mileage**	**Reference Mileage**	**High Mileage**	**Low Years**	**Reference Years**	**High Years**
Transit – Class 8	331,200	500,000	652,836	12	12	12
School Bus – Class 7	221,120	221,120	425,000	10	10	10
Shuttle – Class 5	100,000	200,000	200,000	7	7	7
Delivery Van – Class 3	124,350	136,785	231,000	10	11	11
Delivery – Class 5	124,350	124,350	148,000	10	10	10
Delivery – Class 7	250,000	285,710	360,000	10	10	10
Refuse – Class 8	175,000	250,000	300,000	12	10	7

For the diesel vehicle purchase price, literature sources on public fleet expenditures on buses and shuttles were utilized, as well as retail and data published by CARB and other agencies [34] [35]. Low, moderate, and high costs were selected from the sources found for vehicle costs. Because current EVs are sold at a premium due to their low volumes and high technology costs, the current difference was ignored in this cost study. Manufacturers such as Proterra and BYD expect the base cost of a complete ICE bus to remain constant in 2021 dollars, so this was the assumption for vehicle cost in 2027 for all classes [36]. To determine the incremental costs, the costs of ICE-specific components were determined and subtracted from this price, while the EV component costs were added. The cost difference from the base vehicle price was calculated based on a standard set of options for each scenario. The reference case TCO assumes a mild-hybrid diesel with all improvements needed to reach 2027 emissions standards, an LFP battery EV with heavy-duty specific motors & an on-board charger sized for a 4-hour charge from a depot charger. The low-cost TCO assumes a base diesel ICE vehicle (with all improvements for 2027) and an EV with LFP batteries, light-duty-based motors, and a charging system sized for a 6-hour charge. The high-cost TCO assumes a fully hybridized ICE vehicle compared to an EV with NMC batteries, heavy-duty specific motors, and a DC fast charger shared between three vehicles. To determine the vehicle cost difference between the two, the base vehicle cost was used as a starting point. The costs from the ICE delete package outlined in Sections 2.1 to 2.4 are subtracted from this value, based on the options selected for the given scenario. The electrification add package costs are calculated based on Section 2.5 and added to the vehicle cost after subtracting the powertrain costs.

2.6.2 ICE Vehicle TCO Calculations

Costing elements specific to ICE vehicles include fuel costs, fueling infrastructure, and maintenance. Fuel costs are driven by both the projected fuel efficiency of the vehicle being studied and the projected fuel costs in the 2027 timeframe. The US Energy Information Administration Annual Energy Outlook 2021 was used for fuel costs projections in 2027. A reference, low, and high cost were chosen from the projections seen in Figure 11. It is important to note that diesel fuel costs continue to increase faster than the AEO predicted in 2021, making the TCO analysis more conservative than originally expected.

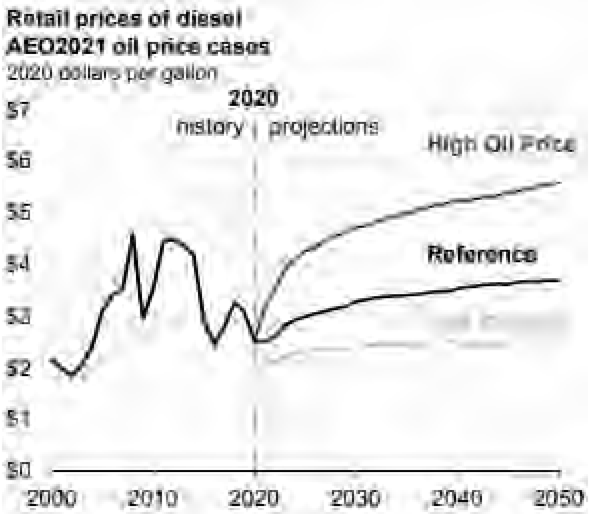


Figure 11: Projected diesel costs per gallon used for the TCO analysis. [37]

Projected fuel economy was sourced from literature sources ([26] [27] [28] [35]) or manufacturer references on the type of vehicle listed, as well as the level of hybridization used in the vehicle. Dividing cost per gallon by miles per gallon provides a $/mi value used in the TCO calculation.

Fueling infrastructure is listed in the literature as a fleet fueling depot and is considered to be \$0.02 per gallon of diesel. These would be costs associated with a fleet that operates its own on-site fueling station, though commercial fueling stations are another option that does not incur this cost.

Maintenance cost can be found for each class in various literature sources and considers the cost of vehicle repairs, oil changes, tire changes, brakes, transmission, body, and other general maintenance that may be required throughout the vehicle's life [26] [35]. This is assessed in the TCO on a per-mile basis.

In the case of the class 7 school and class 8 transit bus applications, a midlife refresh may be required on the engine and transmission [38]. This cost is set to the engine for the reference case, and the full cost of an engine and transmission for the high-cost TCO case. No refresh is costed for the low-cost TCO case.

2.6.3 EV TCO Calculations

Electric vehicles utilize unique components compared to ICE vehicles and accrue costs differently than their ICE counterparts. Maintenance costs are still present, but typically lower than ICE vehicles due to the lower complexity and fewer consumables such as engine oil and filters [34] [29]. Additional consumables such as brake pads and rotors last longer due to regenerative braking performed by the drive motors. In other cases, a straight reduction of \$0.19 per mile was taken from the diesel maintenance costs [29], [34]. The individual costs for each vehicle class are detailed in the TCO section of the results in Section 4.0.

Energy costs consist of the electricity for charging the bus batteries, typically charged on a per-kWh basis. The Energy Information Administration outlook was used for projected energy prices [37]. By assuming charging at off-peak hours, utility-specific demand charges for high power consumption were not considered in this analysis. These charges are not universal in their application or amount and largely apply to the use of DC fast chargers during daytime hours. In these cases, electricity costs could be higher than presented in this analysis.

Infrastructure is a significant cost when building an EV fleet, as chargers need to be purchased and installed specifically to the use case of the fleet's operation. For the reference case analysis, depot chargers were chosen to allow the vehicle to charge within 4 hours at a depot overnight. This assumption would enable future growth of the fleet with managed charging, allowing two buses to use a single charger in an 8-hour overnight while permitting sufficient flexibility in fleet operation. For this study, however, the reference case assumes a single charger per bus as fleets moving to EVs may not have optimized schedules and charging from the outset, making these assumptions conservative. Charger costs were sourced from various literature sources for the different charger levels. [35] [39]

For the low and high cases, different chargers and methods were selected. The low case increased charging time to 6 hours, reducing the cost of the charger and installation, as well as the onboard charger equipment installed in the vehicle. The high case assumed a direct current fast charger (DCFC) was purchased for the fleet, and that one charger could be split across three buses. Some literature sources note that a single DCFC can support up to 8 buses, but this requires precise optimization and placement of the chargers, which may not be practical for all fleets. For this study, 3 vehicles per DC charger were assumed in the high-cost cases for all vehicle segments. This allows room for future optimization of a fleet, but may more realistically reflect the initial outlay of a fleet looking to adopt DC fast charging. Due to the high costs of DCFC equipment, instances, where more vehicles utilize the same charger, will reduce upfront and total costs, as the high DCFC costs are amortized over more vehicles. An instance where this may be useful is the case of a transit bus fleet with a large central station where many routes converge, allowing buses to charge at a common point.

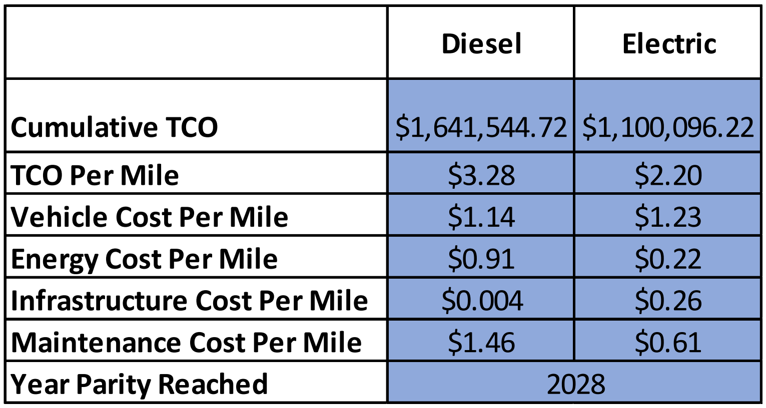
In the case of the class 7 school and class 8 transit bus applications, a midlife refresh is applicable as in the ICE versions. These costs include a refresh of the motor and inverter and a battery replacement. In these cases, the midlife refresh is considered to be only the cost of the battery in the reference case, while the high case considers the battery, inverter, and motor to be replaced. No midlife refresh is considered in the low-cost cases [38].

2.6.4 Calculations

Costs were input to a spreadsheet that captures all of the items listed in previous sections that contribute to the total cost of ownership. Lifetime mileages and lifespans were broken down into an annual mileage used to calculate the yearly cost of the energy, maintenance, and refueling infrastructure. Vehicle purchase costs and charging infrastructure costs were assumed to be incurred in year 1 at the time of purchase.

With both upfront and annual costs calculated, the annual costs for each category were subjected to a 3% discount rate following the year of purchase to account for the present values of future cash flows, a value utilized by NREL when examining costs for energy-related projects [40]. Fuel costs were held constant across the calculation period but can vary significantly and unpredictably.

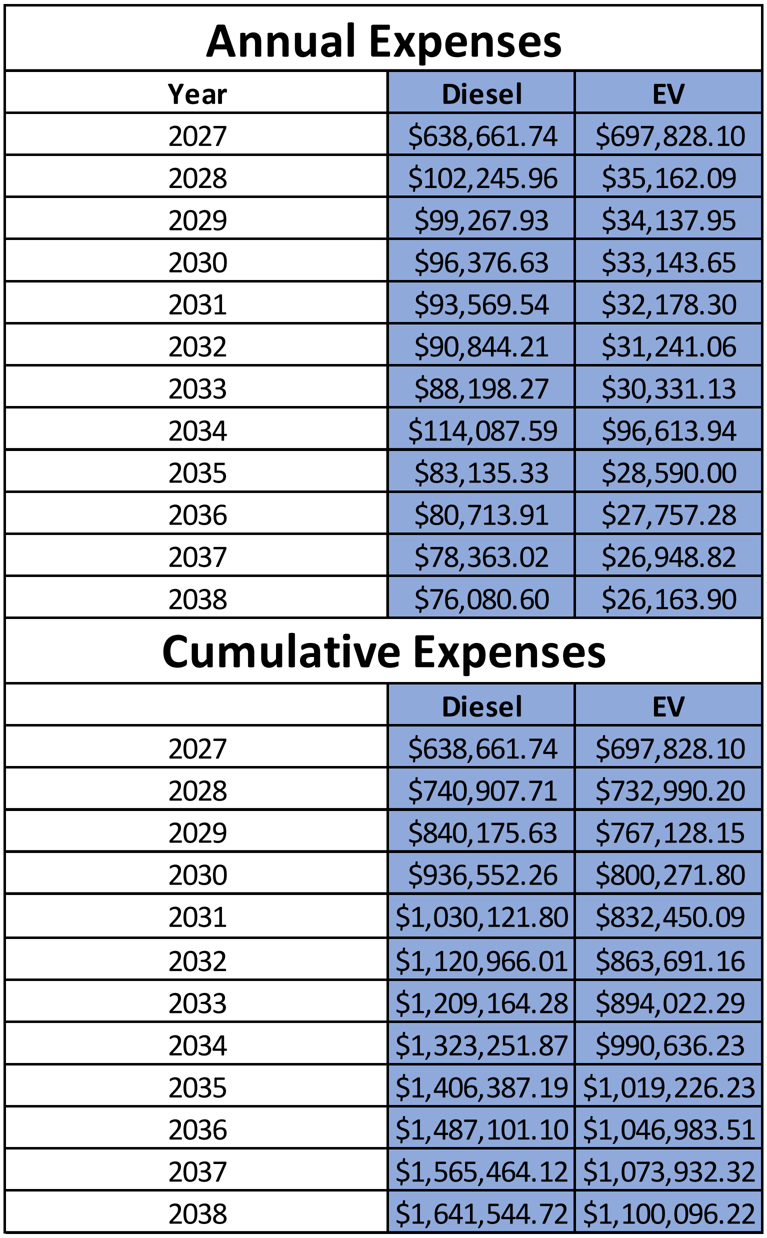
Costs are calculated and presented in a table displaying cumulative (discounted) TCO, as well as cost per mile for each category shown in Figure 12 as an example. Also shown is the year at which cost parity is reached, defined as the year that cumulative costs of an EV are less than or equal to the ICE version.



	Diesel	Electric
Cumulative TCO	$1,641,544.72	$1,100,096.22
TCO Per Mile	$3.28	$2.20
Vehicle Cost Per Mile	$1.14	$1.23
Energy Cost Per Mile	$0.91	$0.22
Infrastructure Cost Per Mile	$0.004	$0.26
Maintenance Cost Per Mile	$1.46	$0.61
Year Parity Reached	2028	

Figure 12: Example output of cumulative TCO and costs per mile from the costing exercise (note: not a real scenario presented in this report).

Costs for each year of expected vehicle life are also calculated and output as well to identify the up-front and recurring costs of ownership of both a Diesel and ICE vehicle. These are shown along with the cumulative expenses to date for each year of vehicle ownership, which is also plotted in a line chart showing the crossover of EV costs with ICE costs. Example outputs from the costing spreadsheet are shown in Figure 13. Full vehicle and charger costs are included in the first year (up front), as the infrastructure must be purchased to operate the fleet. Financing strategies and amortization are possible but are not considered here.



Annual Expenses

Year	Diesel	EV
2027	$638,661.74	$697,828.10
2028	$102,245.96	$35,162.09
2029	$99,267.93	$34,137.95
2030	$96,376.63	$33,143.65
2031	$93,569.54	$32,178.30
2032	$90,844.21	$31,241.06
2033	$88,198.27	$30,331.13
2034	$114,087.59	$96,613.94
2035	$83,135.33	$28,590.00
2036	$80,713.91	$27,757.28
2037	$78,363.02	$26,948.82
2038	$76,080.60	$26,163.90

Cumulative Expenses

	Diesel	EV
2027	$638,661.74	$697,828.10
2028	$740,907.71	$732,990.20
2029	$840,175.63	$767,128.15
2030	$936,552.26	$800,271.80
2031	$1,030,121.80	$832,450.09
2032	$1,120,966.01	$863,691.16
2033	$1,209,164.28	$894,022.29
2034	$1,323,251.87	$990,636.23
2035	$1,406,387.19	$1,019,226.23
2036	$1,487,101.10	$1,046,983.51
2037	$1,565,464.12	$1,073,932.32
2038	$1,641,544.72	$1,100,096.22

Figure 13: Example outputs for annual and cumulative costs from the costing exercise.

3.0 Electrification Technology Review

This section provides an overview of the present state of the art and future trajectory of technology in battery, traction motor, and power electronics. The technology review is guided by the following:

1) Technologies that can significantly reduce the direct manufacturing cost and total cost of ownership of MDHD battery electric vehicles from 2021 to 2027 and beyond.
2) Technologies that can mitigate increases in commodity prices or supply constraints due to geopolitical or other factors of raw materials (like rare earth metals, copper, Cobalt, etc.) that might negatively affect the cost of a BEV and increase the cost of electrification.

3.1 Batteries

The three principal criteria that can be used to evaluate battery technologies for MDHD application are

1. Cost ($/kWh) of the battery pack – The cost of the battery pack forms a significant portion (≈80%) of the cost of an electric powertrain (discussed in detail in Section 3.1). It is by far the most important factor determining the pace of adoption of BEVs in the MDHD segment.
2. Energy Density – The two metrics used to measure energy density are the gravimetric energy density measured in Wh/Kg and the volumetric energy density measured in Wh/liter. For light-duty vehicles, the space for packaging a battery pack is at a premium, and hence the volumetric energy density is more important. MD and HD vehicles have a lot more space to package the battery pack making the volumetric energy density less important. MDHD vehicles are classified according to their gross vehicle weight and a heavy battery pack would result in a vehicle that falls into a higher weight class or can carry less cargo for the same vehicle weight class. Also, increased vehicle weight will result in a higher energy consumption per mile. This is a significant problem only for vehicles such as electric semi-trucks that have a heavy payload and require a long driving range per charge. For all applications studied in this report, the energy density of batteries currently in production is sufficient to meet the vehicle's operational needs.
3. Cycle life - MDHD vehicles are on the roads for longer and many cover significantly longer distances when compared to their light-duty counterparts. An extreme use case is a class 8 Semi-truck that can be on the road for 15 years and cover 1.5 million miles [41] with two engine rebuilds. There are battery technologies today that can last more than 5000-7000 cycles enabling an MDHD vehicle to last over a million miles (assuming a range of 200 miles per charge). High-cycle life batteries that can be charged at a higher rate (along with the development of charging infrastructure comprising fast DC chargers) will result in BEVs that have a smaller battery pack resulting in them being cheaper, lighter, and more efficient (Wh of energy consumed per mile).

3.1.1 Battery Costs

Figure 14 shows the present and future battery cost projections made in 2020-2021. The consensus is that battery cell costs are less than $100 a kWh for NMC and NCA cells. LFP chemistry is more than 20% cheaper when compared to the NMC and NCA. Most studies predict a 20-30% reduction in battery cell cost in the next two to three years. Figure 15 gives a compilation of battery pack cost projections made in 2015-2019. Comparing values in Figure 14 and Figure 15, it is evident that the battery costs are falling faster than projections made 4-5 years back. This is due to the rapid pace of innovation and the inability to accurately predict the timeline to volume production and cost implications of

- New/ improved battery chemistries
- Breakthrough manufacturing process improvements (example: dry battery electrode)
- Improvements in cell and pack construction (tabless anode, new in cell factor, and cell to pack – example BYD blade battery pack)
- The rapid adoption of BEVs and grid-scale battery storage leading to considerably higher economies of scale.

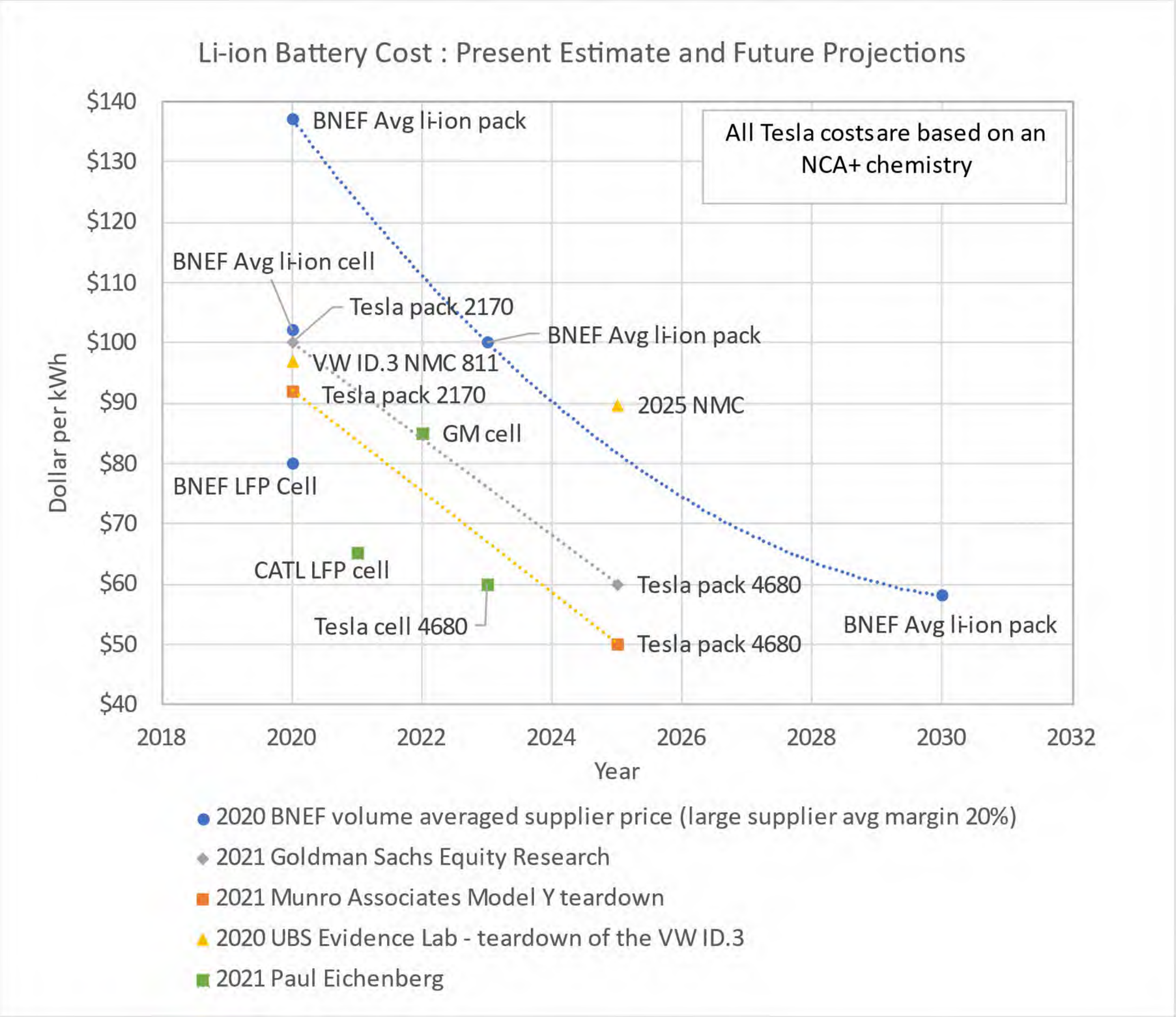


Figure 14: Battery costs. BNEF [42], Goldman Sachs Equity Research [43], Munro & Associates [44], UBS [11]

Several technologies that are currently in pilot production promise a significant reduction in lithium-ion battery costs in the next two to three years without any breakthrough in battery chemistry. Disruptive technologies like high silicon or lithium metal anodes, sulfur-based cathodes, solid-state batteries, etc. will lead to step changes in cost ($/kWh), energy density, and cycle life in 2025-2030. There are several Cobalt-free Lithium-ion cathode chemistries like High Voltage Spinel Lithium Manganese Nickel (LMNO), Nickel Iron Aluminum (NFA), and Nickel Manganese Aluminum (NMA) just to name a few that promise energy densities and costs in between that of LFP and NMC. CATL in 2021 introduced a prototype sodium-ion battery with an energy density of 160 Wh/kg slated for volume production in 2023. It is difficult to accurately predict the costs of these technologies and if and when they will reach commercial adoption. For this study, only NMC and LFP batteries were considered as the basis for calculating the purchase price of a reference case BEV and low-cost BEV (sensitivity 1) respectively. Given the number of technologies that the industry is working on that have the potential to significantly reduce the cost and increase cell and pack energy density, it is likely that the future battery costs will be below than projected in this study.

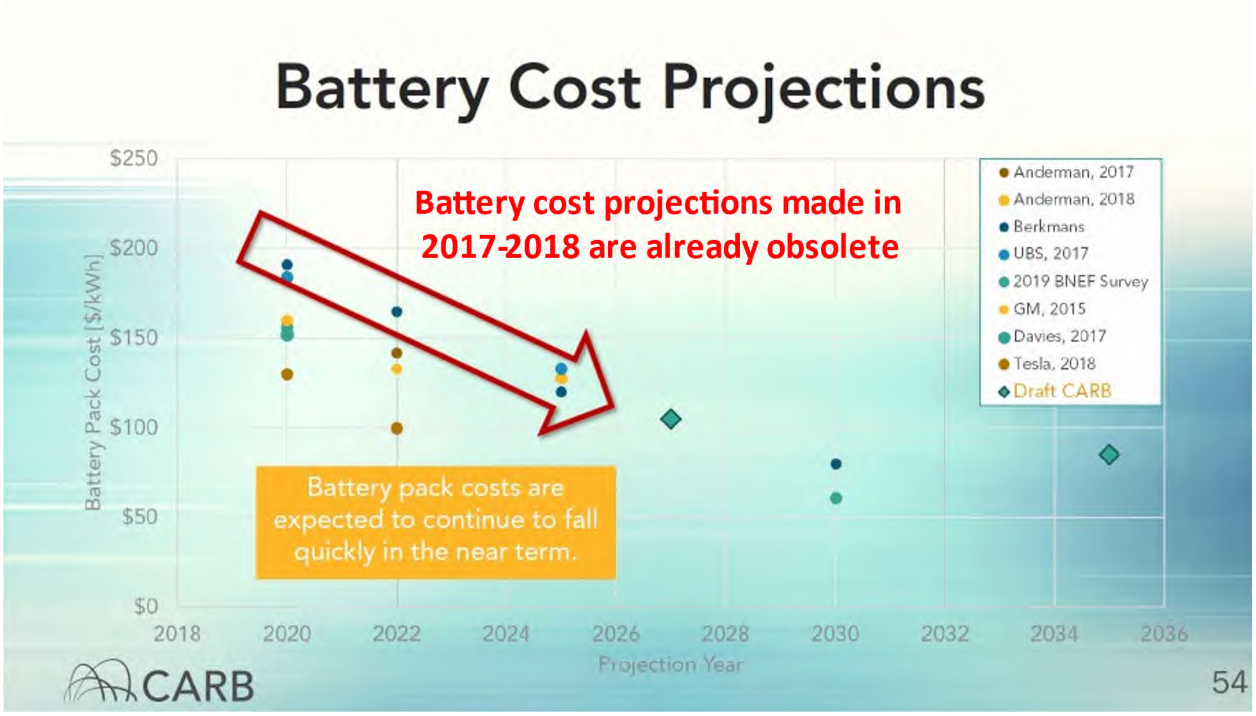


Figure 15: Battery pack cost projection, California ARB [45]

Figure 16 shows the worldwide market share of various BEV chemistries in 2020. The major cathode chemistries in production vehicles are

- LFP – Lithium Iron Phosphate
- NMC – Nickel Manganese Cobalt Oxide
- NCA – Nickel Cobalt Aluminum Oxide
- NCA+ - Nickel Cobalt Aluminum Oxide used by Tesla that uses 8-10% less Cobalt

Figure 17 outlines the amount of each metal in the various battery chemistries available.

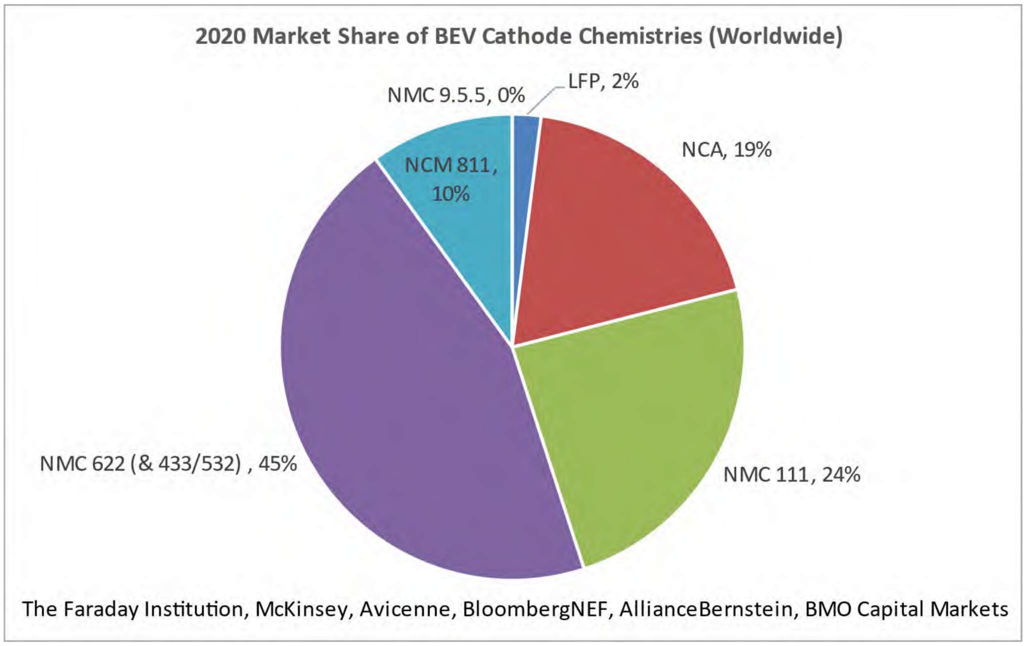


Figure 16: 2020 Market share of BEV cathode chemistries [46]

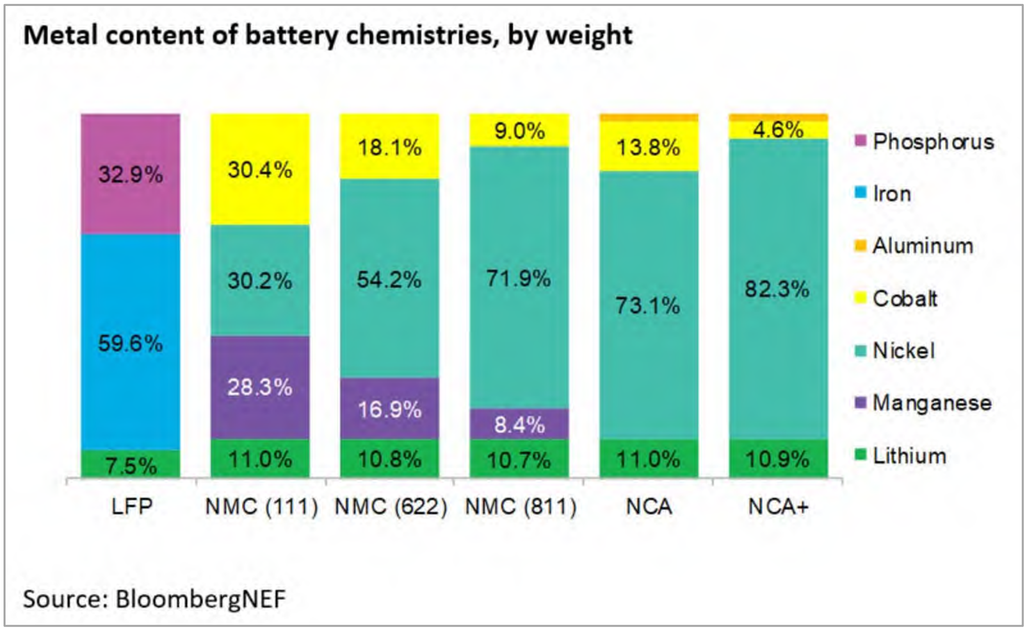


Figure 17: Content of various metals by weighty in different battery chemistries [47]

3.1.2 Production Battery Chemistries and Their Evolution

Nickel Manganese Cobalt Oxide (NMC)

NMC in its various forms (622, 811) comprises a very large portion of the current BEV market (Figure 16). The numbers following “NMC” indicate the relative amounts of Nickel Manganese and Cobalt in the cathode. The industry has been moving in the direction of reducing/ eliminating the use of Cobalt in EV batteries due to its high cost, limited reserves, and human rights violations in countries like the Democratic

Republic of Congo which accounts for 60% of the global production of Cobalt. The industry is moving from high Cobalt NMC variants such as NMC111 and NMC622 to low Cobalt variants such as today's state-of-the-art NMC811 (used in the VW ID.3, BMW iX, Ford Mach-E, etc.) and NCM90 (also known as NMC 9.5.5) in the near future. Figure 17 gives the relative metal content of various battery chemistries by weight. The low Cobalt (and Nickel) NMC variants have higher energy density and lower material costs.

Lithium-Iron Phosphate (LFP)

For most of the last decade, Lithium Iron Phosphate chemistry was considered unsuitable for EV applications due to its low energy density and poor performance at low temperatures (due to high cell internal resistance). The use of Innovative cell form factors and packaging the cells directly into the pack eliminating the use of cell modules has reduced the weight and complexity of the battery pack and increased the Gravimetric Cell to Pack ratio (GCTP: weight of the cells in a battery pack divided by the weight of the battery pack), and Volumetric Cell to Pack ratio (VCTP: volume of the cells in a battery pack divided by the volume of the battery pack). Figure 18 illustrates the large form factor prismatic cell and the cell to pack architecture used by the BYD Blade^{TM} battery pack.

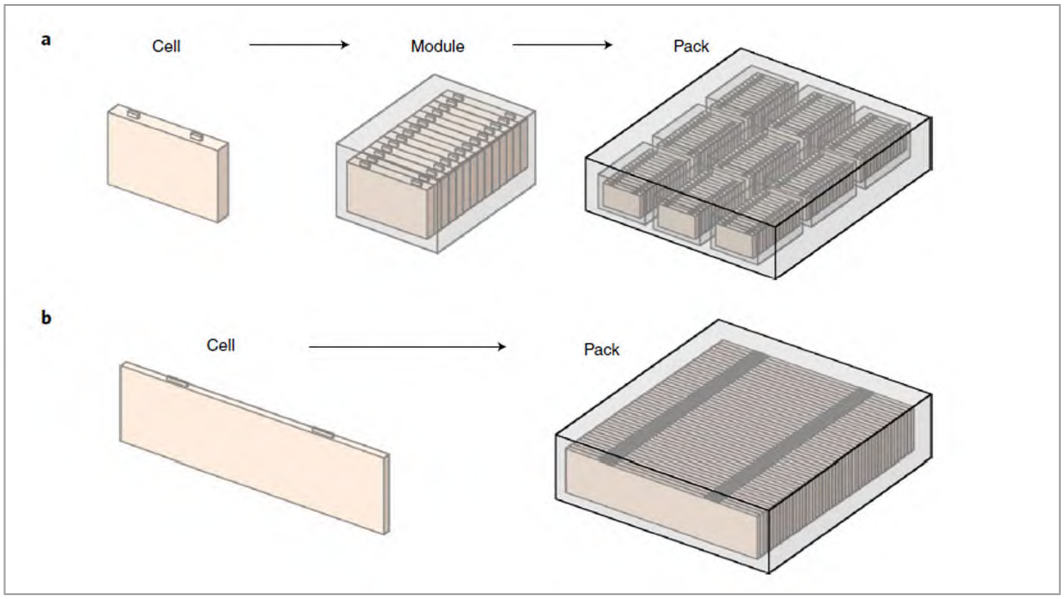


Figure 18: Illustration of a conventional battery pack (a) and the BYD blade battery pack (cell to pack) (b) [48]

This has resulted in an LFP battery pack that has a volumetric energy density higher than the NCA pack used in the Tesla Model 3 and the NMC811 pack used in the VW ID.3 as shown in Table 12. It is also worth noting that LFP cells have a much higher cycler life (7000+ cycles) when compared to NMC and NCA (<3000 cycles) - see Section 3.1.3 for detailed discussion. The cycle life of an LFP battery is less affected (when compared to NCA and NMC) by an increase in the Depth of Discharge enabling manufacturers to reduce/ eliminate the unused buffer capacity needed by NCA and NMC packs to maintain battery cycle life. Being able to use more of the battery capacity (net usable capacity of the battery pack being a larger fraction of the gross battery capacity) increases the real-world energy density of an LFP battery pack and reduces the energy density gap to the more expensive NMC and NCA chemistries.

Table 12: Comparison of battery packs in production vehicles

		2020 VW ID.3[1]	2018 Tesla Model 3[1] *	BYD Blade battery pack[2]
Cell chemistry		**LG NMC**	**Panasonic NCA**	**BYD LFP**
Nominal capacity	kWh	58	75	-
Nominal voltage	V	400	352	294
Gross battery size	kWh	62	78	59.5
Number of modules		9	4	1
Number of cells		216	4416	92
Battery weight	kg	376	474	425
battery volume	L	231	400	213
Gravimetric energy density	Wh/kg	164	164	140
Volumetric energy density	Wh/l	267	195	279

* 2020 Tesla Model 3 has a gross battery capacity of 82 kWh
[1] Source 2020 UBS teardown study **[11]**
[2] Blade battery pack prototype - Source BYD **[49]**

LFP cells can have formulations that are significantly safer than NMC and NCA and immune to thermal runaway when overcharged or punctured. New MIIT (Ministry of Industry and Information Technology - China) regulations approved in May 2020 require EVs to inhibit any fire or explosion within five minutes after a thermal runaway incident occurs [50]. To achieve that level of protection, Chinese EVs using Nickel-based chemistries such as NMC will require mitigation systems such as fire-proof mica plates between pack and vehicle or “aerogel” segments distributed throughout the pack, or battery modules seated by metal beams to isolate the modules, among many other solutions. Such protection systems will decrease the energy density (both volumetric and gravimetric), undoing advances in cell performance of Nickel chemistries. Inherently safer LFP cathode materials would allow for simplified battery packs without modules, and the otherwise necessary but voluminous safety and auxiliary components, decreasing the cost and increasing the real-world energy density of LFP [50].

State-of-the-art battery thermal management systems equipped with a heat pump can keep LFP batteries in the optimum temperature window with minimal energy penalty making their cold-weather performance comparable to that of NMC chemistry. With advances in pack construction and battery pack thermal management, the cheaper LFP chemistry is a viable alternative to more expensive NMC cells (Figure 19). This has resulted in the LFP global EV market share rising from 2% in 2020 to more than 12% in 2022 (Figure 20). (The jagged shape of the graph is due to fluctuating vehicle production numbers of many manufacturers due to chip shortage and supply chain challenges that have plagued the automotive industry in 2020-2021). In 2021 BYD introduced the Gen 3 8TT ER class 8 tandem axis truck with an LFP battery pack size of 563 kWh (GVWR 105,000 lbs, 200-mile range) and Gen 3 6F ER class 6 truck with an LFP battery capacity of 343 kWh (GVWR 26,000 lbs, 200-mile range) (Figure 21) demonstrating the viability of using high capacity LFP battery packs in medium and heavy-duty vehicles.

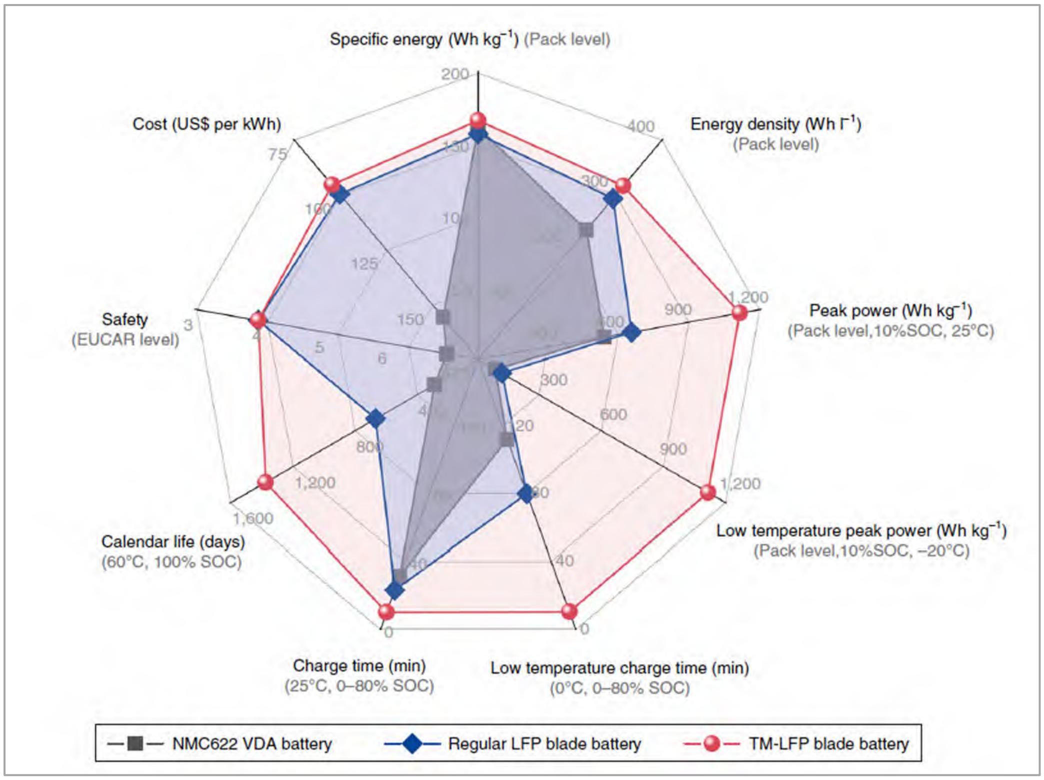


Figure 19: Comparison of TM-LFP blade, LFP blade, and conventional NMC622 battery pack on various requirements for mass-market EVs [48].

Today most of the LFP batteries are produced and used in BEVs and other applications in China. This is due to an agreement between LiFePO4+C AG (The LiFePO consortium comprised of HydroQuebec, University of Montreal, CNRS, and Johnson Matthey), the consortium managing LFP's IP rights, and the Chinese battery industry a decade ago in which, as long as LFP batteries were produced and used within China, the consortium would not charge Chinese manufacturers a licensing fee [50]. As a result, the price of Chinese LFP batteries has always been considerably lower than non-Chinese LFP batteries. However, the patents' restrictions over LFP are expiring in 2021-2022 which will remove the limitations (licensing fees) on LFP exports by Chinese producers, along with the licensing fee for non-Chinese LFP cell producers. The removal of this IP barrier could become a big opportunity for LFP-based Li-ion batteries to rapidly gain market share in the EV market outside China. Thus, LFP was considered as the first cost-reducing sensitivity applied to EV powertrains in this study.

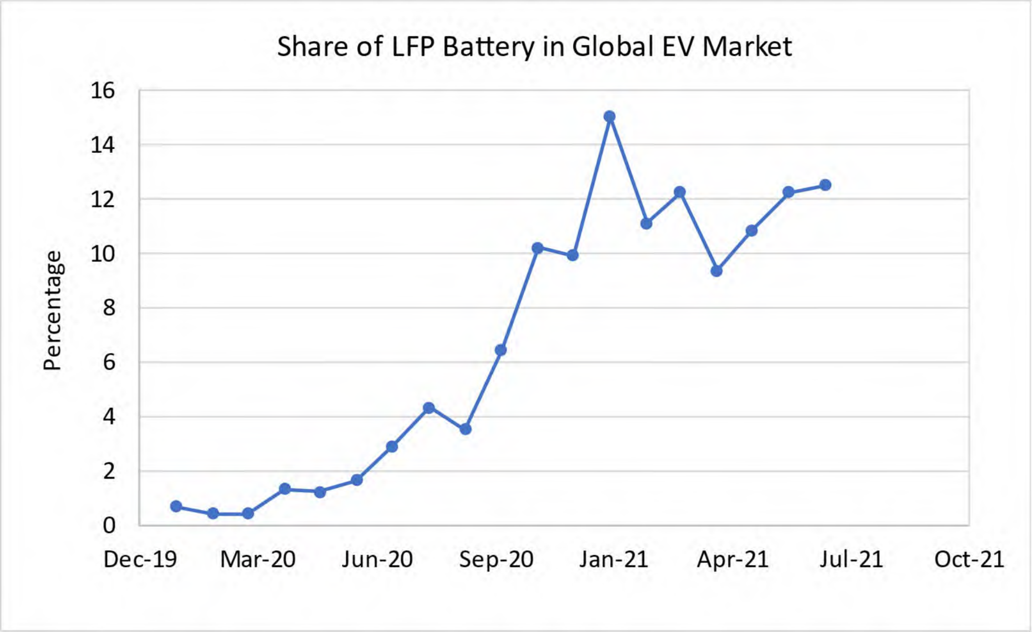


Figure 20: Share of LFP Battery in Global EV Market (Source: Worldwide Monthly BEV & PHEV Tracker from Researcher and Research LLC)

Figure 21: BYD Gen 3 6F (left) and Gen 3 8TT (right) [51]

Several technologies can significantly improve the energy density of the LFP battery making it likely that it will be the predominant lithium-based battery chemistry of the future. Anodes with silicon can improve the energy density from 160-170 Wh/kg to greater than 200 Wh/kg. In 2020 Gotion High Tech, VW's technology partner for developing the "Unified Cell" (prismatic cell for future vehicles) announced a production LFP pouch cell (Anode incorporating Silicon) with an energy density of 210 Wh/kg [52]. A solid-state electrode with a lithium metal anode can further increase the energy density of LFP batteries. Quantumscape [53] working on such an LFP cell architecture estimates an energy density of 600-700 Wh/L and 250 Wh/kg.

Nickel Cobalt Aluminum Oxide (NCA)

Tesla is the world's largest consumer of NCA batteries in the world. Panasonic and Tesla's formulation of the NCA chemistry (NCA+ in Figure 17 [47]) uses 8-10% less Cobalt when compared to standard NCA chemistry and more than 50% less when compared to NMC 811 and 75% less when compared to NMC 622 [47] further reducing costs. NCA cells currently in production have a shorter cycle life when compared to NMC and NCA cells (Figure 22) and are not sufficient for all MDHD applications.

Nickel Cobalt Manganese Aluminum Oxide (NCMA)

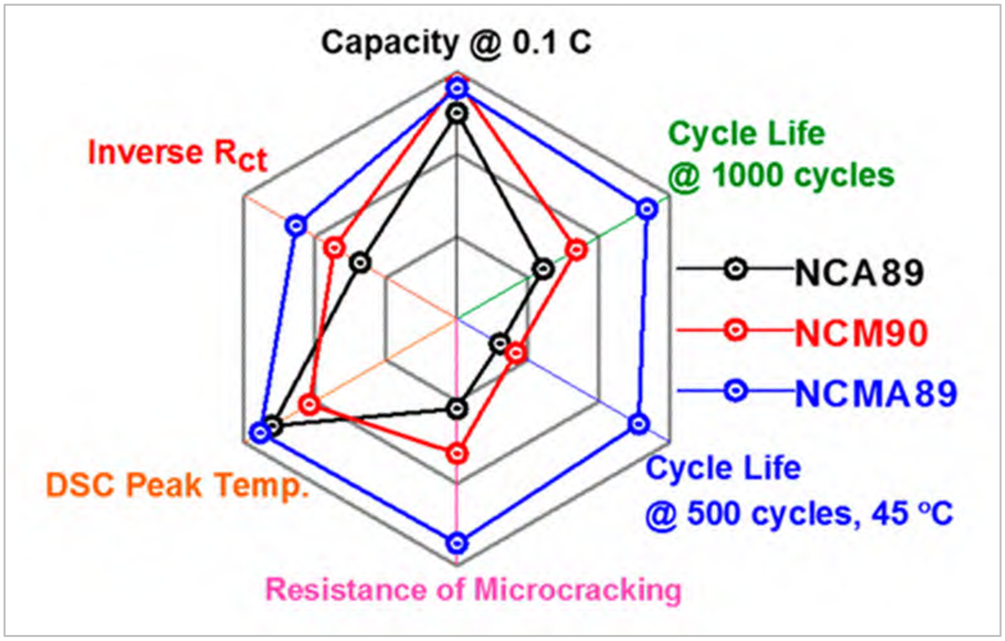


Figure 22: Comparison of NCMA89 chemistry with NCA89 and NCM90 [54]

LG (LG Chem Power, Inc. (LGCPI), a subsidiary of LG Chem, Ltd) is currently ramping up production of the quaternary NCMA battery chemistry that promises similar energy density and significantly higher cycle life compared to NCA and NMC (NCM) chemistries. These cells will initially be used in Tesla and GM (Ultium^{TM} batteries) electric vehicles.

3.1.3 Battery Cycle Life

Cycle life of commercially available cells – NMC, NCA, and LFP

One of the concerns of switching to battery electric vehicles for MDHD applications is that the batteries may not last the life of the vehicle. Figure 23 shows the cycle life for a 100% DOD for commercially available NMC, NCA, and LFP cells used for light-duty applications. Cycle life of a battery pack is defined as the number of cycles at the end of which the battery pack retains 80% of the initial capacity

The cycle life is significantly affected by the depth of discharge (difference between the maximum and minimum charge level between which the cell is charged and discharged) as shown in Figure 23. A small decrease in the depth of discharge can significantly increase the cycle life of the cell. 100% DOD is far from what a production vehicle battery pack is subjected to. Most manufacturers of lithium batteries set software limits for the minimum and maximum pack state of charge (SOC) limits, the usable capacity of the pack being set at 85-90% of the gross capacity significantly increasing the life of the battery pack. When compared to NMC, LFP chemistry can have lower or even no buffer capacity with a negligible effect on battery cycle life. With technology in volume production, the battery cycle life is in the range of 2000-3000 cycles for NMC and more than 7000 cycles for LFP. This range can be further improved by the use of managed charging, especially in fleet applications.

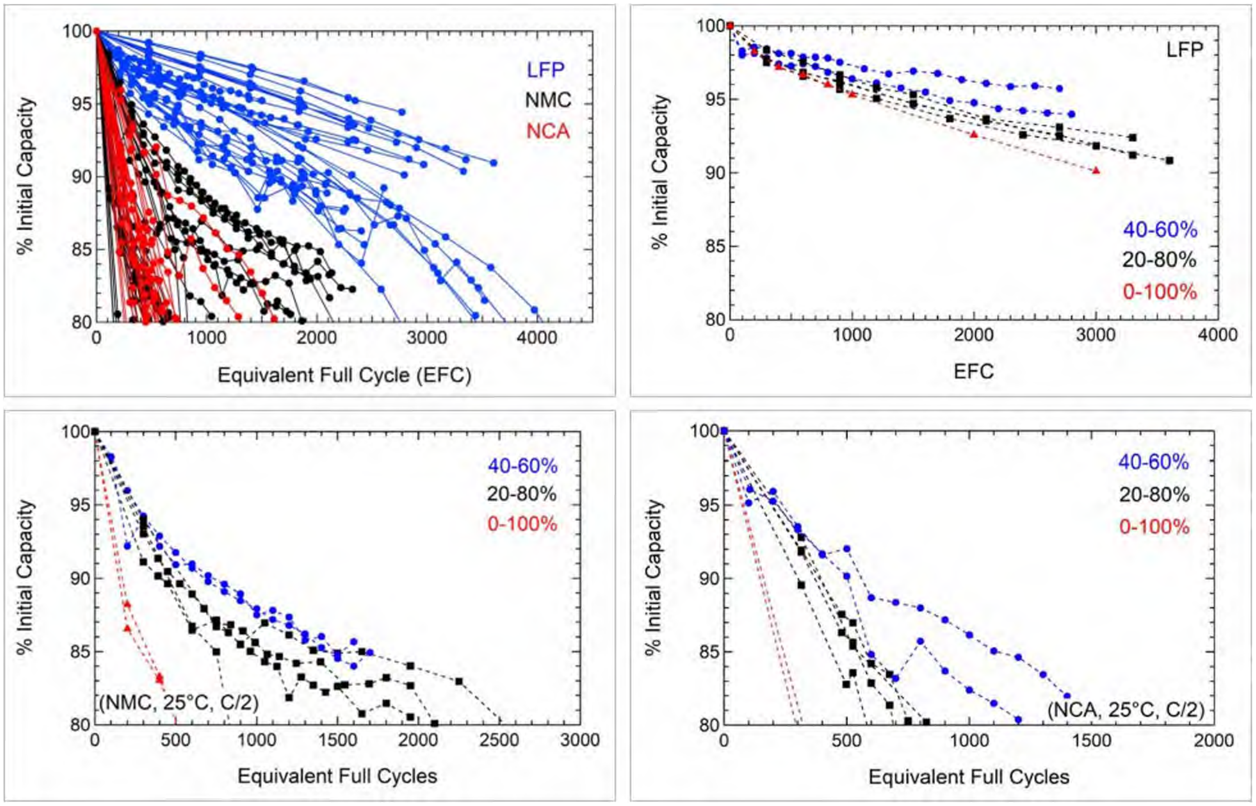


Figure 23: Top left: Capacity retention of various commercially available Lithium cells used in light-duty applications (20°C 100% DOD) others: Effect of depth of discharge on the cycle life of LFP, NMC, and NCA cells. Cycle life = 80% of initial capacity [55]

Present state of the art high cycle life battery technology – Fast Ionic Conductor (FIC) Coatings

NMC batteries with various fast ionic conductor coatings on the cathode particles have demonstrated a significant increase in cycle life [56], [57] [58]. CATL recently unveiled a ready-for-production Lithium NMC battery with a proprietary coating of fast ionic conductor on the cathode particles that can enable it to potentially last 16 years and 1.25 million miles in a vehicle application (CATL did not clarify the assumptions – range of the vehicle, number of cycles, charge-discharge rates used for the mileage calculation). According to CATL, the technology is 10% more expensive than current commercially produced NMC cells used in light-duty applications [59] [60].

Future High cycle life battery technology – Single Crystal cathode materials

Single crystal cathode materials in place of the polycrystalline material used in battery cells today can significantly increase the cycle life of lithium-ion batteries. Under testing, cells with single crystal cathode materials have demonstrated more than 9500 cycles (room temperature, 100% DOD, 1C rate) with capacity retention of over 90% [61]. The industry defines the end of life of a cell/ pack as 80% initial capacity. This paves a way for Semi trucks with over two-million-mile battery life and cell durability to withstand repeated DC fast charging. Companies like NanoOne in collaboration with Johnson Matthey are working on bringing down the production costs of single-crystal cathode materials and are in the pilot production stage before volume production [62], [63]. Single-crystal cathode materials are compatible with commercial battery chemistries with no change required to cell manufacturing process or equipment.

Cathode materials used in commercial applications today are made of aggregates of very small crystals (Figure 24 (A, a)) with the crystal structure oriented in random directions. During cycling (discharging and charging during use), lithium ions are repeatedly inserted between the layers of the cathode material and then extracted, the volume of the cathode material changes. This volume change is much larger in the direction perpendicular to the layers. The random orientation of the crystals results in a volume mismatch in various directions resulting in microcracking of the particles. This leads to a loss of electric contact and access to the cathode's active mass resulting in capacity loss. A single crystal cathode material (Figure 24 (B, b)) has much larger particles, 2-3 microns, each one comprised of a single crystal with no grain boundaries. The whole particle expands and contracts as a unit resulting in virtually no microcracking even after 5000 cycles [64]. The absence of microcracking makes it possible to maintain an electric connection to these particles as they expand and contract resulting in a near 100% connection to the cathode's active mass throughout the charge-discharge cycling.

Figure 25 (right) shows the degradation of the battery capacity vs the projected mileage of a vehicle powered by such a battery at different cell temperatures. Assumptions made were one 6-hour 100% DOD cycle per day and 350 km initial driving range per cycle. With good thermal management, a vehicle equipped with such a pack can last over two million miles with a 10% capacity loss. Such high cycle life can enable the Vehicle to Grid (V2G) technology without a noticeable negative impact on vehicle battery life. When possible, fleets can charge their vehicles when electricity is cheap and export electricity back to the grid during peak demand. Lending a vehicle's V2G capabilities to the utilities will result in subsidizing a vehicle's electricity (fuel) costs. A large number of vehicles with V2G capabilities will enable the grid to switch to renewables at a much faster pace with lower investment. TCO implication of V2G technologies is not a part of this study.

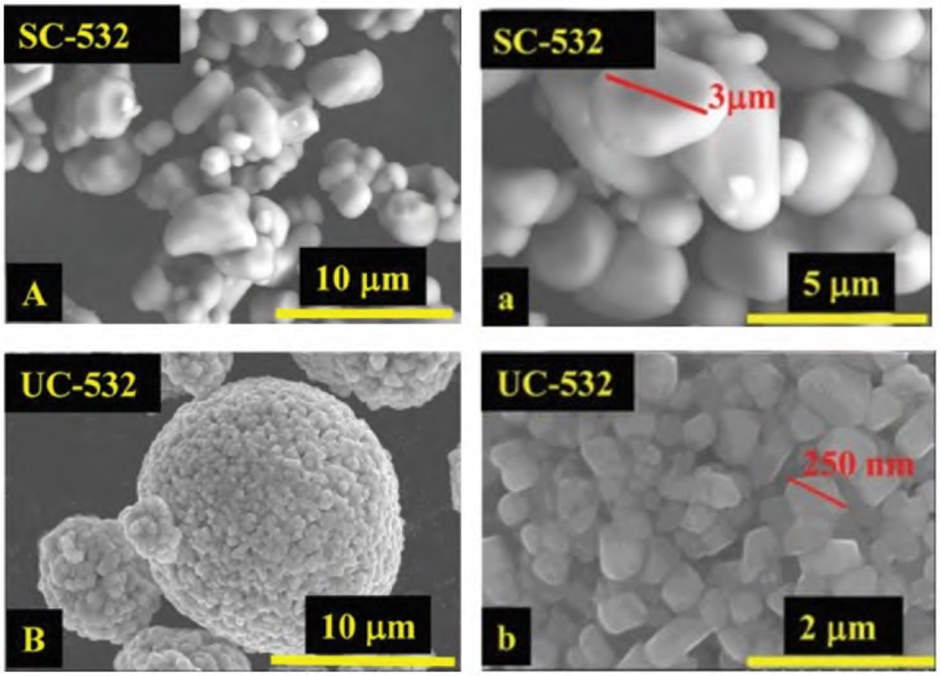


Figure 24: (A, a) – scanning electron microscope (SEM) images of a commercial single crystal NMC532 material with a large grain size of ~3 µm, (B, b) SEM images of commercial polycrystalline (NMC532) [64]

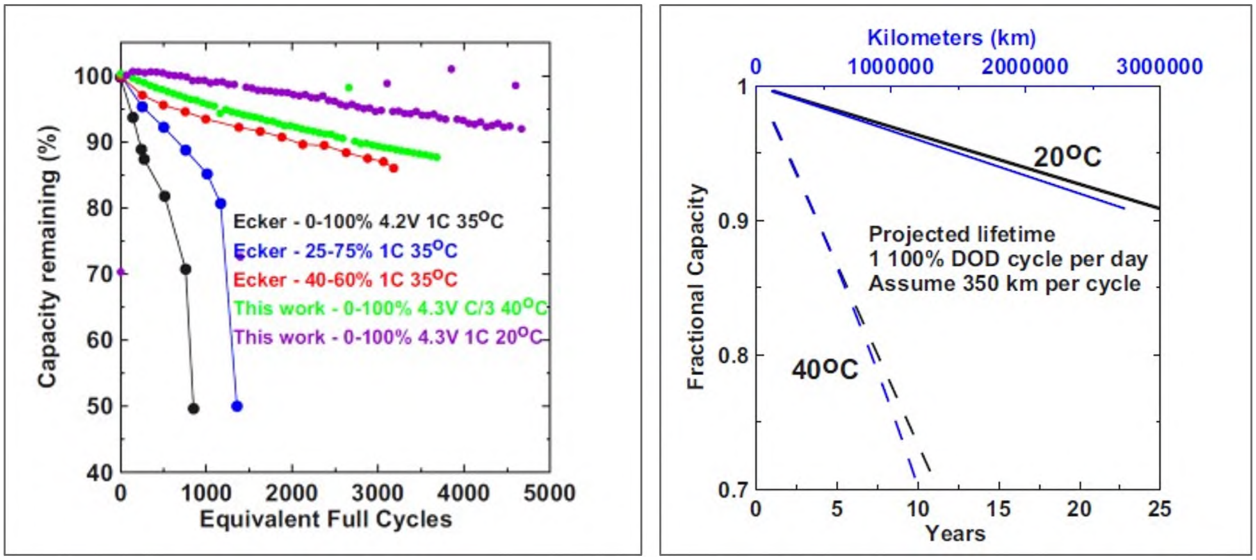


Figure 25: Left: Long-term cycling data plotted as percent initial capacity (left), Right: Worst-case scenario lifetime and total driving range projections for the NMC532/graphite cells 6-hour 100% DOD cycle per day and 350 km initial driving range per cycle [64]

3.1.4 Future Battery Chemistries

Sodium-Ion

CATL unveiled the first generation of Sodium-ion battery with a carbon anode and Prussian White cathode [65] in July 2021, slated for mass production in 2023. The first-generation cell has an energy density of

160 Wh/kg while CATL projected the energy density of the second generation cell to be 200 Wh/kg. The low-temperature performance exceeds that of LFP with capacity retention exceeding 90% at a temperature of -20 °C and the ability to be charged 0% to 80% in 15 minutes. Some analysts estimate the cost of Na-ion cells to be as low 40 $/kWh. The sodium-ion battery uses raw materials that are cheaper, more abundant, free from supply constraints, and is a promising substitute for lithium-based chemistries. Figure 26 shows a comparison to LFP batteries in several performance metrics.

Assuming a similar cell form factor and pack construction of the BYD blade LFP pack (Section 3.1.6 – Gravimetric Cell To Pack (GCTP) ratio of 0.85), a 160-200 Wh/kg cell level gravimetric energy density of sodium-ion will result in a battery pack with a gravimetric energy density of 136-170 Wh/kg, which compares favorably to both 2018 Model 3 NCA and 2020 VW ID.3 NMC811 pack value of 165 Wh/kg and higher than the 2020 BYD blade battery pack value of 140 Wh/kg (Table 12).

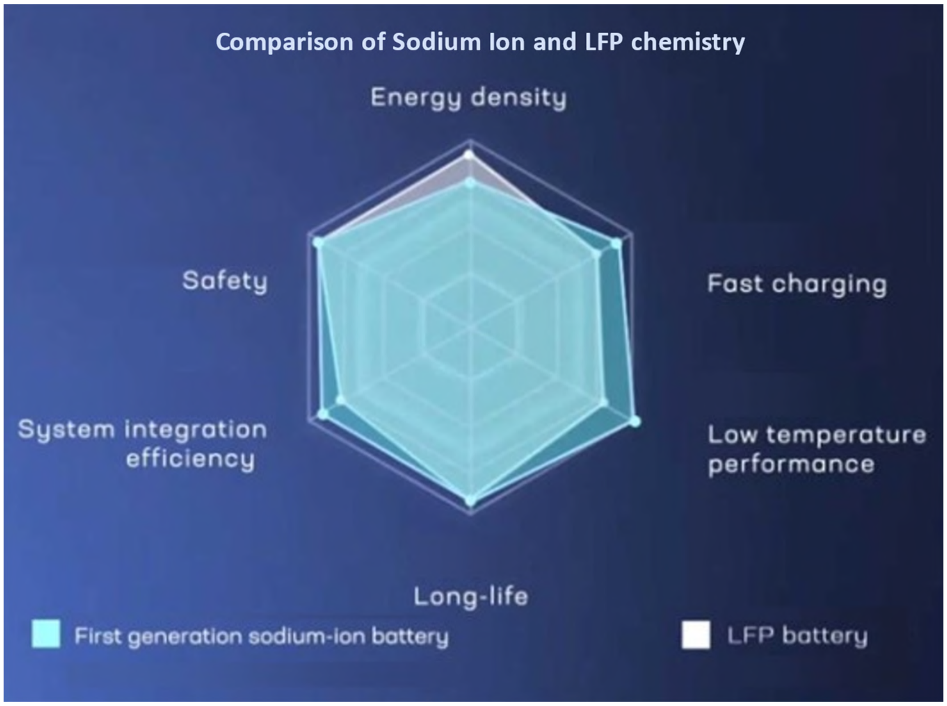


Figure 26: First-generation sodium-ion (2023 volume production) when compared to the state-of-the-art LFP. [66]

Other Battery Chemistries

There are several other promising battery technologies at various levels of technology readiness with various advantages and limitations. Most of them are lithium-based and are focused on using lower cost and more abundant raw materials for their cathodes. Almost all of them eliminate the use of Cobalt. Some of these may include:

- High Voltage Spinel – Lithium Nickel Manganese Oxide (LMNO)
- Lithium Sulphur
- Nickel Iron Aluminum Oxide (NFA)

- Nickel Manganese Aluminum Oxide (NMA)

Some of these technologies may never be adopted for volume production unless their economics and terms of licensing of the intellectual property are attractive to suppliers. Also, they will most certainly need backing from a major OEM for large, assured volume to start production.

3.1.5 Improvements in Cell Manufacture

Dry Battery Electrode (DBE) Process

The DBE process eliminates the wet slurry coating, drying, and solvent recapture steps in a conventional lithium-ion cell manufacturing process. These steps account for 50% of the energy consumption and 23% of the cost of cell manufacture, as shown in Figure 27. The DBE process will significantly reduce the GHG emissions from the battery manufacturing process reducing the gap in GHG emission between the manufacture of an EV and an ICE vehicle. Based on their 10 GWh pilot plant, Tesla estimates the DBE process will result in an 18% cost saving [67]. VW estimates that the dry electrode coating process will result in a 50% reduction in cell manufacturing plant footprint and a 30% reduction in CAPEX [68]. The other advantages of DBE are higher cell energy density due to a higher ratio of active to inactive (binder) material and Higher cycle life. The process also results in a lower cell resistance improving the power density. Alternatively, due to lower cell internal resistance, thicker electrodes can be fabricated for improved energy density.

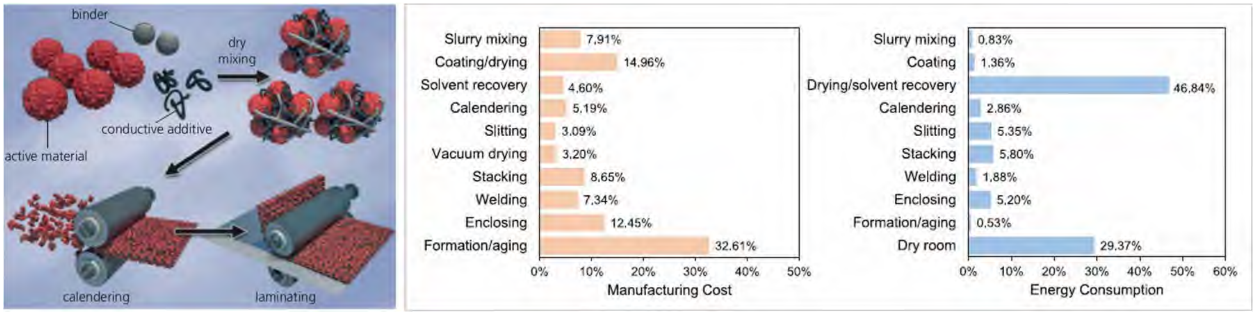


Figure 27: Dry battery electrode (DBE) processing process (left) and the cost and energy consumption breakdown for the conventional wet slurry cell manufacturing process (right) [69]

Tabless Electrode

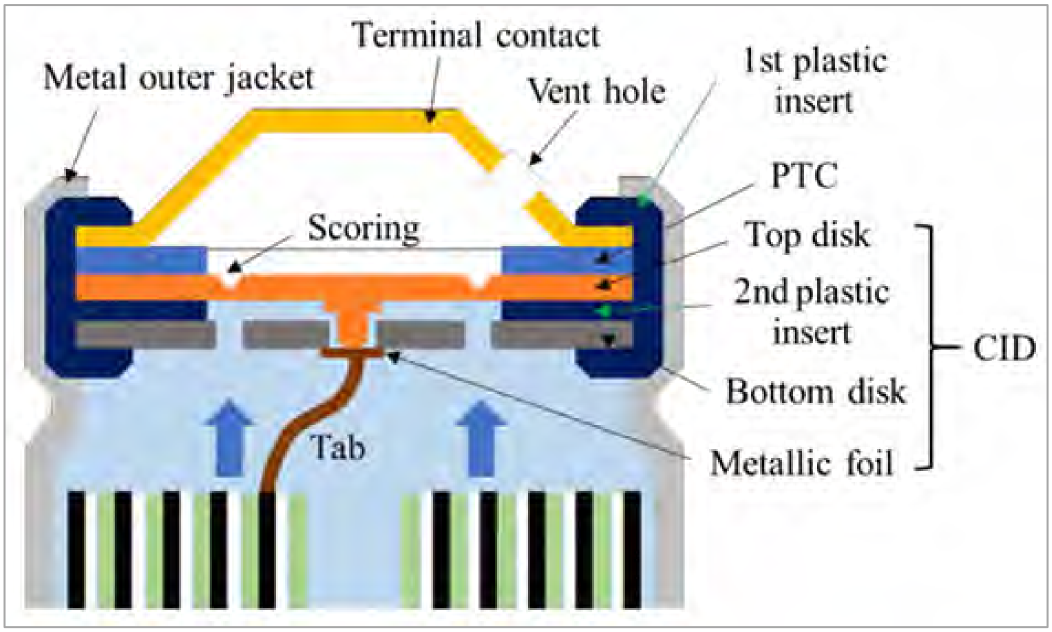


Figure 28: Current Interrupt Device (CID) Source: CALCE (Center for Advanced Life Cycle Engineering)

Figure 28 shows the typical safety mechanism of a cylindrical Li-Ion cell, which consists of a top disk (orange) that breaks under pressure (high pressure or swelling of the cell) and permanently disconnects the current flow. The tab in the figure is part of a fuse-type safety mechanism. Detailed discussion on anode and cathode tab design and failures can be found in [70]. The tab is a good solution in traditional lithium-ion applications which use one or a few cells. In electrical vehicles that use a large number of cells (Tesla Model 3 – 4416 2170 cells), manufacturers use sophisticated battery management systems (BMS) and individual cell fuses external to the cell (Tesla) reducing the reliance on the tab. Some OEMs (Tesla) and battery suppliers are working on tabless electrodes with Tesla establishing a pilot production facility (10 GWh capacity) manufacturing 4680 (cylindrical) cells with tabbed cathode and tabless anode. Tabless electrodes have several advantages.

- Increased cell yield - Welding the tab to the foil is prone to fault, reducing cell yield
- Reduced cell cost - Eliminates the extra step in battery production, reducing cell cost [71]
- Reduced internal resistance – With a tabbed electrode, electrons must travel from all over the electrode to the tab to exit the cell increasing the resistance of the cell. In a tabless electrode Figure 29, the entire edge of the electrode foil is connected to the terminal decreasing the cell internal resistance and the heat generated.

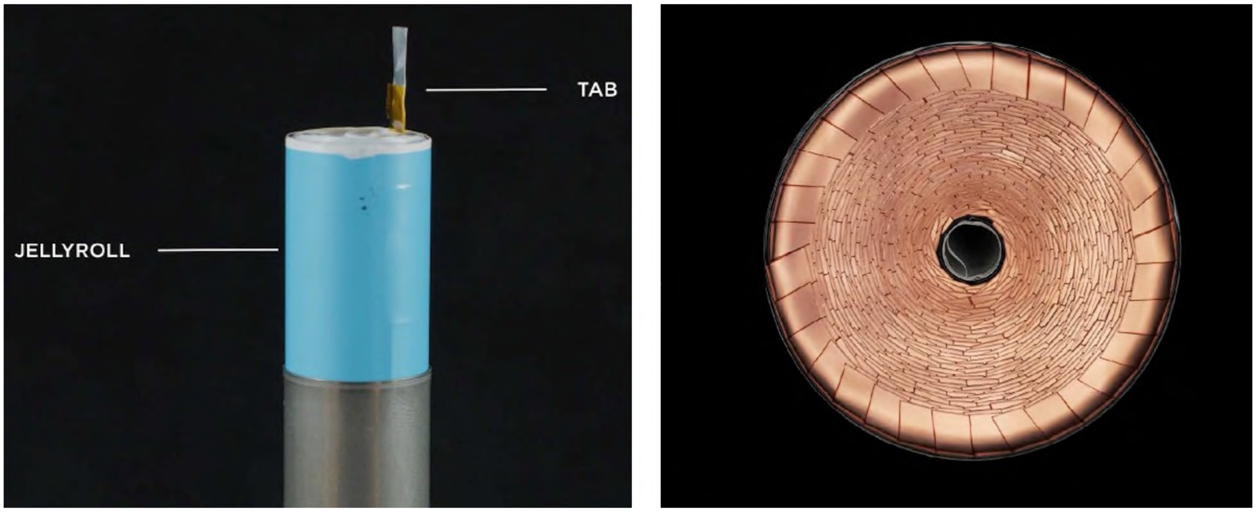


Figure 29: Conventional tabbed electrode (left), Tesla Tabless anode (right)

- Reduced battery wear - Electrons traveling from different parts of the electrode to the tab, create hot sports of electrical activity in the electrode material which also causes hot spots of chemical activity on the electrode and causes undesirable effects like plating of metallic lithium on the surface of the negative electrode. Electrically connecting the entire length of the electrode foil to the cell can evens out the reactions across the battery cell increasing the life of the cell.
- improved thermal management of the cell and reduced battery pack complexity and cost – in a tabless electrode, the entire length of the electrode current collector foil is connected to the cell-can resulting in improved thermal contact and a very short path for the heat generated (height of the cell). The tabless electrode has a significantly larger thermal contact area between the electrode and cell-can enabling the use of a simple cooling plate in contact with the circular face of the cell. This opens the path to manufacturing large diameter (Tesla 4680 vs 2170) cylindrical cells capable of high charging and discharging rates. The smaller number of larger cells simplifies the construction of the battery pack reducing the cost and complexity of the pack.

Since the cost of many of the steps in manufacturing a cell does not increase linearly with the size of the cell, a larger cell is cheaper to manufacture on a $/kWh basis. Moving from 2170 to a larger 4680 cylindrical cell, Tesla achieved an 18% cost reduction per kWh in pilot production. [67]

3.1.6 Improvements in Battery Pack Construction – Cell to Pack and Cell to Chassis

Most vehicles today have cells grouped into modules and multiple modules combined to form the battery pack. The modules are packaged in an enclosure that prevents any stresses from being transmitted to the individual cells or modules (Figure 30 – left VW ID3). This architecture evolved from the reasoning that any faulty module could be replaced without replacing the entire pack. However, this adds weight and complexity and reduces the GCTP and VCTP. With improving quality of and reliability of cell manufacture, pack construction, BMS, and thermal management systems, battery fault rates today are very low. Some manufacturers and suppliers (Tesla, BYD, CATL, etc.) are working on a “cell to pack” architecture (Figure 30 – right BYD “blade” battery pack) that does away with individual modules, reducing the associated cost and complexity, and increasing the GCTP and VCTP. According to CATL, its “cell-to-pack” technology results in a 30% increase in volume utilization of the pack (cell-to-pack volume ratio), a 40% reduction in the number of parts in a battery pack, and a 50% increase in production efficiency [59]. Reduction in battery pack weight will reduce curb weight and increase the payload of MDHD vehicles.

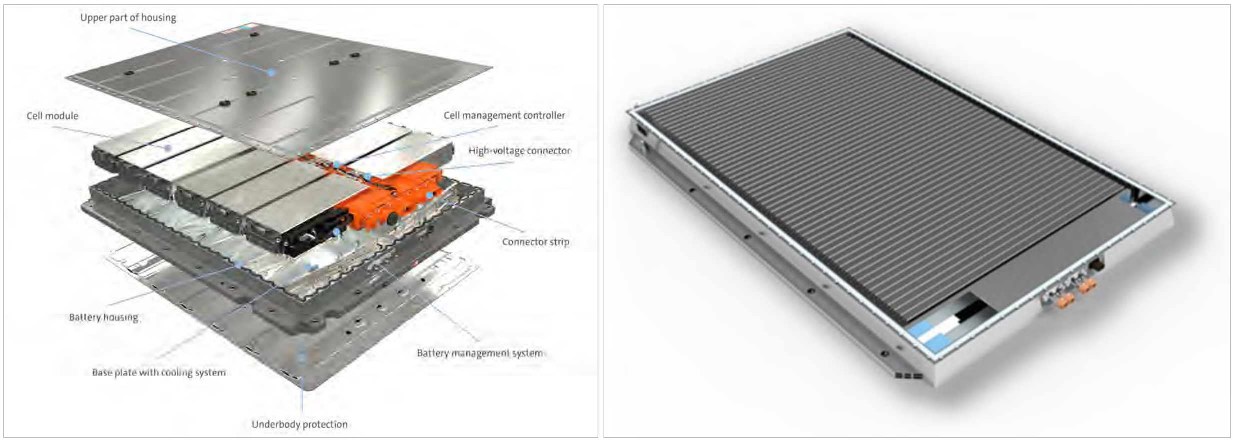


Figure 30: VW ID3 Battery pack with 12 modules (left) [11]. BYD Tang “cell to pack” battery pack (right) [49]

Tesla is going further to mass-produce a structural battery pack, where the pack and the cells are constructed to transmit structural loads resulting in 370 fewer parts, a 10% reduction in mass, and a 14% range improvement of a midsize SUV (production - 2022 Model Y produced in Tesla’s facility in Austin and Berlin) [67]. Structural battery packs may not find wide use in medium and heavy-duty vehicles due to their use of latter frame chassis that takes all the structural loads.

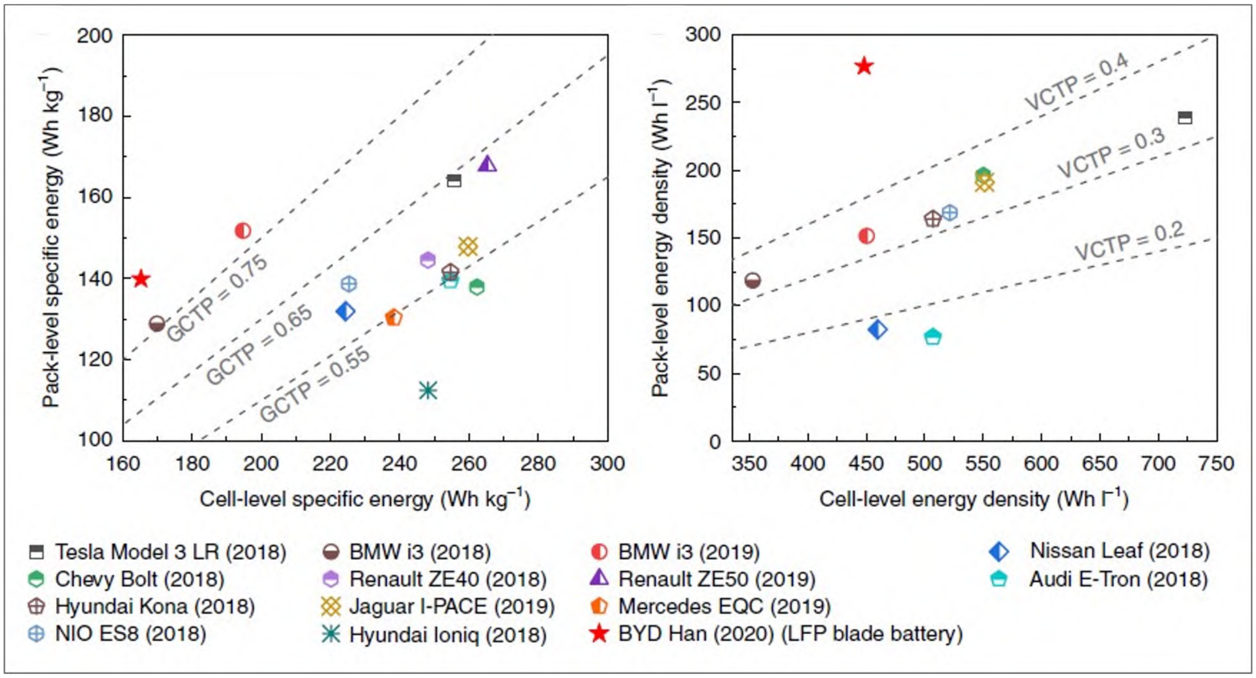


Figure 31: Gravimetric energy density and volumetric energy density of the battery packs in production EVs [48]

Figure 31 shows the gravimetric cell and pack energy density (left) and volumetric cell and pack energy density (right) of various BEVs in production [48]. Most EVs have a GCTP of around 0.55–0.65, i.e., 35 to 45% of pack weight is taken by inactive elements (battery management system, thermal management system, metal casing, cabling, beams, etc.). VCTP of most EVs is below 0.4. The "blade" LFP battery pack in the newly unveiled BYD Han EV achieves a GCTP of 0.85 and VCTP of 0.62, giving gravimetric and volumetric energy densities comparable to NMC and NCA chemistries (Table 13). The LFP battery pack produced by CATL for the Yutong bus in China has an energy density of 161.29 Wh/kg, which is equal to that of the VW ID.3 that uses LG NMC 811 cells [48].

In summary, the EV industry is doing away with battery modules and moving towards cell-to-pack construction that reduces part count, complexity (in construction and manufacturing), weight, and cost of materials and manufacturing.

Table 13: Comparison of battery packs in production vehicles

		2020 VW ID.3[1]	**2018 Tesla Model 3[1] ***	**BYD Blade battery pack[2]**
Cell chemistry		LG NMC	Panasonic NCA	BYD LFP
Nominal capacity	kWh	58	75	-
Nominal voltage	V	400	352	294
Gross battery size	kWh	62	78	59.5
Number of modules		9	4	1
Number of cells		216	4416	92
Battery weight	kg	376	474	425
battery volume	L	231	400	213
Gravimetric energy density	Wh/kg	164	164	140
Volumetric energy density	Wh/l	267	195	279
*** 2020 Tesla Model 3 has a gross battery capacity of 82 kWh** **[1] Source 2020 UBS teardown study [11]** **[2] Blade battery pack prototype - Source BYD [49]**				

3.2 Traction Motors – Technology Review

Internal combustion engine vehicles need a custom-designed engine and transmission for every narrow range of power output and vehicle application. On the contrary, heavy-duty BEVs can combine multiple smaller motors with the right gear ratio to produce the necessary combination of power and torque at the wheels. This modular approach significantly reduces the number of discrete motor sizes that are required to power vehicles from class 1 to class 8, giving EV components significantly more economies of scale compared to ICE components. As the manufacturing scale of motors increases globally, the design and manufacturing methods will converge into an accepted uniform practice, combining heavy- and light-duty production into a few motor types and sizes. Thus, costs predictions for light-duty motors are relevant when predicting the costs of heavy-duty electrification. Figure 32 shows how the Volvo medium-duty (FE) and the heavy-duty (VNR) trucks share motors and gearbox components and how the Tesla Class 8 Semi uses 4 motors based on the motor used in the Model 3.

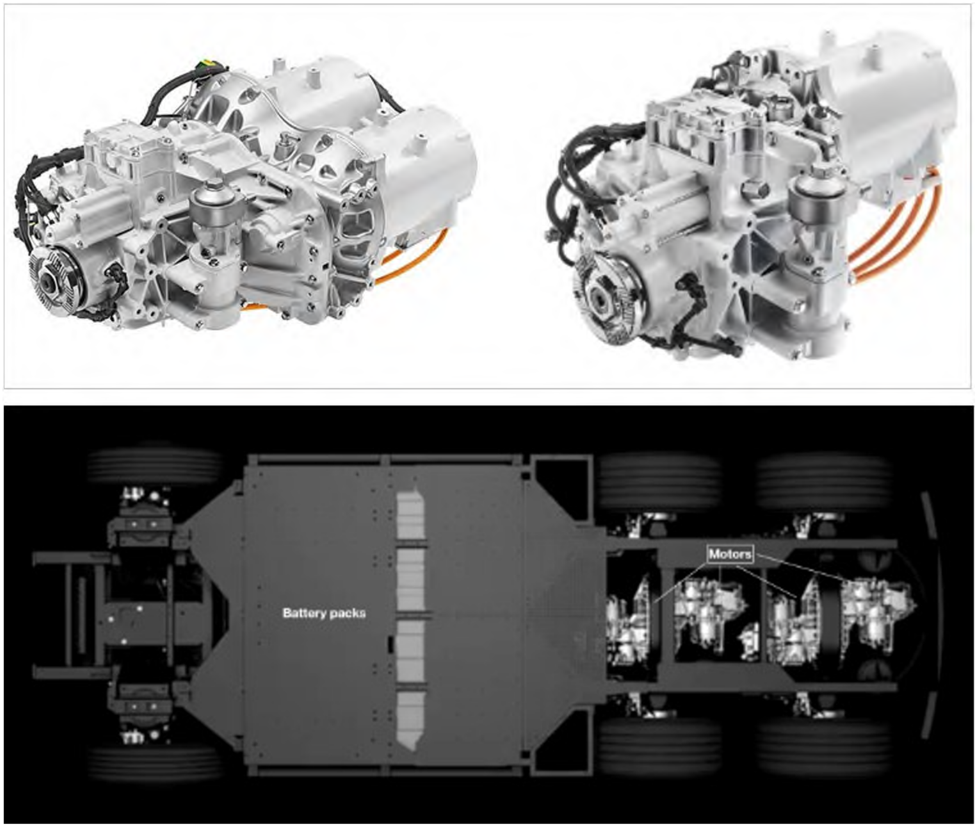


Figure 32: Top: (left) The powertrain of the Volvo VNR and (right) that of the Volvo FE (medium duty). Bottom: The Tesla Class 8 Semi powertrain with 4 PM-SynRMs (motors) and (4) SiC inverters based on the Model 3

Figure 33 shows the different types of electric motors in production EVs in the light-duty segment. Commercial BEVs in many MDHD segments discussed in this report are in a more nascent stage with less optimization of technology and costs, and lower manufacturing scale and automation. It is useful to look at the light-duty space for different types of traction motor technologies, their advantages and limitations since these motor technologies are just as relevant for MDHD vehicles as they are in the light-duty space.

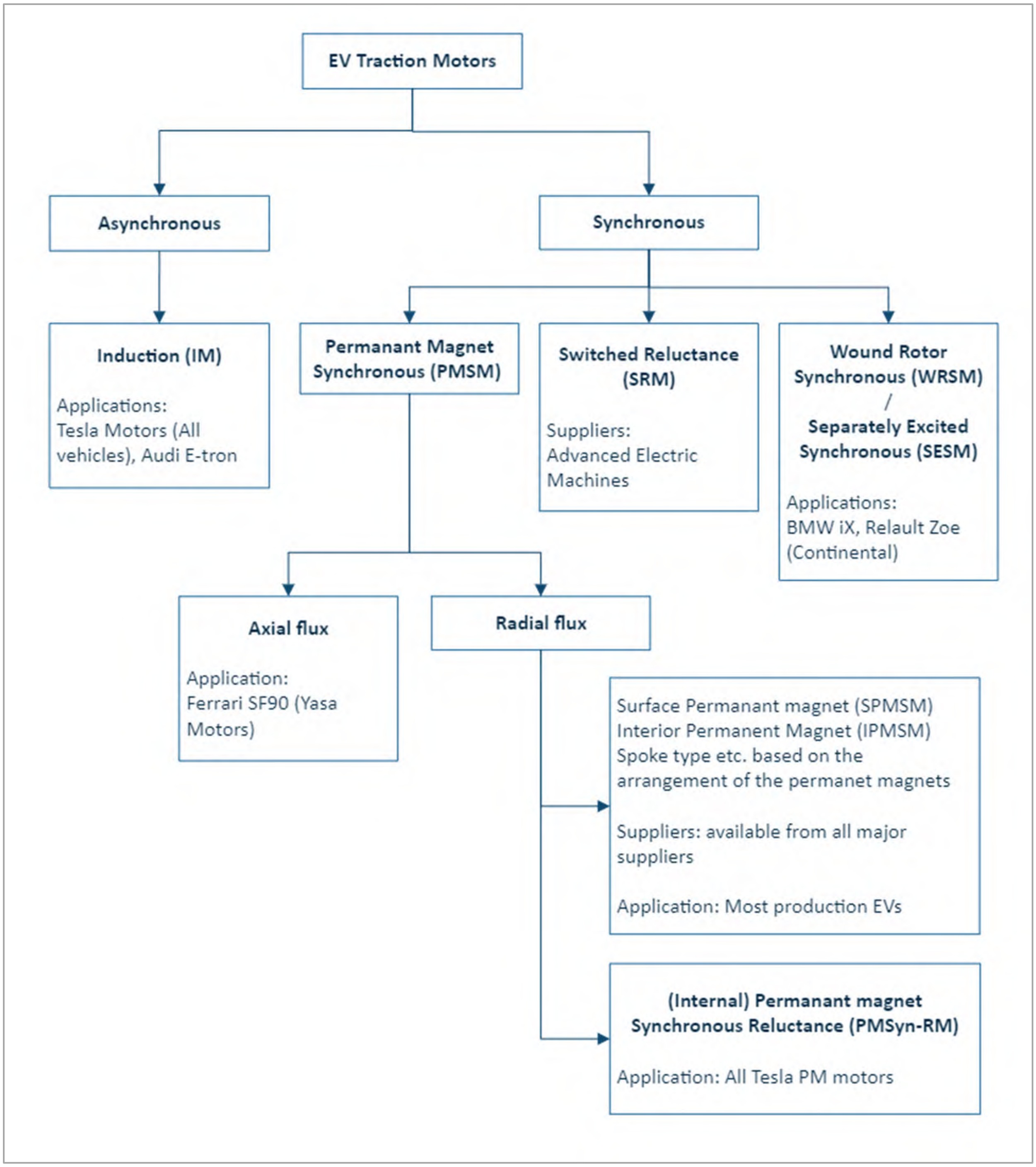
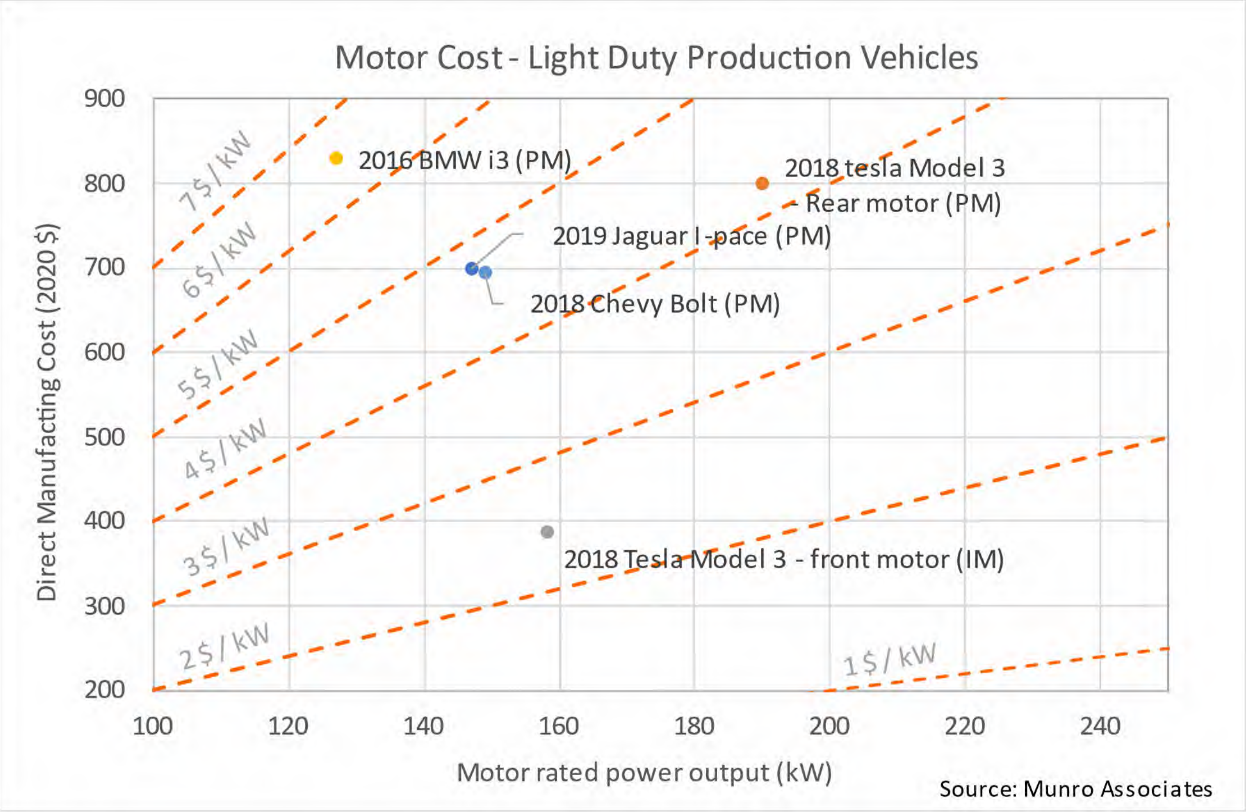


Figure 33: **Different types for traction motors in production battery electric vehicles**

Wound Rotor Synchronous Motors (WRSM), Induction Motors (IM), and Switched Reluctance Motors (SRM) eliminate the use of permanent magnets. In a Permanent Magnet Assisted Synchronous Reluctance Motor (PMSyn-RM) the reluctance torque is significant compared to the PM electrical torque. This results in a motor that matches, and in some cases, exceeds the performance and overall efficiency of a PMSM with a decreased need of expensive permanent magnet (PM) material, which makes it cheaper. The cost of all traction motors can be further reduced by replacing copper stator windings with aluminum windings.

The cost of Induction machines can be further reduced by using aluminum conductor bars in the stator (Tesla Induction motors and Audi E-tron).



Source: Munro Associates

Figure 34: Light Duty Production BEV Motor Cost

Highly automated volume manufacture of motors in the light-duty sector by companies like Tesla has resulted in an impressive reduction in the manufacturing cost of electric motors. Figure 34 plots the results of the motor teardown studies done by Munro & Associates of mass-produced light-duty BEV motors. The cost of permanent magnet synchronous motors is in the range of 4-5 $/kW while that of aluminum rotor induction motors (Tela Model 3 – front motor) is less than 3 $/kW.

3.2.1 Permanent Magnet Synchronous Motor (PMSM)

PMSMs are the most common traction motor technology in production EVs today. PMSMs currently have the highest peak efficiency among the different types of traction motors and are used in most light, medium, and heavy-duty applications. They are classified according to the arrangement of the magnets (Surface mounted, axial, spoke, etc.) and the direction of the magnetic field (axial or radial flux machines). Almost all PMSMs use Neodymium Iron Boron (NdFeB) magnets due to the high magnetic field strength they can generate. Some of these magnets also contain heavy rare earth metals such as dysprosium and terbium. Mining and processing rare-earth metals have a huge environmental impact and are subject to price volatility with increasing demand. Also, China provides 85% of rare earth metals making its supply at risk of geopolitical developments. Hence there is a huge incentive to reduce or eliminate the use of rare-earth magnets in motors.

Magnets with Reduced Rare Earth Metals

In 2016, Honda in collaboration with Daido Steel started manufacturing Neodymium Iron Boron (NdFeB) magnets without heavy rare earth metals such as dysprosium or terbium. In 2018 Toyota started the manufacture of NdFeB magnets which not only eliminated the use of dysprosium and terbium but also reduced the mass fraction of Neodymium by 50% replacing it with Cerium and Lanthanum which are less than a tenth of the cost of Neodymium.

Iron Nitride Magnets

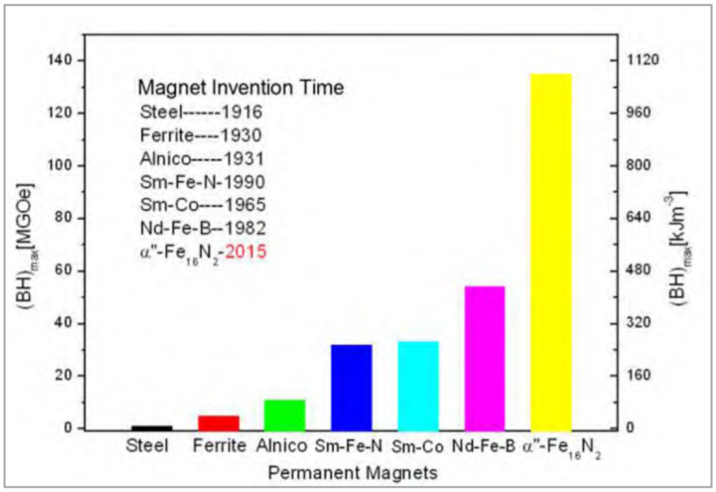


Figure 35: Comparison of energy density (BH)max at room temperature of various permanent magnet materials

Magnet formulations reducing or eliminating the use of rare-earth metals have been a subject of industry research that would significantly reduce the cost of PMSMs widely used in EVs. Iron Nitride Magnets (α”-Fe16N2) are a promising magnet formulation utilizing no rare-earth metals. Research and projections in Figure 35 show that iron nitride magnets can be stronger than current neodymium magnets as well, making them a promising future technology for compact and powerful electric motors. This development has the potential to further reduce motor costs and maintain the sustainability of electric vehicles in the long term.

3.2.2 Permanent Magnet Assisted Synchronous Reluctance Motor (PMSyn-RM)

PMSyn-RMs take advantage of the magnetic and reluctance effect to produce torque. Table 14 shows the comparison between the Internal PMSM used in the 2020 VW ID3 and the PMSyn-RM used in the 2018 Tesla Model 3 Dual Motor Long Range (rear motor). On a Kg/kW basis, Tesla uses 33% less rare earth magnet (by weight) when compared to VW. Mass-produced BEVs are now becoming more prevalent, and this example shows the opportunity available to reduce costs by optimizing the traction motor design to minimize the mass of rare earth magnets used.

Table 14: Comparison of VW ID3 motor and Tesla Model 3 rear motor

		2020 VW ID.3	2018 Tesla Model 3 rear motor
Peak power output	kW	150	190
Overall weight	kg	94	89
Copper weight stator wire + busbar	Kg	6.9	6.8
Magnet (NeFeB) weight - rotor	Kg	2.5	1.8
Magnet (NeFeB) weight / KW output	grams/kW	16.7	9.5
Peak power density	kW/kg	1.6	2.4
Stator copper slot fill factor	%	72	46
Source: Electric Vehicle and Battery Teardowns – UBS Evidence Lab [11]			

3.2.3 Induction Motors

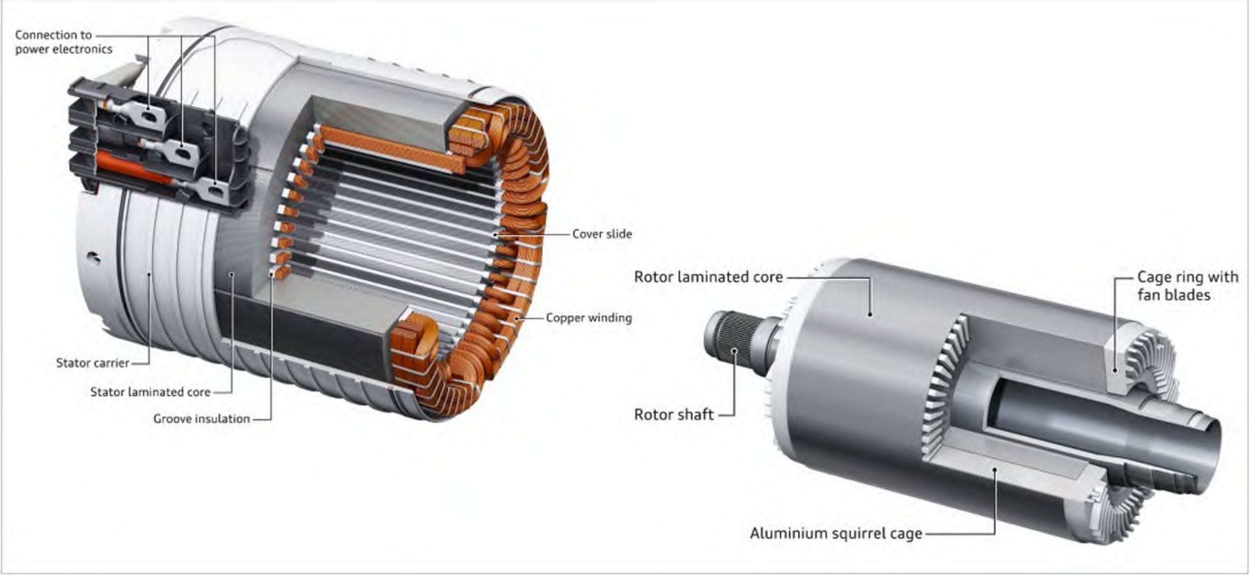


Figure 36: Audi APA250 induction motor with cast aluminum rotor conductors (125kW). Source: Audi

Induction motors (IM) have a lower peak efficiency when compared to PMSM but are attractive due to their significantly lower cost and not needing rare earth permanent magnets. In most current production automotive applications, the copper conductors in the rotor are replaced with aluminum bringing costs down further. An Induction motor with cast aluminum stator conductors is very cost-effective - 2.5$/kW for Tesla Model 3/Y front motor (Figure 34) compared to 4+ $/kWh for PMSMs/ PMSyn-RM. The Tesla Model S, Model X, Model 3, and Model Y use IM on one axle while the Audi E-tron uses induction motors on the front and rear axle. ZF offers a range of MD and HD e-axles and drives based on induction motors- “AxTrax AVE”, “CeTrax [72], [73]. An example of an induction motor used in a current EV is shown in Figure 36.

3.2.4 Wound Rotor Synchronous Motor (WRSM)/ Electrically Excited Synchronous Motor

Wound rotor synchronous motors (alternatively: electrically excited synchronous motors or separately excited synchronous motors) use electromagnets in the place of permanent magnets used in PMSM. The power to magnetize the rotor coils is transmitted wirelessly by inductive (rotating transformer) or capacitive methods. The manufacturing cost of a WRSM is higher than PMSM due to the added complexity of the rotor coils and wireless power transmission to the rotor, but material costs are lower owing to eliminating the NdFeB magnets. The performance characteristics of a WRSM are similar to a PMSM with the peak efficiency being marginally lower. But owing to the ability to adjust the rotor field intensity, a WRSM has a higher efficiency over a larger portion of the operating map (Speed torque map). Figure 37 shows the WRSM powertrain (motor, inverter, and reduction gearbox) used in the BMW-iX, a 5,700 lb. full-size SUV. The two motors on the front and rear axle of an iX M60 produce a combined power output of 447 kW.

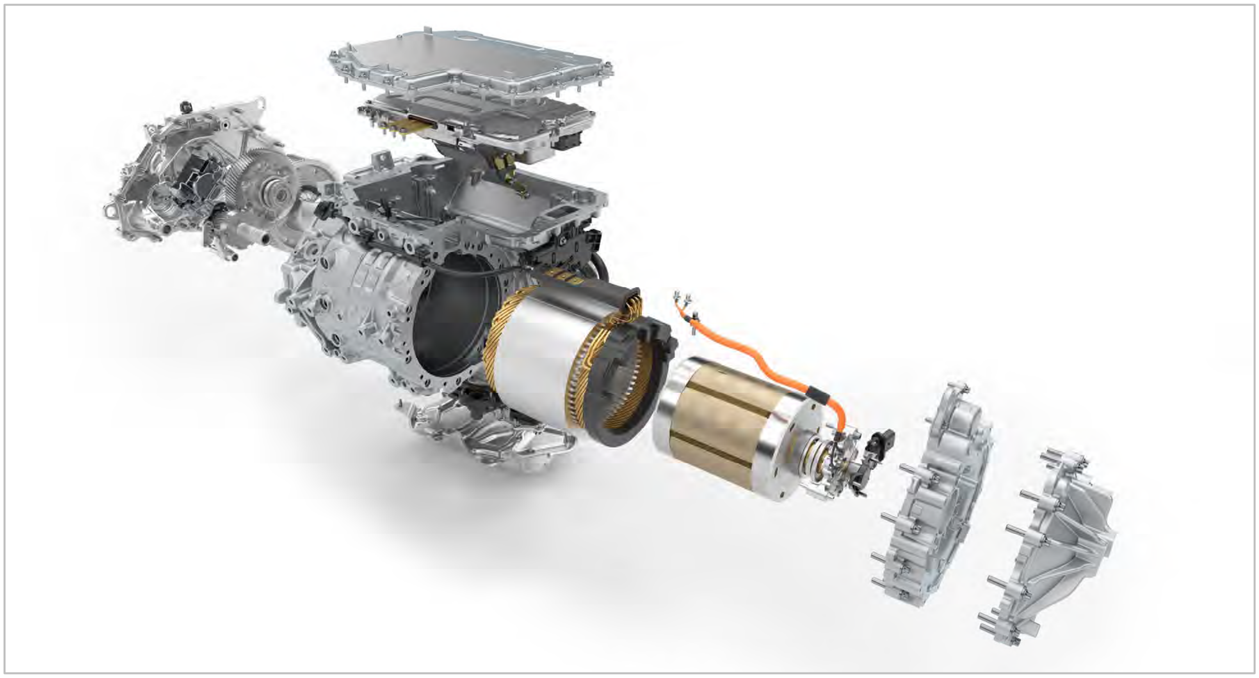
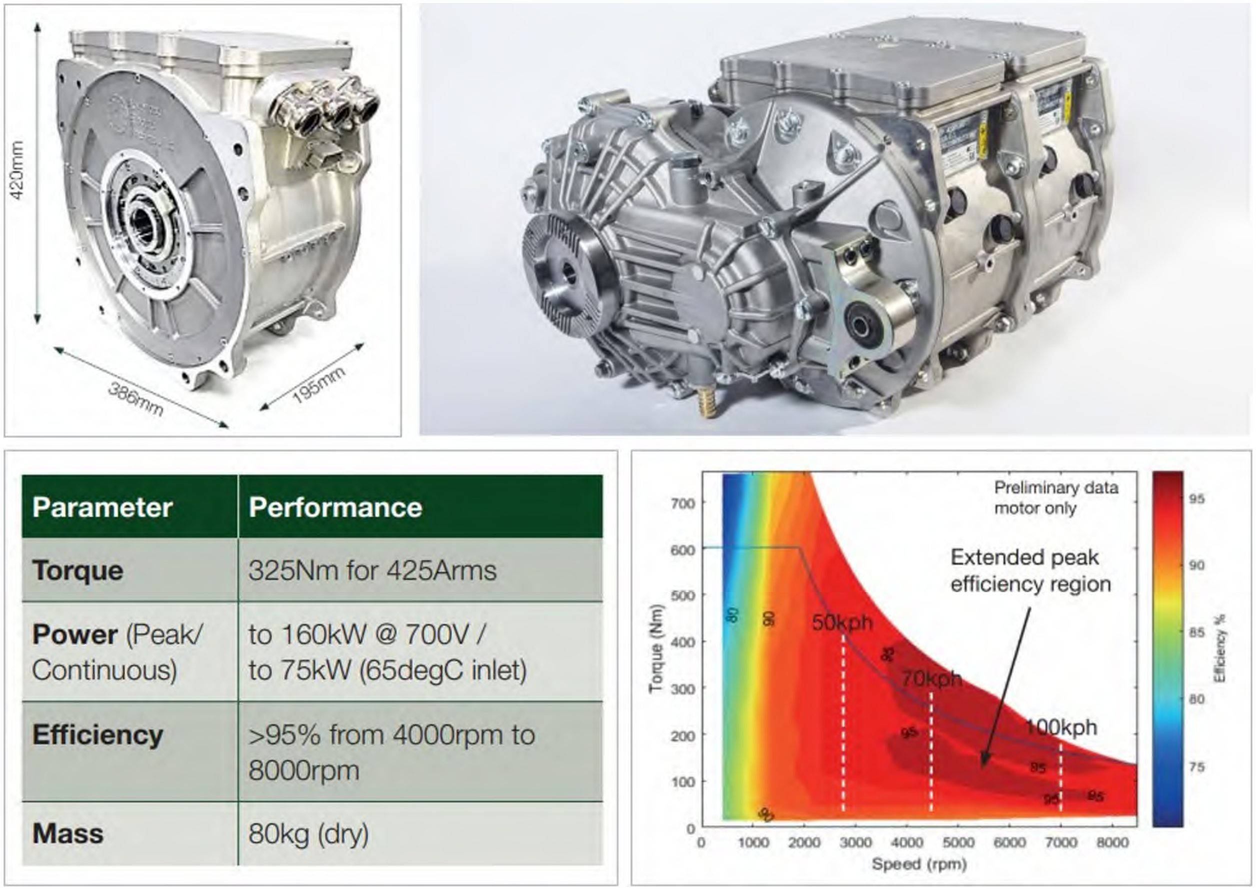


Figure 37: BMW "5th Gen E-drive Technology" employing a wound rotor synchronous rotor used in the BMW iX (Source: BMW)

3.2.5 Switched Reluctance Motor

Switched reluctance motors have the simplest construction (and are the cheapest) among different traction motor technologies with a wound stator and a rotor consisting of toothed laminations. Traditionally these motors have suffered from torque ripple, acoustic noise, and the need for specialized power electronics to drive them (incompatible with standard inverters). Over the past few years, all of these problems have been solved resulting in new motors having started limited production, being available for OEMs to test and integrate into their new product programs. Figure 38 shows the HDSRM300 from Advanced Electric machines (UK), a switched reluctance motor developed for MDHD applications.

The motor is compatible with off-the-shelf 3-phase inverters requiring no special power electronics. To reduce costs the motor also uses compressed aluminum stator windings in place of copper (Figure 40).



Parameter	Performance
Torque	325Nm for 425Arms
Power (Peak/ Continuous)	to 160kW @ 700V / to 75kW (65degC inlet)
Efficiency	>95% from 4000rpm to 8000rpm
Mass	80kg (dry)

Figure 38: SRMs from Advanced Electric Machines UK. Single HDSRM300 motor (top left) and two motors integrated into a single gearbox (top right) (up to 3 motors can be combined into a single drive unit). Bottom: performance numbers and motor efficiency. [74]

3.2.6 Replacing Copper Stator Windings with Aluminum – Reducing The Cost of Electric Motors

Table 14 shows that there is about 6.8 kg of copper in the Tesla and VW ID3 motors. The average annual commodity price of copper (COMEX, average daily closing price) has risen from 1.85 $/kg in 2000 to $9.3 $/kg in 2021 [75] and is projected to be north of 15$/kg in 2025 [76]. Between 2021 and 2030 the global demand for copper is projected to increase by 900% [16] and could result in a significantly higher price of copper.

Aluminum windings as shown in Figure 39 and Figure 40 can be used in place of copper with minimal impact on the performance or efficiency of the electric motor. Cast windings can achieve a 90% slot fill factor compared to 60% achieved by mass-produced machine wound copper wire and 70-75% for hairpin windings. The coils can be manufactured by high-pressure die-casting, investment casting, lost foam casting, low-pressure casting, or metal injection molding.

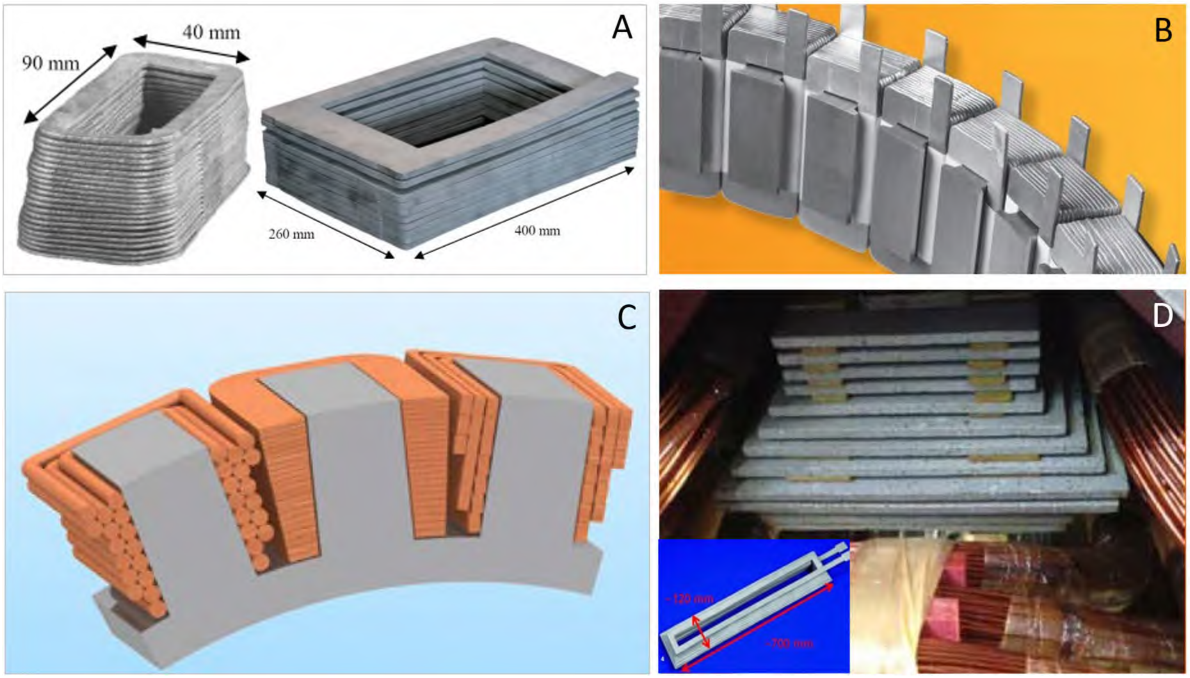
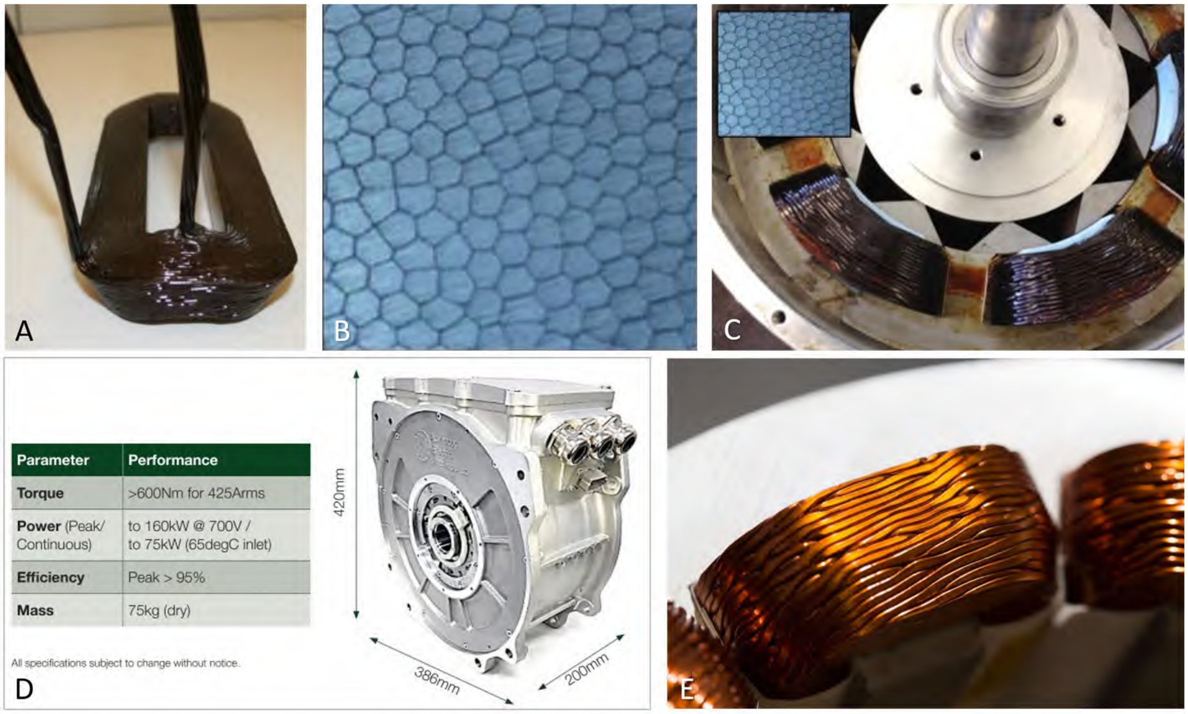


Figure 39: Cast Aluminum Stator Coils (Source: Fraunhofer IFAM). A: Cast coils suitable for all different sizes. B: detail of a stator assembled with cast aluminum coils. C: Illustration of slot fill factor - Comparison of cast coil 90% vs. wound cylindrical wire 60%, and hairpin windings 70-75%. D: Cast coil installed in a 300 kW DC motor



Parameter	Performance
Torque	>600Nm for 425Arms
Power (Peak/ Continuous)	to 160kW @ 700V / to 75kW (65degC inlet)
Efficiency	Peak > 95%
Mass	75kg (dry)

All specifications subject to change without notice.

Figure 40: A: Pre-compressed wound aluminum coil, B: cross-section of the coil showing high slot fill factor, C: coil installed in an 80 kW motor designed for automotive application. E: Specifications of a production switched reluctance traction motor using compressed aluminum winding (Advanced Electric Machines UK) and the detail of its compressed wound aluminum stator coil (E) [74], [77]

Alternatively, wound pre-compressed wound aluminum coils (Figure 40) can be used in place of copper windings. these have demonstrated a slot fill factor of 77% [77]. Advanced Electric machines ltd (UK) offers an MDHD application-specific switched reluctance motor that uses pre-compressed aluminum windings ([74], Figure 38, Figure 40).

3.3 Power Electronics

Inverters convert DC power from the battery to a variable frequency AC power to control the speed of the traction motor. BEVs such as the Nissan Leaf, Chevrolet Bolt, and Jaguar I-Pace use inverters that use Silicon insulated-gate bipolar transistors (Si IGBTs). With the release of the Model 3 in 2018, Tesla became the first company to use silicon carbide (SiC) metal-oxide-semiconductor field-effect transistors (MOSFETs) (sourced from ST Microelectronics, in an in-house inverter design) for a mass-produced vehicle. SiC MOSFET-based inverters have higher efficiency when compared to ones using Si IGBTs. Over low speed and load points (typical light-duty city cycle), an Si IGBT inverter has an efficiency of 96% while the SiC MOSFET-based inverter has an efficiency of 99% [78].

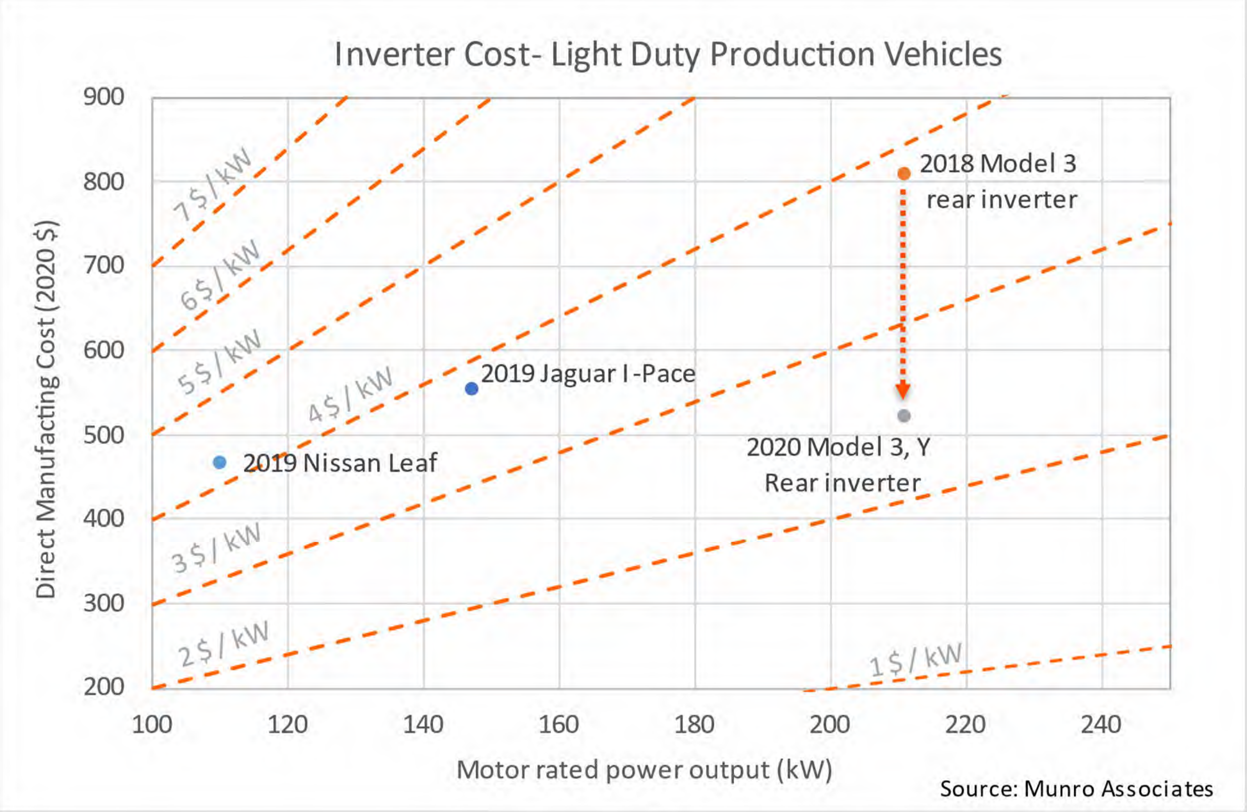


Figure 41: Cost of BEV inverters based on teardown studies. Source: Munro & Associates

Figure 41 shows the cost of various light-duty inverters based on teardown studies by Munro & Associates. The teardown shows that in 2018, the Tesla Model 3 inverter that used SiC MOSFETs (with in-house mass production) was at price parity (≈$4/kW) with the Nissan Leaf and Chevrolet Bolt inverters that used Si IGBTs. The 2020 Tesla Model 3 and Model Y have an inverter with the same performance but at a significantly lower cost (≈$2.5/kW), significantly cheaper than the competition. New BEVs from Hyundai-Kia, Lucid, Riviian, and others all use silicon carbide in their inverters.

New wide bandgap materials like gallium nitride (GaN) and aluminum nitride (AlN) promise inverters with even higher efficiency and performance. These have not been factored into this study.

3.4 Chargers

Chargers for electric vehicles range from low-powered AC chargers in the Level 1 and Level 2 range, which cover chargers up to 2 kW and 20 kW respectively, to higher-powered Level 3 AC chargers up to 70-100 kW, and DC fast chargers of 300 kW or more. The type, power level, and the number of chargers for a given fleet depend on the usage profiles, vehicle battery capacity, depot charging space available, and downtime for charging available for the fleet.

Delivery fleets that depart from a central location in the morning and return at night, while driving varying routes day to day may be more suited to depot charging. Depending on the number of delivery vehicles and overlap in schedules, charging strategies may include one charger per vehicle or one charger shared across multiple vehicles. Other fleets such as transit buses, which travel a set route repeatedly, may opt for overhead or on-route fast DC charging. Fast DC chargers can add a significant amount of range with a 15-minute charge that may overlap with a driver's break. These fleets can use DC chargers as a standalone solution, or in combination with overnight depot chargers.

Other factors may be accounted for in a certain fleet's decision to go with depot, on-route, or a combination charging strategy. Utility costs for power, as well as demand charges, levied on top of the per-kW-h cost for high spikes in use can cause electricity costs to be more favorable to one strategy or another. The length of downtime available for a depot charge, as well as staffing availability to manage charging when depot chargers are shared between vehicles, may determine if depot charging is feasible for a given application. New charger designs are now available in the market that can be connected to multiple vehicles and the individual charge rates can be managed remotely. Finally, the equipment costs of the chargers are a driving factor in the charging decision [79]. The optimum mix of chargers and bus battery/on-board charger specifications depends on the number of buses in a fleet, the route distances, and the ability to amortize the higher cost of DC fast chargers over time.

In addition to the charging equipment, installation is a cost associated with the chargers that must be considered. Installation considers the connection to the utility, wiring, trenching, and facility improvements such as concrete pouring that must be made to install the charger. In general, charger installation costs scale with charging power.

3.4.1 AC Chargers – Depot

Depot chargers are considered to be the standard pedestal type chargers that provide AC power to the vehicle's power port. An on-board charger aboard the vehicle receives this AC power and converts it to DC for charging the batteries. When costing a vehicle and charger, the onboard charger and the depot charger must be properly matched for maximum charging capabilities, or the charge rate will be limited by the lower-rated of the two. AC charging is slower and slightly less efficient due to the conversions that must occur to charge the batteries. AC charging is primarily up to the 19.6 kW level but can exceed that in some applications. Costs for AC charging were sourced for 25, 50, and 70 kW applications, and were extrapolated to a theoretical 100 kW AC charger for the reference case option of the 400 kW-h bus battery capacity to achieve the 4-hour charge time. Table 15 shows the costs for these chargers.

3.4.2 DC Fast Chargers – On-Route Charging

DC fast chargers bypass the onboard charger and deliver Direct Current directly to the battery. DC fast chargers are typically seen in power levels of 50, 150, or 350+ kW, and can deliver significant charge to vehicles in minutes instead of hours.

Due to the fast charging time, DC fast chargers can support an entire fleet with fewer chargers than AC charging would require. In applications where the vehicles operate over a set route repeatedly, such as transit, on-route DC chargers could supplant depot charging. Due to the increased power level and integrated inverting of power from AC to DC, DC chargers are significantly more expensive to procure and install than AC chargers.

3.4.3 Charger Costs

Costs for chargers and their installation are shown per power level in Table 15.

Table 15: Charger costs used in the study

Charger and Installation Costs	
Charger - 25 kW	$3,548
Installation – 25 kW	$3,626
Charger – 50 kW	$25,836
Installation – 50 kW	$14,005
Charger – 70 kW	$54,300
Installation – 70 kW	$21,938
Charger – 100 kW	$85,671
Installation – 100 kW	$34,232
Charger - DCFC 300+	$259,999
Installation - DCFC 300+	$132,707

4.0 Results

This section presents the results of the 2027 BEV vs ICE incremental and TCO cost analysis for the vehicle categories in Table 16. The overall results of the incremental costs and TCO studies are presented, followed by a detailed analysis of each vehicle class.

Table 16: MDHD vehicles studied for 2027 BEV vs ICE TCO

Market Segment	Weight Class	Battery Capacity (kW-h)
Transit Bus	Class 8	400
School Bus	Class 7	60
Shuttle Bus	Class 3-5	200
Delivery and Service Van, Box and Stake Truck	Class 3	100
Short Haul Delivery, Service, Box, and Stake Truck	Class 6-7	150
Short Haul Delivery and Service Van, Box and Stake Truck	Class 4-5	100
Refuse Hauler	Class 8	200

4.1 Incremental Costs – ICE to EV Summary

Incremental costs of each powertrain type were calculated to determine if purchasing an EV over an ICE vehicle in 2027 is an attractive option to a fleet owner. The primary difference in these vehicles is the powertrain, so the combined costs of an engine, aftertreatment system and transmission were compared to the combined costs of an equivalent power battery, inverter, motor, and other power electronics such as an on-board charger.

To cost the ICE powertrain, a representative 2021 regulations-compliant diesel powertrain was selected for each segment and the cost estimated based on published literature sources as shown in Sections 2.1 to 2.3. Sections 4.3 through 4.9 outline the powertrain for each vehicle class costed. To determine the powertrain cost in 2024 and 2027, additional costs for updating the powertrain for compliance with the 2024 and 2027 Phase II GHG rule and the California NOx standards were added to the engine, aftertreatment, and transmission costs as outlined in Sections 2.1, 2.2, and 2.3, respectively. These resulting costs were considered as the base powertrain cost for 2024 and 2027 as “delete costs” to be compared with the electrification “add costs” in the same years. The decreasing cost of electrification and a direct comparison of EV vs emissions-compliant diesel costs in 2027 are shown in Figure 42.

To cost a representative BEV powertrain, the battery, motor, and power electronics (Inverter, DC-DC converter, and onboard charger) costs from published literature are considered as outlined in Section 2.5 for an electric vehicle in 2021, 2024, and 2027.

The incremental costs presented are conservative estimates, in which the lowest-cost diesel option is compared to the highest-cost EV option. For the diesel, the base case does not consider any hybridization, which adds cost and complexity. The EV powertrains consist of a higher-cost NMC battery and heavy-duty specific motors. Even with these conservative estimates, base powertrain incremental costs favored electrification by 2027, except for Class 3 shuttles. Costs required to meet emissions compliance in 2027 caused an increase in the cost of the engine, aftertreatment, and transmission systems, while the projected costs of batteries, motors, and power electronics drop over time due to increasing adoption and advancements in technology. This crossover in incremental cost can be seen in Figure 42, and typically occurs between 2024 and 2027.

To consider the impact of various technologies on the cost of both powertrain types, a cost sensitivity analysis was performed on these incremental powertrain costs. Adoption of technologies such as hybridization of diesels can improve fuel economy, reduce emissions, and help meet more stringent emissions targets, with the effect of increasing the diesel powertrain costs. For electric heavy-duty vehicles, less power-dense battery chemistries such as LFP can provide similar performance (and advantages in some cases, as mentioned in Section 3.1) as NMC while reducing electrification costs. The use of light-duty motors can bring costs down as well. These sensitivities were applied to the 2027 powertrains for both types of vehicles to create a range of possible scenarios.

For the 2027 diesel powertrain cost sensitivity analyses, three ICE powertrain options were considered:

1) Base Case – Lowest cost 2027-compliant powertrain: base powertrain with added costs for emissions compliance in 2027 (shown in Figure 42)
2) Sensitivity 1 – Diesel engine with mild hybridization: 48V system with an integrated starter/generator that enables start/stop operation and some regeneration
3) Sensitivity 2 – Full hybrid powertrain with the diesel engine optimized for hybridization

For the ICE powertrain, hybridization sensitivities were not considered for the 2021 and 2024 timeframes.

For the 2027 EV powertrain cost sensitivity analyses, three BEV powertrain options were considered:

1) Base Case – Highest projected 2027-cost powertrain: NMC Batteries, HD specific motors
2) Sensitivity 1 – EV powertrain with lower-cost battery chemistry: LFP batteries, HD specific motors
3) Sensitivity 2 – Lowest-cost EV powertrain: LFP batteries + Motors based on light duty architecture (based on teardown studies of light-duty vehicles).

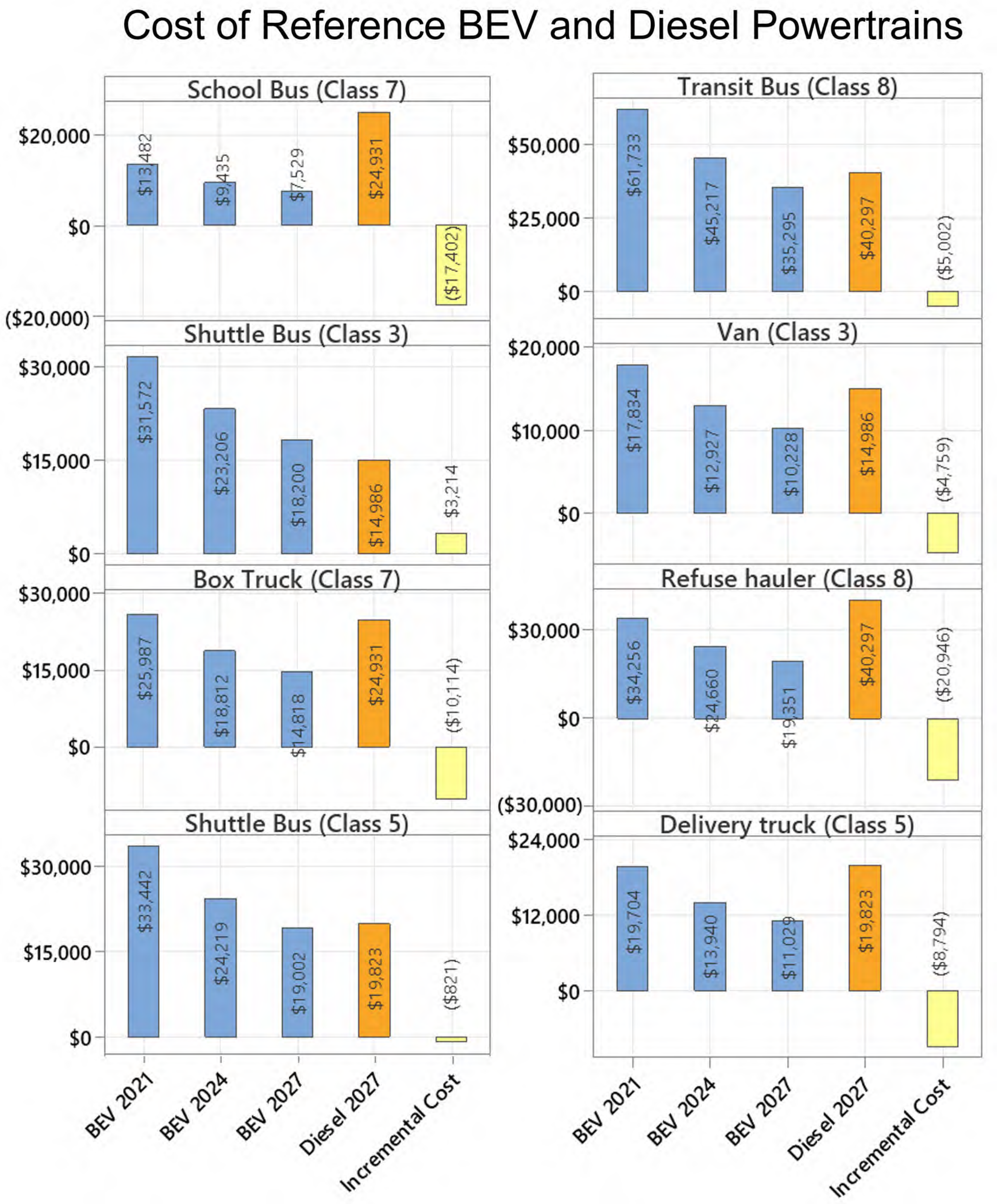


Figure 42: Incremental costs of electrification of MD/HD vehicles. Blue bars are EV powertrain (add) costs in 2021, 2024, and 2027, orange bars are ICE powertrain (delete) costs in 2027, and the yellow bars are incremental costs of the BEV in 2027 (negative value implies that an electric powertrain is cheaper than diesel in 2027

The 2027 differences in costs between the 2027 diesel and EV powertrains were calculated for each combination of costs listed above, resulting in 9 possible incremental costs between a diesel powertrain and an electric powertrain. From these costs for each vehicle class, the low, median, and high incremental cost scenario was selected to highlight the range of possible incremental costs of electrification, which are shown for each vehicle category in Figure 43.

With sensitivities applied, all vehicle classes favor electrification by 2027. Only two scenarios in this analysis do not favor electrification, the median, and the high incremental costs of a class 3 shuttle EV powertrain.

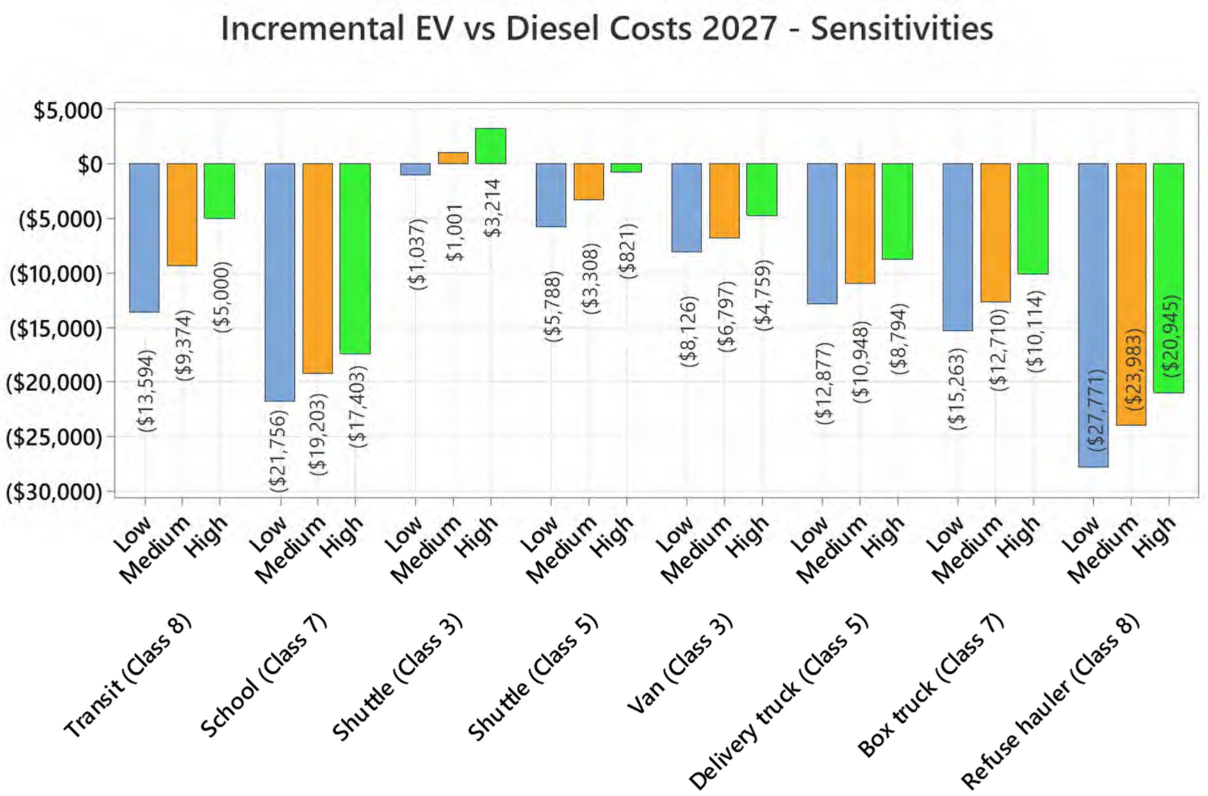


Figure 43: Incremental costs of electrification for three possible scenarios in all classes.

4.2 Total Cost of Ownership Summary

Costs incurred through vehicle operation can far exceed the vehicle purchase price and are a crucial component of evaluating vehicle selection for fleet operators. For calculating the TCO of an ICE vehicle and an EV purchased in 2027, the following categories of expenses were considered:

1. Purchase cost
2. Energy cost (diesel/ electricity)
    a. Fuel or energy economy variances
    b. Diesel or electricity cost variances
3. Maintenance cost (based on published fleet data)

4. Infrastructure type and costs (based on the methodology explained in Section 2.0)
5. Vehicle lifetime in years
6. Yearly vehicle miles

The reference case TCO assumes the approximate average projected cost of all factors and is likely the closest to what a fleet operator would incur over the lifetime of the vehicle. Because the number of factors is too high to account for every possible scenario, a low and high case was created to serve as lower and upper limits, and contain all of the best- and worst-case scenarios, respectively. While unlikely that all these factors overlap simultaneously to create either of these cost scenarios, they work to bound the possible TCO considerations that a fleet operator may consider when making a purchasing decision.

To determine the difference in vehicle cost between an ICE vehicle and an EV, a powertrain assumption is created for each case. The ICE and BEV powertrains for each of the three cases are:

1) Low:
    a. ICE - Base diesel (no hybridization)
    b. BEV - LFP batteries, LD motors, onboard charger sized for 6-hour depot charge
2) Reference:
    a. ICE - Diesel engine with mild hybridization
    b. BEV - LFP batteries, HD motors, onboard charger sized for 4-hour depot charge, mild refresh for transit/school owing to their high mileage, severe driving cycles, and age
3) High:
    a. ICE - Full hybrid
    b. EV - NMC batteries, HD Motors, DC fast charging, full refresh (replacing the battery pack and drive motor)

In addition, a low, reference, and high projected cost for electricity or diesel was used for all TCO cases, based on the EIA Annual Outlook [37]. These costs are shown in Table 17.

Table 17: Energy costs used for the three TCO cases.

	Diesel ($/gal)	Electricity ($/kWh)
Low	$2.10	$0.07
Reference	$3.25	$0.12
High	$4.61	$0.15

Each vehicle class utilized a mileage, lifetime, fuel or energy economy, vehicle price, and maintenance costs specific to the class. These were sourced from available literature, with the lowest values or values resulting in lower costs utilized in the low cases, the highest in the high cases, and the approximate mean value in literature used as the reference case. The values used for each class of vehicle are detailed in the following sections for each class [26] [32] [28] [80] [81] [82] [83] [84] [85] [86] [35] [15] [87] [33] [88].

The report presents the cumulative TCO ($) and a TCO ($/Mile) over the life of the vehicle. A discount rate of 3% is used for calculations. Summary results of the TCO are shown in Figure 44. The specific values and relative effect of the sensitivities studied are detailed in the following sections.

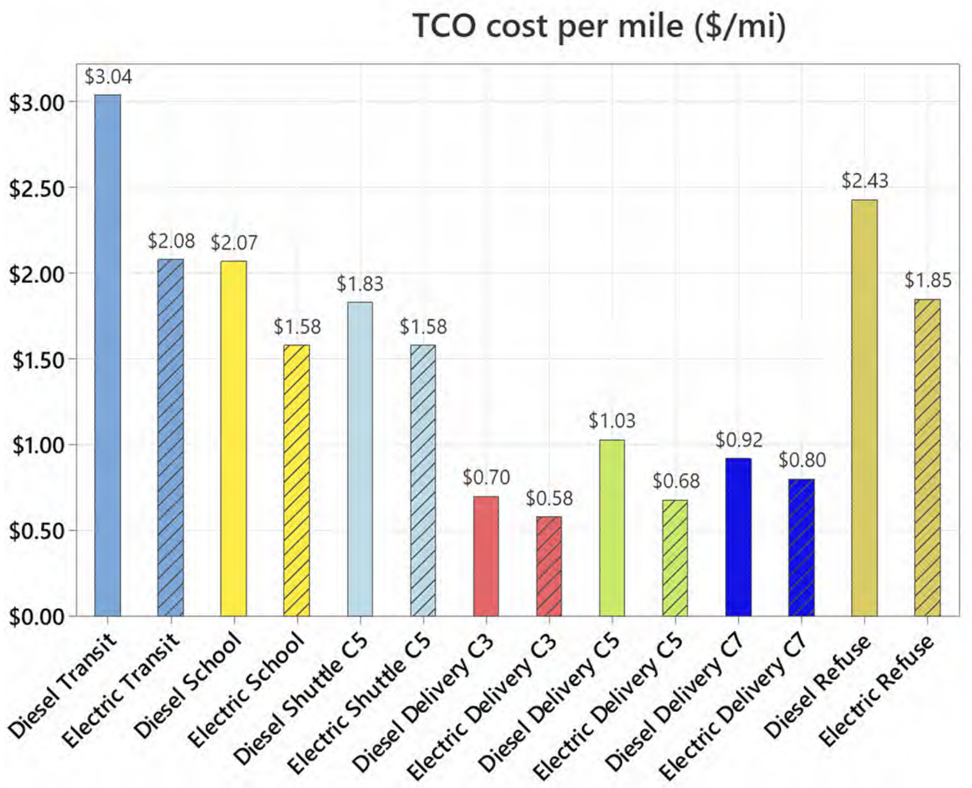


Figure 44: Reference case TCO for all classes considered.

4.3 Class 8 Transit Bus

4.3.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

The representative Class-8 transit bus is assumed to be a 40-foot vehicle equipped with a diesel engine and an automatic transmission. An example powertrain for a 2021 transit bus is shown in Table 18. The representative diesel powertrain was chosen based on offerings in the segment that have a high market share (Example: New Flyer Xcelsior XD40).

Table 18: 2021 Class 8 Transit Bus, 2021 base ICE powertrain example

Engine	Cummins L9 - Transit bus (diesel)
Power	260 kW (350 HP)
Torque	925-1150 lb-ft
Transmission	Allison B400R (Automatic)

The 2021 base powertrain shown in Table 18 consisting of a diesel engine, 2021-compliant aftertreatment system, and an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet GHG regulations in 2024 and 2027, with further improvements for 2027 Low NOx rules. Table 19 breaks down the engine, transmission, and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 19: Class 8 Transit bus - ICE powertrain cost in 2021, 2024, and 2027 to meet regulations.

	2021 w/ GHG	2024 w/ GHG	2027 w/GHG	2027 w/ GHG + Low NOx
Engine	$10,303	$10,775	$10,812	$13,013
Aftertreatment	$6,975	$6,992	$6,993	$9,455
Transmission	$15,628	$15,628	$15,628	$17,829
Total	$23,633	$33,395	$33,433	$40,297

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 20 compares the cost of the regulations-compliant base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 20: Class 8 Transit Bus - ICE, mild-hybrid and full-hybrid cost in 2027

Base Cost	$40,297
Sensitivity 1 - Mild Hybrid	$41,566
Sensitivity 2 - Full Hybrid with improved engine	$44,516

4.3.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 21 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with multiple light-duty-based motors, the costs based on motors mass-produced for light-duty application. All costs assume high-volume manufacturing similar to what OEMs have in the light-duty space.

Table 21: Class 8 Transit Bus - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	400	$49,360	$36,080	$27,360
Inverter	260	$949	$854	$768
Onboard charger	100	$5,594	$5,035	$4,531
DC-DC Converter	10	$559	$503	$453
Motor	260	$4,771	$2,245	$1,683
Gearbox	260	$500	$500	$500
Total Base Case – NMC batteries, HD Motor		**$61,733**	**$45,217**	**$35,295**
LFP battery pack	400	$42,980	$31,416	$23,824
Total Sensitivity 1 Case – LFP batteries, HD motor		**$55,353**	**$40,553**	**$31,760**
Motor, light-duty cost	260	$1,045	$940	$846
Total Sensitivity 2 Case – LFP batteries, LD motor		**$51,627**	**$39,249**	**$30,923**

4.3.3 Incremental Cost - Diesel Vs Battery Electric, Class 8 Transit Bus

Table 22 combines Table 20 and Table 21 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). The incremental cost of BEVs in 2027 is lower than diesel, mild-hybrid, and full hybrid buses for all scenarios. Factoring the different combinations of the diesel engine, level of hybridization, and BEV components, the powertrain of the electric transit bus is estimated to be between $5000 and $13,594 cheaper than the diesel counterpart.

Table 22: Class 8 Transit Bus ICE Delete Vs BEV add costs – 2027

ICE powertrain description	**Diesel**	**Diesel mild hybrid**	**Diesel full hybrid**
ICE powertrain (delete) cost	$40,297	$41,566	$44,516
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$30,923	$31,760	$35,295

Figure 45 compares the Diesel powertrain cost to BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is higher in 2021 and 2024 but lower in 2027. (Data from Table 19, Table 20, and Table 21). Powertrain cost parity between diesel and battery electric is reached sometime between 2024 and 2027.

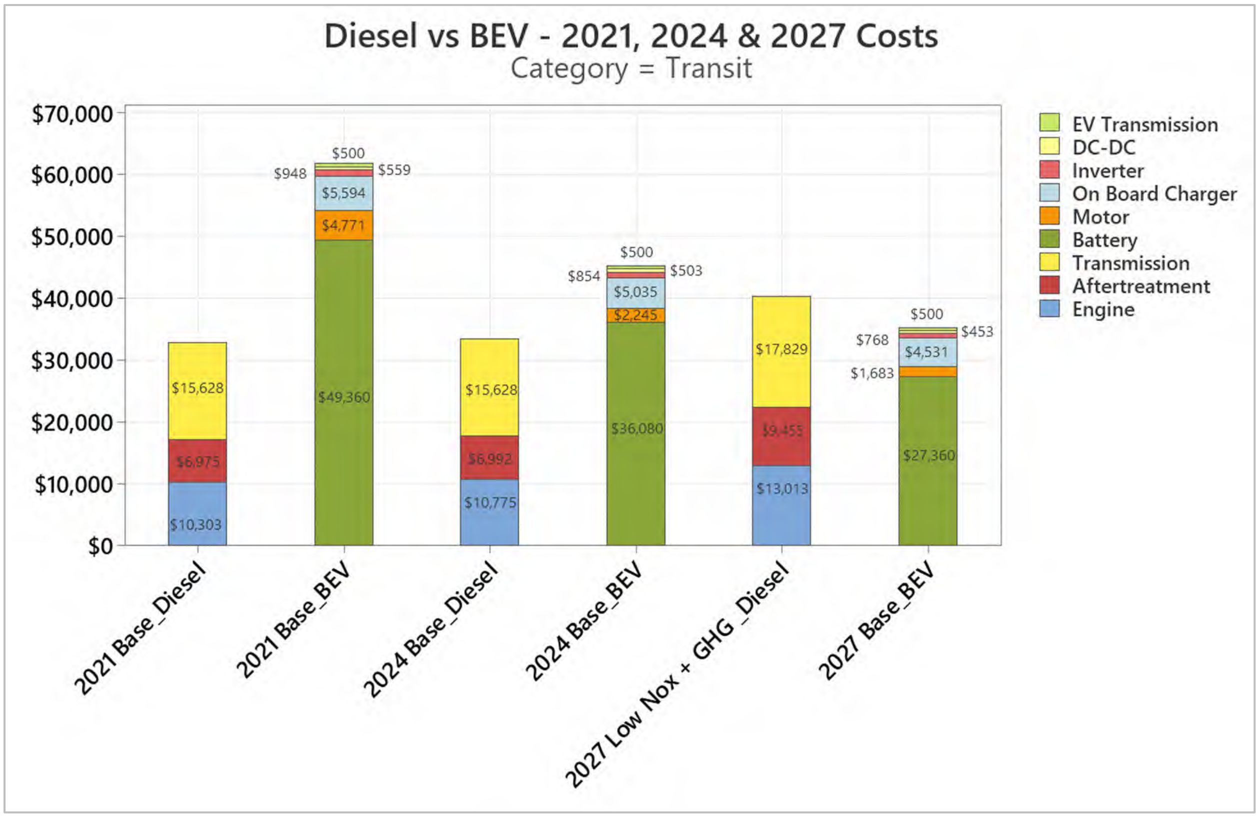


Figure 45: Class 8 Transit bus – Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.3.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 23 gives the main assumptions used in the calculation of TCO of transit buses. Table 24 gives the final value of the cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the electric bus is expected to be more than 27% lower in 2027 when compared to the diesel alternative.

Table 23: Class 8 transit bus - Main inputs TCO Calculation

Bus Type	Diesel			Electric		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	12			12		
Lifetime mileage (mi)	331,200	500,000	652,836	331,200	500,000	652,836
Fuel consumption (kWh/mile, mpg)	7	4	3	1.6	2.16	2.4
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase cost ($)	$345,695	$531,337	$603,965	$340,602	$527,173	$600,642
Refresh ($)	$0	$16,971	$34,800	$0	$23,824	$29,957
Infrastructure cost ($/miles)	$0.002	$0.004	$0.01	$0.23	$0.24	$0.20
Maintenance ($/mile)	$0.63	$1.46	$1.65	$0.33	$0.61	$0.81

Table 24: Total cost of ownership for a class 8 transit bus ($/mile).

TCO	Low	Reference	High
Diesel Transit	$1.84	$3.04	$3.70
Electric Transit	$1.64	$2.08	$2.16

Figure 46 gives the effect of the variation of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric bus. Given the long operating life (12 years) and high mileage, the variation in the purchase cost of both diesel and electric buses has a relatively small impact on the TCO, less than ±5%. For a diesel transit bus, the factors with the highest impact on TCO are the cost of diesel and maintenance cost. For an electric bus, the biggest factors are maintenance and infrastructure cost. With batteries and motors with higher durability and mass production of chargers and associated power electronics, the future costs will most likely be lower than projected in the study.

Figure 47 compares the cumulative cost of the reference diesel transit bus to the reference electric bus purchased in 2027. The electric bus is cheaper to buy because of the rapid decline of battery costs. The annual operating cost of an electric transit bus is significantly lower because of the lower fuel cost (electricity vs diesel), lower maintenance cost, and the high annual mileage. The operating cost of an electric bus is low enough to offset the high infrastructure cost of installing captive chargers by the end of the first year of ownership (2028).

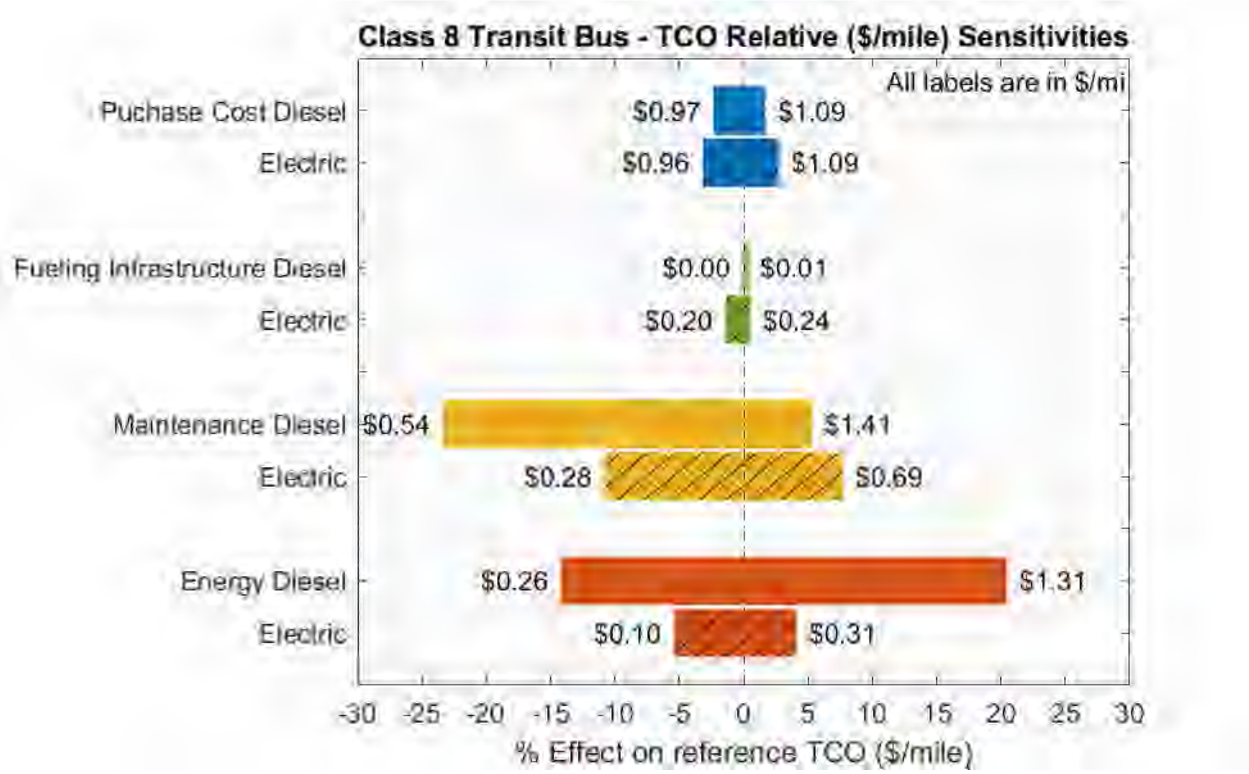


Figure 46: Class 8 Transit Bus TCO sensitivities (listed in Table 23) and their % contribution to reference TCO

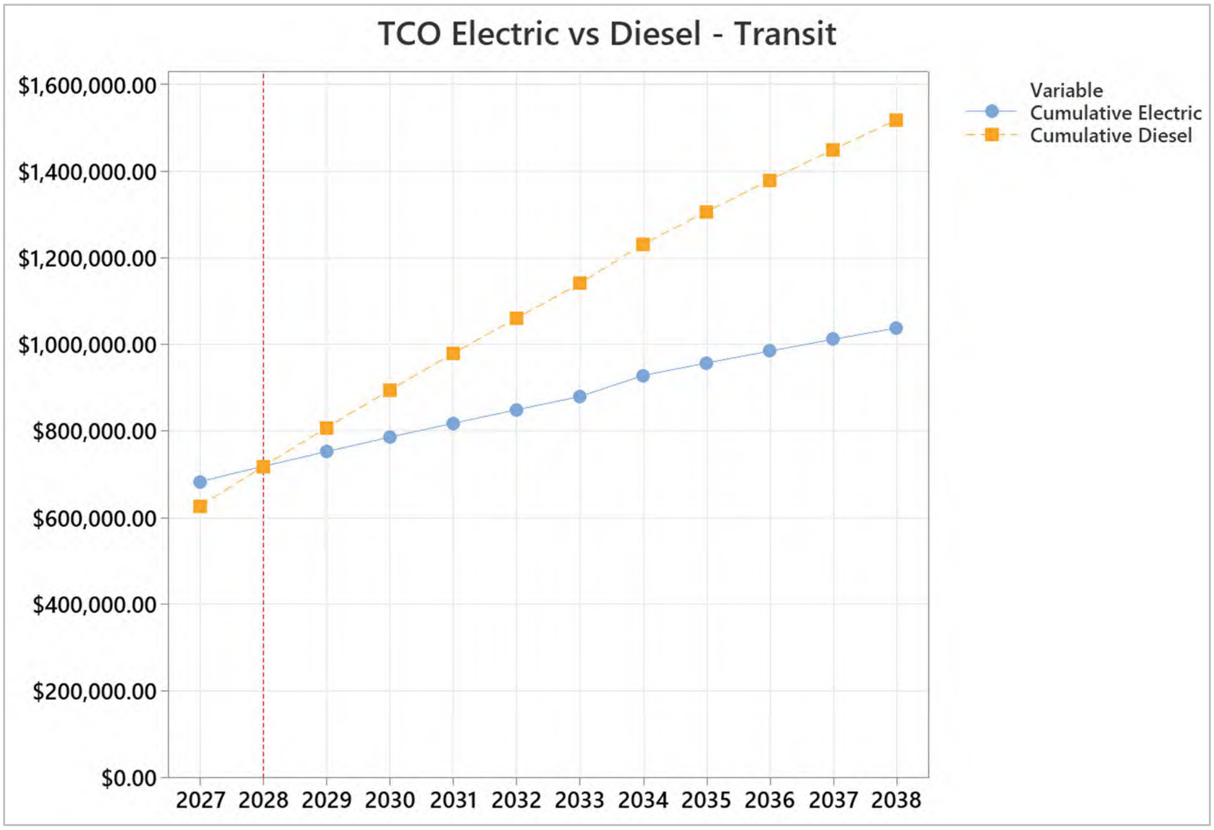


Figure 47: Class 8 Transit bus cumulative cost of ownership for vehicle lifetime (2027-2038)

Figure 48 breaks down the absolute ($/mile) and relative (percentage) contributions of purchase cost, infrastructure cost, powertrain refresh cost, maintenance, and energy costs to the TCO for the low, reference, and high TCO cases of the diesel and electric buses (shown in Table 23).

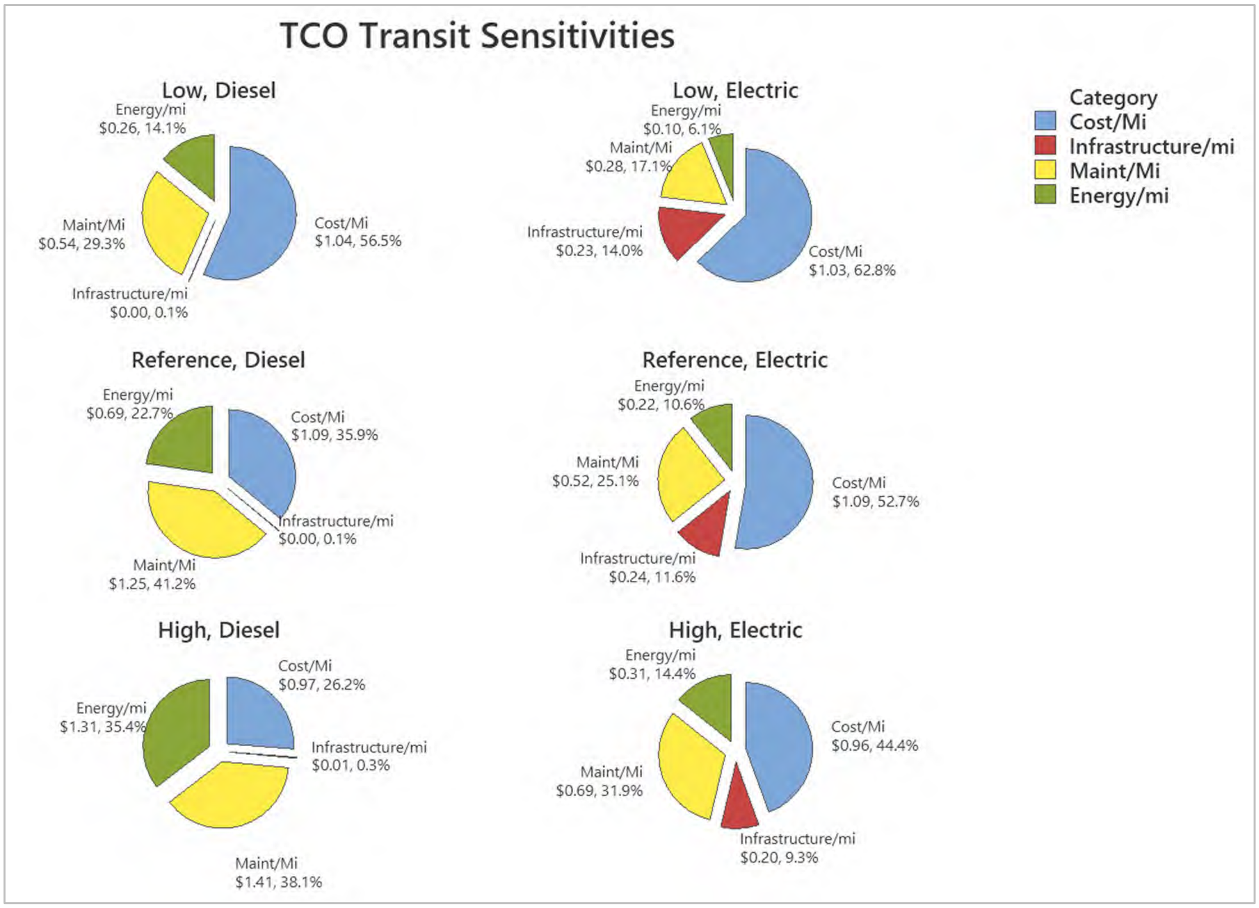


Figure 48: Class 8 Transit bus category contributions to TCO for the low, reference, and high TCO scenarios.

4.4 Class 7 School Bus

4.4.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

An example powertrain for a representative class 7 diesel school bus in 2021 is shown in Table 25

Table 25: 2021 Class 7 School Bus, 2021 base ICE powertrain example

Engine	Cummins B 6.7
Power	191 kW (260 HP)
Torque	660 lb-ft
Transmission	Allison 2500 PTS

The 2021 base powertrain shown in Table 25 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 26 breaks down the engine, transmission,

and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 26: Class 7 school bus - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$6,508	$6,979	$7,016	$8,435
Aftertreatment	$4,338	$4,355	$4,356	$6,618
Transmission	$7,677	$7,677	$9,878	$9,878
Total	$18,523	$19,011	$21,250	$24,931

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 27 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 27: Class 7 school bus - ICE, mild-hybrid and full-hybrid cost in 2027

Base Cost	$24,931
Sensitivity 1 – Mild Hybrid	$26,201
Sensitivity 2 – Full Hybrid with improved engine	$28,142

4.4.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 28 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with motor costs based on high volume mass-produced motors in the light-duty application. All costs assume high-volume manufacture.

Table 28: Class 7 school bus - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	60	$7,404	$5,412	$4,104
Inverter	190	$693	$624	$562
Onboard charger	15	$839	$755	$680
DC-DC Converter	10	$559	$503	$453
Motor	190	$3,486	$1,641	$1,231
Gearbox	190	$500	$500	$500
Total Base Case		**$13,482**	**$9,435**	**$7,529**
LFP battery pack		$6,447	$4,712	$3,573
Total Sensitivity 1 Case		**$12,525**	**$8,736**	**$6,998**
Drive unit, light-duty cost		$763	$687	$618
Total Sensitivity 2 Case		**$9,802**	**$7,782**	**$6,386**

4.4.3 Incremental Cost - Diesel Vs Battery Electric, Class 7 School Bus

Table 29 combines Table 27 and Table 28 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). Assuming high volume manufacture, the incremental cost of BEVs in 2027 is lower than diesel, mild-hybrid, and full hybrid buses for all scenarios evaluated. Factoring in all the different combinations of the diesel engine, level of hybridization, and BEV components, the powertrain of the electric school bus is estimated to be between $17,400 and $19,200 cheaper than the diesel counterpart in 2027. This large difference is due to the small battery pack size required by a school bus to cover the majority of the routes.

Table 29: Class 7 school bus - ICE Delete Vs BEV add costs – 2027

ICE powertrain description	**Diesel**	**Diesel mild hybrid**	**Diesel full hybrid**
ICE powertrain (delete) cost	$24,931	$26,201	$28,142
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$6,386	$6,998	$7,529

Figure 49 compares the Diesel powertrain cost to the base BEV powertrain cost in 2021, 2024, and 2027 (Data from Table 26, Table 27, and Table 28). Due to the small battery size required by a school bus to cover the majority of routes, the cost of the base BEV powertrain is lower than a comparable diesel powertrain today (2021) when using costs achieved by high volume manufacturing (seen in the light-duty space). Some of these cost savings will be realized in the near future with suppliers scaling up the production of battery cells and modules, motors, and power electronics and the ability to share these standardized components between vehicles of different sizes and use cases providing suppliers with significant manufacturing volumes.

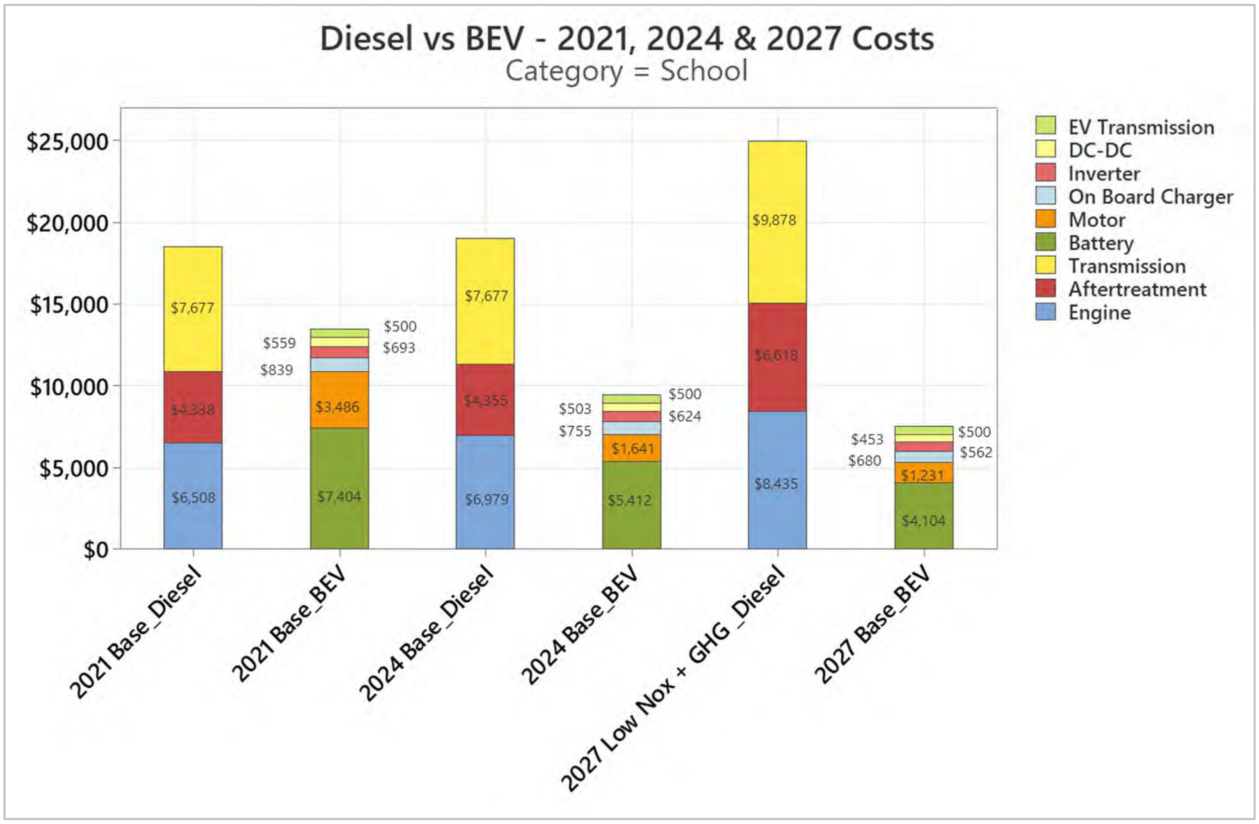


Figure 49: Class 7 school bus – Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.4.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 30 gives the main assumptions used in the calculation of TCO of class 7 school buses. Table 30 gives the breakdown of all the costs used in the calculation of the TCO.

Table 30: Class 7 school bus - Main inputs TCO Calculation

Bus Type	Diesel			Electric		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	10			10		
Lifetime mileage (mi)	221,120	221,120	425,000	221,120	221,120	425,000
Fuel consumption (kWh/mile, mpg)	7	7	3	1.30	1.40	1.40
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase price ($)	$108,683	$117,680	$118,992	$94,467	$103,035	$103,565
Refresh ($)	0	$3,574	$20,479	$0	$6,002	$10,602
Infrastructure cost ($/miles)	$0.003	$0.003	$0.006	$0.032	$0.032	$0.031
Maintenance ($/mile)	$0.63	$1.24	$1.65	$0.44	$1.05	$1.46

Table 31 gives the final value of the cost of ownership calculated in $/mile. In the reference case scenario, the TCO of a class 7 electric school bus purchased in 2027 is more than 27% lower when compared to the diesel alternative.

Table 31: Class 7 School Bus – TCO ($/mile)

TCO	Low	Reference	High
Diesel Transit	$1.31	$2.07	$3.13
Electric Transit	$0.93	$1.58	$2.03

Figure 50 gives the effect of the variation of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric bus. Due to the lower annual miles driven, the purchase cost of the class 7 school bus has a higher impact on the TCO compared to a class 8 transit bus. Fuel cost and maintenance have the highest impact on TCO for a diesel bus. These factors have a relatively low impact on the TCO of the electric school bus due to the low cost of electricity and the reduced maintenance costs. The infrastructure cost of electric school busses is relatively low due to the ability to use relatively slower onboard chargers due to the small battery size and long periods during the day when the vehicle is not used.

Figure 51 compares the cumulative cost of the base diesel school bus to the base electric bus purchased in 2027. Due to the lower purchase cost and the limited infrastructure requirements of an electric school bus, the TCO of an electric school bus is lower from the time of purchase. This advantage that the electric bus has on the TCO over diesel increases during the life of the vehicle due to the lower operating costs.

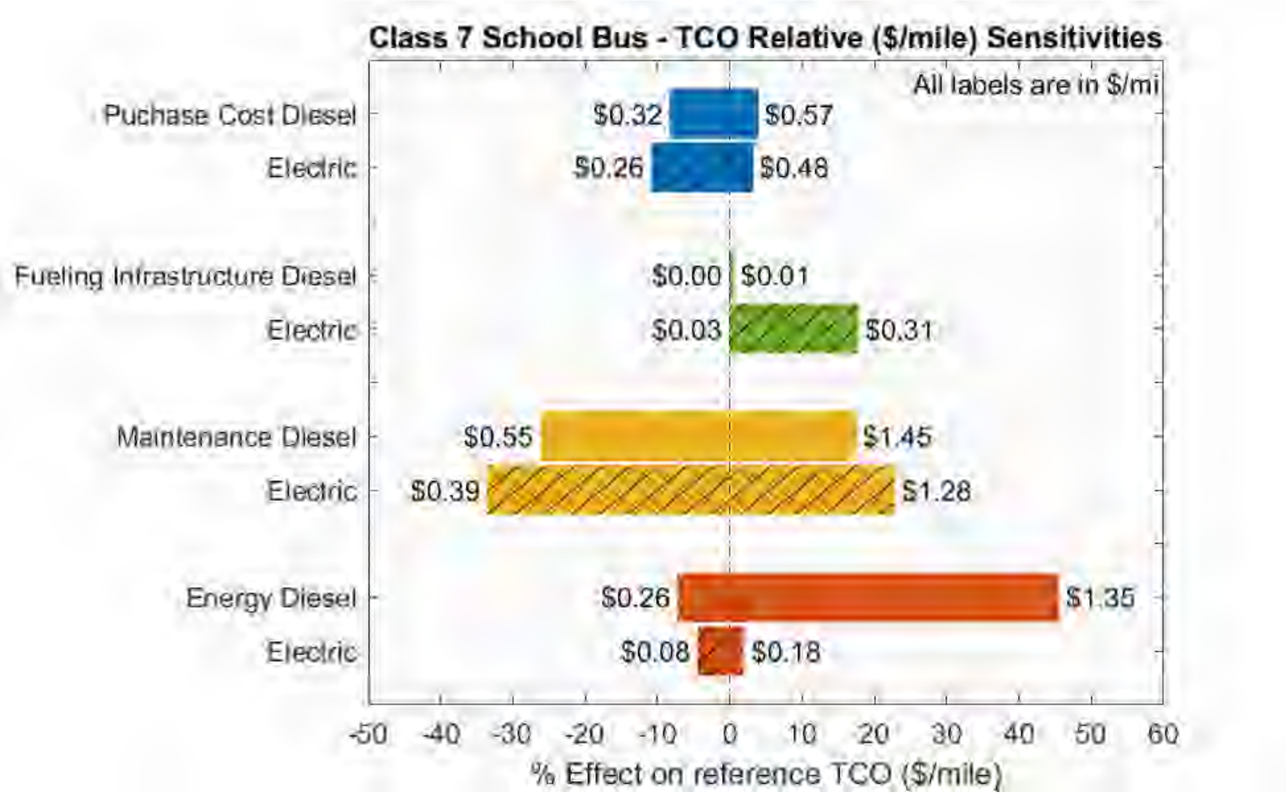


Figure 50: Class 7 School Bus – Sensitivities (listed in Table 30) and their % contribution to reference TCO

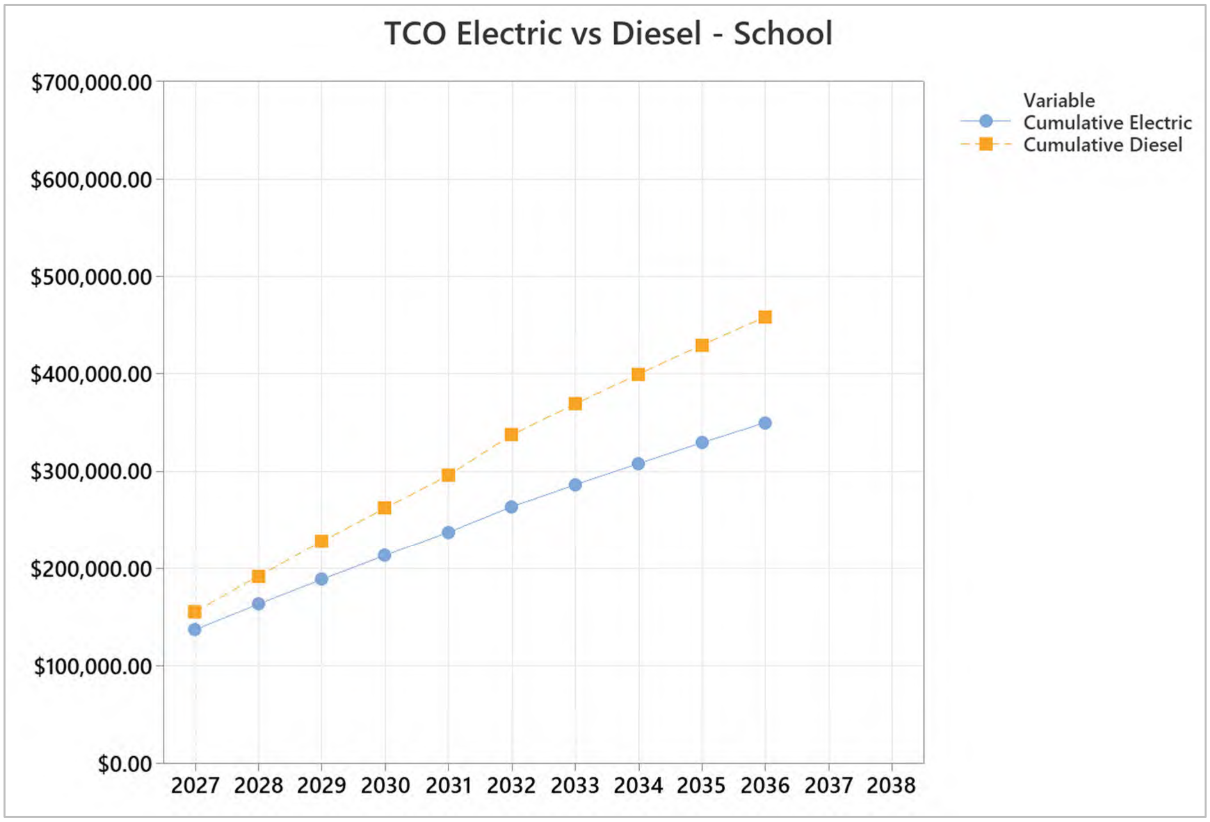


Figure 51: Class 7 school bus - Cumulative cost of ownership for 12 years of ownership (2027-2038)

Figure 52 breaks down the absolute ($/mile) and relative (percentage) contributions of various factors (purchase cost, infrastructure cost, powertrain refresh cost, maintenance, and energy costs) to the TCO for the low reference and high cases of the diesel and electric busses (shown in Table 30).

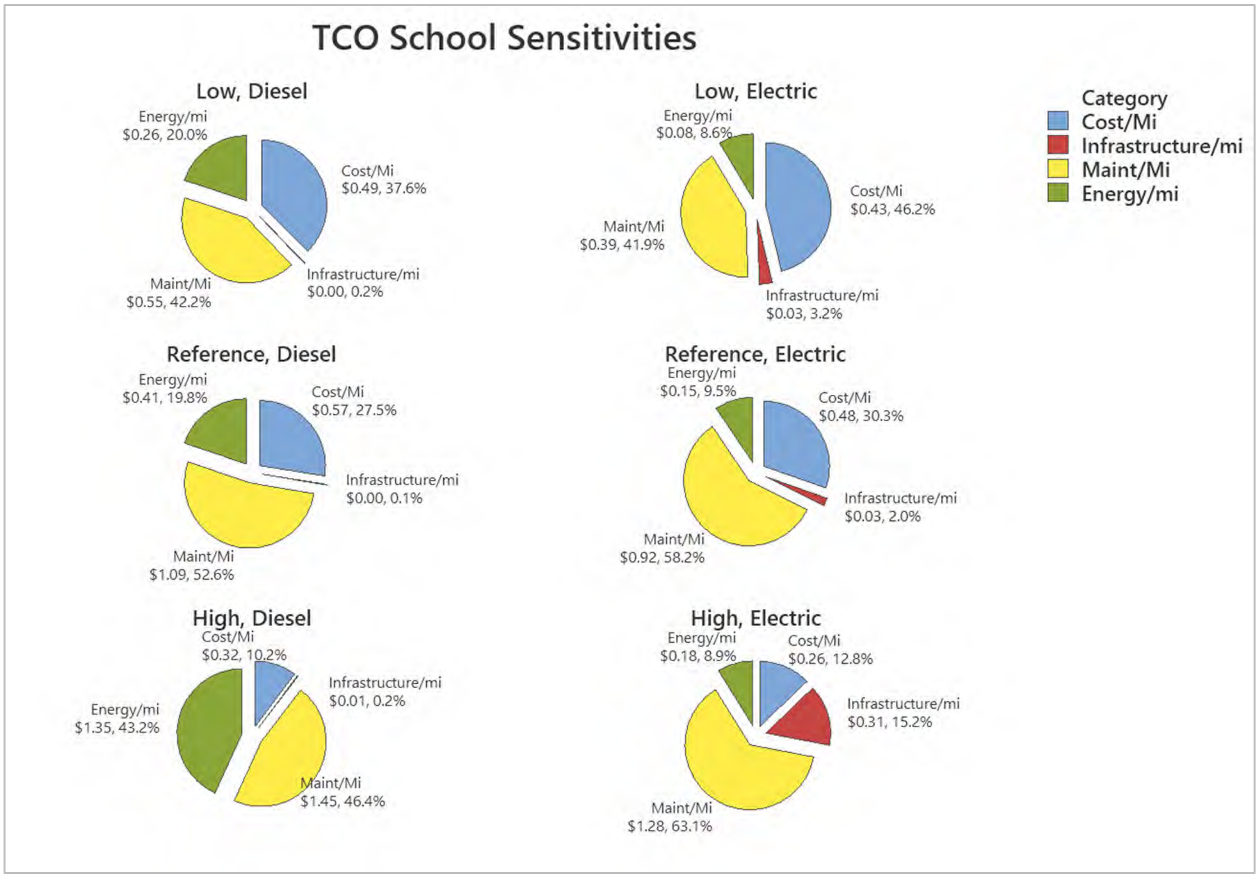


Figure 52: Class 7 school bus: Sensitivities of the total cost of ownership

4.5 Class 5 Shuttle Bus

4.5.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

An example powertrain for a representative class 5 Shuttle bus powertrain in 2021 is shown in Table 32.

Table 32: 2021 class 5 Shuttle Bus, base ICE powertrain example

Engine	6.7-liter V8 Diesel
Power	246 kW (330 HP)
Torque	825 lb-ft
Transmission	6 Speed Automatic SelectShift

The 2021 base powertrain shown in Table 32 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 33 breaks down the engine, transmission,

and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 33: Class 5 shuttle bus - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$8,134	$8,606	$8,643	$10,062
Aftertreatment	$4,881	$4,897	$4,898	$7,161
Transmission	$2,600	$2,600	$2,600	$2,600
Total	$15,615	$16,103	$16,141	$19,823

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 34 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 34: Class 5 shuttle bus - ICE, mild-hybrid, and full-hybrid cost in 2027

Base Cost	$19,823
Sensitivity 1 – Mild Hybrid	$21,093
Sensitivity 2 – Full Hybrid with improved engine	$22,304

4.5.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 35 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with motor cost based on high volume mass-produced motors in the light-duty application. All costs assume high-volume manufacture.

Table 35: Class 5 shuttle bus - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	200	$24,680	$18,040	$13,680
Inverter	223	$814	$732	$659
Onboard charger	50	$2,797	$2,517	$2,266
DC-DC Converter	10	$559	$503	$453
Motor	223	$4,092	$1926	$1444
Gearbox	223	$500	$500	$500
Total Base Case		**$33,442**	**$24,219**	**$19,002**
LFP battery pack		$21,490	$15,708	$11,912
Total Sensitivity 1 Case		**$30,252**	**$21,887**	**$17,234**
Drive unit, light-duty cost		$896	$806	$726
Total Sensitivity 2 Case		**$27,056**	**$20,768**	**$16,515**

4.5.3 Incremental Cost - Diesel Vs Battery Electric, Class 5 Shuttle

Table 36 combines Table 34 and Table 35 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). Assuming high volume manufacture, the cost of a battery-electric powertrain in 2027 is lower than the comparable diesel, mild-hybrid, and full hybrid powertrain in the scenarios evaluated. Factoring in all the different combinations of the diesel engine, level of hybridization, and BEV components, the battery-electric powertrain for a class 5 shuttle bus is estimated to be between $821 and $5,788 cheaper than the diesel counterpart in 2027.

Table 36: Class 5 shuttle bus - ICE Delete Vs BEV add costs – 2027

ICE powertrain description	Diesel	Diesel mild hybrid	Diesel full hybrid
ICE powertrain (delete) cost	$19,823	$21,093	$22,304
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$16,515	$17,234	$19,002

Figure 53 (data from Table 33, Table 34, and Table 35) compares the diesel powertrain cost to BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is higher in 2021 and 2024 but lower in 2027. Powertrain cost parity between diesel and equivalent battery-electric powertrain is reached sometime between 2024 and 2027.

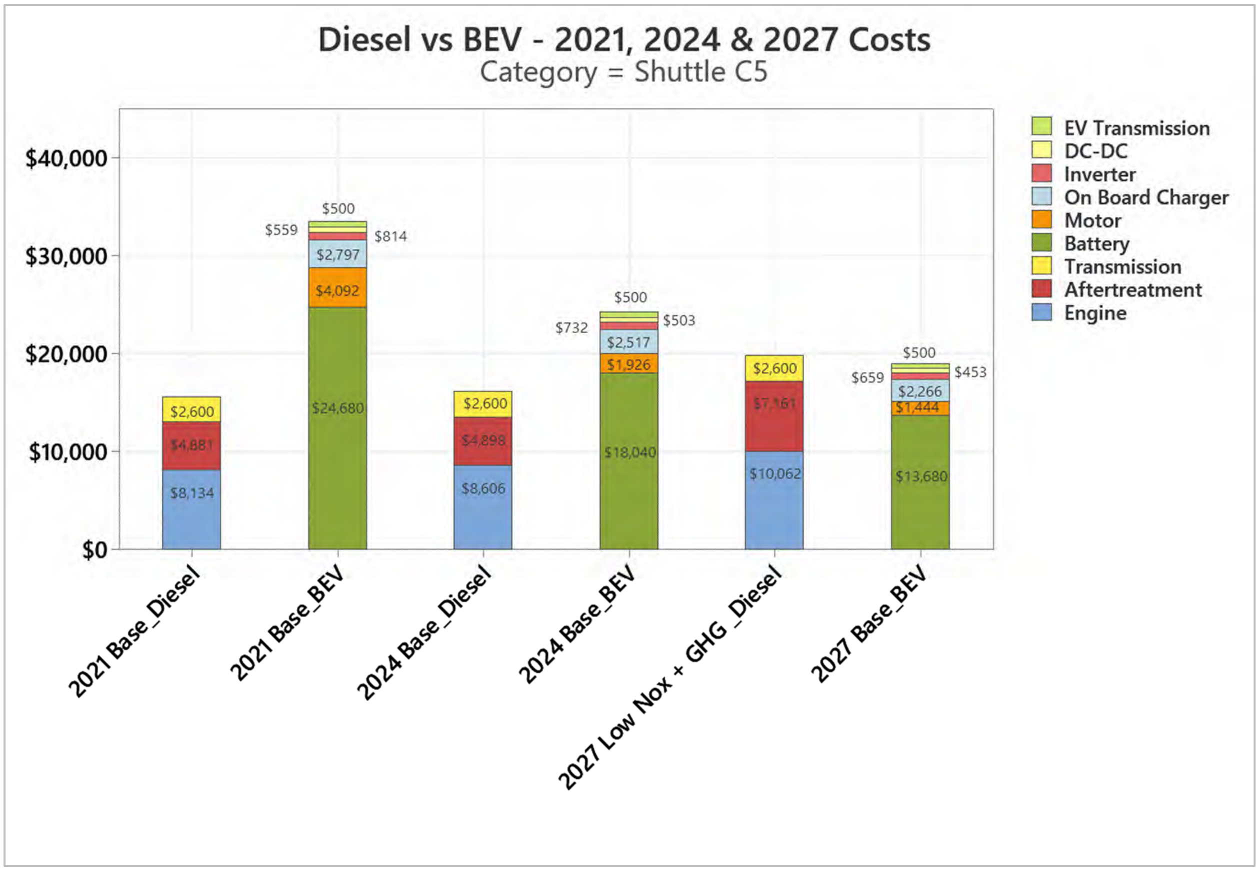


Figure 53: Class 5 shuttle bus – Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.5.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 37 gives the main assumptions used in the calculation of TCO for a class 5 shuttle bus. Table 37 gives more detail and the breakdown of all the costs used in the calculation of the TCO.

Table 37: Class 5 shuttle bus - Main inputs TCO Calculation

Bus Type	Diesel			Electric		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	7			7		
Lifetime mileage (mi)	100,000	200,000	200,000	100,000	200,000	200,000
Fuel consumption (kWh/mile, mpg)	10	7	3	1.30	1.40	2.00
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase price ($)	$43,478	$52,245	$96,079	$43,232	$52,130	$96,089
Refresh ($)	$0	$0	$0	$0	$0	$0
Infrastructure cost ($/miles)	$0.002	$0.003	$0.006	$0.40	$0.199	$0.81
Maintenance ($/mile)	$0.63	$1.24	$1.65	$0.44	$1.05	$1.46

Table 38 gives the final value of the total cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the electric bus is more than 27% lower when compared to the diesel bus

Table 38: Class 5 Shuttle Bus – TCO ($/mile)

TCO	Low	Reference	High
Diesel Transit	$1.21	$1.83	$3.41
Electric Transit	$1.32	$1.58	$2.75

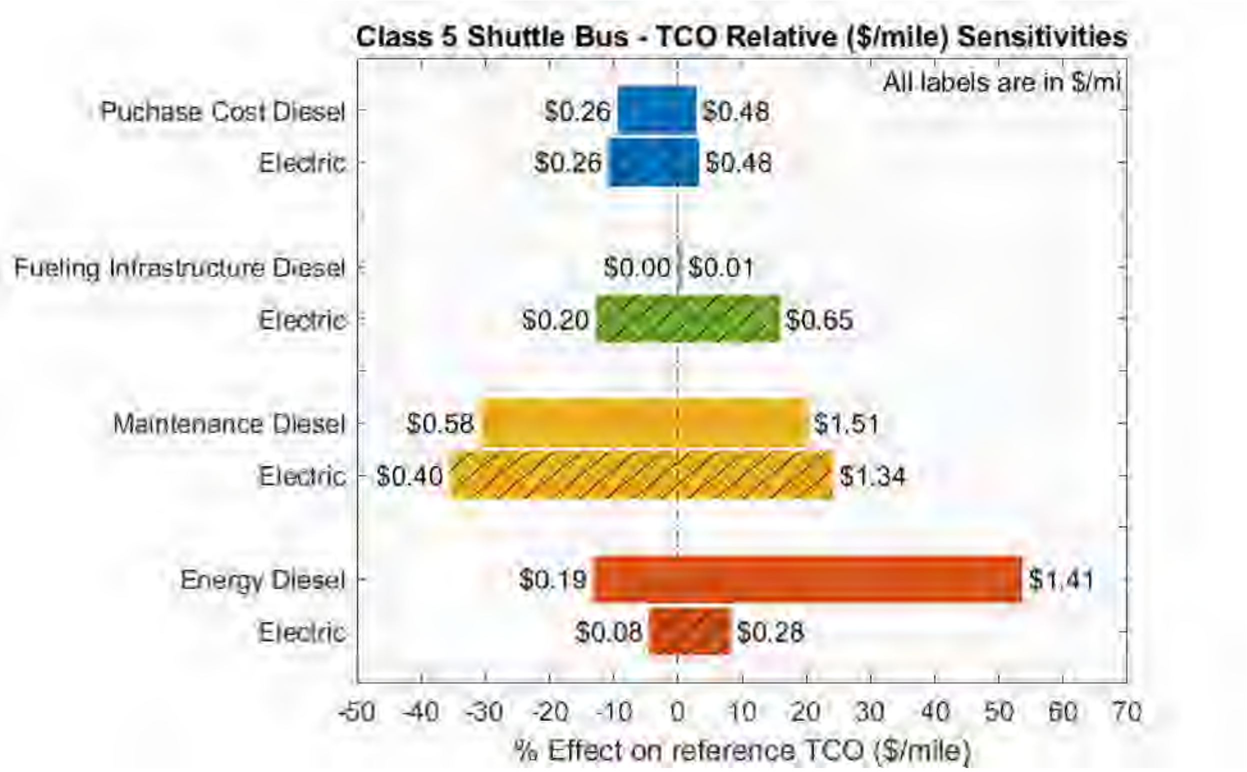


Figure 54: Class 5 shuttle bus – Sensitivities (listed in Table 30) and their % contribution to reference TCO

Figure 54 gives the effect of the variation of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric bus. Maintenance and fuel costs for an electric bus are lower when compared to the equivalent diesel. With the charger costs assumed in the report, it forms a significant part of the total cost of ownership of a BEV. Reducing the charger purchase and installation cost represents an opportunity to significantly reduce the TCO of an electric bus and make switching to a BEV even more attractive.

Figure 55 compares the cumulative cost of ownership of the reference diesel class 5 shuttle to the reference BEV purchased in 2027. The BEV is marginally (about $1000) more expensive to buy. The charging infrastructure that needs to be set up for the BEV adds to this cost. The cumulative TCO parity between the diesel and BEV is reached at the 3-year ownership mark (2029) due to the significantly lower operating cost of the BEV.

Figure 56 breaks down the absolute ($/mile) and relative (percentage) contributions of various factors (purchase cost, infrastructure cost, powertrain refresh cost, maintenance, and energy costs) to the TCO for the low reference and high cases of the diesel and electric class 5 delivery truck. The charging infrastructure accounts for a significant fraction (23.2%-27.2%) of the TCO of a BEV. The development of a robust DC fast-charging network will reduce the amount of spending that fleets have to make to install captive chargers reducing the TCO significantly speeding the adoption of BEVs.

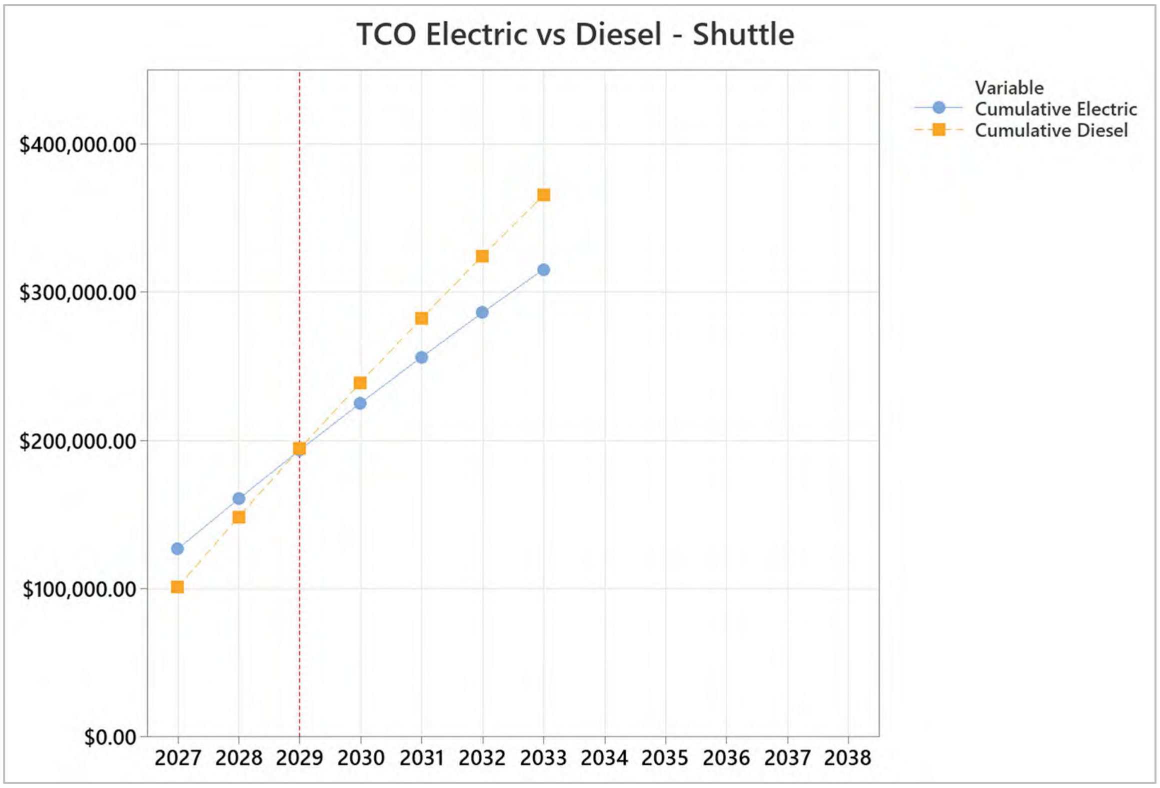


Figure 55: Class 5 shuttle bus - Cumulative cost of ownership for 12 years of ownership (2027-2038)

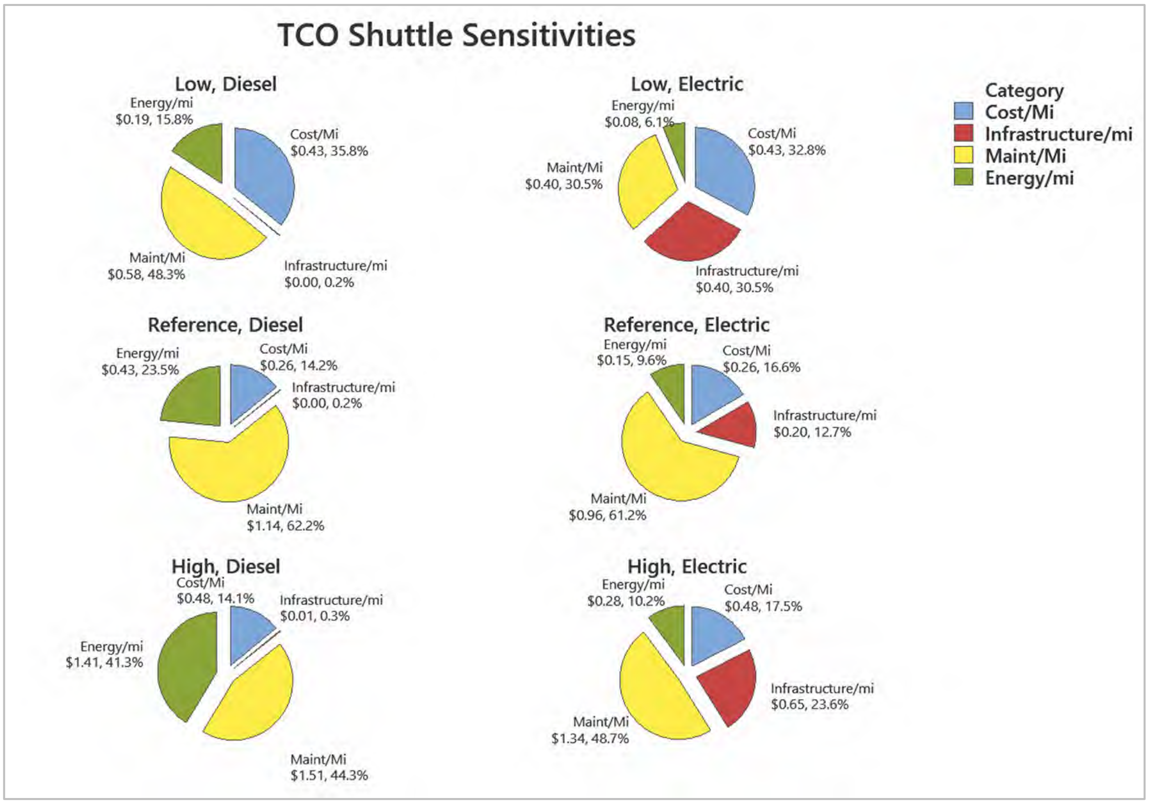


Figure 56: Class 5 shuttle bus: Sensitivities of the total cost of ownership

4.6 Class 3 Delivery Van

4.6.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

An example powertrain for a representative class 3 delivery van powertrain in 2021 is shown in Table 39.

Table 39: 2021 class 3 delivery van, base ICE powertrain example

Engine	3.2 L – I5 Diesel
Power	138 kW (185 HP)
Torque	350 lb-ft
Transmission	6 Speed Automatic SelectShift

The 2021 base powertrain shown in Table 39 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 40 breaks down the engine, transmission, and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 40: Class 3 Delivery Van - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$3,796	$4,308	$4,348	$5,768
Aftertreatment	$4,338	$4,355	$4,356	$6,618
Transmission	$2,600	$2,600	$2,600	$2,600
Total	$10,734	$11,263	$11,304	$14,986

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 41 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 41: Class 3 Delivery Van - ICE, mild-hybrid, and full-hybrid cost in 2027

Base Cost	$14,986
Sensitivity 1 – Mild Hybrid	$16,256
Sensitivity 2 – Full Hybrid with improved engine	$17,025

4.6.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 42 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with multiple smaller motors, the costs based on motors mass-produced for light-duty application. All costs assume high-volume manufacture similar to what OEMs have in the light-duty space.

Table 42: Class 3 Delivery Van - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	100	$12,340	$9,020	$6,840
Inverter	138	$504	$453	$408
Onboard charger	25	$1,399	$1,259	$1,133
DC-DC Converter	10	$559	$503	$453
Motor	138	$2,532	$1,192	$894
Gearbox	138	$500	$500	$500
Total Base Case		**$17,834**	**$12,927**	**$10,228**
LFP battery pack		$10,745	$7,854	$5,956
Total Sensitivity 1 Case		**$16,239**	**$11,761**	**$9,343**
Drive unit, light-duty cost		$555	$499	$449
Total Sensitivity 2 Case		**$14,261**	**$11,069**	**$8,899**

4.6.3 Incremental Cost - Diesel Vs Battery Electric, Class 3 Delivery Van

Table 43 combines Table 41 and Table 42 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). The incremental cost of BEVs in 2027 is expected to be lower than diesel, mild-hybrid, and full hybrid buses for all scenarios evaluated. . Factoring in all the different combinations of the diesel engine, level of hybridization, and BEV components, the battery-electric powertrain for a class 3 delivery van is estimated to be between $4,759 and $8,126 cheaper than the diesel counterpart in 2027.

Table 43: Class 3 Delivery Van - ICE Delete Vs BEV add costs – 2027

ICE powertrain description	Diesel	Diesel mild hybrid	Diesel full hybrid
ICE powertrain (delete) cost	$14,986	$16,256	$17,025
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$8,899	$9,343	$10,228

Figure 57 compares the base Diesel powertrain cost to Base BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is lower today in 2021 with the gap widening in 2024 and 2027. (Data from Table 40, Table 41, and Table 42).

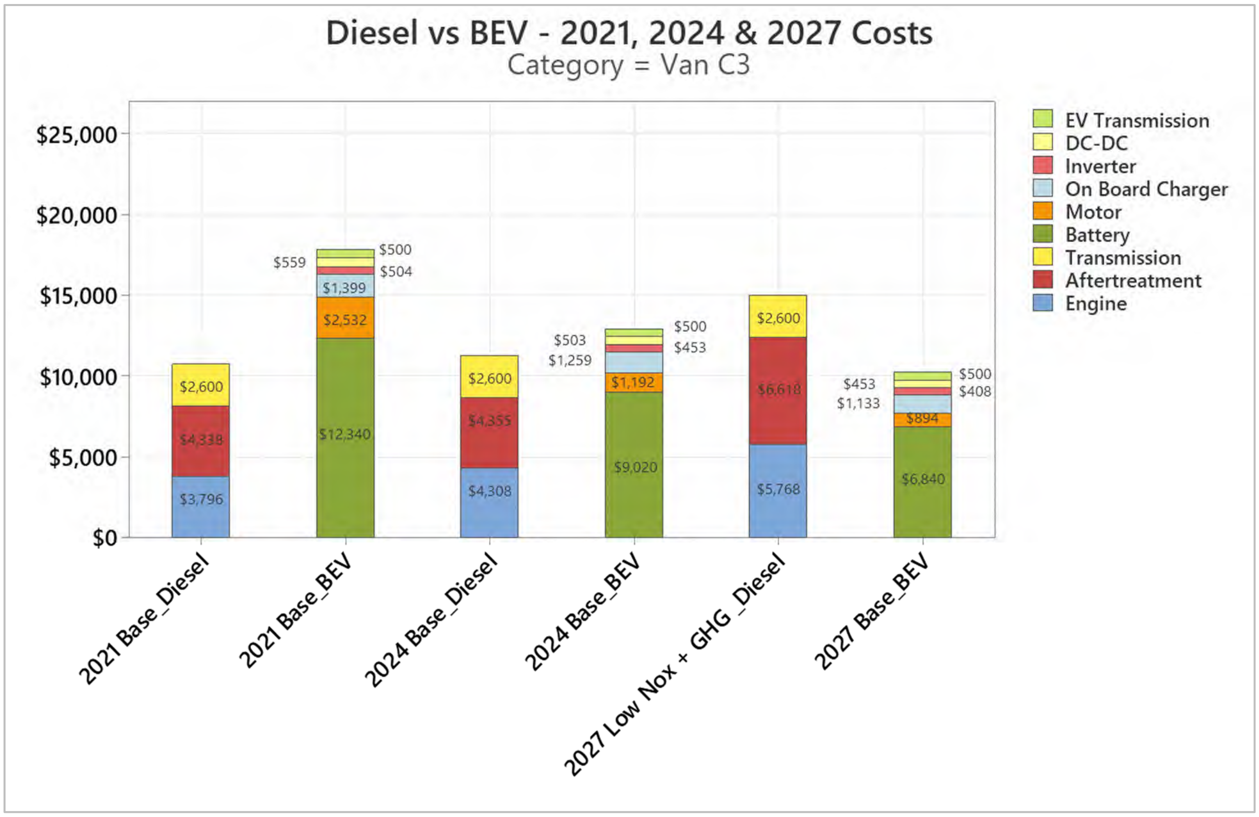


Figure 57: Class 3 delivery van– Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.6.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 23 gives the main assumptions used in the calculation of TCO of transit busses. Table 44 gives the breakdown of all the costs used in the calculation of the TCO.

Table 44: Class 3 Delivery Van- Main inputs TCO Calculation

Bus Type	Diesel			Electric		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	10	11	11	10	11	11
Lifetime mileage (mi)	124,350	136,785	231,000	124,350	136,785	231,000
Fuel consumption (kWh/mile, mpg)	20	15	12	0.70	0.70	1.37
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.070	$0.12	$0.15
Purchase price ($)	$35,000	$44,748	$50,000	$35,278	$44,428	$51,834
Refresh ($)	$0	$0	$0	$0	$0	$0
Infrastructure cost ($/miles)	$0.001	$0.001	$0.001	$0.058	$0.05	$0.567
Maintenance ($/mile)	$0.13	$0.21	$0.24	$0.07	$0.15	$0.19

Table 45 gives the final value of the total cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the electric class 3 delivery van is 22.7 % lower when compared to the comparable diesel vehicle.

Table 45: Class 3 Delivery Van– TCO ($/mile)

TCO	Low	Reference	High
Diesel Transit	$0.49	$0.70	$0.77
Electric Transit	$0.45	$0.58	$1.13

Figure 58 gives the effect of the variation (low to high) of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric delivery van shown in Figure 59.

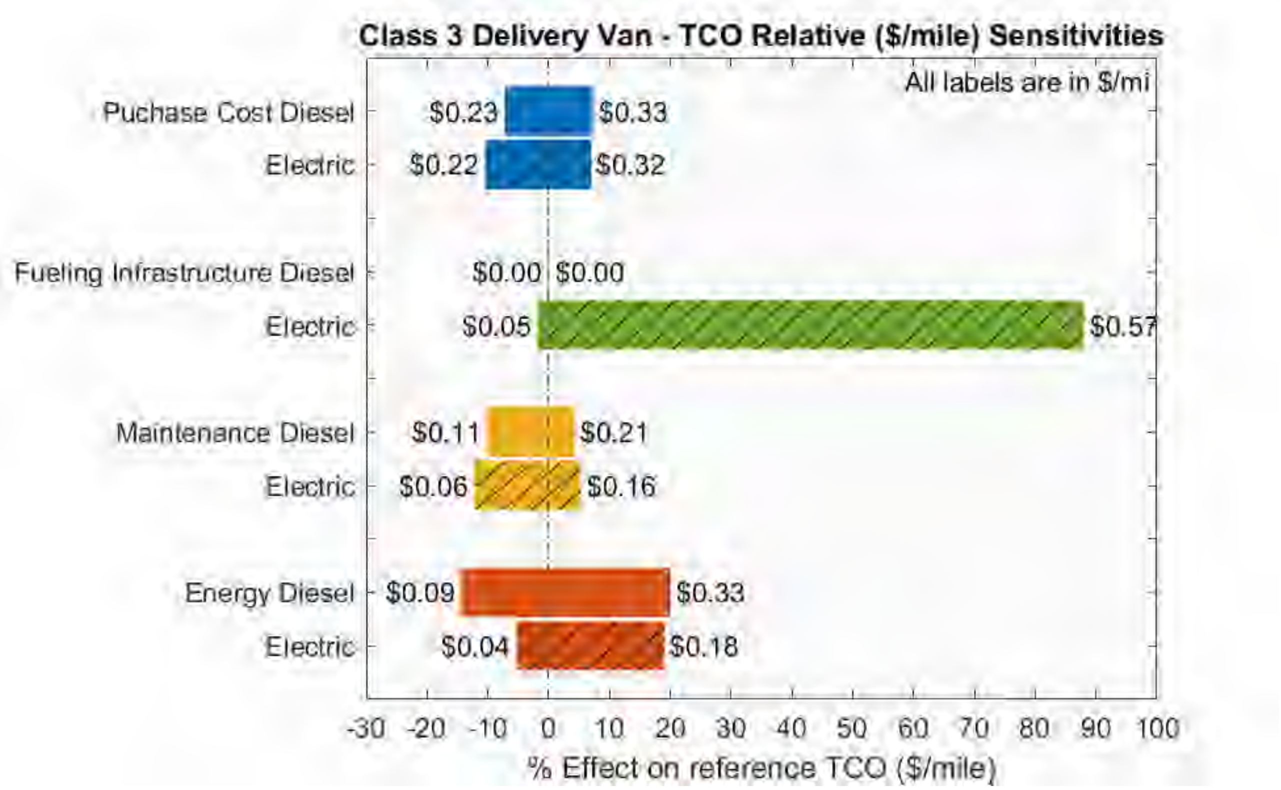


Figure 58: Class 3 Delivery Van – Sensitivities (listed in Table 30) and their % contribution to reference TCO

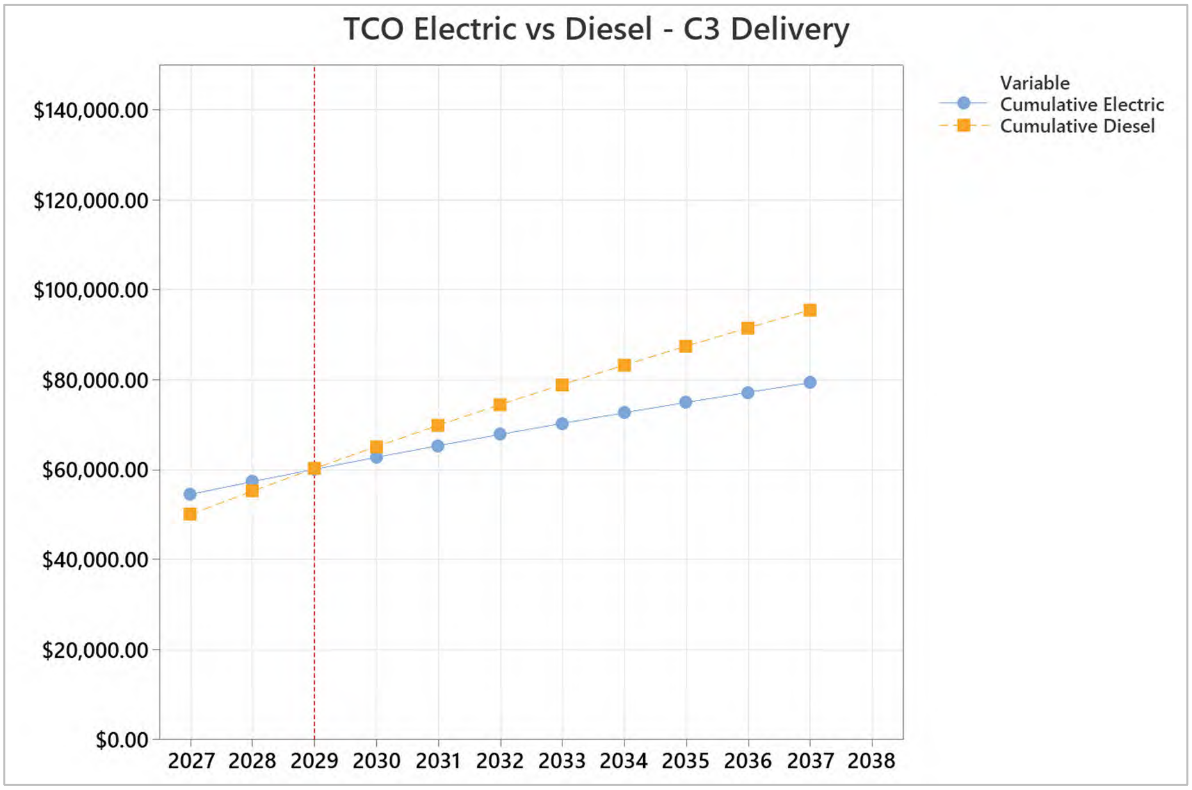


Figure 59: Class 5 shuttle bus - Cumulative cost of ownership for 12 years of ownership (2027-2038)

Figure 59 compares the cumulative cost of the reference class 3 diesel van to the reference electric van purchased in 2027. Even with the extra infrastructure costs incurred (as per our report) by buying electric class 3 delivery vans, due to the lower purchase price, running and maintenance costs, the cumulative TCO of owning a class 3 electric delivery van (bought in 2027) is already lower than the diesel counterpart at the end of the first year of ownership.

Figure 60 breaks down the absolute ($/mile) and relative (percentage) contributions of various factors (purchase cost, infrastructure cost, powertrain refresh cost, maintenance, and energy costs) to the TCO for the low reference and high cases of the diesel and electric class 3 delivery van. From Figure 60, it can be seen the charging infrastructure accounts for a significant fraction (55.4 to 55.9%) of the TCO of a BEV. At the low and high end of the charging infrastructure cost assumption, it can have a huge impact, -40% to +80% of the reference TCO. The development of a robust DC fast-charging network will reduce the amount of spending that fleets have to make to install captive chargers reducing the TCO significantly speeding the adoption of BEVs.

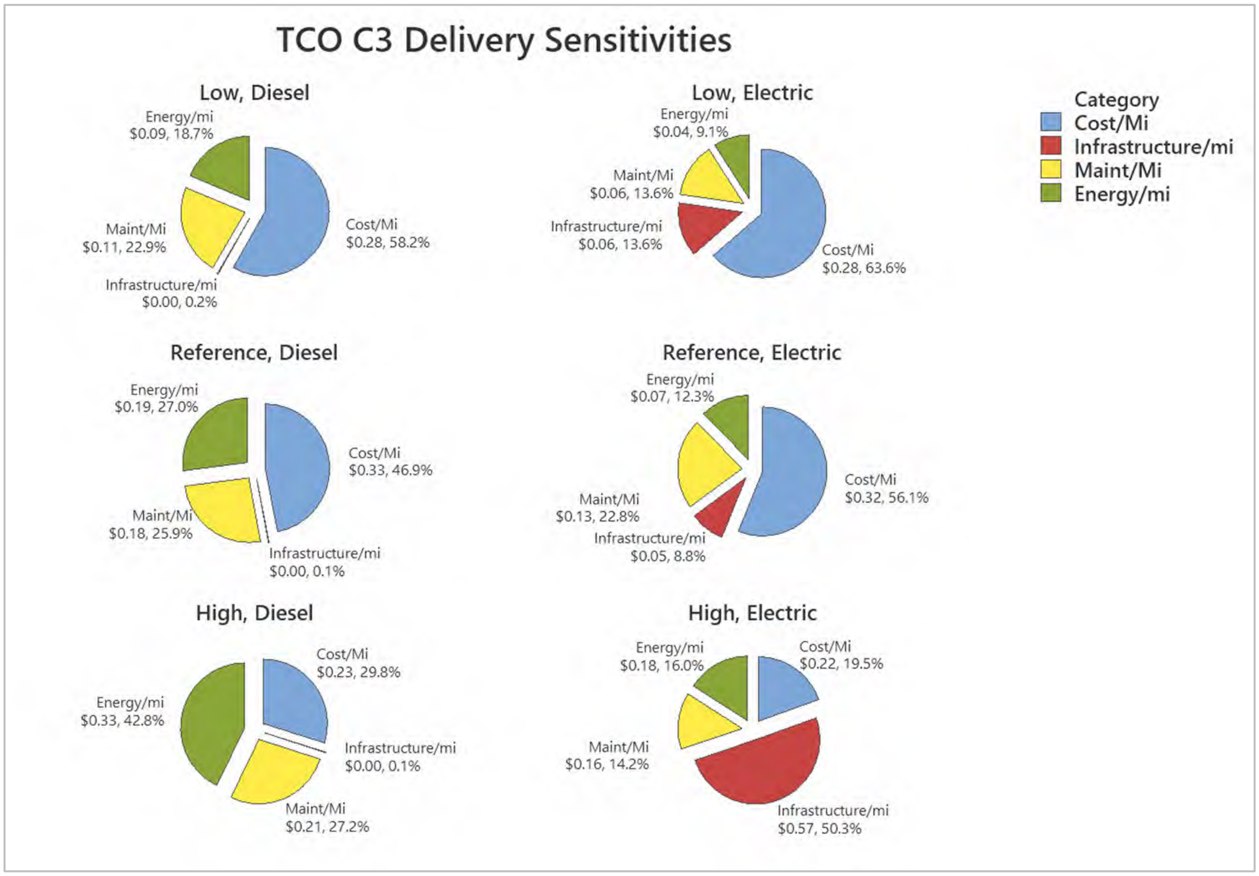


Figure 60: Class 5 shuttle bus: Sensitivities of the total cost of ownership

4.7 Class 5 Delivery Truck

4.7.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

An example powertrain for a representative class 5 delivery truck powertrain in 2021 is shown in Table 46.

Table 46: 2021 class 5 Delivery Truck, base ICE powertrain example

Engine	6.7L Powerstroke
Power	223 kW (300 hp)
Torque	825 lb·ft
Transmission	TorqShift 6 Speed

The 2021 base powertrain shown in Table 46 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 47 breaks down the engine, transmission, and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 47: Class 5 Delivery Truck - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$8,134	$8,606	$8,643	$10,062
Aftertreatment	$4,881	$4,897	$4,898	$7,161
Transmission	$2,600	$2,600	$2,600	$2,600
Total	$15,615	$16,103	$16,141	$19,823

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 48 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 48: Class 5 Delivery Truck - ICE, mild-hybrid, and full-hybrid cost in 2027

Base Cost	$19,823
Sensitivity 1 – Mild Hybrid	$21,093
Sensitivity 2 – Full Hybrid with improved engine	$22,304

4.7.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 49 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with multiple smaller motors, the costs based on motors mass-produced for light-duty application. All costs assume high-volume manufacture similar to what OEMs have in the light-duty space.

Table 49: Class 5 Delivery Truck - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	100	$12,340	$9,020	$6,840
Inverter	223	$814	$732	$659
Onboard charger	25	$1,399	$1,259	$1,133
DC-DC Converter	10	$559	$503	$453
Motor	223	$4,092	$1,926	$1,444
Gearbox	223	$500	$500	$500
Total Base Case		**$19,704**	**$13,940**	**$11,029**
LFP battery pack		$10,745	$7,854	$5,956
Total Sensitivity 1 Case		**$18,109**	**$12,774**	**$10,145**
Drive unit, light-duty cost		$896	$806	$726
Total Sensitivity 2 Case		**$14,913**	**$11,655**	**$9,427**

4.7.3 Incremental Cost - Diesel Vs Battery Electric, Class 5 Delivery Truck

Table 50 combines Table 48 and Table 49 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). Assuming high volume manufacture, the incremental cost of BEV powertrain in 2027 is lower than diesel, mild-hybrid, and full hybrid buses for all scenarios. Considering the different combinations of the diesel engine, level of hybridization, and BEV components, the powertrain of the Class 5 delivery truck is estimated to be between $8,794 and $10,948 cheaper than the diesel counterpart

Table 50: Class 5 Delivery Truck - ICE Delete Vs BEV add costs – 2027

ICE powertrain description	**Diesel**	**Diesel mild hybrid**	**Diesel full hybrid**
ICE powertrain (delete) cost	$19,823	$21,093	$22,304
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$9,427	$10,145	$11,029

Figure 61 compares the base Diesel powertrain cost to Base BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is higher in 2021 and 2024 but lower in 2027. (Data from Table 47, Table 48, and Table 49). For the battery size assumed in the study (100 kWh), the cost of the BEV powertrain in 2021 is lower than the comparable diesel powertrain. With the falling cost of electrification components and increasing cost of ICE powertrain to meet future fuel economy and emission standards, this gas increases from 2021 to 2027.

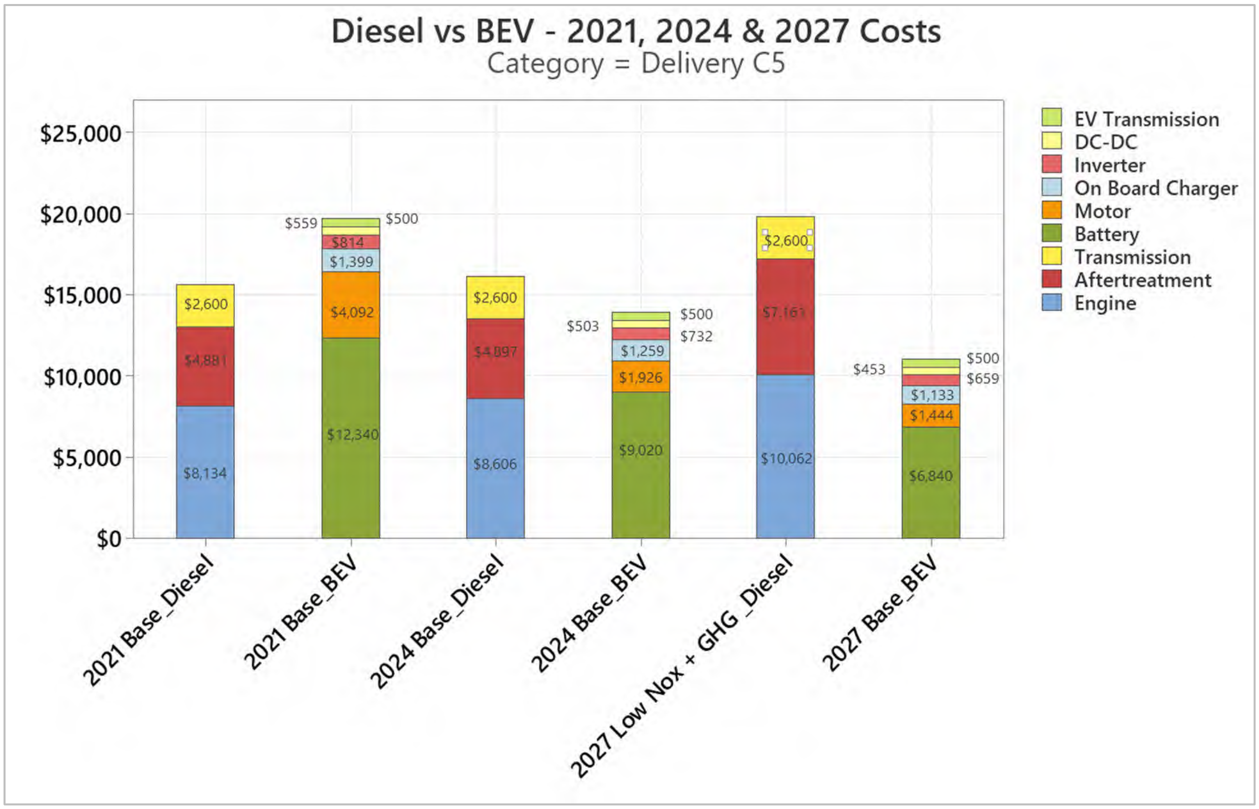


Figure 61: Class 5 Delivery Truck – Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.7.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 51 gives the main assumptions used in the calculation of TCO of class 5 delivery trucks and gives the breakdown of all the costs used in the calculation of the TCO.

Table 51: Class 5 Delivery Truck - Main inputs TCO Calculation

Bus Type	**Diesel**			**Electric**		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	10			10		
Lifetime mileage (mi)	124,350	124,350	148,000	124,350	124,350	148,000
Fuel consumption (kWh/mile, mpg)	12	7	6	0.75	1.00	1.50
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase price ($)	$45,000	$58,270	$72,912	$38,118	$51,065	$64,949
Refresh ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Infrastructure cost ($/miles)	$0.001	$0.002	$0.003	$0.06	$0.06	$0.88
Maintenance ($/mile)	$0.17	$0.17	$0.22	$0.09	$0.12	$0.18

Table 52 gives the final value of the cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the battery-electric class 5 delivery vehicle is estimated to be more than 36% lower when compared to the equivalent diesel-powered vehicle in 2027.

Table 52: Class 5 Delivery Truck – TCO ($/mile)

TCO	**Low**	**Reference**	**High**
Diesel Transit	$0.67	$1.03	$1.36
Electric Transit	$0.49	$0.68	$1.68

Figure 62 gives the effect of the variation (low to high) of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric delivery truck shown in Figure 63. It can be seen that the charging infrastructure assumption introduces the largest swing in the reference TCO value.

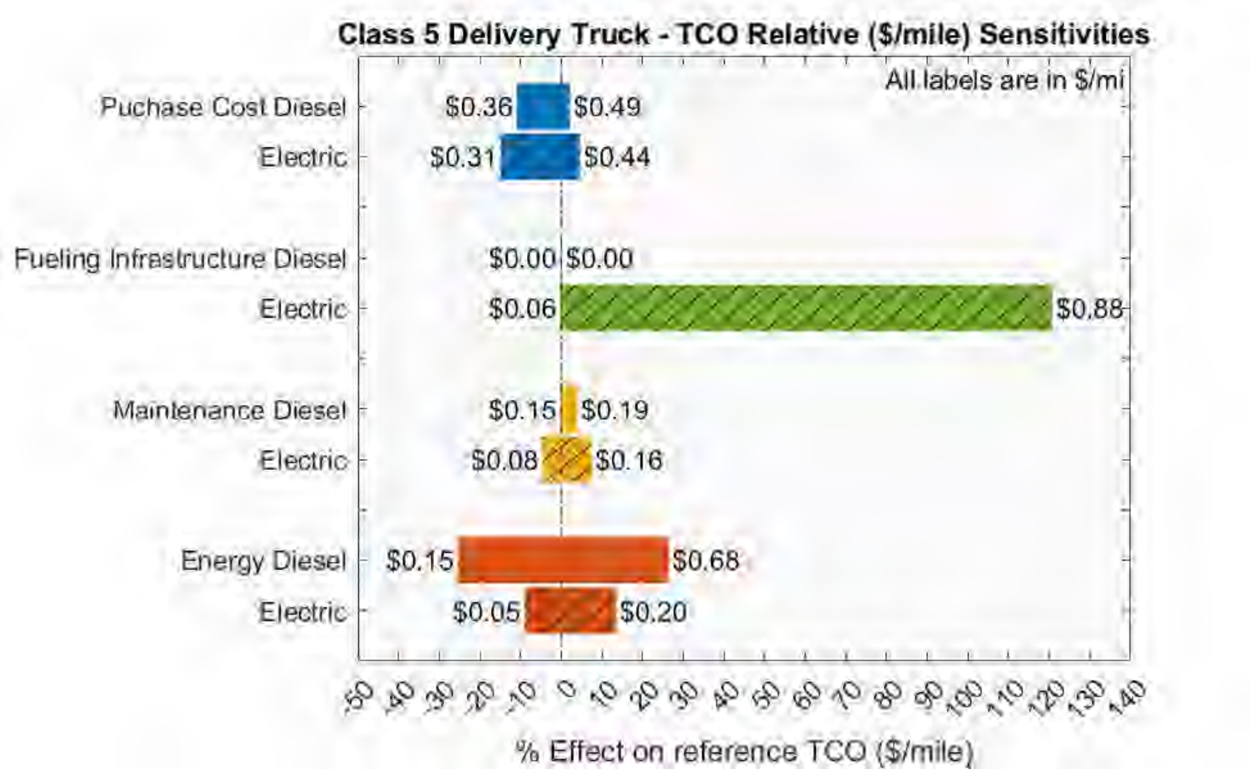


Figure 62: Class 5 Delivery Truck – Sensitivities (listed in Table 30) and their % contribution to reference TCO

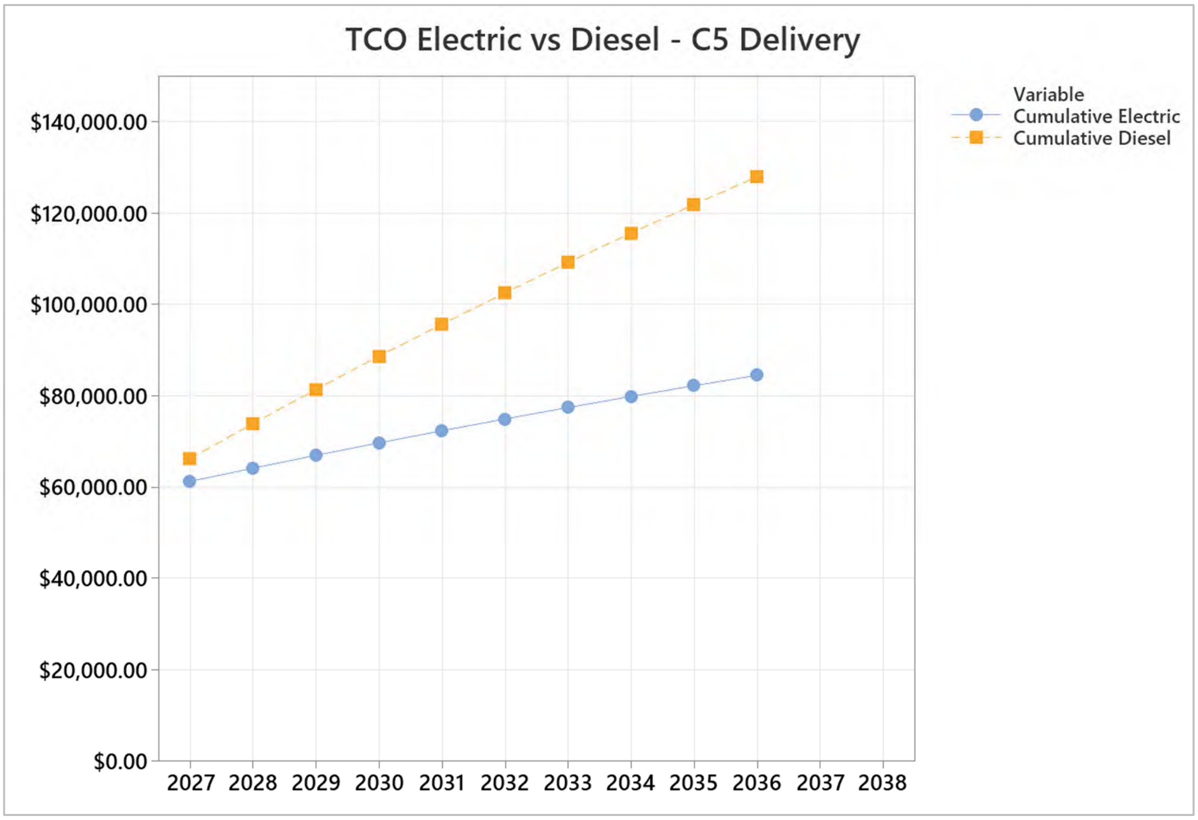


Figure 63: Class 5 Delivery Truck - Cumulative cost of ownership for 12 years of ownership (2027-2038)

Figure 63 compares the cumulative TCO of a Battery electric class 5 delivery truck to the diesel alternative purchased in 2025. Even with the extra infrastructure costs incurred by buying BEVs, due to the lower purchase price, operating costs, the cumulative TCO of owning a BEV (bought in 2027) is already lower than the diesel counterpart at the end of the first year of ownership and this gap widens over the life of the vehicles. Figure 64 breaks down the absolute ($/mile) and relative (percentage) contributions of various factors (purchase cost, infrastructure cost, powertrain refresh cost, maintenance, and energy costs) to the TCO for the low reference and high cases of the diesel and electric delivery truck. Depending on the charging infrastructure assumption, its contribution to the TCO varies from 10.7% (low case) to 42% (high case). The development of a robust public DC fast-charging network or subsidies to set up charging infrastructure will reduce the amount of spending that fleets have to make to install captive chargers reducing the TCO significantly speeding the adoption of BEVs.

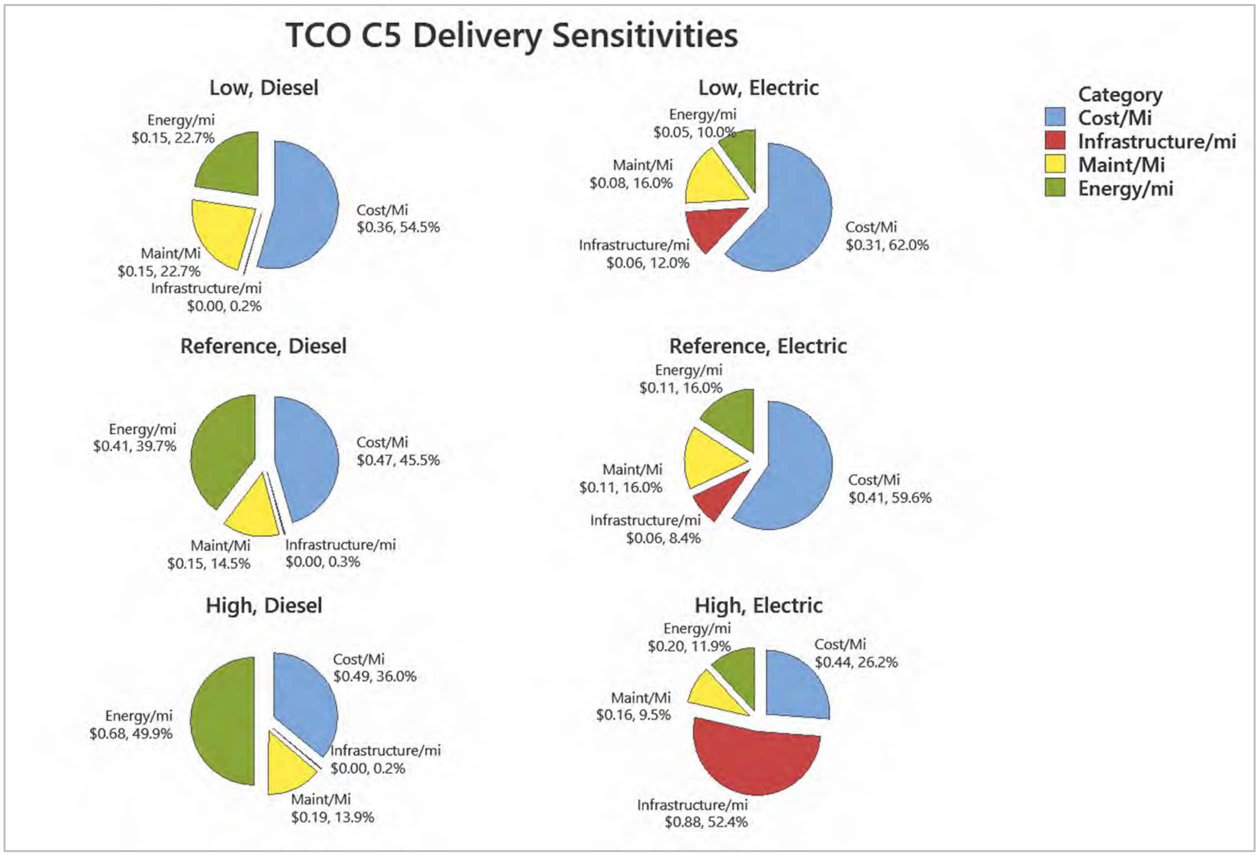


Figure 64: Class 5 Delivery Truck: Sensitivities of the total cost of ownership.

4.8 Class 7 Delivery Truck

4.8.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

A representative diesel powertrain for a class 7 delivery truck in 2021 is shown in Table 53.

Table 53: 2021 Class 7 Delivery Truck, base ICE powertrain example

Engine	Cummins B6.7
Power	190 kW (255 hp)
Torque	750 lb.ft
Transmission	Allison 3000

The 2021 base powertrain shown in Table 53 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 54 breaks down the engine, transmission, and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 54: Class 7 Delivery Truck - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$6,508	$6,979	$7,016	$8,435
Aftertreatment	$4,338	$4,355	$4,356	$6,618
Transmission	$7,677	$7,677	$9,878	$9,878
Total	$18,523	$19,011	$21,250	$24,931

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 55 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 55: Class 7 Delivery Truck - ICE, mild-hybrid and full-hybrid cost in 2027

Base Cost	$24,931
Sensitivity 1 – Mild Hybrid	$26,201
Sensitivity 2 – Full Hybrid with improved engine	$28,142

4.8.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 56 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with multiple smaller motors, the costs based on motors mass-produced for light-duty application. All costs assume high-volume manufacture similar to what OEMs have in the light-duty space.

Table 56: Class 7 Delivery Truck - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	150	$18,510	$13,530	$10,260
Inverter	190	$693	$624	$562
Onboard charger	40	$2,238	$2,014	$1,813
DC-DC Converter	10	$559	$503	$453
Motor	190	$3,486	$1,641	$1,231
Gearbox	190	$500	$500	$500
Total Base Case		**$25,987**	**$18,812**	**$14,818**
LFP battery pack	150	$16,118	$11,781	$8,934
Total Sensitivity 1 Case		**$23,594**	**$17,063**	**$13,492**
Drive unit, light-duty cost	190	$763	$687	$618
Total Sensitivity 2 Case		**$20,871**	**$16,110**	**$12,879**

4.8.3 Incremental Cost - Diesel Vs Battery Electric, Class 7 Delivery Truck

Table 57 combines Table 55 and Table 56 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). Assuming high volume manufacture, the incremental cost of BEVs in 2027 is lower than diesel, mild-hybrid, and full hybrid buses for all scenarios. Considering the different combinations of the diesel engine, level of hybridization, and BEV components, the powertrain of the class 7 delivery truck is estimated to be between $10,114 and $15,263 cheaper than the diesel counterpart.

Table 57: Class 7 Delivery Truck - ICE Delete Vs BEV add costs – 2027

ICE powertrain description	Diesel	Diesel mild hybrid	Diesel full hybrid
ICE powertrain (delete) cost	$24,931	$26,201	$28,142
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$12,879	$13,492	$14,818

Figure 65 compares the base Diesel powertrain cost to Base BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is higher in 2021 and 2024 but lower in 2027. (Data from Table 54, Table 55, Table 56, Table 33, Table 34, and Table 35) Powertrain cost parity between diesel and battery electric is reached sometime between 2024 and 2027.

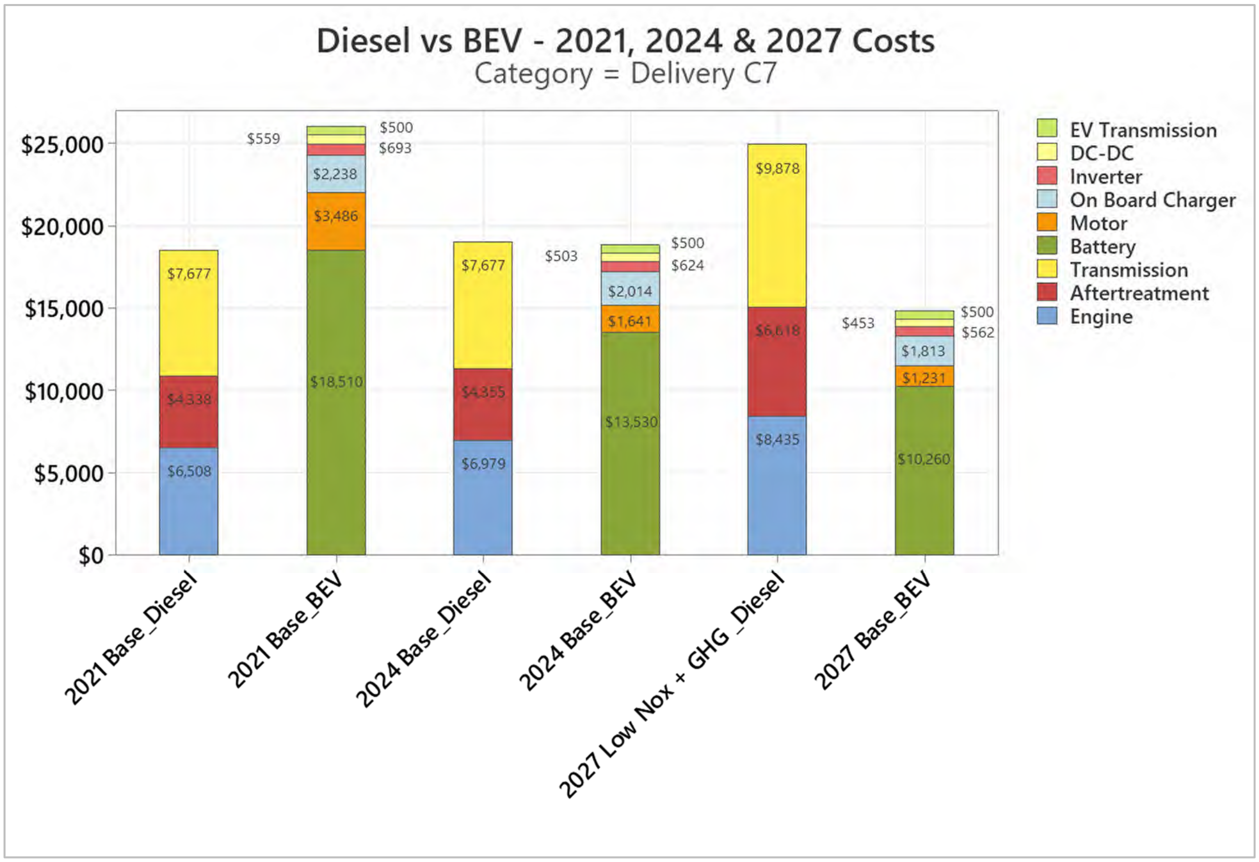


Figure 65: Class 7 Delivery Truck – Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.8.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 58 gives the breakdown of all the costs used in the calculation of the TCO.

Table 58: Class 7 Delivery Truck - Main inputs TCO Calculation

Bus Type	Diesel	Electric

Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)		10			10	
Lifetime mileage (mi)	250,000	285,710	360,000	250,000	285,710	360,000
Fuel consumption (kWh/mile, mpg)	10	8	6	1.50	2.00	2.50
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase price ($)	$50,000	$86,270	$95,749	$41,825	$78,118	$87,611
Refresh ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Infrastructure cost ($/miles)	$0.002	$0.002	$0.003	$0.03	$0.14	$0.36
Maintenance ($/mile)	$0.29	$0.29	$0.29	$0.15	$0.20	$0.23

Table 59 gives the final value of the cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the electric bus is more than 27% lower when compared to the diesel bus

Table 59: Class 7 Delivery Truck – TCO ($/mile)

TCO	Low	Reference	High
Diesel Transit	$0.64	$0.92	$1.20
Electric Transit	$0.42	$0.80	$1.14

Figure 66 gives the effect of the variation of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric truck shown in Figure 67.

Figure 66: Class 7 Delivery Truck – Sensitivities (listed in Table 30) and their % contribution to reference TCO

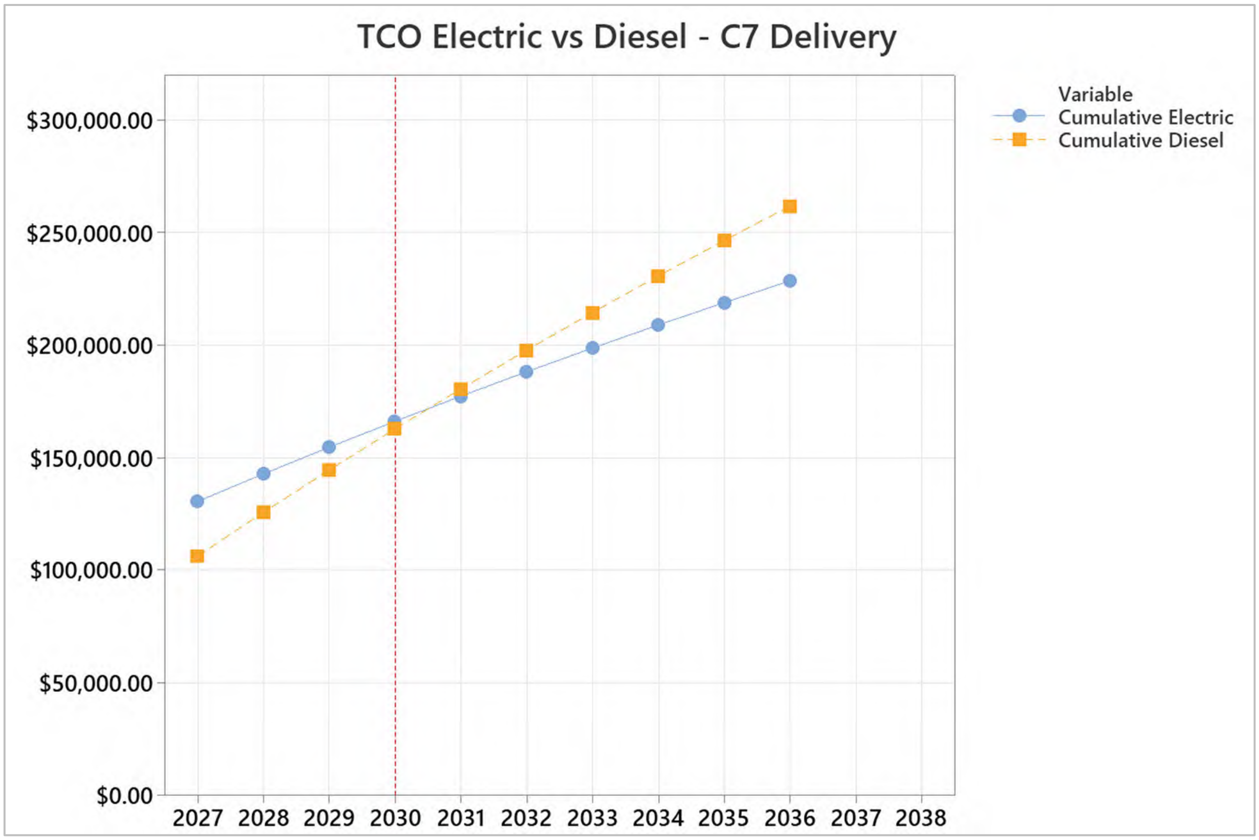


Figure 67: Class 7 Delivery Truck - Cumulative cost of ownership for 12 years of ownership (2027-2038)

Figure 68 compares the total cost of ownership for various sensitivities for diesel and battery electric class 7 delivery trucks.

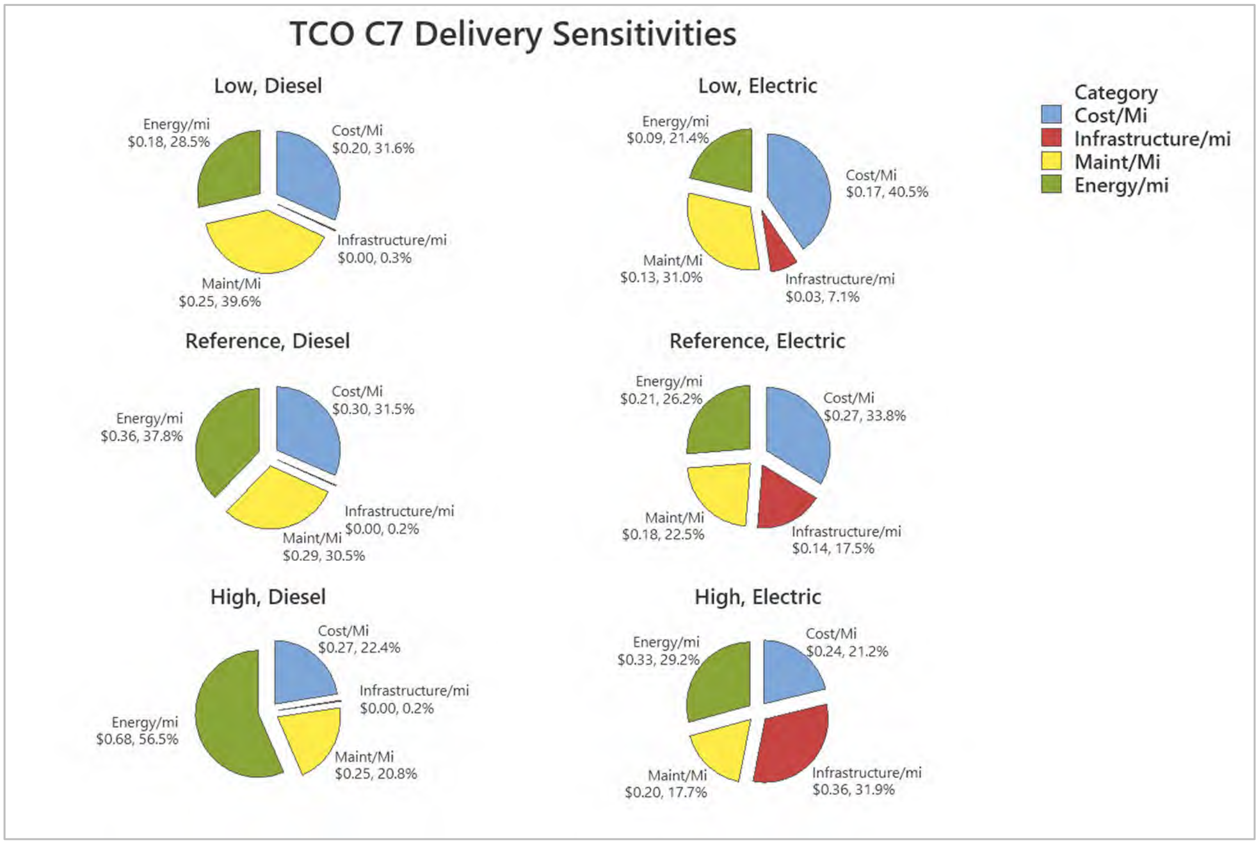


Figure 68: Class 7 Delivery Truck: Sensitivities of the total cost of ownership

4.9 Class 8 Refuse Truck

4.9.1 IC Engine Vehicle Powertrain Cost (Delete Cost)

An example powertrain for a representative class 8 refuse truck bus powertrain in 2021 is shown in Table 60.

Table 60: 2021 Class 8 Refuse Truck, base ICE powertrain example

Engine	Cummins L9 - Transit bus (diesel)
Power	260 kW (350 HP)
Torque	925-1150 lb-ft
Transmission	Allison B400R (Automatic)

The 2021 base powertrain shown in Table 60 consisting of a diesel engine with an automatic transmission will need to be updated with improved engine, transmission, and aftertreatment technologies to meet 2027 (Phase II GHG and the 2027 Low NOx) legislation. Table 61 breaks down the engine, transmission,

and aftertreatment system cost for a conventional diesel ICE engine in 2021, 2024, and 2027 to meet the Phase II greenhouse gas rule and the 2027 Low NOx rule.

Table 61: Class 8 Refuse Truck - ICE powertrain cost in 2021, 2024 and 2027

	2021	2024	2027	2027 Low NOx
Engine	$10,303	$10,775	$10,812	$13,013
Aftertreatment	$6,975	$6,992	$6,993	$9,455
Transmission	$15,628	$15,628	$17,829	$17,829
Total	$32,906	$33,395	$35,634	$40,297

Along with the base conventional diesel powertrain, two alternative ICE powertrains are evaluated for calculating the total cost of ownership in 2027, a mild-hybrid 48-volt system, and a P2 full hybrid system with an optimized engine for increased fuel economy.

Table 62 compares the cost of the base ICE powertrain (diesel engine + automatic transmission) in 2027 with the mild hybrid and full hybrid options in 2027.

Table 62: Class 8 Refuse Truck - ICE, mild-hybrid, and full-hybrid cost in 2027

Base Cost	$40,297
Sensitivity 1 – Mild Hybrid	$41,566
Sensitivity 2 – Full Hybrid with improved engine	$44,516

4.9.2 Electric Vehicle Powertrain Cost – (Add Cost)

Table 63 gives the powertrain component costs of a BEV for 2021, 2024, and 2027. The base cost scenario assumes an NMC battery pack with MDHD-specific motors. Sensitivity 1 case assumes an LFP battery pack that is significantly cheaper ($/kWh). Sensitivity 2 case assumes an LFP battery pack along with multiple smaller motors, the costs based on motors mass-produced for light-duty application. All costs assume high-volume manufacture similar to what OEMs have in the light-duty space.

Table 63: Class 8 Refuse Truck - Electric Powertrain Component Cost

Component	Size kW/ kWh	2021	2024	2027
Battery pack (NMC)	200	$24,680	$18,040	$13,680
Inverter	260	$949	$854	$768
Onboard charger	50	$2,797	$2,517	$2,266
DC-DC Converter	10	$559	$503	$453
Motor	260	$4,771	$2,245	$1,684
Gearbox	260	$500	$500	$500
Total Base Case		**$34,256**	**$24,660**	**$19,351**
LFP battery pack		$21,490	$15,708	$11,912
Total Sensitivity 1 Case		**$31,066**	**$22,328**	**$17,583**
Drive unit, light-duty cost		$1,045	$940	$846
Total Sensitivity 2 Case		**$27,340**	**$21,023**	**$16,745**

4.9.3 Incremental Cost - Diesel Vs Battery Electric, Class 8 Refuse Truck

Table 64 combines Table 62 and Table 63 to compare the three ICE powertrain costs (base, mild, and full hybrid + improved engine) with the three BEV powertrain costs (base, LFP batteries, and LFP batteries + light-duty motors). Assuming high volume manufacture, the incremental cost of BEVs in 2027 is lower than diesel, mild-hybrid, and full hybrid buses for all scenarios. Considering the different combinations of the diesel engine, level of hybridization, and BEV components, the powertrain of a class 8 Refuse Truck is estimated to be between $20,945 and $27,971 cheaper than the diesel counterpart.

Table 64: Class 8 Refuse Truck- ICE Delete Vs BEV add costs – 2027

ICE powertrain description	**Diesel**	**Diesel mild hybrid**	**Diesel full hybrid**
ICE powertrain (delete) cost	$40,297	$41,566	$44,516
BEV powertrain description	**LFP + LD motors**	**LFP + HD motors**	**NMC + HD motors**
BEV powertrain (add) cost	$16,745	$17,583	$19,351

Figure 69 compares the base Diesel powertrain cost to Base BEV powertrain cost in 2021, 2024, and 2027. The cost of the base BEV powertrain is higher in 2021 and 2024 but lower in 2027. (Data from Table 61, Table 62, and Table 63) Powertrain cost parity between diesel and battery electric is reached sometime between 2024 and 2027.

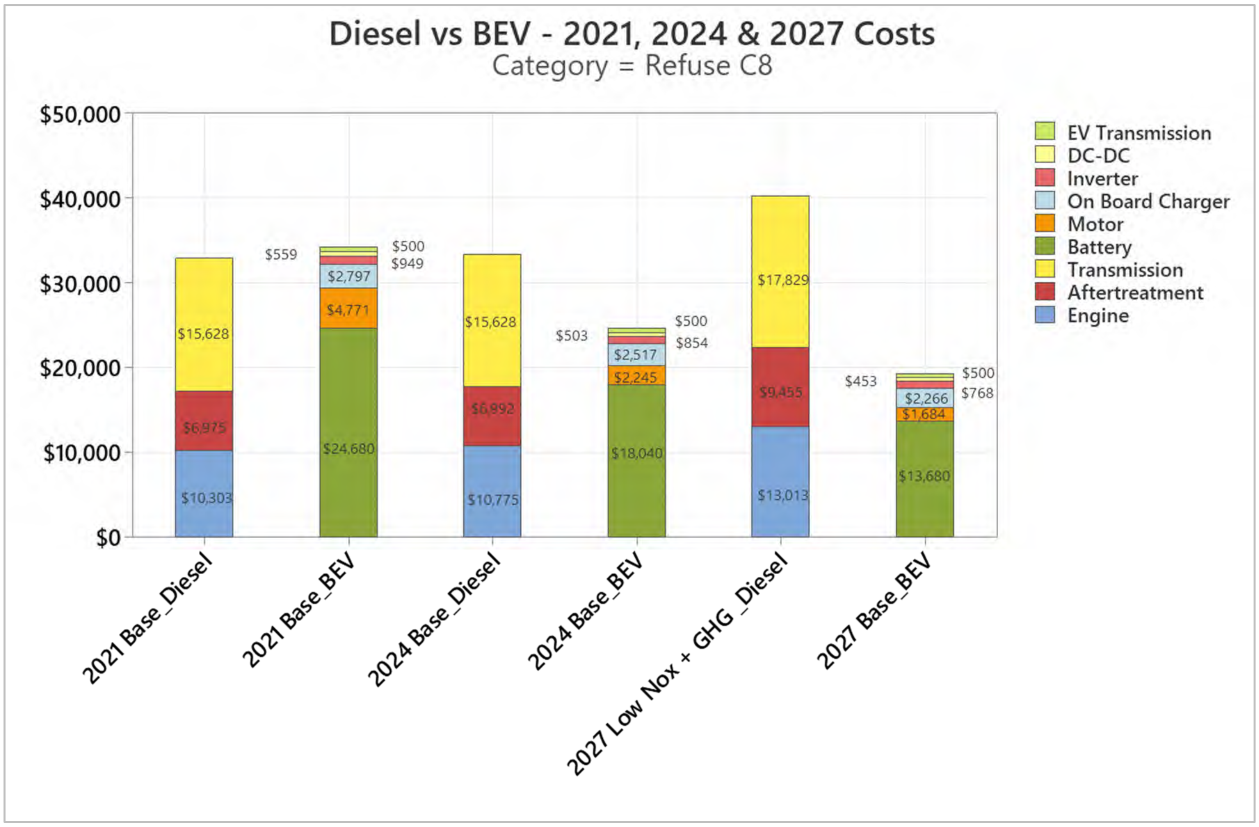


Figure 69: Class 8 Refuse Truck– Base Diesel and BEV powertrain costs 2021, 2024, and 2027

4.9.4 Total Cost of Ownership

The total cost of ownership is calculated in $/mile to compare an electric vehicle purchased in 2027 with the diesel alternative. Table 65 gives the breakdown of all the costs used in the calculation of the TCO.

Table 65: Class 8 Refuse Truck - Main inputs TCO Calculation

Bus Type	**Diesel**			**Electric**		
Case	low	reference	high	low	reference	high
Lifetime age of a vehicle (years)	12	10	7	12	10	7
Total mileage (miles)	175,000	250,000	300000	175,000	250,000	300,000
Fuel consumption (kWh/mile, mpg)	6	4	3	2.00	2.50	4.00
Fuel cost ($/ kWh, $/gal)	$2.10	$3.25	$4.61	$0.07	$0.12	$0.15
Purchase price ($)	$150,000	$251,270	$353,281	$131,409	$232,928	$334,696
Refresh ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Infrastructure cost ($/miles)	$0.003	$0.004	$0.006	$0.13	$0.16	$0.75
Maintenance ($/mile)	$0.80	$0.80	$0.80	$0.40	$0.56	$0.64

Table 66 gives the final value of the cost of ownership calculated in $/mile. In the reference case scenario, the TCO of the electric bus is more than 27% lower when compared to the diesel bus

Table 66: Class 5 Shuttle Bus – TCO ($/mile)

TCO	**Low**	**Reference**	**High**
Diesel Transit	$1.49	$2.43	$4.17
Electric Transit	$1.03	$1.85	$3.80

Figure 70 gives the effect of the variation of the various factors (purchase cost, fuel/ electricity cost/ maintenance, and infrastructure) on the reference TCO of a diesel and electric bus shown in Figure 71.

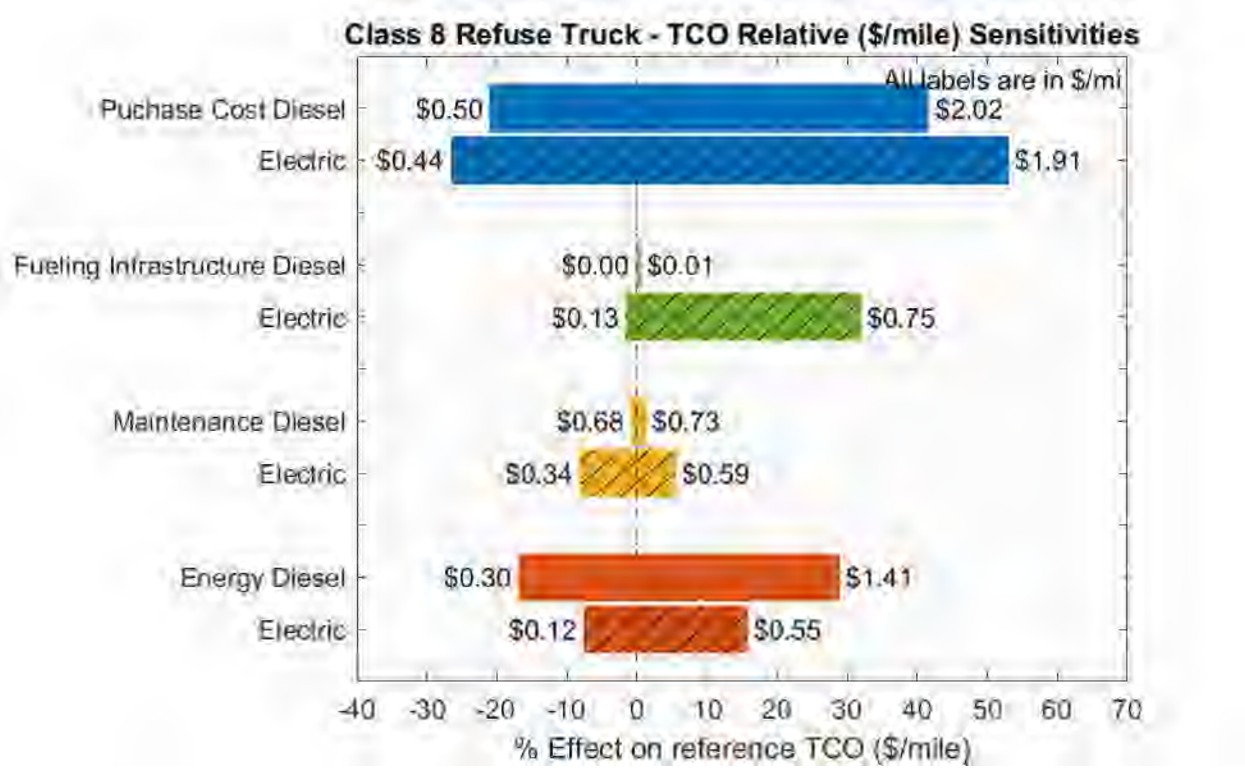


Figure 70: Class 8 Refuse Truck– Sensitivities (listed in Table 30) and their % contribution to reference TCO

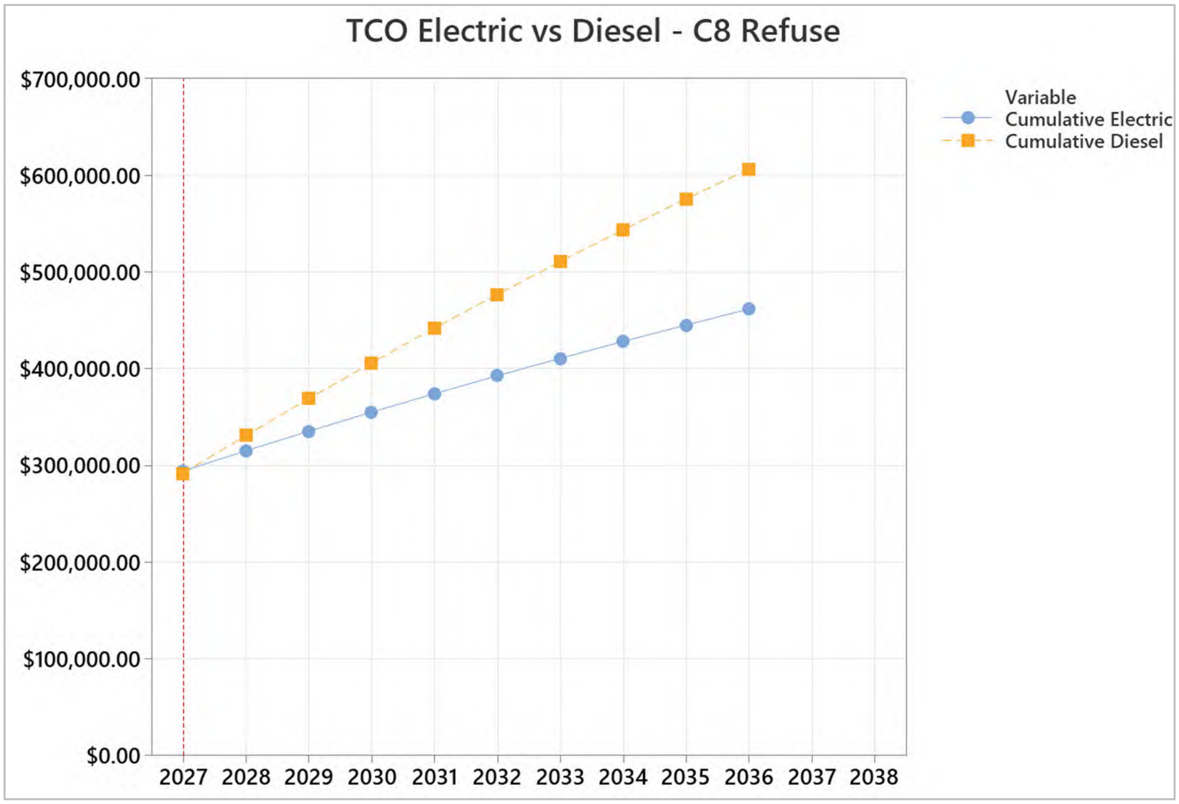


Figure 71: Class 8 Refuse Truck - Cumulative cost of ownership for 12 years of ownership (2027-2038)

Figure 72 compares the total cost of ownership for various sensitivities for diesel and battery electric school busses.

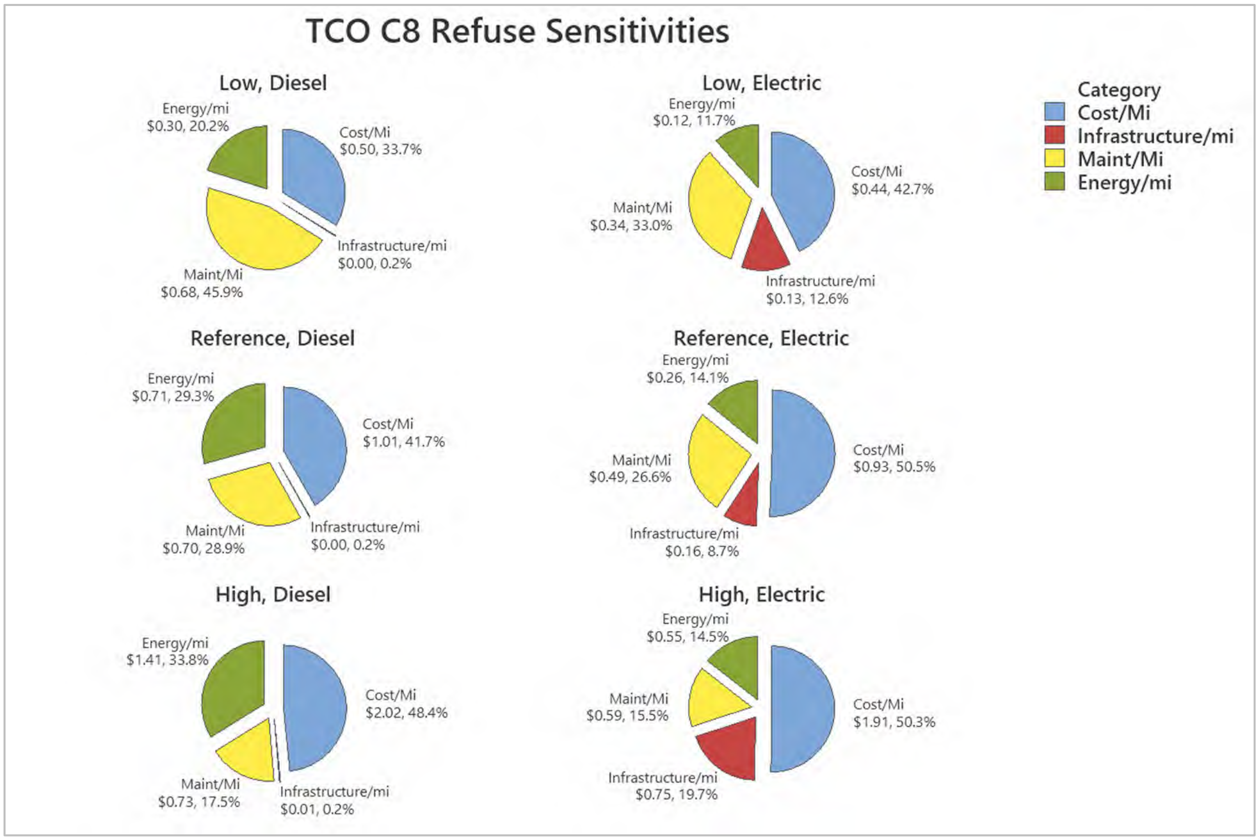


Figure 72: Class 8 Refuse Truck: Sensitivities of the total cost of ownership

5.0 Conclusions

As demonstrated in the analysis of the incremental cost for all transportation segments studied, the cost of electrification significantly decreases, nearing or achieving cost parity with ICE vehicles in 2027. The cost for an ICE vehicle that meets the increasingly stringent GHG regulations and low NOx regulations from EPA and ARB will be higher than a current ICE meeting 2021 regulations. On the opposite side, further technology development of ICE components such as batteries, motors, and power electronics will decrease the costs of these items in the 20207-2035 timeframe, leading to their cost parity or advantage over ICE powertrains. These technology developments decrease EV cost by both improving the scale and efficiency of manufacturing, but by also utilizing new materials, formulations, and architectures to create more power-dense, lighter components with materials that are widely available and not subject to volatile pricing and supply chain issues. In all cases, there is an incremental cost scenario that favors electrification, as shown in Figure 73.

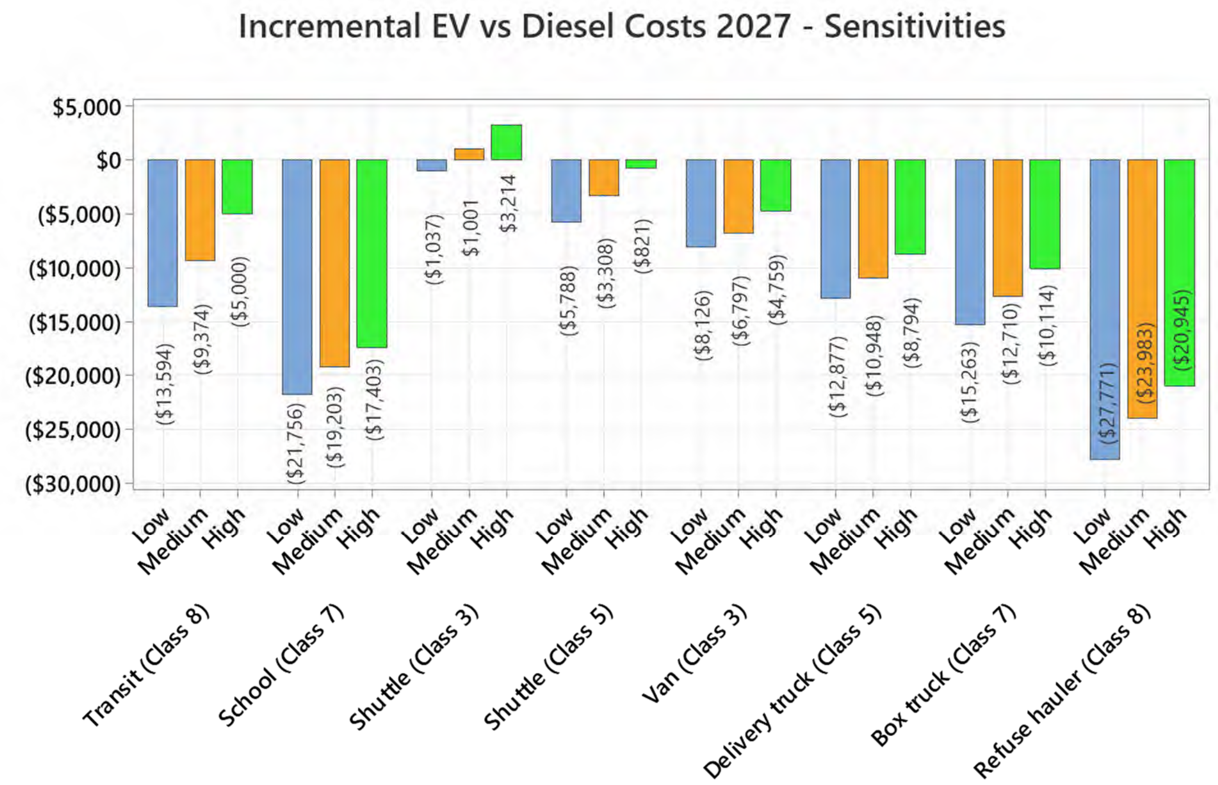


Figure 73: Incremental cost from ICE to EV powertrains in 2027.

Of equal or greater importance to fleet customers than purchase cost parity is the total cost of ownership, representing all capital expenditures related to a vehicle that an owner will encounter over the vehicle's life. EVs are a clear winner in this segment as well due to lower energy and maintenance costs in fleet operation, despite possible high infrastructure costs associated with building out an EV charging solution. To further improve the TCO equation, the cost of chargers and charging infrastructure has significant potential for further cost reduction and optimization through operation optimization and managed charging strategies.

Table 67 summarizes the results of the TCO study reference case. The TCO of BEVs purchased in 2027 for all the different types of vehicles analyzed in the study is lower than the comparable diesel vehicle by a significant margin (between 13.2% and 27.1%).

Table 67: TCO results summary – reference electric vs diesel

Class	Segment	Battery Size	Purchase cost	Operating cost	TCO	Year of TCO parity
		kWh	% Cost Reduction of EV vs ICE			
Class 8	Transit Bus	400	0.8	49.5	31.6	2
Class 7	School Bus	60	12.4	26.5	23.7	1
Class 5	Shuttle Bus	200	0.2	15.9	13.7	3
Class 3	Delivery Van	100	0.7	31.2	16.9	3
Class 5	Delivery Truck	150	12.4	52.0	34.0	1
Class 7	Delivery Truck	100	9.4	14.3	12.7	4
Class 8	Refuse Hauler	200	7.3	35.6	23.9	1

The purchase cost of all vehicles except the class 5 shuttle (only 2% higher – almost at parity) is lower than the equivalent diesel engine vehicle. The purchase price of the vehicles is very sensitive to the size of the battery pack. With the increasing energy density of LFP chemistry (Guoxuan High-Tech – 210 Wh/kg) and the advances in cell form factor and pack construction resulting in higher pack lever energy density (BYD – 140 Wh/kg, 279 Wh/liter), it has a high probability of being the default chemistry of choice for all the applications analyzed in this report. This will reduce the battery pack cost by greater than 13% reducing the purchase price of the vehicle.

As shown in Table 67, the operating cost (fuel + maintenance cost) of BEVs is significantly lower (between 28.7% and 61.8%) when compared to the equivalent diesel vehicle. Even with the cheaper purchase price and significantly lower operating expenses, BEVs in some segments take up to 3 years to reach parity on the cumulative cost of ownership with the comparable diesel vehicle. This is due to the charging infrastructure cost, all of which is assumed to be incurred at the time of purchase. This study assumes that every business that purchases these vehicles installs a captive charging solution which is very expensive. These could be cases where the same charging infrastructure is shared between different MDHD fleets in the city significantly reducing the infrastructure cost per vehicle. Also, there are no studies that look into how the increase in the adoption of BEVs and scaling of production volumes of power electronics, and standardization of processes for installing EV chargers will lead to a lowering of infrastructure costs. Incentives, financing, and government funding for the development of a robust DC fast-charging network will reduce the amount of spending that fleets have to make to install captive chargers reducing the TCO significantly speeding the adoption of BEVs.

In addition to the reduced costs of EV purchase and operation as EVs become more prevalent and charging networks expand, the benefits of switching buses and delivery vehicles to electric are quite significant in indirect costs and societal benefits. Regulations that reduce the emissions of diesel vehicles and encourage EV adoption improves health outcomes, reduces healthcare spending, improves environmental and smog conditions in city centers, and alleviates noise pollution.

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Attachment 5

United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

General Technical
Report NE-343

Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States

**James E. Smith
Linda S. Heath
Kenneth E. Skog
Richard A. Birdsey**

Abstract

This study presents techniques for calculating average net annual additions to carbon in forests and in forest products. Forest ecosystem carbon yield tables, representing stand-level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested wood products are included. Although these calculations are simple and inexpensive to use, the uncertainty of results obtained by using representative average values may be high relative to other techniques that use site- or project-specific data. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. The CD-ROM included with this publication contains a complete set of tables in spreadsheet format.

The Authors

JAMES E. SMITH (jsmith11@fs.fed.us) is a research plant physiologist, USDA Forest Service, Northeastern Research Station, Durham, New Hampshire.

LINDA S. HEATH (Lheath@fs.fed.us) is a research forester/project leader, USDA Forest Service, Northeastern Research Station, Durham, New Hampshire.

KENNETH E. SKOG (kskog@fs.fed.us) is a research forester/project leader, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

RICHARD A. BIRDSEY (rbirdsey@fs.fed.us) is a program manager, USDA Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania.

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Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States

Contents

Preface

In 2002, President George W. Bush directed the Department of Energy and the Department of Agriculture to revise the system for reporting and registering reductions in greenhouse gas emissions. Increasing carbon sequestration by forests and harvested products is equivalent to reducing emissions, and represents a significant opportunity for the private sector to voluntarily take action. Rules and guidelines are needed to provide a basis for consistent estimation of the quantity of carbon sequestered and emissions reduced by forestry activities, and can be used to determine the value of tradable credits. The value of registered carbon credits can provide increased income for landowners, support rural development, and facilitate sustainable forest management.

Many prospective reporting entities require information and decision-support software to evaluate prospects and develop plans for implementing forestry activities, and to estimate rates of carbon sequestration for reporting purposes. Estimating the quantity of carbon sequestered could be a difficult and expensive task, possibly requiring the establishment of a monitoring system based on remote sensing, field measurements, and models. However, there are situations for which a simpler estimation process is acceptable, requiring only a basic familiarity with definitions and accounting rules.

In practice, reporters may choose the simplest available methods that provide estimates with a degree of accuracy that meets reporting objectives. The information provided in this publication can be used to estimate carbon emissions, emission reductions, or sequestration about a forestry activity—data on the forest area affected, type of activity, and region of interest. The quality of the results will depend largely on the quality of the activity data and how closely actual activities are reflected in the factors. The intent in providing this information is to provide consistent and reliable estimates and to simplify the reporting process.

The tables in this publication represent significant updates of similar tables used for more than a decade to analyze forest carbon sequestration activities (Birdsey 1996). Since the previous tables were published, advances have been made in methods that estimate how various carbon components of forest ecosystems change over time, and how carbon in harvested products is retained in use or emitted to the atmosphere. This publication further documents the General Guidelines for reporting greenhouse gas information under Section 1605(b) of the Energy Policy Act of 1992.

Richard A. Birdsey

Richard A. Birdsey
Northern Global Change Program Manager
Forest Service 1605(b) Team Leader
U.S. Department of Agriculture

Introduction

International agreements recognize forestry activities as one way to sequester carbon, and thus mitigate the increase of carbon dioxide in the atmosphere; this may slow possible climate change effects. The United States initiated a voluntary reporting program in the early 1990's (U.S. Dep. Energy 2005). A system for developing estimates of the quantity of carbon sequestered in forest stands and harvested wood products[1] throughout the United States is a vital part of the voluntary program. This system must be relatively easy to use, transparent, economical, and accurate. In this publication, we present methods and regional average tables that meet these criteria.

Carbon is sequestered in growing trees, principally as wood in the tree bole. However, accrual in forest ecosystems also depends on the accumulation of carbon in dead wood, litter, and soil organic matter. When wood is harvested and removed from the forest, not all of the carbon flows immediately to the atmosphere. In fact, the portion of harvested carbon sequestered in long-lasting wood products may not be released to the atmosphere for years or even decades. If carbon remaining in harvested wood products is not part of the accounting system, calculation of the change in carbon stock for the forest area that is harvested will incorrectly indicate that all the harvested carbon is released to the atmosphere immediately. Failing to account for carbon in wood products significantly overestimates emissions to the atmosphere in the year in which the harvest occurs.

We adopted the approach of Birdsey (1996), who developed tables of forest carbon stocks and carbon in harvested wood to provide basic information on average carbon change per area. The tables are commonly referred to as "look-up tables" because users can identify the appropriate table for their forest, and look up the average regional carbon values for that type of forest. We have updated the tables by using new inventory surveys, forest carbon and timber projection models, and a more precise definition of carbon pools. We also include additional forest types and background information for customizing the tables for a user's specific needs.

The look-up tables are categorized by region, forest type, previous land use, and, in some cases, productivity class and management intensity. Users must identify the categories for their forest, estimate the area of forestland, and, if needed, characterize the amount of wood harvested from the area in a way that is compatible with the format of the look-up tables. The average carbon estimates per area in the look-up tables must be multiplied by the area or, as appropriate, harvested volumes, to obtain estimates in total carbon stock or change in carbon stock.

The estimates in the look-up tables are called "average estimates," indicating that they should be used when it is impractical to use more resource-intensive methods to characterize forest carbon, that is, particularly when more specific information is not available. Because these tables represent averages over large areas, the actual carbon stocks and flows for specific forests, or projects, may differ. The look-up tables should not be used when conditions for a project or site differ greatly from the classifications specified for the tables. Some users may require an alternative to an "all-or-nothing" use of the tables because they may have some information and need to use the tables to supplement, or fill in gaps, in carbon stocks. Alternatively, users may require slight alterations to the tabular data provided. Therefore, we also include the underlying assumptions and appropriate citations so that the tables can be adjusted to data availability and information requirements of individual activities.

The focus of this document is to explain the methodology in a transparent way and present sets of look-up tables for quantifying forest carbon when site-specific information is limited. In the sections that follow, we introduce the tables and provide general guidance for their use. First, tables of forest ecosystem carbon are presented; these are followed by tables to calculate the disposition of carbon in harvested wood products. Additional information on methods and data sources

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[1] Traditionally, the phrase "forest products" includes paper, but the phrase "wood products" does not. The literature for forest carbon has not recognized this distinction. Thus, we use the phase "wood products" to include all forest products including paper.

follows these tables. This organization was adopted so that readers interested in using the tables can do so quickly. Both metric and English units are used for measures of area and volume.[2] However, all values for carbon mass are expressed in metric units—tonnes (t)—unless specified otherwise. English units are included because most of the necessary input quantities are commonly expressed in units such as cubic feet/acre (for stand-level growing-stock volume) or thousand square feet of ⅜-inch plywood (a primary wood product), for example. Carbon stocks and stock changes are usually discussed and reported in metric units of carbon mass; this can lead to carbon in forests expressed as tonnes/hectare or in the United States as metric tons/acre. The forest ecosystem carbon tables are in Appendices A, B, and C; ancillary information on carbon in harvested wood is in Appendix D. Spreadsheet versions of the tables are on the CD-ROM that is included with this publication.

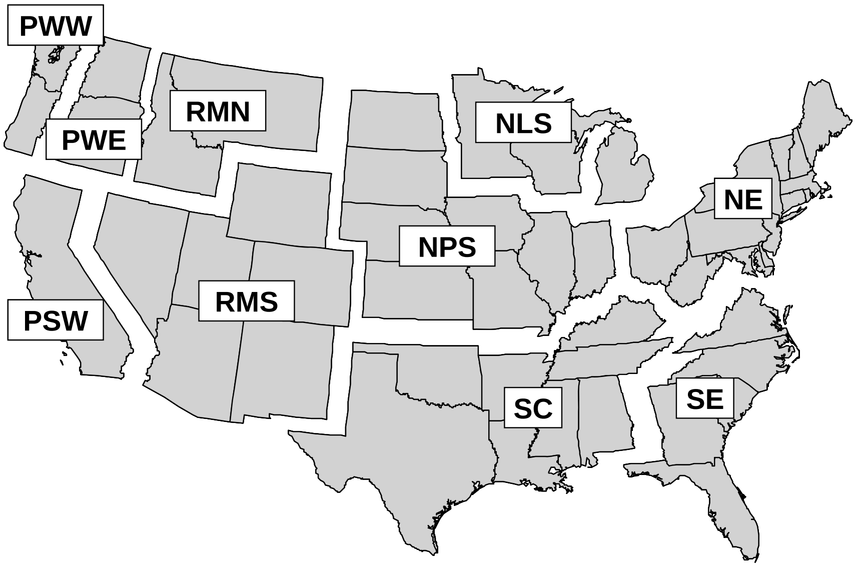

Figure 1.—Definition of regions: Pacific Northwest, West (PWW); Pacific Northwest, East (PWE); Pacific Southwest (PSW); Rocky Mountain, North (RMN); Rocky Mountain, South (RMS); Northern Prairie States (NPS); Northern Lake States (NLS); Northeast (NE); South Central (SC); and Southeast (SE). Note that regions are merged for some tables, these combinations include: NLS and NPS as North Central; PWW, PWE, and PSW as Pacific Coast; RMN and RMS as Rocky Mountain; SC and SE as South; and RMN, RMS, PWE, and PSW as West (except where stated otherwise).

Forest Ecosystem Carbon Tables

Tables of estimates of forest carbon stock are provided for common forest types within each of 10 U.S. regions (Fig. 1). Six distinct forest ecosystem carbon pools are listed: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic carbon. These pools are defined in Table 1. An example of the forest ecosystem tables is provided as Table 2, with the complete set in Appendices A and B. The first two columns in each table are age and growing-stock volume; the remaining columns represent carbon stocks for the various carbon pools and are dependent on age or growing-stock volume. Pools are quantified as carbon densities, that is, tonnes per unit area (acres or hectares).

The use of the tables can be summarized in three steps: 1) identify the most appropriate table for the particular carbon sequestration project; 2) extract the tabular information required for estimating carbon sequestration by the project; and 3) complete any necessary custom modifications or post-processing needed to suit data requirements. The information in the tables is based on a national-level, forest carbon accounting model (FORCARB2; Heath and others 2003, Smith and others 2004a), a timber projection model (ATLAS; Mills and Zhou 2003, Mills and Kincaid 1992, updated for Haynes 2003), and the USDA Forest Service, Forest Inventory and Analysis (FIA) Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Details are provided in the methods section.

The two basic sets of tables in Appendices A and B differ only with respect to assumptions associated with previous land use. The first set displays carbon stocks on forest land remaining forest land, also called "reforestation" or "regrowth" of a stand following a clearcut harvest (Table 2, for example, and Appendix A). The second set displays accumulation of carbon stocks for a stand established

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[2] A tonne (t) is defined as 10^6 grams, or 2,204.62 pounds (lb). Other metric and English equivalents include 0.404686 hectare (ha) = 1 acre (ac), 2.54 centimeter (cm) = 1 inch (in), 0.0283168 cubic meter (m^3) = 1 cubic foot (ft^3), and 0.907185 tonne = 1 short ton = 2,000 pounds.

Table 1.—Classification of carbon in forest ecosystems and in harvested wood

Forest ecosystem carbon pools	
Live trees	Live trees with diameter at breast height (d.b.h.) of at least 2.5 cm (1 inch), including carbon mass of coarse roots (greater than 0.2 to 0.5 cm, published distinctions between fine and coarse roots are not always clear), stems, branches, and foliage.
Standing dead trees	Standing dead trees with d.b.h. of at least 2.5 cm, including carbon mass of coarse roots, stems, and branches.
Understory vegetation	Live vegetation that includes the roots, stems, branches, and foliage of seedlings (trees less than 2.5 cm d.b.h.), shrubs, and bushes.
Down dead wood	Woody material that includes logging residue and other coarse dead wood on the ground and larger than 7.5 cm in diameter, and stumps and coarse roots of stumps.
Forest floor	Organic material on the floor of the forest that includes fine woody debris up to 7.5 cm in diameter, tree litter, humus, and fine roots in the organic forest floor layer above mineral soil.
Soil organic carbon	Belowground carbon without coarse roots but including fine roots and all other organic carbon not included in other pools, to a depth of 1 meter.
Categories for disposition of carbon in harvested wood	
Products in use	End-use products that have not been discarded or otherwise destroyed, examples include residential and nonresidential construction, wooden containers, and paper products.
Landfills	Discarded wood and paper placed in landfills where most carbon is stored long-term and only a small portion of the material is assumed to degrade, at a slow rate.
Emitted with energy capture	Combustion of wood products with concomitant energy capture as carbon is emitted to the atmosphere.
Emitted without energy capture	Carbon in harvested wood emitted to the atmosphere through combustion or decay without concomitant energy recapture.

Table 2.—Example reforestation table with regional estimates of timber volume and carbon stocks on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Understory	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/ha*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	32.0	27.7	69.6	61.8
5	0.0	7.4	0.7	2.1	21.7	20.3	69.6	52.2
15	28.0	31.8	3.2	1.9	11.5	16.3	69.6	64.7
25	58.1	53.2	5.3	1.8	7.8	17.6	69.6	85.7
35	89.6	72.8	6.0	1.7	6.9	20.3	69.6	107.8
45	119.1	87.8	6.6	1.7	7.0	23.0	69.6	126.0
55	146.6	101.1	7.0	1.7	7.5	25.3	69.6	142.7
65	172.1	113.1	7.4	1.7	8.2	27.4	69.6	157.7
75	195.6	123.8	7.7	1.7	8.8	29.2	69.6	171.2
85	217.1	133.5	7.9	1.7	9.5	30.7	69.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.6	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.6	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.6	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.6	218.8

on land that was not forest, called “afforestation” (Appendix B). The separate set of afforestation tables accounts for lower carbon densities of down dead wood, forest floor, and soil carbon in the initial years after forest establishment on nonforest land. However, as stands mature, the level of carbon stocks in these pools approaches the regional averages represented in the reforestation tables.

The tables in Appendices A and B provide estimates of carbon stock. The net change in carbon stock (sometimes called flux) associated with a growing forest can be determined by dividing the difference between two carbon stocks by the time interval between them. (See Examples 1 and 2 for information on using these tables.)

Example 1.—Obtain values for carbon stock and net stock change for stands of maple-beech-birch in the Northeast.

Use Table 2 to determine values for live tree carbon stock at years 25 and 45 and calculate net stock change over the interval.

Reading directly from the table, live tree carbon stocks are 53.2 and 87.8 t/ha for years 25 and 45, respectively.

Net annual stock change in live tree carbon between year 25 and 45, which is from the difference in stocks divided by the length of the interval between stocks:

$$\text{Net annual stock change} = (87.8 - 53.2) / 20 = 1.7 \text{ t/ha/yr}$$

The positive value for stock change indicates a net increase in carbon over the interval; this is consistent with the sign convention used for net stock change in this document. This tabular approach is applicable to all carbon pools in Appendices A, B, and C. Users must first classify the forest of interest and choose the most appropriate table.

Example 2.—Obtain an estimate of carbon stock when the value is not explicitly provided on a table, for stands of maple-beech-birch in the Northeast.

Use Table 2 to calculate live tree carbon stock of a stand with volume of wood (growing-stock volume) of 150 m^3/ha. This value is obtained by linearly interpolating between rows 7 and 8 of Table 2. The estimate of live tree carbon is between rows 7 and 8 because 150 m^3/ha is also between those two rows, and live tree carbon is a function of volume (Fig. 2).

Linear interpolation identifies a value for carbon stock between 101.1 and 113.1 t/ha that is linearly proportional to the position of 150 between 146.6 and 172.1 (from rows 7 and 8 of Table 2).

Live tree carbon (if volume is 150 m^3/ha)

$$= (150.0 - 146.6) / (172.1 - 146.6) \times (113.1 - 101.1) + 101.1$$

$$= 0.133 \times 12.0 + 101.1 \quad = 102.7 \text{ t/ha}$$

The value 0.133 means the carbon stock is 13.3 percent of the distance between the two stocks listed on the table, 101.1 and 113.1 t/ha.

Modifications to Forest Ecosystem Tables

The forest ecosystem tables provide regional averages as scenarios of forest growth and carbon accumulation, but they need not be used as the sole source of information on forest yield or carbon. For instance, a landowner may independently acquire estimates of growth or carbon accumulation that are specific to a particular carbon sequestration project. In this case, an appropriate use of the tables is to combine available data and to selectively use columns of carbon stocks to fill gaps in information.

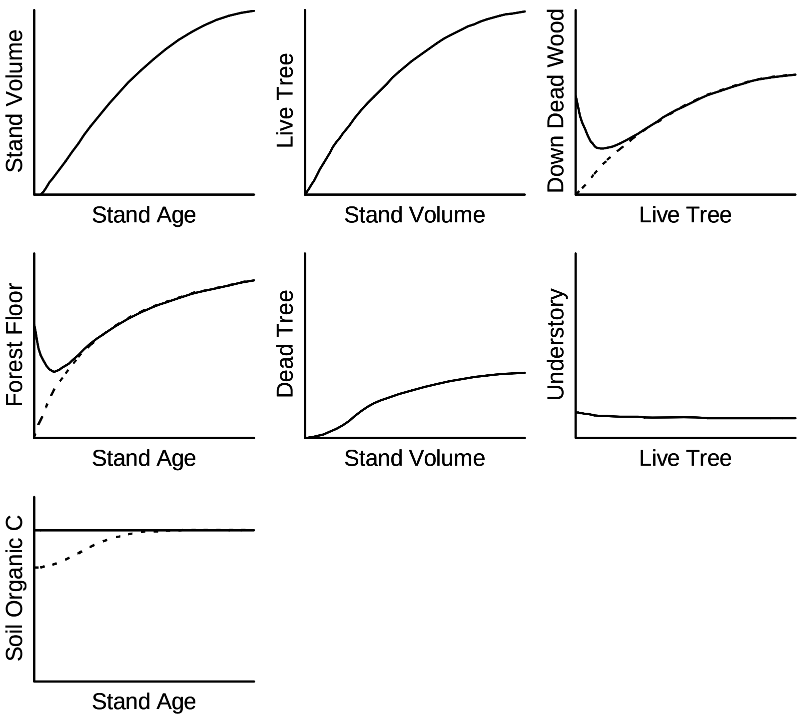

Figure 2.—Graphs indicating the basic relationships between the components of the forest ecosystem carbon tables. Figures are not drawn to scale; numerical representation for each graph is available from the tables. Dashed lines are qualitative representation of where afforestation tables (Appendix B) differ from the reforestation tables (Appendix A). Note that stand volume refers to growing-stock volume of live trees.

Users must have a general understanding of the relationships between the columns of the table to most appropriately substitute site-specific information for a carbon pool. Some columns can be viewed as independent or dependent variables, depending on the carbon pool of interest. If new data are incorporated in a table, any dependent columns (carbon pools) probably will require minor adjustments (recalculations). Figure 2 illustrates the basic relationships underlying calculations of carbon stock. Stand age and growing-stock volume are from the ATLAS model and based on FIA data such that they reflect region, forest type, and typical forest management regimes. Pools of live and standing-dead tree carbon are estimated directly from growing-stock volume. Carbon stocks of understory or down dead wood are estimated directly from live tree carbon and are only indirectly affected by growing-stock volume.

Growing-stock volume (stand volume in Figure 2) is the merchantable volume of wood in live trees as defined by FIA (Smith and others 2004c, Alerich and others 2005). Briefly, trees contributing volume to this stand-level summary value are commercial species that meet specified standards of size and quality or vigor. Users with other volume estimates for their stands must consider how to translate the volumes to be consistent with growing-stock volume. Thus, a landowner interested in applying these carbon estimates to another growth table should link tree carbon from the tables presented here to the new (separately obtained) estimates of growing-stock volume rather than to stand age (see Example 3). The methods section further explains how to use selected carbon pools from the table.

Tables for Harvested Wood Products Carbon

Harvested wood products serve as reservoirs of carbon that are not immediately emitted to the atmosphere at the time of harvest. The amount of carbon sequestered in products depends on how much wood is harvested and removed from the forest, to what products the harvested wood is allocated, and the half-life of wood in these products (Row and Phelps 1996, Skog and others 2004). The central focus of the carbon in harvested wood products estimates is the carbon change from two pools: carbon in products in use and carbon in landfills. Carbon in harvested wood is initially processed or manufactured into primary wood products, such as lumber and paper.

Example 3.—Modify a table to include independently obtained information about a forest carbon project

In this example, assume you have a project with loblolly pine established after clearcut harvest on existing forest land in the South Central region. The volume yields (Wenger, 1984) are:

Age	Mean volume
years	*m^3/ha*
0	0.0
10	30.6
15	122.6
20	187.9
25	238.9
30	277.9

The appropriate carbon table is Table A47, which is partially duplicated for this example. The goal is to construct a hybrid table from the new growth and yield estimates (columns 1-2) and the appropriate estimates for each of the carbon pools (columns 3-8).

A47.—Regional estimates of timber volume and carbon stocks for loblolly and shortleaf pine stands on forest land after clearcut harvest in the South Central

Age	Mean Volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/ha*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
5	0.0	10.8	0.7	4.7	7.7	6.5	41.9	30.3
10	19.1	23.1	1.3	3.9	6.8	6.4	41.9	41.5
15	36.7	32.4	1.6	3.5	6.2	7.5	41.9	51.2
20	60.4	42.2	1.8	3.3	5.9	8.7	41.9	61.9
25	85.5	52.0	2.0	3.1	5.8	9.8	41.9	72.8
30	108.7	59.6	2.1	3.0	5.8	10.7	41.9	81.2
35	131.2	66.6	2.3	2.9	5.9	11.5	41.9	89.1
40	152.3	73.1	2.3	2.9	6.0	12.2	41.9	96.4

To construct the modified table, copy the first two columns directly from the new yield table and then interpolate some of the carbon pool densities from Table A47. Estimates for live- and standing dead trees are dependent on growing-stock volume (as indicated in Fig. 2). These values can be determined by linear interpolation as described in Example 2. Similarly, understory and down dead wood stocks, which are dependent on the updated live tree carbon stocks (Fig. 2), can be determined by interpolation. For example, the value of down dead wood carbon stock in row two is based on linearly interpolating between rows three and four of Table A47, that is, down dead wood = (29.2 - 23.1) / (32.4 - 23.1) × (6.2 - 6.8) + 6.8 = 6.4 t/ha. Interpolation is not necessary for estimates of forest floor or soil organic carbon. Forest floor is a function of stand age, and soil organic carbon is 41.9 t/ha.

The resulting modified defaults for South Central loblolly pine based on separately obtained growth and yield:

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3/ha	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
10	30.6	29.2	1.5	3.6	6.4	6.4	41.9	47.1
15	122.6	63.9	2.2	2.9	5.8	7.5	41.9	82.3
20	187.9	83.7	2.5	2.8	6.3	8.7	41.9	104.0
25	238.9	98.2	2.7	2.6	7.0	9.8	41.9	120.3
30	277.9	109.1	2.8	2.6	7.6	10.7	41.9	132.8

These are then incorporated into end-use products, such as houses and newspapers. Intact primary and end-use products are considered “in use” until they are discarded, and a portion of these discarded products go to landfills. Additionally, a portion of carbon initially sequestered as products is eventually returned to the atmosphere through mechanisms such as combustion and decay. This emitted carbon is classified according to whether it occurred through a process of combustion with some concomitant energy recapture. This distinction between the two paths for carbon emitted to the atmosphere is included to assess potential displacement of other fuel sources. The four categories for the disposition of carbon in harvested wood are defined in Table 1. Note that the carbon in the four categories sum to 100 percent of the carbon harvested and removed from the forest.

The path that transforms trees-in-forests to wood-in-products can be described by the diagram in Figure 3. Quantities defined for the first three boxes in the diagram can serve as starting points, or data sources, for determining the disposition of carbon in wood products. Consistent with this, we provide factors for starting calculations of carbon in harvested wood products on the bases of forestland, the amount of industrial roundwood harvested, or the quantity of primary wood products produced by mills, depending on the data available (see definitions and details in the methods section). The forestland, or land-based, estimates are an extension of the forest ecosystem tables presented above. The other two starting points can be classified as product-based calculations, which are based on harvested logs or the output of mills. It is important to note that calculations from all three starting points (Fig. 3) focus on the same quantities of products in use or in landfills, and they all rely on the same model of allocation and longevity of end uses. They differ only in the level of detail available as the principal source of information on harvested wood—the path from input data to final disposition (Fig. 3). In the methods section, we provide the interrelated methods for calculating carbon in harvested wood for each of these starting points. Additionally, Appendix D provides background data and details on these calculations for wood products.

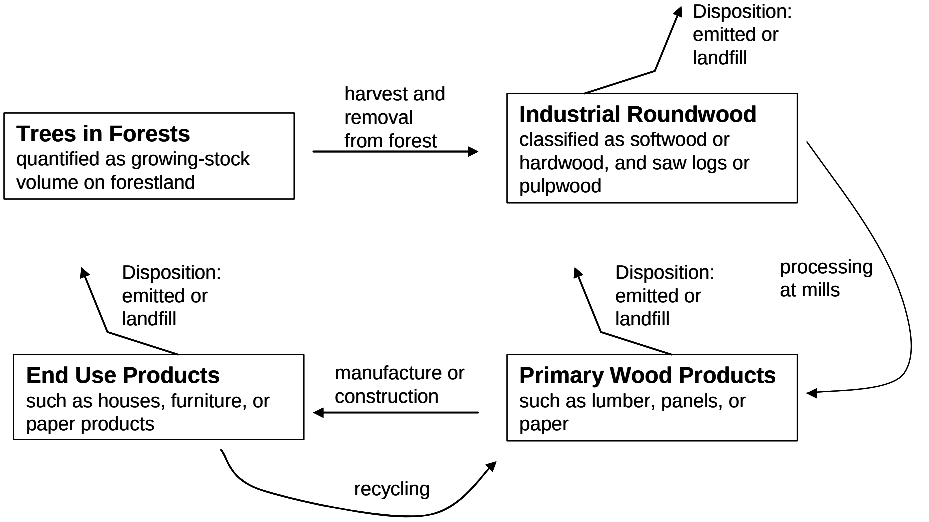

Figure 3.—The transition of carbon in forest trees to end-use products represented by a sequence of distinct pools separated by processes that move carbon between pools. Calculations of carbon in harvested wood products may start with any of the first three pools: trees in forests, industrial roundwood, or primary wood products.

Land-Based Estimates

The land-based estimates are provided as an additional set of forest ecosystem tables with harvest scenarios, which provide carbon estimates for harvested wood products over an interval after harvest (see Table 3 and Appendix C). At harvest, a large portion of carbon in tree biomass is allocated to the harvested wood pools, a second portion is assumed to decay rapidly after harvest (emitted at harvest), and the remainder stays on site in the forest as down dead wood or forest floor. The "emitted at harvest" carbon is assumed emitted at site soon after harvest; this is included to distinguish it from the two products emissions categories, which are emissions associated with processing, use, or disposal of harvested wood after removal from the site. Tree biomass allocated to harvested wood is removed from the site for processing, and it is allocated to the four disposition categories defined in Table 1. Changes in the allocation of this pool of harvested carbon among the categories are tracked over time following harvest (see columns 10, 11, 12, and 13 of Table 3). Note that the harvested products carbon pools are also quantified as carbon densities, that is, tonnes per unit area (acres or hectares), because they are derived from land-based carbon densities.

These land-based estimates of carbon in harvested wood need not be limited to the examples in Table 3 or Appendix C. Similar calculations are possible for other harvest quantities, stand ages, or forest types. Factors for estimating and allocating harvested carbon from the forest ecosystem tables are included in Tables 4, 5, and 6. These are used to calculate the disposition of carbon in harvested wood products (see Example 4). The stand-level volume of growing stock in live trees, such as 172.1 m^3/ha in Table 3, is used as a starting point to estimate total carbon in harvested wood. Growing-stock volume from the ecosystem table is converted to categories of industrial roundwood carbon mass according to factors in Tables 4 and 5. The disposition of this carbon in wood products is then allocated according to Table 6. Additional information on the use or adaptation of the harvest scenario tables can be found in the methods section that follows, Example 4, and Appendix D.

Product-Based Estimates

Harvest information is often available in the form of wood delivered to mills or the output of mills. These product amounts may be used as the starting point for calculating the disposition of carbon. Specifically, these starting points are industrial roundwood logs or primary

Table 3.—Example harvest scenario table with regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*m³/hectare*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	2.1	0.0	0.0	52.2					
5	0.0		7.4	0.7	2.1	0.5	4.2	52.3					
15	28.0		31.8	3.2	1.9	2.3	10.8	53.7					
25	58.1		53.2	5.3	1.8	3.8	15.8	56.0					
35	89.6		72.8	6.0	1.7	5.2	19.7	58.9					
45	119.1		87.8	6.6	1.7	6.2	22.7	61.8					
55	146.6		101.1	7.0	1.7	7.2	25.3	64.4					
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	66.3	34.5	0.0	39.7	14.1	7.5
5	0.0		7.4	0.7	2.1	21.7	20.3	67.1	22.9	4.7	43.1	17.5	
15	28.0		31.8	3.2	1.9	11.5	16.3	68.2	13.2	8.1	46.2	20.7	
25	58.1		53.2	5.3	1.8	7.8	17.6	68.9	10.3	8.8	47.1	22.0	
35	89.6		72.8	6.0	1.7	6.9	20.3	69.2	8.7	9.1	47.5	22.9	
45	119.1		87.8	6.6	1.7	7.0	23.0	69.4	7.6	9.4	47.8	23.5	
55	146.6		101.1	7.0	1.7	7.5	25.3	69.5	6.7	9.6	47.9	24.0	
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	69.5	40.4	9.8	87.8	38.5	7.7

NOTE: Emitted column is shown as positive values so that all nonsoil columns can be summed to check totals.

wood products (such as lumber, panels, or paper) as indicated in Figure 3. Thus, quantities are of total carbon and not directly linked to forest area. The disposition of carbon in products based on an initial quantity, or carbon mass, of industrial roundwood is allocated according to Table 6. The specific carbon content of primary wood products is calculated from factors in Table 7. The disposition of carbon over time for these primary products is according to factors in Tables 8 and 9, which provide the fractions of carbon from original primary products that remain in use or in landfills, respectively. Again, additional information on the use or adaptation of the tables for product-based calculations can be found in the section that follows, Examples 5 and 6, and Appendix D.

Methods and Data Sources for Tables

The purpose of this section is to provide detailed information on data sources, models, and assumptions used in developing the tables or calculations described earlier. Also, we outline linkages between the carbon calculations. These further illustrate how the tables were developed and updated, how the methods were applied, and provide information needed to further modify or customize the tabular carbon summaries.

In these tables, we provide estimates for as many as ten carbon pools. Forest structure provides a convenient modeling framework for assigning carbon to one of six distinct forest ecosystem pools: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic carbon (Table 1). These pools are consistent with guidelines of the Intergovernmental Panel on Climate Change (Penman and others 2003). The disposition of carbon in harvested wood is summarized in four categories that describe the end-fate of the harvested wood: products in use, landfills, emitted with energy capture, and emitted without energy capture (see definitions in Table 1).

Example 4.—Calculate carbon in harvested wood products remaining in use at 15 years after harvest based on volume of growing stock at time of harvest

Starting with an example from the Pacific Northwest, we will calculate the disposition of carbon in harvested wood products that are still in use at 15 years after harvest from the Douglas-fir forest described in Table C12. More specifically, we will show the steps involved to calculate that 53.3 t/ha of harvested carbon are in use at 15 years after harvest, starting from a harvested growing-stock volume of 718.8 m^3/ha (Table C12). We use factors from Tables 4, 5, and 6. These calculations are land-based estimates of carbon in harvested wood products based on the "trees in forests" starting point identified in Figure 3. Additional details on expanding these calculations to other harvested wood categories within the table or to other forest types are in Appendix D.

The sequence of steps required to determine carbon in use at year 15 are: 1) convert growing-stock volume to carbon mass according to four categories; 2) convert carbon in growing-stock volume to carbon in industrial roundwood; and 3) determine carbon remaining in products at the appropriate year.

Step 1: We assume that an average harvest for a forest type group produces roundwood logs that can be classified as softwood or hardwood as well as saw logs and pulpwood. The conversion from volume of wood to carbon mass depends on the specific carbon content of wood. Factors in Table 4 are used to allocate the 718.8 m^3/ha of growing-stock volume to four separate classes of carbon. For example, carbon in the softwood saw log part of growing-stock volume is the product of: growing-stock volume, the softwood fraction of growing-stock volume, the saw log fraction of softwood, softwood specific gravity, and the carbon fraction of wood, which is 50 percent carbon by dry weight. The calculations from Table 4 are:

Softwood saw log carbon in growing-stock volume
= 718.8 × 0.959 × 0.914 × 0.440 × 0.5 = 138.61 t/ha
Softwood pulpwood carbon in growing-stock volume
= 718.8 × 0.959 × (1 – 0.914) × 0.440 × 0.5 = 13.04 t/ha
Hardwood saw log carbon in growing-stock volume
= 718.8 × (1 – 0.959) × 0.415 × 0.426 × 0.5 = 2.61 t/ha
Hardwood pulpwood carbon in growing-stock volume
= 718.8 × (1 – 0.959) × (1 – 0.415) × 0.426 × 0.5 = 3.67 t/ha

Thus, total carbon stock in 718.8 m^3/ha of growing-stock volume is 183.60 t/ha.

Step 2: We need to represent carbon in these four categories in terms of carbon in industrial roundwood, which excludes bark and fuelwood. However, not all growing-stock volume is removed from the site of harvest as roundwood, and some industrial roundwood is from non-growing stock sources. Factors in Table 5 are used to obtain carbon in industrial roundwood. For example, carbon in industrial roundwood is the product of: carbon in growing-stock volume, the fraction of growing-stock volume that is removed as roundwood, and the ratio of industrial roundwood to growing-stock volume removed as roundwood. The calculations from Table 5 are:

Softwood saw log carbon in industrial roundwood = 138.61 × 0.929 × 0.965 = 124.26 t/ha
Softwood pulpwood carbon in industrial roundwood = 13.04 × 0.929 × 1.099 = 13.31 t/ha
Hardwood saw log carbon in industrial roundwood = 2.61 × 0.947 × 0.721 = 1.78 t/ha
Hardwood pulpwood carbon in industrial roundwood = 3.67 × 0.947 × 0.324 = 1.13 t/ha

Thus, total carbon stock in industrial roundwood is 148.36 t/ha.

Step 3: The disposition of carbon in harvested wood products is described by Table 6, which allocates carbon according to region, industrial roundwood category, and years since harvest and processing. The allocation factors for product in use at year 15 for Pacific Northwest, West apply here. The two hardwood categories are pooled in this region. The calculation for carbon density of products in use is the sum of the products of industrial roundwood carbon and the corresponding allocation factor, these are:

Carbon in products in use at year 15
= (124.26 × 0.423) + (13.31 × 0.020) + ((1.78 + 1.03) × 0.174) = 53.33 t/ha.

Example 5.—Calculate the disposition of carbon in harvested wood products at 100 years after harvest and processing from industrial roundwood data

Using Table 6, assume that a harvest in the Northeast produced 2,000 t dry weight of industrial roundwood. This represents 1,000 t of carbon because wood is assumed to be 50 percent carbon. The roundwood was harvested in the following proportions: 79 t carbon as softwood sawtimber, 51 t as softwood pulpwood, 465 t of hardwood sawtimber, and 405 t of hardwood pulpwood. Also assume that these quantities represent industrial roundwood without bark and exclude fuelwood; thus, Table 6 is the correct choice to calculate the disposition of carbon.

The four industrial roundwood categories are allocated to the classifications for the disposition of carbon in wood products by the appropriate factors for 100 years after production from the Northeast portion of Table 6.

Total carbon in use
$= (79 \times 0.095) + (51 \times 0.006) + (465 \times 0.035) + (405 \times 0.103) = 65.80$ t
Total carbon in landfills
$= (79 \times 0.223) + (51 \times 0.084) + (465 \times 0.281) + (405 \times 0.158) = 216.56$ t
Total carbon emitted with energy recapture
$= (79 \times 0.338) + (51 \times 0.510) + (465 \times 0.387) + (405 \times 0.336) = 368.75$ t
Total carbon emitted without energy recapture
$= (79 \times 0.344) + (51 \times 0.400) + (465 \times 0.296) + (405 \times 0.403) = 348.43$ t

Total carbon in industrial roundwood after 100 years is the sum of the four pools. Note that the total in this example is 999.5 t and not the 1,000 t we started with; this is due to rounding.

Forest Ecosystem Carbon

Forest ecosystem carbon is significantly affected by the following factors: region of the United States, forest type, previous land use, management, and productivity. The development and format of the tables are based on Birdsey (1996): current stand-level carbon and growth-and-yield models were compiled as forest carbon yield tables. Forest types correspond to definitions in the FIADB and represent common productive forests within each region.

The first two columns in each forest ecosystem table represent an age-volume relationship (also known as a yield curve) based on information from the timber projection model ATLAS (Mills and Kincaid 1992 with updates for Haynes 2003). ATLAS uses data on timber growth and yield and FIA data to develop a set of tables of growing-stock volume for projecting large-scale forest inventories representing U.S. forests for various policy scenarios. The yields (age-volume) represented in Appendices A, B, and C are broad averages; the basic set is from the appendix tables in Mills and Zhou (2003). Stand ages included in the tables are from the ATLAS yields, and these were limited to 90 years in the South and 125 years elsewhere. We assume all age-volume relationships are based on an average level of planting or stand establishment, that is, after clearcut harvest (reforestation) or as a part of stand establishment (afforestation). Additional tables are included for Southern pines and some Pacific Northwest forests to reflect stands with relatively higher productivity or more intensive management practices (see specific tables in Appendices A through C). These yields are based on ATLAS and timber projections prepared for Haynes (2003).

Example 6.—Calculate stocks of carbon in harvested wood products based on having primary wood products data such as products from a mill

Given the information on softwood lumber and softwood plywood produced from 2000 to 2003 (in the following tabulation) we use Tables 7, 8, and 9 to calculate: 1) carbon in the primary products, 2) the accumulation of carbon stocks over a period of 4 years, and 3) total carbon stocks after 100 years. Note that Tables 8 and 9 provide the fraction of primary product remaining for a given number of years after processing; this example assumes that harvest and processing are at the beginning of each year (2000-2003) and estimates for the amount remaining apply to the end of each year. This is an application of calculating the disposition of carbon in harvested wood based on quantities of primary wood products, as described in Figure 3.

Step 1: Determine initial carbon stocks for two primary products based on given quantities produced each year over the 4-year period by using factors from Table 7. For example, 93,000 thousand board feet softwood lumber × 0.443 = 41,199 t carbon.

The initial carbon stocks for two primary products, softwood lumber and softwood plywood:

Year	Quantity of primary product		Carbon stock	
	Softwood lumber	Softwood plywood	Softwood lumber	Softwood plywood
	thousand board feet	*thousand square feet, 3/8-inch basis*	*tonnes carbon*	*tonnes carbon*
2000	93,000	183,000	41,199	43,188
2001	85,000	175,000	37,655	41,300
2002	95,000	170,000	42,085	40,120
2003	100,000	173,000	44,300	40,828

Step 2: Calculate carbon stocks in end uses and landfills for each product for each year after production for the period 2000-2003 based on inputs of wood harvested and processed in each year. Use Tables 8 and 9 to determine stocks for each year since processing. Note that each of the 20 intermediate values in the following tabulation is based on the sum of carbon contributed from softwood lumber and softwood plywood. For example, the carbon stocks of primary products produced in 2001 are 37,655 t of softwood lumber and 41,300 t of softwood plywood. From this, a total of 3,820 t are in landfills at the end of 2003 (after 3 years). The quantity is calculated as: 3,820 t = (37,655 × 0.051) + (41,300 × 0.046).

Disposition of carbon in primary wood products over four years:

Year of production	Carbon in end uses at end of:				Carbon in landfills at end of:			
	2000	2001	2002	2003	2000	2001	2002	2003
2000	82,238	80,130	78,150	76,255	1,433	2,824	4,088	5,352
2001		76,947	74,977	73,127		1,339	2,640	3,820
2002			80,106	78,049			1,399	2,757
2003				82,952				1,451
Total	82,238	157,078	233,233	310,382	1,433	4,163	8,127	13,379

Thus, total carbon stocks for the end of 2002 are 241,360 t, with 233,233 t in end uses and 8,127 t in landfills. The balance of the cumulative total carbon in products from 2000 through 2002 has been emitted to the atmosphere, that is, 245,547 t initially in primary products minus the 241,360 t sequestered equals 4,187 t emitted from the primary products by 2002.

Step 3: Calculate carbon remaining in end uses or in landfills at 100 years after each of the harvest years. The estimates are based on initial stocks of carbon in each primary product multiplied by the respective fraction remaining as obtained from Tables 8 and 9. For example, carbon in primary product from harvest and processing in 2000 and in use at 100 years is 20,222 t = (41,199 × 0.234) + (43,188 × 0.245).

Year of production	Carbon in: End uses	Carbon in: Landfills
	tonnes carbon	
2000	20,222	33,961
2001	18,930	31,770
2002	19,677	33,092
2003	20,369	34,273
Total	79,198	133,096

Thus, of the 245,547 t of carbon in primary products produced from 2000 through 2002, 24 percent remain sequestered in products in use, 40 percent in landfills, and 36 percent emitted to the atmosphere.

Carbon estimates are derived from the individual carbon-pool estimators in FORCARB2 (Heath and others 2003, Smith and others 2004a, Smith and Heath 2005). FORCARB2 is essentially a national empirical simulation and carbon-accounting model that produces stand-level, inventory-based estimates of carbon stocks for forest ecosystems and regional estimates of carbon in harvested wood. Estimates of carbon in live and standing dead trees are based on the methods of Jenkins and others (2003) and Smith and others (2003). A new set of stand level volume-to-biomass equations[3] was calibrated to the FIADB available on the Internet as of July 29, 2005 (USDA For. Serv. 2005). These are the bases for the carbon values for live and standing dead trees provided here. However the volume-based estimates of tree carbon from FORCARB2 required minor modification for the tables because many yield curves specify zero volume at both 0 and 5 years. This produced discontinuities over time in the estimates of tree carbon, usually in the second and third age classes. Carbon in tree biomass is accruing even if sapling trees remain below the threshold for classification of growing-stock volume[4] but above the classification size where trees are considered part of the understory. Therefore, tree carbon at the first row of the table is set to zero, and carbon for year 5 (and occasionally the third age class) is based on a modification of the volume-based estimates. Briefly, a subset of the FIADB with younger stands was used to develop age-based regressions with biomass from tree data (Jenkins and others 2003); these regressions converged with the volume-based estimates, usually by age 10 to 15. We used a ratio of the two estimates to smooth estimates between the second and third age classes.

Estimates in carbon density in understory vegetation are based on Birdsey (1996); estimates of carbon density in down dead wood were developed by FORCARB2 simulations. Estimates of these two pools are based on region, forest type, and live-tree biomass. (For additional discussion or example values, see Smith and others (2004b) and Smith and Heath (2005)). The carbon density of forest floor is a function of region, forest type, and stand age (Smith and Heath 2002). Estimates of soil organic carbon are based on the national STATSGO spatial database (USDA Soil Conserv. Serv. 1991) and the general approach described by Amichev and Galbraith (2004). These represent average soil organic carbon by region and forest type in the Forest Service's Renewable Resources Planning Act (RPA) 2002 Forest Resource Assessment database. For additional information, see USDA For. Serv. (2005) and Smith and others (2004c).

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[3] Contact the authors for additional information on the volume-to-biomass equations updated from Smith and others (2003).

[4] The minimum tree size for growing stock is 5 inches d.b.h.; significant tree carbon can accumulate in a stand before trees reach this threshold.

Slight modifications to the direct application of FORCARB2 estimators were incorporated to develop the reforestation (Table 2 and Appendix A) and afforestation (Appendix B) tables. The reforestation tables are based on the assumption that at harvest, a portion of slash becomes down dead wood or forest floor at the start of the next rotation; these additional components then decay with time in the new stand (Smith and Heath 2002). The initial carbon densities for down dead wood and forest floor are listed in the first row of the Appendix A tables. Values for down dead wood are proportional to levels at the time of harvest and added logging residue (based on Johnson (2001)). Decay rates for down dead wood and forest floor are calculated from Turner and others (1995) and Smith and Heath (2002). The afforestation tables are based on the reforestation tables with the assumption that the residual carbon of down dead wood and forest floor material remaining after harvest does not exist at the start of the afforested stands. Thus, these pools are set to zero at the first row of the table. Accumulation of soil organic carbon in previously nonforest land (the afforestation tables) is based on the accumulation function described in West and others (2004) with the assumption that soil carbon density is initially at 75 percent of the average forest value, which is within the range of values associated with soil organic carbon after deforestation (Lal 2005). Users with more specific data about soil organic carbon or effects of previous land use can easily modify the tables to reflect this information.

The tables are designed to accommodate modification or replacement of selected data. Estimates for years or stand volumes not defined explicitly can be determined with linear interpolation (Example 2). The separate carbon pools, according to column, allow the user to extract or substitute values as needed to complement separately obtained site-specific information. However, users should be aware of the relationships between the parts as described in Figure 2 to substitute columns.

Figure 2 can be used as a guide in customizing tables. As an example, a user with a model of stand growth for a particular project but still wishing to use the carbon estimates from a table should: 1) choose an appropriate carbon table by matching forest type, 2) make the appropriate substitutions of new data, and 3) then recalculate the carbon columns affected by the substitution. After the age and volume columns are replaced, recalculations based on interpolation are required for carbon pools of live and standing dead trees, understory vegetation, and down dead wood. Forest floor is determined by stand age, and values of soil carbon depend on assumptions that apply to reforestation or afforestation (Fig. 2). The substitutions and recalculations can be made by using a spreadsheet. Example 3 expands on this discussion and provides a numerical example.

As illustrated in Figure 2, most of the relationships between columns of the tables are nonlinear. As a consequence, small errors are possible when interpolating between two points, such as in the volume to tree carbon pairs. However, these errors likely will be minimal. The nonlinearity can produce more significant errors if the tables are applied to aggregate summaries of large forest areas, that is, substantially greater than 10,000 ha (Smith and others 2003). As a result, it is best to apply the tables to relatively smaller forest areas versus calculating large aggregate volume and area.

Harvested Wood Carbon

The basic information required for calculating the disposition of carbon in harvested wood products based on each of the three starting points (Fig. 3) are in Tables 4 through 9. The purpose of this section is to provide sufficient background so that a user can apply these tables. However, some users may want to modify the estimates to incorporate alternate data or assumptions, so we also provide background data and detailed explanations in Appendix D of how these tables are generated.

Methods for calculating the disposition of carbon in harvested wood and the starting points for making such calculations are organized according to the diagram in Figure 3. These starting points, which correspond to possible sources of data (independent variables) are: 1) the volume of wood in a forest available for harvest and subsequent processing (for example, growing-stock volumes in Tables 2 and 3); 2) industrial roundwood harvest from a forest in the form of saw logs and pulpwood, which is a measure of wood available for processing at mills; and 3) primary wood products, that is products produced at mills, such as lumber, panels, or paper. We discuss methods and application of each of these, beginning with estimates based on primary wood products as inputs.

The model that allocates carbon over time since harvest is the same for all three starting points, and this model is based on primary wood products (see Appendix D for details). Thus, the disposition is a function of primary wood product and time. Any of the additional calculations necessary for the "upstream" (see Figure 3) starting points are essentially required to translate input carbon to primary wood product equivalents. Conversely, calculations at "downstream" starting points do not quantify all pools of harvested carbon. For example, a portion of the wood harvested from a forest ecosystem is processed into primary wood products, but carbon in other biomass remains on site as logging residue or is removed from site as fuelwood or what ultimately becomes waste in the production of primary products. Thus, identifying pools such as fuelwood is necessary for starting from the forest ecosystem to partition carbon and obtain the quantity going to primary products. Quantifying fuelwood is not possible, and unnecessary, for starting from data on a quantity of primary wood products.

Before applying tables to calculate carbon in harvested wood, users should identify: 1) the starting point most appropriate for the data available, and 2) the type of summary values or results that are appropriate to the carbon accounting method and the forest carbon project. Each starting point requires slightly different input data and each accounts for somewhat different pools of carbon. Compatibility between available data and the appropriate starting point depends on identifying these differences. In addition to having different starting points to compute carbon stocks or stock change, there may be differences in information needs, such as for carbon reporting. Carbon accounting requirements may specify tracking carbon harvested in one or more years and reporting carbon sequestered at one or more later years. For example, one may be interested in tracking products associated with a particular year or may be interested in the cumulative effects of successive harvests. Alternatively, an accounting method that focuses on the long-term effects of current rates of harvest and processing on future stocks of carbon in harvested wood products requires estimates of carbon in use or in landfills at 100 years after harvest (Miner, in press). Thus, all of our projection tables extend through 100 years.

Consideration of imports or exports of harvested wood can complicate the calculations. The effect of considering the movement of harvested wood or wood products over boundaries depends on the approach used to account for carbon. Basic carbon accounting approaches, as presented by the Intergovernmental Panel on Climate Change (Penman and others 2003) are: stock-change, atmospheric-flow, and production. The accounting method presented here is a production approach: the disposition of carbon is estimated for all wood produced, including exports. Imports are excluded from accounting under the production approach. Currently, the IPCC does not provide guidelines on accounting methods for trade in harvested carbon. However, the additional information required to account for imports or exports is essentially the long-term disposition of the specific quantities of carbon imported or exported. For example, applying the calculations described in this document to exports explicitly assumes that the disposition of carbon is identical to that in products retained in the United States.

Primary Wood Products

Primary wood products such as lumber, plywood, panels, and paper are the products of mills; they provide a product-based starting point for calculating the disposition of carbon in harvested wood products (Fig. 3). Specific primary products are identified in Table 7. Manufacturing or construction incorporates these primary products into end-use products such as houses, furniture, or books. Each end-use product has an expected lifespan, and after use the primary products may be recovered for additional use, burned, or otherwise disposed of. After disposal, carbon in products is allocated to disposal pools, which ultimately leads to long-term storage in landfills or to emission to the atmosphere. Thus, the disposition of primary wood products are modeled through partitioning and residence times of a succession of intermediate pools to the final disposition categories as defined in Table 1.

Table 7 includes factors for converting primary wood products into total mass of carbon. For example, 1,000 ft^2 of 3⁄8-inch softwood plywood averages 0.236 tonne of carbon. Tables 8 and 9 indicate the fraction of each primary product that remains in use or in landfills, respectively, for a given number of years after harvest and production, with the assumption that harvest and production are at time zero. The tables represent national averages. Table 8 indicates the fraction of each primary product remaining in an end use product for up to 100 years after harvest and processing. For example, column 2 of Table 8 indicates that after 10 years, 77.7 percent of softwood lumber remains in an end-use product; end uses include residential or other construction, furniture, and wood containers. The change in carbon between the initial quantity of primary products and the amount specified in later years in Table 8 represents products taken out of use; these are then either sequestered in landfills or emitted to the atmosphere. Table 9 indicates the fraction of each primary product sequestered in landfills for up to 100 years after harvest and processing. In the example of softwood lumber at 10 years, the fraction is 14.1 percent (column 2 of Table 9). Thus, the remaining 8.2 percent of carbon (100-77.7-14.1) in softwood lumber has been emitted to the atmosphere by year 10.

Recycling of paper products is an assumption built into Tables 8 and 9. (See Appendix D for details on paper recycling.) The value of including the effect of recycling on the disposition of carbon in harvested wood products can depend on the carbon accounting information needed. For example, recycling can affect quantities in use or in landfills if calculations are focused on a single cohort of carbon such as paper originally produced in a specific year. That is, accounting for effects of recycling can matter if tracking carbon from a single year or owner is important. We include recycling of paper because recycling is relatively common, its effects may be important, and statistics are available to include recycling in the calculations.

Tables 8 and 9 can be used to calculate net annual change of carbon in harvested wood products, the cumulative effect of successive annual harvests, and carbon remaining at 100 years. The change in carbon stocks between successive years is net annual flux. The tables are based on the assumption that harvest and processing occur in the same year (year set to zero); they provide annual steps for 50 years. Values can be interpolated for annualized estimates between years 50 and 100. Cumulative effects of annual harvests are obtained by repeating calculations for each harvest and summing stock or stock change estimates for each year of interest. A numerical application for calculating the disposition of carbon in primary wood products is provided in Example 6, in which the cumulative effect of annual production at a mill is calculated. See Appendix D for additional information on model assumptions, values used to describe allocation and longevity, and calculations of the factors in Tables 7 through 9.

Industrial Roundwood

Roundwood[5] is logs, bolts or other round sections cut from trees for industrial manufacture or consumer use (Johnson 2001). Most roundwood is processed by mills, and it is this quantity of harvested wood that provides the industrial roundwood starting point in Figure 3. Classification of harvested wood as roundwood is commonly a part of regional or State-wide statistics on timber harvesting or processing (Johnson 2001, Smith and others 2004c). A regional linkage between industrial roundwood and the primary wood products model (discussed earlier) is the basis for establishing the disposition of carbon from roundwood. The allocation of industrial roundwood to domestically produced primary wood products was constructed from Adams and others (2006). The resulting model of the allocation of carbon in industrial roundwood according to region and roundwood category is represented as Table 6.

Table 6 was developed in the style of similar tables in Birdsey (1996), which are based on Row and Phelps

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[5] The definition and classification of roundwood as it is used here is important to quantifying and allocating carbon in harvested wood products. Calculations are based on wood in logs for industrial manufacture. This is the majority of roundwood. The definition of roundwood can also include fuelwood, but fuelwood and bark on industrial roundwood are specifically excluded from "industrial roundwood" as used in this document. Roundwood can be classified as sawtimber versus pulpwood (for example, Birdsey 1996, Row and Phelps 1996) but the more common usage is sawtimber versus poletimber (for example, Johnson 2001) or saw logs versus pulpwood.

(1996). Inputs are carbon mass in industrial roundwood according to region and roundwood category. Total industrial roundwood is allocated to the four disposition categories (see definitions in Table 1), and changes in allocation are tracked as fractions over years 1 through 100 after manufacture or processing. Industrial roundwood is classified by region (Fig. 1) and category: softwood saw logs, softwood pulpwood, hardwood saw logs, and hardwood pulpwood. Saw logs come from larger diameter trees and generally are utilized for solid wood products; pulpwood comes from smaller diameter trees and usually is used for pulpwood products. Some industrial roundwood classifications are pooled across regions for Table 6; this is done where production of a particular type is relatively low. Industrial roundwood, as classified for Table 6, excludes bark on logs and wood used as fuelwood. The allocation of emitted carbon to the fraction associated with energy capture is based on the allocation patterns in Birdsey (1996). A numerical application of Table 6 is provided in Example 5. See Appendix D for additional background information and sample calculations used to generate Table 6.

Growing-Stock Volumes of Forest Ecosystems

The land-based starting point for calculating the disposition of carbon in harvested wood products is from the forest ecosystem carbon tables (for example, Table 3), as described in Figure 3 (trees in forests). Calculations starting with wood in forests are distinctly different from starting with products in two respects: 1) inputs are land-based measures of merchantable wood in a forest (growing-stock volume), and 2) estimates of carbon in harvested wood also include the portion of roundwood identified as fuelwood as well as bark on all logs (industrial roundwood and fuelwood). The bases for linking forest ecosystems to roundwood, and thus the disposition of carbon in products, are compilations of summary values from harvest statistics (Johnson 2001) and estimates of tree biomass (Jenkins and others 2004) applied to current FIADB survey data.

Converting growing-stock volume to carbon mass in industrial roundwood is based on factors in Tables 4 and 5. Table 4 is used to partition growing-stock volume according to species type (softwood or hardwood) and size of logs. This is followed by converting volume to carbon mass according to the carbon content of wood. These values for carbon in growing-stock volume are extended to estimates of carbon in industrial roundwood according to factors in Table 5. The disposition of carbon is then based on Table 6.

The harvest scenario tables were constructed from the ecosystem tables by appending a reforestation table (from Appendix B) to an afforestation table (from Appendix A) at a stand age designated as a clearcut harvest. Carbon in harvested wood products was added by applying factors in Tables 4 through 6. The Appendix C tables are examples of how forest carbon stocks can include carbon in harvested wood; these are not recommendations for rotation length or timing of harvest. Assumptions and background data for compiling Tables 4, 5, and 6 (as well as the other starting points for calculating carbon in harvested wood products) are included in Appendix D. Despite differences in input data and extent of harvested carbon included, all three starting points rely on the same model of allocation and longevity of end uses. They differ only in the level of detail available as the principal source of information on harvested wood (Fig. 3).

Uncertainty

Estimates of carbon stocks and stock changes are based on regional averages and reflect the current best available data for developing regional estimates. Quantitative expressions of uncertainty are not available for most data summaries, coefficients, or model results presented in the tables. However, uncertainty analyses were developed for previous similar estimates of carbon, from which our tables were developed (Heath and Smith 2000, Skog and others 2004, Smith and Heath 2005). Similar quantitative uncertainty analyses are being developed for these estimates of carbon stocks and stock changes in forests and harvested wood products.

Precision is partly dependent on the scale of the forest carbon sequestration project of interest. Overall, precision is expected to be lower as these methods are applied to smaller scale projects rather than regional summaries. That is, precision depends on the degree of specificity in information about a particular forest or project. It may be useful to distinguish between two basic components of uncertainty in the application of these tables. Uncertainty about the regional averages, which are based on data summaries or models, can influence estimates for specific projects, which generally are small subsets of a region. However, variability within region likely will have a much greater influence on uncertainty than regional values. This is shown in Figure 4, which is an example of the volume-to-biomass relationships used to estimate tree carbon from merchantable volume (columns 2 and 3 in Table 2). Each point represents an individual permanent FIA inventory plot where the 95-percent confidence interval about the mean of carbon in live trees is generally less than 5 percent of the mean. The regression line represents the regional average; the 95-percent confidence intervals about this mean are indicated in Table 10. These two relative intervals reflect regional variability in biomass relative to volume. For example, the 99th percentile of stand growing-stock volumes for this forest in the FIADB is 361 m^3/ha and the mean carbon density for these plots is likely between 192 and 197 t/ha (Fig. 4, ±1.4 percent of the expected 194 t/ha). The distinction between uncertainty about coefficients and regional or temporal variability may also apply to calculating the disposition of carbon in harvested wood products as well. Uncertainty about the actual allocation of industrial roundwood to primary products may not be as important as year-to-year change or how activity at a single mill compares with the region as a whole.

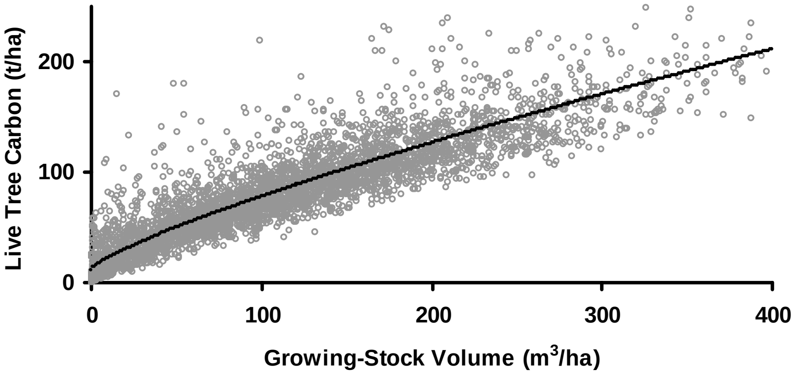

Figure 4.—A component of uncertainty associated with representing an average forest stand in the ecosystem tables. Individual points represent live tree carbon density for FIA permanent inventory plots for maple-beech-birch forests for the Northeast; the line represents carbon in tree biomass as predicted by growing-stock volume as used in Tables 2 and 3.

Conclusions

Summing the two estimates, forest ecosystem carbon and carbon in harvested wood products, gives the total effect of forest carbon sequestration for an activity. To assure accuracy, conducting modest inventories will help show the adequacy of the tables in characterizing carbon sequestration.

Carbon estimates depend on available data. Tables of average values cannot perfectly replicate each individual stand. Growth and yield information applicable to a particular stand can provide greater precision than regional averages. Similarly, carbon stocks in wood products that are calculated from quantities of primary wood products are likely to be more precise than products calculations starting simply from area of forest. However, the link between forest and sequestration in products may be less clear when starting from primary wood products. Forest composition, site conditions, and climate differ by regions, and climate, timber markets, and forest management priorities are subject to change from year to year. The methods described in this publication are most useful in identifying a general expected magnitude of carbon in forests, and to help plan carbon sequestration projects to achieve a certain goal.

Table 4.—Factors to calculate carbon in growing stock volume: softwood fraction, sawtimber-size fraction, and specific gravity by region and forest type group[a]

Region	Forest type	Fraction of growing-stock volume that is softwood[b]	Fraction of softwood growing-stock volume that is sawtimber-size[c]	Fraction of hardwood growing-stock volume that is sawtimber-size[c]	Specific gravity[d] of softwoods	Specific gravity[d] of hardwoods
Northeast	Aspen-birch	0.247	0.439	0.330	0.353	0.428
	Elm-ash-cottonwood	0.047	0.471	0.586	0.358	0.470
	Maple-beech-birch	0.132	0.604	0.526	0.369	0.518
	Oak-hickory	0.039	0.706	0.667	0.388	0.534
	Oak-pine	0.511	0.777	0.545	0.371	0.516
	Spruce-fir	0.870	0.508	0.301	0.353	0.481
	White-red-jack pine	0.794	0.720	0.429	0.361	0.510
Northern Lake States	Aspen-birch	0.157	0.514	0.336	0.351	0.397
	Elm-ash-cottonwood	0.107	0.468	0.405	0.335	0.460
	Maple-beech-birch	0.094	0.669	0.422	0.356	0.496
	Oak-hickory	0.042	0.605	0.473	0.369	0.534
	Spruce-fir	0.876	0.425	0.276	0.344	0.444
	White-red-jack pine	0.902	0.646	0.296	0.389	0.473
Northern Prairie States	Elm-ash-cottonwood	0.004	0.443	0.563	0.424	0.453
	Loblolly-shortleaf pine	0.843	0.686	0.352	0.468	0.544
	Maple-beech-birch	0.010	0.470	0.538	0.437	0.508
	Oak-hickory	0.020	0.497	0.501	0.448	0.565
	Oak-pine	0.463	0.605	0.314	0.451	0.566
	Ponderosa pine	0.982	0.715	0.169	0.381	0.473
Pacific Northwest, East	Douglas-fir	0.989	0.896	0.494	0.429	0.391
	Fir-spruce-m.hemlock	0.994	0.864	0.605	0.370	0.361
	Lodgepole pine	0.992	0.642	0.537	0.380	0.345
	Ponderosa pine	0.996	0.906	0.254	0.385	0.513
Pacific Northwest, West	Alder-maple	0.365	0.895	0.635	0.402	0.385
	Douglas-fir	0.959	0.914	0.415	0.440	0.426
	Fir-spruce-m.hemlock	0.992	0.905	0.296	0.399	0.417
	Hemlock-Sitka spruce	0.956	0.909	0.628	0.405	0.380
Pacific Southwest	Mixed conifer	0.943	0.924	0.252	0.394	0.521
	Douglas-fir	0.857	0.919	0.320	0.429	0.483
	Fir-spruce-m.hemlock	1.000	0.946	0.000	0.372	0.510
	Ponderosa Pine	0.997	0.895	0.169	0.380	0.510
	Redwood	0.925	0.964	0.468	0.376	0.449
Rocky Mountain, North	Douglas-fir	0.993	0.785	0.353	0.428	0.370
	Fir-spruce-m.hemlock	0.999	0.753	0.000	0.355	0.457
	Hemlock-Sitka spruce	0.972	0.735	0.596	0.375	0.441
	Lodgepole pine	0.999	0.540	0.219	0.383	0.391
	Ponderosa pine	0.999	0.816	0.000	0.391	0.374

Continued

Table 4.—continued

Region	Forest type	Fraction of growing-stock volume that is softwood[b]	Fraction of softwood growing-stock volume that is sawtimber-size[c]	Fraction of hardwood growing-stock volume that is sawtimber-size[c]	Specific gravity[d] of softwoods	Specific gravity[d] of hardwoods
Rocky Mountain, South	Aspen-birch	0.297	0.766	0.349	0.355	0.350
	Douglas-fir	0.962	0.758	0.230	0.431	0.350
	Fir-spruce-m.hemlock	0.958	0.770	0.367	0.342	0.350
	Lodgepole pine	0.981	0.607	0.121	0.377	0.350
	Ponderosa pine	0.993	0.773	0.071	0.383	0.386
Southeast	Elm-ash-cottonwood	0.030	0.817	0.551	0.433	0.499
	Loblolly-shortleaf pine	0.889	0.556	0.326	0.469	0.494
	Longleaf-slash pine	0.963	0.557	0.209	0.536	0.503
	Oak-gum-cypress	0.184	0.789	0.500	0.441	0.484
	Oak-hickory	0.070	0.721	0.551	0.438	0.524
	Oak-pine	0.508	0.746	0.425	0.462	0.516
South Central	Elm-ash-cottonwood	0.044	0.787	0.532	0.427	0.494
	Loblolly-shortleaf pine	0.880	0.653	0.358	0.470	0.516
	Longleaf-slash pine	0.929	0.723	0.269	0.531	0.504
	Oak-gum-cypress	0.179	0.830	0.589	0.440	0.513
	Oak-hickory	0.057	0.706	0.534	0.451	0.544
	Oak-pine	0.512	0.767	0.432	0.467	0.537
West[e]	Pinyon-juniper	0.986	0.783	0.042	0.422	0.620
	Tanoak-laurel	0.484	0.909	0.468	0.430	0.459
	Western larch	0.989	0.781	0.401	0.433	0.430
	Western oak	0.419	0.899	0.206	0.416	0.590
	Western white pine	1.000	0.838	0.000	0.376	--

-- = no hardwood trees in this type in this region.

[a] Estimates based on survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005) and include growing stock on timberland stands classified as medium- or large-diameter stands. Proportions are based on volume of growing-stock trees.

[b] To calculate fraction in hardwood, subtract fraction in softwood from 1.

[c] Softwood sawtimber are trees at least 22.9 cm (9 in) d.b.h., hardwood sawtimber is at least 27.9 cm (11 in) d.b.h. To calculate fraction in less-than-sawtimber-size trees, subtract fraction in sawtimber from 1. Trees less than sawtimber-size are at least 12.7 cm (5 in) d.b.h.

[d] Average wood specific gravity is the density of wood divided by the density of water based on wood dry mass associated with green tree volume.

[e] West represents an average over all western regions for these forest types.

Table 5.—Regional factors to estimate carbon in industrial roundwood logs, bark on logs, and fuelwood

Region[a]	Timber type	Industrial roundwood category	Ratio of industrial roundwood to growing-stock volume removed as roundwood[b]	Ratio of carbon in bark to carbon in wood[c]	Fraction of growing-stock volume removed as roundwood[d]	Ratio of fuelwood to growing-stock volume removed as roundwood[b]
Northeast	SW	Saw log	0.991	0.182	0.948	0.136
		Pulpwood	3.079	0.185		
	HW	Saw log	0.927	0.199	0.879	0.547
		Pulpwood	2.177	0.218		
North Central	SW	Saw log	0.985	0.182	0.931	0.066
		Pulpwood	1.285	0.185		
	HW	Saw log	0.960	0.199	0.831	0.348
		Pulpwood	1.387	0.218		
Pacific Coast	SW	Saw log	0.965	0.181	0.929	0.096
		Pulpwood	1.099	0.185		
	HW	Saw log	0.721	0.197	0.947	0.957
		Pulpwood	0.324	0.219		
Rocky Mountain	SW	Saw log	0.994	0.181	0.907	0.217
		Pulpwood	2.413	0.185		
	HW	Saw log	0.832	0.201	0.755	3.165
		Pulpwood	1.336	0.219		
South	SW	Saw log	0.990	0.182	0.891	0.019
		Pulpwood	1.246	0.185		
	HW	Saw log	0.832	0.198	0.752	0.301
		Pulpwood	1.191	0.218		

SW=Softwood, HW=Hardwood.

[a] North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[b] Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[c] Ratios are calculated from carbon mass based on biomass component equations in Jenkins and others (2003) applied to all live trees identified as growing stock on timberland stands classified as medium- or large-diameter stands in the survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Carbon mass is calculated for boles from stump to 4-inch top, outside diameter.

[d] Values and classifications are based on data in Tables 2.9, 3.9, 4.9, 5.9, and 6.9 of Johnson (2001).

Table 6.—Average disposition patterns of carbon as fractions in industrial roundwood by region and roundwood category; factors assume no bark on industrial roundwood, which also excludes fuelwood

	Northeast, Softwood							
	Saw log				Pulpwood			
Year after production	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.569	0.000	0.240	0.190	0.513	0.000	0.306	0.181
1	0.542	0.014	0.246	0.197	0.436	0.025	0.334	0.204
2	0.517	0.027	0.252	0.203	0.372	0.046	0.359	0.223
3	0.495	0.039	0.257	0.209	0.317	0.063	0.381	0.239
4	0.474	0.050	0.262	0.214	0.271	0.077	0.399	0.253
5	0.455	0.060	0.266	0.219	0.232	0.088	0.415	0.265
6	0.438	0.069	0.270	0.223	0.197	0.098	0.429	0.276
7	0.422	0.078	0.274	0.227	0.167	0.106	0.441	0.286
8	0.406	0.085	0.277	0.231	0.139	0.113	0.452	0.296
9	0.392	0.093	0.281	0.235	0.114	0.118	0.463	0.305
10	0.379	0.099	0.284	0.238	0.093	0.123	0.472	0.313
15	0.326	0.126	0.296	0.252	0.037	0.128	0.497	0.338
20	0.288	0.144	0.304	0.264	0.021	0.122	0.505	0.352
25	0.259	0.158	0.311	0.273	0.016	0.114	0.509	0.362
30	0.234	0.168	0.316	0.281	0.014	0.107	0.510	0.369
35	0.214	0.176	0.321	0.289	0.013	0.102	0.510	0.376
40	0.197	0.183	0.324	0.296	0.012	0.098	0.510	0.381
45	0.182	0.189	0.327	0.302	0.011	0.094	0.510	0.385
50	0.169	0.194	0.330	0.307	0.010	0.092	0.510	0.388
55	0.158	0.198	0.332	0.312	0.009	0.090	0.510	0.391
60	0.148	0.202	0.333	0.317	0.009	0.088	0.510	0.393
65	0.139	0.205	0.335	0.321	0.008	0.087	0.510	0.395
70	0.131	0.208	0.336	0.325	0.008	0.086	0.510	0.396
75	0.124	0.211	0.337	0.328	0.007	0.086	0.510	0.397
80	0.117	0.214	0.337	0.332	0.007	0.085	0.510	0.398
85	0.111	0.216	0.338	0.335	0.007	0.085	0.510	0.399
90	0.106	0.219	0.338	0.338	0.006	0.085	0.510	0.399
95	0.100	0.221	0.338	0.341	0.006	0.084	0.510	0.400
100	0.095	0.223	0.338	0.344	0.006	0.084	0.510	0.400

Continued

Table 6.—continued

Year after production	Northeast, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.614	0.000	0.237	0.149	0.650	0.000	0.185	0.166
1	0.572	0.025	0.246	0.157	0.590	0.021	0.202	0.186
2	0.534	0.048	0.255	0.163	0.539	0.039	0.218	0.203
3	0.500	0.067	0.263	0.170	0.496	0.054	0.232	0.218
4	0.469	0.085	0.271	0.175	0.459	0.067	0.244	0.231
5	0.440	0.102	0.278	0.180	0.426	0.078	0.254	0.242
6	0.415	0.116	0.284	0.185	0.398	0.087	0.263	0.253
7	0.391	0.129	0.290	0.190	0.372	0.095	0.271	0.262
8	0.369	0.141	0.295	0.194	0.349	0.102	0.279	0.271
9	0.349	0.152	0.300	0.198	0.327	0.108	0.286	0.279
10	0.331	0.162	0.305	0.202	0.308	0.114	0.292	0.286
15	0.260	0.198	0.324	0.218	0.252	0.127	0.310	0.311
20	0.212	0.221	0.338	0.229	0.226	0.130	0.319	0.325
25	0.178	0.235	0.348	0.239	0.211	0.131	0.323	0.335
30	0.152	0.245	0.356	0.247	0.198	0.132	0.327	0.343
35	0.131	0.253	0.362	0.254	0.187	0.133	0.329	0.351
40	0.115	0.258	0.368	0.260	0.178	0.134	0.331	0.357
45	0.102	0.262	0.372	0.265	0.169	0.136	0.333	0.363
50	0.090	0.265	0.375	0.269	0.160	0.138	0.334	0.368
55	0.081	0.268	0.378	0.273	0.153	0.140	0.335	0.373
60	0.073	0.270	0.380	0.277	0.146	0.142	0.335	0.377
65	0.066	0.272	0.382	0.280	0.139	0.144	0.336	0.381
70	0.059	0.274	0.384	0.283	0.133	0.146	0.336	0.385
75	0.054	0.275	0.385	0.286	0.127	0.148	0.336	0.388
80	0.049	0.277	0.386	0.288	0.122	0.150	0.336	0.392
85	0.045	0.278	0.386	0.290	0.117	0.152	0.336	0.395
90	0.041	0.279	0.387	0.293	0.112	0.154	0.336	0.398
95	0.038	0.280	0.387	0.294	0.108	0.156	0.336	0.400
100	0.035	0.281	0.387	0.296	0.103	0.158	0.336	0.403

Continued

Table 6.—continued

Year after production	North Central, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.630	0.000	0.249	0.121	0.514	0.000	0.305	0.180
1	0.599	0.016	0.257	0.127	0.438	0.025	0.332	0.204
2	0.570	0.032	0.265	0.133	0.374	0.046	0.356	0.223
3	0.544	0.045	0.272	0.138	0.320	0.063	0.377	0.240
4	0.520	0.058	0.279	0.143	0.274	0.077	0.396	0.254
5	0.499	0.069	0.285	0.147	0.235	0.088	0.411	0.266
6	0.478	0.080	0.291	0.151	0.200	0.097	0.425	0.278
7	0.459	0.090	0.296	0.154	0.170	0.105	0.437	0.288
8	0.442	0.099	0.301	0.158	0.143	0.112	0.448	0.297
9	0.425	0.107	0.306	0.162	0.118	0.118	0.458	0.306
10	0.410	0.115	0.310	0.165	0.096	0.122	0.467	0.314
15	0.349	0.145	0.327	0.178	0.041	0.127	0.491	0.340
20	0.306	0.166	0.339	0.189	0.024	0.121	0.500	0.354
25	0.272	0.181	0.348	0.198	0.020	0.113	0.503	0.364
30	0.245	0.193	0.356	0.206	0.018	0.107	0.504	0.372
35	0.222	0.202	0.362	0.213	0.016	0.101	0.504	0.378
40	0.203	0.210	0.367	0.220	0.015	0.097	0.504	0.383
45	0.187	0.216	0.371	0.226	0.014	0.094	0.504	0.387
50	0.173	0.221	0.374	0.231	0.014	0.091	0.504	0.391
55	0.161	0.225	0.377	0.236	0.013	0.089	0.504	0.393
60	0.151	0.229	0.379	0.241	0.012	0.088	0.504	0.395
65	0.141	0.233	0.381	0.245	0.012	0.087	0.504	0.397
70	0.133	0.236	0.382	0.249	0.011	0.086	0.504	0.399
75	0.125	0.239	0.383	0.253	0.010	0.086	0.504	0.400
80	0.118	0.241	0.384	0.257	0.010	0.085	0.504	0.401
85	0.112	0.244	0.385	0.260	0.009	0.085	0.504	0.401
90	0.106	0.246	0.385	0.263	0.009	0.085	0.504	0.402
95	0.101	0.248	0.385	0.266	0.009	0.085	0.504	0.402
100	0.096	0.250	0.385	0.269	0.008	0.084	0.504	0.403

Continued

Table 6.—continued

Year after production	North Central, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.585	0.000	0.253	0.162	0.685	0.000	0.165	0.150
1	0.544	0.024	0.262	0.170	0.630	0.020	0.181	0.169
2	0.507	0.046	0.271	0.177	0.582	0.038	0.196	0.184
3	0.473	0.065	0.279	0.183	0.541	0.052	0.209	0.198
4	0.443	0.082	0.286	0.189	0.506	0.064	0.219	0.210
5	0.416	0.097	0.293	0.194	0.476	0.075	0.229	0.220
6	0.391	0.111	0.299	0.199	0.448	0.084	0.237	0.230
7	0.368	0.124	0.305	0.203	0.424	0.092	0.245	0.239
8	0.347	0.135	0.310	0.208	0.401	0.099	0.252	0.247
9	0.328	0.146	0.315	0.212	0.381	0.106	0.259	0.255
10	0.310	0.155	0.320	0.216	0.362	0.111	0.265	0.262
15	0.242	0.189	0.338	0.231	0.306	0.127	0.282	0.285
20	0.197	0.210	0.350	0.243	0.278	0.132	0.291	0.299
25	0.165	0.224	0.360	0.252	0.259	0.136	0.296	0.309
30	0.140	0.233	0.367	0.260	0.244	0.138	0.300	0.317
35	0.121	0.239	0.373	0.267	0.231	0.141	0.303	0.325
40	0.106	0.244	0.378	0.272	0.219	0.144	0.306	0.331
45	0.093	0.248	0.381	0.278	0.208	0.147	0.308	0.337
50	0.083	0.251	0.384	0.282	0.198	0.150	0.309	0.343
55	0.074	0.253	0.387	0.286	0.189	0.153	0.311	0.348
60	0.066	0.255	0.389	0.290	0.180	0.156	0.312	0.353
65	0.060	0.257	0.390	0.293	0.172	0.159	0.313	0.357
70	0.054	0.259	0.391	0.296	0.164	0.161	0.313	0.361
75	0.049	0.260	0.392	0.299	0.157	0.164	0.314	0.365
80	0.045	0.261	0.393	0.301	0.150	0.167	0.314	0.368
85	0.041	0.262	0.393	0.304	0.144	0.170	0.315	0.372
90	0.038	0.263	0.393	0.306	0.138	0.172	0.315	0.375
95	0.035	0.264	0.393	0.308	0.133	0.175	0.315	0.378
100	0.032	0.265	0.393	0.309	0.127	0.177	0.315	0.381

Continued

Table 6.—continued

Year after production	Pacific Northwest, East, Softwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.637	0.000	0.197	0.166
1	0.601	0.016	0.207	0.176
2	0.569	0.031	0.215	0.185
3	0.541	0.043	0.223	0.192
4	0.516	0.055	0.230	0.199
5	0.494	0.065	0.236	0.205
6	0.473	0.074	0.242	0.211
7	0.454	0.083	0.247	0.216
8	0.437	0.090	0.251	0.221
9	0.420	0.098	0.256	0.226
10	0.405	0.104	0.260	0.231
15	0.351	0.127	0.274	0.248
20	0.315	0.143	0.283	0.260
25	0.287	0.154	0.289	0.270
30	0.264	0.163	0.294	0.279
35	0.245	0.170	0.298	0.287
40	0.228	0.177	0.301	0.294
45	0.213	0.182	0.304	0.301
50	0.199	0.188	0.306	0.307
55	0.187	0.192	0.308	0.313
60	0.176	0.196	0.309	0.318
65	0.166	0.200	0.310	0.323
70	0.157	0.204	0.311	0.328
75	0.149	0.207	0.311	0.333
80	0.141	0.210	0.312	0.337
85	0.134	0.213	0.312	0.341
90	0.128	0.216	0.312	0.345
95	0.121	0.219	0.312	0.348
100	0.116	0.221	0.312	0.351

Continued

Table 6.—continued

Year after production	Pacific Northwest, West, Softwoods							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.740	0.000	0.125	0.135	0.500	0.000	0.352	0.148
1	0.703	0.018	0.134	0.144	0.422	0.026	0.382	0.170
2	0.670	0.035	0.141	0.153	0.357	0.047	0.409	0.187
3	0.640	0.050	0.148	0.161	0.301	0.064	0.433	0.202
4	0.613	0.064	0.154	0.169	0.254	0.078	0.453	0.215
5	0.589	0.076	0.160	0.176	0.215	0.089	0.471	0.226
6	0.566	0.088	0.165	0.182	0.180	0.098	0.486	0.236
7	0.545	0.098	0.169	0.188	0.150	0.106	0.499	0.245
8	0.525	0.108	0.174	0.194	0.121	0.112	0.512	0.254
9	0.506	0.117	0.178	0.199	0.096	0.118	0.523	0.262
10	0.489	0.125	0.182	0.204	0.075	0.122	0.533	0.270
15	0.423	0.157	0.196	0.224	0.020	0.127	0.559	0.295
20	0.376	0.179	0.206	0.239	0.004	0.119	0.567	0.309
25	0.340	0.195	0.213	0.252	0.001	0.110	0.569	0.319
30	0.310	0.208	0.219	0.263	0.000	0.103	0.569	0.327
35	0.284	0.218	0.224	0.273	0.000	0.097	0.569	0.334
40	0.263	0.227	0.228	0.282	0.000	0.092	0.569	0.339
45	0.244	0.234	0.232	0.290	0.000	0.088	0.569	0.342
50	0.228	0.240	0.234	0.298	0.000	0.085	0.569	0.345
55	0.213	0.246	0.237	0.305	0.000	0.083	0.569	0.348
60	0.200	0.251	0.238	0.311	0.000	0.081	0.569	0.349
65	0.188	0.255	0.240	0.317	0.000	0.080	0.569	0.351
70	0.178	0.259	0.240	0.322	0.000	0.079	0.569	0.352
75	0.168	0.263	0.241	0.328	0.000	0.078	0.569	0.353
80	0.159	0.267	0.242	0.332	0.000	0.077	0.569	0.353
85	0.151	0.270	0.242	0.337	0.000	0.077	0.569	0.354
90	0.143	0.273	0.242	0.341	0.000	0.076	0.569	0.354
95	0.136	0.276	0.242	0.345	0.000	0.076	0.569	0.355
100	0.130	0.279	0.242	0.349	0.000	0.076	0.569	0.355

Continued

Table 6.—continued

Year after production	Pacific Northwest, West, Hardwood				Pacific Southwest, Softwood			
	All				All			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.531	0.000	0.288	0.181	0.675	0.000	0.170	0.156
1	0.481	0.021	0.305	0.193	0.637	0.018	0.180	0.166
2	0.438	0.040	0.319	0.204	0.602	0.034	0.189	0.175
3	0.400	0.055	0.332	0.213	0.572	0.048	0.197	0.183
4	0.367	0.069	0.343	0.221	0.545	0.061	0.204	0.191
5	0.338	0.081	0.352	0.229	0.521	0.072	0.210	0.197
6	0.312	0.091	0.361	0.235	0.498	0.082	0.216	0.204
7	0.289	0.100	0.369	0.241	0.478	0.092	0.221	0.209
8	0.268	0.109	0.377	0.247	0.458	0.101	0.226	0.215
9	0.248	0.116	0.383	0.252	0.440	0.109	0.231	0.220
10	0.231	0.122	0.390	0.257	0.424	0.116	0.235	0.225
15	0.174	0.142	0.409	0.275	0.363	0.143	0.250	0.243
20	0.143	0.152	0.420	0.285	0.323	0.161	0.260	0.257
25	0.122	0.157	0.427	0.294	0.292	0.173	0.268	0.267
30	0.107	0.160	0.432	0.301	0.266	0.183	0.273	0.277
35	0.095	0.162	0.436	0.306	0.245	0.192	0.278	0.285
40	0.085	0.164	0.440	0.312	0.226	0.198	0.282	0.293
45	0.076	0.166	0.442	0.316	0.210	0.204	0.285	0.300
50	0.069	0.167	0.444	0.320	0.196	0.210	0.288	0.306
55	0.062	0.169	0.445	0.324	0.184	0.214	0.290	0.312
60	0.057	0.170	0.446	0.327	0.173	0.218	0.292	0.317
65	0.052	0.171	0.447	0.330	0.162	0.222	0.293	0.322
70	0.048	0.172	0.447	0.333	0.153	0.226	0.294	0.327
75	0.044	0.173	0.447	0.336	0.145	0.229	0.295	0.331
80	0.040	0.174	0.448	0.338	0.137	0.232	0.296	0.335
85	0.037	0.175	0.448	0.340	0.130	0.235	0.296	0.339
90	0.035	0.176	0.448	0.342	0.124	0.238	0.296	0.343
95	0.032	0.177	0.448	0.344	0.117	0.240	0.296	0.346
100	0.030	0.177	0.448	0.345	0.112	0.243	0.296	0.349

Continued

Table 6.—continued

Year after production	Rocky Mountain, Softwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.704	0.000	0.209	0.087
1	0.664	0.019	0.223	0.094
2	0.628	0.036	0.235	0.101
3	0.595	0.051	0.247	0.107
4	0.567	0.065	0.256	0.112
5	0.541	0.077	0.265	0.118
6	0.517	0.088	0.273	0.122
7	0.495	0.098	0.280	0.127
8	0.474	0.107	0.287	0.131
9	0.455	0.116	0.294	0.135
10	0.438	0.124	0.300	0.139
15	0.373	0.152	0.320	0.154
20	0.330	0.171	0.333	0.165
25	0.297	0.185	0.343	0.175
30	0.271	0.195	0.350	0.184
35	0.248	0.204	0.356	0.192
40	0.229	0.211	0.360	0.200
45	0.213	0.217	0.364	0.207
50	0.198	0.222	0.367	0.213
55	0.185	0.227	0.369	0.219
60	0.174	0.231	0.371	0.225
65	0.163	0.235	0.372	0.230
70	0.154	0.238	0.373	0.235
75	0.146	0.241	0.373	0.240
80	0.138	0.244	0.373	0.244
85	0.131	0.247	0.373	0.249
90	0.124	0.250	0.373	0.253
95	0.118	0.253	0.373	0.256
100	0.112	0.255	0.373	0.260

Continued

Table 6.—continued

Year after production	Southeast, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.636	0.000	0.260	0.104	0.553	0.000	0.276	0.171
1	0.601	0.017	0.270	0.112	0.482	0.024	0.300	0.193
2	0.570	0.032	0.279	0.119	0.422	0.044	0.323	0.211
3	0.541	0.045	0.288	0.125	0.370	0.061	0.342	0.227
4	0.516	0.057	0.296	0.131	0.327	0.074	0.359	0.241
5	0.493	0.068	0.303	0.136	0.290	0.085	0.373	0.252
6	0.472	0.078	0.310	0.140	0.257	0.094	0.385	0.263
7	0.453	0.087	0.315	0.145	0.229	0.102	0.396	0.273
8	0.435	0.095	0.321	0.149	0.202	0.109	0.407	0.282
9	0.418	0.103	0.326	0.153	0.178	0.115	0.416	0.291
10	0.402	0.110	0.331	0.157	0.158	0.119	0.425	0.298
15	0.345	0.136	0.347	0.172	0.102	0.127	0.448	0.323
20	0.306	0.153	0.357	0.184	0.083	0.123	0.456	0.337
25	0.276	0.166	0.364	0.194	0.075	0.118	0.460	0.347
30	0.251	0.176	0.370	0.203	0.070	0.113	0.462	0.355
35	0.231	0.184	0.374	0.211	0.066	0.110	0.463	0.361
40	0.213	0.190	0.378	0.219	0.063	0.107	0.463	0.367
45	0.198	0.196	0.381	0.226	0.060	0.105	0.463	0.372
50	0.184	0.201	0.383	0.232	0.057	0.104	0.463	0.376
55	0.172	0.206	0.384	0.238	0.054	0.103	0.463	0.380
60	0.162	0.209	0.385	0.244	0.052	0.103	0.463	0.383
65	0.152	0.213	0.386	0.249	0.049	0.103	0.463	0.385
70	0.144	0.216	0.386	0.254	0.047	0.103	0.463	0.387
75	0.136	0.219	0.386	0.259	0.045	0.103	0.463	0.389
80	0.128	0.222	0.386	0.263	0.043	0.103	0.463	0.391
85	0.122	0.225	0.386	0.267	0.041	0.104	0.463	0.392
90	0.116	0.227	0.386	0.271	0.040	0.104	0.463	0.393
95	0.110	0.230	0.386	0.274	0.038	0.105	0.463	0.395
100	0.104	0.232	0.386	0.277	0.036	0.105	0.463	0.396

Continued

Table 6.—continued

Year after production	Southeast, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.609	0.000	0.225	0.166	0.591	0.000	0.225	0.185
1	0.565	0.025	0.234	0.176	0.524	0.023	0.245	0.208
2	0.526	0.047	0.243	0.184	0.467	0.042	0.263	0.227
3	0.491	0.066	0.252	0.192	0.419	0.058	0.279	0.244
4	0.459	0.083	0.259	0.198	0.378	0.071	0.293	0.258
5	0.431	0.099	0.266	0.205	0.343	0.082	0.305	0.271
6	0.405	0.113	0.272	0.210	0.312	0.091	0.315	0.282
7	0.381	0.126	0.278	0.216	0.285	0.099	0.324	0.292
8	0.359	0.137	0.283	0.221	0.259	0.106	0.333	0.302
9	0.339	0.147	0.288	0.225	0.236	0.112	0.341	0.311
10	0.321	0.157	0.293	0.230	0.216	0.117	0.348	0.319
15	0.252	0.190	0.310	0.248	0.161	0.126	0.368	0.345
20	0.207	0.211	0.322	0.261	0.139	0.125	0.376	0.360
25	0.175	0.224	0.331	0.271	0.128	0.123	0.379	0.370
30	0.150	0.233	0.337	0.280	0.121	0.120	0.382	0.378
35	0.131	0.239	0.343	0.287	0.114	0.118	0.383	0.385
40	0.115	0.244	0.347	0.294	0.108	0.117	0.384	0.391
45	0.102	0.248	0.351	0.299	0.103	0.117	0.384	0.396
50	0.091	0.251	0.353	0.304	0.098	0.117	0.385	0.401
55	0.082	0.254	0.355	0.309	0.093	0.117	0.385	0.405
60	0.074	0.256	0.357	0.313	0.089	0.117	0.385	0.409
65	0.067	0.258	0.358	0.317	0.085	0.118	0.385	0.412
70	0.061	0.260	0.359	0.320	0.081	0.119	0.385	0.415
75	0.056	0.261	0.360	0.323	0.078	0.120	0.385	0.418
80	0.051	0.263	0.361	0.326	0.074	0.121	0.385	0.420
85	0.047	0.264	0.361	0.328	0.071	0.122	0.385	0.422
90	0.043	0.265	0.361	0.331	0.068	0.123	0.385	0.424
95	0.040	0.266	0.361	0.333	0.066	0.124	0.385	0.426
100	0.037	0.267	0.361	0.335	0.063	0.125	0.385	0.427

Continued

Table 6.—continued

Year after production	South Central, Softwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.629	0.000	0.228	0.143	0.570	0.000	0.266	0.164
1	0.594	0.016	0.237	0.153	0.501	0.024	0.290	0.185
2	0.563	0.030	0.246	0.160	0.442	0.043	0.312	0.203
3	0.536	0.043	0.254	0.167	0.393	0.059	0.330	0.218
4	0.511	0.055	0.261	0.174	0.350	0.073	0.346	0.231
5	0.489	0.065	0.267	0.179	0.314	0.084	0.360	0.242
6	0.469	0.074	0.272	0.184	0.282	0.093	0.373	0.253
7	0.451	0.083	0.277	0.189	0.254	0.101	0.383	0.262
8	0.433	0.090	0.282	0.194	0.228	0.108	0.394	0.271
9	0.417	0.098	0.287	0.199	0.204	0.114	0.403	0.279
10	0.402	0.104	0.291	0.203	0.184	0.118	0.411	0.287
15	0.347	0.129	0.305	0.219	0.129	0.127	0.434	0.311
20	0.310	0.145	0.314	0.231	0.108	0.125	0.443	0.325
25	0.282	0.156	0.320	0.242	0.099	0.120	0.447	0.334
30	0.258	0.166	0.325	0.251	0.093	0.117	0.449	0.342
35	0.238	0.173	0.329	0.259	0.087	0.114	0.450	0.349
40	0.221	0.180	0.332	0.267	0.083	0.112	0.451	0.354
45	0.206	0.186	0.334	0.274	0.079	0.111	0.451	0.360
50	0.193	0.191	0.336	0.280	0.075	0.110	0.451	0.364
55	0.181	0.195	0.338	0.286	0.071	0.110	0.451	0.368
60	0.170	0.200	0.339	0.292	0.068	0.110	0.451	0.371
65	0.160	0.203	0.340	0.297	0.065	0.110	0.451	0.374
70	0.151	0.207	0.340	0.302	0.062	0.110	0.451	0.377
75	0.143	0.210	0.340	0.307	0.059	0.111	0.451	0.379
80	0.135	0.213	0.340	0.311	0.057	0.112	0.451	0.381
85	0.128	0.216	0.340	0.315	0.054	0.112	0.451	0.383
90	0.122	0.219	0.340	0.319	0.052	0.113	0.451	0.384
95	0.116	0.221	0.340	0.322	0.050	0.114	0.451	0.386
100	0.110	0.224	0.340	0.325	0.048	0.114	0.451	0.387

Continued

Table 6.—continued

Year after production	South Central, Hardwood							
	Saw log				Pulpwood			
	In use	Landfill	Energy	Emitted without energy	In use	Landfill	Energy	Emitted without energy
0	0.587	0.000	0.237	0.176	0.581	0.000	0.228	0.191
1	0.543	0.024	0.247	0.186	0.513	0.023	0.249	0.214
2	0.503	0.046	0.257	0.194	0.455	0.043	0.268	0.234
3	0.468	0.064	0.265	0.202	0.406	0.059	0.285	0.250
4	0.437	0.081	0.273	0.209	0.365	0.072	0.298	0.265
5	0.409	0.096	0.280	0.215	0.329	0.083	0.310	0.278
6	0.383	0.109	0.286	0.221	0.298	0.092	0.321	0.289
7	0.360	0.121	0.292	0.227	0.270	0.100	0.331	0.300
8	0.338	0.132	0.298	0.232	0.244	0.107	0.340	0.310
9	0.319	0.142	0.303	0.237	0.221	0.113	0.348	0.319
10	0.301	0.151	0.307	0.241	0.201	0.117	0.355	0.327
15	0.235	0.182	0.325	0.258	0.146	0.126	0.375	0.353
20	0.192	0.201	0.336	0.271	0.125	0.125	0.383	0.368
25	0.162	0.213	0.344	0.281	0.115	0.121	0.386	0.378
30	0.140	0.221	0.351	0.289	0.108	0.118	0.388	0.386
35	0.122	0.226	0.356	0.297	0.102	0.116	0.390	0.393
40	0.107	0.230	0.360	0.303	0.096	0.114	0.391	0.399
45	0.095	0.234	0.363	0.308	0.092	0.114	0.391	0.404
50	0.085	0.237	0.365	0.313	0.087	0.113	0.391	0.409
55	0.077	0.239	0.367	0.317	0.083	0.113	0.391	0.413
60	0.069	0.241	0.369	0.321	0.079	0.113	0.391	0.416
65	0.063	0.243	0.370	0.325	0.076	0.114	0.391	0.419
70	0.057	0.244	0.371	0.328	0.072	0.115	0.391	0.422
75	0.052	0.246	0.371	0.331	0.069	0.115	0.391	0.424
80	0.048	0.247	0.372	0.334	0.066	0.116	0.391	0.427
85	0.044	0.248	0.372	0.336	0.064	0.117	0.391	0.428
90	0.040	0.249	0.372	0.338	0.061	0.118	0.391	0.430
95	0.037	0.250	0.372	0.341	0.059	0.119	0.391	0.432
100	0.034	0.251	0.372	0.342	0.056	0.120	0.391	0.433

Continued

Table 6.—continued

Year after production	West, Hardwood			
	All			
	In use	Landfill	Energy	Emitted without energy
0	0.568	0.000	0.256	0.177
1	0.529	0.018	0.267	0.186
2	0.494	0.034	0.277	0.195
3	0.464	0.048	0.286	0.202
4	0.437	0.061	0.294	0.208
5	0.412	0.073	0.301	0.214
6	0.390	0.083	0.308	0.220
7	0.369	0.092	0.314	0.225
8	0.350	0.101	0.319	0.230
9	0.332	0.109	0.325	0.234
10	0.316	0.116	0.330	0.239
15	0.256	0.143	0.347	0.255
20	0.217	0.159	0.358	0.266
25	0.188	0.171	0.367	0.275
30	0.165	0.179	0.373	0.283
35	0.146	0.186	0.379	0.289
40	0.130	0.192	0.383	0.295
45	0.116	0.196	0.387	0.300
50	0.105	0.200	0.390	0.305
55	0.095	0.203	0.393	0.309
60	0.087	0.205	0.395	0.313
65	0.079	0.208	0.396	0.316
70	0.073	0.210	0.398	0.319
75	0.067	0.212	0.399	0.322
80	0.062	0.213	0.400	0.325
85	0.058	0.215	0.400	0.327
90	0.053	0.216	0.401	0.330
95	0.050	0.218	0.401	0.332
100	0.046	0.219	0.401	0.334

Table 7.—Factors to convert primary wood products to carbon mass from the units characteristic of each product

Solidwood product or paper	Unit	Factor to convert units to tons (2000 lb) carbon	Factor to convert units to tonnes carbon
Softwood lumber/laminated veneer lumber/glulam lumber/ I-joists	thousand board feet	0.488	0.443
Hardwood lumber	thousand board feet	0.844	0.765
Softwood plywood	thousand square feet, 3/8-inch basis	0.260	0.236
Oriented strandboard	thousand square feet, 3/8-inch basis	0.303	0.275
Non structural panels (average)	thousand square feet, 3/8-inch basis	0.319	0.289
Hardwood veneer/plywood	thousand square feet, 3/8-inch basis	0.315	0.286
Particleboard/medium density fiberboard	thousand square feet, 3/4-inch basis	0.647	0.587
Hardboard	thousand square feet,1/8-inch basis	0.152	0.138
Insulation board	thousand square feet, 1/2-inch basis	0.242	0.220
Other industrial products	thousand cubic feet	8.250	7.484
Paper	tons, air dry	0.450	0.496

Table 8.—Fraction of carbon in primary wood products remaining in end uses up to 100 years after production (year 0 indicates fraction at time of production, with fraction for year 1 the allocation after 1 year)

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
0	1	1	1	1	1	1	1
1	0.973	0.938	0.976	0.983	0.969	0.944	0.845
2	0.947	0.882	0.952	0.967	0.939	0.891	0.713
3	0.922	0.831	0.930	0.952	0.911	0.841	0.603
4	0.898	0.784	0.909	0.937	0.883	0.794	0.509
5	0.875	0.741	0.888	0.922	0.857	0.749	0.430
6	0.854	0.701	0.869	0.908	0.832	0.707	0.360
7	0.833	0.665	0.850	0.895	0.808	0.667	0.299
8	0.813	0.631	0.832	0.881	0.785	0.630	0.243
9	0.795	0.600	0.815	0.869	0.763	0.595	0.192
10	0.777	0.571	0.798	0.856	0.741	0.561	0.149
11	0.760	0.545	0.782	0.844	0.721	0.530	0.115
12	0.743	0.520	0.767	0.832	0.701	0.500	0.088
13	0.728	0.497	0.752	0.821	0.683	0.472	0.068
14	0.712	0.476	0.738	0.810	0.665	0.445	0.052
15	0.698	0.456	0.724	0.799	0.647	0.420	0.040
16	0.684	0.438	0.711	0.789	0.630	0.397	0.030
17	0.671	0.421	0.698	0.778	0.614	0.375	0.023
18	0.658	0.405	0.685	0.768	0.599	0.354	0.018
19	0.645	0.389	0.673	0.759	0.584	0.334	0.013
20	0.633	0.375	0.662	0.749	0.569	0.315	0.009
21	0.622	0.362	0.650	0.740	0.555	0.297	0.006
22	0.611	0.349	0.639	0.731	0.542	0.281	0.005
23	0.600	0.337	0.629	0.722	0.529	0.265	0.004
24	0.589	0.326	0.619	0.713	0.517	0.250	0.003
25	0.579	0.316	0.609	0.705	0.505	0.236	0.002
26	0.569	0.306	0.599	0.697	0.493	0.223	0.002
27	0.560	0.296	0.589	0.689	0.482	0.210	0.001
28	0.551	0.287	0.580	0.681	0.471	0.198	0.001
29	0.542	0.278	0.571	0.673	0.460	0.187	0.001
30	0.533	0.270	0.563	0.666	0.450	0.177	0.001
31	0.525	0.263	0.554	0.658	0.440	0.167	0.000
32	0.517	0.255	0.546	0.651	0.431	0.157	0.000
33	0.509	0.248	0.538	0.644	0.421	0.149	0.000
34	0.501	0.241	0.530	0.637	0.412	0.140	0.000
35	0.494	0.235	0.522	0.630	0.404	0.132	0.000
36	0.487	0.229	0.515	0.623	0.395	0.125	0.000
37	0.480	0.223	0.508	0.617	0.387	0.118	0.000
38	0.473	0.217	0.500	0.610	0.379	0.111	0.000
39	0.466	0.211	0.493	0.604	0.372	0.105	0.000
40	0.459	0.206	0.487	0.598	0.364	0.099	0.000

Continued

Table 8.—continued

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
41	0.453	0.201	0.480	0.592	0.357	0.094	0.000
42	0.447	0.196	0.474	0.586	0.350	0.088	0.000
43	0.441	0.191	0.467	0.580	0.343	0.083	0.000
44	0.435	0.187	0.461	0.574	0.337	0.079	0.000
45	0.429	0.183	0.455	0.568	0.330	0.074	0.000
46	0.423	0.178	0.449	0.563	0.324	0.070	0.000
47	0.418	0.174	0.443	0.557	0.318	0.066	0.000
48	0.413	0.170	0.437	0.552	0.312	0.063	0.000
49	0.407	0.166	0.432	0.546	0.306	0.059	0.000
50	0.402	0.163	0.426	0.541	0.301	0.056	0.000
55	0.378	0.146	0.401	0.516	0.275	0.042	0.000
60	0.356	0.131	0.377	0.493	0.252	0.031	0.000
65	0.336	0.119	0.356	0.471	0.232	0.023	0.000
70	0.318	0.108	0.336	0.450	0.214	0.018	0.000
75	0.301	0.098	0.318	0.431	0.198	0.013	0.000
80	0.286	0.090	0.301	0.413	0.183	0.010	0.000
85	0.271	0.082	0.286	0.395	0.170	0.007	0.000
90	0.258	0.075	0.271	0.379	0.159	0.006	0.000
95	0.246	0.069	0.258	0.364	0.148	0.004	0.000
100	0.234	0.064	0.245	0.349	0.138	0.003	0.000

Table 9.—Fraction of carbon in primary wood products remaining in landfills up to 100 years after production (year 0 indicates fraction at time of production, with fraction for year 1 the allocation after 1 year)

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
0	0	0	0	0	0	0	0
1	0.018	0.041	0.016	0.011	0.021	0.037	0.051
2	0.035	0.078	0.032	0.021	0.040	0.072	0.093
3	0.051	0.111	0.046	0.032	0.059	0.104	0.128
4	0.067	0.141	0.060	0.041	0.076	0.134	0.155
5	0.081	0.168	0.073	0.050	0.093	0.163	0.178
6	0.094	0.193	0.085	0.059	0.108	0.189	0.196
7	0.107	0.215	0.096	0.068	0.123	0.213	0.211
8	0.119	0.235	0.107	0.076	0.137	0.236	0.225
9	0.130	0.254	0.118	0.084	0.151	0.257	0.236
10	0.141	0.270	0.128	0.091	0.163	0.277	0.245
11	0.151	0.285	0.137	0.098	0.176	0.296	0.251
12	0.161	0.299	0.146	0.105	0.187	0.313	0.254
13	0.170	0.312	0.155	0.112	0.198	0.329	0.255
14	0.178	0.323	0.163	0.118	0.208	0.344	0.255
15	0.187	0.334	0.171	0.124	0.218	0.357	0.253
16	0.194	0.344	0.178	0.130	0.227	0.370	0.251
17	0.202	0.352	0.185	0.136	0.236	0.382	0.248
18	0.209	0.361	0.192	0.142	0.245	0.393	0.245
19	0.215	0.368	0.199	0.147	0.253	0.403	0.242
20	0.222	0.375	0.205	0.152	0.261	0.413	0.239
21	0.228	0.381	0.211	0.157	0.268	0.422	0.235
22	0.234	0.387	0.217	0.162	0.275	0.430	0.232
23	0.239	0.392	0.222	0.167	0.282	0.438	0.228
24	0.245	0.397	0.227	0.171	0.288	0.445	0.224
25	0.250	0.402	0.233	0.176	0.294	0.451	0.221
26	0.255	0.406	0.238	0.180	0.300	0.457	0.218
27	0.259	0.410	0.242	0.184	0.306	0.463	0.214
28	0.264	0.414	0.247	0.188	0.311	0.468	0.211
29	0.268	0.417	0.251	0.192	0.316	0.473	0.209
30	0.272	0.421	0.256	0.196	0.321	0.477	0.206
31	0.276	0.424	0.260	0.200	0.326	0.481	0.203
32	0.280	0.426	0.264	0.204	0.330	0.485	0.200
33	0.284	0.429	0.268	0.207	0.335	0.488	0.198
34	0.287	0.432	0.272	0.211	0.339	0.491	0.196
35	0.291	0.434	0.275	0.214	0.343	0.494	0.194
36	0.294	0.436	0.279	0.217	0.347	0.497	0.191
37	0.298	0.438	0.282	0.221	0.350	0.499	0.189
38	0.301	0.440	0.286	0.224	0.354	0.502	0.187
39	0.304	0.442	0.289	0.227	0.357	0.504	0.186
40	0.307	0.444	0.292	0.230	0.361	0.506	0.184

Continued

Table 9.—continued

Year after production	Softwood lumber	Hardwood lumber	Softwood plywood	Oriented strandboard	Non-structural panels	Miscel-laneous products	Paper
41	0.310	0.446	0.295	0.233	0.364	0.507	0.182
42	0.312	0.447	0.298	0.236	0.367	0.509	0.181
43	0.315	0.449	0.301	0.239	0.370	0.510	0.179
44	0.318	0.450	0.304	0.241	0.373	0.512	0.178
45	0.320	0.452	0.307	0.244	0.376	0.513	0.176
46	0.323	0.453	0.309	0.247	0.378	0.514	0.175
47	0.325	0.454	0.312	0.249	0.381	0.515	0.174
48	0.328	0.456	0.315	0.252	0.384	0.516	0.173
49	0.330	0.457	0.317	0.255	0.386	0.516	0.172
50	0.332	0.458	0.320	0.257	0.388	0.517	0.171
55	0.343	0.463	0.331	0.269	0.399	0.520	0.166
60	0.352	0.468	0.342	0.280	0.408	0.521	0.162
65	0.361	0.472	0.351	0.290	0.417	0.521	0.160
70	0.369	0.475	0.360	0.300	0.424	0.521	0.157
75	0.376	0.478	0.368	0.309	0.430	0.521	0.156
80	0.382	0.481	0.375	0.317	0.436	0.521	0.154
85	0.389	0.483	0.382	0.325	0.441	0.520	0.153
90	0.395	0.486	0.388	0.333	0.446	0.519	0.152
95	0.400	0.488	0.394	0.340	0.450	0.519	0.152
100	0.405	0.490	0.400	0.347	0.454	0.518	0.151

Table 10.—Confidence intervals for the estimates of carbon density for live and standing dead trees at the 50th and 99th percentiles of volume. The percentiles reflect the distribution of stand-level volume in survey data for the conterminous United States.[a] The 95-percent intervals about the expected carbon density are represented as the percentage of the carbon density; thus, the interval is ± the percentage.

	Volume at the 50th percentile					Volume at the 99th percentile				
Forest type-region[b]	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3*/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m*^{3}*/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Aspen-birch, Northeast	52	47	3.3	7	7.7	279	140	3.0	17	11.0
Maple-beech-birch, Northeast	118	87	1.0	13	4.3	361	194	1.4	18	7.6
Oak-hickory, Northeast	120	90	1.0	8	5.7	392	226	1.3	10	10.6
Oak-pine, Northeast	124	85	3.1	8	15.8	430	216	3.5	11	29.5
Spruce-balsam fir, Northeast	82	60	2.0	14	6.4	374	170	2.5	18	11.3
White-red-jack pine, Northeast	182	103	2.0	11	12.6	572	241	3.2	14	25.5
Aspen-birch, Northern Lake States	54	44	1.2	10	5.6	311	153	1.2	20	7.7
Elm-ash-cottonwood, Northern Lake States	60	54	2.3	11	9.2	514	270	2.2	18	16.3
Maple-beech-birch, Northern Lake States	108	84	0.8	10	4.8	348	207	1.0	12	9.1
Oak-hickory, Northern Lake States	84	80	1.0	8	5.4	343	230	1.3	12	10.4
Spruce-balsam fir, Northern Lake States	54	44	1.8	9	8.5	329	163	1.7	20	9.8
White-red-jack pine, Northern Lake States	101	61	2.4	10	12.0	725	267	2.6	16	24.2
Elm-ash-cottonwood, Northern Prairie States	76	66	3.7	9	17.5	514	271	2.2	18	16.3
Maple-beech-birch, Northern Prairie States	93	75	1.1	12	4.8	348	194	1.4	18	7.6
Oak-hickory, Northern Prairie States	77	76	1.0	8	5.5	343	202	1.1	10	9.7
Oak-pine, Northern Prairie States	59	52	3.4	7	15.3	355	159	2.8	10	22.6

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m^3/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Douglas-fir, Pacific Northwest, East	138	84	1.5	18	8.8	627	264	1.9	29	16.1
Fir-spruce-mountain hemlock, Pacific Northwest, East	216	98	1.5	31	6.3	746	268	1.4	48	11.1
Lodgepole pine, Pacific Northwest, East	65	36	4.1	10	22.6	528	123	2.3	23	15.9
Ponderosa pine, Pacific Northwest, East	100	51	1.9	8	13.8	508	187	1.7	17	18.7
Alder-maple, Pacific Northwest, West	190	88	4.4	25	25.5	1,005	352	4.2	55	38.3
Douglas-fir, Pacific Northwest, West	308	150	1.3	30	17.1	1,876	727	1.7	84	18.5
Douglas-fir, high productivity and high management intensity, Pacific Northwest, West	147	79	3.4	18	24.3	822	319	2.2	21	38.4
Fir-spruce-mountain hemlock, Pacific Northwest, West	360	179	3.1	49	12.6	1,342	527	3.2	84	20.4
Hemlock-Sitka spruce, Pacific Northwest, West	503	203	2.7	51	17.2	1,795	602	3.2	104	27.4
Hemlock-Sitka spruce, high productivity, Pacific Northwest, West	420	174	2.6	46	20.1	1,795	602	3.2	104	27.4
California mixed conifer, Pacific Southwest	241	121	1.9	28	7.5	983	397	1.8	66	9.4

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Volume at the 99th percentile Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m^3*/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m*^{3}*/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Fir-spruce-mountain hemlock, Pacific Southwest	352	175	3.1	48	12.7	1,342	475	2.7	80	18.8
Western oak, Pacific Southwest	66	61	3.9	9	21.8	570	310	3.5	18	33.5
Douglas-fir, Rocky Mountain, North	128	79	1.6	18	9.1	627	264	1.9	29	16.1
Fir-spruce-mountain hemlock, Rocky Mountain, North	170	81	1.5	29	6.9	746	271	1.4	49	11.2
Lodgepole pine, Rocky Mountain, North	135	58	2.4	14	12.9	528	152	3.2	27	20.1
Ponderosa pine, Rocky Mountain, North	51	30	3.7	6	11.8	508	183	1.7	17	18.6
Aspen-birch, Rocky Mountain, South	89	61	2.9	17	10.1	498	202	3.2	32	16.2
Douglas-fir, Rocky Mountain, South	115	83	2.9	20	13.2	546	270	3.6	40	21.0
Fir-spruce-mountain hemlock, Rocky Mountain, South	188	96	1.7	32	7.0	736	265	2.3	48	13.4
Lodgepole pine, Rocky Mountain, South	150	63	2.5	20	10.6	521	153	3.2	20	10.6
Ponderosa pine, Rocky Mountain, South	83	53	1.7	7	13.7	353	141	2.3	11	26.9
Loblolly-shortleaf pine, Southeast	75	47	2.1	4	10.5	636	210	1.6	8	15.7

Continued

Table 10.—Continued

Forest type-region[b]	Volume at the 50th percentile					Volume at the 99th percentile				
	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval	Growing stock volume	Live tree carbon density	Live tree confidence interval	Standing dead tree carbon density	Standing dead tree confidence interval
	m³/ha	*t C/ha*	*± percent*	*t C/ha*	*± percent*	*m³/ha*	*t C/ha*	*± percent*	*t C/ha*	*± percent*
Loblolly-shortleaf pine, high productivity and management intensity, Southeast	91	53	1.8	3	13.8	385	144	1.8	5	18.3
Longleaf-slash pine, Southeast	46	25	3.6	2	13.7	429	145	2.0	3	21.7
Longleaf-slash pine, high productivity and management intensity, Southeast	82	44	1.5	2	16.4	249	91	2.3	2	20.5
Oak-gum-cypress, Southeast	98	75	2.1	8	10.2	527	237	2.0	14	14.8
Oak-hickory, Southeast	104	81	1.3	7	7.5	536	263	1.4	11	13.1
Oak- pine, Southeast	61	48	2.5	4	9.3	462	201	2.0	9	13.9
Elm-ash-cottonwood, South Central	69	64	3.4	8	17.2	461	245	3.8	14	32.5
Loblolly-shortleaf pine, South Central	71	47	2.3	4	16.0	506	167	2.2	6	24.5
Loblolly-shortleaf pine, high productivity and management intensity, South Central	61	42	1.8	2	17.4	309	116	2.3	2	24.2
Oak-gum-cypress, South Central	100	81	2.0	7	10.9	534	244	2.5	9	21.4
Oak-hickory, South Central	79	69	1.0	5	6.5	390	206	1.2	7	11.9
Oak-pine, South Central	64	53	2.2	5	11.6	436	190	2.5	9	19.2

[a] Data from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005).

[b] These correspond to the table identifiers in Appendix A, B, and C.

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APPENDIX A

Forest Ecosystem Yield Tables for Reforestation[1]

Carbon Stocks on Forest Land After Clearcut Harvest

A1. Aspen-birch, Northeast
A2. Maple-beech-birch, Northeast
A3. Oak-hickory, Northeast
A4. Oak-pine, Northeast
A5. Spruce-balsam fir, Northeast
A6. White-red-jack pine, Northeast
A7. Aspen-birch, Northern Lake States
A8. Elm-ash-cottonwood, Northern Lake States
A9. Maple-beech-birch, Northern Lake States
A10. Oak-hickory, Northern Lake States
A11. Spruce-balsam fir, Northern Lake States
A12. White-red-jack pine, Northern Lake States
A13. Elm-ash-cottonwood, Northern Prairie States
A14. Maple-beech-birch, Northern Prairie States
A15. Oak-hickory, Northern Prairie States
A16. Oak-pine, Northern Prairie States
A17. Douglas-fir, Pacific Northwest, East
A18. Fir-spruce-mountain hemlock, Pacific Northwest, East
A19. Lodgepole pine, Pacific Northwest, East
A20. Ponderosa pine, Pacific Northwest, East
A21. Alder-maple, Pacific Northwest, West
A22. Douglas-fir, Pacific Northwest, West
A23. Douglas-fir, high productivity and high management intensity, Pacific Northwest, West
A24. Fir-spruce-mountain hemlock, Pacific Northwest, West
A25. Hemlock-Sitka spruce, Pacific Northwest, West
A26. Hemlock-Sitka spruce, high productivity, Pacific Northwest, West
A27. Mixed conifer, Pacific Southwest
A28. Fir-spruce-mountain hemlock, Pacific Southwest
A29. Western oak, Pacific Southwest
A30. Douglas-fir, Rocky Mountain, North
A31. Fir-spruce-mountain hemlock, Rocky Mountain, North
A32. Lodgepole pine, Rocky Mountain, North
A33. Ponderosa pine, Rocky Mountain, North
A34. Aspen-birch, Rocky Mountain, South
A35. Douglas-fir, Rocky Mountain, South
A36. Fir-spruce-mountain hemlock, Rocky Mountain, South
A37. Lodgepole pine, Rocky Mountain, South
A38. Ponderosa pine, Rocky Mountain, South
A39. Loblolly-shortleaf pine, Southeast
A40. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
A41. Longleaf-slash pine, Southeast
A42. Longleaf-slash pine, high productivity and management intensity, Southeast
A43. Oak-gum-cypress, Southeast
A44. Oak-hickory, Southeast
A45. Oak-pine, Southeast
A46. Elm-ash-cottonwood, South Central
A47. Loblolly-shortleaf pine, South Central
A48. Loblolly-shortleaf pine, high productivity and management intensity, South Central
A49. Oak-gum-cypress, South Central
A50. Oak-hickory, South Central
A51. Oak-pine, South Central

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[1] Note carbon mass is in metric tons (tonnes) in all tables.

A1.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*---------- tonnes carbon/hectare ----------*						
0	0.0	0.0	0.0	2.0	18.7	10.2	87.4	31.0
5	0.0	6.6	0.6	2.2	12.9	7.5	87.4	29.8
15	12.9	21.3	1.8	2.1	7.1	6.0	87.4	38.4
25	33.8	36.0	2.9	2.1	5.2	6.5	87.4	52.7
35	58.4	50.1	3.8	2.1	4.9	7.5	87.4	68.4
45	84.7	62.7	4.6	2.1	5.3	8.5	87.4	83.1
55	112.4	75.1	5.3	2.0	6.0	9.3	87.4	97.8
65	141.7	87.5	5.9	2.0	6.9	10.1	87.4	112.4
75	172.6	100.0	6.5	2.0	7.8	10.7	87.4	127.1
85	205.0	112.7	7.1	2.0	8.8	11.3	87.4	141.9
95	238.9	125.5	7.7	2.0	9.8	11.8	87.4	156.7
105	274.4	138.5	8.2	2.0	10.8	12.2	87.4	171.7
115	311.4	151.7	8.8	2.0	11.8	12.5	87.4	186.8
125	349.9	165.0	9.3	2.0	12.8	12.9	87.4	202.0
years	*ft^3/acre*	*---------- tonnes carbon/acre ----------*						
0	0	0.0	0.0	0.8	7.6	4.1	35.4	12.5
5	0	2.7	0.2	0.9	5.2	3.0	35.4	12.1
15	184	8.6	0.7	0.9	2.9	2.4	35.4	15.5
25	483	14.6	1.2	0.8	2.1	2.6	35.4	21.3
35	835	20.3	1.5	0.8	2.0	3.0	35.4	27.7
45	1,210	25.4	1.9	0.8	2.2	3.4	35.4	33.6
55	1,607	30.4	2.1	0.8	2.4	3.8	35.4	39.6
65	2,025	35.4	2.4	0.8	2.8	4.1	35.4	45.5
75	2,466	40.5	2.6	0.8	3.2	4.3	35.4	51.4
85	2,929	45.6	2.9	0.8	3.6	4.6	35.4	57.4
95	3,414	50.8	3.1	0.8	4.0	4.8	35.4	63.4
105	3,921	56.0	3.3	0.8	4.4	4.9	35.4	69.5
115	4,450	61.4	3.5	0.8	4.8	5.1	35.4	75.6
125	5,001	66.8	3.8	0.8	5.2	5.2	35.4	81.8

A2.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northeast

Age	Mean Volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	32.0	27.7	69.6	61.8
5	0.0	7.4	0.7	2.1	21.7	20.3	69.6	52.2
15	28.0	31.8	3.2	1.9	11.5	16.3	69.6	64.7
25	58.1	53.2	5.3	1.8	7.8	17.6	69.6	85.7
35	89.6	72.8	6.0	1.7	6.9	20.3	69.6	107.8
45	119.1	87.8	6.6	1.7	7.0	23.0	69.6	126.0
55	146.6	101.1	7.0	1.7	7.5	25.3	69.6	142.7
65	172.1	113.1	7.4	1.7	8.2	27.4	69.6	157.7
75	195.6	123.8	7.7	1.7	8.8	29.2	69.6	171.2
85	217.1	133.5	7.9	1.7	9.5	30.7	69.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.6	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.6	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.6	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.6	218.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	13.0	11.2	28.1	25.0
5	0	3.0	0.3	0.8	8.8	8.2	28.1	21.1
15	400	12.9	1.3	0.8	4.7	6.6	28.1	26.2
25	830	21.5	2.1	0.7	3.2	7.1	28.1	34.7
35	1,280	29.5	2.4	0.7	2.8	8.2	28.1	43.6
45	1,702	35.5	2.7	0.7	2.8	9.3	28.1	51.0
55	2,095	40.9	2.8	0.7	3.0	10.3	28.1	57.7
65	2,460	45.8	3.0	0.7	3.3	11.1	28.1	63.8
75	2,796	50.1	3.1	0.7	3.6	11.8	28.1	69.3
85	3,103	54.0	3.2	0.7	3.8	12.4	28.1	74.1
95	3,382	57.5	3.3	0.7	4.1	12.9	28.1	78.5
105	3,632	60.6	3.4	0.7	4.3	13.4	28.1	82.3
115	3,854	63.3	3.4	0.7	4.5	13.8	28.1	85.7
125	4,047	65.6	3.5	0.7	4.6	14.2	28.1	88.6

A3.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	46.7	8.2	53.1	56.9
5	0.0	6.9	0.7	2.1	31.4	5.7	53.1	46.7
15	54.5	43.0	3.6	1.9	16.5	4.1	53.1	69.1
25	95.7	71.9	4.0	1.9	10.8	4.5	53.1	93.0
35	135.3	96.2	4.2	1.8	9.2	5.3	53.1	116.8
45	173.3	118.2	4.5	1.8	9.2	6.3	53.1	139.9
55	209.6	136.8	4.6	1.8	9.9	7.3	53.1	160.3
65	244.3	154.3	4.8	1.8	10.8	8.1	53.1	179.7
75	277.4	170.6	4.9	1.8	11.8	8.9	53.1	198.0
85	308.9	186.0	5.0	1.8	12.8	9.7	53.1	215.2
95	338.8	200.4	5.1	1.8	13.7	10.3	53.1	231.3
105	367.1	213.9	5.1	1.7	14.6	10.9	53.1	246.4
115	393.7	226.5	5.2	1.7	15.5	11.5	53.1	260.5
125	418.6	238.2	5.3	1.7	16.3	12.0	53.1	273.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	18.9	3.3	21.5	23.0
5	0	2.8	0.3	0.8	12.7	2.3	21.5	18.9
15	779	17.4	1.4	0.8	6.7	1.7	21.5	28.0
25	1,368	29.1	1.6	0.7	4.4	1.8	21.5	37.7
35	1,934	38.9	1.7	0.7	3.7	2.2	21.5	47.3
45	2,477	47.8	1.8	0.7	3.7	2.6	21.5	56.6
55	2,996	55.4	1.9	0.7	4.0	2.9	21.5	64.9
65	3,492	62.4	1.9	0.7	4.4	3.3	21.5	72.7
75	3,965	69.1	2.0	0.7	4.8	3.6	21.5	80.1
85	4,415	75.3	2.0	0.7	5.2	3.9	21.5	87.1
95	4,842	81.1	2.0	0.7	5.6	4.2	21.5	93.6
105	5,246	86.6	2.1	0.7	5.9	4.4	21.5	99.7
115	5,626	91.7	2.1	0.7	6.3	4.7	21.5	105.4
125	5,983	96.4	2.1	0.7	6.6	4.9	21.5	110.7

A4.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m*^{3}*/hectare*	----------	----------	----------	*tonnes carbon/hectare*	----------	----------	----------
0	0.0	0.0	0.0	4.2	30.0	29.7	66.9	63.9
5	0.0	6.2	0.6	4.2	23.0	20.2	66.9	54.3
15	36.5	27.0	2.6	3.3	14.6	15.3	66.9	62.9
25	70.9	48.6	3.2	2.9	10.4	17.1	66.9	82.2
35	103.1	67.9	3.7	2.6	8.4	20.3	66.9	102.9
45	133.1	84.7	4.0	2.5	7.6	23.6	66.9	122.3
55	160.9	99.1	4.2	2.4	7.4	26.6	66.9	139.8
65	186.7	113.0	4.4	2.3	7.7	29.3	66.9	156.6
75	210.2	123.6	4.6	2.3	8.0	31.6	66.9	170.0
85	231.5	133.1	4.7	2.3	8.4	33.6	66.9	182.1
95	250.8	141.7	4.8	2.2	8.8	35.4	66.9	192.9
105	267.9	149.2	4.9	2.2	9.2	37.0	66.9	202.5
115	282.7	155.7	5.0	2.2	9.6	38.4	66.9	210.9
125	295.4	161.3	5.1	2.2	9.9	39.7	66.9	218.2
years	*ft*^{3}*/acre*	----------	----------	----------	*tonnes carbon/acre*	----------	----------	----------
0	0	0.0	0.0	1.7	12.1	12.0	27.1	25.9
5	0	2.5	0.3	1.7	9.3	8.2	27.1	22.0
15	522	10.9	1.1	1.3	5.9	6.2	27.1	25.4
25	1,013	19.7	1.3	1.2	4.2	6.9	27.1	33.3
35	1,473	27.5	1.5	1.1	3.4	8.2	27.1	41.7
45	1,902	34.3	1.6	1.0	3.1	9.6	27.1	49.5
55	2,300	40.1	1.7	1.0	3.0	10.8	27.1	56.6
65	2,668	45.7	1.8	0.9	3.1	11.8	27.1	63.4
75	3,004	50.0	1.8	0.9	3.2	12.8	27.1	68.8
85	3,309	53.9	1.9	0.9	3.4	13.6	27.1	73.7
95	3,584	57.3	1.9	0.9	3.6	14.3	27.1	78.1
105	3,828	60.4	2.0	0.9	3.7	15.0	27.1	82.0
115	4,040	63.0	2.0	0.9	3.9	15.6	27.1	85.4
125	4,222	65.3	2.1	0.9	4.0	16.1	27.1	88.3

A5.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	20.3	33.7	98.0	56.2
5	0.0	7.0	0.7	1.8	16.0	23.6	98.0	49.1
15	11.5	20.1	2.0	1.6	10.6	18.6	98.0	53.0
25	29.1	32.5	3.3	1.5	8.0	20.7	98.0	66.0
35	51.6	45.7	4.6	1.4	7.1	24.2	98.0	83.1
45	76.9	57.4	5.7	1.4	6.9	27.7	98.0	99.2
55	102.6	68.7	6.9	1.4	7.3	30.7	98.0	114.9
65	126.4	78.6	7.4	1.3	7.8	33.3	98.0	128.5
75	149.3	87.9	7.6	1.3	8.4	35.5	98.0	140.8
85	170.9	96.5	7.8	1.3	9.1	37.4	98.0	152.2
95	191.6	104.5	8.0	1.3	9.7	39.1	98.0	162.6
105	211.1	111.9	8.2	1.3	10.4	40.6	98.0	172.3
115	229.6	118.8	8.3	1.3	11.0	41.9	98.0	181.2
125	247.1	125.3	8.4	1.3	11.6	43.0	98.0	189.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	8.2	13.6	39.7	22.7
5	0	2.8	0.3	0.7	6.5	9.5	39.7	19.9
15	164	8.1	0.8	0.6	4.3	7.5	39.7	21.4
25	416	13.2	1.3	0.6	3.2	8.4	39.7	26.7
35	738	18.5	1.9	0.6	2.9	9.8	39.7	33.6
45	1,099	23.2	2.3	0.6	2.8	11.2	39.7	40.1
55	1,466	27.8	2.8	0.6	2.9	12.4	39.7	46.5
65	1,807	31.8	3.0	0.5	3.2	13.5	39.7	52.0
75	2,133	35.6	3.1	0.5	3.4	14.4	39.7	57.0
85	2,443	39.0	3.2	0.5	3.7	15.2	39.7	61.6
95	2,738	42.3	3.2	0.5	3.9	15.8	39.7	65.8
105	3,017	45.3	3.3	0.5	4.2	16.4	39.7	69.7
115	3,281	48.1	3.4	0.5	4.4	16.9	39.7	73.3
125	3,532	50.7	3.4	0.5	4.7	17.4	39.7	76.7

A6.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands on forest land after clearcut harvest in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	20.4	13.8	78.1	36.3
5	0.0	7.3	0.7	2.2	15.8	10.7	78.1	36.8
15	30.0	28.6	2.9	1.8	10.4	9.4	78.1	53.1
25	54.4	44.7	3.9	1.8	7.5	10.1	78.1	68.1
35	77.9	57.7	4.3	1.7	6.1	11.2	78.1	81.0
45	100.6	69.4	4.6	1.7	5.5	12.2	78.1	93.4
55	122.5	78.7	4.8	1.6	5.3	13.1	78.1	103.4
65	142.3	86.8	5.0	1.6	5.3	13.7	78.1	112.5
75	160.9	94.3	5.2	1.6	5.5	14.2	78.1	120.8
85	178.4	101.2	5.3	1.6	5.8	14.7	78.1	128.6
95	194.7	107.6	5.4	1.6	6.0	15.0	78.1	135.7
105	210.0	113.5	5.5	1.6	6.3	15.4	78.1	142.3
115	224.1	118.9	5.6	1.6	6.6	15.6	78.1	148.3
125	237.1	123.8	5.7	1.6	6.8	15.9	78.1	153.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	8.3	5.6	31.6	14.7
5	0	3.0	0.3	0.9	6.4	4.3	31.6	14.9
15	429	11.6	1.2	0.7	4.2	3.8	31.6	21.5
25	777	18.1	1.6	0.7	3.0	4.1	31.6	27.5
35	1,113	23.3	1.7	0.7	2.5	4.6	31.6	32.8
45	1,438	28.1	1.9	0.7	2.2	5.0	31.6	37.8
55	1,751	31.8	2.0	0.7	2.1	5.3	31.6	41.9
65	2,034	35.1	2.0	0.7	2.2	5.5	31.6	45.5
75	2,300	38.2	2.1	0.7	2.2	5.8	31.6	48.9
85	2,550	41.0	2.1	0.6	2.3	5.9	31.6	52.0
95	2,783	43.5	2.2	0.6	2.4	6.1	31.6	54.9
105	3,001	45.9	2.2	0.6	2.6	6.2	31.6	57.6
115	3,202	48.1	2.3	0.6	2.7	6.3	31.6	60.0
125	3,389	50.1	2.3	0.6	2.8	6.4	31.6	62.2

A7.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*-- tonnes carbon/hectare --*						
0	0.0	0.0	0.0	2.0	13.4	10.2	146.1	25.6
5	0.0	7.3	0.5	2.1	9.5	7.5	146.1	26.8
15	2.9	13.9	1.4	2.1	5.0	6.0	146.1	28.4
25	21.5	26.8	2.7	2.1	3.9	6.5	146.1	42.0
35	47.2	40.8	4.1	2.0	4.0	7.5	146.1	58.4
45	72.8	53.5	5.3	2.0	4.6	8.5	146.1	74.0
55	97.1	64.9	6.1	2.0	5.4	9.3	146.1	87.7
65	119.5	75.0	6.7	2.0	6.1	10.1	146.1	99.8
75	139.7	83.8	7.1	2.0	6.8	10.7	146.1	110.4
85	157.5	91.5	7.4	2.0	7.4	11.3	146.1	119.6
95	173.0	98.0	7.7	2.0	7.9	11.8	146.1	127.4
105	186.0	103.4	7.9	2.0	8.4	12.2	146.1	133.9
115	196.4	107.7	8.1	2.0	8.7	12.5	146.1	139.1
125	204.3	110.9	8.3	2.0	9.0	12.9	146.1	143.0
years	*ft^3/acre*	*-------------------------------------- tonnes carbon/acre --*						
0	0	0.0	0.0	0.8	5.4	4.1	59.1	10.4
5	0	3.0	0.2	0.8	3.8	3.0	59.1	10.9
15	42	5.6	0.6	0.8	2.0	2.4	59.1	11.5
25	307	10.9	1.1	0.8	1.6	2.6	59.1	17.0
35	674	16.5	1.6	0.8	1.6	3.0	59.1	23.6
45	1,041	21.6	2.2	0.8	1.9	3.4	59.1	29.9
55	1,388	26.2	2.5	0.8	2.2	3.8	59.1	35.5
65	1,708	30.3	2.7	0.8	2.5	4.1	59.1	40.4
75	1,996	33.9	2.9	0.8	2.8	4.3	59.1	44.7
85	2,251	37.0	3.0	0.8	3.0	4.6	59.1	48.4
95	2,472	39.7	3.1	0.8	3.2	4.8	59.1	51.6
105	2,658	41.8	3.2	0.8	3.4	4.9	59.1	54.2
115	2,807	43.6	3.3	0.8	3.5	5.1	59.1	56.3
125	2,920	44.9	3.3	0.8	3.6	5.2	59.1	57.9

A8.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	9.4	27.7	179.9	39.2
5	0.0	3.9	0.4	1.9	6.5	20.3	179.9	33.0
15	2.4	10.3	1.0	1.9	3.4	16.3	179.9	32.9
25	13.2	20.1	2.0	1.9	2.4	17.6	179.9	44.1
35	25.2	29.8	3.0	1.9	2.4	20.3	179.9	57.3
45	37.4	38.7	3.9	1.9	2.6	23.0	179.9	70.1
55	49.8	47.1	4.7	1.9	3.0	25.3	179.9	82.1
65	62.3	55.6	5.3	1.9	3.5	27.4	179.9	93.8
75	74.9	62.8	5.6	1.9	3.9	29.2	179.9	103.4
85	87.5	69.9	5.8	1.9	4.3	30.7	179.9	112.6
95	100.1	76.8	6.0	1.9	4.7	32.0	179.9	121.4
105	112.9	83.6	6.2	1.9	5.1	33.1	179.9	130.0
115	125.8	90.4	6.4	1.9	5.6	34.2	179.9	138.5
125	139.2	97.4	6.5	1.9	6.0	35.1	179.9	147.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	3.8	11.2	72.8	15.8
5	0	1.6	0.2	0.8	2.6	8.2	72.8	13.3
15	35	4.2	0.4	0.8	1.4	6.6	72.8	13.3
25	189	8.1	0.8	0.8	1.0	7.1	72.8	17.8
35	360	12.0	1.2	0.8	1.0	8.2	72.8	23.2
45	535	15.7	1.6	0.8	1.1	9.3	72.8	28.4
55	712	19.1	1.9	0.8	1.2	10.3	72.8	33.2
65	890	22.5	2.2	0.8	1.4	11.1	72.8	38.0
75	1,070	25.4	2.3	0.8	1.6	11.8	72.8	41.8
85	1,250	28.3	2.4	0.8	1.7	12.4	72.8	45.6
95	1,431	31.1	2.4	0.8	1.9	12.9	72.8	49.1
105	1,613	33.8	2.5	0.8	2.1	13.4	72.8	52.6
115	1,798	36.6	2.6	0.8	2.2	13.8	72.8	56.0
125	1,990	39.4	2.7	0.8	2.4	14.2	72.8	59.5

A9.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under- story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	19.5	27.7	134.3	49.4
5	0.0	5.1	0.5	2.0	13.3	20.3	134.3	41.2
15	4.3	13.4	1.3	1.7	6.7	16.3	134.3	39.4
25	24.6	30.3	3.0	1.6	4.8	17.6	134.3	57.3
35	48.1	47.7	4.0	1.5	4.7	20.3	134.3	78.2
45	72.5	62.9	4.4	1.4	5.2	23.0	134.3	96.9
55	96.9	77.3	4.7	1.4	6.1	25.3	134.3	114.8
65	121.3	91.1	4.9	1.4	7.0	27.4	134.3	131.8
75	145.3	104.4	5.1	1.4	8.0	29.2	134.3	148.0
85	168.9	117.1	5.3	1.3	8.9	30.7	134.3	163.3
95	191.9	129.3	5.4	1.3	9.8	32.0	134.3	177.8
105	214.4	140.9	5.6	1.3	10.7	33.1	134.3	191.6
115	236.0	151.9	5.7	1.3	11.5	34.2	134.3	204.6
125	256.9	162.4	5.8	1.3	12.3	35.1	134.3	216.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	7.9	11.2	54.3	20.0
5	0	2.1	0.2	0.8	5.4	8.2	54.3	16.7
15	62	5.4	0.5	0.7	2.7	6.6	54.3	16.0
25	351	12.2	1.2	0.6	1.9	7.1	54.3	23.2
35	688	19.3	1.6	0.6	1.9	8.2	54.3	31.7
45	1,036	25.4	1.8	0.6	2.1	9.3	54.3	39.2
55	1,385	31.3	1.9	0.6	2.5	10.3	54.3	46.5
65	1,733	36.9	2.0	0.6	2.8	11.1	54.3	53.4
75	2,076	42.2	2.1	0.6	3.2	11.8	54.3	59.9
85	2,414	47.4	2.1	0.5	3.6	12.4	54.3	66.1
95	2,743	52.3	2.2	0.5	4.0	12.9	54.3	72.0
105	3,064	57.0	2.3	0.5	4.3	13.4	54.3	77.5
115	3,373	61.5	2.3	0.5	4.7	13.8	54.3	82.8
125	3,671	65.7	2.3	0.5	5.0	14.2	54.3	87.8

A10.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	20.5	8.2	97.1	30.8
5	0.0	6.7	0.7	2.2	14.1	5.7	97.1	29.3
15	4.1	17.0	1.7	2.0	7.3	4.1	97.1	32.1
25	21.9	33.6	3.1	1.9	5.2	4.5	97.1	48.2
35	42.5	50.3	3.6	1.8	5.0	5.3	97.1	66.1
45	64.9	66.7	3.9	1.8	5.7	6.3	97.1	84.4
55	88.7	83.6	4.2	1.8	6.7	7.3	97.1	103.5
65	113.4	99.1	4.5	1.7	7.8	8.1	97.1	121.2
75	139.0	114.7	4.7	1.7	8.9	8.9	97.1	139.0
85	165.2	130.3	4.9	1.7	10.1	9.7	97.1	156.7
95	192.1	146.0	5.1	1.7	11.3	10.3	97.1	174.4
105	219.2	161.6	5.3	1.7	12.5	10.9	97.1	192.0
115	246.4	177.0	5.4	1.6	13.7	11.5	97.1	209.2
125	272.5	191.6	5.5	1.6	14.8	12.0	97.1	225.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	8.3	3.3	39.3	12.5
5	0	2.7	0.3	0.9	5.7	2.3	39.3	11.9
15	58	6.9	0.7	0.8	2.9	1.7	39.3	13.0
25	313	13.6	1.2	0.8	2.1	1.8	39.3	19.5
35	608	20.4	1.4	0.7	2.0	2.2	39.3	26.7
45	928	27.0	1.6	0.7	2.3	2.6	39.3	34.2
55	1,267	33.8	1.7	0.7	2.7	2.9	39.3	41.9
65	1,620	40.1	1.8	0.7	3.1	3.3	39.3	49.0
75	1,986	46.4	1.9	0.7	3.6	3.6	39.3	56.2
85	2,361	52.7	2.0	0.7	4.1	3.9	39.3	63.4
95	2,745	59.1	2.1	0.7	4.6	4.2	39.3	70.6
105	3,133	65.4	2.1	0.7	5.1	4.4	39.3	77.7
115	3,521	71.6	2.2	0.7	5.5	4.7	39.3	84.7
125	3,895	77.5	2.2	0.7	6.0	4.9	39.3	91.3

A11.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	16.0	33.7	261.8	51.9
5	0.0	3.4	0.3	2.1	12.4	23.6	261.8	41.8
15	3.0	9.3	0.9	2.6	7.7	18.6	261.8	39.1
25	23.2	24.3	2.4	1.9	6.1	20.7	261.8	55.3
35	51.1	41.2	4.1	1.6	5.8	24.2	261.8	77.0
45	77.2	56.0	5.1	1.5	6.1	27.7	261.8	96.4
55	100.7	67.4	5.8	1.4	6.6	30.7	261.8	111.9
65	121.6	77.2	6.4	1.3	7.1	33.3	261.8	125.2
75	140.2	85.5	6.8	1.3	7.6	35.5	261.8	136.8
85	156.5	92.8	7.2	1.2	8.2	37.4	261.8	146.8
95	170.9	99.0	7.5	1.2	8.6	39.1	261.8	155.4
105	183.5	104.3	7.7	1.2	9.1	40.6	261.8	162.9
115	194.4	109.0	7.9	1.2	9.5	41.9	261.8	169.4
125	203.8	112.9	8.1	1.2	9.8	43.0	261.8	174.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	6.5	13.6	105.9	21.0
5	0	1.4	0.1	0.9	5.0	9.5	105.9	16.9
15	43	3.7	0.4	1.0	3.1	7.5	105.9	15.8
25	332	9.8	1.0	0.8	2.5	8.4	105.9	22.4
35	730	16.7	1.7	0.7	2.4	9.8	105.9	31.2
45	1,103	22.7	2.1	0.6	2.5	11.2	105.9	39.0
55	1,439	27.3	2.4	0.6	2.7	12.4	105.9	45.3
65	1,738	31.2	2.6	0.5	2.9	13.5	105.9	50.7
75	2,003	34.6	2.7	0.5	3.1	14.4	105.9	55.4
85	2,237	37.5	2.9	0.5	3.3	15.2	105.9	59.4
95	2,442	40.1	3.0	0.5	3.5	15.8	105.9	62.9
105	2,622	42.2	3.1	0.5	3.7	16.4	105.9	65.9
115	2,778	44.1	3.2	0.5	3.8	16.9	105.9	68.5
125	2,912	45.7	3.3	0.5	4.0	17.4	105.9	70.8

A12.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands on forest land after clearcut harvest in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	-- *tonnes carbon/hectare* --						
0	0.0	0.0	0.0	2.0	25.5	13.8	120.8	41.3
5	0.0	0.4	0.0	2.0	19.3	10.7	120.8	32.5
15	6.6	8.0	0.8	2.0	11.6	9.4	120.8	31.8
25	48.1	35.4	3.5	2.0	8.8	10.1	120.8	59.9
35	104.7	62.9	4.9	2.0	8.1	11.2	120.8	89.1
45	158.9	85.8	5.5	2.0	8.2	12.2	120.8	113.7
55	209.1	105.3	5.9	2.0	8.8	13.1	120.8	135.0
65	255.1	122.2	6.2	2.0	9.5	13.7	120.8	153.6
75	297.4	137.1	6.5	2.0	10.3	14.2	120.8	170.0
85	336.1	150.3	6.7	2.0	11.0	14.7	120.8	184.6
95	371.7	162.0	6.9	2.0	11.8	15.0	120.8	197.7
105	404.2	172.5	7.0	2.0	12.5	15.4	120.8	209.3
115	434.0	182.0	7.2	2.0	13.1	15.6	120.8	219.8
125	461.3	190.5	7.3	1.9	13.7	15.9	120.8	229.3
years	*ft^3/acre*	-------------------------------------- *tonnes carbon/acre* --						
0	0	0.0	0.0	0.8	10.3	5.6	48.9	16.7
5	0	0.2	0.0	0.8	7.8	4.3	48.9	13.2
15	94	3.3	0.3	0.8	4.7	3.8	48.9	12.9
25	688	14.3	1.4	0.8	3.6	4.1	48.9	24.2
35	1,496	25.5	2.0	0.8	3.3	4.6	48.9	36.1
45	2,271	34.7	2.2	0.8	3.3	5.0	48.9	46.0
55	2,988	42.6	2.4	0.8	3.5	5.3	48.9	54.6
65	3,646	49.5	2.5	0.8	3.8	5.5	48.9	62.2
75	4,250	55.5	2.6	0.8	4.1	5.8	48.9	68.8
85	4,804	60.8	2.7	0.8	4.5	5.9	48.9	74.7
95	5,312	65.6	2.8	0.8	4.8	6.1	48.9	80.0
105	5,777	69.8	2.8	0.8	5.1	6.2	48.9	84.7
115	6,203	73.6	2.9	0.8	5.3	6.3	48.9	89.0
125	6,593	77.1	2.9	0.8	5.6	6.4	48.9	92.8

A13.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	11.3	27.7	84.8	41.0
5	0.0	3.9	0.4	2.1	7.7	20.3	84.8	34.4
15	0.0	8.7	0.9	2.7	3.9	16.3	84.8	32.4
25	5.8	15.5	1.6	2.4	2.5	17.6	84.8	39.7
35	21.8	27.7	2.8	2.2	2.5	20.3	84.8	55.5
45	45.1	43.2	4.3	2.0	3.3	23.0	84.8	75.7
55	73.0	60.2	5.6	1.9	4.3	25.3	84.8	97.2
65	104.1	78.9	6.1	1.8	5.5	27.4	84.8	119.7
75	137.4	96.5	6.5	1.8	6.7	29.2	84.8	140.6
85	171.9	114.0	6.9	1.7	7.9	30.7	84.8	161.2
95	206.8	131.3	7.2	1.7	9.1	32.0	84.8	181.3
105	241.7	148.2	7.5	1.6	10.3	33.1	84.8	200.7
115	275.8	164.3	7.8	1.6	11.4	34.2	84.8	219.2
125	308.6	179.6	8.0	1.6	12.4	35.1	84.8	236.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	4.6	11.2	34.3	16.6
5	0	1.6	0.2	0.8	3.1	8.2	34.3	13.9
15	0	3.5	0.4	1.1	1.6	6.6	34.3	13.1
25	83	6.3	0.6	1.0	1.0	7.1	34.3	16.1
35	312	11.2	1.1	0.9	1.0	8.2	34.3	22.5
45	644	17.5	1.7	0.8	1.3	9.3	34.3	30.6
55	1,043	24.3	2.3	0.8	1.7	10.3	34.3	39.4
65	1,488	31.9	2.5	0.7	2.2	11.1	34.3	48.5
75	1,964	39.0	2.6	0.7	2.7	11.8	34.3	56.9
85	2,456	46.1	2.8	0.7	3.2	12.4	34.3	65.2
95	2,956	53.1	2.9	0.7	3.7	12.9	34.3	73.4
105	3,454	60.0	3.0	0.7	4.2	13.4	34.3	81.2
115	3,941	66.5	3.2	0.6	4.6	13.8	34.3	88.7
125	4,410	72.7	3.2	0.6	5.0	14.2	34.3	95.8

A14.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	12.8	27.7	64.9	42.6
5	0.0	5.1	0.5	2.2	8.8	20.3	64.9	37.0
15	0.9	10.5	1.1	1.9	4.4	16.3	64.9	34.2
25	8.2	18.5	1.8	1.7	2.8	17.6	64.9	42.5
35	21.4	29.7	3.0	1.6	2.6	20.3	64.9	57.1
45	38.2	41.3	3.8	1.5	2.9	23.0	64.9	72.4
55	57.4	53.6	4.2	1.4	3.5	25.3	64.9	88.1
65	78.6	66.5	4.5	1.3	4.3	27.4	64.9	104.0
75	101.0	79.6	4.7	1.3	5.1	29.2	64.9	119.9
85	124.4	92.9	4.9	1.2	5.9	30.7	64.9	135.7
95	148.6	106.2	5.1	1.2	6.7	32.0	64.9	151.3
105	173.1	119.4	5.3	1.2	7.6	33.1	64.9	166.6
115	197.4	132.1	5.5	1.2	8.4	34.2	64.9	181.3
125	220.5	144.0	5.6	1.1	9.1	35.1	64.9	195.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	5.2	11.2	26.2	17.3
5	0	2.1	0.2	0.9	3.6	8.2	26.2	15.0
15	13	4.3	0.4	0.8	1.8	6.6	26.2	13.8
25	117	7.5	0.7	0.7	1.1	7.1	26.2	17.2
35	306	12.0	1.2	0.6	1.0	8.2	26.2	23.1
45	546	16.7	1.5	0.6	1.2	9.3	26.2	29.3
55	821	21.7	1.7	0.6	1.4	10.3	26.2	35.6
65	1,123	26.9	1.8	0.5	1.7	11.1	26.2	42.1
75	1,443	32.2	1.9	0.5	2.1	11.8	26.2	48.5
85	1,778	37.6	2.0	0.5	2.4	12.4	26.2	54.9
95	2,123	43.0	2.1	0.5	2.7	12.9	26.2	61.2
105	2,474	48.3	2.2	0.5	3.1	13.4	26.2	67.4
115	2,821	53.5	2.2	0.5	3.4	13.8	26.2	73.4
125	3,151	58.3	2.3	0.5	3.7	14.2	26.2	78.9

A15.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	14.1	8.2	45.9	24.4
5	0.0	6.7	0.6	2.4	9.8	5.7	45.9	25.1
15	2.1	15.6	1.6	2.1	5.2	4.1	45.9	28.6
25	13.0	27.5	2.7	2.0	3.7	4.5	45.9	40.3
35	27.4	40.0	3.2	1.9	3.5	5.3	45.9	53.9
45	43.0	52.2	3.6	1.8	3.9	6.3	45.9	67.8
55	59.1	64.3	3.9	1.8	4.5	7.3	45.9	81.7
65	74.9	74.7	4.1	1.7	5.1	8.1	45.9	93.8
75	90.2	84.6	4.3	1.7	5.7	8.9	45.9	105.2
85	104.7	93.7	4.4	1.7	6.3	9.7	45.9	115.8
95	118.3	102.1	4.5	1.6	6.9	10.3	45.9	125.6
105	130.8	109.7	4.7	1.6	7.4	10.9	45.9	134.4
115	142.0	116.5	4.7	1.6	7.9	11.5	45.9	142.3
125	151.9	122.5	4.8	1.6	8.3	12.0	45.9	149.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	5.7	3.3	18.6	9.9
5	0	2.7	0.2	1.0	4.0	2.3	18.6	10.2
15	30	6.3	0.6	0.9	2.1	1.7	18.6	11.6
25	186	11.1	1.1	0.8	1.5	1.8	18.6	16.3
35	391	16.2	1.3	0.8	1.4	2.2	18.6	21.8
45	615	21.1	1.4	0.7	1.6	2.6	18.6	27.4
55	844	26.0	1.6	0.7	1.8	2.9	18.6	33.0
65	1,070	30.2	1.7	0.7	2.1	3.3	18.6	37.9
75	1,289	34.2	1.7	0.7	2.3	3.6	18.6	42.6
85	1,497	37.9	1.8	0.7	2.6	3.9	18.6	46.9
95	1,691	41.3	1.8	0.7	2.8	4.2	18.6	50.8
105	1,869	44.4	1.9	0.7	3.0	4.4	18.6	54.4
115	2,030	47.2	1.9	0.7	3.2	4.7	18.6	57.6
125	2,171	49.6	2.0	0.7	3.3	4.9	18.6	60.4

A16.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Northern Prairie States

		Mean carbon density						
Age	Mean volume	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	17.8	29.7	36.2	51.7
5	0.0	5.1	0.4	4.2	13.8	20.2	36.2	43.8
15	4.5	13.8	1.2	4.3	8.7	15.3	36.2	43.2
25	28.4	29.8	2.6	3.6	6.5	17.1	36.2	59.5
35	57.9	47.4	3.4	3.3	5.8	20.3	36.2	80.2
45	86.7	63.3	4.0	3.1	5.8	23.6	36.2	99.8
55	113.2	77.0	4.4	2.9	6.2	26.6	36.2	117.1
65	137.1	89.4	4.7	2.9	6.7	29.3	36.2	132.9
75	158.1	98.9	5.0	2.8	7.1	31.6	36.2	145.4
85	176.0	106.8	5.2	2.7	7.5	33.6	36.2	155.9
95	190.8	113.3	5.4	2.7	7.9	35.4	36.2	164.7
105	202.4	118.3	5.5	2.7	8.2	37.0	36.2	171.7
115	210.9	121.9	5.6	2.7	8.5	38.4	36.2	177.1
125	216.1	124.1	5.7	2.7	8.6	39.7	36.2	180.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	7.2	12.0	14.6	20.9
5	0	2.1	0.2	1.7	5.6	8.2	14.6	17.7
15	65	5.6	0.5	1.7	3.5	6.2	14.6	17.5
25	406	12.1	1.0	1.5	2.6	6.9	14.6	24.1
35	828	19.2	1.4	1.3	2.3	8.2	14.6	32.5
45	1,239	25.6	1.6	1.2	2.4	9.6	14.6	40.4
55	1,618	31.2	1.8	1.2	2.5	10.8	14.6	47.4
65	1,959	36.2	1.9	1.2	2.7	11.8	14.6	53.8
75	2,259	40.0	2.0	1.1	2.9	12.8	14.6	58.8
85	2,515	43.2	2.1	1.1	3.1	13.6	14.6	63.1
95	2,727	45.8	2.2	1.1	3.2	14.3	14.6	66.6
105	2,893	47.9	2.2	1.1	3.3	15.0	14.6	69.5
115	3,014	49.3	2.3	1.1	3.4	15.6	14.6	71.7
125	3,088	50.2	2.3	1.1	3.5	16.1	14.6	73.2

A17.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	26.0	37.2	94.8	67.8
5	0.0	2.7	0.3	4.4	22.5	35.4	94.8	65.2
15	3.8	8.7	0.9	4.1	17.2	32.9	94.8	63.7
25	47.7	38.3	3.8	3.7	15.9	31.8	94.8	93.5
35	119.0	75.1	7.5	3.6	16.5	31.6	94.8	134.2
45	184.7	104.0	10.0	3.5	17.1	32.0	94.8	166.5
55	241.8	127.3	10.9	3.4	17.8	32.7	94.8	192.1
65	290.9	146.4	11.5	3.4	18.5	33.6	94.8	213.5
75	332.7	162.2	12.0	3.4	19.2	34.6	94.8	231.4
85	368.3	175.3	12.4	3.4	19.8	35.6	94.8	246.5
95	398.6	186.2	12.7	3.4	20.5	36.6	94.8	259.3
105	424.4	195.4	13.0	3.3	21.0	37.5	94.8	270.2
115	446.4	203.1	13.2	3.3	21.6	38.4	94.8	279.5
125	465.2	209.6	13.3	3.3	22.0	39.2	94.8	287.5
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	10.5	15.1	38.3	27.4
5	0	1.1	0.1	1.8	9.1	14.3	38.3	26.4
15	54	3.5	0.4	1.7	7.0	13.3	38.3	25.8
25	682	15.5	1.5	1.5	6.4	12.9	38.3	37.8
35	1,701	30.4	3.0	1.4	6.7	12.8	38.3	54.3
45	2,639	42.1	4.1	1.4	6.9	12.9	38.3	67.4
55	3,456	51.5	4.4	1.4	7.2	13.2	38.3	77.8
65	4,157	59.3	4.7	1.4	7.5	13.6	38.3	86.4
75	4,755	65.6	4.9	1.4	7.8	14.0	38.3	93.6
85	5,264	70.9	5.0	1.4	8.0	14.4	38.3	99.8
95	5,697	75.4	5.1	1.4	8.3	14.8	38.3	104.9
105	6,065	79.1	5.2	1.4	8.5	15.2	38.3	109.4
115	6,379	82.2	5.3	1.4	8.7	15.5	38.3	113.1
125	6,648	84.8	5.4	1.3	8.9	15.8	38.3	116.3

A18.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	16.6	37.2	62.1	58.6
5	0.0	3.1	0.3	4.1	14.5	35.4	62.1	57.4
15	0.0	5.8	0.6	3.7	11.0	32.9	62.1	54.0
25	15.2	15.5	1.6	3.2	9.3	31.8	62.1	61.3
35	52.1	33.9	3.4	2.8	9.2	31.6	62.1	80.9
45	97.4	53.0	5.3	2.6	9.7	32.0	62.1	102.6
55	144.4	71.3	7.1	2.5	10.6	32.7	62.1	124.3
65	189.7	88.3	8.8	2.4	11.6	33.6	62.1	144.7
75	231.5	103.3	10.3	2.4	12.6	34.6	62.1	163.2
85	268.7	116.4	11.6	2.3	13.6	35.6	62.1	179.6
95	301.0	127.6	12.8	2.3	14.4	36.6	62.1	193.6
105	328.2	136.9	13.7	2.3	15.2	37.5	62.1	205.5
115	350.6	144.4	14.4	2.2	15.8	38.4	62.1	215.2
125	368.3	150.3	15.0	2.2	16.3	39.2	62.1	223.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	6.7	15.1	25.1	23.7
5	0	1.3	0.1	1.7	5.9	14.3	25.1	23.2
15	0	2.3	0.2	1.5	4.5	13.3	25.1	21.9
25	217	6.3	0.6	1.3	3.8	12.9	25.1	24.8
35	745	13.7	1.4	1.1	3.7	12.8	25.1	32.8
45	1,392	21.4	2.1	1.1	3.9	12.9	25.1	41.5
55	2,063	28.9	2.9	1.0	4.3	13.2	25.1	50.3
65	2,711	35.7	3.6	1.0	4.7	13.6	25.1	58.6
75	3,308	41.8	4.2	1.0	5.1	14.0	25.1	66.1
85	3,840	47.1	4.7	0.9	5.5	14.4	25.1	72.7
95	4,302	51.6	5.2	0.9	5.8	14.8	25.1	78.4
105	4,691	55.4	5.5	0.9	6.1	15.2	25.1	83.2
115	5,010	58.4	5.8	0.9	6.4	15.5	25.1	87.1
125	5,264	60.8	6.1	0.9	6.6	15.8	25.1	90.3

A19.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	13.1	24.1	52.0	42.0
5	0.0	1.9	0.2	4.8	11.4	22.0	52.0	40.2
15	6.6	8.1	0.8	3.5	9.0	19.4	52.0	40.7
25	40.8	24.3	2.4	2.6	8.3	18.3	52.0	56.0
35	81.7	40.1	4.0	2.3	8.2	18.2	52.0	72.8
45	120.5	54.0	5.4	2.2	8.3	18.7	52.0	88.5
55	156.3	64.5	6.4	2.1	8.4	19.4	52.0	100.8
65	189.3	73.6	7.4	2.0	8.6	20.4	52.0	111.9
75	219.9	81.7	8.2	1.9	8.9	21.4	52.0	122.0
85	248.0	88.9	8.9	1.9	9.2	22.4	52.0	131.2
95	274.0	95.4	9.5	1.9	9.6	23.3	52.0	139.7
105	298.2	101.2	10.1	1.8	9.9	24.3	52.0	147.4
115	320.5	106.5	10.6	1.8	10.3	25.2	52.0	154.4
125	341.2	111.4	10.9	1.8	10.6	26.0	52.0	160.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	5.3	9.8	21.1	17.0
5	0	0.8	0.1	2.0	4.6	8.9	21.1	16.3
15	95	3.3	0.3	1.4	3.6	7.8	21.1	16.5
25	583	9.8	1.0	1.1	3.4	7.4	21.1	22.7
35	1,168	16.2	1.6	0.9	3.3	7.4	21.1	29.5
45	1,722	21.8	2.2	0.9	3.3	7.6	21.1	35.8
55	2,234	26.1	2.6	0.8	3.4	7.9	21.1	40.8
65	2,706	29.8	3.0	0.8	3.5	8.2	21.1	45.3
75	3,142	33.1	3.3	0.8	3.6	8.6	21.1	49.4
85	3,544	36.0	3.6	0.8	3.7	9.1	21.1	53.1
95	3,916	38.6	3.9	0.8	3.9	9.4	21.1	56.5
105	4,261	41.0	4.1	0.7	4.0	9.8	21.1	59.6
115	4,580	43.1	4.3	0.7	4.2	10.2	21.1	62.5
125	4,876	45.1	4.4	0.7	4.3	10.5	21.1	65.0

A20.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	9.6	24.1	50.7	38.5
5	0.0	3.3	0.3	4.6	8.5	22.0	50.7	38.6
15	4.1	7.9	0.8	3.8	6.8	19.4	50.7	38.7
25	21.6	17.3	1.7	3.2	6.2	18.3	50.7	46.7
35	40.8	26.2	2.6	2.9	5.9	18.2	50.7	55.9
45	61.4	34.9	3.3	2.8	6.0	18.7	50.7	65.5
55	83.3	43.6	3.7	2.6	6.3	19.4	50.7	75.7
65	106.0	52.5	4.2	2.5	6.7	20.4	50.7	86.2
75	129.3	61.3	4.6	2.4	7.3	21.4	50.7	96.9
85	153.0	70.0	4.9	2.4	7.9	22.4	50.7	107.6
95	176.8	78.6	5.3	2.3	8.6	23.3	50.7	118.1
105	200.4	87.0	5.6	2.3	9.4	24.3	50.7	128.4
115	223.6	95.1	5.9	2.2	10.1	25.2	50.7	138.4
125	246.0	102.8	6.1	2.2	10.8	26.0	50.7	147.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	3.9	9.8	20.5	15.6
5	0	1.3	0.1	1.8	3.5	8.9	20.5	15.6
15	59	3.2	0.3	1.5	2.8	7.8	20.5	15.6
25	309	7.0	0.7	1.3	2.5	7.4	20.5	18.9
35	583	10.6	1.1	1.2	2.4	7.4	20.5	22.6
45	878	14.1	1.3	1.1	2.4	7.6	20.5	26.5
55	1,190	17.7	1.5	1.1	2.5	7.9	20.5	30.6
65	1,515	21.2	1.7	1.0	2.7	8.2	20.5	34.9
75	1,848	24.8	1.8	1.0	2.9	8.6	20.5	39.2
85	2,187	28.3	2.0	1.0	3.2	9.1	20.5	43.5
95	2,527	31.8	2.1	0.9	3.5	9.4	20.5	47.8
105	2,864	35.2	2.3	0.9	3.8	9.8	20.5	52.0
115	3,195	38.5	2.4	0.9	4.1	10.2	20.5	56.0
125	3,515	41.6	2.5	0.9	4.4	10.5	20.5	59.8

A21.— Regional estimates of timber volume and carbon stocks for alder-maple stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	32.2	9.3	115.2	46.2
5	0.0	8.0	0.8	4.7	22.0	3.9	115.2	39.5
15	49.5	31.0	3.1	3.7	12.3	4.5	115.2	54.6
25	229.7	99.4	9.9	2.8	13.5	6.2	115.2	131.9
35	380.8	153.8	15.4	2.5	16.4	7.6	115.2	195.7
45	513.7	200.8	20.1	2.4	19.8	8.6	115.2	251.7
55	633.3	242.5	22.2	2.3	23.3	9.4	115.2	299.7
65	742.1	280.1	23.9	2.2	26.7	10.1	115.2	343.0
75	842.1	314.4	25.3	2.2	29.9	10.7	115.2	382.4
85	934.5	346.0	26.6	2.1	32.8	11.1	115.2	418.6
95	1,020.3	375.2	27.7	2.1	35.6	11.5	115.2	452.0
105	1,100.3	402.2	28.7	2.0	38.1	11.9	115.2	483.0
115	1,175.0	427.4	29.6	2.1	40.5	12.2	115.2	511.8
125	1,244.9	450.9	30.4	2.3	42.7	12.4	115.2	538.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	13.0	3.8	46.6	18.7
5	0	3.2	0.3	1.9	8.9	1.6	46.6	16.0
15	708	12.6	1.3	1.5	5.0	1.8	46.6	22.1
25	3,282	40.2	4.0	1.1	5.5	2.5	46.6	53.4
35	5,442	62.3	6.2	1.0	6.6	3.1	46.6	79.2
45	7,342	81.3	8.1	1.0	8.0	3.5	46.6	101.9
55	9,050	98.1	9.0	0.9	9.4	3.8	46.6	121.3
65	10,605	113.3	9.7	0.9	10.8	4.1	46.6	138.8
75	12,034	127.2	10.3	0.9	12.1	4.3	46.6	154.8
85	13,355	140.0	10.8	0.9	13.3	4.5	46.6	169.4
95	14,582	151.8	11.2	0.8	14.4	4.7	46.6	182.9
105	15,725	162.8	11.6	0.8	15.4	4.8	46.6	195.4
115	16,792	173.0	12.0	0.9	16.4	4.9	46.6	207.1
125	17,791	182.5	12.3	0.9	17.3	5.0	46.6	218.0

A22.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	50.3	27.5	94.8	82.4
5	0.0	8.4	0.8	4.5	43.9	23.7	94.8	81.3
15	37.4	30.3	3.0	3.9	34.6	20.7	94.8	92.6
25	208.9	107.1	10.7	3.4	33.9	21.2	94.8	176.3
35	391.8	181.6	17.4	3.2	35.2	23.3	94.8	260.7
45	554.7	246.1	21.2	3.1	37.1	26.0	94.8	333.5
55	698.4	302.2	24.1	3.0	39.4	28.9	94.8	397.6
65	826.0	351.4	26.4	3.0	41.8	31.8	94.8	454.4
75	939.9	394.9	28.4	2.9	44.4	34.5	94.8	505.1
85	1,042.1	433.7	30.1	2.9	47.0	37.0	94.8	550.7
95	1,134.5	468.6	31.6	2.9	49.5	39.3	94.8	591.9
105	1,218.3	500.1	32.9	2.9	51.9	41.5	94.8	629.2
115	1,294.7	528.7	34.0	2.9	54.3	43.4	94.8	663.3
125	1,364.7	554.8	35.0	2.8	56.5	45.3	94.8	694.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	20.3	11.1	38.3	33.3
5	0	3.4	0.3	1.8	17.8	9.6	38.3	32.9
15	535	12.3	1.2	1.6	14.0	8.4	38.3	37.5
25	2,985	43.3	4.3	1.4	13.7	8.6	38.3	71.3
35	5,600	73.5	7.1	1.3	14.2	9.4	38.3	105.5
45	7,927	99.6	8.6	1.3	15.0	10.5	38.3	135.0
55	9,981	122.3	9.7	1.2	15.9	11.7	38.3	160.9
65	11,804	142.2	10.7	1.2	16.9	12.9	38.3	183.9
75	13,432	159.8	11.5	1.2	18.0	14.0	38.3	204.4
85	14,893	175.5	12.2	1.2	19.0	15.0	38.3	222.9
95	16,213	189.6	12.8	1.2	20.0	15.9	38.3	239.5
105	17,411	202.4	13.3	1.2	21.0	16.8	38.3	254.6
115	18,503	213.9	13.8	1.2	22.0	17.6	38.3	268.4
125	19,503	224.5	14.2	1.1	22.9	18.3	38.3	281.0

A23.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood per acre per year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	49.3	27.5	94.8	81.4
5	0.0	9.5	0.9	4.4	43.1	23.7	94.8	81.7
15	19.8	23.4	2.3	4.0	33.3	20.7	94.8	83.8
25	169.7	84.6	8.5	3.5	31.2	21.2	94.8	148.9
35	445.7	187.4	10.0	3.2	35.4	23.3	94.8	259.3
45	718.8	286.2	10.6	3.0	40.8	26.0	94.8	366.7
55	924.1	359.4	10.9	3.0	44.9	28.9	94.8	447.0
65	1,086.5	416.7	11.1	2.9	48.2	31.8	94.8	510.7
75	1,225.8	465.6	11.2	2.9	51.4	34.5	94.8	565.5
85	1,346.8	507.8	11.3	2.9	54.3	37.0	94.8	613.4
95	1,452.4	544.6	11.4	2.8	57.0	39.3	94.8	655.2
105	1,544.4	576.5	11.5	2.9	59.6	41.5	94.8	691.9
115	1,544.4	576.5	11.5	2.9	59.0	43.4	94.8	693.4
125	1,544.4	576.5	11.5	2.9	58.7	45.3	94.8	694.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	19.9	11.1	38.3	32.9
5	0	3.8	0.4	1.8	17.5	9.6	38.3	33.0
15	283	9.5	0.9	1.6	13.5	8.4	38.3	33.9
25	2,425	34.2	3.4	1.4	12.6	8.6	38.3	60.3
35	6,370	75.9	4.1	1.3	14.3	9.4	38.3	104.9
45	10,272	115.8	4.3	1.2	16.5	10.5	38.3	148.4
55	13,207	145.4	4.4	1.2	18.2	11.7	38.3	180.9
65	15,527	168.6	4.5	1.2	19.5	12.9	38.3	206.7
75	17,518	188.4	4.5	1.2	20.8	14.0	38.3	228.9
85	19,248	205.5	4.6	1.2	22.0	15.0	38.3	248.2
95	20,756	220.4	4.6	1.2	23.1	15.9	38.3	265.2
105	22,072	233.3	4.7	1.2	24.1	16.8	38.3	280.0
115	22,072	233.3	4.7	1.2	23.9	17.6	38.3	280.6
125	22,072	233.3	4.7	1.2	23.7	18.3	38.3	281.2

A24.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	23.8	29.5	62.1	58.1
5	0.0	3.2	0.3	4.8	20.7	27.0	62.1	56.0
15	8.2	11.6	1.2	3.9	16.0	25.2	62.1	57.9
25	62.3	42.5	4.3	3.2	14.8	25.6	62.1	90.3
35	145.5	84.3	8.4	2.8	15.6	27.1	62.1	138.2
45	238.7	128.7	12.9	2.6	17.4	28.9	62.1	190.6
55	333.9	168.2	16.8	2.5	19.4	30.8	62.1	237.8
65	427.0	205.1	20.5	2.5	21.6	32.6	62.1	282.2
75	515.8	239.2	23.9	2.4	23.8	34.2	62.1	323.4
85	599.0	270.3	27.0	2.3	25.9	35.6	62.1	361.2
95	676.0	298.5	29.8	2.3	28.0	36.8	62.1	395.5
105	746.6	323.9	32.4	2.3	29.9	37.9	62.1	426.5
115	810.8	346.7	34.1	2.3	31.7	38.9	62.1	453.7
125	869.1	367.2	35.1	2.2	33.4	39.8	62.1	477.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	9.6	11.9	25.1	23.5
5	0	1.3	0.1	1.9	8.4	10.9	25.1	22.7
15	117	4.7	0.5	1.6	6.5	10.2	25.1	23.4
25	890	17.2	1.7	1.3	6.0	10.4	25.1	36.6
35	2,080	34.1	3.4	1.1	6.3	11.0	25.1	55.9
45	3,412	52.1	5.2	1.1	7.1	11.7	25.1	77.1
55	4,772	68.1	6.8	1.0	7.9	12.5	25.1	96.2
65	6,103	83.0	8.3	1.0	8.7	13.2	25.1	114.2
75	7,371	96.8	9.7	1.0	9.6	13.8	25.1	130.9
85	8,560	109.4	10.9	0.9	10.5	14.4	25.1	146.2
95	9,661	120.8	12.1	0.9	11.3	14.9	25.1	160.0
105	10,670	131.1	13.1	0.9	12.1	15.4	25.1	172.6
115	11,588	140.3	13.8	0.9	12.8	15.8	25.1	183.6
125	12,421	148.6	14.2	0.9	13.5	16.1	25.1	193.3

A25.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands on forest land after clearcut harvest in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	43.2	27.5	116.3	75.4
5	0.0	5.9	0.6	4.7	37.6	23.7	116.3	72.5
15	33.7	22.5	2.2	4.1	29.4	20.7	116.3	78.9
25	184.1	78.0	7.8	3.1	27.6	21.2	116.3	137.7
35	350.8	139.8	14.0	2.7	28.4	23.3	116.3	208.2
45	516.7	201.6	20.2	2.5	30.6	26.0	116.3	280.9
55	678.7	256.6	25.7	2.4	33.2	28.9	116.3	346.8
65	835.1	309.1	30.9	2.3	36.2	31.8	116.3	410.4
75	985.6	359.2	35.9	2.2	39.6	34.5	116.3	471.5
85	1,129.8	406.7	40.1	2.2	43.2	37.0	116.3	529.2
95	1,267.4	451.8	42.8	2.3	46.8	39.3	116.3	583.0
105	1,398.3	494.4	45.2	2.5	50.4	41.5	116.3	634.0
115	1,522.4	534.7	47.4	2.7	53.9	43.4	116.3	682.2
125	1,639.6	572.6	49.4	2.9	57.3	45.3	116.3	727.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	17.5	11.1	47.1	30.5
5	0	2.4	0.2	1.9	15.2	9.6	47.1	29.3
15	482	9.1	0.9	1.6	11.9	8.4	47.1	31.9
25	2,631	31.6	3.2	1.3	11.2	8.6	47.1	55.7
35	5,013	56.6	5.7	1.1	11.5	9.4	47.1	84.2
45	7,385	81.6	8.2	1.0	12.4	10.5	47.1	113.7
55	9,699	103.9	10.4	1.0	13.4	11.7	47.1	140.3
65	11,935	125.1	12.5	0.9	14.7	12.9	47.1	166.1
75	14,086	145.4	14.5	0.9	16.0	14.0	47.1	190.8
85	16,146	164.6	16.2	0.9	17.5	15.0	47.1	214.2
95	18,113	182.8	17.3	0.9	18.9	15.9	47.1	235.9
105	19,983	200.1	18.3	1.0	20.4	16.8	47.1	256.6
115	21,757	216.4	19.2	1.1	21.8	17.6	47.1	276.1
125	23,432	231.7	20.0	1.2	23.2	18.3	47.1	294.4

A26.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands on forest land after clearcut harvest in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	42.7	27.5	116.3	74.9
5	0.0	5.9	0.6	4.7	37.1	23.7	116.3	72.0
15	80.3	36.4	3.6	3.7	30.4	20.7	116.3	94.8
25	221.7	90.4	9.0	3.0	28.6	21.2	116.3	152.3
35	413.7	161.0	16.1	2.7	30.3	23.3	116.3	233.3
45	669.6	253.6	25.4	2.4	35.6	26.0	116.3	342.9
55	903.9	332.1	33.2	2.3	40.5	28.9	116.3	437.0
65	1,119.3	403.3	39.9	2.2	45.5	31.8	116.3	522.6
75	1,318.1	468.3	43.7	2.3	50.4	34.5	116.3	599.3
85	1,502.0	528.1	47.1	2.6	55.1	37.0	116.3	669.9
95	1,672.1	583.0	50.0	2.9	59.7	39.3	116.3	735.0
105	1,829.1	633.5	52.6	3.2	64.1	41.5	116.3	794.8
115	1,973.0	679.5	54.9	3.4	68.2	43.4	116.3	849.4
125	2,103.3	721.0	56.9	3.6	72.0	45.3	116.3	898.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	17.3	11.1	47.1	30.3
5	0	2.4	0.2	1.9	15.0	9.6	47.1	29.1
15	1,148	14.7	1.5	1.5	12.3	8.4	47.1	38.4
25	3,169	36.6	3.7	1.2	11.6	8.6	47.1	61.6
35	5,912	65.1	6.5	1.1	12.3	9.4	47.1	94.4
45	9,570	102.6	10.3	1.0	14.4	10.5	47.1	138.8
55	12,918	134.4	13.4	0.9	16.4	11.7	47.1	176.8
65	15,996	163.2	16.1	0.9	18.4	12.9	47.1	211.5
75	18,837	189.5	17.7	0.9	20.4	14.0	47.1	242.5
85	21,465	213.7	19.0	1.1	22.3	15.0	47.1	271.1
95	23,896	235.9	20.2	1.2	24.2	15.9	47.1	297.4
105	26,140	256.4	21.3	1.3	25.9	16.8	47.1	321.6
115	28,197	275.0	22.2	1.4	27.6	17.6	47.1	343.7
125	30,059	291.8	23.0	1.5	29.1	18.3	47.1	363.7

A27.— Regional estimates of timber volume and carbon stocks for mixed conifer stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	12.0	37.2	49.8	54.0
5	0.0	4.2	0.3	4.8	10.7	35.4	49.8	55.4
15	2.0	8.1	0.8	4.8	8.4	32.9	49.8	54.9
25	11.1	14.6	1.5	6.9	7.0	31.8	49.8	61.7
35	24.4	22.3	2.2	4.9	6.3	31.6	49.8	67.3
45	44.5	32.9	3.3	3.6	6.3	32.0	49.8	78.1
55	71.9	46.5	4.7	2.8	6.9	32.7	49.8	93.5
65	106.6	62.8	6.3	2.2	7.9	33.6	49.8	112.8
75	147.9	81.4	8.1	1.8	9.3	34.6	49.8	135.3
85	195.4	102.0	10.2	1.5	11.1	35.6	49.8	160.4
95	248.3	124.2	12.4	1.3	13.1	36.6	49.8	187.5
105	305.6	147.5	14.8	1.1	15.3	37.5	49.8	216.2
115	366.7	171.8	17.2	1.0	17.6	38.4	49.8	245.9
125	430.5	196.6	19.7	1.0	20.0	39.2	49.8	276.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.9	15.1	20.2	21.9
5	0	1.7	0.1	1.9	4.3	14.3	20.2	22.4
15	29	3.3	0.3	1.9	3.4	13.3	20.2	22.2
25	159	5.9	0.6	2.8	2.8	12.9	20.2	25.0
35	349	9.0	0.9	2.0	2.6	12.8	20.2	27.2
45	636	13.3	1.3	1.5	2.5	12.9	20.2	31.6
55	1,028	18.8	1.9	1.1	2.8	13.2	20.2	37.9
65	1,523	25.4	2.5	0.9	3.2	13.6	20.2	45.7
75	2,114	33.0	3.3	0.7	3.8	14.0	20.2	54.8
85	2,793	41.3	4.1	0.6	4.5	14.4	20.2	64.9
95	3,548	50.2	5.0	0.5	5.3	14.8	20.2	75.9
105	4,368	59.7	6.0	0.5	6.2	15.2	20.2	87.5
115	5,240	69.5	7.0	0.4	7.1	15.5	20.2	99.5
125	6,152	79.6	8.0	0.4	8.1	15.8	20.2	111.9

A28.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	16.0	37.2	51.9	58.0
5	0.0	3.2	0.3	4.8	14.0	35.4	51.9	57.7
15	2.0	7.9	0.8	4.2	10.9	32.9	51.9	56.8
25	13.7	17.3	1.7	3.4	9.3	31.8	51.9	63.5
35	32.4	29.5	3.0	2.9	8.6	31.6	51.9	75.6
45	58.8	45.2	4.5	2.6	8.9	32.0	51.9	93.2
55	94.0	63.1	6.3	2.4	9.8	32.7	51.9	114.3
65	136.7	83.5	8.4	2.2	11.2	33.6	51.9	138.9
75	185.6	105.7	10.6	2.1	13.1	34.6	51.9	166.0
85	239.2	128.9	12.9	2.0	15.2	35.6	51.9	194.6
95	296.6	153.0	15.3	1.9	17.5	36.6	51.9	224.2
105	356.8	177.4	17.7	1.8	19.9	37.5	51.9	254.4
115	419.1	202.0	20.2	1.8	22.4	38.4	51.9	284.8
125	482.7	226.6	22.7	1.7	25.0	39.2	51.9	315.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	6.5	15.1	21.0	23.5
5	0	1.3	0.1	1.9	5.7	14.3	21.0	23.4
15	28	3.2	0.3	1.7	4.4	13.3	21.0	23.0
25	196	7.0	0.7	1.4	3.7	12.9	21.0	25.7
35	463	11.9	1.2	1.2	3.5	12.8	21.0	30.6
45	840	18.3	1.8	1.1	3.6	12.9	21.0	37.7
55	1,343	25.5	2.6	1.0	4.0	13.2	21.0	46.3
65	1,954	33.8	3.4	0.9	4.5	13.6	21.0	56.2
75	2,652	42.8	4.3	0.8	5.3	14.0	21.0	67.2
85	3,419	52.2	5.2	0.8	6.1	14.4	21.0	78.8
95	4,239	61.9	6.2	0.8	7.1	14.8	21.0	90.7
105	5,099	71.8	7.2	0.7	8.1	15.2	21.0	102.9
115	5,989	81.8	8.2	0.7	9.1	15.5	21.0	115.2
125	6,899	91.7	9.2	0.7	10.1	15.8	21.0	127.5

A29.— Regional estimates of timber volume and carbon stocks for western oak stands on forest land after clearcut harvest in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	13.3	31.7	27.6	49.7
5	0.0	2.6	0.2	4.6	8.9	28.4	27.6	44.8
15	0.0	5.7	0.6	4.5	4.1	24.6	27.6	39.5
25	1.0	8.8	0.9	4.4	2.1	23.4	27.6	39.5
35	25.9	30.6	3.1	4.2	2.0	23.5	27.6	63.4
45	76.3	65.1	4.5	4.1	3.0	24.3	27.6	101.1
55	127.8	98.3	5.4	4.0	4.2	25.5	27.6	137.5
65	174.4	124.0	6.0	4.0	5.2	26.8	27.6	166.1
75	215.0	145.3	6.5	4.0	6.1	28.1	27.6	189.9
85	249.4	162.7	6.8	4.0	6.8	29.4	27.6	209.7
95	278.4	177.1	7.1	4.0	7.4	30.6	27.6	226.1
105	302.8	189.0	7.3	3.9	7.9	31.7	27.6	239.7
115	323.3	198.8	7.4	3.9	8.3	32.6	27.6	251.1
125	340.6	207.0	7.6	3.9	8.6	33.5	27.6	260.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	5.4	12.8	11.2	20.1
5	0	1.1	0.1	1.9	3.6	11.5	11.2	18.1
15	0	2.3	0.2	1.8	1.7	10.0	11.2	16.0
25	15	3.6	0.4	1.8	0.8	9.5	11.2	16.0
35	370	12.4	1.2	1.7	0.8	9.5	11.2	25.7
45	1,090	26.3	1.8	1.7	1.2	9.8	11.2	40.9
55	1,826	39.8	2.2	1.6	1.7	10.3	11.2	55.6
65	2,493	50.2	2.4	1.6	2.1	10.9	11.2	67.2
75	3,072	58.8	2.6	1.6	2.5	11.4	11.2	76.9
85	3,564	65.9	2.8	1.6	2.7	11.9	11.2	84.9
95	3,979	71.7	2.9	1.6	3.0	12.4	11.2	91.5
105	4,328	76.5	2.9	1.6	3.2	12.8	11.2	97.0
115	4,620	80.5	3.0	1.6	3.3	13.2	11.2	101.6
125	4,868	83.8	3.1	1.6	3.5	13.6	11.2	105.5

A30.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	22.4	37.2	38.8	64.4
5	0.0	2.7	0.3	4.7	20.2	35.4	38.8	63.2
15	1.1	6.1	0.6	4.7	16.3	32.9	38.8	60.6
25	19.7	21.5	2.2	3.4	14.0	31.8	38.8	72.8
35	57.1	44.3	4.4	2.7	12.8	31.6	38.8	95.8
45	100.9	66.5	6.7	2.3	12.1	32.0	38.8	119.5
55	145.9	87.2	8.7	2.1	11.8	32.7	38.8	142.5
65	189.3	105.9	10.1	1.9	11.6	33.6	38.8	163.1
75	229.7	122.5	10.7	1.8	11.6	34.6	38.8	181.3
85	266.3	137.0	11.2	1.8	11.7	35.6	38.8	197.3
95	298.6	149.4	11.6	1.7	11.8	36.6	38.8	211.1
105	326.6	159.9	12.0	1.7	12.0	37.5	38.8	223.0
115	350.1	168.6	12.2	1.6	12.1	38.4	38.8	232.9
125	369.5	175.7	12.4	1.6	12.2	39.2	38.8	241.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	9.1	15.1	15.7	26.0
5	0	1.1	0.1	1.9	8.2	14.3	15.7	25.6
15	16	2.5	0.2	1.9	6.6	13.3	15.7	24.5
25	281	8.7	0.9	1.4	5.6	12.9	15.7	29.5
35	816	17.9	1.8	1.1	5.2	12.8	15.7	38.8
45	1,442	26.9	2.7	0.9	4.9	12.9	15.7	48.4
55	2,085	35.3	3.5	0.8	4.8	13.2	15.7	57.7
65	2,705	42.9	4.1	0.8	4.7	13.6	15.7	66.0
75	3,283	49.6	4.3	0.7	4.7	14.0	15.7	73.4
85	3,806	55.4	4.5	0.7	4.7	14.4	15.7	79.8
95	4,268	60.5	4.7	0.7	4.8	14.8	15.7	85.4
105	4,667	64.7	4.8	0.7	4.8	15.2	15.7	90.2
115	5,003	68.2	4.9	0.7	4.9	15.5	15.7	94.3
125	5,280	71.1	5.0	0.7	4.9	15.8	15.7	97.6

A31.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	25.7	37.2	44.1	67.7
5	0.0	3.1	0.3	4.7	23.2	35.4	44.1	66.8
15	0.0	5.8	0.6	4.7	18.8	32.9	44.1	62.8
25	18.2	17.0	1.7	3.4	16.2	31.8	44.1	70.1
35	61.6	38.1	3.8	2.7	15.3	31.6	44.1	91.4
45	113.8	59.5	5.9	2.3	15.1	32.0	44.1	114.8
55	167.2	80.0	8.0	2.1	15.3	32.7	44.1	138.1
65	218.2	98.6	9.9	2.0	15.7	33.6	44.1	159.7
75	264.6	115.0	11.5	1.9	16.1	34.6	44.1	179.1
85	305.4	129.1	12.9	1.8	16.6	35.6	44.1	196.0
95	340.2	140.9	14.1	1.8	17.0	36.6	44.1	210.4
105	368.8	150.5	15.0	1.7	17.4	37.5	44.1	222.2
115	391.6	158.0	15.8	1.7	17.7	38.4	44.1	231.6
125	408.8	163.7	16.4	1.7	17.9	39.2	44.1	238.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	10.4	15.1	17.9	27.4
5	0	1.3	0.1	1.9	9.4	14.3	17.9	27.0
15	0	2.3	0.2	1.9	7.6	13.3	17.9	25.4
25	260	6.9	0.7	1.4	6.5	12.9	17.9	28.4
35	880	15.4	1.5	1.1	6.2	12.8	17.9	37.0
45	1,626	24.1	2.4	0.9	6.1	12.9	17.9	46.5
55	2,390	32.4	3.2	0.9	6.2	13.2	17.9	55.9
65	3,118	39.9	4.0	0.8	6.3	13.6	17.9	64.6
75	3,782	46.5	4.7	0.8	6.5	14.0	17.9	72.5
85	4,365	52.2	5.2	0.7	6.7	14.4	17.9	79.3
95	4,862	57.0	5.7	0.7	6.9	14.8	17.9	85.1
105	5,271	60.9	6.1	0.7	7.0	15.2	17.9	89.9
115	5,596	63.9	6.4	0.7	7.2	15.5	17.9	93.7
125	5,842	66.2	6.6	0.7	7.2	15.8	17.9	96.6

A32.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	17.7	24.1	37.2	46.5
5	0.0	1.9	0.1	4.8	15.9	22.0	37.2	44.6
15	0.2	4.1	0.3	4.8	12.8	19.4	37.2	41.3
25	15.9	14.3	1.4	3.5	10.8	18.3	37.2	48.3
35	51.6	29.9	3.0	2.4	9.6	18.2	37.2	63.1
45	94.3	45.8	4.6	1.9	8.9	18.7	37.2	79.9
55	138.8	59.4	5.9	1.7	8.4	19.4	37.2	94.9
65	182.1	71.6	7.2	1.5	8.1	20.4	37.2	108.8
75	223.1	82.5	8.3	1.4	7.9	21.4	37.2	121.5
85	261.0	92.1	9.2	1.4	7.8	22.4	37.2	132.9
95	295.3	100.5	10.1	1.3	7.8	23.3	37.2	143.1
105	325.9	107.8	10.7	1.3	7.8	24.3	37.2	151.9
115	353.2	114.2	11.1	1.2	7.9	25.2	37.2	159.6
125	377.3	119.7	11.5	1.2	7.9	26.0	37.2	166.3
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	7.2	9.8	15.0	18.8
5	0	0.8	0.0	1.9	6.4	8.9	15.0	18.0
15	3	1.7	0.1	1.9	5.2	7.8	15.0	16.7
25	227	5.8	0.6	1.4	4.4	7.4	15.0	19.6
35	737	12.1	1.2	1.0	3.9	7.4	15.0	25.5
45	1,348	18.5	1.9	0.8	3.6	7.6	15.0	32.3
55	1,983	24.0	2.4	0.7	3.4	7.9	15.0	38.4
65	2,603	29.0	2.9	0.6	3.3	8.2	15.0	44.0
75	3,189	33.4	3.3	0.6	3.2	8.6	15.0	49.2
85	3,730	37.3	3.7	0.6	3.2	9.1	15.0	53.8
95	4,220	40.7	4.1	0.5	3.2	9.4	15.0	57.9
105	4,658	43.6	4.3	0.5	3.2	9.8	15.0	61.5
115	5,048	46.2	4.5	0.5	3.2	10.2	15.0	64.6
125	5,392	48.4	4.6	0.5	3.2	10.5	15.0	67.3

A33.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	18.8	24.1	34.3	47.7
5	0.0	3.3	0.2	4.8	17.0	22.0	34.3	47.2
15	1.3	6.3	0.6	4.3	13.9	19.4	34.3	44.5
25	18.6	15.9	1.6	3.2	12.0	18.3	34.3	50.9
35	51.8	30.9	3.0	2.5	11.1	18.2	34.3	65.7
45	89.4	46.1	3.9	2.2	10.7	18.7	34.3	81.5
55	127.1	60.4	4.5	2.0	10.6	19.4	34.3	96.9
65	162.2	73.3	5.1	1.9	10.6	20.4	34.3	111.2
75	193.8	84.6	5.5	1.8	10.7	21.4	34.3	124.0
85	221.0	94.2	5.8	1.7	10.9	22.4	34.3	135.0
95	243.7	102.0	6.1	1.7	11.0	23.3	34.3	144.1
105	261.8	108.2	6.3	1.6	11.1	24.3	34.3	151.6
115	275.6	112.9	6.4	1.6	11.2	25.2	34.3	157.3
125	285.1	116.1	6.5	1.6	11.2	26.0	34.3	161.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	7.6	9.8	13.9	19.3
5	0	1.3	0.1	1.9	6.9	8.9	13.9	19.1
15	19	2.6	0.2	1.8	5.6	7.8	13.9	18.0
25	266	6.4	0.6	1.3	4.8	7.4	13.9	20.6
35	740	12.5	1.2	1.0	4.5	7.4	13.9	26.6
45	1,278	18.6	1.6	0.9	4.3	7.6	13.9	33.0
55	1,816	24.5	1.8	0.8	4.3	7.9	13.9	39.2
65	2,318	29.7	2.0	0.8	4.3	8.2	13.9	45.0
75	2,769	34.2	2.2	0.7	4.3	8.6	13.9	50.2
85	3,159	38.1	2.4	0.7	4.4	9.1	13.9	54.6
95	3,483	41.3	2.5	0.7	4.5	9.4	13.9	58.3
105	3,742	43.8	2.5	0.7	4.5	9.8	13.9	61.3
115	3,938	45.7	2.6	0.6	4.5	10.2	13.9	63.6
125	4,075	47.0	2.6	0.6	4.5	10.5	13.9	65.3

A34.— Regional estimates of timber volume and carbon stocks for aspen-birch stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	11.6	31.7	58.8	48.1
5	0.0	3.1	0.3	4.7	9.0	28.4	58.8	45.5
15	0.0	6.4	0.6	4.7	5.5	24.6	58.8	41.9
25	6.3	13.9	1.4	4.8	3.8	23.4	58.8	47.2
35	22.7	25.7	2.6	4.5	3.3	23.5	58.8	59.6
45	45.0	38.8	3.9	4.3	3.5	24.3	58.8	74.7
55	70.7	52.3	5.2	4.2	3.9	25.5	58.8	91.1
65	98.1	64.7	6.5	4.1	4.5	26.8	58.8	106.5
75	126.5	76.6	7.7	4.0	5.1	28.1	58.8	121.5
85	155.0	88.0	8.8	3.9	5.8	29.4	58.8	135.9
95	183.1	98.8	9.9	3.9	6.4	30.6	58.8	149.5
105	210.5	108.8	10.9	3.8	7.0	31.7	58.8	162.2
115	236.8	118.3	11.8	3.8	7.6	32.6	58.8	174.1
125	261.8	127.0	12.4	3.8	8.2	33.5	58.8	184.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.7	12.8	23.8	19.5
5	0	1.2	0.1	1.9	3.6	11.5	23.8	18.4
15	0	2.6	0.3	1.9	2.2	10.0	23.8	17.0
25	90	5.6	0.6	1.9	1.5	9.5	23.8	19.1
35	324	10.4	1.0	1.8	1.4	9.5	23.8	24.1
45	643	15.7	1.6	1.7	1.4	9.8	23.8	30.2
55	1,010	21.2	2.1	1.7	1.6	10.3	23.8	36.9
65	1,402	26.2	2.6	1.6	1.8	10.9	23.8	43.1
75	1,808	31.0	3.1	1.6	2.1	11.4	23.8	49.2
85	2,215	35.6	3.6	1.6	2.3	11.9	23.8	55.0
95	2,617	40.0	4.0	1.6	2.6	12.4	23.8	60.5
105	3,008	44.0	4.4	1.6	2.8	12.8	23.8	65.7
115	3,384	47.9	4.8	1.5	3.1	13.2	23.8	70.5
125	3,741	51.4	5.0	1.5	3.3	13.6	23.8	74.8

A35.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	17.0	37.2	30.9	59.0
5	0.0	2.6	0.3	4.8	15.3	35.4	30.9	58.4
15	1.6	7.2	0.7	4.8	12.6	32.9	30.9	58.3
25	15.3	19.8	2.0	4.4	11.1	31.8	30.9	68.9
35	39.1	37.2	3.7	2.0	10.4	31.6	30.9	84.9
45	66.2	54.6	5.5	1.2	10.2	32.0	30.9	103.5
55	93.9	71.6	7.2	0.9	10.3	32.7	30.9	122.7
65	120.8	85.9	8.6	0.7	10.4	33.6	30.9	139.2
75	146.1	98.8	9.9	0.6	10.6	34.6	30.9	154.5
85	169.5	110.3	11.0	0.6	10.9	35.6	30.9	168.4
95	190.7	120.6	12.1	0.6	11.1	36.6	30.9	180.9
105	209.8	129.5	12.9	0.6	11.4	37.5	30.9	192.0
115	227.0	137.5	13.3	0.7	11.7	38.4	30.9	201.6
125	242.3	144.4	13.8	0.7	12.0	39.2	30.9	210.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	6.9	15.1	12.5	23.9
5	0	1.1	0.1	2.0	6.2	14.3	12.5	23.6
15	23	2.9	0.3	2.0	5.1	13.3	12.5	23.6
25	219	8.0	0.8	1.8	4.5	12.9	12.5	27.9
35	559	15.0	1.5	0.8	4.2	12.8	12.5	34.4
45	946	22.1	2.2	0.5	4.1	12.9	12.5	41.9
55	1,342	29.0	2.9	0.4	4.2	13.2	12.5	49.6
65	1,726	34.8	3.5	0.3	4.2	13.6	12.5	56.3
75	2,088	40.0	4.0	0.2	4.3	14.0	12.5	62.5
85	2,422	44.7	4.5	0.2	4.4	14.4	12.5	68.1
95	2,726	48.8	4.9	0.2	4.5	14.8	12.5	73.2
105	2,999	52.4	5.2	0.3	4.6	15.2	12.5	77.7
115	3,244	55.6	5.4	0.3	4.7	15.5	12.5	81.6
125	3,463	58.5	5.6	0.3	4.9	15.8	12.5	85.0

A36.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	11.3	37.2	31.5	53.3
5	0.0	1.8	0.2	4.8	10.2	35.4	31.5	52.4
15	0.0	4.0	0.4	4.8	8.3	32.9	31.5	50.4
25	8.5	12.0	1.2	4.3	7.3	31.8	31.5	56.5
35	27.7	24.4	2.4	2.8	7.0	31.6	31.5	68.3
45	49.5	36.7	3.7	2.3	6.9	32.0	31.5	81.5
55	71.9	48.7	4.9	1.9	7.0	32.7	31.5	95.2
65	94.1	58.6	5.9	1.7	7.1	33.6	31.5	107.0
75	115.7	67.8	6.8	1.6	7.3	34.6	31.5	118.1
85	136.5	76.2	7.6	1.5	7.6	35.6	31.5	128.5
95	156.4	84.0	8.4	1.4	7.9	36.6	31.5	138.2
105	175.2	91.2	9.1	1.3	8.2	37.5	31.5	147.3
115	193.0	97.8	9.8	1.3	8.5	38.4	31.5	155.7
125	209.6	103.8	10.4	1.2	8.8	39.2	31.5	163.4
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	4.6	15.1	12.7	21.6
5	0	0.7	0.1	2.0	4.1	14.3	12.7	21.2
15	0	1.6	0.2	2.0	3.4	13.3	12.7	20.4
25	122	4.8	0.5	1.7	3.0	12.9	12.7	22.9
35	396	9.9	1.0	1.1	2.8	12.8	12.7	27.6
45	708	14.8	1.5	0.9	2.8	12.9	12.7	33.0
55	1,028	19.7	2.0	0.8	2.8	13.2	12.7	38.5
65	1,345	23.7	2.4	0.7	2.9	13.6	12.7	43.3
75	1,654	27.4	2.7	0.6	3.0	14.0	12.7	47.8
85	1,951	30.8	3.1	0.6	3.1	14.4	12.7	52.0
95	2,235	34.0	3.4	0.6	3.2	14.8	12.7	55.9
105	2,504	36.9	3.7	0.5	3.3	15.2	12.7	59.6
115	2,758	39.6	4.0	0.5	3.4	15.5	12.7	63.0
125	2,995	42.0	4.2	0.5	3.6	15.8	12.7	66.1

A37.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	10.8	24.1	27.0	39.7
5	0.0	2.1	0.2	4.8	9.8	22.0	27.0	38.9
15	0.0	4.3	0.4	4.8	8.1	19.4	27.0	37.0
25	5.0	9.2	0.9	4.8	7.0	18.3	27.0	40.1
35	18.3	16.9	1.7	3.4	6.5	18.2	27.0	46.6
45	37.0	25.9	2.6	2.5	6.4	18.7	27.0	56.0
55	58.5	34.1	3.4	2.0	6.4	19.4	27.0	65.4
65	81.2	42.0	4.2	1.7	6.6	20.4	27.0	74.9
75	104.1	49.5	4.9	1.5	6.8	21.4	27.0	84.1
85	126.7	56.4	5.6	1.4	7.1	22.4	27.0	92.9
95	148.3	62.8	6.3	1.3	7.4	23.3	27.0	101.1
105	168.6	68.6	6.9	1.2	7.7	24.3	27.0	108.6
115	187.3	73.8	7.4	1.1	8.0	25.2	27.0	115.5
125	204.1	78.3	7.8	1.1	8.3	26.0	27.0	121.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	4.4	9.8	10.9	16.1
5	0	0.9	0.1	1.9	4.0	8.9	10.9	15.7
15	0	1.7	0.2	1.9	3.3	7.8	10.9	15.0
25	71	3.7	0.4	1.9	2.8	7.4	10.9	16.2
35	262	6.8	0.7	1.4	2.6	7.4	10.9	18.9
45	529	10.5	1.0	1.0	2.6	7.6	10.9	22.7
55	836	13.8	1.4	0.8	2.6	7.9	10.9	26.5
65	1,160	17.0	1.7	0.7	2.7	8.2	10.9	30.3
75	1,488	20.0	2.0	0.6	2.7	8.6	10.9	34.0
85	1,810	22.8	2.3	0.6	2.9	9.1	10.9	37.6
95	2,120	25.4	2.5	0.5	3.0	9.4	10.9	40.9
105	2,410	27.8	2.8	0.5	3.1	9.8	10.9	44.0
115	2,677	29.8	3.0	0.5	3.2	10.2	10.9	46.7
125	2,917	31.7	3.2	0.4	3.4	10.5	10.9	49.2

A38.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands on forest land after clearcut harvest in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	9.7	24.1	24.1	38.6
5	0.0	1.8	0.2	4.8	8.8	22.0	24.1	37.6
15	0.0	3.7	0.4	4.8	7.1	19.4	24.1	35.4
25	4.4	9.4	0.9	4.8	6.2	18.3	24.1	39.7
35	16.2	18.6	1.9	2.9	5.8	18.2	24.1	47.4
45	32.2	28.8	2.7	2.1	5.8	18.7	24.1	58.1
55	50.3	38.2	3.0	1.7	5.9	19.4	24.1	68.3
65	69.3	47.1	3.3	1.5	6.0	20.4	24.1	78.3
75	88.4	55.5	3.6	1.3	6.3	21.4	24.1	88.0
85	107.2	63.2	3.8	1.2	6.6	22.4	24.1	97.1
95	125.5	70.4	4.0	1.1	6.9	23.3	24.1	105.7
105	143.0	77.1	4.1	1.0	7.2	24.3	24.1	113.7
115	159.5	83.2	4.3	1.0	7.5	25.2	24.1	121.1
125	175.1	88.8	4.4	0.9	7.8	26.0	24.1	127.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	3.9	9.8	9.8	15.6
5	0	0.7	0.1	2.0	3.5	8.9	9.8	15.2
15	0	1.5	0.1	2.0	2.9	7.8	9.8	14.3
25	63	3.8	0.4	2.0	2.5	7.4	9.8	16.1
35	231	7.5	0.8	1.2	2.4	7.4	9.8	19.2
45	460	11.7	1.1	0.9	2.3	7.6	9.8	23.5
55	719	15.5	1.2	0.7	2.4	7.9	9.8	27.6
65	990	19.1	1.4	0.6	2.4	8.2	9.8	31.7
75	1,263	22.4	1.5	0.5	2.5	8.6	9.8	35.6
85	1,532	25.6	1.5	0.5	2.7	9.1	9.8	39.3
95	1,793	28.5	1.6	0.4	2.8	9.4	9.8	42.8
105	2,043	31.2	1.7	0.4	2.9	9.8	9.8	46.0
115	2,280	33.7	1.7	0.4	3.0	10.2	9.8	49.0
125	2,503	35.9	1.8	0.4	3.2	10.5	9.8	51.8

A39.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------------------------------------- *tonnes carbon/hectare* -------------------------------------						
0	0.0	0.0	0.0	4.2	9.9	12.2	72.9	26.3
5	0.0	11.1	0.7	4.0	8.4	6.5	72.9	30.6
10	19.1	22.6	1.3	3.6	7.5	6.4	72.9	41.4
15	36.7	31.3	1.6	3.4	6.8	7.5	72.9	50.7
20	60.4	40.8	1.9	3.2	6.6	8.7	72.9	61.2
25	85.5	50.3	2.1	3.1	6.5	9.8	72.9	71.9
30	108.7	58.2	2.3	3.1	6.6	10.7	72.9	80.8
35	131.2	65.6	2.4	3.0	6.7	11.5	72.9	89.3
40	152.3	72.5	2.5	3.0	6.9	12.2	72.9	97.1
45	172.3	78.9	2.7	2.9	7.2	12.7	72.9	104.4
50	191.4	85.0	2.7	2.9	7.5	13.2	72.9	111.3
55	208.4	90.3	2.8	2.9	7.8	13.7	72.9	117.4
60	223.9	95.1	2.9	2.8	8.1	14.1	72.9	122.9
65	238.4	99.6	2.9	2.8	8.3	14.4	72.9	128.1
70	252.9	104.0	3.0	2.8	8.6	14.7	72.9	133.2
75	264.6	107.6	3.0	2.8	8.9	15.0	72.9	137.3
80	277.1	111.4	3.1	2.8	9.1	15.2	72.9	141.6
85	289.5	115.1	3.1	2.8	9.4	15.5	72.9	145.9
90	299.6	118.2	3.2	2.7	9.6	15.7	72.9	149.4
years	*ft^3/acre*	------------------------------------- *tonnes carbon/acre* -------------------------------------						
0	0	0.0	0.0	1.7	4.0	4.9	29.5	10.7
5	0	4.5	0.3	1.6	3.4	2.6	29.5	12.4
10	273	9.2	0.5	1.4	3.0	2.6	29.5	16.8
15	525	12.7	0.7	1.4	2.8	3.0	29.5	20.5
20	863	16.5	0.8	1.3	2.7	3.5	29.5	24.8
25	1,222	20.4	0.9	1.3	2.6	4.0	29.5	29.1
30	1,554	23.5	0.9	1.2	2.7	4.3	29.5	32.7
35	1,875	26.6	1.0	1.2	2.7	4.7	29.5	36.1
40	2,177	29.3	1.0	1.2	2.8	4.9	29.5	39.3
45	2,462	31.9	1.1	1.2	2.9	5.2	29.5	42.3
50	2,736	34.4	1.1	1.2	3.0	5.4	29.5	45.1
55	2,978	36.5	1.1	1.2	3.1	5.5	29.5	47.5
60	3,200	38.5	1.2	1.1	3.3	5.7	29.5	49.8
65	3,407	40.3	1.2	1.1	3.4	5.8	29.5	51.8
70	3,614	42.1	1.2	1.1	3.5	6.0	29.5	53.9
75	3,782	43.5	1.2	1.1	3.6	6.1	29.5	55.6
80	3,960	45.1	1.3	1.1	3.7	6.2	29.5	57.3
85	4,138	46.6	1.3	1.1	3.8	6.3	29.5	59.1
90	4,281	47.8	1.3	1.1	3.9	6.3	29.5	60.5

A40.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the Southeast; volumes are for high-productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	20.4	12.2	72.9	36.8
5	0.0	11.0	0.7	4.0	15.9	6.5	72.9	38.0
10	47.7	31.9	1.4	3.8	12.9	6.4	72.9	56.3
15	146.5	67.4	1.9	3.7	11.4	7.5	72.9	91.9
20	244.8	102.3	2.1	3.7	10.5	8.7	72.9	127.3
25	315.2	124.2	2.3	3.7	9.7	9.8	72.9	149.7
30	347.3	134.1	2.4	3.7	8.8	10.7	72.9	159.7
35	351.5	135.4	2.4	3.7	8.0	11.5	72.9	160.9
40	355.0	136.5	2.4	3.7	7.3	12.2	72.9	161.9
45	358.5	137.5	2.4	3.6	6.8	12.7	72.9	163.1
50	362.0	138.6	2.4	3.6	6.4	13.2	72.9	164.3
55	362.0	138.6	2.4	3.6	6.1	13.7	72.9	164.4
60	362.0	138.6	2.4	3.6	5.9	14.1	72.9	164.6
65	362.0	138.6	2.4	3.6	5.7	14.4	72.9	164.8
70	362.0	138.6	2.4	3.6	5.6	14.7	72.9	164.9
75	362.0	138.6	2.4	3.6	5.5	15.0	72.9	165.1
80	362.0	138.6	2.4	3.6	5.4	15.2	72.9	165.3
85	362.0	138.6	2.4	3.6	5.4	15.5	72.9	165.5
90	362.0	138.6	2.4	3.6	5.3	15.7	72.9	165.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.3	4.9	29.5	14.9
5	0	4.5	0.3	1.6	6.4	2.6	29.5	15.4
10	682	12.9	0.6	1.6	5.2	2.6	29.5	22.8
15	2,094	27.3	0.8	1.5	4.6	3.0	29.5	37.2
20	3,498	41.4	0.9	1.5	4.3	3.5	29.5	51.5
25	4,504	50.3	0.9	1.5	3.9	4.0	29.5	60.6
30	4,963	54.3	1.0	1.5	3.6	4.3	29.5	64.6
35	5,024	54.8	1.0	1.5	3.2	4.7	29.5	65.1
40	5,074	55.2	1.0	1.5	3.0	4.9	29.5	65.5
45	5,124	55.7	1.0	1.5	2.8	5.2	29.5	66.0
50	5,174	56.1	1.0	1.5	2.6	5.4	29.5	66.5
55	5,174	56.1	1.0	1.5	2.5	5.5	29.5	66.5
60	5,174	56.1	1.0	1.5	2.4	5.7	29.5	66.6
65	5,174	56.1	1.0	1.5	2.3	5.8	29.5	66.7
70	5,174	56.1	1.0	1.5	2.3	6.0	29.5	66.8
75	5,174	56.1	1.0	1.5	2.2	6.1	29.5	66.8
80	5,174	56.1	1.0	1.5	2.2	6.2	29.5	66.9
85	5,174	56.1	1.0	1.5	2.2	6.3	29.5	67.0
90	5,174	56.1	1.0	1.5	2.2	6.3	29.5	67.0

A41.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.7	12.2	110.0	26.1
5	0.0	5.3	0.4	4.2	7.8	6.5	110.0	24.1
10	19.1	14.1	0.9	3.8	6.7	6.4	110.0	31.8
15	36.7	21.4	1.0	3.6	5.9	7.5	110.0	39.4
20	60.4	30.4	1.1	3.4	5.6	8.7	110.0	49.2
25	85.5	39.2	1.1	3.3	5.6	9.8	110.0	59.0
30	108.7	47.2	1.2	3.2	5.6	10.7	110.0	67.9
35	131.2	54.8	1.2	3.1	5.8	11.5	110.0	76.4
40	152.3	61.9	1.3	3.0	6.0	12.2	110.0	84.4
45	172.3	68.5	1.3	3.0	6.3	12.7	110.0	91.9
50	191.4	74.8	1.3	2.9	6.7	13.2	110.0	99.0
55	208.4	80.4	1.3	2.9	7.0	13.7	110.0	105.2
60	223.9	85.4	1.3	2.9	7.3	14.1	110.0	111.0
65	238.4	90.1	1.4	2.9	7.6	14.4	110.0	116.3
70	252.9	94.8	1.4	2.8	7.9	14.7	110.0	121.6
75	264.6	98.6	1.4	2.8	8.1	15.0	110.0	125.9
80	277.1	102.6	1.4	2.8	8.4	15.2	110.0	130.5
85	289.5	106.6	1.4	2.8	8.7	15.5	110.0	135.0
90	299.6	109.8	1.4	2.8	9.0	15.7	110.0	138.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	3.9	4.9	44.5	10.5
5	0	2.2	0.2	1.7	3.1	2.6	44.5	9.8
10	273	5.7	0.3	1.5	2.7	2.6	44.5	12.9
15	525	8.7	0.4	1.4	2.4	3.0	44.5	15.9
20	863	12.3	0.4	1.4	2.3	3.5	44.5	19.9
25	1,222	15.9	0.5	1.3	2.3	4.0	44.5	23.9
30	1,554	19.1	0.5	1.3	2.3	4.3	44.5	27.5
35	1,875	22.2	0.5	1.3	2.4	4.7	44.5	30.9
40	2,177	25.0	0.5	1.2	2.4	4.9	44.5	34.2
45	2,462	27.7	0.5	1.2	2.6	5.2	44.5	37.2
50	2,736	30.3	0.5	1.2	2.7	5.4	44.5	40.1
55	2,978	32.5	0.5	1.2	2.8	5.5	44.5	42.6
60	3,200	34.6	0.5	1.2	2.9	5.7	44.5	44.9
65	3,407	36.5	0.6	1.2	3.1	5.8	44.5	47.1
70	3,614	38.4	0.6	1.1	3.2	6.0	44.5	49.2
75	3,782	39.9	0.6	1.1	3.3	6.1	44.5	51.0
80	3,960	41.5	0.6	1.1	3.4	6.2	44.5	52.8
85	4,138	43.1	0.6	1.1	3.5	6.3	44.5	54.6
90	4,281	44.4	0.6	1.1	3.6	6.3	44.5	56.1

A42.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands on forest land after clearcut harvest in the Southeast; volumes are for high-productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	21.1	12.2	110.0	37.4
5	0.0	8.8	0.4	4.0	16.3	6.5	110.0	36.0
10	47.7	27.2	0.8	3.9	13.1	6.4	110.0	51.3
15	146.5	60.1	0.8	3.8	11.4	7.5	110.0	83.5
20	244.8	91.2	0.9	3.7	10.3	8.7	110.0	114.8
25	315.2	113.5	0.9	3.7	9.5	9.8	110.0	137.3
30	347.3	122.8	0.9	3.7	8.5	10.7	110.0	146.6
35	351.5	124.0	0.9	3.7	7.6	11.5	110.0	147.7
40	355.0	125.0	0.9	3.7	6.9	12.2	110.0	148.7
45	358.5	126.0	0.9	3.7	6.4	12.7	110.0	149.8
50	362.0	127.0	0.9	3.7	6.0	13.2	110.0	150.9
55	362.0	127.0	0.9	3.7	5.7	13.7	110.0	151.0
60	362.0	127.0	0.9	3.7	5.5	14.1	110.0	151.2
65	362.0	127.0	0.9	3.7	5.3	14.4	110.0	151.3
70	362.0	127.0	0.9	3.7	5.2	14.7	110.0	151.5
75	362.0	127.0	0.9	3.7	5.1	15.0	110.0	151.7
80	362.0	127.0	0.9	3.7	5.0	15.2	110.0	151.9
85	362.0	127.0	0.9	3.7	4.9	15.5	110.0	152.0
90	362.0	127.0	0.9	3.7	4.9	15.7	110.0	152.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.5	4.9	44.5	15.2
5	0	3.6	0.2	1.6	6.6	2.6	44.5	14.6
10	682	11.0	0.3	1.6	5.3	2.6	44.5	20.8
15	2,094	24.3	0.3	1.5	4.6	3.0	44.5	33.8
20	3,498	36.9	0.4	1.5	4.2	3.5	44.5	46.5
25	4,504	45.9	0.4	1.5	3.8	4.0	44.5	55.6
30	4,963	49.7	0.4	1.5	3.5	4.3	44.5	59.3
35	5,024	50.2	0.4	1.5	3.1	4.7	44.5	59.8
40	5,074	50.6	0.4	1.5	2.8	4.9	44.5	60.2
45	5,124	51.0	0.4	1.5	2.6	5.2	44.5	60.6
50	5,174	51.4	0.4	1.5	2.4	5.4	44.5	61.1
55	5,174	51.4	0.4	1.5	2.3	5.5	44.5	61.1
60	5,174	51.4	0.4	1.5	2.2	5.7	44.5	61.2
65	5,174	51.4	0.4	1.5	2.2	5.8	44.5	61.2
70	5,174	51.4	0.4	1.5	2.1	6.0	44.5	61.3
75	5,174	51.4	0.4	1.5	2.1	6.1	44.5	61.4
80	5,174	51.4	0.4	1.5	2.0	6.2	44.5	61.5
85	5,174	51.4	0.4	1.5	2.0	6.3	44.5	61.5
90	5,174	51.4	0.4	1.5	2.0	6.3	44.5	61.6

A43.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	10.2	6.0	158.0	18.1
5	0.0	6.7	0.7	1.9	6.2	2.4	158.0	17.9
10	9.8	18.8	1.9	1.8	4.5	2.4	158.0	29.3
15	19.9	28.3	2.4	1.7	3.7	3.0	158.0	39.1
20	32.7	38.0	2.8	1.7	3.5	3.8	158.0	49.7
25	45.4	46.8	3.1	1.6	3.6	4.4	158.0	59.5
30	58.1	54.0	3.4	1.6	3.8	5.0	158.0	67.8
35	73.4	62.3	3.6	1.6	4.2	5.5	158.0	77.2
40	92.2	71.9	3.9	1.6	4.7	6.0	158.0	88.1
45	110.7	80.9	4.2	1.6	5.2	6.4	158.0	98.3
50	128.1	89.0	4.4	1.5	5.7	6.8	158.0	107.5
55	146.3	97.3	4.6	1.5	6.2	7.2	158.0	116.7
60	166.1	105.9	4.7	1.5	6.7	7.5	158.0	126.5
65	186.4	114.5	4.9	1.5	7.3	7.8	158.0	136.1
70	205.7	122.5	5.1	1.5	7.8	8.1	158.0	145.0
75	222.5	129.3	5.2	1.5	8.2	8.4	158.0	152.6
80	237.9	135.4	5.3	1.5	8.6	8.6	158.0	159.4
85	257.3	142.9	5.5	1.5	9.1	8.9	158.0	167.8
90	278.9	151.2	5.6	1.5	9.6	9.1	158.0	177.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	4.1	2.4	63.9	7.3
5	0	2.7	0.3	0.8	2.5	1.0	63.9	7.3
10	140	7.6	0.8	0.7	1.8	1.0	63.9	11.9
15	284	11.5	1.0	0.7	1.5	1.2	63.9	15.8
20	467	15.4	1.1	0.7	1.4	1.5	63.9	20.1
25	649	18.9	1.3	0.7	1.5	1.8	63.9	24.1
30	830	21.9	1.4	0.7	1.5	2.0	63.9	27.4
35	1,049	25.2	1.5	0.6	1.7	2.2	63.9	31.3
40	1,318	29.1	1.6	0.6	1.9	2.4	63.9	35.7
45	1,582	32.7	1.7	0.6	2.1	2.6	63.9	39.8
50	1,830	36.0	1.8	0.6	2.3	2.8	63.9	43.5
55	2,091	39.4	1.8	0.6	2.5	2.9	63.9	47.2
60	2,374	42.9	1.9	0.6	2.7	3.1	63.9	51.2
65	2,664	46.3	2.0	0.6	2.9	3.2	63.9	55.1
70	2,940	49.6	2.1	0.6	3.2	3.3	63.9	58.7
75	3,180	52.3	2.1	0.6	3.3	3.4	63.9	61.8
80	3,400	54.8	2.2	0.6	3.5	3.5	63.9	64.5
85	3,677	57.8	2.2	0.6	3.7	3.6	63.9	67.9
90	3,986	61.2	2.3	0.6	3.9	3.7	63.9	71.6

A44.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	10.8	6.0	45.3	21.0
5	0.0	8.1	0.8	4.2	6.7	2.4	45.3	22.1
10	11.7	21.0	2.1	3.8	4.8	2.4	45.3	34.0
15	21.2	30.3	2.5	3.5	3.8	3.0	45.3	43.1
20	33.8	40.0	2.8	3.3	3.5	3.8	45.3	53.4
25	46.6	49.5	3.0	3.2	3.6	4.4	45.3	63.8
30	60.2	57.5	3.2	3.1	3.8	5.0	45.3	72.6
35	76.3	66.6	3.4	3.0	4.2	5.5	45.3	82.7
40	94.3	76.2	3.6	2.9	4.6	6.0	45.3	93.5
45	114.1	86.4	3.8	2.9	5.2	6.4	45.3	104.7
50	133.0	95.8	4.0	2.8	5.7	6.8	45.3	115.2
55	151.4	104.8	4.1	2.8	6.2	7.2	45.3	125.1
60	168.9	113.0	4.2	2.7	6.7	7.5	45.3	134.2
65	185.6	120.8	4.3	2.7	7.2	7.8	45.3	142.8
70	201.5	128.0	4.4	2.7	7.6	8.1	45.3	150.8
75	215.7	134.4	4.5	2.6	8.0	8.4	45.3	157.9
80	229.4	140.5	4.6	2.6	8.3	8.6	45.3	164.6
85	242.5	146.2	4.6	2.6	8.7	8.9	45.3	171.0
90	254.1	151.3	4.7	2.6	9.0	9.1	45.3	176.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.4	2.4	18.3	8.5
5	0	3.3	0.3	1.7	2.7	1.0	18.3	9.0
10	167	8.5	0.8	1.5	1.9	1.0	18.3	13.8
15	303	12.3	1.0	1.4	1.5	1.2	18.3	17.4
20	483	16.2	1.1	1.3	1.4	1.5	18.3	21.6
25	666	20.1	1.2	1.3	1.5	1.8	18.3	25.8
30	860	23.3	1.3	1.3	1.5	2.0	18.3	29.4
35	1,091	26.9	1.4	1.2	1.7	2.2	18.3	33.5
40	1,348	30.8	1.5	1.2	1.9	2.4	18.3	37.8
45	1,630	35.0	1.5	1.2	2.1	2.6	18.3	42.4
50	1,901	38.8	1.6	1.1	2.3	2.8	18.3	46.6
55	2,164	42.4	1.7	1.1	2.5	2.9	18.3	50.6
60	2,414	45.7	1.7	1.1	2.7	3.1	18.3	54.3
65	2,652	48.9	1.7	1.1	2.9	3.2	18.3	57.8
70	2,880	51.8	1.8	1.1	3.1	3.3	18.3	61.0
75	3,082	54.4	1.8	1.1	3.2	3.4	18.3	63.9
80	3,278	56.8	1.8	1.1	3.4	3.5	18.3	66.6
85	3,465	59.2	1.9	1.0	3.5	3.6	18.3	69.2
90	3,632	61.2	1.9	1.0	3.6	3.7	18.3	71.5

A45.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	11.3	10.3	61.4	25.8
5	0.0	7.4	0.6	4.1	9.0	5.8	61.4	26.9
10	13.6	19.6	1.2	3.6	7.7	5.9	61.4	38.0
15	27.8	29.3	1.6	3.5	6.7	6.8	61.4	47.9
20	43.9	39.0	1.9	3.4	6.2	7.7	61.4	58.2
25	59.3	46.8	2.1	3.3	5.8	8.6	61.4	66.5
30	77.2	55.4	2.3	3.2	5.6	9.2	61.4	75.8
35	96.8	64.4	2.5	3.2	5.7	9.8	61.4	85.5
40	117.2	73.4	2.7	3.1	5.9	10.2	61.4	95.3
45	136.4	81.6	2.8	3.1	6.1	10.6	61.4	104.2
50	154.1	88.9	2.9	3.1	6.3	11.0	61.4	112.2
55	171.4	96.0	3.0	3.0	6.6	11.3	61.4	119.9
60	189.6	103.2	3.1	3.0	6.9	11.5	61.4	127.8
65	204.5	109.1	3.2	3.0	7.2	11.8	61.4	134.3
70	218.8	114.6	3.3	3.0	7.5	12.0	61.4	140.3
75	234.5	120.6	3.4	2.9	7.8	12.1	61.4	146.9
80	247.6	125.5	3.5	2.9	8.1	12.3	61.4	152.3
85	259.4	129.9	3.5	2.9	8.3	12.5	61.4	157.2
90	272.3	134.7	3.6	2.9	8.6	12.6	61.4	162.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	4.6	4.2	24.9	10.4
5	0	3.0	0.3	1.7	3.6	2.4	24.9	10.9
10	195	7.9	0.5	1.5	3.1	2.4	24.9	15.4
15	397	11.9	0.6	1.4	2.7	2.7	24.9	19.4
20	628	15.8	0.8	1.4	2.5	3.1	24.9	23.5
25	848	19.0	0.8	1.3	2.3	3.5	24.9	26.9
30	1,104	22.4	0.9	1.3	2.3	3.7	24.9	30.7
35	1,384	26.1	1.0	1.3	2.3	4.0	24.9	34.6
40	1,675	29.7	1.1	1.3	2.4	4.1	24.9	38.5
45	1,950	33.0	1.1	1.2	2.5	4.3	24.9	42.2
50	2,202	36.0	1.2	1.2	2.6	4.4	24.9	45.4
55	2,450	38.8	1.2	1.2	2.7	4.6	24.9	48.5
60	2,710	41.8	1.3	1.2	2.8	4.7	24.9	51.7
65	2,923	44.1	1.3	1.2	2.9	4.8	24.9	54.3
70	3,127	46.4	1.3	1.2	3.0	4.8	24.9	56.8
75	3,352	48.8	1.4	1.2	3.2	4.9	24.9	59.5
80	3,539	50.8	1.4	1.2	3.3	5.0	24.9	61.6
85	3,707	52.6	1.4	1.2	3.4	5.0	24.9	63.6
90	3,891	54.5	1.4	1.2	3.5	5.1	24.9	65.7

A46.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*------------------------------------- tonnes carbon/hectare -------------------------------------*						
0	0.0	0.0	0.0	4.2	11.2	6.0	49.9	21.4
5	0.0	8.6	0.9	4.9	7.0	2.4	49.9	23.7
10	11.7	18.3	1.8	4.1	4.9	2.4	49.9	31.5
15	21.2	27.0	2.7	3.7	3.9	3.0	49.9	40.3
20	33.8	36.3	3.3	3.5	3.6	3.8	49.9	50.3
25	46.6	45.1	3.6	3.3	3.7	4.4	49.9	60.0
30	60.2	53.8	3.8	3.2	4.0	5.0	49.9	69.7
35	76.3	63.3	4.1	3.1	4.4	5.5	49.9	80.4
40	94.3	73.3	4.4	2.9	5.0	6.0	49.9	91.6
45	114.1	83.8	4.6	2.9	5.6	6.4	49.9	103.4
50	133.0	95.1	4.8	2.8	6.4	6.8	49.9	115.9
55	151.4	104.2	5.0	2.7	7.0	7.2	49.9	126.0
60	168.9	112.7	5.1	2.7	7.5	7.5	49.9	135.5
65	185.6	120.7	5.3	2.6	8.0	7.8	49.9	144.5
70	201.5	128.4	5.4	2.6	8.5	8.1	49.9	153.0
75	215.7	135.1	5.5	2.6	9.0	8.4	49.9	160.6
80	229.4	141.6	5.6	2.5	9.4	8.6	49.9	167.8
85	242.5	147.8	5.7	2.5	9.8	8.9	49.9	174.7
90	254.1	153.4	5.8	2.5	10.2	9.1	49.9	180.9
years	*ft^3/acre*	*------------------------------------- tonnes carbon/acre -------------------------------------*						
0	0	0.0	0.0	1.7	4.5	2.4	20.2	8.7
5	0	3.5	0.3	2.0	2.8	1.0	20.2	9.6
10	167	7.4	0.7	1.7	2.0	1.0	20.2	12.7
15	303	10.9	1.1	1.5	1.6	1.2	20.2	16.3
20	483	14.7	1.3	1.4	1.5	1.5	20.2	20.4
25	666	18.3	1.4	1.3	1.5	1.8	20.2	24.3
30	860	21.8	1.6	1.3	1.6	2.0	20.2	28.2
35	1,091	25.6	1.7	1.2	1.8	2.2	20.2	32.5
40	1,348	29.7	1.8	1.2	2.0	2.4	20.2	37.1
45	1,630	33.9	1.9	1.2	2.3	2.6	20.2	41.8
50	1,901	38.5	1.9	1.1	2.6	2.8	20.2	46.9
55	2,164	42.2	2.0	1.1	2.8	2.9	20.2	51.0
60	2,414	45.6	2.1	1.1	3.0	3.1	20.2	54.8
65	2,652	48.9	2.1	1.1	3.3	3.2	20.2	58.5
70	2,880	52.0	2.2	1.0	3.5	3.3	20.2	61.9
75	3,082	54.7	2.2	1.0	3.6	3.4	20.2	65.0
80	3,278	57.3	2.3	1.0	3.8	3.5	20.2	67.9
85	3,465	59.8	2.3	1.0	4.0	3.6	20.2	70.7
90	3,632	62.1	2.3	1.0	4.1	3.7	20.2	73.2

A47.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	9.2	12.2	41.9	25.6
5	0.0	10.8	0.7	4.7	7.7	6.5	41.9	30.3
10	19.1	23.1	1.3	3.9	6.8	6.4	41.9	41.5
15	36.7	32.4	1.6	3.5	6.2	7.5	41.9	51.2
20	60.4	42.2	1.8	3.3	5.9	8.7	41.9	61.9
25	85.5	52.0	2.0	3.1	5.8	9.8	41.9	72.8
30	108.7	59.6	2.1	3.0	5.8	10.7	41.9	81.2
35	131.2	66.6	2.3	2.9	5.9	11.5	41.9	89.1
40	152.3	73.1	2.3	2.9	6.0	12.2	41.9	96.4
45	172.3	79.0	2.4	2.8	6.1	12.7	41.9	103.1
50	191.4	84.7	2.5	2.8	6.4	13.2	41.9	109.5
55	208.4	89.6	2.6	2.7	6.5	13.7	41.9	115.1
60	223.9	94.0	2.6	2.7	6.7	14.1	41.9	120.1
65	238.4	98.1	2.7	2.6	7.0	14.4	41.9	124.8
70	252.9	102.2	2.7	2.6	7.2	14.7	41.9	129.4
75	264.6	105.5	2.7	2.6	7.3	15.0	41.9	133.1
80	277.1	108.9	2.8	2.6	7.6	15.2	41.9	137.0
85	289.5	112.3	2.8	2.6	7.8	15.5	41.9	140.9
90	299.6	115.1	2.8	2.5	7.9	15.7	41.9	144.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	3.7	4.9	17.0	10.4
5	0	4.4	0.3	1.9	3.1	2.6	17.0	12.3
10	273	9.4	0.5	1.6	2.8	2.6	17.0	16.8
15	525	13.1	0.6	1.4	2.5	3.0	17.0	20.7
20	863	17.1	0.7	1.3	2.4	3.5	17.0	25.1
25	1,222	21.1	0.8	1.3	2.4	4.0	17.0	29.5
30	1,554	24.1	0.9	1.2	2.3	4.3	17.0	32.9
35	1,875	27.0	0.9	1.2	2.4	4.7	17.0	36.1
40	2,177	29.6	0.9	1.2	2.4	4.9	17.0	39.0
45	2,462	32.0	1.0	1.1	2.5	5.2	17.0	41.7
50	2,736	34.3	1.0	1.1	2.6	5.4	17.0	44.3
55	2,978	36.3	1.0	1.1	2.7	5.5	17.0	46.6
60	3,200	38.1	1.1	1.1	2.7	5.7	17.0	48.6
65	3,407	39.7	1.1	1.1	2.8	5.8	17.0	50.5
70	3,614	41.4	1.1	1.1	2.9	6.0	17.0	52.4
75	3,782	42.7	1.1	1.1	3.0	6.1	17.0	53.9
80	3,960	44.1	1.1	1.0	3.1	6.2	17.0	55.5
85	4,138	45.5	1.1	1.0	3.1	6.3	17.0	57.0
90	4,281	46.6	1.1	1.0	3.2	6.3	17.0	58.3

A48.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands on forest land after clearcut harvest in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	20.4	12.2	41.9	36.7
5	0.0	10.8	0.4	4.1	15.8	6.5	41.9	37.6
10	47.7	34.2	0.9	3.9	13.0	6.4	41.9	58.3
15	146.5	68.7	1.0	3.8	11.5	7.5	41.9	92.5
20	244.8	99.2	1.1	3.7	10.5	8.7	41.9	123.2
25	315.2	118.3	1.1	3.7	9.6	9.8	41.9	142.6
30	347.3	126.8	1.1	3.7	8.7	10.7	41.9	151.1
35	351.5	127.9	1.1	3.7	7.8	11.5	41.9	152.1
40	355.0	128.8	1.1	3.7	7.2	12.2	41.9	153.0
45	358.5	129.8	1.1	3.7	6.7	12.7	41.9	154.0
50	362.0	130.7	1.1	3.7	6.3	13.2	41.9	155.0
55	362.0	130.7	1.1	3.7	6.0	13.7	41.9	155.2
60	362.0	130.7	1.1	3.7	5.8	14.1	41.9	155.3
65	362.0	130.7	1.1	3.7	5.6	14.4	41.9	155.5
70	362.0	130.7	1.1	3.7	5.5	14.7	41.9	155.7
75	362.0	130.7	1.1	3.7	5.4	15.0	41.9	155.9
80	362.0	130.7	1.1	3.7	5.3	15.2	41.9	156.0
85	362.0	130.7	1.1	3.7	5.2	15.5	41.9	156.2
90	362.0	130.7	1.1	3.7	5.2	15.7	41.9	156.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	8.2	4.9	17.0	14.9
5	0	4.4	0.2	1.6	6.4	2.6	17.0	15.2
10	682	13.8	0.3	1.6	5.2	2.6	17.0	23.6
15	2,094	27.8	0.4	1.5	4.6	3.0	17.0	37.4
20	3,498	40.1	0.4	1.5	4.2	3.5	17.0	49.9
25	4,504	47.9	0.4	1.5	3.9	4.0	17.0	57.7
30	4,963	51.3	0.5	1.5	3.5	4.3	17.0	61.1
35	5,024	51.8	0.5	1.5	3.2	4.7	17.0	61.6
40	5,074	52.1	0.5	1.5	2.9	4.9	17.0	61.9
45	5,124	52.5	0.5	1.5	2.7	5.2	17.0	62.3
50	5,174	52.9	0.5	1.5	2.6	5.4	17.0	62.7
55	5,174	52.9	0.5	1.5	2.4	5.5	17.0	62.8
60	5,174	52.9	0.5	1.5	2.3	5.7	17.0	62.9
65	5,174	52.9	0.5	1.5	2.3	5.8	17.0	62.9
70	5,174	52.9	0.5	1.5	2.2	6.0	17.0	63.0
75	5,174	52.9	0.5	1.5	2.2	6.1	17.0	63.1
80	5,174	52.9	0.5	1.5	2.1	6.2	17.0	63.1
85	5,174	52.9	0.5	1.5	2.1	6.3	17.0	63.2
90	5,174	52.9	0.5	1.5	2.1	6.3	17.0	63.3

A49.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*------------ tonnes carbon/hectare ------------*						
0	0.0	0.0	0.0	1.8	10.8	6.0	52.8	18.6
5	0.0	5.4	0.5	2.1	6.5	2.4	52.8	16.9
10	9.8	17.8	1.8	1.8	4.6	2.4	52.8	28.4
15	19.9	28.4	2.8	1.7	3.8	3.0	52.8	39.8
20	32.7	39.3	3.2	1.7	3.6	3.8	52.8	51.6
25	45.4	48.8	3.4	1.6	3.7	4.4	52.8	61.9
30	58.1	57.2	3.5	1.6	4.0	5.0	52.8	71.2
35	73.4	66.9	3.6	1.6	4.4	5.5	52.8	82.1
40	92.2	76.9	3.7	1.6	5.0	6.0	52.8	93.1
45	110.7	86.1	3.7	1.5	5.5	6.4	52.8	103.4
50	128.1	94.4	3.8	1.5	6.0	6.8	52.8	112.6
55	146.3	102.8	3.9	1.5	6.5	7.2	52.8	121.9
60	166.1	111.6	3.9	1.5	7.1	7.5	52.8	131.6
65	186.4	120.3	4.0	1.5	7.6	7.8	52.8	141.2
70	205.7	128.3	4.0	1.5	8.1	8.1	52.8	150.1
75	222.5	135.1	4.1	1.5	8.5	8.4	52.8	157.6
80	237.9	141.2	4.1	1.5	8.9	8.6	52.8	164.4
85	257.3	148.8	4.1	1.5	9.4	8.9	52.8	172.6
90	278.9	157.0	4.2	1.4	9.9	9.1	52.8	181.6
years	*ft^3/acre*	*------------ tonnes carbon/acre ------------*						
0	0	0.0	0.0	0.7	4.4	2.4	21.4	7.5
5	0	2.2	0.2	0.8	2.6	1.0	21.4	6.9
10	140	7.2	0.7	0.7	1.9	1.0	21.4	11.5
15	284	11.5	1.1	0.7	1.5	1.2	21.4	16.1
20	467	15.9	1.3	0.7	1.5	1.5	21.4	20.9
25	649	19.7	1.4	0.7	1.5	1.8	21.4	25.1
30	830	23.1	1.4	0.7	1.6	2.0	21.4	28.8
35	1,049	27.1	1.4	0.6	1.8	2.2	21.4	33.2
40	1,318	31.1	1.5	0.6	2.0	2.4	21.4	37.7
45	1,582	34.9	1.5	0.6	2.2	2.6	21.4	41.8
50	1,830	38.2	1.5	0.6	2.4	2.8	21.4	45.6
55	2,091	41.6	1.6	0.6	2.6	2.9	21.4	49.3
60	2,374	45.2	1.6	0.6	2.9	3.1	21.4	53.3
65	2,664	48.7	1.6	0.6	3.1	3.2	21.4	57.1
70	2,940	51.9	1.6	0.6	3.3	3.3	21.4	60.7
75	3,180	54.7	1.6	0.6	3.5	3.4	21.4	63.8
80	3,400	57.2	1.7	0.6	3.6	3.5	21.4	66.5
85	3,677	60.2	1.7	0.6	3.8	3.6	21.4	69.9
90	3,986	63.5	1.7	0.6	4.0	3.7	21.4	73.5

A50.— Regional estimates of timber volume and carbon stocks for oak-hickory stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*------------------------------------- tonnes carbon/hectare ---------------------------------------*						
0	0.0	0.0	0.0	4.2	11.7	6.0	38.6	21.8
5	0.0	9.7	0.9	4.7	7.3	2.4	38.6	25.0
10	11.7	20.9	1.9	4.0	5.2	2.4	38.6	34.3
15	21.2	30.1	2.1	3.6	4.2	3.0	38.6	43.0
20	33.8	39.5	2.3	3.4	3.9	3.8	38.6	52.9
25	46.6	48.2	2.4	3.3	3.9	4.4	38.6	62.2
30	60.2	56.6	2.6	3.1	4.2	5.0	38.6	71.4
35	76.3	65.6	2.7	3.0	4.6	5.5	38.6	81.4
40	94.3	76.2	2.8	2.9	5.2	6.0	38.6	93.1
45	114.1	85.7	2.9	2.8	5.8	6.4	38.6	103.7
50	133.0	94.7	3.0	2.8	6.3	6.8	38.6	113.6
55	151.4	103.3	3.0	2.7	6.9	7.2	38.6	123.1
60	168.9	111.3	3.1	2.7	7.4	7.5	38.6	132.0
65	185.6	118.8	3.2	2.6	7.9	7.8	38.6	140.4
70	201.5	126.0	3.2	2.6	8.4	8.1	38.6	148.3
75	215.7	132.3	3.2	2.6	8.8	8.4	38.6	155.3
80	229.4	138.3	3.3	2.5	9.2	8.6	38.6	162.0
85	242.5	144.0	3.3	2.5	9.6	8.9	38.6	168.3
90	254.1	149.1	3.3	2.5	9.9	9.1	38.6	174.0
years	*ft³/acre*	*------------------------------------- tonnes carbon/acre ---*						
0	0	0.0	0.0	1.7	4.7	2.4	15.6	8.8
5	0	3.9	0.4	1.9	2.9	1.0	15.6	10.1
10	167	8.5	0.8	1.6	2.1	1.0	15.6	13.9
15	303	12.2	0.9	1.5	1.7	1.2	15.6	17.4
20	483	16.0	0.9	1.4	1.6	1.5	15.6	21.4
25	666	19.5	1.0	1.3	1.6	1.8	15.6	25.2
30	860	22.9	1.0	1.3	1.7	2.0	15.6	28.9
35	1,091	26.6	1.1	1.2	1.9	2.2	15.6	33.0
40	1,348	30.8	1.1	1.2	2.1	2.4	15.6	37.7
45	1,630	34.7	1.2	1.2	2.3	2.6	15.6	41.9
50	1,901	38.3	1.2	1.1	2.6	2.8	15.6	46.0
55	2,164	41.8	1.2	1.1	2.8	2.9	15.6	49.8
60	2,414	45.0	1.3	1.1	3.0	3.1	15.6	53.4
65	2,652	48.1	1.3	1.1	3.2	3.2	15.6	56.8
70	2,880	51.0	1.3	1.1	3.4	3.3	15.6	60.0
75	3,082	53.5	1.3	1.0	3.6	3.4	15.6	62.8
80	3,278	56.0	1.3	1.0	3.7	3.5	15.6	65.6
85	3,465	58.3	1.3	1.0	3.9	3.6	15.6	68.1
90	3,632	60.3	1.4	1.0	4.0	3.7	15.6	70.4

A51.— Regional estimates of timber volume and carbon stocks for oak-pine stands on forest land after clearcut harvest in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	12.4	10.3	41.7	26.9
5	0.0	8.7	0.7	4.4	10.0	5.8	41.7	29.6
10	13.6	21.4	1.4	3.7	8.6	5.9	41.7	41.0
15	27.8	31.9	1.7	3.5	7.7	6.8	41.7	51.5
20	43.9	41.8	2.0	3.3	7.1	7.7	41.7	61.9
25	59.3	50.9	2.2	3.2	6.7	8.6	41.7	71.6
30	77.2	59.2	2.5	3.1	6.6	9.2	41.7	80.6
35	96.8	67.9	2.6	3.0	6.7	9.8	41.7	90.0
40	117.2	76.5	2.8	2.9	6.9	10.2	41.7	99.4
45	136.4	84.4	3.0	2.9	7.1	10.6	41.7	108.0
50	154.1	91.4	3.1	2.8	7.4	11.0	41.7	115.7
55	171.4	98.2	3.2	2.8	7.7	11.3	41.7	123.2
60	189.6	105.2	3.3	2.8	8.0	11.5	41.7	130.8
65	204.5	110.7	3.4	2.7	8.3	11.8	41.7	137.0
70	218.8	116.0	3.5	2.7	8.6	12.0	41.7	142.8
75	234.5	121.8	3.6	2.7	9.0	12.1	41.7	149.2
80	247.6	126.5	3.6	2.7	9.3	12.3	41.7	154.4
85	259.4	130.7	3.7	2.7	9.6	12.5	41.7	159.0
90	272.3	135.2	3.8	2.6	9.9	12.6	41.7	164.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	5.0	4.2	16.9	10.9
5	0	3.5	0.3	1.8	4.0	2.4	16.9	12.0
10	195	8.6	0.6	1.5	3.5	2.4	16.9	16.6
15	397	12.9	0.7	1.4	3.1	2.7	16.9	20.9
20	628	16.9	0.8	1.3	2.9	3.1	16.9	25.0
25	848	20.6	0.9	1.3	2.7	3.5	16.9	29.0
30	1,104	24.0	1.0	1.2	2.7	3.7	16.9	32.6
35	1,384	27.5	1.1	1.2	2.7	4.0	16.9	36.4
40	1,675	31.0	1.1	1.2	2.8	4.1	16.9	40.2
45	1,950	34.2	1.2	1.2	2.9	4.3	16.9	43.7
50	2,202	37.0	1.3	1.2	3.0	4.4	16.9	46.8
55	2,450	39.7	1.3	1.1	3.1	4.6	16.9	49.9
60	2,710	42.6	1.3	1.1	3.3	4.7	16.9	52.9
65	2,923	44.8	1.4	1.1	3.4	4.8	16.9	55.4
70	3,127	47.0	1.4	1.1	3.5	4.8	16.9	57.8
75	3,352	49.3	1.4	1.1	3.6	4.9	16.9	60.4
80	3,539	51.2	1.5	1.1	3.8	5.0	16.9	62.5
85	3,707	52.9	1.5	1.1	3.9	5.0	16.9	64.4
90	3,891	54.7	1.5	1.1	4.0	5.1	16.9	66.4

APPENDIX B

Forest Ecosystem Yield Tables for Afforestation (Establishment on Nonforest Land)[2]

Carbon Stocks with Afforestation of Land

B1. Aspen-birch, Northeast
B2. Maple-beech-birch, Northeast
B3. Oak-hickory, Northeast
B4. Oak-pine, Northeast
B5. Spruce-balsam fir, Northeast
B6. White-red-jack pine, Northeast
B7. Aspen-birch, Northern Lake States
B8. Elm-ash-cottonwood, Northern Lake States
B9. Maple-beech-birch, Northern Lake States
B10. Oak-hickory, Northern Lake States
B11. Spruce-balsam fir, Northern Lake States
B12. White-red-jack pine, Northern Lake States
B13. Elm-ash-cottonwood, Northern Prairie States
B14. Maple-beech-birch, Northern Prairie States
B15. Oak-hickory, Northern Prairie States
B16. Oak-pine, Northern Prairie States
B17. Douglas-fir, Pacific Northwest, East
B18. Fir-spruce-mountain hemlock, Pacific Northwest, East
B19. Lodgepole pine, Pacific Northwest, East
B20. Ponderosa pine, Pacific Northwest, East
B21. Alder-maple, Pacific Northwest, West
B22. Douglas-fir, Pacific Northwest, West
B23. Douglas-fir, high productivity and management intensity, Pacific Northwest, West
B24. Fir-spruce-mountain hemlock, Pacific Northwest, West
B25. Hemlock-Sitka spruce, Pacific Northwest, West
B26. Hemlock-Sitka spruce, high productivity and management intensity, Pacific Northwest, West
B27. Mixed conifer, Pacific Southwest
B28. Fir-spruce-mountain hemlock, Pacific Southwest
B29. Western oak, Pacific Southwest
B30. Douglas-fir, Rocky Mountain, North
B31. Fir-spruce-mountain hemlock, Rocky Mountain, North
B32. Lodgepole pine, Rocky Mountain, North
B33. Ponderosa pine, Rocky Mountain, North
B34. Aspen-birch, Rocky Mountain, South
B35. Douglas-fir, Rocky Mountain, South
B36. Fir-spruce-mountain hemlock, Rocky Mountain, South
B37. Lodgepole pine, Rocky Mountain, South
B38. Ponderosa pine, Rocky Mountain, South
B39. Loblolly-shortleaf pine, Southeast
B40. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
B41. Longleaf-slash pine, Southeast
B42. Longleaf-slash pine, high productivity and management intensity, Southeast
B43. Oak-gum-cypress, Southeast
B44. Oak-hickory, Southeast
B45. Oak-pine, Southeast
B46. Elm-ash-cottonwood, South Central
B47. Loblolly-shortleaf pine, South Central
B48. Loblolly-shortleaf pine, high productivity and management intensity, South Central
B49. Oak-gum-cypress, South Central
B50. Oak-hickory, South Central
B51. Oak-pine, South Central

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[2] Note carbon mass is in metric tons (tonnes) in all tables.

B1.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------ *tonnes carbon/hectare* ------						
0	0.0	0.0	0.0	2.0	0.0	0.0	65.6	2.0
5	0.0	6.6	0.6	2.2	0.5	1.6	65.8	11.5
15	12.9	21.3	1.8	2.1	1.7	4.0	67.4	30.9
25	33.8	36.0	2.9	2.1	2.8	5.8	70.4	49.6
35	58.4	50.1	3.8	2.1	3.9	7.3	74.0	67.1
45	84.7	62.7	4.6	2.1	4.9	8.4	77.7	82.6
55	112.4	75.1	5.3	2.0	5.8	9.3	80.9	97.6
65	141.7	87.5	5.9	2.0	6.8	10.1	83.4	112.3
75	172.6	100.0	6.5	2.0	7.8	10.7	85.1	127.1
85	205.0	112.7	7.1	2.0	8.8	11.3	86.2	141.9
95	238.9	125.5	7.7	2.0	9.8	11.8	86.8	156.7
105	274.4	138.5	8.2	2.0	10.8	12.2	87.1	171.7
115	311.4	151.7	8.8	2.0	11.8	12.5	87.3	186.8
125	349.9	165.0	9.3	2.0	12.8	12.9	87.4	202.0
years	*ft^3/acre*	------ *tonnes carbon/acre* ------						
0	0	0.0	0.0	0.8	0.0	0.0	26.5	0.8
5	0	2.7	0.2	0.9	0.2	0.6	26.6	4.7
15	184	8.6	0.7	0.9	0.7	1.6	27.3	12.5
25	483	14.6	1.2	0.8	1.1	2.4	28.5	20.1
35	835	20.3	1.5	0.8	1.6	2.9	30.0	27.2
45	1,210	25.4	1.9	0.8	2.0	3.4	31.4	33.4
55	1,607	30.4	2.1	0.8	2.4	3.8	32.7	39.5
65	2,025	35.4	2.4	0.8	2.8	4.1	33.7	45.5
75	2,466	40.5	2.6	0.8	3.1	4.3	34.4	51.4
85	2,929	45.6	2.9	0.8	3.5	4.6	34.9	57.4
95	3,414	50.8	3.1	0.8	3.9	4.8	35.1	63.4
105	3,921	56.0	3.3	0.8	4.4	4.9	35.3	69.5
115	4,450	61.4	3.5	0.8	4.8	5.1	35.3	75.6
125	5,001	66.8	3.8	0.8	5.2	5.2	35.4	81.8

B2.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	52.2	2.1
5	0.0	7.4	0.7	2.1	0.5	4.2	52.3	15.0
15	28.0	31.8	3.2	1.9	2.3	10.8	53.7	50.0
25	58.1	53.2	5.3	1.8	3.8	15.8	56.0	79.8
35	89.6	72.8	6.0	1.7	5.2	19.7	58.9	105.4
45	119.1	87.8	6.6	1.7	6.2	22.7	61.8	125.0
55	146.6	101.1	7.0	1.7	7.2	25.3	64.4	142.3
65	172.1	113.1	7.4	1.7	8.0	27.4	66.3	157.5
75	195.6	123.8	7.7	1.7	8.8	29.1	67.7	171.1
85	217.1	133.5	7.9	1.7	9.5	30.7	68.6	183.2
95	236.6	142.1	8.1	1.7	10.1	32.0	69.1	193.9
105	254.1	149.7	8.3	1.6	10.6	33.1	69.3	203.4
115	269.7	156.3	8.5	1.6	11.1	34.2	69.5	211.7
125	283.2	162.1	8.6	1.6	11.5	35.1	69.5	218.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	21.1	0.8
5	0	3.0	0.3	0.8	0.2	1.7	21.2	6.1
15	400	12.9	1.3	0.8	0.9	4.4	21.7	20.2
25	830	21.5	2.1	0.7	1.5	6.4	22.7	32.3
35	1,280	29.5	2.4	0.7	2.1	8.0	23.8	42.7
45	1,702	35.5	2.7	0.7	2.5	9.2	25.0	50.6
55	2,095	40.9	2.8	0.7	2.9	10.2	26.0	57.6
65	2,460	45.8	3.0	0.7	3.2	11.1	26.8	63.7
75	2,796	50.1	3.1	0.7	3.5	11.8	27.4	69.2
85	3,103	54.0	3.2	0.7	3.8	12.4	27.8	74.1
95	3,382	57.5	3.3	0.7	4.1	12.9	28.0	78.5
105	3,632	60.6	3.4	0.7	4.3	13.4	28.1	82.3
115	3,854	63.3	3.4	0.7	4.5	13.8	28.1	85.7
125	4,047	65.6	3.5	0.7	4.6	14.2	28.1	88.6

B3.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	39.8	2.1
5	0.0	6.9	0.7	2.1	0.5	0.9	39.9	11.0
15	54.5	43.0	3.6	1.9	2.9	2.5	40.9	54.0
25	95.7	71.9	4.0	1.9	4.9	3.9	42.7	86.6
35	135.3	96.2	4.2	1.8	6.6	5.2	44.9	114.0
45	173.3	118.2	4.5	1.8	8.1	6.3	47.2	138.8
55	209.6	136.8	4.6	1.8	9.4	7.2	49.1	159.8
65	244.3	154.3	4.8	1.8	10.6	8.1	50.6	179.5
75	277.4	170.6	4.9	1.8	11.7	8.9	51.7	197.9
85	308.9	186.0	5.0	1.8	12.7	9.7	52.3	215.1
95	338.8	200.4	5.1	1.8	13.7	10.3	52.7	231.3
105	367.1	213.9	5.1	1.7	14.6	10.9	52.9	246.4
115	393.7	226.5	5.2	1.7	15.5	11.5	53.0	260.5
125	418.6	238.2	5.3	1.7	16.3	12.0	53.1	273.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	16.1	0.8
5	0	2.8	0.3	0.8	0.2	0.4	16.2	4.5
15	779	17.4	1.4	0.8	1.2	1.0	16.6	21.8
25	1,904	29.1	1.6	0.7	2.0	1.6	17.3	35.0
35	1,934	38.9	1.7	0.7	2.7	2.1	18.2	46.1
45	2,477	47.8	1.8	0.7	3.3	2.5	19.1	56.2
55	2,996	55.4	1.9	0.7	3.8	2.9	19.9	64.7
65	3,492	62.4	1.9	0.7	4.3	3.3	20.5	72.6
75	3,965	69.1	2.0	0.7	4.7	3.6	20.9	80.1
85	4,415	75.3	2.0	0.7	5.1	3.9	21.2	87.1
95	4,842	81.1	2.0	0.7	5.5	4.2	21.3	93.6
105	5,246	86.6	2.1	0.7	5.9	4.4	21.4	99.7
115	5,626	91.7	2.1	0.7	6.3	4.7	21.5	105.4
125	5,983	96.4	2.1	0.7	6.6	4.9	21.5	110.7

B4.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------ *tonnes carbon/hectare* ------						
0	0.0	0.0	0.0	4.2	0.0	0.0	50.2	4.2
5	0.0	6.2	0.6	4.2	0.4	3.8	50.3	15.2
15	36.5	27.0	2.6	3.3	1.7	10.3	51.6	44.9
25	70.9	48.6	3.2	2.9	3.0	15.6	53.9	73.3
35	103.1	67.9	3.7	2.6	4.2	19.9	56.6	98.3
45	133.1	84.7	4.0	2.5	5.2	23.5	59.5	119.8
55	160.9	99.1	4.2	2.4	6.1	26.6	61.9	138.4
65	186.7	113.0	4.4	2.3	6.9	29.2	63.8	155.8
75	210.2	123.6	4.6	2.3	7.6	31.6	65.1	169.5
85	231.5	133.1	4.7	2.3	8.1	33.6	66.0	181.8
95	250.8	141.7	4.8	2.2	8.7	35.4	66.4	192.8
105	267.9	149.2	4.9	2.2	9.1	37.0	66.7	202.4
115	282.7	155.7	5.0	2.2	9.5	38.4	66.8	210.9
125	295.4	161.3	5.1	2.2	9.9	39.7	66.9	218.1
years	*ft^3/acre*	------ *tonnes carbon/acre* ------						
0	0	0.0	0.0	1.7	0.0	0.0	20.3	1.7
5	0	2.5	0.3	1.7	0.2	1.6	20.4	6.2
15	522	10.9	1.1	1.3	0.7	4.2	20.9	18.2
25	1,013	19.7	1.3	1.2	1.2	6.3	21.8	29.6
35	1,473	27.5	1.5	1.1	1.7	8.0	22.9	39.8
45	1,902	34.3	1.6	1.0	2.1	9.5	24.1	48.5
55	2,300	40.1	1.7	1.0	2.5	10.8	25.1	56.0
65	2,668	45.7	1.8	0.9	2.8	11.8	25.8	63.1
75	3,004	50.0	1.8	0.9	3.1	12.8	26.4	68.6
85	3,309	53.9	1.9	0.9	3.3	13.6	26.7	73.6
95	3,584	57.3	1.9	0.9	3.5	14.3	26.9	78.0
105	3,828	60.4	2.0	0.9	3.7	15.0	27.0	81.9
115	4,040	63.0	2.0	0.9	3.9	15.6	27.0	85.3
125	4,222	65.3	2.1	0.9	4.0	16.1	27.1	88.3

B5.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	73.5	2.1
5	0.0	7.0	0.7	1.8	0.6	5.0	73.7	15.1
15	11.5	20.1	2.0	1.6	1.9	13.0	75.6	38.5
25	29.1	32.5	3.3	1.5	3.0	19.0	78.9	59.3
35	51.6	45.7	4.6	1.4	4.2	23.7	83.0	79.7
45	76.9	57.4	5.7	1.4	5.3	27.5	87.1	97.4
55	102.6	68.7	6.9	1.4	6.3	30.7	90.7	113.9
65	126.4	78.6	7.4	1.3	7.3	33.3	93.5	127.9
75	149.3	87.9	7.6	1.3	8.1	35.5	95.4	140.5
85	170.9	96.5	7.8	1.3	8.9	37.4	96.6	152.0
95	191.6	104.5	8.0	1.3	9.6	39.1	97.3	162.5
105	211.1	111.9	8.2	1.3	10.3	40.6	97.7	172.2
115	229.6	118.8	8.3	1.3	11.0	41.9	97.9	181.2
125	247.1	125.3	8.4	1.3	11.6	43.0	97.9	189.6
years	ft^3*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	29.7	0.9
5	0	2.8	0.3	0.7	0.3	2.0	29.8	6.1
15	164	8.1	0.8	0.6	0.8	5.2	30.6	15.6
25	416	13.2	1.3	0.6	1.2	7.7	31.9	24.0
35	738	18.5	1.9	0.6	1.7	9.6	33.6	32.2
45	1,099	23.2	2.3	0.6	2.1	11.1	35.2	39.4
55	1,466	27.8	2.8	0.6	2.6	12.4	36.7	46.1
65	1,807	31.8	3.0	0.5	2.9	13.5	37.8	51.8
75	2,133	35.6	3.1	0.5	3.3	14.4	38.6	56.9
85	2,443	39.0	3.2	0.5	3.6	15.2	39.1	61.5
95	2,738	42.3	3.2	0.5	3.9	15.8	39.4	65.8
105	3,017	45.3	3.3	0.5	4.2	16.4	39.5	69.7
115	3,281	48.1	3.4	0.5	4.4	16.9	39.6	73.3
125	3,532	50.7	3.4	0.5	4.7	17.4	39.6	76.7

B6.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands with afforestation of land in the Northeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*------------------------------------- tonnes carbon/hectare ------------------------------------*						
0	0.0	0.0	0.0	2.1	0.0	0.0	58.6	2.1
5	0.0	7.3	0.7	2.2	0.4	3.1	58.8	13.8
15	30.0	28.6	2.9	1.8	1.6	7.1	60.3	41.9
25	54.4	44.7	3.9	1.8	2.5	9.4	62.9	62.3
35	77.9	57.7	4.3	1.7	3.2	11.0	66.2	77.9
45	100.6	69.4	4.6	1.7	3.8	12.2	69.4	91.7
55	122.5	78.7	4.8	1.6	4.3	13.0	72.3	102.5
65	142.3	86.8	5.0	1.6	4.8	13.7	74.5	111.9
75	160.9	94.3	5.2	1.6	5.2	14.2	76.1	120.5
85	178.4	101.2	5.3	1.6	5.6	14.7	77.0	128.4
95	194.7	107.6	5.4	1.6	5.9	15.0	77.6	135.6
105	210.0	113.5	5.5	1.6	6.3	15.4	77.9	142.2
115	224.1	118.9	5.6	1.6	6.6	15.6	78.0	148.2
125	237.1	123.8	5.7	1.6	6.8	15.9	78.1	153.8
years	*ft^3/acre*	*-------------------------------------- tonnes carbon/acre ---------------------------------------*						
0	0	0.0	0.0	0.8	0.0	0.0	23.7	0.8
5	0	3.0	0.3	0.9	0.2	1.3	23.8	5.6
15	429	11.6	1.2	0.7	0.6	2.9	24.4	17.0
25	777	18.1	1.6	0.7	1.0	3.8	25.5	25.2
35	1,113	23.3	1.7	0.7	1.3	4.5	26.8	31.5
45	1,438	28.1	1.9	0.7	1.5	4.9	28.1	37.1
55	1,751	31.8	2.0	0.7	1.8	5.3	29.3	41.5
65	2,034	35.1	2.0	0.7	1.9	5.5	30.2	45.3
75	2,300	38.2	2.1	0.7	2.1	5.8	30.8	48.8
85	2,550	41.0	2.1	0.6	2.3	5.9	31.2	52.0
95	2,783	43.5	2.2	0.6	2.4	6.1	31.4	54.9
105	3,001	45.9	2.2	0.6	2.5	6.2	31.5	57.6
115	3,202	48.1	2.3	0.6	2.7	6.3	31.6	60.0
125	3,389	50.1	2.3	0.6	2.8	6.4	31.6	62.2

B7.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*------------------------------------ tonnes carbon/hectare ------------------------------------*						
0	0.0	0.0	0.0	2.0	0.0	0.0	109.6	2.0
5	0.0	7.3	0.5	2.1	0.6	1.6	109.9	12.1
15	2.9	13.9	1.4	2.1	1.1	4.0	112.7	22.5
25	21.5	26.8	2.7	2.1	2.2	5.8	117.6	39.6
35	47.2	40.8	4.1	2.0	3.3	7.3	123.7	57.4
45	72.8	53.5	5.3	2.0	4.3	8.4	129.8	73.6
55	97.1	64.9	6.1	2.0	5.2	9.3	135.2	87.6
65	119.5	75.0	6.7	2.0	6.1	10.1	139.4	99.8
75	139.7	83.8	7.1	2.0	6.8	10.7	142.2	110.4
85	157.5	91.5	7.4	2.0	7.4	11.3	144.1	119.6
95	173.0	98.0	7.7	2.0	7.9	11.8	145.1	127.4
105	186.0	103.4	7.9	2.0	8.4	12.2	145.6	133.9
115	196.4	107.7	8.1	2.0	8.7	12.5	145.9	139.1
125	204.3	110.9	8.3	2.0	9.0	12.9	146.0	143.0
years	*ft^3/acre*	*-------------------------------------- tonnes carbon/acre --------------------------------------*						
0	0	0.0	0.0	0.8	0.0	0.0	44.3	0.8
5	0	3.0	0.2	0.8	0.2	0.6	44.5	4.9
15	42	5.6	0.6	0.8	0.5	1.6	45.6	9.1
25	307	10.9	1.1	0.8	0.9	2.4	47.6	16.0
35	674	16.5	1.6	0.8	1.3	2.9	50.1	23.2
45	1,041	21.6	2.2	0.8	1.7	3.4	52.5	29.8
55	1,388	26.2	2.5	0.8	2.1	3.8	54.7	35.4
65	1,708	30.3	2.7	0.8	2.5	4.1	56.4	40.4
75	1,996	33.9	2.9	0.8	2.7	4.3	57.6	44.7
85	2,251	37.0	3.0	0.8	3.0	4.6	58.3	48.4
95	2,472	39.7	3.1	0.8	3.2	4.8	58.7	51.5
105	2,658	41.8	3.2	0.8	3.4	4.9	58.9	54.2
115	2,807	43.6	3.3	0.8	3.5	5.1	59.0	56.3
125	2,920	44.9	3.3	0.8	3.6	5.2	59.1	57.9

B8.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.0	0.0	0.0	134.9	2.0
5	0.0	3.9	0.4	1.9	0.2	4.2	135.4	10.7
15	2.4	10.3	1.0	1.9	0.6	10.8	138.8	24.7
25	13.2	20.1	2.0	1.9	1.2	15.8	144.9	41.1
35	25.2	29.8	3.0	1.9	1.8	19.7	152.4	56.2
45	37.4	38.7	3.9	1.9	2.4	22.7	159.9	69.7
55	49.8	47.1	4.7	1.9	2.9	25.3	166.5	81.9
65	62.3	55.6	5.3	1.9	3.4	27.4	171.6	93.7
75	74.9	62.8	5.6	1.9	3.9	29.1	175.2	103.4
85	87.5	69.9	5.8	1.9	4.3	30.7	177.4	112.6
95	100.1	76.8	6.0	1.9	4.7	32.0	178.7	121.4
105	112.9	83.6	6.2	1.9	5.1	33.1	179.4	130.0
115	125.8	90.4	6.4	1.9	5.6	34.2	179.7	138.5
125	139.2	97.4	6.5	1.9	6.0	35.1	179.8	147.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	54.6	0.8
5	0	1.6	0.2	0.8	0.1	1.7	54.8	4.3
15	35	4.2	0.4	0.8	0.3	4.4	56.2	10.0
25	189	8.1	0.8	0.8	0.5	6.4	58.6	16.6
35	360	12.0	1.2	0.8	0.7	8.0	61.7	22.7
45	535	15.7	1.6	0.8	1.0	9.2	64.7	28.2
55	712	19.1	1.9	0.8	1.2	10.2	67.4	33.1
65	890	22.5	2.2	0.8	1.4	11.1	69.5	37.9
75	1,070	25.4	2.3	0.8	1.6	11.8	70.9	41.8
85	1,250	28.3	2.4	0.8	1.7	12.4	71.8	45.6
95	1,431	31.1	2.4	0.8	1.9	12.9	72.3	49.1
105	1,613	33.8	2.5	0.8	2.1	13.4	72.6	52.6
115	1,798	36.6	2.6	0.8	2.2	13.8	72.7	56.0
125	1,990	39.4	2.7	0.8	2.4	14.2	72.8	59.5

B9.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	100.7	2.1
5	0.0	5.1	0.5	2.0	0.4	4.2	101.0	12.2
15	4.3	13.4	1.3	1.7	1.0	10.8	103.6	28.3
25	24.6	30.3	3.0	1.6	2.3	15.8	108.1	53.0
35	48.1	47.7	4.0	1.5	3.6	19.7	113.7	76.5
45	72.5	62.9	4.4	1.4	4.8	22.7	119.3	96.2
55	96.9	77.3	4.7	1.4	5.9	25.3	124.3	114.5
65	121.3	91.1	4.9	1.4	6.9	27.4	128.1	131.7
75	145.3	104.4	5.1	1.4	7.9	29.1	130.7	147.9
85	168.9	117.1	5.3	1.3	8.9	30.7	132.4	163.3
95	191.9	129.3	5.4	1.3	9.8	32.0	133.4	177.8
105	214.4	140.9	5.6	1.3	10.7	33.1	133.9	191.6
115	236.0	151.9	5.7	1.3	11.5	34.2	134.1	204.6
125	256.9	162.4	5.8	1.3	12.3	35.1	134.2	216.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	40.8	0.9
5	0	2.1	0.2	0.8	0.2	1.7	40.9	4.9
15	62	5.4	0.5	0.7	0.4	4.4	41.9	11.5
25	351	12.2	1.2	0.6	0.9	6.4	43.8	21.4
35	688	19.3	1.6	0.6	1.5	8.0	46.0	31.0
45	1,036	25.4	1.8	0.6	1.9	9.2	48.3	38.9
55	1,385	31.3	1.9	0.6	2.4	10.2	50.3	46.3
65	1,733	36.9	2.0	0.6	2.8	11.1	51.8	53.3
75	2,076	42.2	2.1	0.6	3.2	11.8	52.9	59.9
85	2,414	47.4	2.1	0.5	3.6	12.4	53.6	66.1
95	2,743	52.3	2.2	0.5	4.0	12.9	54.0	72.0
105	3,064	57.0	2.3	0.5	4.3	13.4	54.2	77.5
115	3,373	61.5	2.3	0.5	4.7	13.8	54.3	82.8
125	3,671	65.7	2.3	0.5	5.0	14.2	54.3	87.8

B10.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	72.8	2.1
5	0.0	6.7	0.7	2.2	0.5	0.9	73.1	11.0
15	4.1	17.0	1.7	2.0	1.3	2.5	74.9	24.5
25	21.9	33.6	3.1	1.9	2.6	3.9	78.2	45.0
35	42.5	50.3	3.6	1.8	3.9	5.2	82.2	64.8
45	64.9	66.7	3.9	1.8	5.2	6.3	86.3	83.9
55	88.7	83.6	4.2	1.8	6.5	7.2	89.9	103.3
65	113.4	99.1	4.5	1.7	7.7	8.1	92.6	121.1
75	139.0	114.7	4.7	1.7	8.9	8.9	94.5	138.9
85	165.2	130.3	4.9	1.7	10.1	9.7	95.8	156.7
95	192.1	146.0	5.1	1.7	11.3	10.3	96.4	174.4
105	219.2	161.6	5.3	1.7	12.5	10.9	96.8	192.0
115	246.4	177.0	5.4	1.6	13.7	11.5	97.0	209.2
125	272.5	191.6	5.5	1.6	14.8	12.0	97.1	225.6
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	29.5	0.8
5	0	2.7	0.3	0.9	0.2	0.4	29.6	4.4
15	58	6.9	0.7	0.8	0.5	1.0	30.3	9.9
25	313	13.6	1.2	0.8	1.0	1.6	31.6	18.2
35	608	20.4	1.4	0.7	1.6	2.1	33.3	26.2
45	928	27.0	1.6	0.7	2.1	2.5	34.9	33.9
55	1,267	33.8	1.7	0.7	2.6	2.9	36.4	41.8
65	1,620	40.1	1.8	0.7	3.1	3.3	37.5	49.0
75	1,986	46.4	1.9	0.7	3.6	3.6	38.3	56.2
85	2,361	52.7	2.0	0.7	4.1	3.9	38.7	63.4
95	2,745	59.1	2.1	0.7	4.6	4.2	39.0	70.6
105	3,133	65.4	2.1	0.7	5.1	4.4	39.2	77.7
115	3,521	71.6	2.2	0.7	5.5	4.7	39.2	84.7
125	3,895	77.5	2.2	0.7	6.0	4.9	39.3	91.3

B11.— Regional estimates of timber volume and carbon stocks for spruce-balsam fir stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	196.4	2.1
5	0.0	3.4	0.3	2.1	0.3	5.0	197.0	11.1
15	3.0	9.3	0.9	2.6	0.8	13.0	202.0	26.5
25	23.2	24.3	2.4	1.9	2.1	19.0	210.8	49.7
35	51.1	41.2	4.1	1.6	3.6	23.7	221.7	74.2
45	77.2	56.0	5.1	1.5	4.8	27.5	232.7	94.9
55	100.7	67.4	5.8	1.4	5.8	30.7	242.3	111.1
65	121.6	77.2	6.4	1.3	6.7	33.3	249.7	124.8
75	140.2	85.5	6.8	1.3	7.4	35.5	254.9	136.5
85	156.5	92.8	7.2	1.2	8.0	37.4	258.2	146.6
95	170.9	99.0	7.5	1.2	8.6	39.1	260.0	155.3
105	183.5	104.3	7.7	1.2	9.0	40.6	261.0	162.9
115	194.4	109.0	7.9	1.2	9.4	41.9	261.5	169.3
125	203.8	112.9	8.1	1.2	9.8	43.0	261.7	174.9
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	79.5	0.9
5	0	1.4	0.1	0.9	0.1	2.0	79.7	4.5
15	43	3.7	0.4	1.0	0.3	5.2	81.7	10.7
25	332	9.8	1.0	0.8	0.8	7.7	85.3	20.1
35	730	16.7	1.7	0.7	1.4	9.6	89.7	30.0
45	1,103	22.7	2.1	0.6	2.0	11.1	94.2	38.4
55	1,439	27.3	2.4	0.6	2.4	12.4	98.0	45.0
65	1,738	31.2	2.6	0.5	2.7	13.5	101.1	50.5
75	2,003	34.6	2.7	0.5	3.0	14.4	103.2	55.3
85	2,237	37.5	2.9	0.5	3.2	15.2	104.5	59.3
95	2,442	40.1	3.0	0.5	3.5	15.8	105.2	62.9
105	2,622	42.2	3.1	0.5	3.7	16.4	105.6	65.9
115	2,778	44.1	3.2	0.5	3.8	16.9	105.8	68.5
125	2,912	45.7	3.3	0.5	4.0	17.4	105.9	70.8

B12.— Regional estimates of timber volume and carbon stocks for white-red-jack pine stands with afforestation of land in the Northern Lake States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	------------------------------------	*tonnes carbon/hectare*					------------------------------------
0	0.0	0.0	0.0	2.0	0.0	0.0	90.6	2.0
5	0.0	0.4	0.0	2.0	0.0	3.1	90.9	5.7
15	6.6	8.0	0.8	2.0	0.6	7.1	93.2	18.5
25	48.1	35.4	3.5	2.0	2.5	9.4	97.3	52.9
35	104.7	62.9	4.9	2.0	4.5	11.0	102.3	85.3
45	158.9	85.8	5.5	2.0	6.2	12.2	107.4	111.6
55	209.1	105.3	5.9	2.0	7.6	13.0	111.8	133.8
65	255.1	122.2	6.2	2.0	8.8	13.7	115.2	152.9
75	297.4	137.1	6.5	2.0	9.9	14.2	117.6	169.6
85	336.1	150.3	6.7	2.0	10.8	14.7	119.1	184.4
95	371.7	162.0	6.9	2.0	11.7	15.0	120.0	197.5
105	404.2	172.5	7.0	2.0	12.4	15.4	120.5	209.3
115	434.0	182.0	7.2	2.0	13.1	15.6	120.7	219.8
125	461.3	190.5	7.3	1.9	13.7	15.9	120.8	229.2
years	ft^3*/acre*	------------------------------------	*tonnes carbon/acre*					------------------------------------
0	0	0.0	0.0	0.8	0.0	0.0	36.7	0.8
5	0	0.2	0.0	0.8	0.0	1.3	36.8	2.3
15	94	3.3	0.3	0.8	0.2	2.9	37.7	7.5
25	688	14.3	1.4	0.8	1.0	3.8	39.4	21.4
35	1,496	25.5	2.0	0.8	1.8	4.5	41.4	34.5
45	2,271	34.7	2.2	0.8	2.5	4.9	43.5	45.2
55	2,988	42.6	2.4	0.8	3.1	5.3	45.3	54.2
65	3,646	49.5	2.5	0.8	3.6	5.5	46.6	61.9
75	4,250	55.5	2.6	0.8	4.0	5.8	47.6	68.6
85	4,804	60.8	2.7	0.8	4.4	5.9	48.2	74.6
95	5,312	65.6	2.8	0.8	4.7	6.1	48.6	79.9
105	5,777	69.8	2.8	0.8	5.0	6.2	48.7	84.7
115	6,203	73.6	2.9	0.8	5.3	6.3	48.8	88.9
125	6,593	77.1	2.9	0.8	5.5	6.4	48.9	92.8

B13.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the Northern Prairie States

		Mean carbon density						
Age	Mean volume	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	63.6	2.1
5	0.0	3.9	0.4	2.1	0.3	4.2	63.8	10.8
15	0.0	8.7	0.9	2.7	0.6	10.8	65.4	23.7
25	5.8	15.5	1.6	2.4	1.1	15.8	68.3	36.4
35	21.8	27.7	2.8	2.2	1.9	19.7	71.8	54.3
45	45.1	43.2	4.3	2.0	3.0	22.7	75.4	75.3
55	73.0	60.2	5.6	1.9	4.2	25.3	78.5	97.1
65	104.1	78.9	6.1	1.8	5.5	27.4	80.9	119.7
75	137.4	96.5	6.5	1.8	6.7	29.1	82.6	140.6
85	171.9	114.0	6.9	1.7	7.9	30.7	83.6	161.2
95	206.8	131.3	7.2	1.7	9.1	32.0	84.2	181.3
105	241.7	148.2	7.5	1.6	10.3	33.1	84.5	200.7
115	275.8	164.3	7.8	1.6	11.4	34.2	84.7	219.2
125	308.6	179.6	8.0	1.6	12.4	35.1	84.7	236.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	25.7	0.8
5	0	1.6	0.2	0.8	0.1	1.7	25.8	4.4
15	0	3.5	0.4	1.1	0.2	4.4	26.5	9.6
25	83	6.3	0.6	1.0	0.4	6.4	27.6	14.7
35	312	11.2	1.1	0.9	0.8	8.0	29.1	22.0
45	644	17.5	1.7	0.8	1.2	9.2	30.5	30.5
55	1,043	24.3	2.3	0.8	1.7	10.2	31.8	39.3
65	1,488	31.9	2.5	0.7	2.2	11.1	32.7	48.4
75	1,964	39.0	2.6	0.7	2.7	11.8	33.4	56.9
85	2,456	46.1	2.8	0.7	3.2	12.4	33.8	65.2
95	2,956	53.1	2.9	0.7	3.7	12.9	34.1	73.4
105	3,454	60.0	3.0	0.7	4.2	13.4	34.2	81.2
115	3,941	66.5	3.2	0.6	4.6	13.8	34.3	88.7
125	4,410	72.7	3.2	0.6	5.0	14.2	34.3	95.8

B14.— Regional estimates of timber volume and carbon stocks for maple-beech-birch stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	48.6	2.1
5	0.0	5.1	0.5	2.2	0.3	4.2	48.8	12.4
15	0.9	10.5	1.1	1.9	0.7	10.8	50.0	25.0
25	8.2	18.5	1.8	1.7	1.2	15.8	52.2	39.0
35	21.4	29.7	3.0	1.6	1.9	19.7	54.9	55.7
45	38.2	41.3	3.8	1.5	2.6	22.7	57.7	71.9
55	57.4	53.6	4.2	1.4	3.4	25.3	60.0	87.9
65	78.6	66.5	4.5	1.3	4.2	27.4	61.9	103.9
75	101.0	79.6	4.7	1.3	5.1	29.1	63.2	119.8
85	124.4	92.9	4.9	1.2	5.9	30.7	64.0	135.7
95	148.6	106.2	5.1	1.2	6.7	32.0	64.4	151.2
105	173.1	119.4	5.3	1.2	7.6	33.1	64.7	166.6
115	197.4	132.1	5.5	1.2	8.4	34.2	64.8	181.3
125	220.5	144.0	5.6	1.1	9.1	35.1	64.8	195.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.9	0.0	0.0	19.7	0.9
5	0	2.1	0.2	0.9	0.1	1.7	19.8	5.0
15	13	4.3	0.4	0.8	0.3	4.4	20.3	10.1
25	117	7.5	0.7	0.7	0.5	6.4	21.1	15.8
35	306	12.0	1.2	0.6	0.8	8.0	22.2	22.6
45	546	16.7	1.5	0.6	1.1	9.2	23.3	29.1
55	821	21.7	1.7	0.6	1.4	10.2	24.3	35.6
65	1,123	26.9	1.8	0.5	1.7	11.1	25.0	42.1
75	1,443	32.2	1.9	0.5	2.0	11.8	25.6	48.5
85	1,778	37.6	2.0	0.5	2.4	12.4	25.9	54.9
95	2,123	43.0	2.1	0.5	2.7	12.9	26.1	61.2
105	2,474	48.3	2.2	0.5	3.1	13.4	26.2	67.4
115	2,821	53.5	2.2	0.5	3.4	13.8	26.2	73.4
125	3,151	58.3	2.3	0.5	3.7	14.2	26.2	78.9

B15.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Northern Prairie States

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	2.1	0.0	0.0	34.5	2.1
5	0.0	6.7	0.6	2.4	0.5	0.9	34.6	11.0
15	2.1	15.6	1.6	2.1	1.1	2.5	35.4	22.9
25	13.0	27.5	2.7	2.0	1.9	3.9	37.0	37.9
35	27.4	40.0	3.2	1.9	2.7	5.2	38.9	53.0
45	43.0	52.2	3.6	1.8	3.5	6.3	40.8	67.4
55	59.1	64.3	3.9	1.8	4.3	7.2	42.5	81.5
65	74.9	74.7	4.1	1.7	5.0	8.1	43.8	93.7
75	90.2	84.6	4.3	1.7	5.7	8.9	44.7	105.2
85	104.7	93.7	4.4	1.7	6.3	9.7	45.3	115.8
95	118.3	102.1	4.5	1.6	6.9	10.3	45.6	125.5
105	130.8	109.7	4.7	1.6	7.4	10.9	45.8	134.4
115	142.0	116.5	4.7	1.6	7.9	11.5	45.9	142.3
125	151.9	122.5	4.8	1.6	8.3	12.0	45.9	149.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.8	0.0	0.0	13.9	0.8
5	0	2.7	0.2	1.0	0.2	0.4	14.0	4.5
15	30	6.3	0.6	0.9	0.4	1.0	14.3	9.3
25	186	11.1	1.1	0.8	0.8	1.6	15.0	15.3
35	391	16.2	1.3	0.8	1.1	2.1	15.7	21.4
45	615	21.1	1.4	0.7	1.4	2.5	16.5	27.3
55	844	26.0	1.6	0.7	1.8	2.9	17.2	33.0
65	1,070	30.2	1.7	0.7	2.0	3.3	17.7	37.9
75	1,289	34.2	1.7	0.7	2.3	3.6	18.1	42.6
85	1,497	37.9	1.8	0.7	2.6	3.9	18.3	46.9
95	1,691	41.3	1.8	0.7	2.8	4.2	18.5	50.8
105	1,869	44.4	1.9	0.7	3.0	4.4	18.5	54.4
115	2,030	47.2	1.9	0.7	3.2	4.7	18.6	57.6
125	2,171	49.6	2.0	0.7	3.3	4.9	18.6	60.4

B16.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Northern Prairie States

		Mean carbon density						
Age	Mean volume	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------------------------------------ *tonnes carbon/hectare* ------------------------------------						
0	0.0	0.0	0.0	4.2	0.0	0.0	27.1	4.2
5	0.0	5.1	0.4	4.2	0.4	3.8	27.2	13.9
15	4.5	13.8	1.2	4.3	1.0	10.3	27.9	30.6
25	28.4	29.8	2.6	3.6	2.1	15.6	29.1	53.6
35	57.9	47.4	3.4	3.3	3.3	19.9	30.6	77.2
45	86.7	63.3	4.0	3.1	4.4	23.5	32.1	98.2
55	113.2	77.0	4.4	2.9	5.3	26.6	33.5	116.2
65	137.1	89.4	4.7	2.9	6.2	29.2	34.5	132.5
75	158.1	98.9	5.0	2.8	6.8	31.6	35.2	145.1
85	176.0	106.8	5.2	2.7	7.4	33.6	35.7	155.7
95	190.8	113.3	5.4	2.7	7.8	35.4	35.9	164.6
105	202.4	118.3	5.5	2.7	8.2	37.0	36.0	171.7
115	210.9	121.9	5.6	2.7	8.4	38.4	36.1	177.1
125	216.1	124.1	5.7	2.7	8.6	39.7	36.1	180.8
years	*ft^3/acre*	-------------------------------------- *tonnes carbon/acre* --						
0	0	0.0	0.0	1.7	0.0	0.0	11.0	1.7
5	0	2.1	0.2	1.7	0.1	1.6	11.0	5.6
15	65	5.6	0.5	1.7	0.4	4.2	11.3	12.4
25	406	12.1	1.0	1.5	0.8	6.3	11.8	21.7
35	828	19.2	1.4	1.3	1.3	8.0	12.4	31.3
45	1,239	25.6	1.6	1.2	1.8	9.5	13.0	39.7
55	1,618	31.2	1.8	1.2	2.2	10.8	13.5	47.0
65	1,959	36.2	1.9	1.2	2.5	11.8	14.0	53.6
75	2,259	40.0	2.0	1.1	2.8	12.8	14.2	58.7
85	2,515	43.2	2.1	1.1	3.0	13.6	14.4	63.0
95	2,727	45.8	2.2	1.1	3.2	14.3	14.5	66.6
105	2,893	47.9	2.2	1.1	3.3	15.0	14.6	69.5
115	3,014	49.3	2.3	1.1	3.4	15.6	14.6	71.7
125	3,088	50.2	2.3	1.1	3.5	16.1	14.6	73.2

B17.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	2.7	0.3	4.4	0.3	5.2	71.3	12.7
15	3.8	8.7	0.9	4.1	0.9	13.0	73.1	27.5
25	47.7	38.3	3.8	3.7	3.9	18.6	76.3	68.3
35	119.0	75.1	7.5	3.6	7.7	22.9	80.2	116.7
45	184.7	104.0	10.0	3.5	10.7	26.2	84.2	154.3
55	241.8	127.3	10.9	3.4	13.1	28.9	87.7	183.6
65	290.9	146.4	11.5	3.4	15.0	31.1	90.4	207.5
75	332.7	162.2	12.0	3.4	16.6	33.0	92.3	227.2
85	368.3	175.3	12.4	3.4	18.0	34.5	93.4	243.6
95	398.6	186.2	12.7	3.4	19.1	35.9	94.1	257.2
105	424.4	195.4	13.0	3.3	20.0	37.0	94.5	268.7
115	446.4	203.1	13.2	3.3	20.8	38.0	94.6	278.4
125	465.2	209.6	13.3	3.3	21.5	39.0	94.7	286.7
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	1.1	0.1	1.8	0.1	2.1	28.9	5.2
15	54	3.5	0.4	1.7	0.4	5.2	29.6	11.1
25	682	15.5	1.5	1.5	1.6	7.5	30.9	27.7
35	1,701	30.4	3.0	1.4	3.1	9.3	32.5	47.2
45	2,639	42.1	4.1	1.4	4.3	10.6	34.1	62.5
55	3,456	51.5	4.4	1.4	5.3	11.7	35.5	74.3
65	4,157	59.3	4.7	1.4	6.1	12.6	36.6	84.0
75	4,755	65.6	4.9	1.4	6.7	13.3	37.3	91.9
85	5,264	70.9	5.0	1.4	7.3	14.0	37.8	98.6
95	5,697	75.4	5.1	1.4	7.7	14.5	38.1	104.1
105	6,065	79.1	5.2	1.4	8.1	15.0	38.2	108.8
115	6,379	82.2	5.3	1.4	8.4	15.4	38.3	112.7
125	6,648	84.8	5.4	1.3	8.7	15.8	38.3	116.0

B18.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	46.6	4.8
5	0.0	3.1	0.3	4.1	0.3	5.2	46.8	13.0
15	0.0	5.8	0.6	3.7	0.6	13.0	47.9	23.7
25	15.2	15.5	1.6	3.2	1.6	18.6	50.0	40.5
35	52.1	33.9	3.4	2.8	3.6	22.9	52.6	66.6
45	97.4	53.0	5.3	2.6	5.6	26.2	55.2	92.7
55	144.4	71.3	7.1	2.5	7.6	28.9	57.5	117.5
65	189.7	88.3	8.8	2.4	9.4	31.1	59.3	140.0
75	231.5	103.3	10.3	2.4	11.0	33.0	60.5	160.0
85	268.7	116.4	11.6	2.3	12.4	34.5	61.3	177.3
95	301.0	127.6	12.8	2.3	13.6	35.9	61.7	192.0
105	328.2	136.9	13.7	2.3	14.5	37.0	62.0	204.4
115	350.6	144.4	14.4	2.2	15.3	38.0	62.1	214.4
125	368.3	150.3	15.0	2.2	16.0	39.0	62.1	222.5
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	18.9	1.9
5	0	1.3	0.1	1.7	0.1	2.1	18.9	5.3
15	0	2.3	0.2	1.5	0.2	5.2	19.4	9.6
25	217	6.3	0.6	1.3	0.7	7.5	20.3	16.4
35	745	13.7	1.4	1.1	1.5	9.3	21.3	27.0
45	1,392	21.4	2.1	1.1	2.3	10.6	22.4	37.5
55	2,063	28.9	2.9	1.0	3.1	11.7	23.3	47.5
65	2,711	35.7	3.6	1.0	3.8	12.6	24.0	56.7
75	3,308	41.8	4.2	1.0	4.4	13.3	24.5	64.7
85	3,840	47.1	4.7	0.9	5.0	14.0	24.8	71.7
95	4,302	51.6	5.2	0.9	5.5	14.5	25.0	77.7
105	4,691	55.4	5.5	0.9	5.9	15.0	25.1	82.7
115	5,010	58.4	5.8	0.9	6.2	15.4	25.1	86.8
125	5,264	60.8	6.1	0.9	6.5	15.8	25.1	90.0

B19.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	39.0	4.8
5	0.0	1.9	0.2	4.8	0.2	2.4	39.1	9.5
15	6.6	8.1	0.8	3.5	0.8	6.4	40.1	19.6
25	40.8	24.3	2.4	2.6	2.3	9.8	41.9	41.4
35	81.7	40.1	4.0	2.3	3.7	12.6	44.1	62.8
45	120.5	54.0	5.4	2.2	5.0	14.9	46.2	81.5
55	156.3	64.5	6.4	2.1	6.0	17.0	48.1	95.9
65	189.3	73.6	7.4	2.0	6.9	18.7	49.6	108.5
75	219.9	81.7	8.2	1.9	7.6	20.3	50.7	119.7
85	248.0	88.9	8.9	1.9	8.3	21.7	51.3	129.6
95	274.0	95.4	9.5	1.9	8.9	22.9	51.7	138.5
105	298.2	101.2	10.1	1.8	9.4	24.0	51.9	146.6
115	320.5	106.5	10.6	1.8	9.9	25.0	52.0	153.8
125	341.2	111.4	10.9	1.8	10.4	25.8	52.0	160.3
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	15.8	2.0
5	0	0.8	0.1	2.0	0.1	1.0	15.8	3.8
15	95	3.3	0.3	1.4	0.3	2.6	16.2	7.9
25	583	9.8	1.0	1.1	0.9	4.0	17.0	16.8
35	1,168	16.2	1.6	0.9	1.5	5.1	17.8	25.4
45	1,722	21.8	2.2	0.9	2.0	6.0	18.7	33.0
55	2,234	26.1	2.6	0.8	2.4	6.9	19.5	38.8
65	2,706	29.8	3.0	0.8	2.8	7.6	20.1	43.9
75	3,142	33.1	3.3	0.8	3.1	8.2	20.5	48.4
85	3,544	36.0	3.6	0.8	3.3	8.8	20.8	52.4
95	3,916	38.6	3.9	0.8	3.6	9.3	20.9	56.1
105	4,261	41.0	4.1	0.7	3.8	9.7	21.0	59.3
115	4,580	43.1	4.3	0.7	4.0	10.1	21.0	62.2
125	4,876	45.1	4.4	0.7	4.2	10.5	21.0	64.9

B20.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Pacific Northwest, East

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	38.0	4.8
5	0.0	3.3	0.3	4.6	0.3	2.4	38.1	10.8
15	4.1	7.9	0.8	3.8	0.8	6.4	39.1	19.7
25	21.6	17.3	1.7	3.2	1.8	9.8	40.8	33.7
35	40.8	26.2	2.6	2.9	2.7	12.6	42.9	47.0
45	61.4	34.9	3.3	2.8	3.6	14.9	45.1	59.4
55	83.3	43.6	3.7	2.6	4.5	17.0	46.9	71.5
65	106.0	52.5	4.2	2.5	5.4	18.7	48.4	83.3
75	129.3	61.3	4.6	2.4	6.3	20.3	49.4	94.9
85	153.0	70.0	4.9	2.4	7.2	21.7	50.0	106.2
95	176.8	78.6	5.3	2.3	8.1	22.9	50.3	117.2
105	200.4	87.0	5.6	2.3	9.0	24.0	50.5	127.7
115	223.6	95.1	5.9	2.2	9.8	25.0	50.6	137.9
125	246.0	102.8	6.1	2.2	10.6	25.8	50.7	147.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.4	1.9
5	0	1.3	0.1	1.8	0.1	1.0	15.4	4.4
15	59	3.2	0.3	1.5	0.3	2.6	15.8	8.0
25	309	7.0	0.7	1.3	0.7	4.0	16.5	13.7
35	583	10.6	1.1	1.2	1.1	5.1	17.4	19.0
45	878	14.1	1.3	1.1	1.5	6.0	18.2	24.0
55	1,190	17.7	1.5	1.1	1.8	6.9	19.0	28.9
65	1,515	21.2	1.7	1.0	2.2	7.6	19.6	33.7
75	1,848	24.8	1.8	1.0	2.6	8.2	20.0	38.4
85	2,187	28.3	2.0	1.0	2.9	8.8	20.2	43.0
95	2,527	31.8	2.1	0.9	3.3	9.3	20.4	47.4
105	2,864	35.2	2.3	0.9	3.6	9.7	20.5	51.7
115	3,195	38.5	2.4	0.9	4.0	10.1	20.5	55.8
125	3,515	41.6	2.5	0.9	4.3	10.5	20.5	59.7

B21.— Regional estimates of timber volume and carbon stocks for alder-maple stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	86.4	4.7
5	0.0	8.0	0.8	4.7	0.8	1.8	86.7	16.1
15	49.5	31.0	3.1	3.7	2.9	4.4	88.9	45.2
25	229.7	99.4	9.9	2.8	9.4	6.2	92.8	127.8
35	380.8	153.8	15.4	2.5	14.6	7.6	97.6	193.9
45	513.7	200.8	20.1	2.4	19.0	8.6	102.4	250.9
55	633.3	242.5	22.2	2.3	23.0	9.4	106.7	299.4
65	742.1	280.1	23.9	2.2	26.5	10.1	109.9	342.8
75	842.1	314.4	25.3	2.2	29.8	10.7	112.2	382.4
85	934.5	346.0	26.6	2.1	32.8	11.1	113.6	418.6
95	1,020.3	375.2	27.7	2.1	35.5	11.5	114.5	452.0
105	1,100.3	402.2	28.7	2.0	38.1	11.9	114.9	483.0
115	1,175.0	427.4	29.6	2.1	40.5	12.2	115.1	511.8
125	1,244.9	450.9	30.4	2.3	42.7	12.4	115.2	538.7
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.0	1.9
5	0	3.2	0.3	1.9	0.3	0.7	35.1	6.5
15	708	12.6	1.3	1.5	1.2	1.8	36.0	18.3
25	3,282	40.2	4.0	1.1	3.8	2.5	37.6	51.7
35	5,442	62.3	6.2	1.0	5.9	3.1	39.5	78.5
45	7,342	81.3	8.1	1.0	7.7	3.5	41.5	101.5
55	9,050	98.1	9.0	0.9	9.3	3.8	43.2	121.1
65	10,605	113.3	9.7	0.9	10.7	4.1	44.5	138.7
75	12,034	127.2	10.3	0.9	12.1	4.3	45.4	154.7
85	13,355	140.0	10.8	0.9	13.3	4.5	46.0	169.4
95	14,582	151.8	11.2	0.8	14.4	4.7	46.3	182.9
105	15,725	162.8	11.6	0.8	15.4	4.8	46.5	195.4
115	16,792	173.0	12.0	0.9	16.4	4.9	46.6	207.1
125	17,791	182.5	12.3	0.9	17.3	5.0	46.6	218.0

B22.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	8.4	0.8	4.5	0.8	3.6	71.3	18.1
15	37.4	30.3	3.0	3.9	3.0	10.0	73.1	50.3
25	208.9	107.1	10.7	3.4	10.7	15.4	76.3	147.3
35	391.8	181.6	17.4	3.2	18.2	20.2	80.2	240.6
45	554.7	246.1	21.2	3.1	24.6	24.4	84.2	319.4
55	698.4	302.2	24.1	3.0	30.2	28.0	87.7	387.5
65	826.0	351.4	26.4	3.0	35.1	31.3	90.4	447.2
75	939.9	394.9	28.4	2.9	39.5	34.2	92.3	500.0
85	1,042.1	433.7	30.1	2.9	43.4	36.9	93.4	547.0
95	1,134.5	468.6	31.6	2.9	46.9	39.3	94.1	589.1
105	1,218.3	500.1	32.9	2.9	50.0	41.4	94.5	627.2
115	1,294.7	528.7	34.0	2.9	52.9	43.4	94.6	661.8
125	1,364.7	554.8	35.0	2.8	55.5	45.3	94.7	693.4
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	3.4	0.3	1.8	0.3	1.5	28.9	7.3
15	535	12.3	1.2	1.6	1.2	4.0	29.6	20.3
25	2,985	43.3	4.3	1.4	4.3	6.2	30.9	59.6
35	5,600	73.5	7.1	1.3	7.3	8.2	32.5	97.4
45	7,927	99.6	8.6	1.3	10.0	9.9	34.1	129.2
55	9,981	122.3	9.7	1.2	12.2	11.3	35.5	156.8
65	11,804	142.2	10.7	1.2	14.2	12.7	36.6	181.0
75	13,432	159.8	11.5	1.2	16.0	13.9	37.3	202.3
85	14,893	175.5	12.2	1.2	17.6	14.9	37.8	221.3
95	16,213	189.6	12.8	1.2	19.0	15.9	38.1	238.4
105	17,411	202.4	13.3	1.2	20.2	16.8	38.2	253.8
115	18,503	213.9	13.8	1.2	21.4	17.6	38.3	267.8
125	19,503	224.5	14.2	1.1	22.5	18.3	38.3	280.6

B23.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.6	0.0	0.0	71.1	4.6
5	0.0	9.5	0.9	4.4	0.9	3.6	71.3	19.3
15	19.8	23.4	2.3	4.0	2.3	10.0	73.1	42.0
25	169.7	84.6	8.5	3.5	8.5	15.4	76.3	120.5
35	445.7	187.4	10.0	3.2	18.7	20.2	80.2	239.6
45	718.8	286.2	10.6	3.0	28.6	24.4	84.2	352.8
55	924.1	359.4	10.9	3.0	35.9	28.0	87.7	437.2
65	1,086.5	416.7	11.1	2.9	41.7	31.3	90.4	503.6
75	1,225.8	465.6	11.2	2.9	46.6	34.2	92.3	560.5
85	1,346.8	507.8	11.3	2.9	50.8	36.9	93.4	609.7
95	1,452.4	544.6	11.4	2.8	54.5	39.3	94.1	652.5
105	1,544.4	576.5	11.5	2.9	57.6	41.4	94.5	690.0
115	1,544.4	576.5	11.5	2.9	57.6	43.4	94.6	692.0
125	1,544.4	576.5	11.5	2.9	57.6	45.3	94.7	693.8
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	28.8	1.9
5	0	3.8	0.4	1.8	0.4	1.5	28.9	7.8
15	283	9.5	0.9	1.6	0.9	4.0	29.6	17.0
25	2,425	34.2	3.4	1.4	3.4	6.2	30.9	48.8
35	6,370	75.9	4.1	1.3	7.6	8.2	32.5	97.0
45	10,272	115.8	4.3	1.2	11.6	9.9	34.1	142.8
55	13,207	145.4	4.4	1.2	14.5	11.3	35.5	176.9
65	15,527	168.6	4.5	1.2	16.9	12.7	36.6	203.8
75	17,518	188.4	4.5	1.2	18.8	13.9	37.3	226.8
85	19,248	205.5	4.6	1.2	20.6	14.9	37.8	246.7
95	20,756	220.4	4.6	1.2	22.0	15.9	38.1	264.1
105	22,072	233.3	4.7	1.2	23.3	16.8	38.2	279.2
115	22,072	233.3	4.7	1.2	23.3	17.6	38.3	280.0
125	22,072	233.3	4.7	1.2	23.3	18.3	38.3	280.8

B24.— Regional estimates of timber volume, and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	46.6	4.8
5	0.0	3.2	0.3	4.8	0.3	5.5	46.8	14.0
15	8.2	11.6	1.2	3.9	1.0	13.6	47.9	31.4
25	62.3	42.5	4.3	3.2	3.8	19.4	50.0	73.2
35	145.5	84.3	8.4	2.8	7.6	23.8	52.6	126.9
45	238.7	128.7	12.9	2.6	11.5	27.2	55.2	183.0
55	333.9	168.2	16.8	2.5	15.1	29.9	57.5	232.5
65	427.0	205.1	20.5	2.5	18.4	32.1	59.3	278.5
75	515.8	239.2	23.9	2.4	21.4	33.9	60.5	320.8
85	599.0	270.3	27.0	2.3	24.2	35.4	61.3	359.3
95	676.0	298.5	29.8	2.3	26.8	36.8	61.7	394.2
105	746.6	323.9	32.4	2.3	29.0	37.9	62.0	425.5
115	810.8	346.7	34.1	2.3	31.1	38.9	62.1	453.0
125	869.1	367.2	35.1	2.2	32.9	39.8	62.1	477.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	18.9	1.9
5	0	1.3	0.1	1.9	0.1	2.2	18.9	5.7
15	117	4.7	0.5	1.6	0.4	5.5	19.4	12.7
25	890	17.2	1.7	1.3	1.5	7.9	20.3	29.6
35	2,080	34.1	3.4	1.1	3.1	9.6	21.3	51.3
45	3,412	52.1	5.2	1.1	4.7	11.0	22.4	74.0
55	4,772	68.1	6.8	1.0	6.1	12.1	23.3	94.1
65	6,103	83.0	8.3	1.0	7.4	13.0	24.0	112.7
75	7,371	96.8	9.7	1.0	8.7	13.7	24.5	129.8
85	8,560	109.4	10.9	0.9	9.8	14.3	24.8	145.4
95	9,661	120.8	12.1	0.9	10.8	14.9	25.0	159.5
105	10,670	131.1	13.1	0.9	11.7	15.3	25.1	172.2
115	11,588	140.3	13.8	0.9	12.6	15.7	25.1	183.3
125	12,421	148.6	14.2	0.9	13.3	16.1	25.1	193.1

B25.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands with afforestation of land in the Pacific Northwest, West

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	87.3	4.7
5	0.0	5.9	0.6	4.7	0.6	3.6	87.6	15.3
15	33.7	22.5	2.2	4.1	2.2	10.0	89.8	41.0
25	184.1	78.0	7.8	3.1	7.7	15.4	93.7	112.1
35	350.8	139.8	14.0	2.7	13.8	20.2	98.5	190.5
45	516.7	201.6	20.2	2.5	19.9	24.4	103.4	268.5
55	678.7	256.6	25.7	2.4	25.3	28.0	107.7	338.0
65	835.1	309.1	30.9	2.3	30.5	31.3	111.0	404.1
75	985.6	359.2	35.9	2.2	35.4	34.2	113.3	467.0
85	1,129.8	406.7	40.1	2.2	40.1	36.9	114.7	526.0
95	1,267.4	451.8	42.8	2.3	44.5	39.3	115.6	580.7
105	1,398.3	494.4	45.2	2.5	48.7	41.4	116.0	632.3
115	1,522.4	534.7	47.4	2.7	52.7	43.4	116.2	680.9
125	1,639.6	572.6	49.4	2.9	56.4	45.3	116.3	726.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	35.3	1.9
5	0	2.4	0.2	1.9	0.2	1.5	35.4	6.2
15	482	9.1	0.9	1.6	0.9	4.0	36.3	16.6
25	2,631	31.6	3.2	1.3	3.1	6.2	37.9	45.3
35	5,013	56.6	5.7	1.1	5.6	8.2	39.9	77.1
45	7,385	81.6	8.2	1.0	8.0	9.9	41.8	108.7
55	9,699	103.9	10.4	1.0	10.2	11.3	43.6	136.8
65	11,935	125.1	12.5	0.9	12.3	12.7	44.9	163.6
75	14,086	145.4	14.5	0.9	14.3	13.9	45.8	189.0
85	16,146	164.6	16.2	0.9	16.2	14.9	46.4	212.8
95	18,113	182.8	17.3	0.9	18.0	15.9	46.8	235.0
105	19,983	200.1	18.3	1.0	19.7	16.8	46.9	255.9
115	21,757	216.4	19.2	1.1	21.3	17.6	47.0	275.6
125	23,432	231.7	20.0	1.2	22.8	18.3	47.1	294.0

B26.— Regional estimates of timber volume and carbon stocks for hemlock-Sitka spruce stands with afforestation of land in the Pacific Northwest, West; volumes are for high productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*				*tonnes carbon/hectare*			
0	0.0	0.0	0.0	4.7	0.0	0.0	87.3	4.7
5	0.0	5.9	0.6	4.7	0.6	3.6	87.6	15.3
15	80.3	36.4	3.6	3.7	3.6	10.0	89.8	57.2
25	221.7	90.4	9.0	3.0	8.9	15.4	93.7	126.8
35	413.7	161.0	16.1	2.7	15.9	20.2	98.5	215.8
45	669.6	253.6	25.4	2.4	25.0	24.4	103.4	330.7
55	903.9	332.1	33.2	2.3	32.7	28.0	107.7	428.3
65	1,119.3	403.3	39.9	2.2	39.8	31.3	111.0	516.4
75	1,318.1	468.3	43.7	2.3	46.2	34.2	113.3	594.8
85	1,502.0	528.1	47.1	2.6	52.1	36.9	114.7	666.7
95	1,672.1	583.0	50.0	2.9	57.5	39.3	115.6	732.7
105	1,829.1	633.5	52.6	3.2	62.5	41.4	116.0	793.1
115	1,973.0	679.5	54.9	3.4	67.0	43.4	116.2	848.2
125	2,103.3	721.0	56.9	3.6	71.1	45.3	116.3	897.8
years	*ft^3/acre*				*tonnes carbon/acre*			
0	0	0.0	0.0	1.9	0.0	0.0	35.3	1.9
5	0	2.4	0.2	1.9	0.2	1.5	35.4	6.2
15	1,148	14.7	1.5	1.5	1.5	4.0	36.3	23.2
25	3,169	36.6	3.7	1.2	3.6	6.2	37.9	51.3
35	5,912	65.1	6.5	1.1	6.4	8.2	39.9	87.3
45	9,570	102.6	10.3	1.0	10.1	9.9	41.8	133.8
55	12,918	134.4	13.4	0.9	13.2	11.3	43.6	173.3
65	15,996	163.2	16.1	0.9	16.1	12.7	44.9	209.0
75	18,837	189.5	17.7	0.9	18.7	13.9	45.8	240.7
85	21,465	213.7	19.0	1.1	21.1	14.9	46.4	269.8
95	23,896	235.9	20.2	1.2	23.3	15.9	46.8	296.5
105	26,140	256.4	21.3	1.3	25.3	16.8	46.9	321.0
115	28,197	275.0	22.2	1.4	27.1	17.6	47.0	343.2
125	30,059	291.8	23.0	1.5	28.8	18.3	47.1	363.3

B27.— Regional estimates of timber volume and carbon stocks for mixed conifer stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	37.4	4.8
5	0.0	4.2	0.3	4.8	0.4	5.2	37.5	14.8
15	2.0	8.1	0.8	4.8	0.8	13.0	38.4	27.4
25	11.1	14.6	1.5	6.9	1.5	18.6	40.1	43.0
35	24.4	22.3	2.2	4.9	2.2	22.9	42.2	54.5
45	44.5	32.9	3.3	3.6	3.3	26.2	44.3	69.4
55	71.9	46.5	4.7	2.8	4.7	28.9	46.1	87.5
65	106.6	62.8	6.3	2.2	6.3	31.1	47.5	108.7
75	147.9	81.4	8.1	1.8	8.2	33.0	48.5	132.5
85	195.4	102.0	10.2	1.5	10.2	34.5	49.1	158.5
95	248.3	124.2	12.4	1.3	12.4	35.9	49.5	186.2
105	305.6	147.5	14.8	1.1	14.8	37.0	49.7	215.2
115	366.7	171.8	17.2	1.0	17.2	38.0	49.7	245.2
125	430.5	196.6	19.7	1.0	19.7	39.0	49.8	275.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.1	1.9
5	0	1.7	0.1	1.9	0.2	2.1	15.2	6.0
15	29	3.3	0.3	1.9	0.3	5.2	15.5	11.1
25	159	5.9	0.6	2.8	0.6	7.5	16.2	17.4
35	349	9.0	0.9	2.0	0.9	9.3	17.1	22.1
45	636	13.3	1.3	1.5	1.3	10.6	17.9	28.1
55	1,028	18.8	1.9	1.1	1.9	11.7	18.7	35.4
65	1,523	25.4	2.5	0.9	2.6	12.6	19.2	44.0
75	2,114	33.0	3.3	0.7	3.3	13.3	19.6	53.6
85	2,793	41.3	4.1	0.6	4.1	14.0	19.9	64.1
95	3,548	50.2	5.0	0.5	5.0	14.5	20.0	75.3
105	4,368	59.7	6.0	0.5	6.0	15.0	20.1	87.1
115	5,240	69.5	7.0	0.4	7.0	15.4	20.1	99.2
125	6,152	79.6	8.0	0.4	8.0	15.8	20.1	111.7

B28.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Understory	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	38.9	4.8
5	0.0	3.2	0.3	4.8	0.3	5.2	39.1	13.8
15	2.0	7.9	0.8	4.2	0.9	13.0	40.0	26.7
25	13.7	17.3	1.7	3.4	1.9	18.6	41.8	43.0
35	32.4	29.5	3.0	2.9	3.2	22.9	43.9	61.5
45	58.8	45.2	4.5	2.6	4.9	26.2	46.1	83.5
55	94.0	63.1	6.3	2.4	6.9	28.9	48.0	107.6
65	136.7	83.5	8.4	2.2	9.1	31.1	49.5	134.3
75	185.6	105.7	10.6	2.1	11.5	33.0	50.5	162.7
85	239.2	128.9	12.9	2.0	14.0	34.5	51.2	192.4
95	296.6	153.0	15.3	1.9	16.6	35.9	51.5	222.6
105	356.8	177.4	17.7	1.8	19.3	37.0	51.7	253.3
115	419.1	202.0	20.2	1.8	22.0	38.0	51.8	284.0
125	482.7	226.6	22.7	1.7	24.6	39.0	51.9	314.6
years	ft^3*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	15.8	1.9
5	0	1.3	0.1	1.9	0.1	2.1	15.8	5.6
15	28	3.2	0.3	1.7	0.3	5.2	16.2	10.8
25	196	7.0	0.7	1.4	0.8	7.5	16.9	17.4
35	463	11.9	1.2	1.2	1.3	9.3	17.8	24.9
45	840	18.3	1.8	1.1	2.0	10.6	18.7	33.8
55	1,343	25.5	2.6	1.0	2.8	11.7	19.4	43.5
65	1,954	33.8	3.4	0.9	3.7	12.6	20.0	54.3
75	2,652	42.8	4.3	0.8	4.6	13.3	20.4	65.9
85	3,419	52.2	5.2	0.8	5.7	14.0	20.7	77.8
95	4,239	61.9	6.2	0.8	6.7	14.5	20.9	90.1
105	5,099	71.8	7.2	0.7	7.8	15.0	20.9	102.5
115	5,989	81.8	8.2	0.7	8.9	15.4	21.0	114.9
125	6,899	91.7	9.2	0.7	10.0	15.8	21.0	127.3

B29.— Regional estimates of timber volume and carbon stocks for western oak stands with afforestation of land in the Pacific Southwest

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	20.7	4.7
5	0.0	2.6	0.2	4.6	0.1	3.7	20.8	11.3
15	0.0	5.7	0.6	4.5	0.2	9.8	21.3	20.8
25	1.0	8.8	0.9	4.4	0.4	14.4	22.2	28.8
35	25.9	30.6	3.1	4.2	1.3	18.1	23.4	57.3
45	76.3	65.1	4.5	4.1	2.7	21.1	24.5	97.5
55	127.8	98.3	5.4	4.0	4.1	23.6	25.5	135.3
65	174.4	124.0	6.0	4.0	5.1	25.6	26.3	164.8
75	215.0	145.3	6.5	4.0	6.0	27.4	26.9	189.2
85	249.4	162.7	6.8	4.0	6.8	29.0	27.2	209.2
95	278.4	177.1	7.1	4.0	7.4	30.3	27.4	225.8
105	302.8	189.0	7.3	3.9	7.8	31.5	27.5	239.6
115	323.3	198.8	7.4	3.9	8.3	32.6	27.5	251.0
125	340.6	207.0	7.6	3.9	8.6	33.5	27.6	260.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	8.4	1.9
5	0	1.1	0.1	1.9	0.0	1.5	8.4	4.6
15	0	2.3	0.2	1.8	0.1	3.9	8.6	8.4
25	15	3.6	0.4	1.8	0.1	5.8	9.0	11.7
35	370	12.4	1.2	1.7	0.5	7.3	9.5	23.2
45	1,090	26.3	1.8	1.7	1.1	8.5	9.9	39.4
55	1,826	39.8	2.2	1.6	1.7	9.5	10.3	54.8
65	2,493	50.2	2.4	1.6	2.1	10.4	10.6	66.7
75	3,072	58.8	2.6	1.6	2.4	11.1	10.9	76.6
85	3,564	65.9	2.8	1.6	2.7	11.7	11.0	84.7
95	3,979	71.7	2.9	1.6	3.0	12.3	11.1	91.4
105	4,328	76.5	2.9	1.6	3.2	12.7	11.1	97.0
115	4,620	80.5	3.0	1.6	3.3	13.2	11.1	101.6
125	4,868	83.8	3.1	1.6	3.5	13.6	11.2	105.5

B30.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	29.1	4.7
5	0.0	2.7	0.3	4.7	0.2	5.2	29.2	13.0
15	1.1	6.1	0.6	4.7	0.4	13.0	30.0	24.8
25	19.7	21.5	2.2	3.4	1.3	18.6	31.3	47.0
35	57.1	44.3	4.4	2.7	2.8	22.9	32.9	77.0
45	100.9	66.5	6.7	2.3	4.1	26.2	34.5	105.8
55	145.9	87.2	8.7	2.1	5.4	28.9	35.9	132.3
65	189.3	105.9	10.1	1.9	6.6	31.1	37.1	155.6
75	229.7	122.5	10.7	1.8	7.6	33.0	37.8	175.6
85	266.3	137.0	11.2	1.8	8.5	34.5	38.3	193.0
95	298.6	149.4	11.6	1.7	9.3	35.9	38.6	207.9
105	326.6	159.9	12.0	1.7	9.9	37.0	38.7	220.5
115	350.1	168.6	12.2	1.6	10.5	38.0	38.8	231.0
125	369.5	175.7	12.4	1.6	10.9	39.0	38.8	239.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	11.8	1.9
5	0	1.1	0.1	1.9	0.1	2.1	11.8	5.2
15	16	2.5	0.2	1.9	0.2	5.2	12.1	10.0
25	281	8.7	0.9	1.4	0.5	7.5	12.7	19.0
35	816	17.9	1.8	1.1	1.1	9.3	13.3	31.2
45	1,442	26.9	2.7	0.9	1.7	10.6	14.0	42.8
55	2,085	35.3	3.5	0.8	2.2	11.7	14.5	53.6
65	2,705	42.9	4.1	0.8	2.7	12.6	15.0	63.0
75	3,283	49.6	4.3	0.7	3.1	13.3	15.3	71.1
85	3,806	55.4	4.5	0.7	3.4	14.0	15.5	78.1
95	4,268	60.5	4.7	0.7	3.8	14.5	15.6	84.1
105	4,667	64.7	4.8	0.7	4.0	15.0	15.7	89.2
115	5,003	68.2	4.9	0.7	4.2	15.4	15.7	93.5
125	5,280	71.1	5.0	0.7	4.4	15.8	15.7	97.0

B31.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------------------------------------ *tonnes carbon/hectare* ------------------------------------						
0	0.0	0.0	0.0	4.7	0.0	0.0	33.1	4.7
5	0.0	3.1	0.3	4.7	0.3	5.2	33.2	13.6
15	0.0	5.8	0.6	4.7	0.6	13.0	34.0	24.7
25	18.2	17.0	1.7	3.4	1.7	18.6	35.5	42.4
35	61.6	38.1	3.8	2.7	3.8	22.9	37.4	71.2
45	113.8	59.5	5.9	2.3	6.0	26.2	39.2	100.0
55	167.2	80.0	8.0	2.1	8.0	28.9	40.8	127.0
65	218.2	98.6	9.9	2.0	9.9	31.1	42.1	151.4
75	264.6	115.0	11.5	1.9	11.6	33.0	43.0	172.9
85	305.4	129.1	12.9	1.8	13.0	34.5	43.5	191.3
95	340.2	140.9	14.1	1.8	14.2	35.9	43.8	206.8
105	368.8	150.5	15.0	1.7	15.1	37.0	44.0	219.4
115	391.6	158.0	15.8	1.7	15.9	38.0	44.1	229.4
125	408.8	163.7	16.4	1.7	16.4	39.0	44.1	237.1
years	*ft^3/acre*	------------------------------------ *tonnes carbon/acre* ------------------------------------						
0	0	0.0	0.0	1.9	0.0	0.0	13.4	1.9
5	0	1.3	0.1	1.9	0.1	2.1	13.4	5.5
15	0	2.3	0.2	1.9	0.2	5.2	13.8	10.0
25	260	6.9	0.7	1.4	0.7	7.5	14.4	17.2
35	880	15.4	1.5	1.1	1.5	9.3	15.1	28.8
45	1,626	24.1	2.4	0.9	2.4	10.6	15.9	40.4
55	2,390	32.4	3.2	0.9	3.3	11.7	16.5	51.4
65	3,118	39.9	4.0	0.8	4.0	12.6	17.0	61.3
75	3,782	46.5	4.7	0.8	4.7	13.3	17.4	70.0
85	4,365	52.2	5.2	0.7	5.2	14.0	17.6	77.4
95	4,862	57.0	5.7	0.7	5.7	14.5	17.7	83.7
105	5,271	60.9	6.1	0.7	6.1	15.0	17.8	88.8
115	5,596	63.9	6.4	0.7	6.4	15.4	17.8	92.8
125	5,842	66.2	6.6	0.7	6.7	15.8	17.8	95.9

B32.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	27.9	4.8
5	0.0	1.9	0.1	4.8	0.1	2.4	28.0	9.2
15	0.2	4.1	0.3	4.8	0.2	6.4	28.7	15.9
25	15.9	14.3	1.4	3.5	0.8	9.8	29.9	29.8
35	51.6	29.9	3.0	2.4	1.7	12.6	31.5	49.6
45	94.3	45.8	4.6	1.9	2.7	14.9	33.0	69.9
55	138.8	59.4	5.9	1.7	3.4	17.0	34.4	87.5
65	182.1	71.6	7.2	1.5	4.2	18.7	35.5	103.2
75	223.1	82.5	8.3	1.4	4.8	20.3	36.2	117.3
85	261.0	92.1	9.2	1.4	5.3	21.7	36.7	129.7
95	295.3	100.5	10.1	1.3	5.8	22.9	36.9	140.6
105	325.9	107.8	10.7	1.3	6.3	24.0	37.1	150.0
115	353.2	114.2	11.1	1.2	6.6	25.0	37.1	158.1
125	377.3	119.7	11.5	1.2	6.9	25.8	37.2	165.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	11.3	1.9
5	0	0.8	0.0	1.9	0.0	1.0	11.3	3.7
15	3	1.7	0.1	1.9	0.1	2.6	11.6	6.4
25	227	5.8	0.6	1.4	0.3	4.0	12.1	12.1
35	737	12.1	1.2	1.0	0.7	5.1	12.7	20.1
45	1,348	18.5	1.9	0.8	1.1	6.0	13.4	28.3
55	1,983	24.0	2.4	0.7	1.4	6.9	13.9	35.4
65	2,603	29.0	2.9	0.6	1.7	7.6	14.4	41.8
75	3,189	33.4	3.3	0.6	1.9	8.2	14.6	47.5
85	3,730	37.3	3.7	0.6	2.2	8.8	14.8	52.5
95	4,220	40.7	4.1	0.5	2.4	9.3	14.9	56.9
105	4,658	43.6	4.3	0.5	2.5	9.7	15.0	60.7
115	5,048	46.2	4.5	0.5	2.7	10.1	15.0	64.0
125	5,392	48.4	4.6	0.5	2.8	10.5	15.0	66.8

B33.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Rocky Mountain, North

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	25.7	4.8
5	0.0	3.3	0.2	4.8	0.3	2.4	25.8	10.9
15	1.3	6.3	0.6	4.3	0.6	6.4	26.5	18.2
25	18.6	15.9	1.6	3.2	1.4	9.8	27.6	31.8
35	51.8	30.9	3.0	2.5	2.7	12.6	29.0	51.6
45	89.4	46.1	3.9	2.2	4.0	14.9	30.5	71.1
55	127.1	60.4	4.5	2.0	5.3	17.0	31.7	89.2
65	162.2	73.3	5.1	1.9	6.4	18.7	32.7	105.4
75	193.8	84.6	5.5	1.8	7.4	20.3	33.4	119.6
85	221.0	94.2	5.8	1.7	8.2	21.7	33.8	131.6
95	243.7	102.0	6.1	1.7	8.9	22.9	34.1	141.6
105	261.8	108.2	6.3	1.6	9.5	24.0	34.2	149.6
115	275.6	112.9	6.4	1.6	9.9	25.0	34.3	155.7
125	285.1	116.1	6.5	1.6	10.1	25.8	34.3	160.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	10.4	1.9
5	0	1.3	0.1	1.9	0.1	1.0	10.4	4.4
15	19	2.6	0.2	1.8	0.2	2.6	10.7	7.4
25	266	6.4	0.6	1.3	0.6	4.0	11.2	12.9
35	740	12.5	1.2	1.0	1.1	5.1	11.8	20.9
45	1,278	18.6	1.6	0.9	1.6	6.0	12.3	28.8
55	1,816	24.5	1.8	0.8	2.1	6.9	12.8	36.1
65	2,318	29.7	2.0	0.8	2.6	7.6	13.2	42.7
75	2,769	34.2	2.2	0.7	3.0	8.2	13.5	48.4
85	3,159	38.1	2.4	0.7	3.3	8.8	13.7	53.3
95	3,483	41.3	2.5	0.7	3.6	9.3	13.8	57.3
105	3,742	43.8	2.5	0.7	3.8	9.7	13.8	60.5
115	3,938	45.7	2.6	0.6	4.0	10.1	13.9	63.0
125	4,075	47.0	2.6	0.6	4.1	10.5	13.9	64.8

B34.— Regional estimates of timber volume and carbon stocks for aspen-birch stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.7	0.0	0.0	44.1	4.7
5	0.0	3.1	0.3	4.7	0.2	3.7	44.2	12.1
15	0.0	6.4	0.6	4.7	0.4	9.8	45.4	22.0
25	6.3	13.9	1.4	4.8	0.9	14.4	47.4	35.3
35	22.7	25.7	2.6	4.5	1.7	18.1	49.8	52.5
45	45.0	38.8	3.9	4.3	2.5	21.1	52.3	70.5
55	70.7	52.3	5.2	4.2	3.4	23.6	54.4	88.6
65	98.1	64.7	6.5	4.1	4.2	25.6	56.1	105.0
75	126.5	76.6	7.7	4.0	4.9	27.4	57.3	120.6
85	155.0	88.0	8.8	3.9	5.7	29.0	58.0	135.3
95	183.1	98.8	9.9	3.9	6.3	30.3	58.4	149.2
105	210.5	108.8	10.9	3.8	7.0	31.5	58.6	162.1
115	236.8	118.3	11.8	3.8	7.6	32.6	58.7	174.0
125	261.8	127.0	12.4	3.8	8.2	33.5	58.8	184.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	17.8	1.9
5	0	1.2	0.1	1.9	0.1	1.5	17.9	4.9
15	0	2.6	0.3	1.9	0.2	3.9	18.4	8.9
25	90	5.6	0.6	1.9	0.4	5.8	19.2	14.3
35	324	10.4	1.0	1.8	0.7	7.3	20.2	21.3
45	643	15.7	1.6	1.7	1.0	8.5	21.1	28.5
55	1,010	21.2	2.1	1.7	1.4	9.5	22.0	35.9
65	1,402	26.2	2.6	1.6	1.7	10.4	22.7	42.5
75	1,808	31.0	3.1	1.6	2.0	11.1	23.2	48.8
85	2,215	35.6	3.6	1.6	2.3	11.7	23.5	54.8
95	2,617	40.0	4.0	1.6	2.6	12.3	23.6	60.4
105	3,008	44.0	4.4	1.6	2.8	12.7	23.7	65.6
115	3,384	47.9	4.8	1.5	3.1	13.2	23.8	70.4
125	3,741	51.4	5.0	1.5	3.3	13.6	23.8	74.8

B35.— Regional estimates of timber volume and carbon stocks for Douglas-fir stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	23.2	4.8
5	0.0	2.6	0.3	4.8	0.2	5.2	23.3	13.1
15	1.6	7.2	0.7	4.8	0.6	13.0	23.8	26.3
25	15.3	19.8	2.0	4.4	1.5	18.6	24.9	46.2
35	39.1	37.2	3.7	2.0	2.8	22.9	26.2	68.6
45	66.2	54.6	5.5	1.2	4.2	26.2	27.5	91.7
55	93.9	71.6	7.2	0.9	5.5	28.9	28.6	114.1
65	120.8	85.9	8.6	0.7	6.6	31.1	29.5	132.9
75	146.1	98.8	9.9	0.6	7.6	33.0	30.1	149.8
85	169.5	110.3	11.0	0.6	8.5	34.5	30.5	164.9
95	190.7	120.6	12.1	0.6	9.2	35.9	30.7	178.3
105	209.8	129.5	12.9	0.6	9.9	37.0	30.8	190.0
115	227.0	137.5	13.3	0.7	10.5	38.0	30.9	200.1
125	242.3	144.4	13.8	0.7	11.1	39.0	30.9	208.9
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	9.4	2.0
5	0	1.1	0.1	2.0	0.1	2.1	9.4	5.3
15	23	2.9	0.3	2.0	0.2	5.2	9.7	10.6
25	219	8.0	0.8	1.8	0.6	7.5	10.1	18.7
35	559	15.0	1.5	0.8	1.2	9.3	10.6	27.8
45	946	22.1	2.2	0.5	1.7	10.6	11.1	37.1
55	1,342	29.0	2.9	0.4	2.2	11.7	11.6	46.2
65	1,726	34.8	3.5	0.3	2.7	12.6	11.9	53.8
75	2,088	40.0	4.0	0.2	3.1	13.3	12.2	60.6
85	2,422	44.7	4.5	0.2	3.4	14.0	12.3	66.7
95	2,726	48.8	4.9	0.2	3.7	14.5	12.4	72.2
105	2,999	52.4	5.2	0.3	4.0	15.0	12.5	76.9
115	3,244	55.6	5.4	0.3	4.3	15.4	12.5	81.0
125	3,463	58.5	5.6	0.3	4.5	15.8	12.5	84.6

B36.— Regional estimates of timber volume and carbon stocks for fir-spruce-mountain hemlock stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*------------------------------------ tonnes carbon/hectare ------------------------------------*						
0	0.0	0.0	0.0	4.8	0.0	0.0	23.6	4.8
5	0.0	1.8	0.2	4.8	0.1	5.2	23.7	12.1
15	0.0	4.0	0.4	4.8	0.3	13.0	24.3	22.5
25	8.5	12.0	1.2	4.3	0.9	18.6	25.3	37.0
35	27.7	24.4	2.4	2.8	1.9	22.9	26.7	54.5
45	49.5	36.7	3.7	2.3	2.9	26.2	28.0	71.7
55	71.9	48.7	4.9	1.9	3.8	28.9	29.1	88.2
65	94.1	58.6	5.9	1.7	4.6	31.1	30.0	101.9
75	115.7	67.8	6.8	1.6	5.3	33.0	30.6	114.4
85	136.5	76.2	7.6	1.5	6.0	34.5	31.0	125.8
95	156.4	84.0	8.4	1.4	6.6	35.9	31.3	136.3
105	175.2	91.2	9.1	1.3	7.2	37.0	31.4	145.8
115	193.0	97.8	9.8	1.3	7.7	38.0	31.4	154.6
125	209.6	103.8	10.4	1.2	8.2	39.0	31.5	162.6
years	*ft^3/acre*	*------------------------------------- tonnes carbon/acre --------------------------------------*						
0	0	0.0	0.0	2.0	0.0	0.0	9.6	2.0
5	0	0.7	0.1	2.0	0.1	2.1	9.6	4.9
15	0	1.6	0.2	2.0	0.1	5.2	9.8	9.1
25	122	4.8	0.5	1.7	0.4	7.5	10.3	15.0
35	396	9.9	1.0	1.1	0.8	9.3	10.8	22.1
45	708	14.8	1.5	0.9	1.2	10.6	11.3	29.0
55	1,028	19.7	2.0	0.8	1.6	11.7	11.8	35.7
65	1,345	23.7	2.4	0.7	1.9	12.6	12.1	41.2
75	1,654	27.4	2.7	0.6	2.2	13.3	12.4	46.3
85	1,951	30.8	3.1	0.6	2.4	14.0	12.6	50.9
95	2,235	34.0	3.4	0.6	2.7	14.5	12.7	55.1
105	2,504	36.9	3.7	0.5	2.9	15.0	12.7	59.0
115	2,758	39.6	4.0	0.5	3.1	15.4	12.7	62.6
125	2,995	42.0	4.2	0.5	3.3	15.8	12.7	65.8

B37.— Regional estimates of timber volume and carbon stocks for lodgepole pine stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	20.2	4.8
5	0.0	2.1	0.2	4.8	0.2	2.4	20.3	9.7
15	0.0	4.3	0.4	4.8	0.4	6.4	20.8	16.4
25	5.0	9.2	0.9	4.8	0.9	9.8	21.7	25.5
35	18.3	16.9	1.7	3.4	1.7	12.6	22.8	36.2
45	37.0	25.9	2.6	2.5	2.5	14.9	24.0	48.4
55	58.5	34.1	3.4	2.0	3.4	17.0	25.0	59.9
65	81.2	42.0	4.2	1.7	4.1	18.7	25.7	70.8
75	104.1	49.5	4.9	1.5	4.9	20.3	26.3	81.1
85	126.7	56.4	5.6	1.4	5.6	21.7	26.6	90.7
95	148.3	62.8	6.3	1.3	6.2	22.9	26.8	99.4
105	168.6	68.6	6.9	1.2	6.8	24.0	26.9	107.4
115	187.3	73.8	7.4	1.1	7.3	25.0	26.9	114.5
125	204.1	78.3	7.8	1.1	7.7	25.8	27.0	120.8
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.9	0.0	0.0	8.2	1.9
5	0	0.9	0.1	1.9	0.1	1.0	8.2	3.9
15	0	1.7	0.2	1.9	0.2	2.6	8.4	6.6
25	71	3.7	0.4	1.9	0.4	4.0	8.8	10.3
35	262	6.8	0.7	1.4	0.7	5.1	9.2	14.6
45	529	10.5	1.0	1.0	1.0	6.0	9.7	19.6
55	836	13.8	1.4	0.8	1.4	6.9	10.1	24.2
65	1,160	17.0	1.7	0.7	1.7	7.6	10.4	28.7
75	1,488	20.0	2.0	0.6	2.0	8.2	10.6	32.8
85	1,810	22.8	2.3	0.6	2.2	8.8	10.8	36.7
95	2,120	25.4	2.5	0.5	2.5	9.3	10.8	40.2
105	2,410	27.8	2.8	0.5	2.7	9.7	10.9	43.5
115	2,677	29.8	3.0	0.5	2.9	10.1	10.9	46.3
125	2,917	31.7	3.2	0.4	3.1	10.5	10.9	48.9

B38.— Regional estimates of timber volume and carbon stocks for ponderosa pine stands with afforestation of land in the Rocky Mountain, South

Age	Mean volume	Mean carbon density						
		Live Tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m³/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.8	0.0	0.0	18.1	4.8
5	0.0	1.8	0.2	4.8	0.2	2.4	18.1	9.4
15	0.0	3.7	0.4	4.8	0.3	6.4	18.6	15.6
25	4.4	9.4	0.9	4.8	0.8	9.8	19.4	25.7
35	16.2	18.6	1.9	2.9	1.5	12.6	20.4	37.5
45	32.2	28.8	2.7	2.1	2.4	14.9	21.4	50.9
55	50.3	38.2	3.0	1.7	3.1	17.0	22.3	63.1
65	69.3	47.1	3.3	1.5	3.9	18.7	23.0	74.5
75	88.4	55.5	3.6	1.3	4.6	20.3	23.5	85.2
85	107.2	63.2	3.8	1.2	5.2	21.7	23.8	95.1
95	125.5	70.4	4.0	1.1	5.8	22.9	24.0	104.2
105	143.0	77.1	4.1	1.0	6.3	24.0	24.0	112.5
115	159.5	83.2	4.3	1.0	6.8	25.0	24.1	120.2
125	175.1	88.8	4.4	0.9	7.3	25.8	24.1	127.2
years	*ft³/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	2.0	0.0	0.0	7.3	2.0
5	0	0.7	0.1	2.0	0.1	1.0	7.3	3.8
15	0	1.5	0.1	2.0	0.1	2.6	7.5	6.3
25	63	3.8	0.4	2.0	0.3	4.0	7.9	10.4
35	231	7.5	0.8	1.2	0.6	5.1	8.3	15.2
45	460	11.7	1.1	0.9	1.0	6.0	8.7	20.6
55	719	15.5	1.2	0.7	1.3	6.9	9.0	25.5
65	990	19.1	1.4	0.6	1.6	7.6	9.3	30.2
75	1,263	22.4	1.5	0.5	1.8	8.2	9.5	34.5
85	1,532	25.6	1.5	0.5	2.1	8.8	9.6	38.5
95	1,793	28.5	1.6	0.4	2.3	9.3	9.7	42.2
105	2,043	31.2	1.7	0.4	2.6	9.7	9.7	45.5
115	2,280	33.7	1.7	0.4	2.8	10.1	9.7	48.6
125	2,503	35.9	1.8	0.4	3.0	10.5	9.8	51.5

B39.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	54.7	4.2
5	0.0	11.1	0.7	4.0	0.9	3.2	54.9	19.8
10	19.1	22.6	1.3	3.6	1.8	5.5	55.4	34.8
15	36.7	31.3	1.6	3.4	2.5	7.3	56.3	46.1
20	60.4	40.8	1.9	3.2	3.3	8.7	57.4	57.9
25	85.5	50.3	2.1	3.1	4.1	9.8	58.7	69.4
30	108.7	58.2	2.3	3.1	4.7	10.7	60.2	79.0
35	131.2	65.6	2.4	3.0	5.3	11.5	61.8	87.9
40	152.3	72.5	2.5	3.0	5.9	12.2	63.3	96.1
45	172.3	78.9	2.7	2.9	6.4	12.7	64.8	103.6
50	191.4	85.0	2.7	2.9	6.9	13.2	66.2	110.7
55	208.4	90.3	2.8	2.9	7.3	13.7	67.5	116.9
60	223.9	95.1	2.9	2.8	7.7	14.1	68.6	122.6
65	238.4	99.6	2.9	2.8	8.1	14.4	69.6	127.8
70	252.9	104.0	3.0	2.8	8.4	14.7	70.4	133.0
75	264.6	107.6	3.0	2.8	8.7	15.0	71.0	137.1
80	277.1	111.4	3.1	2.8	9.0	15.2	71.5	141.5
85	289.5	115.1	3.1	2.8	9.3	15.5	71.9	145.8
90	299.6	118.2	3.2	2.7	9.6	15.7	72.2	149.3
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	22.1	1.7
5	0	4.5	0.3	1.6	0.4	1.3	22.2	8.0
10	273	9.2	0.5	1.4	0.7	2.2	22.4	14.1
15	525	12.7	0.7	1.4	1.0	2.9	22.8	18.7
20	863	16.5	0.8	1.3	1.3	3.5	23.2	23.4
25	1,222	20.4	0.9	1.3	1.6	4.0	23.8	28.1
30	1,554	23.5	0.9	1.2	1.9	4.3	24.4	32.0
35	1,875	26.6	1.0	1.2	2.2	4.7	25.0	35.6
40	2,177	29.3	1.0	1.2	2.4	4.9	25.6	38.9
45	2,462	31.9	1.1	1.2	2.6	5.2	26.2	41.9
50	2,736	34.4	1.1	1.2	2.8	5.4	26.8	44.8
55	2,978	36.5	1.1	1.2	3.0	5.5	27.3	47.3
60	3,200	38.5	1.2	1.1	3.1	5.7	27.8	49.6
65	3,407	40.3	1.2	1.1	3.3	5.8	28.2	51.7
70	3,614	42.1	1.2	1.1	3.4	6.0	28.5	53.8
75	3,782	43.5	1.2	1.1	3.5	6.1	28.7	55.5
80	3,960	45.1	1.3	1.1	3.7	6.2	28.9	57.3
85	4,138	46.6	1.3	1.1	3.8	6.3	29.1	59.0
90	4,281	47.8	1.3	1.1	3.9	6.3	29.2	60.4

B40.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	54.7	4.1
5	0.0	11.0	0.7	4.0	0.4	3.2	54.9	19.3
10	47.7	31.9	1.4	3.8	1.2	5.5	55.4	43.8
15	146.5	67.4	1.9	3.7	2.5	7.3	56.3	82.9
20	244.8	102.3	2.1	3.7	3.8	8.7	57.4	120.6
25	315.2	124.2	2.3	3.7	4.7	9.8	58.7	144.6
30	347.3	134.1	2.4	3.7	5.0	10.7	60.2	155.8
35	351.5	135.4	2.4	3.7	5.1	11.5	61.8	158.0
40	355.0	136.5	2.4	3.7	5.1	12.2	63.3	159.8
45	358.5	137.5	2.4	3.6	5.2	12.7	64.8	161.4
50	362.0	138.6	2.4	3.6	5.2	13.2	66.2	163.1
55	362.0	138.6	2.4	3.6	5.2	13.7	67.5	163.5
60	362.0	138.6	2.4	3.6	5.2	14.1	68.6	163.9
65	362.0	138.6	2.4	3.6	5.2	14.4	69.6	164.2
70	362.0	138.6	2.4	3.6	5.2	14.7	70.4	164.5
75	362.0	138.6	2.4	3.6	5.2	15.0	71.0	164.8
80	362.0	138.6	2.4	3.6	5.2	15.2	71.5	165.1
85	362.0	138.6	2.4	3.6	5.2	15.5	71.9	165.3
90	362.0	138.6	2.4	3.6	5.2	15.7	72.2	165.5
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	22.1	1.7
5	0	4.5	0.3	1.6	0.2	1.3	22.2	7.8
10	682	12.9	0.6	1.6	0.5	2.2	22.4	17.7
15	2,094	27.3	0.8	1.5	1.0	2.9	22.8	33.5
20	3,498	41.4	0.9	1.5	1.5	3.5	23.2	48.8
25	4,504	50.3	0.9	1.5	1.9	4.0	23.8	58.5
30	4,963	54.3	1.0	1.5	2.0	4.3	24.4	63.1
35	5,024	54.8	1.0	1.5	2.1	4.7	25.0	63.9
40	5,074	55.2	1.0	1.5	2.1	4.9	25.6	64.7
45	5,124	55.7	1.0	1.5	2.1	5.2	26.2	65.3
50	5,174	56.1	1.0	1.5	2.1	5.4	26.8	66.0
55	5,174	56.1	1.0	1.5	2.1	5.5	27.3	66.2
60	5,174	56.1	1.0	1.5	2.1	5.7	27.8	66.3
65	5,174	56.1	1.0	1.5	2.1	5.8	28.2	66.5
70	5,174	56.1	1.0	1.5	2.1	6.0	28.5	66.6
75	5,174	56.1	1.0	1.5	2.1	6.1	28.7	66.7
80	5,174	56.1	1.0	1.5	2.1	6.2	28.9	66.8
85	5,174	56.1	1.0	1.5	2.1	6.3	29.1	66.9
90	5,174	56.1	1.0	1.5	2.1	6.3	29.2	67.0

B41.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	82.5	4.2
5	0.0	5.3	0.4	4.2	0.4	3.2	82.8	13.6
10	19.1	14.1	0.9	3.8	1.1	5.5	83.6	25.4
15	36.7	21.4	1.0	3.6	1.7	7.3	84.9	34.9
20	60.4	30.4	1.1	3.4	2.5	8.7	86.6	46.0
25	85.5	39.2	1.1	3.3	3.2	9.8	88.6	56.6
30	108.7	47.2	1.2	3.2	3.8	10.7	90.9	66.1
35	131.2	54.8	1.2	3.1	4.4	11.5	93.2	75.1
40	152.3	61.9	1.3	3.0	5.0	12.2	95.5	83.4
45	172.3	68.5	1.3	3.0	5.6	12.7	97.8	91.1
50	191.4	74.8	1.3	2.9	6.1	13.2	99.9	98.4
55	208.4	80.4	1.3	2.9	6.5	13.7	101.8	104.8
60	223.9	85.4	1.3	2.9	6.9	14.1	103.5	110.6
65	238.4	90.1	1.4	2.9	7.3	14.4	105.0	116.1
70	252.9	94.8	1.4	2.8	7.7	14.7	106.2	121.4
75	264.6	98.6	1.4	2.8	8.0	15.0	107.1	125.8
80	277.1	102.6	1.4	2.8	8.3	15.2	107.9	130.3
85	289.5	106.6	1.4	2.8	8.6	15.5	108.5	134.9
90	299.6	109.8	1.4	2.8	8.9	15.7	109.0	138.5
years	ft^3*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	33.4	1.7
5	0	2.2	0.2	1.7	0.2	1.3	33.5	5.5
10	273	5.7	0.3	1.5	0.5	2.2	33.8	10.3
15	525	8.7	0.4	1.4	0.7	2.9	34.4	14.1
20	863	12.3	0.4	1.4	1.0	3.5	35.0	18.6
25	1,222	15.9	0.5	1.3	1.3	4.0	35.9	22.9
30	1,554	19.1	0.5	1.3	1.5	4.3	36.8	26.7
35	1,875	22.2	0.5	1.3	1.8	4.7	37.7	30.4
40	2,177	25.0	0.5	1.2	2.0	4.9	38.7	33.7
45	2,462	27.7	0.5	1.2	2.2	5.2	39.6	36.9
50	2,736	30.3	0.5	1.2	2.5	5.4	40.4	39.8
55	2,978	32.5	0.5	1.2	2.6	5.5	41.2	42.4
60	3,200	34.6	0.5	1.2	2.8	5.7	41.9	44.8
65	3,407	36.5	0.6	1.2	3.0	5.8	42.5	47.0
70	3,614	38.4	0.6	1.1	3.1	6.0	43.0	49.1
75	3,782	39.9	0.6	1.1	3.2	6.1	43.4	50.9
80	3,960	41.5	0.6	1.1	3.4	6.2	43.7	52.7
85	4,138	43.1	0.6	1.1	3.5	6.3	43.9	54.6
90	4,281	44.4	0.6	1.1	3.6	6.3	44.1	56.1

B42.— Regional estimates of timber volume and carbon stocks for longleaf-slash pine stands with afforestation of land in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	82.5	4.1
5	0.0	8.8	0.4	4.0	0.3	3.2	82.8	16.7
10	47.7	27.2	0.8	3.9	1.0	5.5	83.6	38.4
15	146.5	60.1	0.8	3.8	2.2	7.3	84.9	74.2
20	244.8	91.2	0.9	3.7	3.4	8.7	86.6	107.9
25	315.2	113.5	0.9	3.7	4.2	9.8	88.6	132.1
30	347.3	122.8	0.9	3.7	4.6	10.7	90.9	142.7
35	351.5	124.0	0.9	3.7	4.6	11.5	93.2	144.8
40	355.0	125.0	0.9	3.7	4.7	12.2	95.5	146.5
45	358.5	126.0	0.9	3.7	4.7	12.7	97.8	148.1
50	362.0	127.0	0.9	3.7	4.8	13.2	99.9	149.6
55	362.0	127.0	0.9	3.7	4.8	13.7	101.8	150.1
60	362.0	127.0	0.9	3.7	4.8	14.1	103.5	150.4
65	362.0	127.0	0.9	3.7	4.8	14.4	105.0	150.8
70	362.0	127.0	0.9	3.7	4.8	14.7	106.2	151.1
75	362.0	127.0	0.9	3.7	4.8	15.0	107.1	151.4
80	362.0	127.0	0.9	3.7	4.8	15.2	107.9	151.6
85	362.0	127.0	0.9	3.7	4.8	15.5	108.5	151.9
90	362.0	127.0	0.9	3.7	4.8	15.7	109.0	152.1
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	33.4	1.7
5	0	3.6	0.2	1.6	0.1	1.3	33.5	6.8
10	682	11.0	0.3	1.6	0.4	2.2	33.8	15.5
15	2,094	24.3	0.3	1.5	0.9	2.9	34.4	30.0
20	3,498	36.9	0.4	1.5	1.4	3.5	35.0	43.6
25	4,504	45.9	0.4	1.5	1.7	4.0	35.9	53.5
30	4,963	49.7	0.4	1.5	1.9	4.3	36.8	57.7
35	5,024	50.2	0.4	1.5	1.9	4.7	37.7	58.6
40	5,074	50.6	0.4	1.5	1.9	4.9	38.7	59.3
45	5,124	51.0	0.4	1.5	1.9	5.2	39.6	59.9
50	5,174	51.4	0.4	1.5	1.9	5.4	40.4	60.6
55	5,174	51.4	0.4	1.5	1.9	5.5	41.2	60.7
60	5,174	51.4	0.4	1.5	1.9	5.7	41.9	60.9
65	5,174	51.4	0.4	1.5	1.9	5.8	42.5	61.0
70	5,174	51.4	0.4	1.5	1.9	6.0	43.0	61.1
75	5,174	51.4	0.4	1.5	1.9	6.1	43.4	61.3
80	5,174	51.4	0.4	1.5	1.9	6.2	43.7	61.4
85	5,174	51.4	0.4	1.5	1.9	6.3	43.9	61.5
90	5,174	51.4	0.4	1.5	1.9	6.3	44.1	61.5

B43.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	m^3*/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	0.0	0.0	118.5	1.8
5	0.0	6.7	0.7	1.9	0.4	1.1	118.9	10.9
10	9.8	18.8	1.9	1.8	1.2	2.1	120.1	25.8
15	19.9	28.3	2.4	1.7	1.8	3.0	121.9	37.2
20	32.7	38.0	2.8	1.7	2.4	3.7	124.4	48.6
25	45.4	46.8	3.1	1.6	3.0	4.4	127.2	58.9
30	58.1	54.0	3.4	1.6	3.4	5.0	130.5	67.5
35	73.4	62.3	3.6	1.6	4.0	5.5	133.8	77.0
40	92.2	71.9	3.9	1.6	4.6	6.0	137.2	88.0
45	110.7	80.9	4.2	1.6	5.1	6.4	140.4	98.2
50	128.1	89.0	4.4	1.5	5.7	6.8	143.5	107.4
55	146.3	97.3	4.6	1.5	6.2	7.2	146.2	116.7
60	166.1	105.9	4.7	1.5	6.7	7.5	148.7	126.4
65	186.4	114.5	4.9	1.5	7.3	7.8	150.7	136.1
70	205.7	122.5	5.1	1.5	7.8	8.1	152.4	145.0
75	222.5	129.3	5.2	1.5	8.2	8.4	153.8	152.6
80	237.9	135.4	5.3	1.5	8.6	8.6	155.0	159.4
85	257.3	142.9	5.5	1.5	9.1	8.9	155.8	167.8
90	278.9	151.2	5.6	1.5	9.6	9.1	156.5	177.0
years	ft^3*/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	0.0	0.0	48.0	0.7
5	0	2.7	0.3	0.8	0.2	0.5	48.1	4.4
10	140	7.6	0.8	0.7	0.5	0.9	48.6	10.4
15	284	11.5	1.0	0.7	0.7	1.2	49.3	15.1
20	467	15.4	1.1	0.7	1.0	1.5	50.3	19.7
25	649	18.9	1.3	0.7	1.2	1.8	51.5	23.8
30	830	21.9	1.4	0.7	1.4	2.0	52.8	27.3
35	1,049	25.2	1.5	0.6	1.6	2.2	54.2	31.2
40	1,318	29.1	1.6	0.6	1.9	2.4	55.5	35.6
45	1,582	32.7	1.7	0.6	2.1	2.6	56.8	39.7
50	1,830	36.0	1.8	0.6	2.3	2.8	58.1	43.5
55	2,091	39.4	1.8	0.6	2.5	2.9	59.2	47.2
60	2,374	42.9	1.9	0.6	2.7	3.1	60.2	51.2
65	2,664	46.3	2.0	0.6	2.9	3.2	61.0	55.1
70	2,940	49.6	2.1	0.6	3.2	3.3	61.7	58.7
75	3,180	52.3	2.1	0.6	3.3	3.4	62.3	61.8
80	3,400	54.8	2.2	0.6	3.5	3.5	62.7	64.5
85	3,677	57.8	2.2	0.6	3.7	3.6	63.1	67.9
90	3,986	61.2	2.3	0.6	3.9	3.7	63.3	71.6

B44.—Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	33.9	4.2
5	0.0	8.1	0.8	4.2	0.5	1.1	34.1	14.7
10	11.7	21.0	2.1	3.8	1.2	2.1	34.4	30.2
15	21.2	30.3	2.5	3.5	1.8	3.0	34.9	41.0
20	33.8	40.0	2.8	3.3	2.4	3.7	35.6	52.2
25	46.6	49.5	3.0	3.2	2.9	4.4	36.4	63.1
30	60.2	57.5	3.2	3.1	3.4	5.0	37.4	72.3
35	76.3	66.6	3.4	3.0	4.0	5.5	38.3	82.5
40	94.3	76.2	3.6	2.9	4.5	6.0	39.3	93.3
45	114.1	86.4	3.8	2.9	5.1	6.4	40.2	104.6
50	133.0	95.8	4.0	2.8	5.7	6.8	41.1	115.1
55	151.4	104.8	4.1	2.8	6.2	7.2	41.9	125.0
60	168.9	113.0	4.2	2.7	6.7	7.5	42.6	134.2
65	185.6	120.8	4.3	2.7	7.2	7.8	43.2	142.8
70	201.5	128.0	4.4	2.7	7.6	8.1	43.7	150.8
75	215.7	134.4	4.5	2.6	8.0	8.4	44.1	157.9
80	229.4	140.5	4.6	2.6	8.3	8.6	44.4	164.6
85	242.5	146.2	4.6	2.6	8.7	8.9	44.6	171.0
90	254.1	151.3	4.7	2.6	9.0	9.1	44.8	176.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	13.7	1.7
5	0	3.3	0.3	1.7	0.2	0.5	13.8	6.0
10	167	8.5	0.8	1.5	0.5	0.9	13.9	12.2
15	303	12.3	1.0	1.4	0.7	1.2	14.1	16.6
20	483	16.2	1.1	1.3	1.0	1.5	14.4	21.1
25	666	20.1	1.2	1.3	1.2	1.8	14.7	25.5
30	860	23.3	1.3	1.3	1.4	2.0	15.1	29.3
35	1,091	26.9	1.4	1.2	1.6	2.2	15.5	33.4
40	1,348	30.8	1.5	1.2	1.8	2.4	15.9	37.8
45	1,630	35.0	1.5	1.2	2.1	2.6	16.3	42.4
50	1,901	38.8	1.6	1.1	2.3	2.8	16.6	46.6
55	2,164	42.4	1.7	1.1	2.5	2.9	16.9	50.6
60	2,414	45.7	1.7	1.1	2.7	3.1	17.2	54.3
65	2,652	48.9	1.7	1.1	2.9	3.2	17.5	57.8
70	2,880	51.8	1.8	1.1	3.1	3.3	17.7	61.0
75	3,082	54.4	1.8	1.1	3.2	3.4	17.8	63.9
80	3,278	56.8	1.8	1.1	3.4	3.5	18.0	66.6
85	3,465	59.2	1.9	1.0	3.5	3.6	18.1	69.2
90	3,632	61.2	1.9	1.0	3.6	3.7	18.1	71.5

B45.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the Southeast

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	---------- *tonnes carbon/hectare* ----------						
0	0.0	0.0	0.0	4.2	0.0	0.0	46.1	4.2
5	0.0	7.4	0.6	4.1	0.5	3.1	46.2	15.6
10	13.6	19.6	1.2	3.6	1.2	5.1	46.7	30.8
15	27.8	29.3	1.6	3.5	1.9	6.6	47.4	42.8
20	43.9	39.0	1.9	3.4	2.5	7.7	48.3	54.5
25	59.3	46.8	2.1	3.3	3.0	8.5	49.5	63.7
30	77.2	55.4	2.3	3.2	3.5	9.2	50.7	73.7
35	96.8	64.4	2.5	3.2	4.1	9.8	52.0	83.9
40	117.2	73.4	2.7	3.1	4.7	10.2	53.3	94.1
45	136.4	81.6	2.8	3.1	5.2	10.6	54.6	103.3
50	154.1	88.9	2.9	3.1	5.6	11.0	55.8	111.5
55	171.4	96.0	3.0	3.0	6.1	11.3	56.8	119.4
60	189.6	103.2	3.1	3.0	6.6	11.5	57.8	127.4
65	204.5	109.1	3.2	3.0	6.9	11.8	58.6	134.0
70	218.8	114.6	3.3	3.0	7.3	12.0	59.2	140.1
75	234.5	120.6	3.4	2.9	7.7	12.1	59.8	146.7
80	247.6	125.5	3.5	2.9	8.0	12.3	60.2	152.2
85	259.4	129.9	3.5	2.9	8.2	12.5	60.6	157.1
90	272.3	134.7	3.6	2.9	8.5	12.6	60.8	162.3
years	*ft^3/acre*	---------- *tonnes carbon/acre* ----------						
0	0	0.0	0.0	1.7	0.0	0.0	18.6	1.7
5	0	3.0	0.3	1.7	0.2	1.2	18.7	6.3
10	195	7.9	0.5	1.5	0.5	2.1	18.9	12.5
15	397	11.9	0.6	1.4	0.8	2.7	19.2	17.3
20	628	15.8	0.8	1.4	1.0	3.1	19.6	22.0
25	848	19.0	0.8	1.3	1.2	3.5	20.0	25.8
30	1,104	22.4	0.9	1.3	1.4	3.7	20.5	29.8
35	1,384	26.1	1.0	1.3	1.7	4.0	21.0	34.0
40	1,675	29.7	1.1	1.3	1.9	4.1	21.6	38.1
45	1,950	33.0	1.1	1.2	2.1	4.3	22.1	41.8
50	2,202	36.0	1.2	1.2	2.3	4.4	22.6	45.1
55	2,450	38.8	1.2	1.2	2.5	4.6	23.0	48.3
60	2,710	41.8	1.3	1.2	2.7	4.7	23.4	51.6
65	2,923	44.1	1.3	1.2	2.8	4.8	23.7	54.2
70	3,127	46.4	1.3	1.2	2.9	4.8	24.0	56.7
75	3,352	48.8	1.4	1.2	3.1	4.9	24.2	59.4
80	3,539	50.8	1.4	1.2	3.2	5.0	24.4	61.6
85	3,707	52.6	1.4	1.2	3.3	5.0	24.5	63.6
90	3,891	54.5	1.4	1.2	3.5	5.1	24.6	65.7

B46.— Regional estimates of timber volume and carbon stocks for elm-ash-cottonwood stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	------------------------------------- *tonnes carbon/hectare* -------------------------------------						
0	0.0	0.0	0.0	4.2	0.0	0.0	37.4	4.2
5	0.0	8.6	0.9	4.9	0.6	1.1	37.5	16.0
10	11.7	18.3	1.8	4.1	1.2	2.1	37.9	27.6
15	21.2	27.0	2.7	3.7	1.8	3.0	38.5	38.2
20	33.8	36.3	3.3	3.5	2.4	3.7	39.2	49.1
25	46.6	45.1	3.6	3.3	3.0	4.4	40.2	59.4
30	60.2	53.8	3.8	3.2	3.6	5.0	41.2	69.4
35	76.3	63.3	4.1	3.1	4.2	5.5	42.2	80.2
40	94.3	73.3	4.4	2.9	4.9	6.0	43.3	91.5
45	114.1	83.8	4.6	2.9	5.6	6.4	44.3	103.3
50	133.0	95.1	4.8	2.8	6.3	6.8	45.3	115.9
55	151.4	104.2	5.0	2.7	6.9	7.2	46.2	126.0
60	168.9	112.7	5.1	2.7	7.5	7.5	46.9	135.5
65	185.6	120.7	5.3	2.6	8.0	7.8	47.6	144.5
70	201.5	128.4	5.4	2.6	8.5	8.1	48.1	153.0
75	215.7	135.1	5.5	2.6	9.0	8.4	48.6	160.6
80	229.4	141.6	5.6	2.5	9.4	8.6	48.9	167.8
85	242.5	147.8	5.7	2.5	9.8	8.9	49.2	174.7
90	254.1	153.4	5.8	2.5	10.2	9.1	49.4	180.9
years	*ft^3/acre*	------------------------------------- *tonnes carbon/acre* -------------------------------------						
0	0	0.0	0.0	1.7	0.0	0.0	15.1	1.7
5	0	3.5	0.3	2.0	0.2	0.5	15.2	6.5
10	167	7.4	0.7	1.7	0.5	0.9	15.3	11.2
15	303	10.9	1.1	1.5	0.7	1.2	15.6	15.5
20	483	14.7	1.3	1.4	1.0	1.5	15.9	19.9
25	666	18.3	1.4	1.3	1.2	1.8	16.3	24.0
30	860	21.8	1.6	1.3	1.4	2.0	16.7	28.1
35	1,091	25.6	1.7	1.2	1.7	2.2	17.1	32.4
40	1,348	29.7	1.8	1.2	2.0	2.4	17.5	37.0
45	1,630	33.9	1.9	1.2	2.3	2.6	17.9	41.8
50	1,901	38.5	1.9	1.1	2.6	2.8	18.3	46.9
55	2,164	42.2	2.0	1.1	2.8	2.9	18.7	51.0
60	2,414	45.6	2.1	1.1	3.0	3.1	19.0	54.8
65	2,652	48.9	2.1	1.1	3.2	3.2	19.3	58.5
70	2,880	52.0	2.2	1.0	3.5	3.3	19.5	61.9
75	3,082	54.7	2.2	1.0	3.6	3.4	19.7	65.0
80	3,278	57.3	2.3	1.0	3.8	3.5	19.8	67.9
85	3,465	59.8	2.3	1.0	4.0	3.6	19.9	70.7
90	3,632	62.1	2.3	1.0	4.1	3.7	20.0	73.2

B47.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	31.4	4.2
5	0.0	10.8	0.7	4.7	0.7	3.2	31.5	20.1
10	19.1	23.1	1.3	3.9	1.6	5.5	31.8	35.4
15	36.7	32.4	1.6	3.5	2.2	7.3	32.3	47.0
20	60.4	42.2	1.8	3.3	2.9	8.7	33.0	58.9
25	85.5	52.0	2.0	3.1	3.6	9.8	33.7	70.5
30	108.7	59.6	2.1	3.0	4.1	10.7	34.6	79.5
35	131.2	66.6	2.3	2.9	4.6	11.5	35.5	87.8
40	152.3	73.1	2.3	2.9	5.0	12.2	36.4	95.4
45	172.3	79.0	2.4	2.8	5.4	12.7	37.2	102.4
50	191.4	84.7	2.5	2.8	5.8	13.2	38.0	108.9
55	208.4	89.6	2.6	2.7	6.1	13.7	38.8	114.6
60	223.9	94.0	2.6	2.7	6.4	14.1	39.4	119.8
65	238.4	98.1	2.7	2.6	6.7	14.4	40.0	124.5
70	252.9	102.2	2.7	2.6	7.0	14.7	40.4	129.2
75	264.6	105.5	2.7	2.6	7.2	15.0	40.8	133.0
80	277.1	108.9	2.8	2.6	7.4	15.2	41.1	136.9
85	289.5	112.3	2.8	2.6	7.7	15.5	41.3	140.8
90	299.6	115.1	2.8	2.5	7.9	15.7	41.5	144.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	4.4	0.3	1.9	0.3	1.3	12.8	8.1
10	273	9.4	0.5	1.6	0.6	2.2	12.9	14.3
15	525	13.1	0.6	1.4	0.9	2.9	13.1	19.0
20	863	17.1	0.7	1.3	1.2	3.5	13.3	23.8
25	1,222	21.1	0.8	1.3	1.4	4.0	13.7	28.5
30	1,554	24.1	0.9	1.2	1.6	4.3	14.0	32.2
35	1,875	27.0	0.9	1.2	1.8	4.7	14.4	35.5
40	2,177	29.6	0.9	1.2	2.0	4.9	14.7	38.6
45	2,462	32.0	1.0	1.1	2.2	5.2	15.1	41.4
50	2,736	34.3	1.0	1.1	2.3	5.4	15.4	44.1
55	2,978	36.3	1.0	1.1	2.5	5.5	15.7	46.4
60	3,200	38.1	1.1	1.1	2.6	5.7	16.0	48.5
65	3,407	39.7	1.1	1.1	2.7	5.8	16.2	50.4
70	3,614	41.4	1.1	1.1	2.8	6.0	16.4	52.3
75	3,782	42.7	1.1	1.1	2.9	6.1	16.5	53.8
80	3,960	44.1	1.1	1.0	3.0	6.2	16.6	55.4
85	4,138	45.5	1.1	1.0	3.1	6.3	16.7	57.0
90	4,281	46.6	1.1	1.0	3.2	6.3	16.8	58.3

B48.— Regional estimates of timber volume and carbon stocks for loblolly-shortleaf pine stands with afforestation of land in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.1	0.0	0.0	31.4	4.1
5	0.0	10.8	0.4	4.1	0.4	3.2	31.5	18.9
10	47.7	34.2	0.9	3.9	1.3	5.5	31.8	45.7
15	146.5	68.7	1.0	3.8	2.7	7.3	32.3	83.4
20	244.8	99.2	1.1	3.7	3.8	8.7	33.0	116.5
25	315.2	118.3	1.1	3.7	4.6	9.8	33.7	137.6
30	347.3	126.8	1.1	3.7	4.9	10.7	34.6	147.3
35	351.5	127.9	1.1	3.7	5.0	11.5	35.5	149.2
40	355.0	128.8	1.1	3.7	5.0	12.2	36.4	150.8
45	358.5	129.8	1.1	3.7	5.0	12.7	37.2	152.4
50	362.0	130.7	1.1	3.7	5.1	13.2	38.0	153.8
55	362.0	130.7	1.1	3.7	5.1	13.7	38.8	154.2
60	362.0	130.7	1.1	3.7	5.1	14.1	39.4	154.6
65	362.0	130.7	1.1	3.7	5.1	14.4	40.0	155.0
70	362.0	130.7	1.1	3.7	5.1	14.7	40.4	155.3
75	362.0	130.7	1.1	3.7	5.1	15.0	40.8	155.6
80	362.0	130.7	1.1	3.7	5.1	15.2	41.1	155.8
85	362.0	130.7	1.1	3.7	5.1	15.5	41.3	156.0
90	362.0	130.7	1.1	3.7	5.1	15.7	41.5	156.2
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	4.4	0.2	1.6	0.2	1.3	12.8	7.6
10	682	13.8	0.3	1.6	0.5	2.2	12.9	18.5
15	2,094	27.8	0.4	1.5	1.1	2.9	13.1	33.8
20	3,498	40.1	0.4	1.5	1.6	3.5	13.3	47.1
25	4,504	47.9	0.4	1.5	1.9	4.0	13.7	55.7
30	4,963	51.3	0.5	1.5	2.0	4.3	14.0	59.6
35	5,024	51.8	0.5	1.5	2.0	4.7	14.4	60.4
40	5,074	52.1	0.5	1.5	2.0	4.9	14.7	61.0
45	5,124	52.5	0.5	1.5	2.0	5.2	15.1	61.7
50	5,174	52.9	0.5	1.5	2.0	5.4	15.4	62.2
55	5,174	52.9	0.5	1.5	2.0	5.5	15.7	62.4
60	5,174	52.9	0.5	1.5	2.0	5.7	16.0	62.6
65	5,174	52.9	0.5	1.5	2.0	5.8	16.2	62.7
70	5,174	52.9	0.5	1.5	2.0	6.0	16.4	62.8
75	5,174	52.9	0.5	1.5	2.0	6.1	16.5	63.0
80	5,174	52.9	0.5	1.5	2.0	6.2	16.6	63.1
85	5,174	52.9	0.5	1.5	2.0	6.3	16.7	63.1
90	5,174	52.9	0.5	1.5	2.0	6.3	16.8	63.2

B49.— Regional estimates of timber volume and carbon stocks for oak-gum-cypress stands with afforestation of land in the South Central

		Mean carbon density						
Age	Mean volume	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	1.8	0.0	0.0	39.6	1.8
5	0.0	5.4	0.5	2.1	0.3	1.1	39.7	9.5
10	9.8	17.8	1.8	1.8	1.1	2.1	40.1	24.7
15	19.9	28.4	2.8	1.7	1.8	3.0	40.7	37.8
20	32.7	39.3	3.2	1.7	2.5	3.7	41.5	50.4
25	45.4	48.8	3.4	1.6	3.1	4.4	42.5	61.3
30	58.1	57.2	3.5	1.6	3.6	5.0	43.6	70.9
35	73.4	66.9	3.6	1.6	4.2	5.5	44.7	81.8
40	92.2	76.9	3.7	1.6	4.9	6.0	45.8	93.0
45	110.7	86.1	3.7	1.5	5.4	6.4	46.9	103.3
50	128.1	94.4	3.8	1.5	6.0	6.8	47.9	112.6
55	146.3	102.8	3.9	1.5	6.5	7.2	48.8	121.9
60	166.1	111.6	3.9	1.5	7.0	7.5	49.7	131.6
65	186.4	120.3	4.0	1.5	7.6	7.8	50.3	141.2
70	205.7	128.3	4.0	1.5	8.1	8.1	50.9	150.0
75	222.5	135.1	4.1	1.5	8.5	8.4	51.4	157.6
80	237.9	141.2	4.1	1.5	8.9	8.6	51.8	164.4
85	257.3	148.8	4.1	1.5	9.4	8.9	52.0	172.6
90	278.9	157.0	4.2	1.4	9.9	9.1	52.3	181.6
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	0.7	0.0	0.0	16.0	0.7
5	0	2.2	0.2	0.8	0.1	0.5	16.1	3.9
10	140	7.2	0.7	0.7	0.5	0.9	16.2	10.0
15	284	11.5	1.1	0.7	0.7	1.2	16.5	15.3
20	467	15.9	1.3	0.7	1.0	1.5	16.8	20.4
25	649	19.7	1.4	0.7	1.2	1.8	17.2	24.8
30	830	23.1	1.4	0.7	1.5	2.0	17.6	28.7
35	1,049	27.1	1.4	0.6	1.7	2.2	18.1	33.1
40	1,318	31.1	1.5	0.6	2.0	2.4	18.5	37.6
45	1,582	34.9	1.5	0.6	2.2	2.6	19.0	41.8
50	1,830	38.2	1.5	0.6	2.4	2.8	19.4	45.6
55	2,091	41.6	1.6	0.6	2.6	2.9	19.8	49.3
60	2,374	45.2	1.6	0.6	2.9	3.1	20.1	53.3
65	2,664	48.7	1.6	0.6	3.1	3.2	20.4	57.1
70	2,940	51.9	1.6	0.6	3.3	3.3	20.6	60.7
75	3,180	54.7	1.6	0.6	3.5	3.4	20.8	63.8
80	3,400	57.2	1.7	0.6	3.6	3.5	20.9	66.5
85	3,677	60.2	1.7	0.6	3.8	3.6	21.1	69.9
90	3,986	63.5	1.7	0.6	4.0	3.7	21.1	73.5

B50.— Regional estimates of timber volume and carbon stocks for oak-hickory stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	29.0	4.2
5	0.0	9.7	0.9	4.7	0.6	1.1	29.1	17.1
10	11.7	20.9	1.9	4.0	1.4	2.1	29.4	30.3
15	21.2	30.1	2.1	3.6	2.0	3.0	29.8	40.8
20	33.8	39.5	2.3	3.4	2.6	3.7	30.4	51.6
25	46.6	48.2	2.4	3.3	3.2	4.4	31.1	61.5
30	60.2	56.6	2.6	3.1	3.8	5.0	31.9	71.0
35	76.3	65.6	2.7	3.0	4.4	5.5	32.7	81.2
40	94.3	76.2	2.8	2.9	5.1	6.0	33.5	92.9
45	114.1	85.7	2.9	2.8	5.7	6.4	34.3	103.6
50	133.0	94.7	3.0	2.8	6.3	6.8	35.1	113.6
55	151.4	103.3	3.0	2.7	6.9	7.2	35.8	123.1
60	168.9	111.3	3.1	2.7	7.4	7.5	36.4	132.0
65	185.6	118.8	3.2	2.6	7.9	7.8	36.9	140.4
70	201.5	126.0	3.2	2.6	8.4	8.1	37.3	148.3
75	215.7	132.3	3.2	2.6	8.8	8.4	37.6	155.3
80	229.4	138.3	3.3	2.5	9.2	8.6	37.9	162.0
85	242.5	144.0	3.3	2.5	9.6	8.9	38.1	168.3
90	254.1	149.1	3.3	2.5	9.9	9.1	38.3	174.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	11.7	1.7
5	0	3.9	0.4	1.9	0.3	0.5	11.8	6.9
10	167	8.5	0.8	1.6	0.6	0.9	11.9	12.2
15	303	12.2	0.9	1.5	0.8	1.2	12.1	16.5
20	483	16.0	0.9	1.4	1.1	1.5	12.3	20.9
25	666	19.5	1.0	1.3	1.3	1.8	12.6	24.9
30	860	22.9	1.0	1.3	1.5	2.0	12.9	28.7
35	1,091	26.6	1.1	1.2	1.8	2.2	13.2	32.9
40	1,348	30.8	1.1	1.2	2.0	2.4	13.6	37.6
45	1,630	34.7	1.2	1.2	2.3	2.6	13.9	41.9
50	1,901	38.3	1.2	1.1	2.5	2.8	14.2	46.0
55	2,164	41.8	1.2	1.1	2.8	2.9	14.5	49.8
60	2,414	45.0	1.3	1.1	3.0	3.1	14.7	53.4
65	2,652	48.1	1.3	1.1	3.2	3.2	14.9	56.8
70	2,880	51.0	1.3	1.1	3.4	3.3	15.1	60.0
75	3,082	53.5	1.3	1.0	3.6	3.4	15.2	62.8
80	3,278	56.0	1.3	1.0	3.7	3.5	15.3	65.5
85	3,465	58.3	1.3	1.0	3.9	3.6	15.4	68.1
90	3,632	60.3	1.4	1.0	4.0	3.7	15.5	70.4

B51.— Regional estimates of timber volume and carbon stocks for oak-pine stands with afforestation of land in the South Central

Age	Mean volume	Mean carbon density						
		Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Total nonsoil
years	*m^3/hectare*	*tonnes carbon/hectare*						
0	0.0	0.0	0.0	4.2	0.0	0.0	31.3	4.2
5	0.0	8.7	0.7	4.4	0.6	3.1	31.4	17.5
10	13.6	21.4	1.4	3.7	1.5	5.1	31.7	33.1
15	27.8	31.9	1.7	3.5	2.3	6.6	32.2	46.0
20	43.9	41.8	2.0	3.3	3.0	7.7	32.8	57.8
25	59.3	50.9	2.2	3.2	3.7	8.5	33.6	68.5
30	77.2	59.2	2.5	3.1	4.3	9.2	34.4	78.2
35	96.8	67.9	2.6	3.0	4.9	9.8	35.3	88.2
40	117.2	76.5	2.8	2.9	5.5	10.2	36.2	98.1
45	136.4	84.4	3.0	2.9	6.1	10.6	37.0	107.0
50	154.1	91.4	3.1	2.8	6.6	11.0	37.9	115.0
55	171.4	98.2	3.2	2.8	7.1	11.3	38.6	122.6
60	189.6	105.2	3.3	2.8	7.6	11.5	39.2	130.4
65	204.5	110.7	3.4	2.7	8.0	11.8	39.8	136.7
70	218.8	116.0	3.5	2.7	8.4	12.0	40.2	142.6
75	234.5	121.8	3.6	2.7	8.8	12.1	40.6	149.0
80	247.6	126.5	3.6	2.7	9.2	12.3	40.9	154.2
85	259.4	130.7	3.7	2.7	9.5	12.5	41.1	158.9
90	272.3	135.2	3.8	2.6	9.8	12.6	41.3	164.0
years	*ft^3/acre*	*tonnes carbon/acre*						
0	0	0.0	0.0	1.7	0.0	0.0	12.7	1.7
5	0	3.5	0.3	1.8	0.3	1.2	12.7	7.1
10	195	8.6	0.6	1.5	0.6	2.1	12.8	13.4
15	397	12.9	0.7	1.4	0.9	2.7	13.0	18.6
20	628	16.9	0.8	1.3	1.2	3.1	13.3	23.4
25	848	20.6	0.9	1.3	1.5	3.5	13.6	27.7
30	1,104	24.0	1.0	1.2	1.7	3.7	13.9	31.7
35	1,384	27.5	1.1	1.2	2.0	4.0	14.3	35.7
40	1,675	31.0	1.1	1.2	2.2	4.1	14.6	39.7
45	1,950	34.2	1.2	1.2	2.5	4.3	15.0	43.3
50	2,202	37.0	1.3	1.2	2.7	4.4	15.3	46.5
55	2,450	39.7	1.3	1.1	2.9	4.6	15.6	49.6
60	2,710	42.6	1.3	1.1	3.1	4.7	15.9	52.8
65	2,923	44.8	1.4	1.1	3.2	4.8	16.1	55.3
70	3,127	47.0	1.4	1.1	3.4	4.8	16.3	57.7
75	3,352	49.3	1.4	1.1	3.6	4.9	16.4	60.3
80	3,539	51.2	1.5	1.1	3.7	5.0	16.5	62.4
85	3,707	52.9	1.5	1.1	3.8	5.0	16.6	64.3
90	3,891	54.7	1.5	1.1	4.0	5.1	16.7	66.4

APPENDIX C

Scenarios of Harvest and Carbon Accumulation in Harvested Wood Products[3,4]

Carbon Stocks on Forest Land and in Harvested Wood Products After Clearcut Harvest

C1. Maple-beech-birch, Northeast
C2. Oak-hickory, Northeast
C3. Spruce-balsam fir, Northeast
C4. Aspen-birch, Northern Lake States
C5. Maple-beech-birch, Northern Lake States
C6. White-red-jack pine, Northern Lake States
C7. Elm-ash-cottonwood, Northern Prairie States
C8. Oak-hickory, Northern Prairie States
C9. Douglas-fir, Pacific Northwest, East
C10. Ponderosa pine, Pacific Northwest, East
C11. Alder-maple, Pacific Northwest, West
C12. Douglas-fir, high productivity and management intensity, Pacific Northwest, West
C13. Hemlock-Sitka spruce, high productivity, Pacific Northwest, West
C14. Mixed conifer, Pacific Southwest
C15. Western oak, Pacific Southwest
C16. Douglas-fir, Rocky Mountain, North
C17. Lodgepole pine, Rocky Mountain, North
C18. Fir-spruce-mountain hemlock, Rocky Mountain, South
C19. Ponderosa pine, Rocky Mountain, South
C20. Loblolly-shortleaf pine, high productivity and management intensity, Southeast
C21. Oak-gum-cypress, Southeast
C22. Oak-hickory, Southeast
C23. Oak-pine, Southeast
C24. Loblolly-shortleaf pine, high productivity and management intensity, South Central
C25. Oak-gum-cypress, South Central
C26. Oak-hickory, South Central
C27. Oak-pine, South Central

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[3] Note carbon mass is in metric tons (tonnes) in all tables, and age refers to stand age.
[4] These tables are example harvest scenarios; they are not recommendations for timing of harvest.

C1.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	-------- *m^3/hectare* -------		--- *tonnes carbon/hectare* --										
0	0.0		0.0	0.0	2.1	0.0	0.0	52.2					
5	0.0		7.4	0.7	2.1	0.5	4.2	52.3					
15	28.0		31.8	3.2	1.9	2.3	10.8	53.7					
25	58.1		53.2	5.3	1.8	3.8	15.8	56.0					
35	89.6		72.8	6.0	1.7	5.2	19.7	58.9					
45	119.1		87.8	6.6	1.7	6.2	22.7	61.8					
55	146.6		101.1	7.0	1.7	7.2	25.3	64.4					
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	66.3	34.5	0.0	39.7	14.1	7.5
5	0.0		7.4	0.7	2.1	21.7	20.3	67.1	22.9	4.7	43.1	17.5	
15	28.0		31.8	3.2	1.9	11.5	16.3	68.2	13.2	8.1	46.2	20.7	
25	58.1		53.2	5.3	1.8	7.8	17.6	68.9	10.3	8.8	47.1	22.0	
35	89.6		72.8	6.0	1.7	6.9	20.3	69.2	8.7	9.1	47.5	22.9	
45	119.1		87.8	6.6	1.7	7.0	23.0	69.4	7.6	9.4	47.8	23.5	
55	146.6		101.1	7.0	1.7	7.5	25.3	69.5	6.7	9.6	47.9	24.0	
65	0.0	172.1	0.0	0.0	2.1	32.0	27.7	69.5	40.4	9.8	87.8	38.5	7.7
years	--------- *ft^3/acre* ----------		-- *tonnes carbon/acre* ---										
0	0		0.0	0.0	0.8	0.0	0.0	21.1					
5	0		3.0	0.3	0.8	0.2	1.7	21.2					
15	400		12.9	1.3	0.8	0.9	4.4	21.7					
25	830		21.5	2.1	0.7	1.5	6.4	22.7					
35	1,280		29.5	2.4	0.7	2.1	8.0	23.8					
45	1,702		35.5	2.7	0.7	2.5	9.2	25.0					
55	2,095		40.9	2.8	0.7	2.9	10.2	26.0					
65	0	2,460	0.0	0.0	0.8	13.0	11.2	26.8	13.9	0.0	16.1	5.7	3.0
5	0		3.0	0.3	0.8	8.8	8.2	27.2	9.3	1.9	17.5	7.1	
15	400		12.9	1.3	0.8	4.7	6.6	27.6	5.3	3.3	18.7	8.4	
25	830		21.5	2.1	0.7	3.2	7.1	27.9	4.2	3.6	19.0	8.9	
35	1,280		29.5	2.4	0.7	2.8	8.2	28.0	3.5	3.7	19.2	9.3	
45	1,702		35.5	2.7	0.7	2.8	9.3	28.1	3.1	3.8	19.3	9.5	
55	2,095		40.9	2.8	0.7	3.0	10.3	28.1	2.7	3.9	19.4	9.7	
65	0	2,460	0.0	0.0	0.8	13.0	11.2	28.1	16.4	4.0	35.5	15.6	3.1

C2.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	-------- *m^3/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.1	0.0	0.0	39.8					
5	0.0		6.9	0.7	2.1	0.5	0.9	39.9					
15	54.5		43.0	3.6	1.9	2.9	2.5	40.9					
25	95.7		71.9	4.0	1.9	4.9	3.9	42.7					
35	135.3		96.2	4.2	1.8	6.6	5.2	44.9					
45	173.3		118.2	4.5	1.8	8.1	6.3	47.2					
55	209.6		136.8	4.6	1.8	9.4	7.2	49.1					
65	0.0	244.3	0.0	0.0	2.1	46.7	8.2	50.6	45.0	0.0	57.5	17.8	2.2
5	0.0		6.9	0.7	2.1	31.4	5.7	51.2	30.6	6.3	61.6	21.8	
15	54.5		43.0	3.6	1.9	16.5	4.1	52.1	18.0	11.3	65.3	25.7	
25	95.7		71.9	4.0	1.9	10.8	4.5	52.6	13.8	12.7	66.6	27.3	
35	135.3		96.2	4.2	1.8	9.2	5.3	52.8	11.4	13.3	67.3	28.4	
45	173.3		118.2	4.5	1.8	9.2	6.3	53.0	9.7	13.7	67.7	29.2	
55	209.6		136.8	4.6	1.8	9.9	7.3	53.0	8.4	14.0	68.0	29.9	
65	0.0	244.3	0.0	0.0	2.1	46.7	8.2	53.1	52.4	14.3	125.7	48.2	2.4
years	--------- *ft^3/acre* ---------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.8	0.0	0.0	16.1					
5	0		2.8	0.3	0.8	0.2	0.4	16.2					
15	779		17.4	1.4	0.8	1.2	1.0	16.6					
25	1,368		29.1	1.6	0.7	2.0	1.6	17.3					
35	1,934		38.9	1.7	0.7	2.7	2.1	18.2					
45	2,477		47.8	1.8	0.7	3.3	2.5	19.1					
55	2,996		55.4	1.9	0.7	3.8	2.9	19.9					
65	0	3,492	0.0	0.0	0.8	18.9	3.3	20.5	18.2	0.0	23.3	7.2	0.9
5	0		2.8	0.3	0.8	12.7	2.3	20.7	12.4	2.5	24.9	8.8	
15	779		17.4	1.4	0.8	6.7	1.7	21.1	7.3	4.6	26.4	10.4	
25	1,368		29.1	1.6	0.7	4.4	1.8	21.3	5.6	5.1	26.9	11.0	
35	1,934		38.9	1.7	0.7	3.7	2.2	21.4	4.6	5.4	27.2	11.5	
45	2,477		47.8	1.8	0.7	3.7	2.6	21.4	3.9	5.5	27.4	11.8	
55	2,996		55.4	1.9	0.7	4.0	2.9	21.5	3.4	5.7	27.5	12.1	
65	0	3,492	0.0	0.0	0.8	18.9	3.3	21.5	21.2	5.8	50.9	19.5	1.0

C3.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for spruce-balsam fir stands in the Northeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- *m*^{3}*/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.1	0.0	0.0	73.5					
5	0.0		7.0	0.7	1.8	0.6	5.0	73.7					
15	11.5		20.1	2.0	1.6	1.9	13.0	75.6					
25	29.1		32.5	3.3	1.5	3.0	19.0	78.9					
35	51.6		45.7	4.6	1.4	4.2	23.7	83.0					
45	76.9		57.4	5.7	1.4	5.3	27.5	87.1					
55	102.6		68.7	6.9	1.4	6.3	30.7	90.7					
65	0.0	126.4	0.0	0.0	2.1	20.3	33.7	93.5	23.6	0.0	22.2	11.1	14.8
5	0.0		7.0	0.7	1.8	16.0	23.6	94.5	13.4	3.5	25.8	14.2	
15	11.5		20.1	2.0	1.6	10.6	18.6	96.1	5.7	5.6	28.8	16.9	
25	29.1		32.5	3.3	1.5	8.0	20.7	97.0	4.1	5.6	29.3	17.9	
35	51.6		45.7	4.6	1.4	7.1	24.2	97.5	3.5	5.4	29.5	18.6	
45	76.9		57.4	5.7	1.4	6.9	27.7	97.8	3.0	5.4	29.6	19.0	
55	102.6		68.7	6.9	1.4	7.3	30.7	97.9	2.6	5.3	29.6	19.3	
65	0.0	126.4	0.0	0.0	2.1	20.3	33.7	98.0	26.0	5.4	51.9	30.7	15.4
years	-------- *ft*^{3}*/acre* ----------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.9	0.0	0.0	29.7					
5	0		2.8	0.3	0.7	0.3	2.0	29.8					
15	164		8.1	0.8	0.6	0.8	5.2	30.6					
25	416		13.2	1.3	0.6	1.2	7.7	31.9					
35	738		18.5	1.9	0.6	1.7	9.6	33.6					
45	1,099		23.2	2.3	0.6	2.1	11.1	35.2					
55	1,466		27.8	2.8	0.6	2.6	12.4	36.7					
65	0	1,807	0.0	0.0	0.9	8.2	13.6	37.8	9.6	0.0	9.0	4.5	6.0
5	0		2.8	0.3	0.7	6.5	9.5	38.3	5.4	1.4	10.5	5.7	
15	164		8.1	0.8	0.6	4.3	7.5	38.9	2.3	2.3	11.6	6.8	
25	416		13.2	1.3	0.6	3.2	8.4	39.3	1.7	2.3	11.9	7.3	
35	738		18.5	1.9	0.6	2.9	9.8	39.5	1.4	2.2	11.9	7.5	
45	1,099		23.2	2.3	0.6	2.8	11.2	39.6	1.2	2.2	12.0	7.7	
55	1,466		27.8	2.8	0.6	2.9	12.4	39.6	1.1	2.2	12.0	7.8	
65	0	1,807	0.0	0.0	0.9	8.2	13.6	39.6	10.5	2.2	21.0	12.4	6.2

C4.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for aspen-birch stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare*-------		------------ *tonnes carbon/hectare* ------------										
0	0.0		0.0	0.0	2.0	0.0	0.0	109.6					
5	0.0		7.3	0.5	2.1	0.6	1.6	109.9					
15	2.9		13.9	1.4	2.1	1.1	4.0	112.7					
25	21.5		26.8	2.7	2.1	2.2	5.8	117.6					
35	47.2		40.8	4.1	2.0	3.3	7.3	123.7					
45	72.8		53.5	5.3	2.0	4.3	8.4	129.8					
55	0.0	97.1	0.0	0.0	2.0	13.4	10.2	135.2	12.7	0.0	12.1	4.8	32.4
5	0.0		7.3	0.5	2.1	9.5	7.5	137.4	8.7	1.6	13.3	6.0	
15	2.9		13.9	1.4	2.1	5.0	6.0	140.9	5.4	2.8	14.3	7.1	
25	21.5		26.8	2.7	2.1	3.9	6.5	143.3	4.3	3.1	14.6	7.6	
35	47.2		40.8	4.1	2.0	4.0	7.5	144.7	3.7	3.2	14.8	7.9	
45	72.8		53.5	5.3	2.0	4.6	8.5	145.4	3.2	3.3	14.9	8.1	
55	0.0	97.1	0.0	0.0	2.0	13.4	10.2	145.8	15.5	3.4	27.1	13.1	32.5
years	--------*ft^3/acre* ---------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	0.8	0.0	0.0	44.3					
5	0		3.0	0.2	0.8	0.2	0.6	44.5					
15	42		5.6	0.6	0.8	0.5	1.6	45.6					
25	307		10.9	1.1	0.8	0.9	2.4	47.6					
35	674		16.5	1.6	0.8	1.3	2.9	50.1					
45	1,041		21.6	2.2	0.8	1.7	3.4	52.5					
55	0	1,388	0.0	0.0	0.8	5.4	4.1	54.7	5.1	0.0	4.9	1.9	13.1
5	0		3.0	0.2	0.8	3.8	3.0	55.6	3.5	0.6	5.4	2.4	
15	42		5.6	0.6	0.8	2.0	2.4	57.0	2.2	1.1	5.8	2.9	
25	307		10.9	1.1	0.8	1.6	2.6	58.0	1.7	1.2	5.9	3.1	
35	674		16.5	1.6	0.8	1.6	3.0	58.5	1.5	1.3	6.0	3.2	
45	1,041		21.6	2.2	0.8	1.9	3.4	58.8	1.3	1.3	6.0	3.3	
55	0	1,388	0.0	0.0	0.8	5.4	4.1	59.0	6.3	1.4	11.0	5.3	13.2

C5.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for maple-beech-birch stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare*-------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	2.1	0.0	0.0	100.7					
5	0.0		5.1	0.5	2.0	0.4	4.2	101.0					
15	4.3		13.4	1.3	1.7	1.0	10.8	103.6					
25	24.6		30.3	3.0	1.6	2.3	15.8	108.1					
35	48.1		47.7	4.0	1.5	3.6	19.7	113.7					
45	72.5		62.9	4.4	1.4	4.8	22.7	119.3					
55	96.9		77.3	4.7	1.4	5.9	25.3	124.3					
65	0.0	121.3	0.0	0.0	2.1	19.5	27.7	128.1	19.0	0.0	19.0	7.2	37.1
5	0.0		5.1	0.5	2.0	13.3	20.3	129.5	13.3	2.4	20.7	8.9	
15	4.3		13.4	1.3	1.7	6.7	16.3	131.7	8.3	4.3	22.2	10.5	
25	24.6		30.3	3.0	1.6	4.8	17.6	132.9	6.6	4.8	22.6	11.2	
35	48.1		47.7	4.0	1.5	4.7	20.3	133.6	5.6	5.1	22.9	11.6	
45	72.5		62.9	4.4	1.4	5.2	23.0	134.0	4.9	5.3	23.1	12.0	
55	96.9		77.3	4.7	1.4	6.1	25.3	134.2	4.3	5.5	23.2	12.3	
65	0.0	121.3	0.0	0.0	2.1	19.5	27.7	134.2	22.9	5.6	42.3	19.8	37.2
years	--------*ft^3/acre* ---------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	0.9	0.0	0.0	40.8					
5	0		2.1	0.2	0.8	0.2	1.7	40.9					
15	62		5.4	0.5	0.7	0.4	4.4	41.9					
25	351		12.2	1.2	0.6	0.9	6.4	43.8					
35	688		19.3	1.6	0.6	1.5	8.0	46.0					
45	1,036		25.4	1.8	0.6	1.9	9.2	48.3					
55	1,385		31.3	1.9	0.6	2.4	10.2	50.3					
65	0	1,733	0.0	0.0	0.9	7.9	11.2	51.8	7.7	0.0	7.7	2.9	15.0
5	0		2.1	0.2	0.8	5.4	8.2	52.4	5.4	1.0	8.4	3.6	
15	62		5.4	0.5	0.7	2.7	6.6	53.3	3.3	1.7	9.0	4.3	
25	351		12.2	1.2	0.6	1.9	7.1	53.8	2.7	2.0	9.2	4.5	
35	688		19.3	1.6	0.6	1.9	8.2	54.1	2.3	2.1	9.3	4.7	
45	1,036		25.4	1.8	0.6	2.1	9.3	54.2	2.0	2.1	9.3	4.9	
55	1,385		31.3	1.9	0.6	2.5	10.3	54.3	1.7	2.2	9.4	5.0	
65	0	1,733	0.0	0.0	0.9	7.9	11.2	54.3	9.3	2.3	17.1	8.0	15.1

C6.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for white-red-jack pine stands in the Northern Lake States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	-------- m^3/*hectare* -------		------------------------ *tonnes carbon/hectare* ------------------------										
0	0.0		0.0	0.0	2.0	0.0	0.0	90.6					
5	0.0		0.4	0.0	2.0	0.0	3.1	90.9					
15	6.6		8.0	0.8	2.0	0.6	7.1	93.2					
25	48.1		35.4	3.5	2.0	2.5	9.4	97.3					
35	104.7		62.9	4.9	2.0	4.5	11.0	102.3					
45	158.9		85.8	5.5	2.0	6.2	12.2	107.4					
55	0.0	209.1	0.0	0.0	2.0	25.5	13.8	111.8	25.0	0.0	20.5	9.1	37.9
5	0.0		0.4	0.0	2.0	19.3	10.7	113.7	16.8	3.3	23.2	11.3	
15	6.6		8.0	0.8	2.0	11.6	9.4	116.6	9.7	5.8	25.7	13.4	
25	48.1		35.4	3.5	2.0	8.8	10.1	118.5	7.4	6.5	26.4	14.3	
35	104.7		62.9	4.9	2.0	8.1	11.2	119.6	6.1	6.8	26.7	14.9	
45	158.9		85.8	5.5	2.0	8.2	12.2	120.3	5.2	7.0	27.0	15.4	
55	0.0	209.1	0.0	0.0	2.0	25.5	13.8	120.6	29.5	7.2	47.6	24.8	39.1
years	----------- ft^3/*acre* ---------		------------------------ *tonnes carbon/acre* ------------------------										
0	0		0.0	0.0	0.8	0.0	0.0	36.7					
5	0		0.2	0.0	0.8	0.0	1.3	36.8					
15	94		3.3	0.3	0.8	0.2	2.9	37.7					
25	688		14.3	1.4	0.8	1.0	3.8	39.4					
35	1,496		25.5	2.0	0.8	1.8	4.5	41.4					
45	2,271		34.7	2.2	0.8	2.5	4.9	43.5					
55	0	2,988	0.0	0.0	0.8	10.3	5.6	45.3	10.1	0.0	8.3	3.7	15.3
5	0		0.2	0.0	0.8	7.8	4.3	46.0	6.8	1.3	9.4	4.6	
15	94		3.3	0.3	0.8	4.7	3.8	47.2	3.9	2.4	10.4	5.4	
25	688		14.3	1.4	0.8	3.6	4.1	48.0	3.0	2.6	10.7	5.8	
35	1,496		25.5	2.0	0.8	3.3	4.6	48.4	2.5	2.7	10.8	6.0	
45	2,271		34.7	2.2	0.8	3.3	5.0	48.7	2.1	2.8	10.9	6.2	
55	0	2,988	0.0	0.0	0.8	10.3	5.6	48.8	12.0	2.9	19.3	10.1	15.8

C7.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for elm-ash-cottonwood stands in the Northern Prairie States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	-------- m^3/*hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	2.1	0.0	0.0	63.6					
5	0.0		3.9	0.4	2.1	0.3	4.2	63.8					
15	0.0		8.7	0.9	2.7	0.6	10.8	65.4					
25	5.8		15.5	1.6	2.4	1.1	15.8	68.3					
35	21.8		27.7	2.8	2.2	1.9	19.7	71.8					
45	45.1		43.2	4.3	2.0	3.0	22.7	75.4					
55	0.0	73.0	0.0	0.0	2.1	11.3	27.7	78.5	10.0	0.0	10.9	3.9	31.2
5	0.0		3.9	0.4	2.1	7.7	20.3	79.8	7.0	1.3	11.7	4.7	
15	0.0		8.7	0.9	2.7	3.9	16.3	81.8	4.3	2.5	12.5	5.5	
25	5.8		15.5	1.6	2.4	2.5	17.6	83.1	3.4	2.8	12.7	5.9	
35	21.8		27.7	2.8	2.2	2.5	20.3	84.0	2.8	2.9	12.9	6.1	
45	45.1		43.2	4.3	2.0	3.3	23.0	84.4	2.4	3.1	13.0	6.3	
55	0.0	73.0	0.0	0.0	2.1	11.3	27.7	84.6	12.2	3.1	23.9	10.4	31.4
years	---------- ft^3/*acre* ----------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	0.8	0.0	0.0	25.7					
5	0		1.6	0.2	0.8	0.1	1.7	25.8					
15	0		3.5	0.4	1.1	0.2	4.4	26.5					
25	83		6.3	0.6	1.0	0.4	6.4	27.6					
35	312		11.2	1.1	0.9	0.8	8.0	29.1					
45	644		17.5	1.7	0.8	1.2	9.2	30.5					
55	0	1,043	0.0	0.0	0.8	4.6	11.2	31.8	4.1	0.0	4.4	1.6	12.6
5	0		1.6	0.2	0.8	3.1	8.2	32.3	2.8	0.5	4.7	1.9	
15	0		3.5	0.4	1.1	1.6	6.6	33.1	1.8	1.0	5.0	2.2	
25	83		6.3	0.6	1.0	1.0	7.1	33.6	1.4	1.1	5.2	2.4	
35	312		11.2	1.1	0.9	1.0	8.2	34.0	1.1	1.2	5.2	2.5	
45	644		17.5	1.7	0.8	1.3	9.3	34.2	1.0	1.2	5.3	2.6	
55	0	1,043	0.0	0.0	0.8	4.6	11.2	34.2	4.9	1.3	9.7	4.2	12.7

C8.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Northern Prairie States

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3*/hectare*-------		------------ *tonnes carbon/hectare* ------------										
0	0.0		0.0	0.0	2.1	0.0	0.0	34.5					
5	0.0		6.7	0.6	2.4	0.5	0.9	34.6					
15	2.1		15.6	1.6	2.1	1.1	2.5	35.4					
25	13.0		27.5	2.7	2.0	1.9	3.9	37.0					
35	27.4		40.0	3.2	1.9	2.7	5.2	38.9					
45	43.0		52.2	3.6	1.8	3.5	6.3	40.8					
55	59.1		64.3	3.9	1.8	4.3	7.2	42.5					
65	0.0	74.9	0.0	0.0	2.1	14.1	8.2	43.8	13.2	0.0	13.9	5.1	37.1
5	0.0		6.7	0.6	2.4	9.8	5.7	44.3	9.2	1.7	15.0	6.2	
15	2.1		15.6	1.6	2.1	5.2	4.1	45.1	5.7	3.1	16.0	7.3	
25	13.0		27.5	2.7	2.0	3.7	4.5	45.5	4.5	3.5	16.4	7.8	
35	27.4		40.0	3.2	1.9	3.5	5.3	45.7	3.8	3.7	16.5	8.1	
45	43.0		52.2	3.6	1.8	3.9	6.3	45.9	3.3	3.9	16.7	8.3	
55	59.1		64.3	3.9	1.8	4.5	7.3	45.9	2.9	4.0	16.8	8.5	
65	0.0	74.9	0.0	0.0	2.1	14.1	8.2	45.9	15.8	4.1	30.7	13.8	37.2
years	--------ft^3*/acre* ---------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	0.8	0.0	0.0	13.9					
5	0		2.7	0.2	1.0	0.2	0.4	14.0					
15	30		6.3	0.6	0.9	0.4	1.0	14.3					
25	186		11.1	1.1	0.8	0.8	1.6	15.0					
35	391		16.2	1.3	0.8	1.1	2.1	15.7					
45	615		21.1	1.4	0.7	1.4	2.5	16.5					
55	844		26.0	1.6	0.7	1.8	2.9	17.2					
65	0	1,070	0.0	0.0	0.8	5.7	3.3	17.7	5.4	0.0	5.6	2.1	15.0
5	0		2.7	0.2	1.0	4.0	2.3	17.9	3.7	0.7	6.1	2.5	
15	30		6.3	0.6	0.9	2.1	1.7	18.2	2.3	1.3	6.5	3.0	
25	186		11.1	1.1	0.8	1.5	1.8	18.4	1.8	1.4	6.6	3.1	
35	391		16.2	1.3	0.8	1.4	2.2	18.5	1.5	1.5	6.7	3.3	
45	615		21.1	1.4	0.7	1.6	2.6	18.6	1.3	1.6	6.7	3.4	
55	844		26.0	1.6	0.7	1.8	2.9	18.6	1.2	1.6	6.8	3.5	
65	0	1,070	0.0	0.0	0.8	5.7	3.3	18.6	6.4	1.6	12.4	5.6	15.1

C9.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Pacific Northwest, East

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.6	0.0	0.0	71.1					
5	0.0		2.7	0.3	4.4	0.3	5.2	71.3					
15	3.8		8.7	0.9	4.1	0.9	13.0	73.1					
25	47.7		38.3	3.8	3.7	3.9	18.6	76.3					
35	119.0		75.1	7.5	3.6	7.7	22.9	80.2					
45	184.7		104.0	10.0	3.5	10.7	26.2	84.2					
55	241.8		127.3	10.9	3.4	13.1	28.9	87.7					
65	290.9		146.4	11.5	3.4	15.0	31.1	90.4					
75	0.0	332.7	0.0	0.0	4.6	26.0	37.2	92.3	41.1	0.0	27.3	16.1	74.9
5	0.0		2.7	0.3	4.4	22.5	35.4	92.9	31.8	4.2	29.9	18.6	
15	3.8		8.7	0.9	4.1	17.2	32.9	93.8	22.6	8.2	32.3	21.3	
25	47.7		38.3	3.8	3.7	15.9	31.8	94.3	18.5	9.9	33.3	22.8	
35	119.0		75.1	7.5	3.6	16.5	31.6	94.6	15.8	11.0	33.9	23.9	
45	184.7		104.0	10.0	3.5	17.1	32.0	94.7	13.7	11.8	34.2	24.8	
55	241.8		127.3	10.9	3.4	17.8	32.7	94.7	12.1	12.4	34.5	25.6	
65	290.9		146.4	11.5	3.4	18.5	33.6	94.8	10.7	12.9	34.6	26.2	
75	0.0	332.7	0.0	0.0	4.6	26.0	37.2	94.8	50.7	13.4	62.0	42.9	79.1

Continued

C9.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft^3/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	28.8					
5	0		1.1	0.1	1.8	0.1	2.1	28.9					
15	54		3.5	0.4	1.7	0.4	5.2	29.6					
25	682		15.5	1.5	1.5	1.6	7.5	30.9					
35	1,701		30.4	3.0	1.4	3.1	9.3	32.5					
45	2,639		42.1	4.1	1.4	4.3	10.6	34.1					
55	3,456		51.5	4.4	1.4	5.3	11.7	35.5					
65	4,157		59.3	4.7	1.4	6.1	12.6	36.6					
75	0	4,755	0.0	0.0	1.9	10.5	15.1	37.3	16.6	0.0	11.1	6.5	30.3
5	0		1.1	0.1	1.8	9.1	14.3	37.6	12.9	1.7	12.1	7.5	
15	54		3.5	0.4	1.7	7.0	13.3	38.0	9.1	3.3	13.1	8.6	
25	682		15.5	1.5	1.5	6.4	12.9	38.2	7.5	4.0	13.5	9.2	
35	1,701		30.4	3.0	1.4	6.7	12.8	38.3	6.4	4.5	13.7	9.7	
45	2,639		42.1	4.1	1.4	6.9	12.9	38.3	5.5	4.8	13.9	10.0	
55	3,456		51.5	4.4	1.4	7.2	13.2	38.3	4.9	5.0	14.0	10.3	
65	4,157		59.3	4.7	1.4	7.5	13.6	38.3	4.3	5.2	14.0	10.6	
75	0	4,755	0.0	0.0	1.9	10.5	15.1	38.3	20.5	5.4	25.1	17.4	32.0

C10.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for ponderosa pine stands in the Pacific Northwest, East

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3*/hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.8	0.0	0.0	38.0					
5	0.0		3.3	0.3	4.6	0.3	2.4	38.1					
15	4.1		7.9	0.8	3.8	0.8	6.4	39.1					
25	21.6		17.3	1.7	3.2	1.8	9.8	40.8					
35	40.8		26.2	2.6	2.9	2.7	12.6	42.9					
45	61.4		34.9	3.3	2.8	3.6	14.9	45.1					
55	83.3		43.6	3.7	2.6	4.5	17.0	46.9					
65	106.0		52.5	4.2	2.5	5.4	18.7	48.4					
75	0.0	129.3	0.0	0.0	4.8	9.6	24.1	49.4	14.4	0.0	9.4	5.6	27.0
5	0.0		3.3	0.3	4.6	8.5	22.0	49.7	11.1	1.5	10.3	6.5	
15	4.1		7.9	0.8	3.8	6.8	19.4	50.2	7.9	2.9	11.2	7.5	
25	21.6		17.3	1.7	3.2	6.2	18.3	50.5	6.5	3.5	11.5	8.0	
35	40.8		26.2	2.6	2.9	5.9	18.2	50.6	5.5	3.8	11.7	8.3	
45	61.4		34.9	3.3	2.8	6.0	18.7	50.7	4.8	4.1	11.8	8.7	
55	83.3		43.6	3.7	2.6	6.3	19.4	50.7	4.2	4.3	11.9	8.9	
65	106.0		52.5	4.2	2.5	6.7	20.4	50.7	3.8	4.5	12.0	9.2	
75	0.0	129.3	0.0	0.0	4.8	9.6	24.1	50.7	17.7	4.7	21.4	15.0	29.0

Continued

C10.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3/acre --------		------- *tonnes carbon/acre* -------										
0	0		0.0	0.0	1.9	0.0	0.0	15.4					
5	0		1.3	0.1	1.8	0.1	1.0	15.4					
15	59		3.2	0.3	1.5	0.3	2.6	15.8					
25	309		7.0	0.7	1.3	0.7	4.0	16.5					
35	583		10.6	1.1	1.2	1.1	5.1	17.4					
45	878		14.1	1.3	1.1	1.5	6.0	18.2					
55	1,190		17.7	1.5	1.1	1.8	6.9	19.0					
65	1,515		21.2	1.7	1.0	2.2	7.6	19.6					
75	0	1,848	0.0	0.0	1.9	3.9	9.8	20.0	5.8	0.0	3.8	2.3	10.9
5	0		1.3	0.1	1.8	3.5	8.9	20.1	4.5	0.6	4.2	2.6	
15	59		3.2	0.3	1.5	2.8	7.8	20.3	3.2	1.2	4.5	3.0	
25	309		7.0	0.7	1.3	2.5	7.4	20.4	2.6	1.4	4.7	3.2	
35	583		10.6	1.1	1.2	2.4	7.4	20.5	2.2	1.6	4.7	3.4	
45	878		14.1	1.3	1.1	2.4	7.6	20.5	1.9	1.7	4.8	3.5	
55	1,190		17.7	1.5	1.1	2.5	7.9	20.5	1.7	1.8	4.8	3.6	
65	1,515		21.2	1.7	1.0	2.7	8.2	20.5	1.5	1.8	4.8	3.7	
75	0	1,848	0.0	0.0	1.9	3.9	9.8	20.5	7.2	1.9	8.7	6.1	11.7

C11.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for alder-maple stands in the Pacific Northwest, West

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3/*hectare* -------		------------ *tonnes carbon/hectare* ------------										
0	0.0		0.0	0.0	4.7	0.0	0.0	86.4					
5	0.0		8.0	0.8	4.7	0.8	1.8	86.7					
15	49.5		31.0	3.1	3.7	2.9	4.4	88.9					
25	229.7		99.4	9.9	2.8	9.4	6.2	92.8					
35	380.8		153.8	15.4	2.5	14.6	7.6	97.6					
45	0.0	513.7	0.0	0.0	4.7	32.2	9.3	102.4	42.6	0.0	95.0	16.6	50.6
5	0.0		8.0	0.8	4.7	22.0	3.9	104.6	30.3	5.4	98.7	19.8	
15	49.5		31.0	3.1	3.7	12.3	4.5	108.4	18.8	10.1	102.1	23.1	
25	229.7		99.4	9.9	2.8	13.5	6.2	111.2	14.5	11.7	103.3	24.7	
35	380.8		153.8	15.4	2.5	16.4	7.6	113.0	11.8	12.5	103.9	25.8	
45	0.0	513.7	0.0	0.0	4.7	32.2	9.3	114.1	52.6	13.1	199.3	43.3	51.4
years	------ ft^3/*acre* ---------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	1.9	0.0	0.0	35.0					
5	0		3.2	0.3	1.9	0.3	0.7	35.1					
15	708		12.6	1.3	1.5	1.2	1.8	36.0					
25	3,282		40.2	4.0	1.1	3.8	2.5	37.6					
35	5,442		62.3	6.2	1.0	5.9	3.1	39.5					
45	0	7,342	0.0	0.0	1.9	13.0	3.8	41.5	17.2	0.0	38.4	6.7	20.5
5	0		3.2	0.3	1.9	8.9	1.6	42.3	12.2	2.2	39.9	8.0	
15	708		12.6	1.3	1.5	5.0	1.8	43.9	7.6	4.1	41.3	9.3	
25	3,282		40.2	4.0	1.1	5.5	2.5	45.0	5.9	4.7	41.8	10.0	
35	5,442		62.3	6.2	1.0	6.6	3.1	45.7	4.8	5.1	42.1	10.4	
45	0	7,342	0.0	0.0	1.9	13.0	3.8	46.2	21.3	5.3	80.7	17.5	20.8

C12.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Pacific Northwest, West; volumes are for high-productivity sites (growth rate greater than 165 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock, fertilization, and precommercial thinning)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	---- *m³/hectare* --------		------------ *tonnes carbon/hectare* ------------										
0	0.0		0.0	0.0	4.6	0.0	0.0	71.1					
5	0.0		9.5	0.9	4.4	0.9	3.6	71.3					
15	19.8		23.4	2.3	4.0	2.3	10.0	73.1					
25	169.7		84.6	8.5	3.5	8.5	15.4	76.3					
35	445.7		187.4	10.0	3.2	18.7	20.2	80.2					
45	0.0	718.8	0.0	0.0	4.6	49.3	27.5	84.2	100.1	0.0	57.0	31.8	82.6
5	0.0		9.5	0.9	4.4	43.1	23.7	86.0	76.9	10.9	63.0	38.0	
15	19.8		23.4	2.3	4.0	33.3	20.7	89.2	53.3	21.6	68.9	45.1	
25	169.7		84.6	8.5	3.5	31.2	21.2	91.4	42.5	26.1	71.2	49.0	
35	445.7		187.4	10.0	3.2	35.4	23.3	92.9	35.6	28.8	72.6	51.8	
45	0.0	718.8	0.0	0.0	4.6	49.3	27.5	93.8	130.6	30.7	130.5	85.9	96.5
years	-------- *ft³/acre* --------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	1.9	0.0	0.0	28.8					
5	0		3.8	0.4	1.8	0.4	1.5	28.9					
15	283		9.5	0.9	1.6	0.9	4.0	29.6					
25	2,425		34.2	3.4	1.4	3.4	6.2	30.9					
35	6,370		75.9	4.1	1.3	7.6	8.2	32.5					
45	0	10,272	0.0	0.0	1.9	19.9	11.1	34.1	40.5	0.0	23.1	12.9	33.4
5	0		3.8	0.4	1.8	17.5	9.6	34.8	31.1	4.4	25.5	15.4	
15	283		9.5	0.9	1.6	13.5	8.4	36.1	21.6	8.7	27.9	18.3	
25	2,425		34.2	3.4	1.4	12.6	8.6	37.0	17.2	10.6	28.8	19.8	
35	6,370		75.9	4.1	1.3	14.3	9.4	37.6	14.4	11.7	29.4	21.0	
45	0	10,272	0.0	0.0	1.9	19.9	11.1	38.0	52.9	12.4	52.8	34.8	39.0

C13.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for hemlock-Sitka spruce stands in the Pacific Northwest, West; volumes are for high productivity sites (growth rate greater than 225 cubic feet wood/acre/year)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.7	0.0	0.0	87.3					
5	0.0		5.9	0.6	4.7	0.6	3.6	87.6					
15	80.3		36.4	3.6	3.7	3.6	10.0	89.8					
25	221.7		90.4	9.0	3.0	8.9	15.4	93.7					
35	413.7		161.0	16.1	2.7	15.9	20.2	98.5					
45	0.0	669.6	0.0	0.0	4.7	42.7	27.5	103.4	85.8	0.0	49.3	27.3	93.4
5	0.0		5.9	0.6	4.7	37.1	23.7	105.6	65.8	9.4	54.5	32.7	
15	80.3		36.4	3.6	3.7	30.4	20.7	109.5	45.5	18.5	59.6	38.8	
25	221.7		90.4	9.0	3.0	28.6	21.2	112.3	36.3	22.4	61.6	42.1	
35	413.7		161.0	16.1	2.7	30.3	23.3	114.1	30.4	24.7	62.8	44.6	
45	0.0	669.6	0.0	0.0	4.7	42.7	27.5	115.2	111.8	26.3	112.9	73.8	105.6
years	-------- ft^3/*acre*--------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	1.9	0.0	0.0	35.3					
5	0		2.4	0.2	1.9	0.2	1.5	35.4					
15	1,148		14.7	1.5	1.5	1.5	4.0	36.3					
25	3,169		36.6	3.7	1.2	3.6	6.2	37.9					
35	5,912		65.1	6.5	1.1	6.4	8.2	39.9					
45	0	9,570	0.0	0.0	1.9	17.3	11.1	41.8	34.7	0.0	20.0	11.1	37.8
5	0		2.4	0.2	1.9	15.0	9.6	42.8	26.6	3.8	22.1	13.2	
15	1,148		14.7	1.5	1.5	12.3	8.4	44.3	18.4	7.5	24.1	15.7	
25	3,169		36.6	3.7	1.2	11.6	8.6	45.4	14.7	9.1	24.9	17.0	
35	5,912		65.1	6.5	1.1	12.3	9.4	46.2	12.3	10.0	25.4	18.0	
45	0	9,570	0.0	0.0	1.9	17.3	11.1	46.6	45.3	10.6	45.7	29.9	42.7

C14.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for mixed conifer stands in the Pacific Southwest

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3*/hectare* ------		--- *tonnes carbon/hectare* ---										
0	0.0		0.0	0.0	4.8	0.0	0.0	37.4					
5	0.0		4.2	0.3	4.8	0.4	5.2	37.5					
15	2.0		8.1	0.8	4.8	0.8	13.0	38.4					
25	11.1		14.6	1.5	6.9	1.5	18.6	40.1					
35	24.4		22.3	2.2	4.9	2.2	22.9	42.2					
45	44.5		32.9	3.3	3.6	3.3	26.2	44.3					
55	71.9		46.5	4.7	2.8	4.7	28.9	46.1					
65	106.6		62.8	6.3	2.2	6.3	31.1	47.5					
75	0.0	147.9	0.0	0.0	4.8	12.0	37.2	48.5	17.3	0.0	12.2	6.3	42.7
5	0.0		4.2	0.3	4.8	10.7	35.4	48.8	13.3	1.9	13.2	7.3	
15	2.0		8.1	0.8	4.8	8.4	32.9	49.3	9.3	3.7	14.3	8.5	
25	11.1		14.6	1.5	6.9	7.0	31.8	49.6	7.4	4.5	14.7	9.1	
35	24.4		22.3	2.2	4.9	6.3	31.6	49.7	6.2	4.9	15.0	9.6	
45	44.5		32.9	3.3	3.6	6.3	32.0	49.8	5.3	5.3	15.2	10.0	
55	71.9		46.5	4.7	2.8	6.9	32.7	49.8	4.7	5.5	15.3	10.3	
65	106.6		62.8	6.3	2.2	7.9	33.6	49.8	4.1	5.7	15.4	10.5	
75	0.0	147.9	0.0	0.0	4.8	12.0	37.2	49.8	20.9	5.9	27.6	17.0	45.6

Continued

C14.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3*/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	15.1					
5	0		1.7	0.1	1.9	0.2	2.1	15.2					
15	29		3.3	0.3	1.9	0.3	5.2	15.5					
25	159		5.9	0.6	2.8	0.6	7.5	16.2					
35	349		9.0	0.9	2.0	0.9	9.3	17.1					
45	636		13.3	1.3	1.5	1.3	10.6	17.9					
55	1,028		18.8	1.9	1.1	1.9	11.7	18.7					
65	1,523		25.4	2.5	0.9	2.6	12.6	19.2					
75	0	2,114	0.0	0.0	1.9	4.9	15.1	19.6	7.0	0.0	4.9	2.5	17.3
5	0		1.7	0.1	1.9	4.3	14.3	19.8	5.4	0.8	5.4	3.0	
15	29		3.3	0.3	1.9	3.4	13.3	20.0	3.7	1.5	5.8	3.4	
25	159		5.9	0.6	2.8	2.8	12.9	20.1	3.0	1.8	6.0	3.7	
35	349		9.0	0.9	2.0	2.6	12.8	20.1	2.5	2.0	6.1	3.9	
45	636		13.3	1.3	1.5	2.5	12.9	20.1	2.2	2.1	6.1	4.0	
55	1,028		18.8	1.9	1.1	2.8	13.2	20.1	1.9	2.2	6.2	4.2	
65	1,523		25.4	2.5	0.9	3.2	13.6	20.2	1.7	2.3	6.2	4.3	
75	0	2,114	0.0	0.0	1.9	4.9	15.1	20.2	8.5	2.4	11.2	6.9	18.4

C15.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for western oak stands in the Pacific Southwest

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.7	0.0	0.0	20.7					
5	0.0		2.6	0.2	4.6	0.1	3.7	20.8					
15	0.0		5.7	0.6	4.5	0.2	9.8	21.3					
25	1.0		8.8	0.9	4.4	0.4	14.4	22.2					
35	25.9		30.6	3.1	4.2	1.3	18.1	23.4					
45	76.3		65.1	4.5	4.1	2.7	21.1	24.5					
55	127.8		98.3	5.4	4.0	4.1	23.6	25.5					
65	174.4		124.0	6.0	4.0	5.1	25.6	26.3					
75	0.0	215.0	0.0	0.0	4.7	13.3	31.7	26.9	19.5	0.0	52.4	7.8	59.7
5	0.0		2.6	0.2	4.6	8.9	28.4	27.1	14.7	2.3	53.7	9.1	
15	0.0		5.7	0.6	4.5	4.1	24.6	27.3	9.8	4.4	55.1	10.4	
25	1.0		8.8	0.9	4.4	2.1	23.4	27.5	7.6	5.4	55.7	11.1	
35	25.9		30.6	3.1	4.2	2.0	23.5	27.5	6.2	5.9	56.0	11.6	
45	76.3		65.1	4.5	4.1	3.0	24.3	27.6	5.2	6.3	56.2	12.0	
55	127.8		98.3	5.4	4.0	4.2	25.5	27.6	4.5	6.5	56.4	12.4	
65	174.4		124.0	6.0	4.0	5.2	26.8	27.6	3.9	6.7	56.5	12.7	
75	0.0	215.0	0.0	0.0	4.7	13.3	31.7	27.6	22.9	6.9	109.0	20.7	60.4

Continued

C15.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft^3/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	8.4					
5	0		1.1	0.1	1.9	0.0	1.5	8.4					
15	0		2.3	0.2	1.8	0.1	3.9	8.6					
25	15		3.6	0.4	1.8	0.1	5.8	9.0					
35	370		12.4	1.2	1.7	0.5	7.3	9.5					
45	1,090		26.3	1.8	1.7	1.1	8.5	9.9					
55	1,826		39.8	2.2	1.6	1.7	9.5	10.3					
65	2,493		50.2	2.4	1.6	2.1	10.4	10.6					
75	0	3,072	0.0	0.0	1.9	5.4	12.8	10.9	7.9	0.0	21.2	3.2	24.1
5	0		1.1	0.1	1.9	3.6	11.5	10.9	5.9	0.9	21.7	3.7	
15	0		2.3	0.2	1.8	1.7	10.0	11.1	4.0	1.8	22.3	4.2	
25	15		3.6	0.4	1.8	0.8	9.5	11.1	3.1	2.2	22.5	4.5	
35	370		12.4	1.2	1.7	0.8	9.5	11.1	2.5	2.4	22.7	4.7	
45	1,090		26.3	1.8	1.7	1.2	9.8	11.2	2.1	2.5	22.8	4.9	
55	1,826		39.8	2.2	1.6	1.7	10.3	11.2	1.8	2.6	22.8	5.0	
65	2,493		50.2	2.4	1.6	2.1	10.9	11.2	1.6	2.7	22.9	5.1	
75	0	3,072	0.0	0.0	1.9	5.4	12.8	11.2	9.3	2.8	44.1	8.4	24.4

C16.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for Douglas-fir stands in the Rocky Mountain, North

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3*/hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.7	0.0	0.0	29.1					
5	0.0		2.7	0.3	4.7	0.2	5.2	29.2					
15	1.1		6.1	0.6	4.7	0.4	13.0	30.0					
25	19.7		21.5	2.2	3.4	1.3	18.6	31.3					
35	57.1		44.3	4.4	2.7	2.8	22.9	32.9					
45	100.9		66.5	6.7	2.3	4.1	26.2	34.5					
55	145.9		87.2	8.7	2.1	5.4	28.9	35.9					
65	189.3		105.9	10.1	1.9	6.6	31.1	37.1					
75	0.0	229.7	0.0	0.0	4.7	22.4	37.2	37.8	40.7	0.0	31.8	8.1	30.6
5	0.0		2.7	0.3	4.7	20.2	35.4	38.1	31.2	4.4	35.1	9.9	
15	1.1		6.1	0.6	4.7	16.3	32.9	38.5	21.5	8.8	38.3	12.0	
25	19.7		21.5	2.2	3.4	14.0	31.8	38.7	17.2	10.7	39.6	13.3	
35	57.1		44.3	4.4	2.7	12.8	31.6	38.8	14.3	11.8	40.3	14.2	
45	100.9		66.5	6.7	2.3	12.1	32.0	38.8	12.3	12.5	40.8	15.1	
55	145.9		87.2	8.7	2.1	11.8	32.7	38.8	10.7	13.1	41.1	15.8	
65	189.3		105.9	10.1	1.9	11.6	33.6	38.8	9.4	13.6	41.3	16.4	
75	0.0	229.7	0.0	0.0	4.7	22.4	37.2	38.8	49.1	13.9	73.2	25.1	36.3

Continued

C16.—Continued

Age	Mean volume		Mean carbon density										
	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3*/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.9	0.0	0.0	11.8					
5	0		1.1	0.1	1.9	0.1	2.1	11.8					
15	16		2.5	0.2	1.9	0.2	5.2	12.1					
25	281		8.7	0.9	1.4	0.5	7.5	12.7					
35	816		17.9	1.8	1.1	1.1	9.3	13.3					
45	1,442		26.9	2.7	0.9	1.7	10.6	14.0					
55	2,085		35.3	3.5	0.8	2.2	11.7	14.5					
65	2,705		42.9	4.1	0.8	2.7	12.6	15.0					
75	0	3,283	0.0	0.0	1.9	9.1	15.1	15.3	16.5	0.0	12.9	3.3	12.4
5	0		1.1	0.1	1.9	8.2	14.3	15.4	12.6	1.8	14.2	4.0	
15	16		2.5	0.2	1.9	6.6	13.3	15.6	8.7	3.6	15.5	4.9	
25	281		8.7	0.9	1.4	5.6	12.9	15.6	6.9	4.3	16.0	5.4	
35	816		17.9	1.8	1.1	5.2	12.8	15.7	5.8	4.8	16.3	5.8	
45	1,442		26.9	2.7	0.9	4.9	12.9	15.7	5.0	5.1	16.5	6.1	
55	2,085		35.3	3.5	0.8	4.8	13.2	15.7	4.3	5.3	16.6	6.4	
65	2,705		42.9	4.1	0.8	4.7	13.6	15.7	3.8	5.5	16.7	6.6	
75	0	3,283	0.0	0.0	1.9	9.1	15.1	15.7	19.9	5.6	29.6	10.2	14.7

C17.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for lodgepole pine stands in the Rocky Mountain, North

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3/*hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.8	0.0	0.0	27.9					
5	0.0		1.9	0.1	4.8	0.1	2.4	28.0					
15	0.2		4.1	0.3	4.8	0.2	6.4	28.7					
25	15.9		14.3	1.4	3.5	0.8	9.8	29.9					
35	51.6		29.9	3.0	2.4	1.7	12.6	31.5					
45	94.3		45.8	4.6	1.9	2.7	14.9	33.0					
55	138.8		59.4	5.9	1.7	3.4	17.0	34.4					
65	182.1		71.6	7.2	1.5	4.2	18.7	35.5					
75	0.0	223.1	0.0	0.0	4.8	17.7	24.1	36.2	32.3	0.0	25.6	6.4	6.4
5	0.0		1.9	0.1	4.8	15.9	22.0	36.5	24.8	3.5	28.2	7.9	
15	0.2		4.1	0.3	4.8	12.8	19.4	36.8	17.1	7.0	30.7	9.5	
25	15.9		14.3	1.4	3.5	10.8	18.3	37.0	13.6	8.5	31.8	10.5	
35	51.6		29.9	3.0	2.4	9.6	18.2	37.1	11.4	9.3	32.4	11.3	
45	94.3		45.8	4.6	1.9	8.9	18.7	37.1	9.8	9.9	32.7	11.9	
55	138.8		59.4	5.9	1.7	8.4	19.4	37.2	8.5	10.4	33.0	12.5	
65	182.1		71.6	7.2	1.5	8.1	20.4	37.2	7.5	10.8	33.1	13.0	
75	0.0	223.1	0.0	0.0	4.8	17.7	24.1	37.2	39.0	11.1	58.8	19.9	10.6

Continued

C17.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft*^{3}*/acre* --------		------------------------- *tonnes carbon/acre* -------------------------										
0	0		0.0	0.0	1.9	0.0	0.0	11.3					
5	0		0.8	0.0	1.9	0.0	1.0	11.3					
15	3		1.7	0.1	1.9	0.1	2.6	11.6					
25	227		5.8	0.6	1.4	0.3	4.0	12.1					
35	737		12.1	1.2	1.0	0.7	5.1	12.7					
45	1,348		18.5	1.9	0.8	1.1	6.0	13.4					
55	1,983		24.0	2.4	0.7	1.4	6.9	13.9					
65	2,603		29.0	2.9	0.6	1.7	7.6	14.4					
75	0	3,189	0.0	0.0	1.9	7.2	9.8	14.6	13.1	0.0	10.4	2.6	2.6
5	0		0.8	0.0	1.9	6.4	8.9	14.8	10.0	1.4	11.4	3.2	
15	3		1.7	0.1	1.9	5.2	7.8	14.9	6.9	2.8	12.4	3.9	
25	227		5.8	0.6	1.4	4.4	7.4	15.0	5.5	3.4	12.8	4.3	
35	737		12.1	1.2	1.0	3.9	7.4	15.0	4.6	3.8	13.1	4.6	
45	1,348		18.5	1.9	0.8	3.6	7.6	15.0	3.9	4.0	13.2	4.8	
55	1,983		24.0	2.4	0.7	3.4	7.9	15.0	3.4	4.2	13.3	5.1	
65	2,603		29.0	2.9	0.6	3.3	8.2	15.0	3.0	4.4	13.4	5.3	
75	0	3,189	0.0	0.0	1.9	7.2	9.8	15.0	15.8	4.5	23.8	8.1	4.3

C18.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for fir-spruce-mountain hemlock stands in the Rocky Mountain, South

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m³/hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.8	0.0	0.0	23.6					
5	0.0		1.8	0.2	4.8	0.1	5.2	23.7					
15	0.0		4.0	0.4	4.8	0.3	13.0	24.3					
25	8.5		12.0	1.2	4.3	0.9	18.6	25.3					
35	27.7		24.4	2.4	2.8	1.9	22.9	26.7					
45	49.5		36.7	3.7	2.3	2.9	26.2	28.0					
55	71.9		48.7	4.9	1.9	3.8	28.9	29.1					
65	94.1		58.6	5.9	1.7	4.6	31.1	30.0					
75	0.0	115.7	0.0	0.0	4.8	11.3	37.2	30.6	16.4	0.0	14.8	3.4	26.5
5	0.0		1.8	0.2	4.8	10.2	35.4	30.9	12.6	1.8	16.1	4.1	
15	0.0		4.0	0.4	4.8	8.3	32.9	31.2	8.7	3.6	17.4	5.0	
25	8.5		12.0	1.2	4.3	7.3	31.8	31.3	6.9	4.3	17.9	5.5	
35	27.7		24.4	2.4	2.8	7.0	31.6	31.4	5.7	4.8	18.2	5.9	
45	49.5		36.7	3.7	2.3	6.9	32.0	31.4	4.9	5.1	18.4	6.2	
55	71.9		48.7	4.9	1.9	7.0	32.7	31.5	4.3	5.3	18.6	6.5	
65	94.1		58.6	5.9	1.7	7.1	33.6	31.5	3.8	5.5	18.6	6.7	
75	0.0	115.7	0.0	0.0	4.8	11.3	37.2	31.5	19.8	5.6	33.5	10.3	30.2

Continued

C18.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft*^{3}*/acre* --------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	2.0	0.0	0.0	9.6					
5	0		0.7	0.1	2.0	0.1	2.1	9.6					
15	0		1.6	0.2	2.0	0.1	5.2	9.8					
25	122		4.8	0.5	1.7	0.4	7.5	10.3					
35	396		9.9	1.0	1.1	0.8	9.3	10.8					
45	708		14.8	1.5	0.9	1.2	10.6	11.3					
55	1,028		19.7	2.0	0.8	1.6	11.7	11.8					
65	1,345		23.7	2.4	0.7	1.9	12.6	12.1					
75	0	1,654	0.0	0.0	2.0	4.6	15.1	12.4	6.6	0.0	6.0	1.4	10.7
5	0		0.7	0.1	2.0	4.1	14.3	12.5	5.1	0.7	6.5	1.7	
15	0		1.6	0.2	2.0	3.4	13.3	12.6	3.5	1.4	7.0	2.0	
25	122		4.8	0.5	1.7	3.0	12.9	12.7	2.8	1.7	7.3	2.2	
35	396		9.9	1.0	1.1	2.8	12.8	12.7	2.3	1.9	7.4	2.4	
45	708		14.8	1.5	0.9	2.8	12.9	12.7	2.0	2.0	7.5	2.5	
55	1,028		19.7	2.0	0.8	2.8	13.2	12.7	1.7	2.1	7.5	2.6	
65	1,345		23.7	2.4	0.7	2.9	13.6	12.7	1.5	2.2	7.5	2.7	
75	0	1,654	0.0	0.0	2.0	4.6	15.1	12.7	8.0	2.3	13.5	4.2	12.2

C19.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for ponderosa pine stands in the Rocky Mountain, South

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m³/hectare* ------		------------ *tonnes carbon/hectare* ------------										
0	0.0		0.0	0.0	4.8	0.0	0.0	18.1					
5	0.0		1.8	0.2	4.8	0.2	2.4	18.1					
15	0.0		3.7	0.4	4.8	0.3	6.4	18.6					
25	4.4		9.4	0.9	4.8	0.8	9.8	19.4					
35	16.2		18.6	1.9	2.9	1.5	12.6	20.4					
45	32.2		28.8	2.7	2.1	2.4	14.9	21.4					
55	50.3		38.2	3.0	1.7	3.1	17.0	22.3					
65	69.3		47.1	3.3	1.5	3.9	18.7	23.0					
75	0.0	88.4	0.0	0.0	4.8	9.7	24.1	23.5	14.2	0.0	11.1	2.8	18.5
5	0.0		1.8	0.2	4.8	8.8	22.0	23.6	10.9	1.6	12.2	3.5	
15	0.0		3.7	0.4	4.8	7.1	19.4	23.9	7.5	3.1	13.3	4.2	
25	4.4		9.4	0.9	4.8	6.2	18.3	24.0	6.0	3.7	13.8	4.6	
35	16.2		18.6	1.9	2.9	5.8	18.2	24.1	5.0	4.1	14.1	5.0	
45	32.2		28.8	2.7	2.1	5.8	18.7	24.1	4.3	4.4	14.2	5.3	
55	50.3		38.2	3.0	1.7	5.9	19.4	24.1	3.7	4.6	14.3	5.5	
65	69.3		47.1	3.3	1.5	6.0	20.4	24.1	3.3	4.7	14.4	5.7	
75	0.0	88.4	0.0	0.0	4.8	9.7	24.1	24.1	17.1	4.9	25.5	8.8	21.3

Continued

C19.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft³/acre* --------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	2.0	0.0	0.0	7.3					
5	0		0.7	0.1	2.0	0.1	1.0	7.3					
15	0		1.5	0.1	2.0	0.1	2.6	7.5					
25	63		3.8	0.4	2.0	0.3	4.0	7.9					
35	231		7.5	0.8	1.2	0.6	5.1	8.3					
45	460		11.7	1.1	0.9	1.0	6.0	8.7					
55	719		15.5	1.2	0.7	1.3	6.9	9.0					
65	990		19.1	1.4	0.6	1.6	7.6	9.3					
75	0	1,263	0.0	0.0	2.0	3.9	9.8	9.5	5.8	0.0	4.5	1.2	7.5
5	0		0.7	0.1	2.0	3.5	8.9	9.6	4.4	0.6	4.9	1.4	
15	0		1.5	0.1	2.0	2.9	7.8	9.7	3.0	1.2	5.4	1.7	
25	63		3.8	0.4	2.0	2.5	7.4	9.7	2.4	1.5	5.6	1.9	
35	231		7.5	0.8	1.2	2.4	7.4	9.7	2.0	1.7	5.7	2.0	
45	460		11.7	1.1	0.9	2.3	7.6	9.8	1.7	1.8	5.8	2.1	
55	719		15.5	1.2	0.7	2.4	7.9	9.8	1.5	1.9	5.8	2.2	
65	990		19.1	1.4	0.6	2.4	8.2	9.8	1.3	1.9	5.8	2.3	
75	0	1,263	0.0	0.0	2.0	3.9	9.8	9.8	6.9	2.0	10.3	3.6	8.6

C20.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for loblolly-shortleaf pine stands in the Southeast; volumes are for high productivity sites (growth rate greater than 85 cubic feet wood/acre/year) with high intensity management (replanting with genetically improved stock)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- *m^3/hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.1	0.0	0.0	54.7					
5	0.0		11.0	0.7	4.0	0.4	3.2	54.9					
10	47.7		31.9	1.4	3.8	1.2	5.5	55.4					
15	146.5		67.4	1.9	3.7	2.5	7.3	56.3					
20	244.8		102.3	2.1	3.7	3.8	8.7	57.4					
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	58.7	41.1	0.0	30.3	14.2	22.2
5	0.0		11.0	0.7	4.0	15.9	6.5	60.2	26.9	5.4	35.2	18.3	
10	47.7		31.9	1.4	3.8	12.9	6.4	61.8	19.1	8.0	37.9	20.7	
15	146.5		67.4	1.9	3.7	11.4	7.5	63.3	15.2	9.2	39.3	22.1	
20	244.8		102.3	2.1	3.7	10.5	8.7	64.8	13.2	9.6	39.9	23.0	
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	66.2	53.0	9.9	70.6	37.9	27.3
years	------- *ft^3/acre* --------		------ *tonnes carbon/acre* ------										
0	0		0.0	0.0	1.7	0.0	0.0	22.1					
5	0		4.5	0.3	1.6	0.2	1.3	22.2					
10	682		12.9	0.6	1.6	0.5	2.2	22.4					
15	2,094		27.3	0.8	1.5	1.0	2.9	22.8					
20	3,498		41.4	0.9	1.5	1.5	3.5	23.2					
25	0	4,504	0.0	0.0	1.7	8.3	4.9	23.8	16.6	0.0	12.3	5.8	9.0
5	0		4.5	0.3	1.6	6.4	2.6	24.4	10.9	2.2	14.2	7.4	
10	682		12.9	0.6	1.6	5.2	2.6	25.0	7.7	3.2	15.3	8.4	
15	2,094		27.3	0.8	1.5	4.6	3.0	25.6	6.1	3.7	15.9	8.9	
20	3,498		41.4	0.9	1.5	4.3	3.5	26.2	5.3	3.9	16.2	9.3	
25	0	4,504	0.0	0.0	1.7	8.3	4.9	26.8	21.4	4.0	28.6	15.3	11.0

C21.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-gum-cypress stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m^3/hectare* ------		--- *tonnes carbon/hectare* ---										
0	0.0		0.0	0.0	1.8	0.0	0.0	118.5					
5	0.0		6.7	0.7	1.9	0.4	1.1	118.9					
10	9.8		18.8	1.9	1.8	1.2	2.1	120.1					
15	19.9		28.3	2.4	1.7	1.8	3.0	121.9					
20	32.7		38.0	2.8	1.7	2.4	3.7	124.4					
25	45.4		46.8	3.1	1.6	3.0	4.4	127.2					
30	58.1		54.0	3.4	1.6	3.4	5.0	130.5					
35	73.4		62.3	3.6	1.6	4.0	5.5	133.8					
40	92.2		71.9	3.9	1.6	4.6	6.0	137.2					
45	110.7		80.9	4.2	1.6	5.1	6.4	140.4					
50	0.0	128.1	0.0	0.0	1.8	10.2	6.0	143.5	14.5	0.0	15.5	6.0	53.4
5	0.0		6.7	0.7	1.9	6.2	2.4	146.2	9.4	2.1	17.0	7.5	
10	9.8		18.8	1.9	1.8	4.5	2.4	148.7	6.6	3.1	17.8	8.4	
15	19.9		28.3	2.4	1.7	3.7	3.0	150.7	5.2	3.6	18.3	8.9	
20	32.7		38.0	2.8	1.7	3.5	3.8	152.4	4.4	3.8	18.5	9.3	
25	45.4		46.8	3.1	1.6	3.6	4.4	153.8	3.9	3.9	18.7	9.5	
30	58.1		54.0	3.4	1.6	3.8	5.0	155.0	3.5	4.0	18.8	9.7	
35	73.4		62.3	3.6	1.6	4.2	5.5	155.8	3.2	4.0	18.8	9.9	
40	92.2		71.9	3.9	1.6	4.7	6.0	156.5	3.0	4.1	18.9	10.0	
45	110.7		80.9	4.2	1.6	5.2	6.4	156.9	2.8	4.1	18.9	10.2	
50	0.0	128.1	0.0	0.0	1.8	10.2	6.0	157.3	17.0	4.2	34.4	16.3	53.4

Continued

C21.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft*^{3}*/acre* --------		------------ *tonnes carbon/acre* ------------										
0	0		0.0	0.0	0.7	0.0	0.0	48.0					
5	0		2.7	0.3	0.8	0.2	0.5	48.1					
10	140		7.6	0.8	0.7	0.5	0.9	48.6					
15	284		11.5	1.0	0.7	0.7	1.2	49.3					
20	467		15.4	1.1	0.7	1.0	1.5	50.3					
25	649		18.9	1.3	0.7	1.2	1.8	51.5					
30	830		21.9	1.4	0.7	1.4	2.0	52.8					
35	1,049		25.2	1.5	0.6	1.6	2.2	54.2					
40	1,318		29.1	1.6	0.6	1.9	2.4	55.5					
45	1,582		32.7	1.7	0.6	2.1	2.6	56.8					
50	0	1,830	0.0	0.0	0.7	4.1	2.4	58.1	5.9	0.0	6.3	2.4	21.6
5	0		2.7	0.3	0.8	2.5	1.0	59.2	3.8	0.8	6.9	3.0	
10	140		7.6	0.8	0.7	1.8	1.0	60.2	2.7	1.3	7.2	3.4	
15	284		11.5	1.0	0.7	1.5	1.2	61.0	2.1	1.4	7.4	3.6	
20	467		15.4	1.1	0.7	1.4	1.5	61.7	1.8	1.5	7.5	3.7	
25	649		18.9	1.3	0.7	1.5	1.8	62.3	1.6	1.6	7.6	3.8	
30	830		21.9	1.4	0.7	1.5	2.0	62.7	1.4	1.6	7.6	3.9	
35	1,049		25.2	1.5	0.6	1.7	2.2	63.1	1.3	1.6	7.6	4.0	
40	1,318		29.1	1.6	0.6	1.9	2.4	63.3	1.2	1.6	7.6	4.1	
45	1,582		32.7	1.7	0.6	2.1	2.6	63.5	1.1	1.7	7.7	4.1	
50	0	1,830	0.0	0.0	0.7	4.1	2.4	63.7	6.9	1.7	13.9	6.6	21.6

C22.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3*/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.2	0.0	0.0	33.9					
5	0.0		8.1	0.8	4.2	0.5	1.1	34.1					
10	11.7		21.0	2.1	3.8	1.2	2.1	34.4					
15	21.2		30.3	2.5	3.5	1.8	3.0	34.9					
20	33.8		40.0	2.8	3.3	2.4	3.7	35.6					
25	46.6		49.5	3.0	3.2	2.9	4.4	36.4					
30	60.2		57.5	3.2	3.1	3.4	5.0	37.4					
35	76.3		66.6	3.4	3.0	4.0	5.5	38.3					
40	94.3		76.2	3.6	2.9	4.5	6.0	39.3					
45	114.1		86.4	3.8	2.9	5.1	6.4	40.2					
50	0.0	133.0	0.0	0.0	4.2	10.8	6.0	41.1	15.7	0.0	17.9	6.8	53.7
5	0.0		8.1	0.8	4.2	6.7	2.4	41.9	10.1	2.3	19.5	8.5	
10	11.7		21.0	2.1	3.8	4.8	2.4	42.6	7.0	3.5	20.5	9.4	
15	21.2		30.3	2.5	3.5	3.8	3.0	43.2	5.4	4.0	21.0	10.0	
20	33.8		40.0	2.8	3.3	3.5	3.8	43.7	4.6	4.3	21.2	10.4	
25	46.6		49.5	3.0	3.2	3.6	4.4	44.1	4.0	4.4	21.4	10.6	
30	60.2		57.5	3.2	3.1	3.8	5.0	44.4	3.6	4.5	21.5	10.9	
35	76.3		66.6	3.4	3.0	4.2	5.5	44.6	3.3	4.5	21.6	11.1	
40	94.3		76.2	3.6	2.9	4.6	6.0	44.8	3.0	4.6	21.6	11.2	
45	114.1		86.4	3.8	2.9	5.2	6.4	44.9	2.8	4.6	21.7	11.4	
50	0.0	133.0	0.0	0.0	4.2	10.8	6.0	45.0	18.2	4.6	39.6	18.3	53.7

Continued

C22.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *ft^3/acre* ----------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.7	0.0	0.0	13.7					
5	0		3.3	0.3	1.7	0.2	0.5	13.8					
10	167		8.5	0.8	1.5	0.5	0.9	13.9					
15	303		12.3	1.0	1.4	0.7	1.2	14.1					
20	483		16.2	1.1	1.3	1.0	1.5	14.4					
25	666		20.1	1.2	1.3	1.2	1.8	14.7					
30	860		23.3	1.3	1.3	1.4	2.0	15.1					
35	1,091		26.9	1.4	1.2	1.6	2.2	15.5					
40	1,348		30.8	1.5	1.2	1.8	2.4	15.9					
45	1,630		35.0	1.5	1.2	2.1	2.6	16.3					
50	0	1,901	0.0	0.0	1.7	4.4	2.4	16.6	6.3	0.0	7.3	2.8	21.7
5	0		3.3	0.3	1.7	2.7	1.0	16.9	4.1	0.9	7.9	3.4	
10	167		8.5	0.8	1.5	1.9	1.0	17.2	2.8	1.4	8.3	3.8	
15	303		12.3	1.0	1.4	1.5	1.2	17.5	2.2	1.6	8.5	4.1	
20	483		16.2	1.1	1.3	1.4	1.5	17.7	1.9	1.7	8.6	4.2	
25	666		20.1	1.2	1.3	1.5	1.8	17.8	1.6	1.8	8.6	4.3	
30	860		23.3	1.3	1.3	1.5	2.0	18.0	1.5	1.8	8.7	4.4	
35	1,091		26.9	1.4	1.2	1.7	2.2	18.1	1.3	1.8	8.7	4.5	
40	1,348		30.8	1.5	1.2	1.9	2.4	18.1	1.2	1.8	8.8	4.5	
45	1,630		35.0	1.5	1.2	2.1	2.6	18.2	1.1	1.9	8.8	4.6	
50	0	1,901	0.0	0.0	1.7	4.4	2.4	18.2	7.4	1.9	16.0	7.4	21.7

C23.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-pine stands in the Southeast

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	----- m^3*/hectare* -------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.2	0.0	0.0	46.1					
5	0.0		7.4	0.6	4.1	0.5	3.1	46.2					
10	13.6		19.6	1.2	3.6	1.2	5.1	46.7					
15	27.8		29.3	1.6	3.5	1.9	6.6	47.4					
20	43.9		39.0	1.9	3.4	2.5	7.7	48.3					
25	59.3		46.8	2.1	3.3	3.0	8.5	49.5					
30	77.2		55.4	2.3	3.2	3.5	9.2	50.7					
35	96.8		64.4	2.5	3.2	4.1	9.8	52.0					
40	117.2		73.4	2.7	3.1	4.7	10.2	53.3					
45	136.4		81.6	2.8	3.1	5.2	10.6	54.6					
50	0.0	154.1	0.0	0.0	4.2	11.3	10.3	55.8	19.5	0.0	17.6	7.2	41.4
5	0.0		7.4	0.6	4.1	9.0	5.8	56.8	13.0	2.6	19.6	9.1	
10	13.6		19.6	1.2	3.6	7.7	5.9	57.8	9.4	3.9	20.8	10.2	
15	27.8		29.3	1.6	3.5	6.7	6.8	58.6	7.6	4.5	21.4	10.9	
20	43.9		39.0	1.9	3.4	6.2	7.7	59.2	6.5	4.8	21.7	11.3	
25	59.3		46.8	2.1	3.3	5.8	8.6	59.8	5.9	5.0	21.9	11.6	
30	77.2		55.4	2.3	3.2	5.6	9.2	60.2	5.3	5.1	22.0	11.9	
35	96.8		64.4	2.5	3.2	5.7	9.8	60.6	4.9	5.2	22.1	12.1	
40	117.2		73.4	2.7	3.1	5.9	10.2	60.8	4.5	5.3	22.2	12.3	
45	136.4		81.6	2.8	3.1	6.1	10.6	61.0	4.2	5.3	22.2	12.5	
50	0.0	154.1	0.0	0.0	4.2	11.3	10.3	61.1	23.5	5.4	39.9	19.9	42.1

Continued

C23.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *ft³/acre*	----------	-------------------------------					*tonnes carbon/acre*					-------------------------------
0	0		0.0	0.0	1.7	0.0	0.0	18.6					
5	0		3.0	0.3	1.7	0.2	1.2	18.7					
10	195		7.9	0.5	1.5	0.5	2.1	18.9					
15	397		11.9	0.6	1.4	0.8	2.7	19.2					
20	628		15.8	0.8	1.4	1.0	3.1	19.6					
25	848		19.0	0.8	1.3	1.2	3.5	20.0					
30	1,104		22.4	0.9	1.3	1.4	3.7	20.5					
35	1,384		26.1	1.0	1.3	1.7	4.0	21.0					
40	1,675		29.7	1.1	1.3	1.9	4.1	21.6					
45	1,950		33.0	1.1	1.2	2.1	4.3	22.1					
50	0	2,202	0.0	0.0	1.7	4.6	4.2	22.6	7.9	0.0	7.1	2.9	16.8
5	0		3.0	0.3	1.7	3.6	2.4	23.0	5.3	1.0	7.9	3.7	
10	195		7.9	0.5	1.5	3.1	2.4	23.4	3.8	1.6	8.4	4.1	
15	397		11.9	0.6	1.4	2.7	2.7	23.7	3.1	1.8	8.7	4.4	
20	628		15.8	0.8	1.4	2.5	3.1	24.0	2.6	1.9	8.8	4.6	
25	848		19.0	0.8	1.3	2.3	3.5	24.2	2.4	2.0	8.9	4.7	
30	1,104		22.4	0.9	1.3	2.3	3.7	24.4	2.2	2.1	8.9	4.8	
35	1,384		26.1	1.0	1.3	2.3	4.0	24.5	2.0	2.1	8.9	4.9	
40	1,675		29.7	1.1	1.3	2.4	4.1	24.6	1.8	2.1	9.0	5.0	
45	1,950		33.0	1.1	1.2	2.5	4.3	24.7	1.7	2.2	9.0	5.1	
50	0	2,202	0.0	0.0	1.7	4.6	4.2	24.7	9.5	2.2	16.1	8.1	17.0

C24.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for loblolly-shortleaf pine stands in the South Central; volumes are for high-productivity sites (growth rate greater than 120 cubic feet wood/acre/year) with high-intensity management (replanting with genetically improved stock)

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*----- m^3/hectare -------*		*tonnes carbon/hectare*										
0	0.0		0.0	0.0	4.1	0.0	0.0	31.4					
5	0.0		10.8	0.4	4.1	0.4	3.2	31.5					
10	47.7		34.2	0.9	3.9	1.3	5.5	31.8					
15	146.5		68.7	1.0	3.8	2.7	7.3	32.3					
20	244.8		99.2	1.1	3.7	3.8	8.7	33.0					
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	33.7	39.7	0.0	27.3	15.0	18.8
5	0.0		10.8	0.4	4.1	15.8	6.5	34.6	27.1	4.9	31.4	18.7	
10	47.7		34.2	0.9	3.9	13.0	6.4	35.5	20.1	7.4	33.8	20.9	
15	146.5		68.7	1.0	3.8	11.5	7.5	36.4	16.4	8.5	34.9	22.2	
20	244.8		99.2	1.1	3.7	10.5	8.7	37.2	14.5	9.1	35.5	23.0	
25	0.0	315.2	0.0	0.0	4.1	20.4	12.2	38.0	52.8	9.4	63.2	38.7	23.8
years	*------ ft^3/acre --------*		*tonnes carbon/acre*										
0	0		0.0	0.0	1.7	0.0	0.0	12.7					
5	0		4.4	0.2	1.6	0.2	1.3	12.8					
10	682		13.8	0.3	1.6	0.5	2.2	12.9					
15	2,094		27.8	0.4	1.5	1.1	2.9	13.1					
20	3,498		40.1	0.4	1.5	1.6	3.5	13.3					
25	0	4,504	0.0	0.0	1.7	8.2	4.9	13.7	16.1	0.0	11.1	6.1	7.6
5	0		4.4	0.2	1.6	6.4	2.6	14.0	11.0	2.0	12.7	7.6	
10	682		13.8	0.3	1.6	5.2	2.6	14.4	8.1	3.0	13.7	8.4	
15	2,094		27.8	0.4	1.5	4.6	3.0	14.7	6.7	3.4	14.1	9.0	
20	3,498		40.1	0.4	1.5	4.2	3.5	15.1	5.9	3.7	14.4	9.3	
25	0	4,504	0.0	0.0	1.7	8.2	4.9	15.4	21.4	3.8	25.6	15.7	9.6

C25.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-gum-cypress stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *m^3/hectare* -----		-- *tonnes carbon/hectare* --										
0	0.0		0.0	0.0	1.8	0.0	0.0	39.6					
5	0.0		5.4	0.5	2.1	0.3	1.1	39.7					
10	9.8		17.8	1.8	1.8	1.1	2.1	40.1					
15	19.9		28.4	2.8	1.7	1.8	3.0	40.7					
20	32.7		39.3	3.2	1.7	2.5	3.7	41.5					
25	45.4		48.8	3.4	1.6	3.1	4.4	42.5					
30	58.1		57.2	3.5	1.6	3.6	5.0	43.6					
35	73.4		66.9	3.6	1.6	4.2	5.5	44.7					
40	92.2		76.9	3.7	1.6	4.9	6.0	45.8					
45	110.7		86.1	3.7	1.5	5.4	6.4	46.9					
50	0.0	128.1	0.0	0.0	1.8	10.8	6.0	47.9	14.5	0.0	16.0	6.5	57.0
5	0.0		5.4	0.5	2.1	6.5	2.4	48.8	9.4	2.1	17.5	7.9	
10	9.8		17.8	1.8	1.8	4.6	2.4	49.7	6.6	3.2	18.3	8.8	
15	19.9		28.4	2.8	1.7	3.8	3.0	50.3	5.2	3.7	18.8	9.3	
20	32.7		39.3	3.2	1.7	3.6	3.8	50.9	4.4	3.9	19.0	9.7	
25	45.4		48.8	3.4	1.6	3.7	4.4	51.4	3.9	4.0	19.2	9.9	
30	58.1		57.2	3.5	1.6	4.0	5.0	51.8	3.5	4.1	19.3	10.1	
35	73.4		66.9	3.6	1.6	4.4	5.5	52.0	3.2	4.1	19.3	10.3	
40	92.2		76.9	3.7	1.6	5.0	6.0	52.3	2.9	4.2	19.4	10.4	
45	110.7		86.1	3.7	1.5	5.5	6.4	52.4	2.7	4.2	19.4	10.6	
50	0.0	128.1	0.0	0.0	1.8	10.8	6.0	52.5	17.0	4.3	35.5	17.2	57.0

Continued

C25.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	*ft^3/acre*		*tonnes carbon/acre*										
0	0		0.0	0.0	0.7	0.0	0.0	16.0					
5	0		2.2	0.2	0.8	0.1	0.5	16.1					
10	140		7.2	0.7	0.7	0.5	0.9	16.2					
15	284		11.5	1.1	0.7	0.7	1.2	16.5					
20	467		15.9	1.3	0.7	1.0	1.5	16.8					
25	649		19.7	1.4	0.7	1.2	1.8	17.2					
30	830		23.1	1.4	0.7	1.5	2.0	17.6					
35	1,049		27.1	1.4	0.6	1.7	2.2	18.1					
40	1,318		31.1	1.5	0.6	2.0	2.4	18.5					
45	1,582		34.9	1.5	0.6	2.2	2.6	19.0					
50	0	1,830	0.0	0.0	0.7	4.4	2.4	19.4	5.9	0.0	6.5	2.6	23.1
5	0		2.2	0.2	0.8	2.6	1.0	19.8	3.8	0.8	7.1	3.2	
10	140		7.2	0.7	0.7	1.9	1.0	20.1	2.7	1.3	7.4	3.6	
15	284		11.5	1.1	0.7	1.5	1.2	20.4	2.1	1.5	7.6	3.8	
20	467		15.9	1.3	0.7	1.5	1.5	20.6	1.8	1.6	7.7	3.9	
25	649		19.7	1.4	0.7	1.5	1.8	20.8	1.6	1.6	7.8	4.0	
30	830		23.1	1.4	0.7	1.6	2.0	20.9	1.4	1.7	7.8	4.1	
35	1,049		27.1	1.4	0.6	1.8	2.2	21.1	1.3	1.7	7.8	4.2	
40	1,318		31.1	1.5	0.6	2.0	2.4	21.1	1.2	1.7	7.9	4.2	
45	1,582		34.9	1.5	0.6	2.2	2.6	21.2	1.1	1.7	7.9	4.3	
50	0	1,830	0.0	0.0	0.7	4.4	2.4	21.3	6.9	1.7	14.4	7.0	23.1

C26.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-hickory stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ m^3*/hectare* ------		------ *tonnes carbon/hectare* ------										
0	0.0		0.0	0.0	4.2	0.0	0.0	29.0					
5	0.0		9.7	0.9	4.7	0.6	1.1	29.1					
10	11.7		20.9	1.9	4.0	1.4	2.1	29.4					
15	21.2		30.1	2.1	3.6	2.0	3.0	29.8					
20	33.8		39.5	2.3	3.4	2.6	3.7	30.4					
25	46.6		48.2	2.4	3.3	3.2	4.4	31.1					
30	60.2		56.6	2.6	3.1	3.8	5.0	31.9					
35	76.3		65.6	2.7	3.0	4.4	5.5	32.7					
40	94.3		76.2	2.8	2.9	5.1	6.0	33.5					
45	114.1		85.7	2.9	2.8	5.7	6.4	34.3					
50	0.0	133.0	0.0	0.0	4.2	11.7	6.0	35.1	16.0	0.0	18.9	7.5	49.5
5	0.0		9.7	0.9	4.7	7.3	2.4	35.8	10.0	2.4	20.6	9.2	
10	11.7		20.9	1.9	4.0	5.2	2.4	36.4	6.8	3.6	21.6	10.3	
15	21.2		30.1	2.1	3.6	4.2	3.0	36.9	5.2	4.1	22.1	10.9	
20	33.8		39.5	2.3	3.4	3.9	3.8	37.3	4.4	4.3	22.4	11.2	
25	46.6		48.2	2.4	3.3	3.9	4.4	37.6	3.8	4.4	22.5	11.5	
30	60.2		56.6	2.6	3.1	4.2	5.0	37.9	3.4	4.4	22.7	11.7	
35	76.3		65.6	2.7	3.0	4.6	5.5	38.1	3.1	4.5	22.7	11.9	
40	94.3		76.2	2.8	2.9	5.2	6.0	38.3	2.9	4.5	22.8	12.1	
45	114.1		85.7	2.9	2.8	5.8	6.4	38.4	2.7	4.5	22.8	12.3	
50	0.0	133.0	0.0	0.0	4.2	11.7	6.0	38.5	18.4	4.6	41.8	19.8	49.5

Continued

C26.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- ft^3*/acre* ---------		---------- *tonnes carbon/acre* ----------										
0	0		0.0	0.0	1.7	0.0	0.0	11.7					
5	0		3.9	0.4	1.9	0.3	0.5	11.8					
10	167		8.5	0.8	1.6	0.6	0.9	11.9					
15	303		12.2	0.9	1.5	0.8	1.2	12.1					
20	483		16.0	0.9	1.4	1.1	1.5	12.3					
25	666		19.5	1.0	1.3	1.3	1.8	12.6					
30	860		22.9	1.0	1.3	1.5	2.0	12.9					
35	1,091		26.6	1.1	1.2	1.8	2.2	13.2					
40	1,348		30.8	1.1	1.2	2.0	2.4	13.6					
45	1,630		34.7	1.2	1.2	2.3	2.6	13.9					
50	0	1,901	0.0	0.0	1.7	4.7	2.4	14.2	6.5	0.0	7.6	3.0	20.0
5	0		3.9	0.4	1.9	2.9	1.0	14.5	4.1	1.0	8.3	3.7	
10	167		8.5	0.8	1.6	2.1	1.0	14.7	2.8	1.4	8.8	4.2	
15	303		12.2	0.9	1.5	1.7	1.2	14.9	2.1	1.7	9.0	4.4	
20	483		16.0	0.9	1.4	1.6	1.5	15.1	1.8	1.7	9.1	4.6	
25	666		19.5	1.0	1.3	1.6	1.8	15.2	1.6	1.8	9.1	4.7	
30	860		22.9	1.0	1.3	1.7	2.0	15.3	1.4	1.8	9.2	4.8	
35	1,091		26.6	1.1	1.2	1.9	2.2	15.4	1.3	1.8	9.2	4.8	
40	1,348		30.8	1.1	1.2	2.1	2.4	15.5	1.2	1.8	9.2	4.9	
45	1,630		34.7	1.2	1.2	2.3	2.6	15.5	1.1	1.8	9.2	5.0	
50	0	1,901	0.0	0.0	1.7	4.7	2.4	15.6	7.5	1.9	16.9	8.0	20.0

C27.— Regional estimates of timber volume, carbon stocks, and carbon in harvested wood products on forest land after clearcut harvest for oak-pine stands in the South Central

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------ *m*^{3}*/hectare* ------		---------- *tonnes carbon/hectare* ----------										
0	0.0		0.0	0.0	4.2	0.0	0.0	31.3					
5	0.0		8.7	0.7	4.4	0.6	3.1	31.4					
10	13.6		21.4	1.4	3.7	1.5	5.1	31.7					
15	27.8		31.9	1.7	3.5	2.3	6.6	32.2					
20	43.9		41.8	2.0	3.3	3.0	7.7	32.8					
25	59.3		50.9	2.2	3.2	3.7	8.5	33.6					
30	77.2		59.2	2.5	3.1	4.3	9.2	34.4					
35	96.8		67.9	2.6	3.0	4.9	9.8	35.3					
40	117.2		76.5	2.8	2.9	5.5	10.2	36.2					
45	136.4		84.4	3.0	2.9	6.1	10.6	37.0					
50	0.0	154.1	0.0	0.0	4.2	12.4	10.3	37.9	19.7	0.0	17.4	8.2	42.8
5	0.0		8.7	0.7	4.4	10.0	5.8	38.6	13.2	2.6	19.4	10.1	
10	13.6		21.4	1.4	3.7	8.6	5.9	39.2	9.6	3.9	20.6	11.3	
15	27.8		31.9	1.7	3.5	7.7	6.8	39.8	7.7	4.5	21.2	11.9	
20	43.9		41.8	2.0	3.3	7.1	7.7	40.2	6.7	4.8	21.5	12.4	
25	59.3		50.9	2.2	3.2	6.7	8.6	40.6	6.0	4.9	21.6	12.7	
30	77.2		59.2	2.5	3.1	6.6	9.2	40.9	5.5	5.0	21.8	13.0	
35	96.8		67.9	2.6	3.0	6.7	9.8	41.1	5.1	5.1	21.9	13.2	
40	117.2		76.5	2.8	2.9	6.9	10.2	41.3	4.7	5.2	21.9	13.4	
45	136.4		84.4	3.0	2.9	7.1	10.6	41.4	4.4	5.3	22.0	13.6	
50	0.0	154.1	0.0	0.0	4.2	12.4	10.3	41.5	23.8	5.4	39.4	22.0	43.6

Continued

C27.—Continued

	Mean volume		Mean carbon density										
Age	Inventory	Harvested	Live tree	Standing dead tree	Under-story	Down dead wood	Forest floor	Soil organic	Products in use	In landfills	Emitted with energy capture	Emitted without energy capture	Emitted at harvest
years	------- *ft³/acre* ---------		------------------------ *tonnes carbon/acre* ------------------------										
0	0		0.0	0.0	1.7	0.0	0.0	12.7					
5	0		3.5	0.3	1.8	0.3	1.2	12.7					
10	195		8.6	0.6	1.5	0.6	2.1	12.8					
15	397		12.9	0.7	1.4	0.9	2.7	13.0					
20	628		16.9	0.8	1.3	1.2	3.1	13.3					
25	848		20.6	0.9	1.3	1.5	3.5	13.6					
30	1,104		24.0	1.0	1.2	1.7	3.7	13.9					
35	1,384		27.5	1.1	1.2	2.0	4.0	14.3					
40	1,675		31.0	1.1	1.2	2.2	4.1	14.6					
45	1,950		34.2	1.2	1.2	2.5	4.3	15.0					
50	0	2,202	0.0	0.0	1.7	5.0	4.2	15.3	8.0	0.0	7.0	3.3	17.3
5	0		3.5	0.3	1.8	4.0	2.4	15.6	5.3	1.0	7.9	4.1	
10	195		8.6	0.6	1.5	3.5	2.4	15.9	3.9	1.6	8.3	4.6	
15	397		12.9	0.7	1.4	3.1	2.7	16.1	3.1	1.8	8.6	4.8	
20	628		16.9	0.8	1.3	2.9	3.1	16.3	2.7	1.9	8.7	5.0	
25	848		20.6	0.9	1.3	2.7	3.5	16.4	2.4	2.0	8.8	5.1	
30	1,104		24.0	1.0	1.2	2.7	3.7	16.5	2.2	2.0	8.8	5.3	
35	1,384		27.5	1.1	1.2	2.7	4.0	16.6	2.1	2.1	8.8	5.4	
40	1,675		31.0	1.1	1.2	2.8	4.1	16.7	1.9	2.1	8.9	5.4	
45	1,950		34.2	1.2	1.2	2.9	4.3	16.8	1.8	2.1	8.9	5.5	
50	0	2,202	0.0	0.0	1.7	5.0	4.2	16.8	9.6	2.2	16.0	8.9	17.6

Appendix D

Detailed Information on Development and Use of Tables for Calculating Carbon in Harvested Wood Products (Tables 4 through 9)

This appendix features detailed information on the source of coefficients for Tables 4 through 9. This will help users in adapting carbon calculations to specific needs. Information is organized by the three starting points: primary wood products (Tables D1 through D5), industrial roundwood (principally Tables D6 and D7), and forest ecosystems (principally Tables D8 through D12).

The choice of starting points depends on the available wood products information. For example, a landowner may want to know potential carbon sequestration for a given area of forest. This is addressed by the principally land-based estimate that starts from a measure of trees in a forest, specifically growing-stock volume. Alternatively, a measure of wood removed at harvest, such as logs transported to mills for processing, volume or mass of industrial roundwood, is another starting point. Finally, a starting point with relatively precise information is based on quantities of primary wood products. These latter two starting points can be considered product-based. Data on roundwood and primary products are often available as State-level or regional statistics.

The methods for these three starting points will result in identical core results, if consistent data are available corresponding to the starting points. This is because estimates of the disposition—or fate—of carbon in products over time are based on likely uses and longevity of primary wood products. Thus, the data and assumptions on primary wood products serve as the model for the disposition of carbon over time. These data and assumptions are discussed below in the section on primary wood products. All additional calculations associated with the other two starting points (industrial roundwood or forest ecosystem) are based on linking inputs to the disposition of these primary wood products. If industrial roundwood is the starting point, or input quantity, then the disposition of carbon is calculated by linking carbon in roundwood to the separate primary wood product classifications. Similarly, volume of merchantable wood in forests is linked to quantities of roundwood before calculating the disposition of carbon over time. These links can include some additional output estimates which are not associated with all three starting points, such as the fraction of emitted carbon associated with energy recapture. Data and assumptions used to link the different inputs to a common quantity of harvested wood are presented below in the section on industrial roundwood and the section on forest ecosystem.

Primary Wood Products

Primary wood products are the initial results of processing at mills; examples of primary products include lumber, panels, and paper. These primary products are usually incorporated into end-use products with the long-term disposition of carbon classified as remaining in use, in landfills, or emitted to the atmosphere following burning or decomposition. Calculations are in three parts: 1) converting quantity of primary product to quantity of carbon, 2) determining the fraction of carbon in primary product in use as a function of time since production, and 3) determining the fraction of carbon in primary product in landfills as a function of time since production. These steps correspond to Tables 7, 8, and 9, respectively. Total carbon emissions to the atmosphere for a given year are the difference between the initial quantity of carbon in primary wood products and the sum of carbon in use or in landfills.

Carbon in primary wood products is based on conversion factors in Table 7, which were computed using data in Table D1. Specific carbon content of wood fiber in solid wood products (those in Table D1) is 50 percent, and the carbon content of air dry weight paper is 45 percent. Table D1 includes factors to convert the customary units used for each primary product to a standard mass and volume for calculating carbon mass of the wood fibers.

The fractions of primary wood products remaining in use for a given number of years after production in Table 8 were developed by first allocating the primary product to a number of end-uses and then determining the fraction remaining in each end use over time. The allocation of primary products to end uses is presented in Table D2. The fraction remaining in use over time is determined using first-order decay functions and the half-lives presented in Table D3. The fraction of primary products (and thus the fraction of carbon) remaining in use can be calculated by the following:

[Equation D1]
Fraction of carbon in solid wood products remaining in use in year n
= (fraction used in single family houses) × $e^{(-n \times \ln(2)/\text{ half-life for sf houses})}$
+ (fraction used in multifamily houses) × $e^{(-n \times \ln(2)/\text{ half-life for mf houses})}$
+ (fraction used in mobile homes) × $e^{(-n \times \ln(2)/\text{ half-life mobile homes})}$
+ (fraction used in repair and alteration) × $e^{(-n \times \ln(2)/\text{ half-life repair})}$
+ (fraction used in nonresidential except railroads) × $e^{(-n \times \ln(2)/\text{ half-life non res ex rr})}$
+ (fraction used in railroad ties) × $e^{(-n \times \ln(2)/\text{ half-life rr ties})}$
+ (fraction used in railroad cars) × $e^{(-n \times \ln(2)/\text{ half-life rr cars})}$
+ (fraction used in household furniture) × $e^{(-n \times \ln(2)/\text{ half-life hh furn})}$
+ (fraction used in commercial furniture) × $e^{(-n \times \ln(2)/\text{ half-life com furn})}$
+ (fraction used in other manufacturing) × $e^{(-n \times \ln(2)/\text{ half-life oth manf})}$
+ (fraction used in wood containers) × $e^{(-n \times \ln(2)/\text{ half-life wood cont})}$
+ (fraction used in pallets) × $e^{(-n \times \ln(2)/\text{ half-life pallets})}$
+ (fraction used in dunnage) × $e^{(-n \times \ln(2)/\text{ half-life dunnage})}$
+ (fraction used in other uses) × $e^{(-n \times \ln(2)/\text{ half-life other uses})}$
+ (fraction used in exports) × $e^{(-n \times \ln(2)/\text{ half-life exports})}$

[Equation D2]
Fraction of paper products remaining in use in year n
= $e^{(-n \times \ln(2)/\text{ half-life for paper})}$

The fractions of paper in use, as provided in Table 8, are based on Equation D2 and the assumption that some paper is recycled. To include the effects of recycling in these calculations, the following general assumptions are necessary: an average half-life of paper products, a rate of paper recovery and recycling, and the efficiency of reuse of paper fibers (Skog and Nicholson 1998, Row and Phelps 1996). We use a half-life of 2.6 years, a paper recovery rate of 0.48, and an efficiency of reuse of 0.70.[5]

The difference between a fraction of paper in use calculated by Equation D2 for a particular year and the fraction from the previous year represents the amount of paper discarded during that year.

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[5] Klungness, J. 2005. Personal communication.Chemical Engineer, USDA Forest Service, Forest Products Lab, One Gifford Pinchot Drive, Madison, WI 53726-2398.

We assume that 48 percent of the discarded paper is recycled and 70 percent of the fibers in recycled paper are recovered and incorporated into new paper products. This represents a net recovery of 33.6 percent of fibers from discarded paper. The fraction of these recycled fibers remaining in use in subsequent years also is determined according to Equation D2. This sequence of calculations can be repeated for the fraction of paper discarded each year. Thus, the summed remaining fractions of the original paper and all subsequently recycled fractions are included in Table 8. All these successive calculations pertain to the original paper fibers produced from wood at the beginning of the first year, yet none of the fiber from the original paper production is expected to remain in paper products beyond five rounds of recycling.[5] Therefore, the estimates provided in Table 8 are based on five rounds of recycling, because beyond this point the effects of additional rounds are negligible. Thus, each fiber has the potential to be included in the recycling process up to five times. However, if the fiber is in the 66.4 percent (1- 0.336) of discarded paper that is lost during recycling, there is no potential for additional recycling because it is no longer in the system.

The fractions of primary wood product remaining in landfills for a given number of years after production in Table 9 were developed by determining the fraction discarded to landfills each year and then determining the part of those fractions remaining in landfills over subsequent years. Thus, Table 9 is based on years since production but accounts for both rate of disposal to landfills and cumulative effect of residence times in landfills. Allocation to landfills occurs in two parts: 1) the fraction discarded at year n after production is the difference in the in-use fractions between two successive years from Table 8, that is, fraction at year n minus fraction at year n-1; and 2) the part of the discarded fraction that is placed in landfills is determined by fractions in Table D4 (the fractions for the year 2002). The fraction going to landfills is further divided into nondegradable and degradable pools, which are supplied in Table D5. The nondegradable pool is sequestered permanently. The fraction of the degradable pool remaining in subsequent years is determined by first-order decay, that is, fraction remaining=exp(-years×ln(2)/half-life), and the half-life is shown in Table D5.

Example calculations and applications of selected factors in Tables 7, 8, and 9—disposition from primary wood products

This set of example calculations determines the disposition of carbon in a primary wood product at 3 and 100 years after production. The product for this example is 320,000 ft^2 of ⅜-inch softwood plywood. These calculations are possible with factors from Tables 7, 8, and 9, but this example illustrates the foundation for those factors by using Tables D1 through D5. Note that some of these calculations are spreadsheet-intensive, so we show only enough work to illustrate the basic process.

Specifically, we calculate:

1) Initial quantity of carbon in the primary wood product (Table D1, used to make Table 7)
2) Amount of this carbon in single-family houses at years 3 and 100 (Equation D1 and Tables D2 and D3; this is an applications example)
3) Amount of this carbon in use in all end-use products at years 3 and 100 (Equation D1 and Tables D2 and D3; resulting fractions presented in Table 8)
4) Amount of this carbon in landfills from all end-use products at years 3 and 100 (Tables 8, D4, and D5; resulting fractions presented in Table 9)

Part 1: Initial quantity of carbon, from Table D1:

320,000 ft^2 × 31.25 ft^3/1,000 ft^2 × 35.0 lb/ft^2 × 0.95 = 332,500 lb of wood fiber

332,500 lb × 0.5 × (1 short ton / 2000 lb) = 83.13 tons of carbon

332,500 lb × 0.5 × (1 metric ton / 2204.62 lb) = 75.41 t of carbon

Note this is the only table that includes non-metric units.

Part 2: Amount of softwood plywood carbon in single-family houses at years 3 and 100, from Equation D1 and Tables D2 and D3:

In single-family houses at 3 years

= 75.41 × 0.334 × exp(-3×ln(2)/100) = 24.67 t

In single-family houses at 100 years

= 75.41 × 0.334 × exp(-100×ln(2)/100) = 12.59 t

Part 3: Amount of softwood plywood carbon in use in all end-use products at years 3 and 100, from Equation D1 and Tables D2 and D3:

Amount of carbon in use at 3 years (showing the 15 terms from Equation D1)

= 75.41 × (0.327 + 0.032 + 0.029 + 0.227 + 0.087 + 0.000 + 0.001 + 0.043 + 0.047 + 0.070 + 0.006 + 0.018 + 0.000 + 0.008 + 0.036) = 75.41 × 0.930 = 70.1 t

Amount of carbon in use at 100 years (showing the 15 terms from Equation D1)

= 75.41 × (0.167 + 0.012 + 0.000 + 0.024 + 0.032 + 0.000 + 0.000 + 0.005 + 0.005 + 0.000 + 0.000 + 0.000 + 0.000 + 0.000 + 0.000) = 75.41 × 0.245 = 18.5 t

Note that the sum of terms from equation D1 is the fraction remaining in use at the end of a given year. These fractions are calculated and provided in Table 8, for example the fractions 0.930 and 0.245, which are for years 3 and 100, respectively.

Part 4: Amount of carbon in landfills from all end-use products at years 3 and 100, from Tables 8, D4, and D5:

Note that the amount of carbon in landfills at the end of year 3 is a sum from material discarded in each of the years, that is: from year 1, the nondegradable fraction of carbon discarded in year 1 plus the remaining part of the degradable fraction after two years of decay; from year 2, the nondegradable fraction of carbon discarded in year 2 plus the remaining part of the degradable fraction after one year of decay; and from year 3, the carbon discarded to landfills in year 3.

Coefficients from Table 8 are necessary because the amount discarded each year is based on the difference between the amounts in use at the start and end of each year. By multiplying 75.41 by the first four softwood plywood coefficients in Table 8, we obtain in-use stocks of 75.41, 73.60, 71.79, and 70.13 t carbon, which represent the time of processing (the beginning of year 1) and the ends of years 1, 2, and 3, respectively.

Nondegradable fraction from year 1

= (75.41-73.60) × 0.67 × 0.77 = 0.9337 t

Degradable fraction from year 1 remaining at year 3
= (75.41-73.60) × 0.67 × (1-0.77) × exp(-2×ln(2)/14) = 0.2526 t
Nondegradable fraction from year 2
= (73.60-71.79) × 0.67 × 0.77 = 0.9337 t
Degradable fraction from year 2 remaining at year 3
= (73.60-71.79) × 0.67 × (1-0.77) × exp(-1×ln(2)/14) = 0.2654 t
Nondegradable fraction from year 3
= (71.79-70.13) × 0.67 × 0.77 = 0.8559 t
Degradable fraction from year 3 remaining at year 3
= (71.79-70.13) × 0.67 × (1-0.77) × exp(-0×ln(2)/14) = 0.2557 t

Thus, total carbon in landfills at the end of the third year = 3.5 t.

Note that the fraction of softwood plywood in landfills at the end of year 3 in Table 9 can be determined from the previous series of calculations by changing the first factor in each line to represent the relative amount discarded each year rather than the absolute amount. The calculations are:
Nondegradable fraction from year 1
= (1-0.976) × 0.67 × 0.77 = 0.0124
Degradable fraction from year 1 remaining at year 3
= (1-0.976) × 0.67 × (1-0.77) × exp(-2×ln(2)/14) = 0.0034
Nondegradable fraction from year 2
= (0.976-0.952) × 0.67 × 0.77 = 0.0124
Degradable fraction from year 2 remaining at year 3
= (0.976-0.952) × 0.67 × (1-0.77) × exp(-1×ln(2)/14) = 0.0035
Nondegradable fraction from year 3
= (0.952-0.930) × 0.67 × 0.77 = 0.0114
Degradable fraction from year 3 remaining at year 3
= (0.952-0.930) × 0.67 × (1-0.77) × exp(-0×ln(2)/14) = 0.0034

Thus, total fraction in landfills at year the end of the third year = 0.047. The difference between this value and the 0.046 in Table 9 is due to rounding.

Net flux of carbon to landfills at year 3 is the difference between the previous values and similar calculations for year 2, or more simply from Table 9:

75.41 × (0.046 - 0.032) = 1.06 t in year 3

A similar series of calculations can be repeated for year 100, or more simply from Tables 8 and 9: the amount of carbon in landfills at 100 years = 75.41 × 0.400 = 3.2 t, and the flux of carbon in landfills at 100 years = 75.41 × (0.400-0.394)/5 = 0.09 t in year 100.

Industrial Roundwood

Industrial roundwood is basically harvested logs brought to mills for processing. Roundwood, as used here, refers to wood that is processed to primary wood products; it excludes bark or roundwood that is identified as fuelwood. Input values for calculations from this starting point are carbon mass of roundwood logs grouped by categories defined for Table 6. The links between these inputs and the disposition of carbon in primary wood products are the allocation patterns described in Tables D6 and D7.

Carbon mass of industrial roundwood logs is categorized as softwood or hardwood and saw logs or pulpwood. However, if roundwood data are not classified according to type or size of logs, this appendix includes factors for distributing roundwood to appropriate categories according to regional averages. Additionally, roundwood data in the form of volume of wood can be converted to carbon with average values for specific gravity of softwood or hardwood species. These factors are included in Tables 4 or D8. See additional discussion of their use in the section on Forest Ecosystem.

Average disposition patterns of industrial roundwood carbon by region and roundwood category are presented in Table 6. These values were developed from regional average allocation of industrial roundwood to primary wood products in Table D6. Disposition of carbon allocated to primary wood products then follows the patterns described above by Tables 8 and 9, which allocate carbon to in-use or landfill classifications. The balance of carbon originally in roundwood but no longer in use or in landfills is emitted to the atmosphere. The fraction emitted to the atmosphere that occurs with energy recapture is calculated using Table D7 (Birdsey 1996). These fractions for primary products are pooled within regions to allocate industrial roundwood carbon for up to four categories per region. These fractional values are displayed in Table 6, which is the resulting net effect of linking information in Tables D6, 8, 9, and D7.

Example calculations related to constructing and applying Table 6—disposition from industrial roundwood

This example calculates the disposition of carbon in industrial roundwood. We calculate the disposition of carbon at 15 years after harvest and the processing of 10,000 m^3 of hardwood saw logs from a maple-beech-birch forest in the Northeast. The example demonstrates the basic set of calculations used to develop and apply Table 6. It is limited in scope because factorial combinations of year, roundwood categories, and classifications for the disposition of carbon in harvested wood products can require a sequence of many repeated spreadsheet calculations.

We calculate:

1) Carbon mass based on volume of saw logs
2) The allocation of carbon from saw logs at year 15—the allocation values in Table 6
3) The disposition of carbon—apply the allocation factors from Table 6 to carbon mass from step 1

Part 1: The carbon mass of roundwood can be determined using the volume. The product of volume of roundwood and specific gravity (from Tables 4 or D8) is mass; 50 percent of this is carbon mass. Based on specific gravity from Table 4, total carbon for this example is:

$$= 10{,}000 \times 0.518 \times 0.5 = 2{,}590 \text{ t}$$

Part 2: The allocation of industrial roundwood logs to primary wood products according to region and category are provided in Table D6. The fractions of primary products remaining in use or in landfills at a given year are provided in Tables 8 and 9, respectively. The fraction of emitted carbon associated with energy recapture is from Table D7. The calculations for hardwood saw logs from the Northeast at 15 years are:

Fraction of carbon in products in use (summed products from Table D6 and Table 8)
= (0 × 0.698) + (0.492 × 0.456) + (0 × 0.724) + (0 × 0.799) + ((0.005 + 0.022) × 0.647)
+ (0.038 × 0.420) + (0.058 × 0.040)
= 0 + 0.224 + 0 + 0 + 0.017 + 0.016 + 0.002 = 0.260

Fraction of carbon in landfills (summed products from Table D6 and Table 9)
= (0 × 0.187) + (0.492 × 0.334) + (0 × 0.171) + (0 × 0.124) + ((0.005 + 0.022) × 0.218)
+ (0.038 × 0.357) + (0.058 × 0.253)
= 0 + 0.164 + 0 + 0 + 0.006 + 0.014 + 0.015 = 0.198

Fraction of carbon emitted by year 15 (one minus the fractions in use or in landfills)
= 1 – 0.260 – 0.198 = 0.542
Fraction of carbon emitted with energy recapture (from Table D7)
= 0.542 × 0.6143 × exp(-((15/6812)0.5953)) = 0.324
Fraction of carbon emitted without energy recapture
= 0.542 – 0.324 = 0.218

These fractions allocate the disposition of carbon at year 15 after harvest for hardwood saw logs in the Northeast (see Table 6).

Part 3: The application of the factors from Table 6 (calculated in Step 2) to carbon in industrial roundwood (calculated in Step 1) determines the disposition of carbon at year 15, which is:

In use = 0.260 × 2,590 = 673 t
Landfills = 0.198 × 2,590 = 513 t
Emitted with energy = 0.324 × 2,590 = 839 t
Emitted without energy = 0.218 × 2,590 = 565 t

Forest Ecosystems

Wood in trees in a forest is often characterized according to the total volume of merchantable wood. Merchantable volume can be expressed per unit of forest area; in this case, we use the volume of growing stock of live trees as defined by the USDA Forest Service, Forest Inventory and Analysis Database (FIADB; Alerich and others 2005). Merchantable volume must be linked to amount of roundwood carbon to calculate the expected disposition of carbon in harvested wood products (as described above for industrial roundwood and primary wood products).

A set of regional average factors (Tables D8 through D12) is used for the calculations to transform growing-stock volume to carbon in industrial roundwood, which is then allocated to the expected disposition of carbon in primary wood products. This land-based approach for calculating the disposition of carbon in harvested wood products differs from the previously described product-based approaches in two important respects: the disposition of carbon is expressed as mass per area of forest rather than as an absolute mass, and additional carbon pools must be considered such as ecosystem carbon and carbon removed at harvest but not incorporated into wood products. Calculations can include carbon in roundwood removed as fuelwood as well as carbon in bark on roundwood. Furthermore, estimates of forest carbon at the time of harvest place constraints on quantities harvested. For instance, total carbon mass allocated to harvest, as in Table 3, is calculated from volume but is limited to a portion of live tree biomass.

The starting variable for the forest ecosystem calculation is volume at harvest (for example, 172.1 m^3/ha in Table 3). Carbon in growing-stock volume is allocated to the four categories of roundwood using the factors in Table 4. The first three factors allocate growing stock based on two separate divisions among trees contributing to stand-level growing-stock volume: first, to hardwood or softwood types, and second, to sawtimber diameter- or less-than-sawtimber diameter trees. These factors were developed from the most recent forest inventory data for each State in the FIADB and are summarized according to region and forest type. Data from the FIADB were compiled to reflect types and sizes of trees in stands that are likely to be harvested; thus, trees are classified as growing stock and stands are identified as medium- or large-diameter (Alerich and others 2005). Finally, volumes of wood are converted to carbon mass according to the specific gravity of wood. Values for specific gravity (Jenkins and others 2004) were summarized from the FIADB with the same criteria as the other factors in Table 4. Table D8 contains regional averages for the factors in Table 4. Thus, the product of growing-stock volume and the first, second, and fourth columns of factors (in Tables 4 or D8) is the average dry weight of softwood sawtimber in that growing-stock volume. To convert dry weight to carbon mass, multiply by 0.5.

The next step in the process is to calculate carbon in industrial roundwood from the previously calculated values of carbon in growing-stock volume. The definition of industrial roundwood is the same as elsewhere in this text; as such, it excludes bark and the portion of roundwood identified as fuelwood. Not all roundwood is from growing-stock volume. Similarly, not all of growing-stock volume is removed from the site of harvest as roundwood, some remains as logging residue, for example. Table 5 includes the fraction of growing-stock volume that is removed as roundwood and the ratio of industrial roundwood to growing-stock volume removed as roundwood. These factors are from Johnson (2001) and are also in Tables D9 and D10. The product of carbon in growing-stock volume and these two factors from Table 5 is the mass of carbon in industrial roundwood for each of the roundwood categories.

Fuelwood and bark on roundwood are also carbon pools removed from site at harvest. These are calculated separately because they are not part of the industrial roundwood carbon pool allocated according to Table 6. Fuelwood, as used here, is a portion of total roundwood as defined in Johnson (2001). For the harvest scenario tables (Appendix C), we assume that carbon from these pools is emitted the same year as harvest. Thus, the carbon is added to the two emitted categories at the time of harvest; all of the fuelwood and a portion of the bark on roundwood are emitted with energy capture. Tables 5 and D11 provide ratios of carbon in bark to carbon in wood summarized according to region. The ratios apply to roundwood logs and are based on biomass component equations of Jenkins and others (2003); they are summaries from the FIADB by types and sizes of stem wood and bark in stands that are likely to be harvested (as described above for Table 4). The product of carbon in roundwood and the bark ratio (from Tables 5 or D11) is carbon in bark on roundwood. Fuelwood is estimated from the ratio of fuelwood to growing-stock volume removed as roundwood (Johnson

2001), which is summarized in Tables 5 and D12. Thus, total carbon in fuelwood is the product of carbon in growing-stock volume removed as roundwood, the fuelwood ratio, and one plus the bark ratio.

Ecosystem carbon is removed, emitted, or remains on site at harvest. Thus, total non-soil carbon at the time of harvest in the Appendix C tables (the harvest scenarios) equals the non-soil carbon in the corresponding year of the Appendix B tables (afforestation). Similarly, total non-soil forest ecosystem carbon at the time of harvest in the Appendix C tables (the harvest scenarios) equals the non-soil carbon at age zero of the Appendix A tables (reforestation). The pools of carbon in down dead wood and forest floor at the time of harvest reflect logging residue. These decay over time even as new material accumulates in these pools with stand regrowth (Turner and others 1995, Johnson 2001, Smith and Heath 2002, Smith and others 2004b). The pool of carbon removed at harvest is based on regional average values and calculated as described above. The residual carbon—not on-site or removed—is assigned to the "emitted at harvest" column in Appendix C. While site disturbance associated with harvest likely results in carbon emissions, this pool is also likely to include carbon in wood removed but not classified as roundwood. The use of regional averages to allocate ecosystem and harvested carbon also suggests that values in the final column (in Appendix C) may be larger or smaller, depending on actual forests or harvests. The Appendix C tables are examples of how forest carbon stocks can include carbon in harvested wood; these are not recommendations for rotation length or timing of harvest.

The use of regional fractions or ratios to allocate carbon for a number of forest types within the region has potential for occasional extreme or unrealistic values. That is, the sum of carbon in industrial roundwood, fuelwood, and bark is limited by live tree carbon density. To avoid extreme values, some limits are set for the use of these regional averages. The fuelwood ratios used for calculating the fuelwood components of the harvest scenario tables (Appendix C) are averages by type but not size (that is, columns 3 and 6 in Table D12). We also limit the proportion of live tree carbon allocated to industrial roundwood plus bark to 66 percent, and the limit for total carbon removed (industrial roundwood, bark, and fuelwood) is 78 percent of live tree carbon. These limits are based on generalized tree biomass component equations from Jenkins and others (2003). Calculated values for carbon removed at harvest (such as for Appendix C) seldom exceed these limits, but one of the exceptions is included in the example below.

Example calculations of carbon in harvested wood products for Table 3—disposition from forest ecosystems

This example illustrates the calculations to determine the disposition of carbon in wood products for the harvest scenario tables in Appendix C. We calculate the disposition of carbon at 15 years after harvest from a maple-beech-birch forest in the Northeast (see Table 3). Most of the following example can be completed with factors in Tables 4 through 6 (as opposed to tables in this section), but it is included here because it illustrates the above discussion.

We calculate:

1) Carbon in growing-stock volume according to the industrial roundwood categories (Table 4)
2) Carbon in industrial roundwood from carbon in growing-stock volume removed as roundwood (Table 5)

3) The additional pools of carbon in fuelwood and bark on roundwood, which are assumed emitted with or without energy capture soon after harvest
4) Modifications to totals for industrial roundwood or fuelwood if necessary
5) The disposition of carbon at 15 years after harvest (Table 6)

Part 1: Carbon in growing-stock volume is calculated with the factors in Table 4, which allocates volume to four categories based on wood type and log size. The example growing-stock volume harvested in Table 3 is 172.1 m^3/ha. Three steps are needed to calculate total carbon in growing-stock volume: growing stock is allocated to softwood or hardwood; volumes are partitioned to saw logs and pulpwood; and finally, carbon mass is determined from specific gravity of wood, which is 50 percent carbon by dry weight. Thus, the softwood saw log part of growing stock = (growing-stock volume) × (softwood fraction) × (sawtimber-size fraction) × (softwood specific gravity) × (carbon fraction of wood). The calculated values from growing-stock volume are:

Softwood sawtimber carbon
= 172.1 × 0.132 × 0.604 × 0.369 × 0.5 = 2.53 t/ha
Softwood poletimber carbon
= 172.1 × 0.132 × (1 – 0.604) × 0.369 × 0.5 = 1.66 t/ha
Hardwood sawtimber carbon
= 172.1 × (1 – 0.132) × 0.526 × 0.518 × 0.5 = 20.35 t/ha
Hardwood poletimber carbon
= 172.1 × (1 – 0.132) × (1 – 0.526) × 0.518 × 0.5 = 18.34 t/ha

Total carbon stock in 172.1 m^3/ha of growing-stock volume is 42.88 t/ha.

Part 2: Carbon in roundwood, which excludes bark and fuelwood, is determined from factors in Table 5. The two factors are the fraction of growing-stock volume that is removed as roundwood, and the ratio of total industrial roundwood to growing-stock volume removed as roundwood. The calculated values for industrial roundwood are:

Softwood saw log carbon
= 2.53 × 0.948 × 0.991 = 2.38 t/ha
Softwood pulpwood carbon
= 1.66 × 0. 948 × 3.079 = 4.84 t/ha
Hardwood saw log carbon
= 20.35 × 0.879 × 0.927 = 16.58 t/ha
Hardwood pulpwood carbon
= 18.34 × 0. 879 × 2.177 = 35.09 t/ha

Thus, total carbon in industrial roundwood is 58.90 t/ha.

Part 3: Pools of carbon in bark on roundwood are based on ratios in Table 5; these are also applied to calculate bark on fuelwood. The portion of bark on industrial roundwood allocated to emitted with energy capture is according to coefficient A from Table D7. Carbon in fuelwood is calculated from factors in Table 5. The calculations are:

Softwood saw log bark carbon = 2.38 × 0.182 = 0.43 t/ha
Softwood pulpwood bark carbon = 4.84 × 0. 185 = 0.90 t/ha

Hardwood saw log bark carbon = 16.58 × 0.199 = 3.30 t/ha
Hardwood pulpwood bark carbon = 35.09 × 0. 218 = 7.65 t/ha

Thus, total carbon in bark on industrial roundwood is 12.28 t/ha.

Part of carbon in bark on industrial roundwood emitted with energy capture is
= (0.43 × 0.5582) + (0.90 × 0.6289) + (3.30 × 0.6143) + (7.65 × 0.5272)
= 6.87 t/ha
Part of carbon in bark on industrial roundwood emitted without energy capture is
= 12.28 – 6.87 = 5.41 t/ha

Softwood saw log carbon in fuelwood with bark
= 2.53 × 0.948 × 0.136 × (1 + 0.182) = 0.39 t/ha
Softwood pulpwood carbon in fuelwood with bark
= 1.66 × 0. 948 × 0.136 × (1 + 0.185) = 0.25 t/ha
Hardwood saw log carbon in fuelwood with bark
= 20.35 × 0.879 × 0.547 × (1 + 0.199) = 11.73 t/ha
Hardwood pulpwood carbon in fuelwood with bark
= 18.34 × 0. 879 × 0.547 × (1 + 0.218) = 10.74 t/ha

Thus, total carbon in fuelwood with bark is 23.11 t/ha.

Part 4: Limits are placed on values calculated for industrial roundwood and fuelwood where the regional average factors result in extreme values for some forest types (as discussed above). Based on biomass component equations, total carbon in industrial roundwood with bark is limited to 66 percent of live tree carbon density, and the sum of industrial roundwood, fuelwood, and bark is limited to 78 percent. Live tree carbon density at harvest is 113.1 t/ha (from Table B2).

The sum of industrial roundwood and bark is less than 66 percent of live tree carbon
(58.90 + 12.28) / 113.1 = 0.629

However, the sum of industrial roundwood, fuelwood, and bark is greater than 78 percent of live tree carbon
(58.90 + 12.28 + 23.11) / 113.1 = 0.834

Therefore, the seven carbon pools are reduced by the factor 0.78/0.834=0.935
Industrial roundwood softwood saw log = 2.38 × 0. 935 = 2.22 t/ha
Industrial roundwood softwood pulpwood = 4.84 × 0. 935 = 4.53 t/ha
Industrial roundwood hardwood saw log = 16.58 × 0. 935 = 15.50 t/ha
Industrial roundwood hardwood pulpwood = 35.09 × 0. 935 = 32.81 t/ha

Industrial roundwood bark emitted with energy capture = 6.87 × 0. 935 = 6.42 t/ha
Industrial roundwood bark emitted without energy capture = 5.41 × 0. 935 = 5.06 t/ha

Fuelwood with bark = 23.11 × 0. 935 = 21.61 t/ha

These modified values are used in subsequent calculations and are applied to the harvest scenario tables. Such modifications occur infrequently with the tables presented in Appendix C.

Part 5: The four pools of industrial roundwood carbon are each allocated to the four disposition categories for carbon in wood products according to Table 6. Totals are the summed products of industrial roundwood carbon and allocation at year 15. Carbon in fuelwood and bark are one-time additions to the emitted columns (in Appendix C). Thus the disposition of carbon at year 15 is calculated as:

Total industrial roundwood carbon in use
= (2.22 × 0.326) + (4.53 × 0.037) + (15.50 × 0.260) + (32.81 × 0.252) = 13.19 t/ha
Total industrial roundwood carbon in landfills
= (2.22 × 0.126) + (4.53 × 0.128) + (15.50 × 0.198) + (32.81 × 0.127) = 8.10 t/ha
Total industrial roundwood carbon emitted with energy recapture
= (2.22 × 0.296) + (4.53 × 0.497) + (15.50 × 0.324) + (32.81 × 0.310) = 18.10 t/ha
Total industrial roundwood carbon emitted without energy recapture
= (2.22 × 0.252) + (4.53 × 0.338) + (15.50 × 0.218) + (32.81 × 0.311) = 15.67 t/ha

Total carbon emitted with energy recapture is the sum of industrial roundwood, bark, and fuelwood
= 18.10 + 6.42 + 21.61 = 46.13 t/ha

Total carbon emitted without energy recapture is the sum of industrial roundwood and bark
= 15.67 + 5.06 = 20.73 t/ha

These are the carbon density values for the four harvested wood classifications at 15 years after harvest in Table 3 (that is, 13.2, 8.1, 46.1, and 20.7). The differences between values in this example and those in the table are due to rounding subtotals in this example.

Table D1.—Factors to convert solid wood products in customary units to carbon[a]

Solid wood product	Unit	Cubic feet per unit	Pounds/ cubic foot	Fraction of product that is wood fiber	Factor to convert units to tons (2000 lb) carbon	Factor to convert units to tonnes carbon
Softwood lumber/ laminated veneer lumber/ glulam lumber/ I-joists	thousand board feet	59.17	33.0	1.00	0.488	0.443
Hardwood lumber	thousand board feet	83.33	40.5	1.00	0.844	0.765
Softwood plywood	thousand square feet, 3/8-inch basis	31.25	35.0	0.95	0.260	0.236
Oriented strandboard	thousand square feet, 3/8-inch basis	31.25	40.0	0.97	0.303	0.275
Nonstructural panels (average)	thousand square feet, 3/8- inch basis	31.25	--	--	0.319	0.289
Hardwood veneer/ plywood	thousand square feet, 3/8- inch basis	31.25	42.0	0.96	0.315	0.286
Particleboard / Medium density fiberboard	thousand square feet, 3/4-inch basis	62.50	45.0	0.92	0.647	0.587
Hardboard	thousand square feet, 1/8-inch basis	10.42	60.0	0.97	0.152	0.138
Insulation board	thousand square feet, 1/2-inch basis	41.67	23.5	0.99	0.242	0.220
Other industrial products	thousand cubic feet	1.00	33.0	1.00	8.250	7.484

-- = not applicable.

[a] Factors in the last two columns are calculated by multiplying the previous three columns to provide the mass of product in pounds, the fraction of carbon in wood (assumed to be 0.5), and converting mass to tons or tonnes.

Table D2.—Fraction of solid wood product production used for various end uses in the United States, and used for export, 1998

End use	Product				
	Lumber[a]		Structural panels[b]		Non-structural panels[c]
	Softwood	Hardwood	Softwood plywood	Oriented strandboard	
New residential construction					
Single family	0.332	0.039	0.334	0.578	0.130
Multifamily	0.031	0.004	0.033	0.047	0.019
Mobile homes	0.039	0.002	0.035	0.060	0.037
Residential upkeep and improvement	0.253	0.039	0.243	0.164	0.112
New nonresidential construction					
All except railroads	0.079	0.028	0.090	0.071	0.053
Railroad ties	0.001	0.047	0.000	0.000	0.000
Railcar repair	0.000	0.008	0.001	0.000	0.000
Manufacturing					
Household furniture	0.023	0.235	0.046	0.002	0.138
Commercial furniture	0.004	0.048	0.050	0.006	0.218
Other products	0.035	0.095	0.083	0.021	0.094
Shipping					
Wooden containers	0.006	0.008	0.008	0.000	0.005
Pallets	0.037	0.349	0.025	0.001	0.001
Dunnage etc	0.002	0.007	0.000	0.000	0.000
Other uses[d]	0.126	0.007	0.009	0.041	0.139
Total domestic use	0.967	0.917	0.957	0.991	0.946
Export	0.033	0.083	0.043	0.009	0.054

[a] Includes hardwood and softwood dimension and boards, glulam, and lumber I-joist flanges.

[b] Includes softwood plywood, OSB, structural composite lumber, and I-joist webs.

[c] Includes hardwood plywood, particleboard, medium-density fiberboard, hardboard, and insulation board.

[d] Other uses for lumber and panels include: 1) upkeep and improvement of nonresidential structures, 2) roof supports and other construction in mines, 3) made-at-home projects such as furniture, boats, and picnic tables, 4) made-on-the-job products such as advertising and display structures, and 5) any other uses.

Source: Calculated from tables in McKeever (2002).

Table D3.—Half-life for products by end use

End use or product	Half-life
	years
New residential construction	
Single family	100
Multifamily	70
Mobile homes	12
Residential upkeep and improvement	30
New nonresidential construction	
All except railroads	67
Railroad ties	12
Railcar repair	12
Manufacturing	
Household furniture	30
Commercial furniture	30
Other products	12
Shipping	
Wooden containers	6
Pallets	6
Dunnage etc	6
Other uses for lumber and panels	12
Solid wood exports	12
Paper	2.6

Sources: Skog and Nicholson (1998), Row and Phelps (1996), Klungness, J. 2005. Personal communication. Chemical Engineer, USDA Forest Service, Forest Products Lab, One Gifford Pinchot Drive, Madison, WI 53726-2398.

Table D4.—Fraction of discarded wood and paper placed in landfills

Year	Wood to landfills	Paper to landfills	Year (continued)	Wood to landfills	Paper to landfills
1950	0.05	0.05	1977	0.49	0.38
1951	0.06	0.05	1978	0.55	0.43
1952	0.06	0.06	1979	0.62	0.48
1953	0.07	0.06	1980	0.68	0.52
1954	0.07	0.06	1981	0.69	0.53
1955	0.08	0.06	1982	0.71	0.53
1956	0.08	0.07	1983	0.72	0.53
1957	0.09	0.07	1984	0.73	0.54
1958	0.09	0.07	1985	0.74	0.54
1959	0.10	0.07	1986	0.76	0.54
1960	0.11	0.09	1987	0.77	0.54
1961	0.12	0.09	1988	0.78	0.54
1962	0.13	0.10	1989	0.79	0.54
1963	0.13	0.10	1990	0.74	0.54
1964	0.14	0.11	1991	0.79	0.50
1965	0.15	0.11	1992	0.71	0.48
1966	0.17	0.13	1993	0.70	0.48
1967	0.19	0.15	1994	0.70	0.44
1968	0.22	0.17	1995	0.73	0.39
1969	0.24	0.19	1996	0.71	0.37
1970	0.26	0.21	1997	0.69	0.38
1971	0.29	0.23	1998	0.68	0.39
1972	0.32	0.25	1999	0.68	0.39
1973	0.35	0.27	2000	0.67	0.37
1974	0.37	0.29	2001	0.67	0.35
1975	0.40	0.32	2002	0.67	0.34
1976	0.43	0.34			

Source: Freed, R. 2004. Personal communication. Environmental Scientist, ICF Consulting, 9300 Lee Highway, Fairfax, VA 22031.

Table D5.—Nondegradable fraction of wood and paper in landfills and half-life for degradable fraction

Nondegradable fraction in landfills[a]	
wood	0.77
paper	0.44
Half-life of degradable fraction (yr)[b]	14

[a] Source: Freed, R. and C. Mintz. 2003 (29 Aug). Letter to H. Ferland (EPA), K. Skog (USDA), T. Wirth (EPA) and E. Scheehle (EPA). Revised input data for WOODCARB. On file with: Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398

[b] Source: de Silva Alves and others (2000).

Table D6.—Fraction of each classification of industrial roundwood according to category as allocated to primary wood products (based on data from 2002)[a]

Region	Category[b]		Softwood lumber	Hardwood lumber	Softwood plywood	Hardwood plywood[c]	Oriented strandboard	Non-structural panels	Other industrial products	Wood pulp	Fuel and other emissions
	SW/HW	SL/PW									
Northeast	SW	SL	0.391	0	0.004	0	0	0.020	0.083	0.072	0.431
		PW	0	0	0	0	0.010	0.016	0	0.487	0.487
	HW	SL	0	0.492	0	0.005	0	0.022	0.038	0.058	0.386
		PW	0	0	0	0	0.293	0.007	0	0.350	0.350
North Central	SW	SL	0.378	0	0	0	0	0.049	0.120	0.084	0.370
		PW	0	0	0	0	0.020	0.009	0	0.486	0.486
	HW	SL	0	0.458	0	0.006	0	0.013	0.044	0.064	0.415
		PW	0	0	0	0	0.361	0.009	0	0.315	0.315
Pacific Northwest, East	SW	All	0.422	0	0.069	0	0	0.001	0.001	0.144	0.363
Pacific Northwest, West	SW	SL	0.455	0	0.089	0	0	0.009	0.073	0.114	0.260
		PW	0	0	0	0	0	0	0	0.500	0.500
	HW	All	0	0.160	0	0.140	0	0.002	0	0.229	0.469
Pacific Southwest	SW	All	0.454	0	0	0	0	0.040	0.036	0.145	0.325
Rocky Mountain	SW	All	0.402	0	0.054	0	0	0.033	0.062	0.153	0.296
Southeast	SW	SL	0.350	0	0.076	0	0	0.027	0.054	0.129	0.364
		PW	0	0	0	0	0.103	0.004	0	0.447	0.447
	HW	SL	0	0.455	0	0.006	0	0.049	0.012	0.087	0.391
		PW	0	0	0	0	0.180	0.002	0	0.409	0.409
South Central	SW	SL	0.324	0	0.130	0	0	0.019	0.023	0.133	0.371
		PW	0	0	0	0	0.135	0.006	0	0.430	0.430
	HW	SL	0	0.434	0	0.023	0	0.025	0.003	0.102	0.413
		PW	0	0	0	0	0.160	0.001	0	0.419	0.419
West[d]	HW	All	0	0.039	0	0.301	0	0.015	0.066	0.147	0.432

[a] Data based on Adams and others (2006).

[b] SW/HW=Softwood/Hardwood, SL/PW=Saw log/Pulpwood. Saw log includes veneer logs.

[c] Hardwood plywood fractions are pooled with nonstructural panels when allocating roundwood to the primary products listed in Tables 8 and 9.

[d] West includes hardwoods in Pacific Northwest, East; Pacific Southwest; Rocky Mountain, North; and Rocky Mountain, South.

Table D7.—Coefficients for estimating fraction of emitted carbon associated with energy recapture with emission for industrial roundwood

Region	Roundwood category[a]		Coefficients[b]		
	SW/HW	SL/PW	a	b	c
Northeast	SW	SL	0.5582	2594	0.6557
		PW	0.6289	3062	0.5432
	HW	SL	0.6143	6812	0.5953
		PW	0.5272	3483	0.5364
North Central	SW	SL	0.6728	2162	0.6550
		PW	0.6284	3494	0.5117
	HW	SL	0.6097	5144	0.6236
		PW	0.5243	3399	0.5451
Pacific Northwest, East	SW	All	0.5421	1144	0.7958
Pacific Northwest, West	SW	SL	0.4823	823	0.8561
		PW	0.7040	2376	0.5184
	HW	All	0.6147	4746	0.6306
Pacific Southwest	SW	All	0.5216	1278	0.8061
Rocky Mountain	SW	All	0.7072	992	0.7353
Southeast	SW	SL	0.7149	1313	0.6051
		PW	0.6179	3630	0.5054
	HW	SL	0.5749	4574	0.5954
		PW	0.5490	3731	0.5025
South Central	SW	SL	0.6136	1264	0.6634
		PW	0.6190	3455	0.5148
	HW	SL	0.5744	4541	0.6070
		PW	0.5449	3239	0.5324
West[c]	HW	All	0.5917	6433	0.6054

[a] Applicable to industrial roundwood without bark or fuelwood, which is classified as: SW/HW=Softwood/Hardwood, SL/PW=Saw log/Pulpwood.

[b] Estimates are calculated according to: fraction $=a\times\exp(-((\text{year}/b)^{c}))$, based on proportions in Table 1.7 of Birdsey (1996). We assume that values in the Birdsey (1996) table are that portion of the growing-stock volume harvested and removed from the forest, so that the values are generally accurate when applied to roundwood categories.

[c] West includes hardwoods in Pacific Northwest, East; Pacific Southwest; Rocky Mountain, North; and Rocky Mountain, South.

Table D8.—Average regional factors to calculate carbon in growing-stock volume: softwood fraction, sawtimber-size fraction, and specific gravity[a,b]

Region	Fraction of growing-stock volume that is softwood[c]	Fraction of softwood growing-stock volume that is sawtimber-size[d]	Fraction of hardwood growing-stock volume that is sawtimber-size[d]	Specific gravity[e] of softwoods	Specific gravity[e] of hardwoods
Northeast	0.226	0.647	0.579	0.371	0.518
Northern Lake States	0.292	0.556	0.407	0.360	0.473
Northern Prairie States	0.093	0.622	0.511	0.434	0.537
Pacific Northwest, East	0.980	0.865	0.501	0.396	0.424
Pacific Northwest, West	0.890	0.911	0.538	0.426	0.415
Pacific Southwest	0.829	0.925	0.308	0.399	0.510
Rocky Mountain, North	0.983	0.734	0.442	0.394	0.389
Rocky Mountain, South	0.865	0.742	0.337	0.369	0.353
Southeast	0.423	0.612	0.512	0.462	0.508
South Central	0.358	0.693	0.523	0.463	0.529

[a] These factors correspond to the values in Table 4.

[b] Estimates based on survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program’s database of forest surveys (FIADB; USDA For. Serv. 2005) and include growing-stock on timberland stands classified as medium- or large-diameter stands. Fractions are based on volumes of growing-stock trees.

[c] To calculate fraction in hardwood, subtract fraction in softwood from 1.

[d] Softwood sawtimber are trees at least 22.9 cm (9 in) d.b.h., hardwood sawtimber is at least 27.9 cm (11 in) d.b.h. To calculate fraction in less-than-sawtimber-size trees, subtract fraction in sawtimber from 1. Trees less than sawtimber-size are at least 12.7 cm (5 in) d.b.h.

[e] Average wood specific gravity is the density of wood divided by the density of water based on wood dry mass associated with green tree volume.

Table D9.—Fraction of growing-stock volume that is removed as roundwood and ratio of volume of logging residue to growing-stock volume by region and wood type[a]

Region[b]	Fraction of growing-stock volume removed as roundwood			Ratio of volume of logging residue to growing-stock volume[c]		
	Softwood	Hardwood	All	Softwood	Hardwood	All
Northeast	0.948	0.879	0.901	0.471	0.602	0.560
North Central	0.931	0.831	0.848	0.384	0.441	0.431
Pacific Coast	0.929	0.947	0.930	0.133	0.081	0.131
Rocky Mountain	0.907	0.755	0.899	0.305	0.246	0.301
South	0.891	0.752	0.840	0.090	0.254	0.149

[a] Values and classifications are based on data in Tables 2.9, 3.9, 4.9, 5.9, and 6.9 of Johnson (2001).

[b] North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[c] Ratios used as part of estimates of down dead wood following harvest in Appendix A and C.

Table D10.—Ratios of industrial roundwood (without fuelwood) to growing-stock volume that is removed as roundwood by category[a]

Region[c]	Industrial roundwood:growing-stock volume removed as hardwood[b]					
	Softwood			Hardwood		
	Sawtimber-size	Less than sawtimber-size	All	Sawtimber-size	Less than sawtimber-size	All
Northeast	0.991	3.079	1.253	0.927	2.177	1.076
North Central	0.985	1.285	1.077	0.960	1.387	1.071
Pacific Coast	0.965	1.099	1.005	0.721	0.324	0.606
Rocky Mountain	0.994	2.413	1.089	0.832	1.336	0.862
South	0.990	1.246	1.047	0.832	1.191	0.933

[a] Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[b] Ratios are to calculate industrial roundwood (that is, without fuelwood) and are based on volumes. The denominators are portions of growing-stock volume removed as roundwood according to wood type and size. Numerators for “less than sawtimber-size” include poletimber and nongrowing-stock sources. We assume the ratios do not include bark and use these values as a step in determining the allocation of carbon for Table 5 and Appendix C, based on growing stock.

[c] North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

Table D11.—Regional average ratios of carbon in bark to carbon in wood according to wood type and size

Region[b]	Ratio of carbon in bark to carbon in wood[a]					
	Softwood[c]			Hardwood[d]		
	Sawtimber-size[e]	Poletimber-size[e]	All	Sawtimber-size	Poletimber-size	All
Northeast	0.182	0.185	0.183	0.199	0.218	0.205
North Central	0.182	0.185	0.183	0.199	0.218	0.206
Pacific Coast	0.181	0.185	0.181	0.197	0.219	0.203
Rocky Mountain	0.181	0.185	0.182	0.201	0.219	0.210
South	0.182	0.185	0.183	0.198	0.218	0.204

[a] Ratios are calculated from carbon mass based on biomass component equations in Jenkins and others (2003) applied to all live trees identified as growing stock on timberland stands classified as medium- or large-diameter stands in the survey data for the conterminous United States from USDA Forest Service, Forest Inventory and Analysis Program's database of forest surveys (FIADB; USDA For. Serv. 2005, Alerich and others 2005). Note that "sawtimber trees" and "poletimber trees" are not stand-level classifications as used here; these terms apply to individual trees. Carbon mass is calculated for boles from stump to 4-inch top, outside diameter.

[b] North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

[c] Softwood sawtimber-size are trees at least 22.9 cm (9 in) d.b.h., and softwood poletimber-size trees are 12.7 to 22.6 cm (5.0 to 8.9 in) d.b.h.

[d] Hardwood sawtimber-size is at least 27.9 cm (11 in) d.b.h., and hardwood poletimber-size trees are 12.7 to 27.7 cm (5.0 to 10.9 in) d.b.h.

[e] When applying these ratios to roundwood, we assume that ratios based on sawtimber-size trees and ratios based on poletimber-size trees in the forest apply to saw log roundwood and pulpwood roundwood, respectively.

Table D12.—Ratios of total fuelwood (both growing-stock and nongrowing-stock sources) to corresponding portion of growing-stock volume that is removed as roundwood[a]

Region[c]	Fuelwood:growing-stock volume removed as hardwood[b]					
	Softwood			Hardwood		
	Sawtimber-size	Less than sawtimber-size	All	Sawtimber-size	Less than sawtimber-size	All
Northeast	0.009	1.017	0.136	0.073	4.051	0.547
North Central	0.015	0.180	0.066	0.040	1.230	0.348
Pacific Coast	0.035	0.242	0.096	0.279	2.627	0.957
Rocky Mountain	0.006	3.145	0.217	0.168	50.200	3.165
South	0.010	0.049	0.019	0.168	0.644	0.301

[a] Values and classifications are based on data in Tables 2.2, 3.2, 4.2, 5.2, and 6.2 of Johnson (2001).

[b] Ratios are to calculate fuelwood and are based on volumes. The denominators are portions of growing-stock volume removed as roundwood according to size. Numerators for “less than sawtimber-size” include poletimber and nongrowing-stock sources. We assume the ratios do not include bark and use these values as a step in determining the allocation of carbon for Table 5 and Appendix C, based on growing stock.

[c] North Central includes the Northern Prairie States and the Northern Lake States; Pacific Coast includes the Pacific Northwest (West and East) and the Pacific Southwest; Rocky Mountain includes Rocky Mountain, North and South; and South includes the Southeast and South Central.

Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. **Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States.** Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.

This study presents techniques for calculating average net annual additions to carbon in forests and in forest products. Forest ecosystem carbon yield tables, representing stand-level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested forest products are included. Although these calculations are simple and inexpensive to use, the uncertainty of results obtained by using representative average values may be high relative to other techniques that use site- or project-specific data. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. The CD-ROM included with this publication contains a complete set of tables in spreadsheet format.

Keywords: forest carbon sequestration project, harvested wood carbon, carbon yield tables, stock change, voluntary reporting

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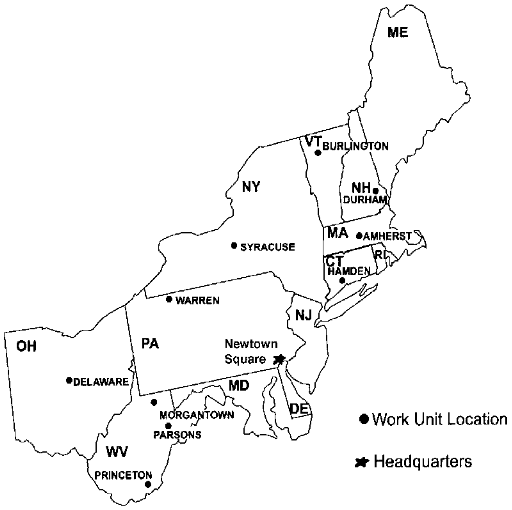

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

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Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

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Attachment 6

Estimating the Present Value of Carbon Sequestration in U.S. Forests, 2015–2050, for Evaluating Federal Climate Change Mitigation Policies

Robert G. Haight, Randall Bluffstone, Jeffrey D. Kline, John W. Coulston, David N. Wear, and Kate Zook

Abstract

We demonstrate an application evaluating carbon sequestration benefits from federal policy alternatives. Using detailed forest inventory data, we projected carbon sequestration outcomes in the coterminous 48 states for a baseline scenario and three policy scenarios through 2050. Alternatives included (1) reducing deforestation from development, (2) afforestation in the eastern United States and reforestation in the western United States, and (3) reducing stand-replacing wildfires. We used social cost of carbon estimates to evaluate the present value of carbon sequestration benefits gained with each policy. Results suggest that afforestation and reforestation would provide the greatest marginal increase in carbon benefit, far exceeding policy cost.

Key Words: afforestation, carbon sequestration, climate change mitigation and adaptation, land-use change, reforestation

JEL Classifications: Q5, Q51, Q54, Q57, Q58

Introduction

Policy making often depends on sound analysis of policy alternatives to evaluate likely outcomes. Given an array of policy questions concerning ecosystem services, and climate change mitigation and adaptation, federal forest policy makers and managers need relevant and timely economic metrics and analyses for evaluating policy alternatives using the best data and methods currently available (e.g., Kline et al. 2013). Although developing

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Robert G. Haight, Research Forester, USDA Forest Service, Northern Research Station, St. Paul, MN, USA. Randall Bluffstone, Professor of Economics and Director, Institute for Economics and the Environment, Portland State University, Portland, OR, USA. Jeffrey D. Kline, Research Forester, USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR, USA. John W. Coulston, Supervisory Research Forester, USDA Forest Service, Southern Research Station, Asheville, NC, USA. David N. Wear, Former Project Leader, USDA Forest Service, Southern Research Station, Research Triangle Park, NC, USA. Kate Zook, Program Analyst, USDA Office of Chief Economist, Washington, DC, USA. *Correspondence: Jeffrey D. Kline, USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, USA, Email: jeff.kline@usda.gov*

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sound economic analysis and valuation methodologies is a necessary first step in this process, it is also important to demonstrate whether existing data and methods permit conducting applied analysis of policy questions given staffing and other resources at hand. In line with U.S. Department of Agriculture (USDA) workshop objectives to “explore new methods, data, and approaches to valuing ecosystem services and applying the results to Federal programs and policies” (https://www.fs.fed.us/esv2019/), our focus in this article is to demonstrate applied analysis of USDA policy alternatives focused on increasing carbon sequestration in U.S. forests, to support policy analysis and program development.

Forests of the United States sequester significant amounts of atmospheric carbon. According to the 2017 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. Environmental Protection Agency 2017), 272 million hectares of forest land in the coterminous 48 states and southeast and south-central Alaska sequestered 571.1 Tg CO_2eq through forest growth in 2015 alone. This amount equaled 8.7% of total U.S. carbon emissions that year (6,586.7 Tg CO_2eq). Should the United States opt to implement a domestic greenhouse gas reduction strategy, improvements in forest management and increases in forest land are likely to play prominent roles in any cost-effective policy portfolio (Jackson and Schlesinger 2004; Lubowski, Plantinga, and Stavins 2006). Proposed USDA programs seeking to improve forest sequestration include using financial and other incentives to protect private forest land from development, increase afforestation of marginal agricultural lands, and improve the management of nonindustrial forest lands (Lewandrowski et al. 2004; McKinley et al. 2011). The degree to which policy alternatives such as these would lead to significant increases in carbon sequestration has been of significant policy interest, leading to a significant body of research examining carbon sequestration potential is the United States with a focus on interactions between policy, prices, land-use change, and other factors (e.g., Alig et al. 1997, 2010; Adams et al. 1999; Stavins 1999; Newell and Stavins 2000; Lewandrowski et al. 2004; Murray et al. 2005; Lubowski, Plantinga, and Stavins 2006; Latta et al. 2016).

In this article, we focus on demonstrating how existing data and models, based on this body of previous research, can be used to conduct routine policy analysis to support USDA policy and program development and applications. Rates of forest carbon sequestration are forecast to slow in coming decades because of forest aging, disturbance, and overall reductions in forest land because of development (Wear and Coulston 2015). These uncertainties point to a continued need for economic evaluation of policy alternatives currently under consideration to facilitate further development and implementation of strategies for sequestering and mitigating greenhouse gases in the United States. For such analysis to be routinely incorporated into policy decisions, it must be of sufficient conceptual and methodological rigor to reasonably address key factors in land-use and carbon interactions and dynamics, while allowing for timely development of applications by USDA staff that meet the needs of policy makers.

With these objectives in mind, we estimated the amount of additional carbon sequestration, as well as the dollar value of associated carbon benefits, likely to result from policy alternatives included in the proposed USDA programs. Specifically, we use existing data and models to project national-level estimates of forest carbon sequestration and its value for the period 2015–2050, for a baseline scenario representing business as usual, and for three policy scenarios: (1) a land-use policy to reduce deforestation from development; (2) an afforestation policy targeting rural landowners in the eastern United States and a reforestation policy targeting understocked federal forest lands in the western United States; and (3) a policy reducing stand-replacing fire events by 10%. For each policy scenario, we first developed forecasts of increased carbon sequestration projected to result from implementation of each policy alternative. We then estimated the dollar value of the increased carbon sequestration using estimates of the social cost of carbon (SCC), which is the present value of monetized damages associated with an additional ton of carbon dioxide emissions. Finally, we compared our estimates of carbon sequestration benefits with rough estimates of the likely costs of implementing each policy alternative examined. A diagram of our modeling framework is shown in Figure 1, using an afforestation/reforestation program as an example.

We used models of forest dynamics and land-use change to forecast our national-level estimates of forest carbon stocks and fluxes. These models were previously developed by Coulston, Wear, and Vose (2015) and Wear and Coulston (2015) for *The U.S. Forest Carbon Accounting Framework* (Woodall et al. 2015). The models were subsequently used for the *2016 Second Biennial Report of the United States of America, Under the United Nations Framework Convention on Climate Change* (U.S. Department of State 2016) to forecast forest carbon stocks and sequestration as part of an assessment of U.S. programs to meet 2025 carbon emissions targets. The forest dynamics module includes a stage-structured model of forest growth by forest type, combined with carbon stock models that estimate eight different carbon pools: down dead wood, forest floor, live trees aboveground, live trees belowground, standing dead wood, soil organic carbon, understory vegetation aboveground, and understory vegetation belowground. These models account for disturbances, including harvesting, wind, wildfire, and flooding. The land-use dynamics module was used to assess carbon stock transfers to and from forest land associated with afforestation and deforestation. The forecasting models project the forest stage distribution and carbon sequestration by forest type at the state and regional levels starting with 2015 forest stage distributions estimated from USDA Forest Inventory and Analysis (FIA) plots. The key feature of our approach is that the initial carbon stock and parameters of the forecasting models are estimated from observations of forest attributes in FIA inventory plots throughout the United States during the period 1990–2015 (Woodall et al. 2015).

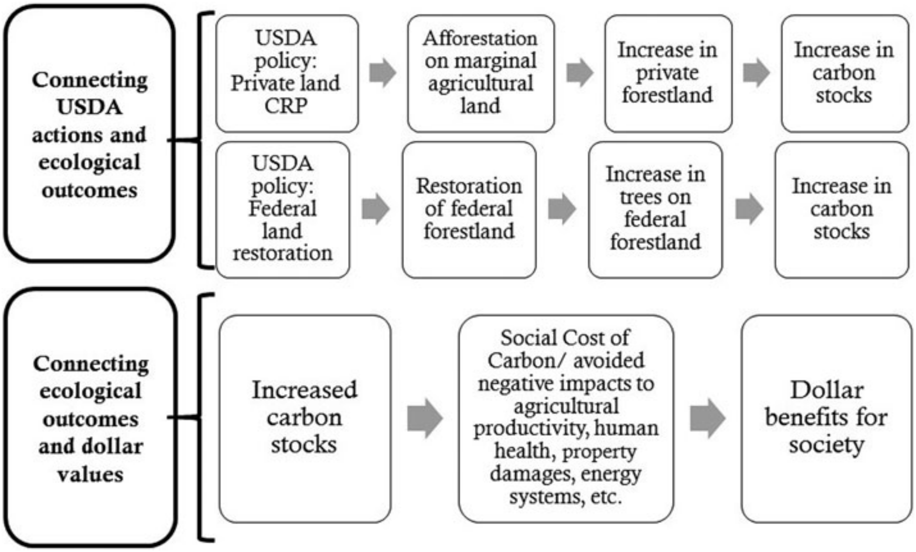

Figure 1. Conceptual Diagram Connecting Actions, Ecological Outcomes, and Dollar Values

Note: CRP, Conservation Reserve Program; USDA, U.S. Department of Agriculture.

For comparison, carbon sequestration in the U.S. forest sector more typically has been forecast using structural dynamic economic models that allow price endogenous forest management and land-use choices (e.g., Adams et al. 1999; Sohngen and Mendelsohn 2003; Latta et al. 2013; Tian et al. 2018). In these models, future harvest levels, replanting rates, and intensity of replanting are determined to maximize the present value of consumer and producer surplus subject to forest age class dynamics. Carbon stocks in forest and wood products pools are computed from the forest age structure and harvest levels that result from optimization. These models simulate the impacts of alternative policies on carbon sequestration (e.g., Tian et al. 2018) or determine policies that minimize the social cost of achieving a desired level of sequestration (e.g., Adams et al. 1999). A key feature of these models is that they allow for carbon stocks to be an outcome of endogenous forest management and land-use decisions, which in turn depend on endogenous prices. However, their resulting aggregate forecasts of forest conditions may not be as precise as forecasts based on observations of individual plots. Moreover, such models require estimation of many additional economic parameters. Our alternative approach thus takes advantage of the additional information provided by individual FIA plots, while avoiding the necessity of developing estimates of additional economic parameters.

Additionally, economists have long called for developing dollar estimates (or pricing) of carbon to reflect the social damages associated with the adverse impacts resulting from carbon dioxide emissions on the global climate (see Aldy et al. [2010] for a review). For policy makers, estimates of this SCC can be used to monetize the benefits of reduced carbon emissions associated with incremental investments in climate change mitigation programs. Comparing the dollar value of carbon emission abatement to likely mitigation program costs enables policy makers to determine which proposed programs are likely to yield net benefits to society. However, estimating the SCC can involve contentious issues, including how to evaluate adverse climate impacts, extreme climate risks, and intergenerational discounting (Aldy et al. 2010). To address these issues, the U.S. government tasked an Interagency Working Group on the Social Cost of Carbon with developing a transparent and economically rigorous way to value reductions in CO_2 emissions resulting from federal programs (Greenstone, Kopits, and Wolverton 2013). These estimates have been integrated into the evaluation of rules and programs (those with costs or benefits above $100 million in any given year) across several federal agencies (Greenstone, Kopits, and Wolverton 2013). We used these estimates to develop our dollar value estimates of likely program benefits resulting from increased carbon sequestration in U.S. forests.

Policies that increase carbon sequestration on forest lands or the expansion of private forest lands via afforestation would likely influence the provision of other valued ecosystem services, including water quality, habitat for terrestrial and aquatic species, and timber, to name a few. In particular, increasing carbon sequestration potentially would increase the provision of complementary ecosystem services and decrease competitive services (e.g., Englin and Callaway 1995; Kline et al. 2016). Although enhancing valued ecosystem services has long been a goal of USDA policies and programs (e.g., Claassen et al. 2001), we do not address associated changes in other ecosystem services and instead focus on a key component of an overall climate change strategy: increasing forest carbon sequestration to mitigate climate change.

We begin with an overview of the estimates of the SCC. Then, we describe the two primary tasks needed to evaluate the benefits of increased carbon sequestration associated with changes in USDA policy: (1) projecting forest carbon stocks and fluxes over time for the baseline and alternative policy scenarios, and (2) estimating the value per ton of carbon sequestered over time. We present the results of our analysis followed by a discussion of caveats. Finally, we present our conclusions.

The Social Cost of Carbon

Carbon sequestration on U.S. forest land is valuable because carbon that would otherwise be emitted into the atmosphere as CO_2 is instead trapped in living trees, thereby mitigating climate change and its damages. Reducing or avoiding the economic damages associated with carbon emissions are key economic benefits of carbon sequestered in forests. Because the value of carbon sequestration involves avoided social costs, the unit value of a ton of carbon dioxide sequestered is typically referred to as the SCC and is measured in dollars (e.g., U.S. dollars per ton of CO_2 sequestered).

Economists typically use integrated climate-economy simulation models—called integrated assessment models—to estimate the SCC. Three of the more commonly used models are the dynamic integrated climate economy (DICE) model (Nordhaus 1992); the climate framework for uncertainty, negotiation and distribution (FUND) model (Tol 1999); and the policy analysis of the greenhouse effect (PAGE) model (Hope, Anderson, and Wenman 1993). Each model estimates the SCC for a given year of a defined time horizon while accounting for likely damages to agricultural productivity, human health, and property, as well as ecosystem services, at spatial scales ranging from regional to global. According to convention, the SCC in any given time period during which carbon is emitted is a nominal value that measures the economic cost of future damages discounted to that period. Estimating the SCC therefore requires the selection of a discount rate that reflects societal impatience and the effect of output growth over time (Arrow et al. 2014).

In 2009, the U.S. government convened an interagency working group to estimate the SCC over time (Greenstone, Kopits, and Wolverton 2013). The working group assumed a global perspective and estimated the SCC using the three major integrated assessment models, three discount rates, and five socioeconomic scenarios. Focusing on a global SCC was deemed appropriate, because climate change is, of course, a global problem. Perhaps for this reason, in its report recommending revisions to SCC estimation methodologies, the National Academies of Sciences, Engineering, and Medicine (2017) does not recommend using a country-specific SCC. Indeed, it finds that even defining a country-level SCC would be very difficult.

One recommendation of the National Academies of Sciences, Engineering, and Medicine (2017) is to use a more theoretically motivated discount rate based on the so-called Ramsey formula (Ramsey 1928) that is amended to take into account uncertainties in future capital productivity and potential linkages between productivity and climate change.[1] This recommendation is in contrast to the discount rate sensitivity analysis approach used by the interagency working group. As discussed by Arrow et al. (2014) and elsewhere, if implemented, this revision would imply a declining discount rate as a function of time and almost assuredly a lower average discount rate than the 3% preferred scenario discount rate discussed subsequently and used in this article.

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[1] Moore and Diaz (2015) found that including feedbacks from climate change into capital productivity and GDP increases the estimated global SCC from $33 to about $220 per ton of CO_2. Ricke et al. (2018) also found much higher global SCC estimates than those used in this article—specifically, a median of $417 per ton, which is almost an order of magnitude greater than the estimates from the interagency working group.

The interagency working group recognized that projections of Earth's average surface temperature increase associated with a doubling of CO_2 concentrations in the atmosphere are highly uncertain and modeled this uncertainty with an appropriate probability distribution. Because this climate sensitivity parameter was modeled probabilistically, the group used stochastic simulation to produce a distribution of SCC values for each year to 2050. This exercise produced 45 separate distributions of the SCC for a given year—one for each model, discount rate, and socioeconomic scenario.

To produce a range of plausible estimates, the distributions from each of the models and socioeconomic scenarios were weighed equally and combined to produce three separate probability distributions for the SCC in a given year, one for each of the three discount rates. The average of each distribution was taken as the point estimate of the SCC. For example, the nominal 2010 SCC was $21 per additional ton of CO_2 emitted measured in 2007 U.S. dollars and computed with a 3% discount rate. The SCC estimates were revised in 2013 and again in 2015 using updated versions of the DICE, PAGE, and FUND models.

For our calculations, we used estimates of the SCC from the 2015 interagency working group report (U.S. Interagency Working Group on Social Cost of Carbon 2015). Columns 2–4 of Table 1 show the estimates of the nominal, average SCC (2016 U.S. dollars per ton of CO_2 sequestered) over time for discount rates from 5%, 3%, and 2.5%. The SCC estimates increase over time because CO_2 concentrations in the atmosphere are expected to rise, and higher concentrations imply greater damages from each additional ton emitted. Because sequestering carbon in the future mitigates more damages than sequestration in the present, the estimated value of sequestering CO_2 increases over time. Column 5 of Table 1 uses the 95th percentile of the distribution of SCC estimates and a 3% discount rate. This scenario shows what would happen to the SCC if the climate-changing effects of CO_2 emissions turn out to be much stronger than expected. In this SCC scenario, economic damages are larger and SCC estimates are three times greater than average estimates for a 3% discount rate.

Estimates for the SCC have been made in other countries, and most are higher than the U.S. values. Table 2 presents estimates over four time frames for select Organization for Economic Cooperation and Development countries reported as "carbon values" in Smith and Braathen (2015). This table is for evaluation of public policies, but values (typically lower than in Table 2) are reported (though not for the United States) for transportation, energy, and other investments. Ricke et al. (2018) estimate country-level SCCs along with global figures and find that India has the highest SCC at $86 per ton of CO_2 and the United States is second at $48 per ton.

Quantifying and Projecting Forest Carbon

We start by estimating current (2015) carbon stocks and flux for the 264 million hectares of forest land in the coterminous 48 states. Our estimates

Table 1. Nominal Social Cost of Carbon (SCC) Estimates (2016 U.S. dollars per ton of CO_2 sequestered)

	Average Annual Discount Rate			
Year	**5%**	**3%**	**2.5%**	**3% Discount Rate and 95th Percentile of the SCC Distribution**
2015	$13	$42	$65	$121
2020	$14	$49	$72	$142
2025	$16	$53	$79	$160
2030	$19	$58	$84	$176
2035	$21	$64	$90	$194
2040	$24	$69	$97	$212
2045	$27	$74	$103	$228
2050	$30	$80	$110	$245

Source: U.S. Interagency Working Group on Social Cost of Carbon (2015). SCC estimates from the interagency working group were reported in 2017 U.S. dollars. We inflated those values to 2016 U.S. dollars using the consumer price index from the Bureau of Labor Statistics.

Table 2. Carbon Values per Ton of CO_2eq (2014 U.S. dollars) for Ex Ante Evaluations of Public Policies

Country	**2014**	**2020**	**2030**	**2050**
Canada	39	46	56	77
France	53	N/A	133	319
Germany	133	159	206	365
Ireland	24	52	N/A	N/A
United Kingdom	95	105	122	348
United States	41	48	57	78

Source: Smith and Braathen (2015).

rely on empirical data from the USDA Forest Service's FIA Program (Woodall et al. 2015). These data include measurements of live and dead trees, dead wood, forest litter, understory vegetation, and soils in more than 350,000 permanent plots across the coterminous 48 states. From these data, carbon densities (mg/ha) were predicted in each plot for eight carbon pools (live trees aboveground, live trees belowground, standing dead wood, down dead wood, forest floor, soil organic carbon, understory vegetation aboveground, and understory vegetation belowground) using models of the 2017 national greenhouse gas inventory (U.S. Environmental Protection Agency 2017). The

Figure 2. Carbon Assessment Regions

carbon stock and annual carbon flux in year 2015 are 332,000 Tg CO_2eq and 480 Tg CO_2eq/yr., respectively (Woodall et al. 2015). The carbon flux in year 2015 is 16% less than the carbon flux (571.1 Tg CO^2/yr.) reported in the 2017 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. Environmental Protection Agency 2017). In contrast to the 2017 inventory, we excluded Alaska from our projections and do not count the current transfer of soil carbon into the forest land base because of afforestation.

Our models for projecting forest carbon were developed by Coulston, Wear, and Vose (2015) and Wear and Coulston (2015). We projected forest carbon stocks and fluxes over a 35-year horizon (2015–2050). Forest carbon flux results from the net effects of carbon accumulations and emissions of standing forests, emissions from disturbances (e.g., fire, insects, weather, and harvest), and conversions of forest land to and from other uses. The largest share (~85%) of carbon flux occurs in standing forests, where carbon accumulation has long exceeded emissions from disturbances. Land-use changes generally result in concurrent gains or losses in forest area, with net gains accruing in the United States over the past 20 years (Oswalt et al. 2014).

To project forest carbon in the coterminous 48 states, we divided forest land into four regions—Pacific Coast, Rocky Mountain, North, and South (Figure 2). We modeled change in forest carbon in each region as the sum of the forest growth component, including disturbances, and a land conversion component. The projection models differ in the western and eastern United States because of differences in the intensity of permanent plot sampling.

Western Projection Model

In the western regions (Pacific Coast and Rocky Mountain) where forest sampling is less intense and repeated measures of forest plots are not available, we modeled carbon flux using a stage class model of forest population growth. We quantified and predicted changes in forest carbon at the state level except in California, Oregon, and Washington where we separated the states into areas on the western and eastern sides of the Cascade mountain divide because of vast differences in forest productivity. For each state/substate, we queried the FIA inventory for all plot records and stratified them by stage class i and forest type j. Each stage was defined by a 5-year age class (from age 1–5 to greater than age 200) for each of 27 forest types. From the plot records, we estimated the initial area (ha) F_{ij0} and carbon density (mg/ha) D_{ij} of each stage and forest type. The estimate of current forest carbon for state/substates is the sum of the products of forest area and carbon density across stages and forest types:

$$C_0 = \sum_{i,j} F_{ij0} D_{ij} \tag{1}$$

We projected forest carbon in each state/substate using a stage-class model of forest dynamics. Given parameters p_{ij} for the proportion of stage i forest type j that moves up one stage; d_{ij} for the proportion of stage i and type j that is subject to stand-replacing disturbance by fire, insects, weather, or harvest; and L_{ijt} for the area of land of stage i forest type j in period t that conversions to or from forest land use during projection interval t, the stage class model for each forest type is as follows:

$$F_{1jt+1} = F_{1jt} - F_{1jt} p_{1j} + \sum_{i=1}^{n} F_{ijt} d_{ij} + L_{1jt} \tag{2}$$

$$F_{ijt+1} = F_{ijt} - F_{ijt}(p_{ij} + d_{ij}) + F_{i-1jt} p_{i-1j} + L_{ijt} \qquad i = 2, \ldots, n-1 \tag{3}$$

$$F_{njt+1} = F_{njt} - F_{njt} d_{ij} + F_{n-1jt} p_{n-1j} + L_{njt} \tag{4}$$

for periods $t = 0,\ldots,T - 1$. Equation (1) updates the area in of the youngest stage by subtracting the proportion of area that moves up one stage, adding all of the disturbed area across the forest, and adding the net change in forest land use (positive for net additions, negative for net subtractions). Equation (2) subtracts the areas that either move up one stage or are subject to stand-replacing disturbance, adds the area that moves up from the younger stage, and adds net change in forest land use. Equation (3) accumulates area in the oldest stage while accounting for changes because of disturbance and land use of the oldest stage. Given these dynamics, the time-sequence of total forest carbon for the state/substate is the following:

$$C_{t+1} = \sum_{ij} F_{ijt+1} D_{ij} \qquad t = 0, \ldots, T-1 \tag{5}$$

Table 3. Disturbance Levels by Region and Disturbance Type

	Disturbance Percent			
Region	**Cutting**	**Fire**	**Insect and Disease**	**Weather**
North	7.0	0.5	4.4	3.3
South	12.7	3.4	1.3	2.1
Rocky Mountain	1.9	3.9	9.6	1.0
Pacific Coast	8.2	3.7	10.3	1.9

Simulations proceeded by applying equations (2) to (5) over the T-period horizon. Then, change in forest carbon during period t is as follows:

$$\Delta C_{t+1} = C_{t+1} - C_t \qquad t = 0, \ldots, T-1 \tag{6}$$

To apply the model, we made several assumptions about its parameter values. The average historical stand-replacing disturbance rate d_{ij} was obtained by dividing the area of forest of type j currently in the youngest stage, F_{1j0}, by total forest area, $\sum_{ij} F_{ij0}$. Assuming that the recent disturbance pattern leading to forest replacement carries into the future, we divided this average disturbance rate equally across stages. Note that d_{ij} includes all events that reset the forest to the youngest stage including fire, weather, insects, and harvesting. We also estimated the average annual disturbance rate (percent of forest area) for each type of disturbance (Table 3). For example 8.2% of the forest area in the Pacific Coast region had some amount of forest cutting. Then, the harvested forest carbon was transferred to a durable forest product carbon pool, and the change in forest carbon associated with the harvested portion of disturbance was adjusted to account for carbon storage in wood products. From a subset of plots with repeated observations, we observed that not all of the plots moved up one stage every 5 years. Therefore, we defined a stage transition rate p_{ij} of 0.85 for all stages. The values of L_{ijt}, $t = 1$, ..., T are defined for a set of projection scenarios (described subsequently). For net gains in forest area, we assumed that new forest is added to the youngest stage; for losses, we removed forest area proportionately across stages. We assumed that carbon density associated with each land-use conversion $L_{ijt}$is limited to the soil organic carbon pool. Separate simulations were constructed for each of the 18 state/substate units, and results were summarized for Pacific Coast and Rocky Mountain regions.

Eastern Projection Model

The projection models for the two eastern regions (North and South in Figure 2) are based on estimates of land use and forest stage transitions obtained from remeasured, permanent inventory plots in those regions. For each region, remeasured plots were grouped according to seven land-use change and disturbance classes: undisturbed forest remaining as undisturbed forest, nonforest to forest conversion, forest to nonforest conversion, cut forest remaining as forest, forest remaining as forest disturbed by fire, forest remaining as forest disturbed by weather, and forest remaining as forest disturbed by insects and diseases. Plots were not grouped by forest type, so we drop the index j. For each land-use and disturbance class (indexed by k), the observed transitions of plot conditions were used to estimate forest stage transitions p_{ik}, forest disturbance proportions d_{ik}, carbon density change by age class δD_{ik}, and land conversions L_{ik0}.

The primary disturbance in the east was cutting, where 12.7% and 7.0% of the forest area in the South and North, respectively, experiences some level of forest cutting over the remeasurement period (Table 3). Given assumptions about future land conversions (see the next section), L_{ikt}, $t = 1, \ldots, T-1$, these parameters were used to update the forest age distribution, F_{ikt} $t = 0, \ldots, T-1$, for each disturbance class k using equations (2)–(4), and then compute the carbon flux for each region:

$$\Delta C_{t+1} = \sum_{ik} F_{ikt+1} \delta D_{ik} \qquad t = 0, \ldots, T-1 \tag{7}$$

Projection Scenarios

We projected carbon sequestration in each region under a baseline scenario and three alternative policy scenarios that are structured in an additive fashion (Table 4). The baseline scenario anticipates the elimination of net gains in forest area by 2025, followed by a slight decline in forest area through 2050, and represents assumptions developed for the 2016 U.S. biennial report (U.S. Department of Agriculture 2016).

The first policy scenario—reduced development—assumes that land-use policies are implemented to reduce development intensities in future years, resulting in no net loss of forest area beginning in 2025. Current USDA projections anticipate increasing land development in response to a growing U.S. population and economy resulting in a net decline in forest area over the coming decades (e.g., USDA 2016), and so this policy alternative anticipates countering that trend.

The second policy scenario—afforestation and reforestation—assumes that landowner incentives can be implemented to encourage afforestation of private land in the eastern United States and funding is provided for reforestation of understocked federal forest land in the western United States, along with implementation of land-use policies to reduce development as described in the first policy scenario. In the eastern United States, the Conservation Reserve Program (CRP) currently funds the retirement of

Table 4. Definition of the Baseline and Policy Scenarios Used to Estimate the Present Value of the Increase in Forest Carbon Sequestration

	Scenario Components		
Scenario Label	**Land-Use Scenario**[a]	**Afforestation + Restoration Program**	**Fire Mitigation Program**
Baseline	USDA-BR reference		
Reduced development	USDA-BR low development		
Afforestation/ reforestation	USDA-BR low development	Yes	
Fire mitigation	USDA-BR low development	Yes	Yes

[a] Land-use scenarios are from the 2016 U.S. biennial report by the U.S. Department of Agriculture (2016).
Note: See text for explanation of scenario components.

private marginal cropland to support conservation efforts, and the cap on program size has reached as high as 14.9 million hectares. In this second policy scenario, we assume in the eastern United States that a CRP-like program compensates landowners for establishing trees on 12.1 million hectares of marginal cropland between 2015 and 2020. Currently, in the western United States, 5.3 million hectares of forest land remains persistently understocked, of which 3.7 million hectares is federal forest land. We assumed that funding is provided for reforestation of 80% (3.0 million hectares) of the understocked federal forest land between 2015 and 2020.

The third policy scenario—wildfire mitigation—assumes a 10% reduction in the area of stand-replacing wildfires throughout the United States, along with the land-use and afforestation and reforestation policies. Wildfire causes significant releases of carbon and lateral transfer of carbon among pools followed by recapture of carbon by growing forests. Wildfire, therefore, is an important consideration in any overall carbon sequestration strategy.

Estimating the Value of Forest Carbon Sequestration

We estimated the present value (PV) of forest carbon sequestration associated with the baseline and three alternative policy scenarios in Table 4. The increase in PV under each of the three policy scenarios relative to the baseline scenario is an estimate of the dollar value of carbon sequestration under each policy scenario. Because the policy scenarios are structured in an additive fashion, we also report estimates of the incremental changes in the PV of each additional policy component. In this way, our analysis assumes that the effects of each policy component are strictly additive—that land-use policies would have the same incremental carbon sequestration effect if implemented on their own as if implemented along with an afforestation and reforestation policy, for example.

To compute the PV of the stream of carbon sequestration benefits under any one of the three alternative policy scenarios relative to a baseline scenario, we needed three sets of parameter values. Let ΔC_t^b and ΔC_t^p be the Tg CO_2eq sequestered in period t for the baseline and policy scenarios (based on equations 6 and 7, for the western and eastern regions). Let SCC_t be the social cost of carbon ($ per ton CO_2) in period t, which is the discounted value of the annual damage caused by 1 metric ton of CO_2 released in period t, summed over the expected number of years that the unit of CO_2 is present in the atmosphere, and discounted to period t. Let i be the discount rate used to discount the nominal values of SCC back to the base year $t = 0$. Then, the PVs of the baseline and policy scenarios (in millions of dollars), computed over a T-period planning horizon, are as follows:

$$PV^b = \sum_{t=1}^{T} \frac{SCC_t \Delta C_t^b}{(1+i)^t}$$

$$PV^p = \sum_{t=1}^{T} \frac{SCC_t \Delta C_t^p}{(1+i)^t}$$

The difference, $PV^p - PV^b$, is our estimate of the additional value of carbon sequestered under each policy scenario. This difference in PV assumes that the activities and resulting carbon sequestration in the policy scenario are additive, reducing atmospheric CO_2 beyond what would occur without the policy.

Further, we assumed that activities to promote carbon sequestration in the policy scenario do not affect activities and carbon emissions in other sectors (i.e., no leakage). For example, leakage occurs when afforestation policy converts marginal agricultural land to forest but simultaneously results in the conversion of forest to agriculture in other areas (beyond the amount specified by the transition probabilities) to make up for portions of the afforested agricultural land. When our assumption of no leakage is violated, our estimate of the difference, $PV^p - PV^b$, is an overstatement of the value of the policy to promote forest carbon sequestration. We note that we have not considered the costs of implementing and administering any of the alternative policies considered; we are only valuing the benefits of carbon sequestration and will consider the implications of this approach in our later discussion.

We computed the PVs of the baseline and three alternative policy scenarios (Table 4) using projections of annual carbon sequestration (Tg CO_2eq/yr., 2015–2050). For each of the reference and policy scenarios in Table 4, we made four PV calculations using the four SCC scenarios in Table 1. First, for each SCC scenario, we computed annual SCC levels ($/t CO_2) for the years 2015–2050 by interpolating between the SCC estimates for the 5-year intervals in Table 1. We then multiplied the projections of annual carbon sequestration and SCC together, discounted each product to the base year, and summed to get total PV (in millions of dollars).

Results

Forest Carbon Projections

Our results project annual carbon sequestration for the baseline scenario to decline from 480 Tg CO_2eq/yr. in 2015 to 323 Tg CO_2eq/yr. by 2050, largely because of the combination and interaction among forest aging, forest disturbance, and land-use change (Figure 3). This projected decline is projected in all four regions of the United States. Projections indicate that carbon sequestration by 2050 would be 85% of 2015 levels in the North, 65% of 2015 levels in the South, and 68% of 2015 levels in the Pacific Coast region. Sequestration in the Rocky Mountain region is projected to decline to near zero by 2030 and is slightly negative thereafter, suggesting that forests in this region become sources of carbon emissions because of disturbances such as wildfire and insect infestations. Nationally, projections suggest that 80% or more of baseline carbon sequestration would occur in the eastern U.S. forests.

Our projections indicate that implementing land-use policies to reduce development (resulting in no net loss in forest area beginning 2025) would increase the annual rate of forest carbon sequestration in all four regions relative to the baseline scenario (Figure 3). The largest gains in annual sequestration rates relative to the baseline would occur in the Rocky Mountain region, at 10–40 Tg CO_2eq/yr. after 2025. These gains in the Rocky Mountain region keep the region from going to a net source of CO_2 emissions beyond 2030 (which is the case under the reference scenario). In 2050, the sum of the annual sequestration rates across all four regions would increase from 323 Tg CO_2eq/yr. in the baseline scenario to 362 Tg CO_2eq/yr. in the reduced development scenario. Despite these projected regional gains in sequestration relative to the baseline, nationwide annual carbon sequestration under the reduced development is projected to decline throughout the United States over the time period examined.

Policy intervention to increase afforestation and reforestation, in addition to the policy to reduce development, would greatly increase annual carbon sequestration relative to the baseline scenario. By 2050, total annual sequestration would increase from 323 Tg CO_2eq/yr. in the baseline scenario to 469 Tg CO_2eq/yr. in the afforestation and reforestation scenario (Figure 3). Gains in sequestration would occur in all four regions, with the largest gains in the South (25–75 Tg CO_2eq/yr.) after 2030. This result would largely mitigate nationwide losses in annual sequestration projected under the baseline scenario.

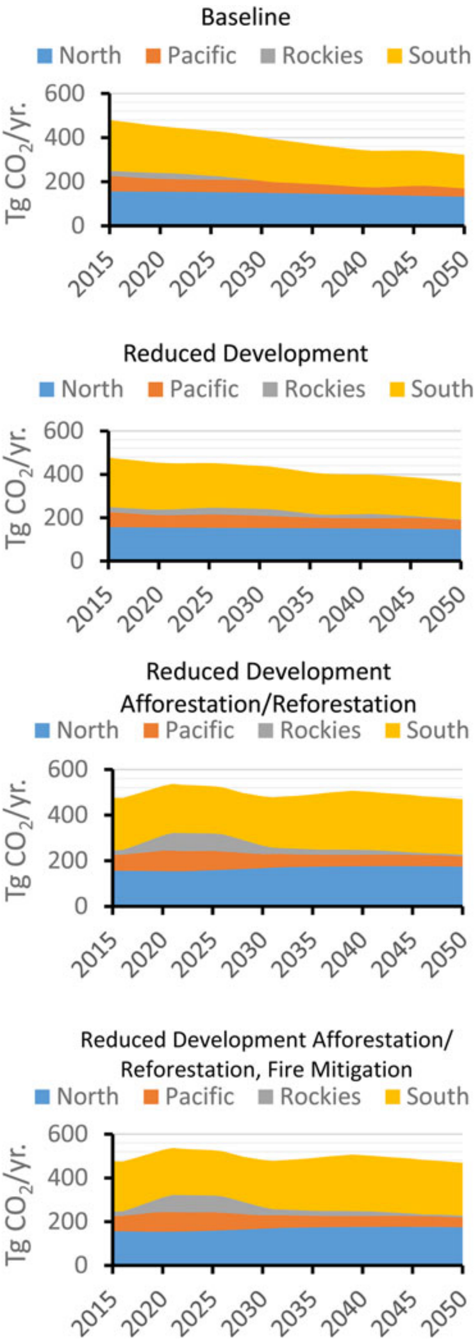

Figure 3. Projected Annual Forest Carbon Sequestration in Regions of the Coterminous 48 States

Policy intervention to mitigate wildfire, in addition to policies to reduce development and increase afforestation and reforestation, were projected to have relatively minor effects on annual carbon sequestration (Figure 3). Projected effects were greatest in the Pacific Coast and Rocky Mountain regions, where average annual sequestration rates would increase by 7–11 Tg CO_2eq/yr. over the horizon.

The Value of Forest Carbon Sequestration

Our results concerning the dollar value of carbon sequestration suggest that under the baseline scenario, sequestration in U.S. forests over a 35-year horizon (2015–2050) would have a very high PV (Table 4). Further, changes in USDA policy to boost forest carbon sequestration would also have very high value (Table 5 and Figure 4).

Under the baseline scenario, in which net gains in forest area in the next decade fade into a decline in forest area through 2050, forest carbon sequestration values would range from $125.5 billion (5% discount rate) to more than $1,551 billion at a 95th percentile of the probability distribution of SCC (3% discount rate) (Table 5). Although these forest carbon sequestration values are high, they are not unreasonable on a per hectare basis. Using a 3% discount rate, the PV of carbon sequestration in the years 2015 to 2050 is $517.3 billion, which is $1,959 per hectare over the 264 million hectares of forest land in the 48 coterminous states. These values suggest that, at a minimum, maintaining current forest policy has a clear value to society, especially when projections estimate declines in forest land and carbon sequestration over the next several decades.

The carbon sequestration values resulting from the reduced development scenario range from $134 billion (5% discount rate) to $555.4 billion (3% discount rate), to $1,668 billion at a 95th percentile scenario discounted at 3% (Table 5). Implementing policies to protect forest land from development would result in an increase in net PV over the baseline scenario of about $38 billion (3% discount rate) (Figure 4). Although all four regions exhibit gains in PV, most of the gain (54%) occurs in the Rocky Mountain region, where annual carbon sequestration would increase 10–40 Tg CO_2eq/yr. relative to the baseline scenario following 2025. These results suggest that there would be significant social gains in using policy to minimize adverse development effects on forests over the next 35 years.

The policy scenario advancing afforestation in the eastern United States and reforestation in the western United States, in addition to reducing development, would result in a carbon sequestration value of $649 billion (3% discount rate) (Table 5) with an increase in PV over the reference scenario of $131.6 billion and an increase in PV over the reduced-development scenario of $93.6 billion (Figure 4). The biggest gains in PV (58%) would occur in the eastern United States, where 12.1 million hectares of currently unforested rural land would be converted to forest cover. Gains in the PV from reforesting more than 3

Table 5. Present Value (billions of dollars) of Projected Annual CO_2eq Sequestered in U.S. Forests from 2015 to 2050 under Alternative Policy and Social Cost of Carbon (SCC) Scenarios

	SCC Scenario			
Policy Scenario	**5%**	**3%**	**2.5%**	**3% and 95th Percentile**
Baseline	125.5	517.3	806.7	1,551.8
Reduced development	134.0	555.4	866.8	1,668.0
Afforestation/reforestation	155.4	649.0	1,013.9	1,951.4
Fire mitigation	158.0	660.1	1,031.4	1,985.0

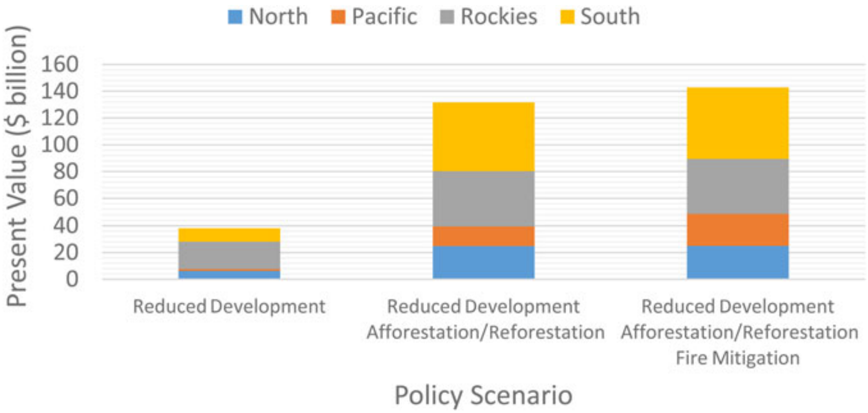

Figure 4. Increase in Present Value (billions of dollars) of Each Policy Scenario Relative to the Baseline Scenario (discount rate = 3%).

million hectares of forest land in the western United States would be almost as large as gains in the east, because boosts in carbon sequestration from reforestation would occur earlier in the time horizon of analysis (Figure 3). The afforestation and reforestation policy would yield the greatest marginal increase in PV ($93.6 billion), suggesting that there would be high social gains to increasing USDA policy emphasis on afforestation of marginal agricultural lands in the eastern United States and reforestation of currently understocked forest lands in the western United States.

To help put the projected increase in carbon sequestration benefits resulting from the afforestation and reforestation scenario into perspective, we computed an approximate cost of implementing such a policy using data describing the actual costs of tree-planting projects proposed by individual national forests in the western United States during the 2017 fiscal year (USDA Forest

Service National Forest Systems' National Reforestation and Nurseries Program). These costs varied, for example, depending on the seedling costs for each species to be planted, project size (number of hectares), access to the planting site, and contract labor costs. The average project cost for the western national forests was $1,178 per hectare. Assuming that this average project cost represents typical reforestation costs throughout the western United States, the cost of a program to reforest 3.0 million hectares of understocked federal forest land would be about $3.5 billion. Assuming that a government subsidy of $247 per hectare paid to private landowners would induce afforestation of 12.1 million hectares of other rural lands in the eastern United States (Lubowski, Plantinga, and Stavins 2006), we estimated that the cost of the afforestation program would be about $3.0 billion. Under these assumptions, the total cost of the afforestation and reforestation policy ($6.5 billion) is a fraction (0.07) of the marginal increase in carbon benefit ($93.6 billion) relative to the reduced development policy.

The wildfire mitigation scenario, which assumes a 10% reduction in the area of stand-replacing wildfires throughout the United States in addition to the policies to reduce development and increase afforestation and reforestation, would have a PV of $660 billion (3% discount rate) (Table 5), for a gain in PV relative to the baseline scenario of $142.8 billion (Figure 4). Although the projected gain in PV relative to the baseline scenario is highest of all of the scenarios we examined, the marginal gain from adding wildfire mitigation to the afforestation and reforestation scenario is relatively small ($11.1 billion), suggesting that wildfire mitigation alone would not yield significant benefits toward the goal of carbon sequestration. Most of the marginal gain in PV from wildfire mitigation (80%) would occur in the Pacific Coast region.

To help put the marginal gain in carbon benefits from wildfire mitigation ($11.1 billion) in perspective, we computed a rough estimate of the cost of attaining a 10% reduction in the area of stand-replacing wildfire in the United States (see also Sohngen and Haynes 1997). Federal appropriations for wildfire management, including preparedness, suppression, hazardous fuels reduction, and rehabilitation activities at the USDA Forest Service and Department of Interior averaged $3.3 billion per year for FY2011–FY2015 (Hoover and Bracmort 2015). On average, 29% ($0.966 billion) of this annual funding was for preparedness to support fire prevention and detection, equipment purchase, and personnel training, and10% ($0.327 billion) was for hazardous fuel reduction on federal lands to make fires less intense and more controllable. Assuming that a 10% increase in the annual preparedness and fuel reduction appropriations ($0.129 billion) results in a 10% reduction in the annual area of stand-replacing wildfire, then the discounted (3% discount rate) annual cost of this fire mitigation policy over the period 2015–2050 is $2.855 billion, which is 26% of the marginal increase in carbon benefit ($11.1 billion). These estimates are consistent with those produced by Sohngen and Haynes (1997) in their pioneering analysis.

Caveats Associated with the Analysis

Cobenefits

Our analysis estimated changes in carbon sequestration rates and their monetized values resulting from hypothetical USDA policies and did not address potential changes to other valued ecosystem services that would potentially result from changes in carbon sequestration or other alternative policy effects. These changes could involve either enhancement or impairment of water quality, habitat for terrestrial and aquatic species, and resource outputs, including timber and wood fiber, among many others. Regional analysis of forest management effects on carbon sequestration suggest that increased sequestration can be associated with both increases in some ecosystem services and decreases in others (e.g., Seidl et al. 2007; Schwenk et al. 2012; Kline et al. 2016). In analysis from the United States, for example, Schwenk et al. (2012) found in their Vermont study that forest management prescriptions that increased carbon sequestration also resulted in reduced timber harvest. Kline et al. (2016) found in western Oregon that forest management alternatives that increased carbon sequestration led to increases in species favoring late successional forest conditions, decreases in species favoring more open conditions, and highly variable responses for species that depend on particular spatial patterns of key ecological conditions, such as edge contrast involving tree heights.

Similarly, afforestation also can affect a range of other ecosystem services, both positively and negatively. For example, McKinley et al. (2011) suggested that although afforestation of agricultural lands and grasslands generally improves water quality, it can reduce water quantity (e.g., streamflow) when trees uptake more water than crops or grass cover. Plantinga and Wu (2003) found that conversion of agricultural lands to forest via afforestation programs reduces negative externalities associated with agricultural land, such as soil erosion, and improves wildlife habitat roughly commensurate with the costs of administering such programs. Afforestation cobenefits, including species diversity, generally are enhanced where seedlings are established on lands that historically were tree covered, with the greatest improvements to wildlife habitat and biodiversity arising from plantings of native species (McKinley et al. 2011).

Although the potential cobenefits and costs associated with complementary and competitive ecosystem services undoubtedly should be an important consideration in evaluating the efficacy of proposed USDA efforts to increase carbon sequestration, we elected not to attempt to address such effects largely because of the complexity of doing so at a national scale. We feel that such effects are likely to be highly variable across regions and localities, as well as across the spatial and temporal scales of analysis. For these reasons, we suspect that evaluating potential cobenefits (and costs) associated with changes in other ecosystem services may be more feasible at the regional scales or at individual national forest levels. Alternatively, opportunities may exist to draw on existing national-level analysis of other ecosystem services to augment our analysis of carbon sequestration.

Policy Costs

Our analysis considered only rough estimates of the costs associated with the policies and program alternatives that define our scenarios. Ideally, a more detailed accounting of the costs would be included in any analysis of the efficacy of policy and program options, such as would be accomplished in a cost-benefit analysis (e.g., Mishan and Quah 2007). Such an analysis would be necessary to determine whether the net gains in carbon sequestration resulting from the policy and programmatic scenarios examined are worth the investment necessary to achieve those gains.

One thing to consider when thinking about likely policy costs is that our baseline scenario itself is the result of an array of policies, programs, and market forces that have affected changes in land use and forest cover in the several decades leading up to the present. These factors have exerted influence at a variety of spatial scales and via various administrative or jurisdictional authorities. For example, land use—and thus the amount of forest land—can be influenced by federal, state, and local policies, which all carry their own costs borne by the entities that enforce those policies. Similarly, how forests are managed can be influenced by local, regional, and international market forces. Although a full accounting of the costs and benefits of any given policy change to increase carbon sequestration necessarily would focus on the costs of implementing the policy and expected incremental gains in sequestration, it is important to remember that current levels of sequestration are at least partly because of past investments in various policies and programs that have, for example, incentivized landowners to retain land in forest and to manage it in a particular way.

Forest Carbon Projections

There are several uncertainties associated with our forest carbon sequestration projections that are common to all similar studies, including sample error, measurement error, modeling error, and error in the future state (Coulston, Wear, and Vose 2015). Because FIA data are sampled based, each estimated component (e.g., forest carbon sequestration by age class) has a standard error. Westfall and Patterson (2007) found that measurement error of changes in tree volume was approximately 4% of sampling error. Tree volume change is highly correlated with carbon sequestration in the live tree carbon pool. The combined uncertainty of historical sequestration estimates, developed using Monte Carlo analysis, is about ±17% (US EPA 2017). However, uncertainty approaches ±40% using error propagation techniques, suggesting that uncertainty is somewhat dependent on the assessment method. Our projected change in sequestration encompasses the previously mentioned uncertainties but has additional modeling uncertainty and error in the future state. Error in the future state includes error arising from, for example, unknowable future land-use changes, potential atmospheric CO_2 and N fertilization effects on sequestration rate by age class, and changes in temperature and precipitation patterns. Further, our projection approach relies on an age transition matrix arising from field observations of disturbance, cutting, and normal mortality rates. There can be significant temporal variability in the amount and types of forest cutting (e.g., clearcutting, partial cutting) and in the amount and severity of disturbance, which suggests that there could be significant variability in the age transition matrix.

Social Cost of Carbon

Discount rates (typically annual) make present and future benefits (or costs) fully comparable, because they take account of (a) human (including policy maker) impatience and (b) the effect of output and consumption growth over time. If discount rates are positive, future benefits are worth less than current benefits, and higher discount rates imply lower future values relative to present benefits. The choice of discount rates is therefore very important for our analysis.

Discount rate choice affects our results through two channels. First, it is a particularly important SCC parameter, because the SCC is essentially an estimated PV of the future damages of climate change at the time a ton of CO_2 is emitted. Second, we estimate the effect of carbon sequestration over the coming several decades. The rates chosen to discount values from the time of sequestration back to 2016 also have very important effects on our estimates. Analysts differ in their estimates of the impatience and output growth that underpin discount rates, and therefore, discount rates vary across studies. Because there is no universally accepted set of discount rates, analysts (e.g., Greenstone, Kopits, and Wolverton 2013) often conduct sensitivity analysis to illuminate the influence of the discount rate.

As discussed by many authors (e.g., Arrow et al. 2014), uncertainties about the future affect discount rates and make them uncertain. As shown by Weitzman (2001) and many others, when key aspects of the future (e.g., output and consumption) are uncertain, lower discount rates should be applied to benefits and costs that occur further into the future. For example, Weitzman (2001) suggests that the immediate future (1–5 years) be discounted at 4% per year; 6 to 25 years, at 3%; 26 to 75 years, at 2%; 76 to 300 years, at 1%; and more than 300 years, at 0%. These findings are not incorporated into the interagency working group analysis, but as discussed in Arrow et al. (2014), the French and British governments apply lower discount rates to benefits and costs that occur further in the future, and revisions in this vein are recommended by the National Academies of Sciences, Engineering, and Medicine (2017).

An additional and particularly important type of uncertainty related to climate change is uncertainty regarding climate-induced catastrophe. Climate change is expected to create many types of damages in the United States, but how large will they be? How likely are extreme damages that significantly affect future welfare? There is, of course, significant uncertainty regarding such extreme effects, but hedge investments like carbon sequestration can reduce the chance of catastrophes.

Healthy forests often enhance and support ecosystem services (e.g., water quality and biodiversity) that are endangered by climate change and help mitigate extreme downside risk. As Weitzman (2013) discusses, if investments like carbon sequestration mitigate large downside risks, this also reduces the discount rate(s) that should be applied and increases the SCC. As possible in the three integrated assessment models used, the interagency working group included aspects of extreme risk in its SCC estimates. Fully incorporating risk and especially risk of catastrophe in such models is very challenging, however, particularly when analyzing forests, which likely reduce those risks.

Voluntary Incentives and Adverse Selection

Two of the scenarios include afforestation of 12.1 million hectares in the eastern United States, which would largely be achieved by providing incentives to private landowners. The USDA has five voluntary incentive programs, which account for more than 95% of USDA conservation spending (USDA 2014). When estimating benefits, the possibility of incentive-related adverse selection would need to be taken into account (Claassen, Cattaneo, and Johnson 2008).

First, it is possible in practice that carbon estimated to be sequestered by voluntary incentive programs may not be fully additional. The USDA is unable to observe what would have happened had a given incentive program not been implemented, and it is possible that some of the resulting gains in carbon would have been sequestered without the program. For example, landowners concerned about climate change may enroll in USDA conservation programs to get credit for steps they would have taken without such programs (Duke, Dundas, and Messer 2013). Lubowski, Plantinga, and Stavins (2006) estimate that about 10% of land enrolled in the CRP between 1982 and 1997 would have been taken out of agricultural production anyway, because of market factors.

Second, slippage (or leakage) can also occur. Although steps are taken to avoid landowners "gaming" USDA incentive programs (Claassen, Cattaneo, and Johnson 2008), landowners may sometimes bring land into production that was previously unfarmed to compensate for land enrolled in a USDA voluntary conservation incentive program. Murray, McCarl, and Lee (2004), for example, estimated that leakage from program effects can range from less than 10% to more than 90% depending on sequestration activity and where it occurs. Wu (2000) found that in the central United States, such slippage offset between 9% and 14% of erosion control benefits resulting from the CRP, for example. Lubowski, Plantinga, and Stavins (2006) estimated that the CRP reduced unenrolled forested area by about 200,000 acres or approximately 15% of the measured impact on forests. Despite leakage effects, carbon-positive externalities also can accrue from USDA conservation policies and programs targeted toward other ecosystem services. For example, landowners interested in retiring land may participate in the Wetlands Reserve Enhancement Program, which will likely generate carbon benefits. Incorporating carbon-specific criteria in project selection may help moderate leakage while improving multibenefit returns on program investments. Accounting for leakage, as well as potential complementary benefits, would enable further refinement of our estimates of carbon sequestration policy effects but was beyond the scope of this particular study.

Conclusions

Federal forest policy makers and managers need timely and relevant economic analyses using the best data and methods currently available for evaluating policy alternatives. We found that existing data and models permit developing national-level estimates of carbon sequestration and its monetary value, in response to hypothetical land-use and forest disturbance policy scenarios. Our projections of carbon sequestration resulting from various policy scenarios suggest that U.S. forests hold large amounts of valuable carbon that will over time become more valuable. The greatest carbon gains and monetary values are estimated to be generated from the afforestation/reforestation policy, followed by reduced development, and then reducing wildfire. Our rough estimates of the costs of the afforestation/reforestation and fire mitigation policies suggest that both policies are cost effective. Full cost-benefit analyses of these polices are called for and would provide a more complete picture of net economic benefits.

Given that afforestation/reforestation policies have long played roles in USDA conservation efforts, they would seem to be viable approaches should the USDA choose to pursue opportunities for increasing carbon sequestration in the United States by offering financial incentives to private landowners to plant trees and emphasizing the reforestation of public forest lands. Although afforestation and restoration policies may be viable approaches for increasing carbon sequestration, analyses of the degree to which landowners might respond to any afforestation or restoration incentives, including analysis of potential slippage, are somewhat limited. Focused research may be warranted to improve understanding of the degree to which private landowners might respond to incentives of varying amounts, as well as whether some behavioral changes might be possible in the absence of financial incentives (e.g., outreach and technical assistance).

Key components of our analysis were the models of forest dynamics and land-use change to forecast national-level estimates of forest carbon stocks and fluxes (Coulston, Wear, and Vose 2015; Wear and Coulston 2015; Woodall et al. 2015). We believe continued support of the USDA Forest Service's FIA Program, which develops and maintains data useful for making national-level carbon estimates and projections, is warranted, as is support for research and development efforts to improve data development, including refining estimates of the per ton value of carbon. Additionally, improvements in the ability to evaluate regional differences in per ton and per hectare values of carbon, including the nature of sequestration over time for different management regimes, would allow for more specific policy recommendations.

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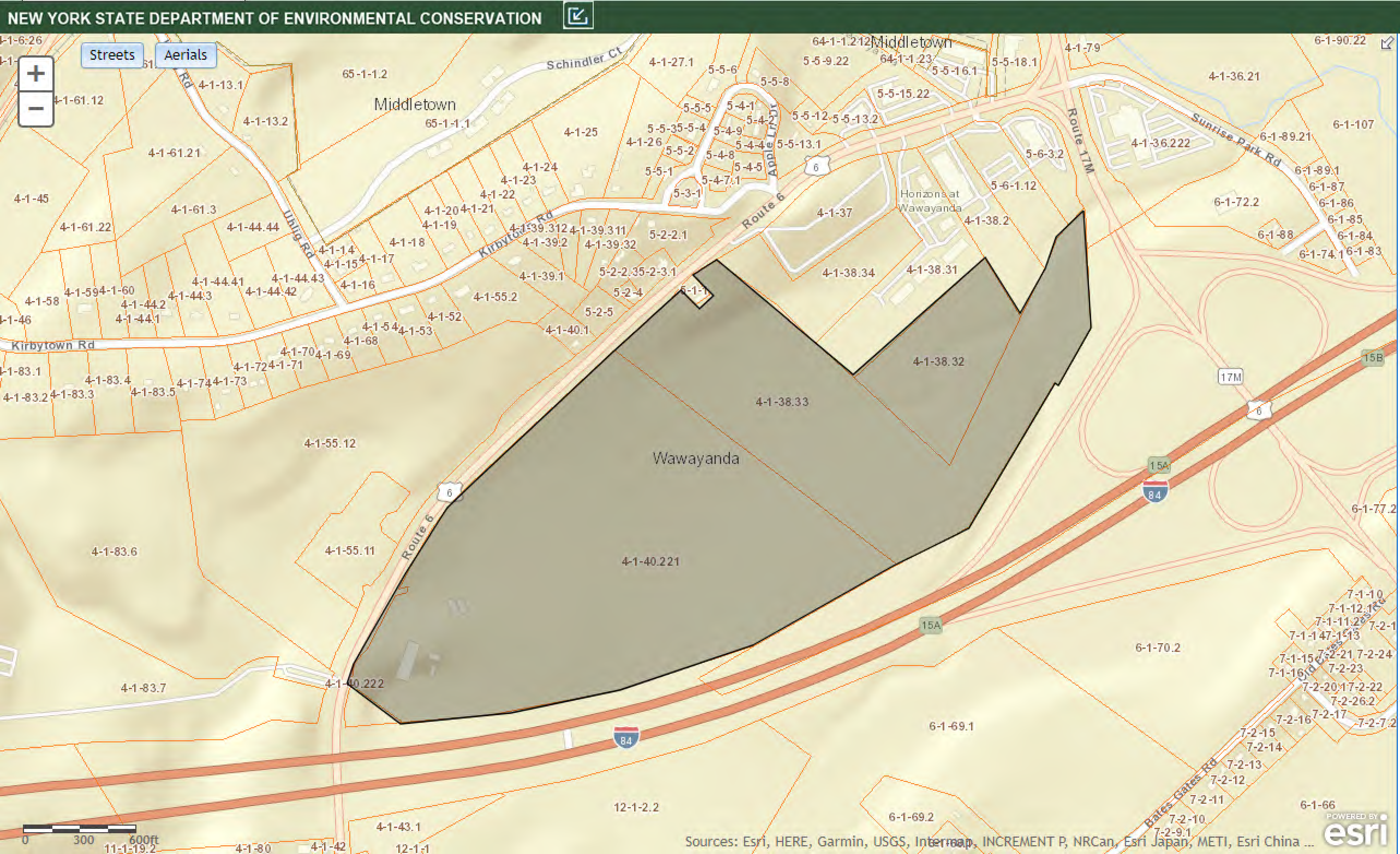
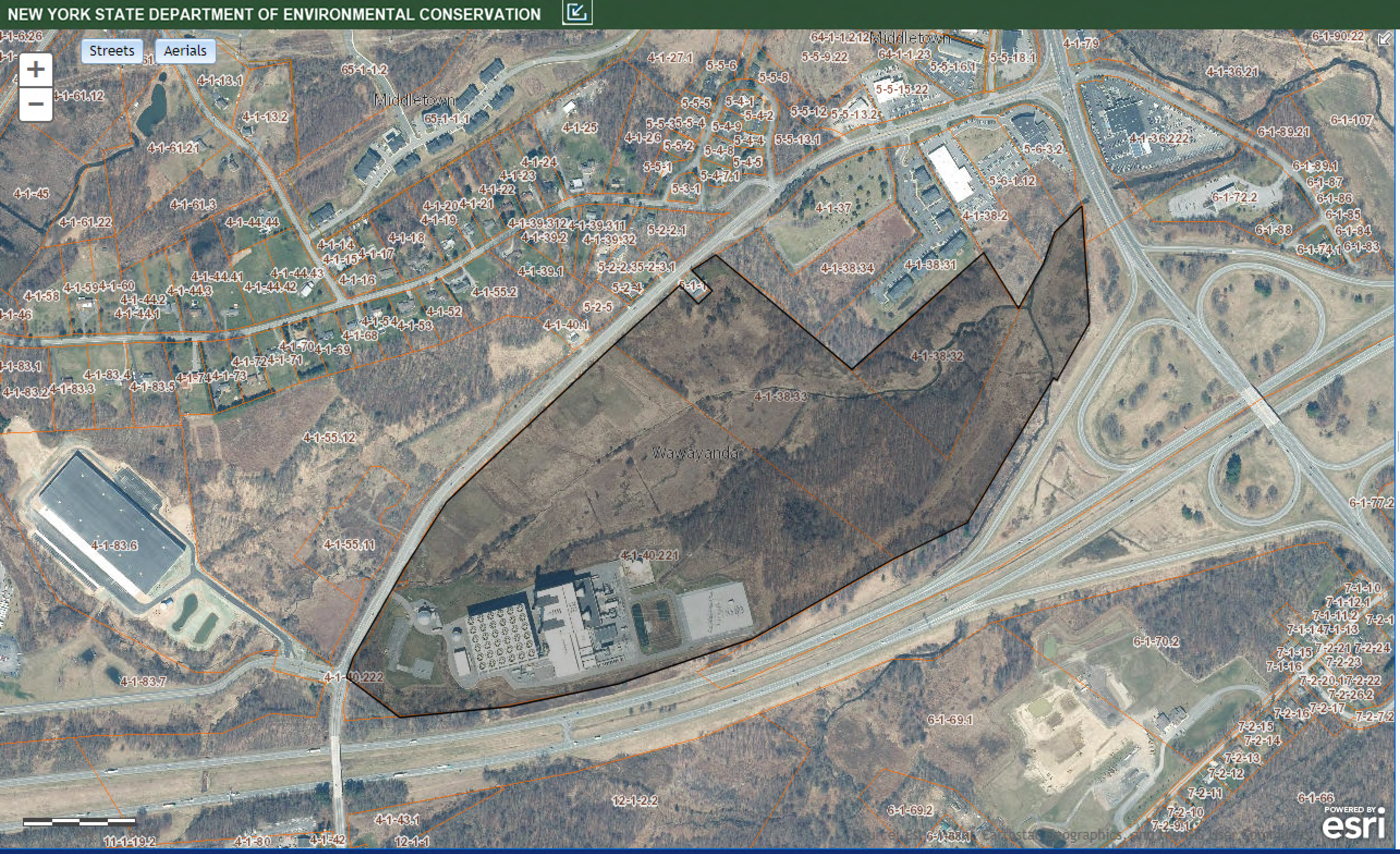
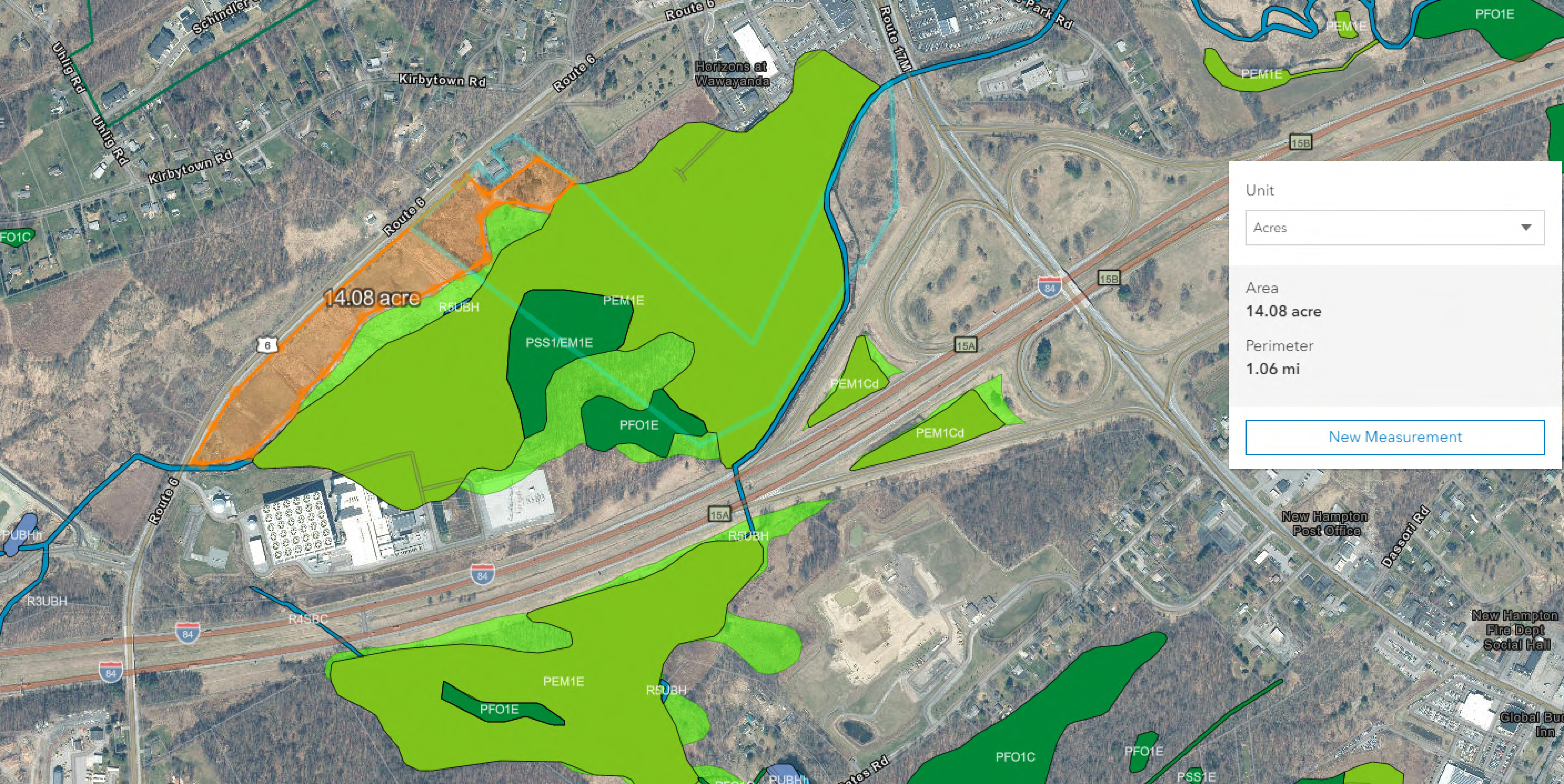
Attachment 7

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION




NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION



Unit

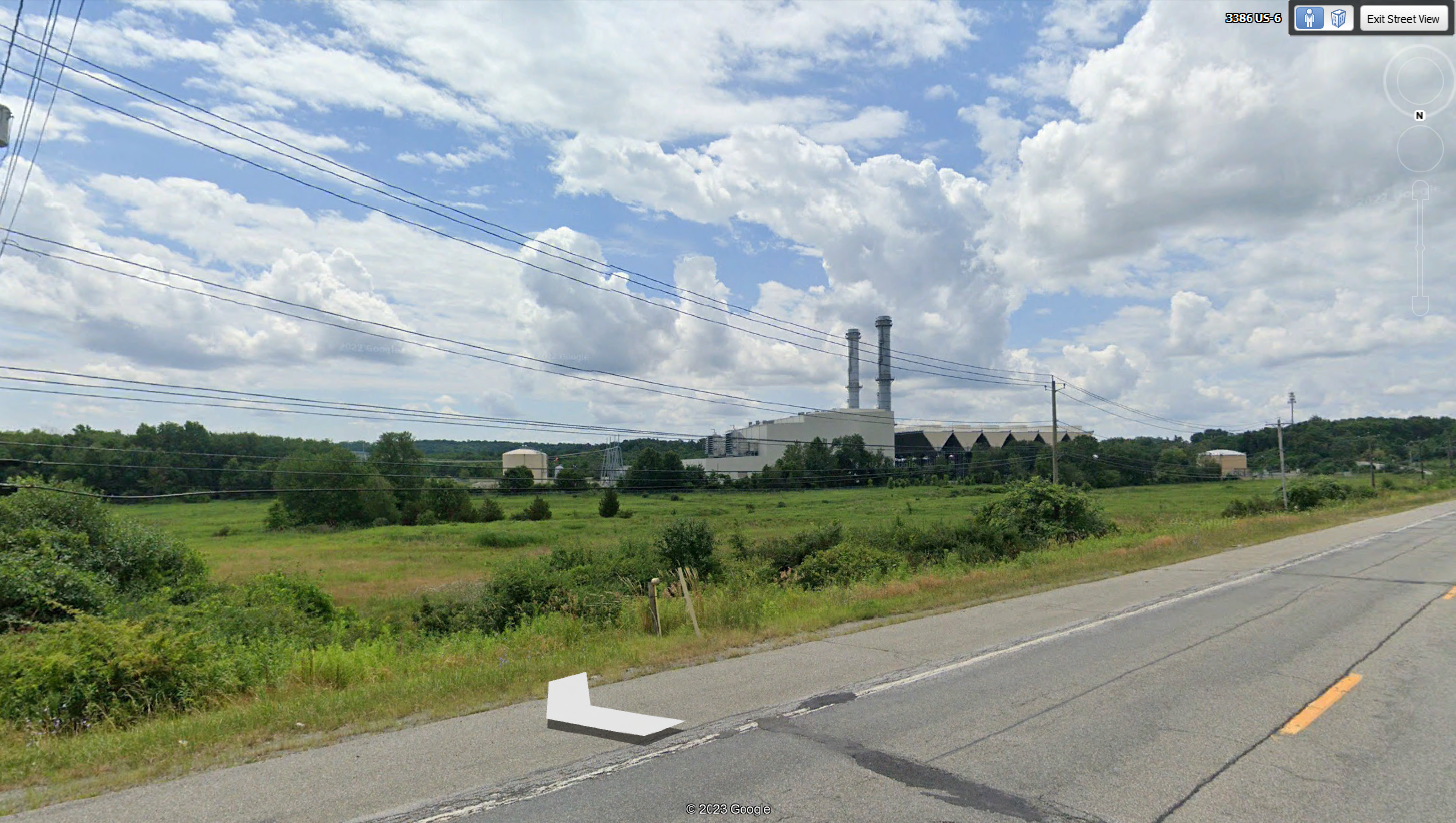
Acres ▾

Area
14.08 acre

Perimeter
1.06 mi


3407 US-6
Exit Street View
N


3401 US-6
Exit Street View
N
© 2022 Google


3386 US-6
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© 2023 Google


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Attachment 8

Full Environmental Assessment Form
Part 1 - Project and Setting

Instructions for Completing Part 1

Part 1 is to be completed by the applicant or project sponsor. Responses become part of the application for approval or funding, are subject to public review, and may be subject to further verification.

Complete Part 1 based on information currently available. If additional research or investigation would be needed to fully respond to any item, please answer as thoroughly as possible based on current information; indicate whether missing information does not exist, or is not reasonably available to the sponsor; and, when possible, generally describe work or studies which would be necessary to update or fully develop that information.

Applicants/sponsors must complete all items in Sections A & B. In Sections C, D & E, most items contain an initial question that must be answered either "Yes" or "No". If the answer to the initial question is "Yes", complete the sub-questions that follow. If the answer to the initial question is "No", proceed to the next question. Section F allows the project sponsor to identify and attach any additional information. Section G requires the name and signature of the applicant or project sponsor to verify that the information contained in Part 1is accurate and complete.

A. Project and Applicant/Sponsor Information.

Name of Action or Project: CPV Valley Energy Center - Title IV / V Permit Application		
Project Location (describe, and attach a general location map): 3330 ROUTE 6, MIDDLETOWN, NY 10940 - Town of Wawayanda, Orange County Tax Parcels 4-1-38.32, 4-1-38.3, and 4-1-40.22.		
Brief Description of Proposed Action (include purpose or need): ------------------------[SEE ATTACHMENT 1]---------------------------		
Name of Applicant/Sponsor: CPV VALLEY LLC	Telephone: (781) 848-2202 E-Mail: datwood@cpv.com	
Address: 8403 Colesville Rd Ste 915		
City/PO: Silver Spring	State: MD	Zip Code: 20910
Project Contact (if not same as sponsor; give name and title/role): Donald Atwood, Asset Manager	Telephone: (781) 848-2202 E-Mail: datwood@cpv.com	
Address:		
City/PO:	State:	Zip Code:
Property Owner (if not same as sponsor):	Telephone: E-Mail:	
Address:		
City/PO:	State:	Zip Code:

B. Government Approvals

B. Government Approvals, Funding, or Sponsorship. ("Funding" includes grants, loans, tax relief, and any other forms of financial assistance.)

Government Entity	If Yes: Identify Agency and Approval(s) Required	Application Date (Actual or projected)
a. City Counsel, Town Board, or Village Board of Trustees ☐Yes☑No		
b. City, Town or Village Planning Board or Commission ☑Yes☐No	Town of Wawayanda Planning Board (SEQRA Lead Agency) - no further review required	DEIS / FEIS complete; SEQRA Findings Statement adopted May 23, 2012
c. City, Town or Village Zoning Board of Appeals ☐Yes☑No		
d. Other local agencies ☐Yes☑No		
e. County agencies ☐Yes☑No		
f. Regional agencies ☐Yes☑No		
g. State agencies ☐Yes☑No		
h. Federal agencies ☑Yes☐No	US EPA	N/A

i. Coastal Resources.

i. Is the project site within a Coastal Area, or the waterfront area of a Designated Inland Waterway? ☐Yes☑No

ii. Is the project site located in a community with an approved Local Waterfront Revitalization Program? ☐ Yes☑No

iii. Is the project site within a Coastal Erosion Hazard Area? ☐ Yes☑No

C. Planning and Zoning

C.1. Planning and zoning actions.

Will administrative or legislative adoption, or amendment of a plan, local law, ordinance, rule or regulation be the only approval(s) which must be granted to enable the proposed action to proceed? ☐Yes☑No

- **If Yes,** complete sections C, F and G.
- **If No,** proceed to question C.2 and complete all remaining sections and questions in Part 1

C.2. Adopted land use plans.

a. Do any municipally- adopted (city, town, village or county) comprehensive land use plan(s) include the site where the proposed action would be located? ☑Yes☐No

If Yes, does the comprehensive plan include specific recommendations for the site where the proposed action would be located? ☐Yes☑No

b. Is the site of the proposed action within any local or regional special planning district (for example: Greenway; Brownfield Opportunity Area (BOA); designated State or Federal heritage area; watershed management plan; or other?) ☐Yes☑No

If Yes, identify the plan(s):

c. Is the proposed action located wholly or partially within an area listed in an adopted municipal open space plan, or an adopted municipal farmland protection plan? ☐Yes☑No

If Yes, identify the plan(s):

C.3. Zoning

a. Is the site of the proposed action located in a municipality with an adopted zoning law or ordinance. ☑ Yes ☐ No
If Yes, what is the zoning classification(s) including any applicable overlay district?
Facility approved and operating under Town Manufacturing / Industrial Zoning District regulations (pre-existing use)

b. Is the use permitted or allowed by a special or conditional use permit? ☑ Yes ☐ No

c. Is a zoning change requested as part of the proposed action? ☐ Yes ☑ No
If Yes,
i. What is the proposed new zoning for the site? ______

C.4. Existing community services.

a. In what school district is the project site located? See DEIS 3-10 to 3-13

b. What police or other public protection forces serve the project site?
See DEIS 6.3.2.2

c. Which fire protection and emergency medical services serve the project site?
See DEIS 6.3.2.2

d. What parks serve the project site?
See DEIS p. 3-8

D. Project Details

D.1. Proposed and Potential Development

a. What is the general nature of the proposed action (e.g., residential, industrial, commercial, recreational; if mixed, include all components)? The proposed action is for the approval of an application for permits under Title V (Air) and Title IV (Acid Rain) of the Clean Air Act for an existing and operational electric generation facility operating under an ASF permit.

b. a. Total acreage of the site of the proposed action? 122 acres
b. Total acreage to be physically disturbed? 0 acres
c. Total acreage (project site and any contiguous properties) owned or controlled by the applicant or project sponsor? 122 acres

c. Is the proposed action an expansion of an existing project or use? ☑ Yes ☐ No
i. If Yes, what is the approximate percentage of the proposed expansion and identify the units (e.g., acres, miles, housing units, square feet)? % 0 % physical expansion Units: permit for existing use

d. Is the proposed action a subdivision, or does it include a subdivision? ☐ Yes ☑ No
If Yes,
i. Purpose or type of subdivision? (e.g., residential, industrial, commercial; if mixed, specify types)
______
ii. Is a cluster/conservation layout proposed? ☐ Yes ☑ No
iii. Number of lots proposed? ______
iv. Minimum and maximum proposed lot sizes? Minimum ______ Maximum ______

e. Will the proposed action be constructed in multiple phases? ☐ Yes ☑ No
i. If No, anticipated period of construction: _____ months
ii. If Yes:
- Total number of phases anticipated _____
- Anticipated commencement date of phase 1 (including demolition) _____ month _____ year
- Anticipated completion date of final phase _____ month _____ year
- Generally describe connections or relationships among phases, including any contingencies where progress of one phase may determine timing or duration of future phases: ______

f. Does the project include new residential uses? ☐Yes ☑No
If Yes, show numbers of units proposed.

	One Family	Two Family	Three Family	Multiple Family (four or more)
Initial Phase	___________	___________	___________	________________________
At completion of all phases	___________	___________	___________	________________________

g. Does the proposed action include new non-residential construction (including expansions)? ☐Yes ☑No
If Yes,
i. Total number of structures ___________
ii. Dimensions (in feet) of largest proposed structure: ________height; ________width; and _______ length
iii. Approximate extent of building space to be heated or cooled: ______________________ square feet

h. Does the proposed action include construction or other activities that will result in the impoundment of any liquids, such as creation of a water supply, reservoir, pond, lake, waste lagoon or other storage? ☐Yes ☑No
If Yes,
i. Purpose of the impoundment: ____
ii. If a water impoundment, the principal source of the water: ☐ Ground water ☐Surface water streams ☐Other specify: ____
iii. If other than water, identify the type of impounded/contained liquids and their source.
____
iv. Approximate size of the proposed impoundment. Volume: ____________ million gallons; surface area: ____________ acres
v. Dimensions of the proposed dam or impounding structure: ________ height; _______ length
vi. Construction method/materials for the proposed dam or impounding structure (e.g., earth fill, rock, wood, concrete):
____

D.2. Project Operations

a. Does the proposed action include any excavation, mining, or dredging, during construction, operations, or both? ☐Yes ☑No
(Not including general site preparation, grading or installation of utilities or foundations where all excavated materials will remain onsite)
If Yes:
i .What is the purpose of the excavation or dredging? ____
ii. How much material (including rock, earth, sediments, etc.) is proposed to be removed from the site?
- Volume (specify tons or cubic yards): ____________________________________
- Over what duration of time? ____________________________________

iii. Describe nature and characteristics of materials to be excavated or dredged, and plans to use, manage or dispose of them.
____
____
iv. Will there be onsite dewatering or processing of excavated materials? ☐Yes ☐No
If yes, describe. ____
____
v. What is the total area to be dredged or excavated? ______________________________acres
vi. What is the maximum area to be worked at any one time? __________________________ acres
vii. What would be the maximum depth of excavation or dredging? ____________________ feet
viii. Will the excavation require blasting? ☐Yes ☐No
ix. Summarize site reclamation goals and plan: ____
____
____

b. Would the proposed action cause or result in alteration of, increase or decrease in size of, or encroachment into any existing wetland, waterbody, shoreline, beach or adjacent area? ☐Yes ☑No
If Yes:
i. Identify the wetland or waterbody which would be affected (by name, water index number, wetland map number or geographic description): ____
____

ii. Describe how the proposed action would affect that waterbody or wetland, e.g. excavation, fill, placement of structures, or alteration of channels, banks and shorelines. Indicate extent of activities, alterations and additions in square feet or acres:

____

iii. Will the proposed action cause or result in disturbance to bottom sediments? ☐Yes ☐No

If Yes, describe: ____________________

iv. Will the proposed action cause or result in the destruction or removal of aquatic vegetation? ☐Yes ☐No

If Yes:

- acres of aquatic vegetation proposed to be removed: ____________________
- expected acreage of aquatic vegetation remaining after project completion: ____________________
- purpose of proposed removal (e.g. beach clearing, invasive species control, boat access): ____________________
- proposed method of plant removal: ____________________
- if chemical/herbicide treatment will be used, specify product(s): ____________________

v. Describe any proposed reclamation/mitigation following disturbance: ____________________

---

c. Will the proposed action use, or create a new demand for water? ☑Yes ☐No

If Yes:

i. Total anticipated water usage/demand per day: See DEIS section 12.2 gallons/day

ii. Will the proposed action obtain water from an existing public water supply? ☐Yes ☐No

If Yes:

- Name of district or service area: Greywater from City of Middletown Sewage Treatment Plant
- Does the existing public water supply have capacity to serve the proposal? ☑Yes ☐No
- Is the project site in the existing district? ☑Yes ☐No
- Is expansion of the district needed? ☐Yes ☑No
- Do existing lines serve the project site? ☑Yes ☐No

iii. Will line extension within an existing district be necessary to supply the project? ☐Yes ☑No

If Yes:

- Describe extensions or capacity expansions proposed to serve this project: ____________________
- Source(s) of supply for the district: ____________________

iv. Is a new water supply district or service area proposed to be formed to serve the project site? ☐Yes ☑No

If, Yes:

- Applicant/sponsor for new district: ____________________
- Date application submitted or anticipated: ____________________
- Proposed source(s) of supply for new district: ____________________

v. If a public water supply will not be used, describe plans to provide water supply for the project: ____________________

vi. If water supply will be from wells (public or private), what is the maximum pumping capacity: _______ gallons/minute.

---

d. Will the proposed action generate liquid wastes? ☑Yes ☐No

If Yes:

i. Total anticipated liquid waste generation per day: DEIS section 12.3 gallons/day

ii. Nature of liquid wastes to be generated (e.g., sanitary wastewater, industrial; if combination, describe all components and approximate volumes or proportions of each):

Process wastewater

iii. Will the proposed action use any existing public wastewater treatment facilities? ☑Yes ☐No

If Yes:

- Name of wastewater treatment plant to be used: City of Middletown Sewage Treatment Plant
- Name of district: ____________________
- Does the existing wastewater treatment plant have capacity to serve the project? ☑Yes ☐No
- Is the project site in the existing district? ☑Yes ☐No
- Is expansion of the district needed? ☐Yes ☑No

- Do existing sewer lines serve the project site? ☑Yes ☐No
- Will a line extension within an existing district be necessary to serve the project? ☐Yes ☑No

  If Yes:
  - Describe extensions or capacity expansions proposed to serve this project: ____

iv. Will a new wastewater (sewage) treatment district be formed to serve the project site? ☐Yes ☑No

If Yes:
- Applicant/sponsor for new district: ____
- Date application submitted or anticipated: ____
- What is the receiving water for the wastewater discharge? ____

v. If public facilities will not be used, describe plans to provide wastewater treatment for the project, including specifying proposed receiving water (name and classification if surface discharge or describe subsurface disposal plans):

n/a

vi. Describe any plans or designs to capture, recycle or reuse liquid waste: ____

See DEIS section 12.3

e. Will the proposed action disturb more than one acre and create stormwater runoff, either from new point sources (i.e. ditches, pipes, swales, curbs, gutters or other concentrated flows of stormwater) or non-point source (i.e. sheet flow) during construction or post construction? ☐Yes ☑No

If Yes:

i. How much impervious surface will the project create in relation to total size of project parcel?

____ Square feet or ____ acres (impervious surface)
____ Square feet or ____ acres (parcel size)

ii. Describe types of new point sources. ____

iii. Where will the stormwater runoff be directed (i.e. on-site stormwater management facility/structures, adjacent properties, groundwater, on-site surface water or off-site surface waters)?

See DEIS section 2.7

- If to surface waters, identify receiving water bodies or wetlands: ____
- Will stormwater runoff flow to adjacent properties? ☐Yes ☑No

iv. Does the proposed plan minimize impervious surfaces, use pervious materials or collect and re-use stormwater? ☑Yes ☐No

f. Does the proposed action include, or will it use on-site, one or more sources of air emissions, including fuel combustion, waste incineration, or other processes or operations? ☑Yes ☐No

If Yes, identify:

i. Mobile sources during project operations (e.g., heavy equipment, fleet or delivery vehicles)

n/a Facility is already constructed and operational

ii. Stationary sources during construction (e.g., power generation, structural heating, batch plant, crushers)

n/a Facility is already constructed and operational

iii. Stationary sources during operations (e.g., process emissions, large boilers, electric generation)

see Title V application and attachments

g. Will any air emission sources named in D.2.f (above), require a NY State Air Registration, Air Facility Permit, or Federal Clean Air Act Title IV or Title V Permit? ☑Yes ☐No

If Yes:

i. Is the project site located in an Air quality non-attainment area? (Area routinely or periodically fails to meet ambient air quality standards for all or some parts of the year) ☑Yes ☐No

ii. In addition to emissions as calculated in the application, the project will generate:
- ~2.16M Tons/year (short tons) of Carbon Dioxide (CO_2)
- 183.0 Tons/year (short tons) of Nitrous Oxide (N_2O)
- 0 Tons/year (short tons) of Perfluorocarbons (PFCs)
- 0 Tons/year (short tons) of Sulfur Hexafluoride (SF_6)
- 0 Tons/year (short tons) of Carbon Dioxide equivalent of Hydroflourocarbons (HFCs)
- 13.8 Tons/year (short tons) of Hazardous Air Pollutants (HAPs)

h. Will the proposed action generate or emit methane (including, but not limited to, sewage treatment plants, landfills, composting facilities)? ☐Yes ☑No

If Yes:

i. Estimate methane generation in tons/year (metric): ______

ii. Describe any methane capture, control or elimination measures included in project design (e.g., combustion to generate heat or electricity, flaring): ______

i. Will the proposed action result in the release of air pollutants from open-air operations or processes, such as quarry or landfill operations? ☐Yes ☑No

If Yes: Describe operations and nature of emissions (e.g., diesel exhaust, rock particulates/dust):

j. Will the proposed action result in a substantial increase in traffic above present levels or generate substantial new demand for transportation facilities or services? ☐Yes ☑No

If Yes:

i. When is the peak traffic expected (Check all that apply): ☐ Morning ☐ Evening ☐Weekend

☐ Randomly between hours of ______ to ______.

ii. For commercial activities only, projected number of truck trips/day and type (e.g., semi trailers and dump trucks): ______

See DEIS section 8.0

iii. Parking spaces: Existing ______ Proposed ______ Net increase/decrease 0

iv. Does the proposed action include any shared use parking? ☐Yes ☐No

v. If the proposed action includes any modification of existing roads, creation of new roads or change in existing access, describe:

vi. Are public/private transportation service(s) or facilities available within ½ mile of the proposed site? ☐Yes ☐No

vii Will the proposed action include access to public transportation or accommodations for use of hybrid, electric or other alternative fueled vehicles? ☐Yes ☐No

viii. Will the proposed action include plans for pedestrian or bicycle accommodations for connections to existing pedestrian or bicycle routes? ☐Yes ☐No

k. Will the proposed action (for commercial or industrial projects only) generate new or additional demand for energy? ☐Yes ☑No

If Yes:

i. Estimate annual electricity demand during operation of the proposed action: ______

ii. Anticipated sources/suppliers of electricity for the project (e.g., on-site combustion, on-site renewable, via grid/local utility, or other): ______

iii. Will the proposed action require a new, or an upgrade, to an existing substation? ☐Yes ☐No

l. Hours of operation. Answer all items which apply.

i. During Construction:

- Monday - Friday: n/a
- Saturday: n/a
- Sunday: n/a
- Holidays: n/a

ii. During Operations:

- Monday - Friday: 24/7/365
- Saturday: ______
- Sunday: ______
- Holidays: ______

m. Will the proposed action produce noise that will exceed existing ambient noise levels during construction, operation, or both? ☐ Yes ☑ No

If yes:

i. Provide details including sources, time of day and duration:

Noise addressed in DEIS section 10.0

ii. Will the proposed action remove existing natural barriers that could act as a noise barrier or screen? ☐ Yes ☑ No

Describe: addressed in DEIS section 10.0

n. Will the proposed action have outdoor lighting? ☐ Yes ☑ No

If yes:

i. Describe source(s), location(s), height of fixture(s), direction/aim, and proximity to nearest occupied structures:

lighting addressed in DEIS section 2.4.3, 5.4.8, 5.5

ii. Will proposed action remove existing natural barriers that could act as a light barrier or screen? ☐ Yes ☑ No

Describe: lighting addressed in DEIS section 2.4.3, 5.4.8, 5.5

o. Does the proposed action have the potential to produce odors for more than one hour per day? ☐ Yes ☑ No

If Yes, describe possible sources, potential frequency and duration of odor emissions, and proximity to nearest occupied structures:

p. Will the proposed action include any bulk storage of petroleum (combined capacity of over 1,100 gallons) or chemical products 185 gallons in above ground storage or any amount in underground storage? ☑ Yes ☐ No

If Yes:

i. Product(s) to be stored petroleum, ammonia, water

ii. Volume(s) 965k gal per unit time __________ (e.g., month, year)

iii. Generally, describe the proposed storage facilities:

See DEIS section 2.4.2.10

q. Will the proposed action (commercial, industrial and recreational projects only) use pesticides (i.e., herbicides, insecticides) during construction or operation? ☐ Yes ☑ No

If Yes:

i. Describe proposed treatment(s):

ii. Will the proposed action use Integrated Pest Management Practices? ☐ Yes ☐ No

r. Will the proposed action (commercial or industrial projects only) involve or require the management or disposal of solid waste (excluding hazardous materials)? ☑ Yes ☐ No

If Yes:

i. Describe any solid waste(s) to be generated during construction or operation of the facility:

- Construction: n/a tons per __________ (unit of time)
- Operation : See DEIS 12.8 tons per __________ (unit of time)

ii. Describe any proposals for on-site minimization, recycling or reuse of materials to avoid disposal as solid waste:

- Construction:
- Operation: See DEIS 12.8

iii. Proposed disposal methods/facilities for solid waste generated on-site:

- Construction:
- Operation: See DEIS 12.8

s. Does the proposed action include construction or modification of a solid waste management facility? ☐ Yes ☑ No
If Yes:
i. Type of management or handling of waste proposed for the site (e.g., recycling or transfer station, composting, landfill, or other disposal activities): ______
ii. Anticipated rate of disposal/processing:
- ______ Tons/month, if transfer or other non-combustion/thermal treatment, or
- ______ Tons/hour, if combustion or thermal treatment

iii. If landfill, anticipated site life: ______ years

t. Will the proposed action at the site involve the commercial generation, treatment, storage, or disposal of hazardous waste? ☐ Yes ☑ No
If Yes:
i. Name(s) of all hazardous wastes or constituents to be generated, handled or managed at facility: ______
ii. Generally describe processes or activities involving hazardous wastes or constituents: ______
iii. Specify amount to be handled or generated ______ tons/month
iv. Describe any proposals for on-site minimization, recycling or reuse of hazardous constituents: ______
v. Will any hazardous wastes be disposed at an existing offsite hazardous waste facility? ☐ Yes ☐ No
If Yes: provide name and location of facility: ______
If No: describe proposed management of any hazardous wastes which will not be sent to a hazardous waste facility: ______

E. Site and Setting of Proposed Action

E.1. Land uses on and surrounding the project site

a. Existing land uses.
i. Check all uses that occur on, adjoining and near the project site.
☐ Urban ☑ Industrial ☑ Commercial ☑ Residential (suburban) ☐ Rural (non-farm)
☐ Forest ☑ Agriculture ☐ Aquatic ☐ Other (specify): ______
ii. If mix of uses, generally describe:
See DEIS section 3.3

b. Land uses and covertypes on the project site.

Land use or Covertype	Current Acreage	Acreage After Project Completion	Change (Acres +/-)
• Roads, buildings, and other paved or impervious surfaces	21.5	21.5	0
• Forested			
• Meadows, grasslands or brushlands (non-agricultural, including abandoned agricultural)	100.75	100.75	0
• Agricultural (includes active orchards, field, greenhouse etc.)			
• Surface water features (lakes, ponds, streams, rivers, etc.)			
• Wetlands (freshwater or tidal)			
• Non-vegetated (bare rock, earth or fill)			
• Other Describe: ______			

c. Is the project site presently used by members of the community for public recreation? ☐Yes☑No
i. If Yes: explain: ______

d. Are there any facilities serving children, the elderly, people with disabilities (e.g., schools, hospitals, licensed day care centers, or group homes) within 1500 feet of the project site? ☐Yes☑No
If Yes,
i. Identify Facilities:
______
______

e. Does the project site contain an existing dam? ☐Yes☑No
If Yes:
i. Dimensions of the dam and impoundment:

- Dam height: ______ feet
- Dam length: ______ feet
- Surface area: ______ acres
- Volume impounded: ______ gallons OR acre-feet

ii. Dam's existing hazard classification: ______
iii. Provide date and summarize results of last inspection:
______
______

f. Has the project site ever been used as a municipal, commercial or industrial solid waste management facility, or does the project site adjoin property which is now, or was at one time, used as a solid waste management facility? ☐Yes☑No
If Yes:
i. Has the facility been formally closed? ☐Yes☐ No

- If yes, cite sources/documentation: ______

ii. Describe the location of the project site relative to the boundaries of the solid waste management facility:
______
______
iii. Describe any development constraints due to the prior solid waste activities: ______
______

g. Have hazardous wastes been generated, treated and/or disposed of at the site, or does the project site adjoin property which is now or was at one time used to commercially treat, store and/or dispose of hazardous waste? ☐Yes☑No
If Yes:
i. Describe waste(s) handled and waste management activities, including approximate time when activities occurred:
______
______

h. Potential contamination history. Has there been a reported spill at the proposed project site, or have any remedial actions been conducted at or adjacent to the proposed site? ☐Yes☑ No
If Yes:
i. Is any portion of the site listed on the NYSDEC Spills Incidents database or Environmental Site Remediation database? Check all that apply: ☐Yes☐No
☐ Yes – Spills Incidents database Provide DEC ID number(s): ______
☐ Yes – Environmental Site Remediation database Provide DEC ID number(s): ______
☐ Neither database

ii. If site has been subject of RCRA corrective activities, describe control measures:______
______
______

iii. Is the project within 2000 feet of any site in the NYSDEC Environmental Site Remediation database? ☐Yes☑No
If yes, provide DEC ID number(s): ______
iv. If yes to (i), (ii) or (iii) above, describe current status of site(s):
______
______

v. Is the project site subject to an institutional control limiting property uses? ☐ Yes ☑ No

- If yes, DEC site ID number: __________
- Describe the type of institutional control (e.g., deed restriction or easement): __________
- Describe any use limitations: __________
- Describe any engineering controls: __________
- Will the project affect the institutional or engineering controls in place? ☐ Yes ☐ No
- Explain: __________

E.2. Natural Resources On or Near Project Site

a. What is the average depth to bedrock on the project site? 50-82 feet

b. Are there bedrock outcroppings on the project site? ☐ Yes ☑ No
If Yes, what proportion of the site is comprised of bedrock outcroppings? __________%

c. Predominant soil type(s) present on project site:

silty loams	DEIS 11.3.2 %
sandy loams	DEIS 11.3.2 %
gravelly loams	DEIS 11.3.2 %

d. What is the average depth to the water table on the project site? Average: Table 11-1 feet

e. Drainage status of project site soils: **See DEIS Table 11-1**

☐ Well Drained:	_____% of site
☐ Moderately Well Drained:	_____% of site
☐ Poorly Drained	_____% of site

f. Approximate proportion of proposed action site with slopes: **See DEIS section 11.3.1**

☐ 0-10%:	_____% of site
☐ 10-15%:	_____% of site
☐ 15% or greater:	_____% of site

g. Are there any unique geologic features on the project site? ☐ Yes ☑ No
If Yes, describe: __________

h. Surface water features. **See DEIS section 13.3**

i. Does any portion of the project site contain wetlands or other waterbodies (including streams, rivers, ponds or lakes)? ☑ Yes ☐ No

ii. Do any wetlands or other waterbodies adjoin the project site? ☑ Yes ☐ No

If Yes to either *i* or *ii*, continue. If No, skip to E.2.i.

iii. Are any of the wetlands or waterbodies within or adjoining the project site regulated by any federal, state or local agency? ☑ Yes ☐ No

iv. For each identified regulated wetland and waterbody on the project site, provide the following information:

- Streams: Name 855.5-183 Classification B
- Lakes or Ponds: Name __________ Classification __________
- Wetlands: Name Federal Waters, NYS Wetland, Federal Waters, Fe... Approximate Size NYS Wetland (in a...
- Wetland No. (if regulated by DEC) MD-23

v. Are any of the above water bodies listed in the most recent compilation of NYS water quality-impaired waterbodies? ☑ Yes ☐ No

If yes, name of impaired water body/bodies and basis for listing as impaired:
Name - Pollutants - Uses:Monhagen Brook and tribs – Nutrients;Unknown Toxicity – Recreation;Aquatic Life

i. Is the project site in a designated Floodway? ☐ Yes ☑ No

j. Is the project site in the 100-year Floodplain? ☐ Yes ☑ No

k. Is the project site in the 500-year Floodplain? ☐ Yes ☑ No

l. Is the project site located over, or immediately adjoining, a primary, principal or sole source aquifer? ☑ Yes ☐ No
If Yes:
i. Name of aquifer: Principal Aquifer

m. Identify the predominant wildlife species that occupy or use the project site:
See DEIS Table 14-1

n. Does the project site contain a designated significant natural community? ☐Yes ☑No

If Yes:

i. Describe the habitat/community (composition, function, and basis for designation):

ii. Source(s) of description or evaluation:

iii. Extent of community/habitat:

- Currently: acres
- Following completion of project as proposed: acres
- Gain or loss (indicate + or -): acres

o. Does project site contain any species of plant or animal that is listed by the federal government or NYS as endangered or threatened, or does it contain any areas identified as habitat for an endangered or threatened species? ☑ Yes ☐No

If Yes:

i. Species and listing (endangered or threatened):

Indiana Bat

p. Does the project site contain any species of plant or animal that is listed by NYS as rare, or as a species of special concern? ☐Yes ☑No

If Yes:

i. Species and listing:

q. Is the project site or adjoining area currently used for hunting, trapping, fishing or shell fishing? ☐Yes ☑No

If yes, give a brief description of how the proposed action may affect that use:

E.3. Designated Public Resources On or Near Project Site

a. Is the project site, or any portion of it, located in a designated agricultural district certified pursuant to Agriculture and Markets Law, Article 25-AA, Section 303 and 304? ☑Yes ☐No

If Yes, provide county plus district name/number: ORAN002

b. Are agricultural lands consisting of highly productive soils present? ☐Yes ☑No

i. If Yes: acreage(s) on project site?

ii. Source(s) of soil rating(s):

c. Does the project site contain all or part of, or is it substantially contiguous to, a registered National Natural Landmark? ☐Yes ☑No

If Yes:

i. Nature of the natural landmark: ☐ Biological Community ☐ Geological Feature

ii. Provide brief description of landmark, including values behind designation and approximate size/extent:

d. Is the project site located in or does it adjoin a state listed Critical Environmental Area? ☑Yes ☐No

If Yes:

i. CEA name: Ridge Preservation Areas

ii. Basis for designation: Preserve ridgelines to reduce erosion

iii. Designating agency and date: Agency:Wawayanda, Town of, Date:12-2-93

e. Does the project site contain, or is it substantially contiguous to, a building, archaeological site, or district which is listed on the National or State Register of Historic Places, or that has been determined by the Commissioner of the NYS Office of Parks, Recreation and Historic Preservation to be eligible for listing on the State Register of Historic Places? ☐ Yes ☑ No

If Yes:

i. Nature of historic/archaeological resource: ☐ Archaeological Site ☐ Historic Building or District

ii. Name: ________________

iii. Brief description of attributes on which listing is based:

____

f. Is the project site, or any portion of it, located in or adjacent to an area designated as sensitive for archaeological sites on the NY State Historic Preservation Office (SHPO) archaeological site inventory? ☑ Yes ☐ No

g. Have additional archaeological or historic site(s) or resources been identified on the project site? ☐ Yes ☑ No

If Yes:

i. Describe possible resource(s): ________________

ii. Basis for identification: ________________

h. Is the project site within fives miles of any officially designated and publicly accessible federal, state, or local scenic or aesthetic resource? ☐ Yes ☑ No

If Yes:

i. Identify resource: ________________

ii. Nature of, or basis for, designation (e.g., established highway overlook, state or local park, state historic trail or scenic byway, etc.): ________________

iii. Distance between project and resource: __________ miles.

i. Is the project site located within a designated river corridor under the Wild, Scenic and Recreational Rivers Program 6 NYCRR 666? ☐ Yes ☑ No

If Yes:

i. Identify the name of the river and its designation: ________________

ii. Is the activity consistent with development restrictions contained in 6NYCRR Part 666? ☐ Yes ☐ No

F. Additional Information

Attach any additional information which may be needed to clarify your project.

If you have identified any adverse impacts which could be associated with your proposal, please describe those impacts plus any measures which you propose to avoid or minimize them.

G. Verification

I certify that the information provided is true to the best of my knowledge.

Applicant/Sponsor Name Donald Atwood

Date March 06 , 2023

Signature ________________

Title Asset Manager Representative

PRINT FORM

EAF Mapper Summary Report

Friday, March 3, 2023 8:29 AM

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Disclaimer: The EAF Mapper is a screening tool intended to assist project sponsors and reviewing agencies in preparing an environmental assessment form (EAF). Not all questions asked in the EAF are answered by the EAF Mapper. Additional information on any EAF question can be obtained by consulting the EAF Workbooks. Although the EAF Mapper provides the most up-to-date digital data available to DEC, you may also need to contact local or other data sources in order to obtain data not provided by the Mapper. Digital data is not a substitute for agency determinations.

EMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri
OpenStreetMap contributors, and the GIS User Community

B.i.i [Coastal or Waterfront Area]	No
B.i.ii [Local Waterfront Revitalization Area]	No
C.2.b. [Special Planning District]	Digital mapping data are not available or are incomplete. Refer to EAF Workbook.
E.1.h [DEC Spills or Remediation Site - Potential Contamination History]	Digital mapping data are not available or are incomplete. Refer to EAF Workbook.
E.1.h.i [DEC Spills or Remediation Site - Listed]	Digital mapping data are not available or are incomplete. Refer to EAF Workbook.
E.1.h.i [DEC Spills or Remediation Site - Environmental Site Remediation Database]	Digital mapping data are not available or are incomplete. Refer to EAF Workbook.
E.1.h.iii [Within 2,000' of DEC Remediation Site]	No
E.2.g [Unique Geologic Features]	No
E.2.h.i [Surface Water Features]	Yes
E.2.h.ii [Surface Water Features]	Yes
E.2.h.iii [Surface Water Features]	Yes - Digital mapping information on local and federal wetlands and waterbodies is known to be incomplete. Refer to EAF Workbook.
E.2.h.iv [Surface Water Features - Stream Name]	855.5-183
E.2.h.iv [Surface Water Features - Stream Classification]	B
E.2.h.iv [Surface Water Features - Wetlands Name]	Federal Waters, NYS Wetland
E.2.h.iv [Surface Water Features - Wetlands Size]	NYS Wetland (in acres):114.2
E.2.h.iv [Surface Water Features - DEC Wetlands Number]	MD-23
E.2.h.v [Impaired Water Bodies]	Yes

E.2.h.v [Impaired Water Bodies - Name and Basis for Listing]	Name - Pollutants - Uses:Monhagen Brook and tribs – Nutrients;Unknown Toxicity – Recreation;Aquatic Life
E.2.i. [Floodway]	No
E.2.j. [100 Year Floodplain]	No
E.2.k. [500 Year Floodplain]	No
E.2.l. [Aquifers]	Yes
E.2.l. [Aquifer Names]	Principal Aquifer
E.2.n. [Natural Communities]	No
E.2.o. [Endangered or Threatened Species]	Yes
E.2.o. [Endangered or Threatened Species - Name]	Indiana Bat
E.2.p. [Rare Plants or Animals]	No
E.3.a. [Agricultural District]	Yes
E.3.a. [Agricultural District]	ORAN002
E.3.c. [National Natural Landmark]	No
E.3.d [Critical Environmental Area]	Yes
E.3.d [Critical Environmental Area - Name]	Ridge Preservation Areas
E.3.d.ii [Critical Environmental Area - Reason]	Preserve ridgelines to reduce erosion
E.3.d.iii [Critical Environmental Area – Date and Agency]	Agency:Wawayanda, Town of, Date:12-2-93
E.3.e. [National or State Register of Historic Places or State Eligible Sites]	Digital mapping data are not available or are incomplete. Refer to EAF Workbook.
E.3.f. [Archeological Sites]	Yes
E.3.i. [Designated River Corridor]	No

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

EAF Attachment 1

The proposed action is for the approval of an application for permits under Title V (Air) and Title IV (Acid Rain) of the Clean Air Act.

CPV Valley Energy LLC (Valley) currently operates the CPV Valley Energy Center (the Facility), a nominal net 680-megawatt (MW) combined-cycle gas turbine electric generating facility, on a site located in Wawayanda, Orange County, New York.

The Facility consists of two Siemens F-class combustion turbine generators (CTGs) operating in combined-cycle mode with supplemental firing of the heat recovery steam generators (HRSGs). The Facility includes a natural gas-fired auxiliary boiler and a ULSD-fired emergency fire pump engine. The auxiliary boiler and emergency fire pump engine have the same rating and emissions as those contained in the original ASF permit issued by NYS DEC. In addition to the air emitting equipment, the Facility has one steam turbine generators (STGs), an air-cooled condenser (ACC) and associated auxiliary equipment and systems. Each combined cycle generating unit consisting of the CTG, HRSG and STG is exhausted through its own stack.

The Facility was previously approved (ASF Permit ID: 3-3356-00136/00001) by the New York State Department of Environmental Conservation (NYS DEC). After a full environmental review, including the preparation of an environmental impact statement (EIS), the initial ASF permit for the Facility was issued on August 1, 2013 and required Valley to apply for a Title V permit within 1 year from start of operations. The Facility commenced operations January 2018. Valley submitted applications for Title V and Title IV Acid Rain air permits to NYS DEC under to 6 NYCRR Part 201 in August 2018 and continued operations under SAPA § 401. Valley's application was deemed complete by the Department on May 27, 2019 commencing an 18-month technical review period under Part 201. NYS DEC revoked its initial completeness determination on November 29, 2020, in part, due to new requirements under Section 7 of the Climate Leadership and Community Protection Act (Chapter 106 of the Laws of 2019, eff. Jan. 2020)(the "CLCPA").

Valley has since supplemented its initial application with additional information necessary to satisfy the CLCPA requirements.