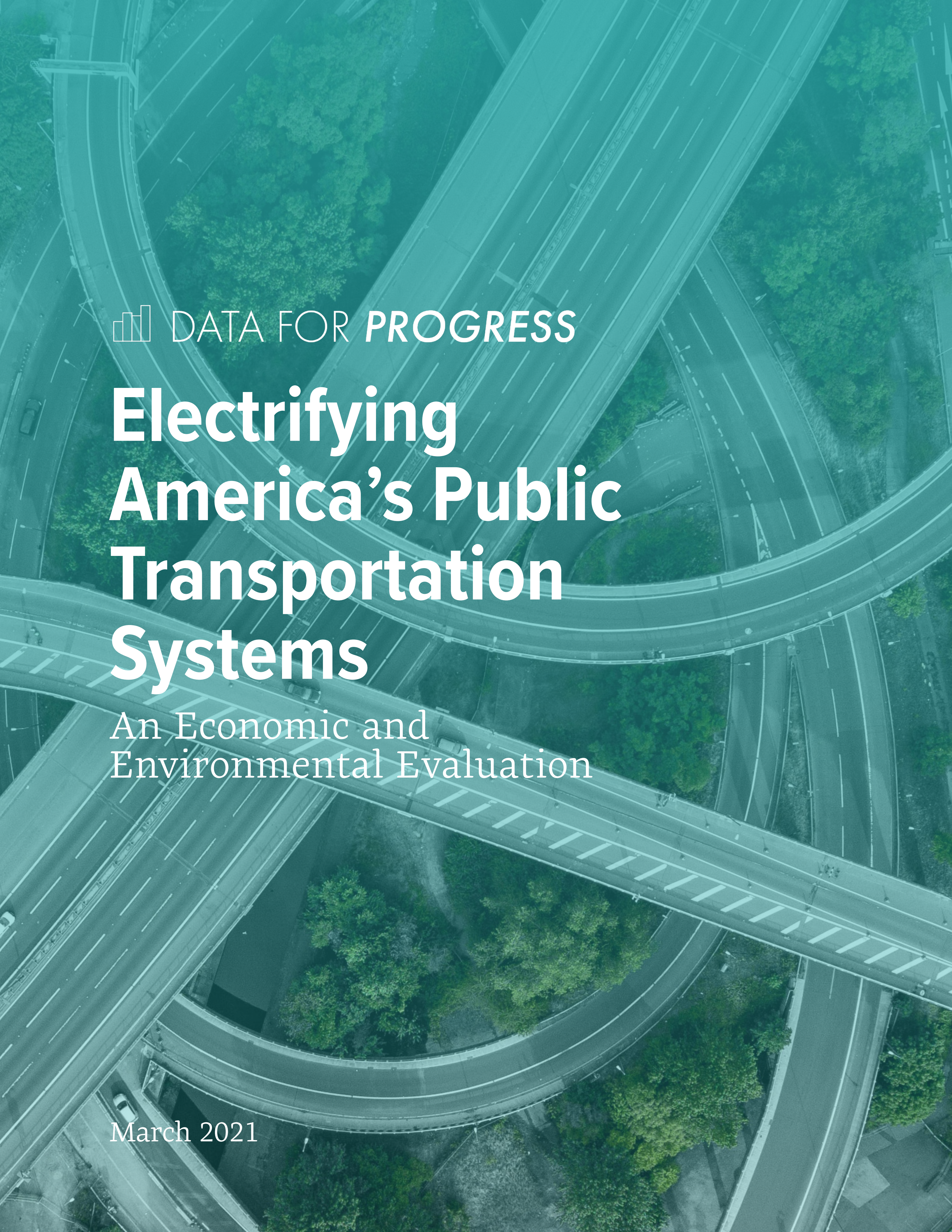

DATA FOR *PROGRESS*

Electrifying America's Public Transportation Systems

An Economic and Environmental Evaluation

March 2021

RESEARCH DISCLAIMER

This research document reflects a rapid-response scoring of a specific proposed bill in the U.S. Senate conducted by a team of independent researchers. Given certain time and information constraints, and uncertainty in predicting the types of grants and proposals that would be received during the bid process, this analysis takes a conservative approach that likely underestimates some of the potential benefits of this transformation. This analysis also does not assess the efficacy of the specific policy mechanisms for achieving their stated goals.

This evaluation is in the process of peer review at Columbia University's Earth Institute. It is in many ways a proof of concept and should be treated as the first product of an iterative process of evaluating an expansive set of policy strategies proposed for achieving the goal of electrifying America's mass transit system and rolling out electric vehicle charging infrastructure and associated renewable energy generating capacity.

DESIGNED BY BILLIE KANFER
billiekk13@gmail.com

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EXECUTIVE SUMMARY

Electrifying America's Public Transportation Systems

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Greening America's public transportation infrastructure is a vital component of tackling the climate crisis. These investments will create American jobs, raise American wages, and most importantly, save American lives – both today through improved health and lower air pollution, as well as tomorrow by reducing the odds of climate-change driven catastrophes.

One piece of proposed legislation undertaking these goals is the "Better Utilizing Investments to Leverage Development and Generate Renewable Energy for Electrification Now Act" – the **BUILD GREEN Act.** This proposed legislation would invest $500 billion over ten years in projects to electrify public transportation, install electric vehicle (EV) charging infrastructure nationwide, and expand associated renewable energy generation capacity.

This brief summarizes the results of a preliminary evaluation of some of the economic and environmental benefits of this transformation of the public transportation system.

Summary of Investments

Overall, the estimated net investment to achieve the transformation evaluated here is **$200 billion over ten years** – with a range of $45 to $300 billion. This average figure breaks down to:

- $160 billion invested for replacing the entire existing public bus fleet nationally with electric buses – including transit buses, demand-response vehicles, and school buses.
- $65 billion net invested for electrifying the commuter rail system.

- $60 billion saved for fuel and maintenance costs.
- $7.5 billion invested in additional energy generation capacity.
- $20 billion invested in energy storage infrastructure.
- $5.7 billion invested in EV charging stations.

Compared to the $500 billion funding level over ten years in the proposed BUILD GREEN Act, this leaves approximately $300 billion that could be dedicated to broader changes to the transportation sector beyond the scope of this analysis – such as an expansion of service.

Summary of National Benefits

JOBS

This transformation would create approximately **960,000 jobs** – including direct jobs within the target industries and indirect jobs affected by those industries. This breaks down to:

- 320,000 direct jobs and 640,000 indirect jobs.
- 140,000 jobs associated with the newly installed solar and wind energy capacity.
- 380,000 jobs associated with new battery storage for both the new generation and the electrified vehicles.
- 340,000 jobs associated with catenary installation for commuter rail.
- 95,000 jobs associated with EV charging infrastructure.

HUMAN HEALTH

Replacing the entire bus and railroad fleet would result in approximately **4,200 fewer deaths annually**, many of these children and the elderly who are, on average, more susceptible to suffer acute, adverse responses to ambient air pollution.

In terms of deaths and other disabilities caused by local pollutant releases, this amounts to avoided health damages of around **$100 billion** for each year this transition brings forward in time the electrification of buses and rail.

GREENHOUSE GAS EMISSIONS

In terms of emissions, the transportation sector is the primary source of CO_2 emissions in the United States in 2017 – over 1,800 million metric tons of CO_2 equivalent, or 29 percent of all emissions.[1] Within this sector, public transportation under the control of local and state governments – namely, public transit buses, school buses, and commuter or suburban rail – is both considerably less emissions intensive than private vehicles per passenger mile (even when unelectrified) and under-used (approximately 1.5 percent of all passenger-miles in 2017). And still, the emission reduction benefits of the vehicle electrification alone include:

- **21.5 million metric tons of CO_2 reduced annually**, equivalent to taking 4.5 million cars off the road.[2] This would also reduce significant sources of local air pollution: harmful particulate matter, nitrous oxides, and carbon monoxide.
- **Over $1 billion of averted damages** using the social cost of carbon (SCC) associated with the annual emission reductions.

While light-duty passenger vehicles account for 59 percent of total transportation emissions, it is hard to estimate the annual net reduction in internal combustion engine vehicles via expanded EV charging infrastructure. Therefore, this analysis did not consider the health and emissions effects associated with expanding publicly accessible EV charging infrastructure, such as EV charging stations on highways, nor the job effects of EV adoption. However, expanding EV charging infrastructure would undoubtedly accelerate the uptake of privately-owned and commercial EVs, thereby reducing local air pollution and greenhouse gas emissions.

Implications

To an extent, this analysis is conducted against the backdrop of its counterfactual. Yet in some ways, the electrification of America's public transportation infrastructure has already begun. Some rail lines – notably within Amtrak's Northeast Corridor – have already been electrified. Moreover, there are several pilot bus electrification projects in cities across the country. The transition, however, is proceeding slowly. Local and state transit agencies are capital-constrained and risk-averse. In 2018, there were about 425,000 electric buses in service worldwide; nearly 99 percent of those were in China.

If America is to accelerate the decarbonization of public transportation and remain competitive in the production and operation of electric vehicles, now is the time to invest in developing these capacities. Doing so can also generate technical and financial complementarities leading to further private and local investment and adoption.

The benefits of electrifying America's public transportation systems are time-sensitive, especially with the increasing urgency with which the world must tackle the climate crisis. Moving this transition substantially forward in time – as pursued by the proposed investments in the **BUILD GREEN Act** – can avert health and social damages, avoid climate-change inducing emissions, generate jobs, and restore some of America's vital infrastructure.

Methodological Notes

Introduction

Given certain time and information constraints, and uncertainty in predicting the types of grants and proposals that would be received during the bid process, this analysis takes a conservative approach that likely underestimates some of the potential benefits of this transformation.

In particular, this evaluation:

- Focuses on shovel-ready projects rather than transformative projects that have greater potential in the long-run – for example, electrifying existing rail lines, rather than extending rail into new service areas – because the nature and timescales of legislative and legal hurdles are difficult to predict at the local scale.
- Assumes no complementarity between bus charging infrastructure and the adoption of electric vehicles for private use, as network externalities are notoriously difficult to project and may be highly nonlinear.
- Assumes that all compliance for grant eligibility would be met by installing new renewable electric generating capacity, rather than through a modification to the state's renewable portfolio standard (RPS) or the purchase of existing renewable capacity – both options within the proposed legislation. Notably, this assumption likely leads our analysis to overestimate the potential employment effects of this component. This assumption is discussed in more detail below.

This analysis therefore focused foremost on the adoption of electric buses by school districts and public transportation agencies and the electrification of commuter rail lines. The total capital investment of this undertaking is estimated at approximately $200 billion, whereas the proposed bill specifies $500 billion of spending. This leaves approximately $300 billion that could be dedicated to broader changes to the transportation sector beyond the scope of this analysis.

Overview of Approach

We calculated the investments required to replace the existing public transportation fleet to electric vehicles (EV), its related energy requirements (assuming all new energy comes from solar and wind), and the necessary infrastructure (catenary investments for rails and storage/battery technology) to support this change. We provide results for three different scenarios, labeled "optimistic", "pessimistic," or "average," depending on whether the parameters determine high, low, or an average investment of achieving total transformation of each sector.

The optimistic scenario assumes that all parameters that determine net costs take values that go in favor of a lower net cost, while in the pessimistic scenario all parameters take values that go in favor of higher net costs. These estimations suggest bounds for total cost. Intermediate scenarios can be constructed combining optimistic, average, or pessimistic scenarios for each of the components of total cost. The "average" scenario is mostly defined by the current value of the parameter. For example, an electric transit bus is assumed to cost today's market value. This cost, with a great degree of confidence, will drop in the future, so our "average" scenario is actually pessimistic in that sense.

Also of note is that this analysis is "static"; we assume no changes in ridership behavior due to bus and rail electrification. If passengers were to prefer the quiet, cleanliness, and novelty of electrified transit options, these estimates are likely to be lower bounds on emissions effects in a world of dynamic choice.

Electrifying Public Bus Transportation

According to the American Public Transportation Association (APTA), there are around 65,000 transit buses, 68,000 demand-response vehicles, and 470,000 school buses in the U.S. public transportation system.[3] In general, while EVs are more expensive upfront, fuel and maintenance spending are smaller than for diesel, compressed natural gas (CNG), and hybrid vehicles. Additional energy generation capacity costs are small compared to the costs above, while required storage costs are significant. The following table provides a summary of these results.

Below, we briefly explain our calculations, referring to the central "average" estimates, based mostly on current values of the parameters that determine total costs.

The current fleet of public transportation buses is around 40 percent diesel, 40 percent CNG, and 20 percent hybrid. School buses in turn are almost entirely diesel. Data for the fuel mix of demand response buses in unavailable, but our conservative approach assumes a similar fleet composition as that of transit buses. We suspect, however, that demand-response buses are more likely than public buses to be powered by diesel.

The current cost of an EV transit bus is around $700,000, while comparable diesel, CNG, and hybrid alternatives cost around $500,000, $425,000, and $500,000, respectively. An EV school bus costs around $220,000, while its diesel alternative costs around $120,000. We assume an average cost of $120,000, $85,700, $72,800, and $85,700 for EV, diesel, CNG, and hybrid demand response buses, respectively.

Diesel vehicles are cheaper to acquire but exhibit lower efficiency, higher fuel prices, and higher maintenance costs than their alternatives. Electric vehicles are the most expensive vehicles to acquire but exhibit the lowest maintenance and fuel costs of bus options. Given this, we estimate that replacement of the entire fleet would cost on average $160 billion, while fuel and maintenance costs savings would be around $30 billion for EV.

Following Heal (2016), additional electricity generation needed for powering the fleet is assumed to be 50 percent wind and 50 percent solar, and storage needs to be installed.[4] Using standard estimates of the efficiency of electric vehicles (for each type in the fleet), we estimate that an additional 4,000 MW of solar and 3,300 MW of wind must be installed, leading to an investment of approximately $7.4 billion. Given the intermittent nature of these generating technologies, we present costs for 2 days of electricity storage at $21 billion.

SUMMARY (BILLION $)	OPTIMISTIC	AVERAGE	PESSIMISTIC
Fleet Replacement Cost	118.45	157.94	157.94
Fuel Savings	67.26	29.50	4.70
Maintenance Savings	47.23	29.65	12.06
Clean Energy Capacity	3.19	7.41	10.93
Storage	9.00	20.89	40.18
Net Cost	16.15	127.09	192.27

COMMENTS:

While public transit districts have been slowly replacing older fleets with electric and hybrid buses for over a decade, there has been a recent uptick in efforts to replace diesel school buses with electric vehicles in pilot projects. For example, a partnership between Dominion Energy and the state of Virginia to replace diesel buses with electric buses at a rate of 200 per year for five years beginning in 2021 was announced on September 25, 2019.[5] Diesel school buses have been substituted with electric school buses in California in a handful of school districts since 2014, with a July 2019 allocation of $70 million from the California Energy Commission to replace 200 diesel school buses with electric vehicles. Given the size and distribution of the school bus fleet nationwide, a federal policy that complements state efforts to electrify school buses could be an effective means of meeting the proposed legislative requirement to apportion a minimum $2 billion in funding to each state to address geographic funding distribution, especially in smaller states that lack developed public transportation networks for commuters.

Electrifying Commuter Rail Transportation

In this analysis, we also consider the conversion of diesel locomotives currently used for commuter rail to an electric train fleet. Most public subways and light rail systems established in urban areas along high density population corridors are already electrified, and there is little need to replace cars before they reach the end of their life. Although new models of electric subway or light rail cars may have higher efficiency than those currently running, the marginal gains from technology improvements are not as great as the transition of diesel-based transportation to electricity-based counterparts. While there is demand for expanding public train networks in urban areas that have the population density to support mass transport, the vast costs of expanding the transportation system would be related to the construction costs and labor, and outside the purview of the proposed legislation.

From an energy efficiency perspective, there is not much motivation to improve the efficiency of freight rail when passenger rail represents lower hanging fruit. Freight rail is already fairly energy efficient because it runs at a low speed (23 miles per hour, designed to reduce aerodynamic drag), with fewer starts and stops than passenger rail. In contrast, passenger rail experiences high acceleration, higher speeds (more aerodynamic drag), and frequent stops, all of which waste energy. Most freight rail in the United States is powered by diesel, but given that freight rail requires long distances and low frequency trips, it is unlikely that freight rail electrification projects would be on the short list to receive funds from this proposal.

To estimate the investment required to transition commuter rail from diesel trains to electric trains, we use costs associated with the replacement of diesel fleet in the Caltrain system between San Francisco and San Jose with electric train cars. The associated costs include the price of the electric train cars themselves ($6.25 million per train car from Stadler) and the infrastructure to install overhead catenary electric wire inputs. In our analysis of potential commuter rail grant proposals, we estimate optimistic and pessimistic scenarios around an average cost of installing overhead catenaries at $5 million per mile, and a range of values for the efficiency of current diesel locomotives in passenger miles-per-gallon diesel. In the United States, there are currently approximately 26 commuter rail networks servicing 29 metropolitan areas and covering approximately 4,000 miles of tracks. Our analysis in this section investigates the costs and benefits of electrifying existing commuter rail network and adding electric train cars to replace the aging fleet.

Using U.S. Department of Transportation values from 2017, the vehicle-miles traveled by commuter rail was 376 million miles, and passenger-miles traveled by commuter rail at 12.32 billion miles.[6] One study comparing fuel efficiency across several modes of transportation estimated the average energy use of commuter rail trains at 90.3 passenger miles per gallon equivalent of diesel, with a low range estimate of 32.1 passenger miles per gallon diesel and a high range estimate of 169.5 passenger miles per gallon diesel.[7] The more inefficient we estimate the train stock, the greater we expect the fuel savings to be. However, replacing inefficient train stock also implies that we would need to replace the energy content of diesel with energy capacity and storage. Thus, in the table below, high savings achieved by swapping diesel fuel costs out are coupled with high clean energy capacity costs and storage costs, because we assume a 1:1 ratio of energy replacement.

The table below does not consider the reduction in maintenance costs in the transition from diesel locomotives to electric powertrains. Anecdotally, electric train cars, with fewer moving parts and simpler components, cost less to maintain than diesel combustion engines, but reliable numbers were hard to obtain and therefore excluded from the summary table below.

In summary, we find the investment required to electrify the existing commuter rail system in a range from $28-100 billion. These costs resemble those of electrifying the public transit bus and school bus fleets in order of magnitude but are likely spread over fewer passengers. It is also worthwhile to note that installation of overhead catenary wires over active rail tracks is disruptive, and therefore, the electrification of the train network is likely more time- and resource-intensive, and thus less shovel-ready than the integration of electric bus counterparts.

Effects on Jobs

Estimating effects on jobs is a difficult task. Some of the investment detailed above is just for replacement. For example, there may be no additional drivers if the number of buses is the same, even if there is a significant investment in an EV fleet. Similarly, it is hard to estimate the impact on vehicle manufacturers if they are simply building different but not additional equipment. On the other hand, building and operating the new electricity generation capacity will most likely translate into job creation. It is also important to consider that some of the necessary equipment will be imported – this might be particularly important for solar and battery storage, as wind turbines are mostly built in the United States. All these considerations make the estimation of job creation difficult.

SUMMARY (BILLION $)	OPTIMISTIC	AVERAGE	PESSIMISTIC
Fleet Replacement Cost	21.48	41.74	66.91
Catenary Installations	16.74	20.92	29.29
Clean Energy Capacity	0.73	0.82	1.28
Storage	2.59	2.32	2.68
Fuel Savings	13.38	0.16	0.00
Net Cost	28.16	65.65	100.16

With this in mind, we consider job creation only on total electricity generation and storage and catenary investments for rails. We use construction job multipliers by the Economic Policy Institute, which suggest that for each million dollars spent there are 5.5 direct jobs and 10.9 indirect jobs created.[8] It is important to highlight that these numbers are very preliminary and more detailed work should be done to characterize the quantity and nature of jobs created.

The table below summarizes job creation estimates under this methodology.

Notice that this methodology implies that when spending levels are higher, job creation is higher. So, under our pessimistic scenarios in the previous sections, job creation will be higher. These multipliers are from construction which is very labor intensive. It makes sense to use these multipliers if we are building all this infrastructure. These numbers might be over-estimating the effect on jobs to the extent that some of the necessary parts, in particular for storage and solar panels, are imported. A detailed inspection of each sector is in progress. Wind turbines are, currently, around 80 percent built in the United States; that number is significantly lower for solar panels and batteries.

A second way of estimating the effects on jobs would be to use the current number of people employed in each sector and extrapolate these numbers to the future with the increase in size of each one. We provide some estimates for electricity generation and note that results in the first method are higher than with this alternate methodology.

When it comes to the required additional clean energy generation, according to the National Solar Foundation, there are currently approximately 240,000 people employed in solar energy related jobs with current installed capacity of 67 GW.[9] With an estimated approximately 4,400 MW additional installed capacity, this could lead to the creation of around 16,000 jobs.

	LOW COST JOB CREATION SCENARIO	AVERAGE COST JOB CREATION SCENARIO	HIGH COST JOB CREATION SCENARIO
Generation Capacity			
Direct	30,762	45,499	47,798
Indirect	60,964	90,170	94,728
Storage			
Direct	79,703	127,675	176,766
Indirect	157,957	253,029	350,318
Rail (Catenary Services)			
Direct	115,060	115,060	120,813
Indirect	228,028	228,028	239,429
Totals			
Direct	225,525	288,233	345,377
Indirect	446,949	571,226	684,475
Total	**672,474**	**859,460**	**1,029,852**

On the other hand, the American Wind Association estimates that currently 114,000 people are employed in wind energy related jobs.[10] Considering that installed capacity today is approximately 82,000 MW and that our estimates point to approximately 3,300 MW of additional installed capacity, additional generation could support 4,600 workers in wind energy related jobs.

In total then, the expansion of generating capacity could support around 20,600 jobs, which is significantly lower than with the methodology described above.

The National Association of State Energy Officials (NASEO) estimates that in the United States there are 65,000 jobs related to battery energy storage with a total of 0.75 GW of rated power. Our calculations imply increasing rated power from storage by roughly 1.5 GW could support 130,000 new jobs under this alternate methodology.

Effects on Health

BUSES

Each year, America's diesel and CNG public and school buses cause health damages of around $100 billion through their emissions of criteria pollutants – 11 million kg of carbon monoxide, 107 million kg of NOx, 333 million kg of particulate matter, and unassessed quantities of ozone, lead, and sulfur dioxide. In many residential areas, buses are a dominant source of local air pollutants, nearly all of which could be averted by electrifying the fleet. Even in the absence of renewable generation – a compliance mandate in the proposed legislation – bus electrification would effectively move processes that power buses to efficient, baseload electricity generation facilities that are on average further from people's homes, offices, and places of leisure, reducing local ambient pollution levels.

Of course, which buses are replaced first matters: replacing older buses – which often do not feature emissions control devices – in dense urban areas has a relatively larger direct impact on human health, while replacing newer buses operating in rural areas does not. It is likely that these routes and bus types are more amenable to earlier replacement, too, given their age and the use patterns they exhibit – for example, stop-and-go, significant idling, shorter route length, and lower average speeds.

Part of this cost comes from the aggravation of chronic or acute respiratory or cardiovascular conditions but also from mortality. We estimate the bus emissions lead to around 4,000 excess American deaths each year, many of these children or the elderly who are on average more susceptible to suffer acute adverse responses to ambient pollution.

As described in more detail above, we see this legislation as moving forward in time a process that would likely happen more gradually and in general later. The outcome of interest is then the sum of annually averted deaths multiplied by the average number of years we believe this legislation is accelerating the transition to electric buses. For example, if this legislation accelerates the transition by 20 years, we would then consider that it likely averts 50,000 excess deaths due to reductions in ambient pollution alone.

TRAINS

The electrification of the nation's commuter rail network, under the assumption that all energy would derive from 100 percent clean energy sources with no emissions (as compared to current annual emissions of 13 million kg NOx, 370 thousand kg CO, and 440 thousand kg of particulate matter), would also avert social costs of pollution. Under assumptions similar to those used for buses above, we estimate averted damages of $540 million and 200 deaths for each year this legislation brings forward in time the transition to electric rail.

Effects on Greenhouse Gas Emissions and the Costs of Climate Change

BUSES

In addition to direct health effects, electrifying America's bus infrastructure would avert carbon dioxide emissions that contribute to global climate change. This attribution exercise, though, is a bit more delicate because carbon dioxide has a long residence time in the atmosphere. This affects our analysis in two ways: first, emitted carbon dioxide will cause damages now and in the distant future (meaning the rate at which we discount future damages becomes more significant); second, carbon dioxide causes mostly indirect damages through a large number of channels. To accurately assess the sum of these distant, diffuse damages, we typically rely on the social cost of carbon (SCC). For the purposes of this analysis, we use an SCC of $40 per ton, fairly close to the central estimates preferred in the economics literature and that used by the EPA per OMB Circular A-4. Using this SCC, we find annually averted damages of around $1 billion for annual bus emissions of 20 million tons of CO_2.

As above, a portion of health damages result in death. Best working estimates of this relationship suggest that electrifying America's bus infrastructure would avert around 2,000 deaths for each year that that electrification is brought forward in time.[11] Unlike the death estimates discussed above, however, only a portion of those who die will be American—most excess death, in fact, will occur in places most vulnerable to the sorts of environmental risks exacerbated by climate change – heat waves, tropical cyclones, etc. We by no means argue that only the lives of Americans should count in this exercise; indeed, this restricted analytical frame is the foundation of present inaction on climate change.

TRAINS

The electrification of the nation's commuter rail network, under the assumption that all energy would derive from 100 percent clean energy sources with no emissions, would also avert social costs of pollution. Under assumptions similar to those used for buses above, we estimate averted climate damages of $60 million annually and around 150 annually averted deaths worldwide over the next century for annually averted CO_2 emissions of around 1.5 million tons.[12]

ENDNOTES

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