2020

Accelerating Deep Decarbonization in the U.S. Transportation Sector

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America's ZERO CARBON ACTION PLAN

The Zero Carbon Consortium

2020

5.2 Accelerating Deep Decarbonization in the U.S. Transportation Sector

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5.2.1 Introduction, Context, and Goals

Introduction

Transportation is the largest GHG-emitting sector in the U.S., accounting for 28 percent of total emissions (See Figure 5.2.1).[1] Reducing emissions in this sector is therefore critical in order to achieve the pathways to zero carbon laid out in Chapter 2. Thus, the focus of this chapter is on-road vehicle transportation (cars, buses, trucks) and domestic aviation. These sources contribute 93 percent of transportation-sector emissions in the United States.[2] Rail (2 percent), water-borne transport (2 percent), pipeline (2 percent), and off-road vehicles (<1 percent) will be addressed lightly. International aviation and maritime will not be directly addressed, nor will upstream emissions from producing energy, manufacturing vehicles, and transportation road infrastructure. All of these additional sources of GHG emissions are important, and merit study and policy attention, but are beyond the scope of this chapter.

The most compelling strategy for deep GHG emissions reductions, elaborated upon in this chapter, is to electrify surface vehicles: to switch vehicles from fossil fuel combustion (e.g., gasoline and diesel) to electric propulsion (e.g., battery, plug-in hybrid, and fuel cell electric vehicles). California has set aggressive sales targets for zero-emission vehicles, including a new executive order on September 23, 2020 to reach 100 percent of light-duty sales by 2035, along with a recent rule requiring up to 75 percent of truck sales by that date. The cost of transitioning to electric propulsion is not expected to be great. A comparison of recent studies of a rapid transition to an electric-vehicle dominated car and truck system in California estimated $7 billion between 2020 and 2030 in additional cost for vehicles, energy systems, and refueling/recharging infrastructure due to declining costs.[3] This equates to less than 1 percent of the costs residents of the state would otherwise be paying over those years for gasoline and diesel vehicles and fuels. Approximately after 2030, with this rapid transition, there would be no additional costs. Indeed, the savings to consumers would steadily increase—on a total cost of ownership basis—as a result of the lower energy and maintenance costs more than offsetting the higher (but diminishing) purchase cost of the vehicles. With this affordability in mind, in the near term, policies are needed to accelerate fuel efficiency in the gasoline and diesel fleets. Parallel and increasingly important is to accompany vehicle electrification strategies with policies to expand the production of low-carbon hydrogen and sustainable, low-carbon biofuels.

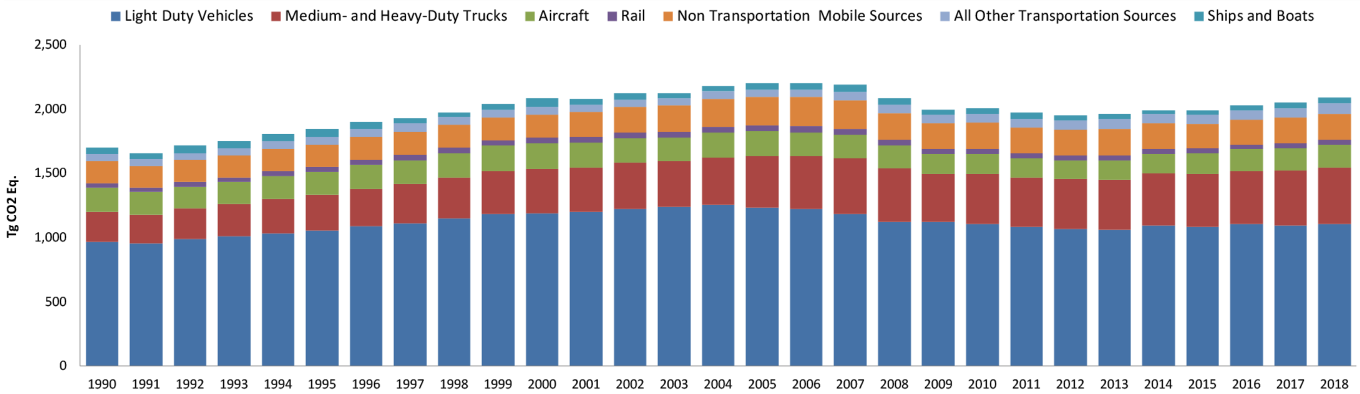

Figure 5.2.1. Change in GHG emissions by source: 1990-2018 (U.S. EPA, 2015).

The second most compelling strategy is reduction in vehicle use—while enhancing accessibility to health, education, jobs, and other services for the mobility disadvantaged. In recent years, vehicle use per capita has been increasing—heightening the need to address vehicle use. Even if most vehicles were powered by electricity and renewable hydrogen, significant GHG emissions would be emitted in vehicle manufacturing and building and maintaining roads. The justification for reducing vehicle use is heightened by the large economic, health, land use, and social equity co-benefits. Strong policies and strategies are needed to alter the travel behavior of Americans; most, but not all of these policies are the prerogative of state, regional, and local governments. The Federal Government does retain a very important role, though. Through legislation and funding, it can empower and support state and local efforts to reduce single-occupant vehicle use and increase the use of less carbon-intense mobility. Federal and state policies can award more funding for low-carbon infrastructure, low-carbon modes of travel, pooled and shared private mobility services, and alter fuel and vehicle taxation practices. These federal policies could assure that most automated vehicles in urban areas are used to carry multiple riders (not zero or one occupants), impose pricing on interstate highways to favor pooled (and electric) vehicles, and support local governments adopting zero-emission zones. A diversity of policies will be needed; the path forward will be at times uneven due to the dramatic variation across states and urban, suburban, and rural communities.

What this chapter does not address is: 1) upstream emissions for producing vehicle energy (e.g., in oil refineries, electricity generation facilities, bio-refineries, and hydrogen production plants); and 2) manufacturing of vehicles and batteries, and manufacturing and building infrastructure, including roads, ports, and other terminals.[4] These manufacturing and upstream emissions are considerable; with today's gasoline cars, manufacturing emissions are less than 10 percent of total emissions, but for battery electric vehicles they account for about 40 percent of total emissions (in part because there are no tailpipe emissions and upstream emissions are relatively small), and could amount to as much as two-thirds of a future battery electric vehicle (BEV) operated on a primarily renewable grid.[5] Upstream emissions of oil production amount to another 20 percent (and increasing) of vehicle energy use, and emissions associated with the manufacture of cement and concrete for roads adding another few percent. Both direct energy emissions as well as upstream and manufacturing emissions would be reduced if the carbon intensity of electricity were lowered, a necessary change detailed in the first section of this chapter.

In summary, the potential for large reductions in transportation emissions is achievable, but a diverse mix of strategies and policies will be needed. The most effective approach, given political realities, is a suite of policy instruments that address the production and use of vehicles and fuels, while providing enhanced mobility and accessibility to disadvantaged travelers. In other words, we must address the sale and use of the vast array of bicycles, scooters, cars, trucks, buses, ships, trains and planes, and reduce the carbon footprint of the energy and fuels that power them. A simple carbon tax could be effective, but most research suggests that to be successful it would need to be far higher than taxpayers and consumers would accept in order to accomplish significant emissions reduction.[6] The behavior of a vast array of travelers, companies, and governments must be altered to achieve deep carbon reductions—which requires a diverse mix of regulations, investments, incentives, and education.

We organize this chapter as follows: the social, economic, and equity implications of transportation investments and policy; overarching scenarios of deep decarbonization; and then strategies and policies to reduce car and truck use, the carbon intensity of car and truck technology, and jet travel, followed by conclusions and recommendations.

Societal Context and Goals

The U.S. transportation system is vital to the national economy and has major impacts on equity, access to jobs and services, and public health. In addition to travel by individuals, the U.S. transports a daily average of over $50 billion in freight.[7] Across all levels of government, the U.S. spends approximately $300 billion annually on transportation infrastructure; still, major investments are needed to repair, maintain, and improve our network of transit, roads, waterways, rail, and aviation systems.[8]

Transportation emissions have been relatively flat in the past 15 years, the result of small reductions in emissions per vehicle (cars and trucks), largely offset by small increases in car and truck use (measured as vehicle miles traveled (VMT)). Total aviation emissions have increased slightly, with substantial increases in passenger airplane travel somewhat mitigated by small continuing improvements in aircraft efficiency as well as operational savings due to routing, take-offs, landings, and ground operations (see Figure 5.2.1). Deep decarbonization will therefore have an enormous impact, and will require reprioritizing transportation infrastructure investments to facilitate low-carbon mobility while growing jobs and our economy.

The transportation system is also a major contributor to air pollution, which impacts public health. Policies to reduce transportation emissions that contribute to air pollution are largely under the jurisdiction of federal and state governments. As authorized by the Air Quality Act of 1967, the precursor to the Clean Air Act of 1970, car and truck emissions are regulated by the US Environmental Protection Agency, with California allowed to set its own standards, including zero emission requirements, as long as they are more stringent. A later amendment to the Clean Air Act (1977) allowed other states to follow either the California or U.S. standards, although the Trump Administration's 2019 attempt to withdraw California's waiver, granting it authority to regulate GHGs, is being litigated. As of 2020, 9 other states have adopted California's zero emission vehicle requirements and 13 states have adopted California's GHG vehicle emission standards. These states, representing 30-40 percent of total light duty vehicle sales, accelerate emissions reduction, as well as the development and commercialization of advanced technology.

With the transportation sector's vast reach and impact, it is critical as we plan and implement pathways for deep decarbonization that we take the social and economic impacts of our regulatory policies into account such that transportation infrastructure investments maximize opportunities for co-benefits that are equitably shared.

Economic Impact

The policies and investments described in this chapter are expected to come at a relatively small net monetary cost to society and can be designed to have a minimal net fiscal impact.[9] Considerable additional resources will be needed during the early years of the transition to accelerate the introduction of low and zero-carbon vehicles and fuels. But most or perhaps all of these additional costs need not come from taxpayers. They can come as transfers between industries and companies, as in California where Chrysler buys zero emission vehicle credits from Tesla, and Chevron buys low-carbon fuel standard credits from electric utilities. Moreover, revenue generated from carbon pricing programs, such as carbon cap-and-trade, and fuel use fees, can be used to incentivize low-carbon transportation investments. Carbon pricing policies that have generated significant proceeds for low-carbon investments include California's cap-and-trade program, which has generated over $11 billion in auction proceeds over the past decade for various clean transportation programs.[10] In addition to direct carbon pricing and investment, other means of incentivizing electric vehicles include revenue neutral fee-bate programs, where high-carbon and less efficient vehicles pay a fee based on their emissions, and low-carbon vehicles (especially ZEVs) receive a rebate.

The likelihood of electric vehicles eventually costing little or nothing additional to society is dependent on the continued drop in the cost of batteries and electric vehicles. In 2010, batteries cost around $1,000/kWh. Now, they are estimated to be around $150/kWh and are projected to drop below $100/kWh by 2025 or sooner.[11] With vehicle prices dropping and significantly lower operating costs, breakeven purchase prices compared to internal combustion engines (ICE) could be achieved before 2025 for many light duty vehicles.

There are significant opportunities to expand domestic clean transportation manufacturing and technology production throughout the supply chain for vehicles and batteries, which can create significant job growth and economic activity. In assessing the economic impact of decarbonization pathways, it is important to also consider the indirect economic benefits of policies such as smart growth and sustainable community planning—for example, transit investment and transit-oriented development patterns. These indirect economic benefits can increase incomes and housing values in local communities.

A key consideration is how the costs and the benefits of the policies impact different groups of people—including between households of different income levels, social and racial demographics, geographies, and place types. Transportation policies and investments should be designed to account for these differences and enhance equity.

Equity and Public Health

An equitable transportation decarbonization pathway addresses the needs of individuals in communities underserved by the transportation system, as well as those overburdened by transportation pollution.

Decarbonization policies can lead to major improvements in public health through the reduction of co-pollutant emissions and the resulting air quality improvements. The transportation sector is responsible for over 50 percent of emissions from nitrogen oxides and a significant contributor of particulate matter and volatile organic compounds emissions, contributors to smog, respiratory ailments, cancer, and other health impacts.[12] The transition to zero-emission vehicles provides a critical opportunity to reduce these tailpipe pollutants. There are particularly impactful opportunities to reduce harmful air pollution through the electrification of medium- and heavy-duty vehicles, including urban delivery trucks, transit fleets, school buses, and port equipment.

Air pollution from transportation sources is concentrated in low-income communities and communities of color, often as a result of historical inequities and policy decisions, such as the siting of highways, ports, industrial facilities, airports, and bus depots. A just and equitable transportation decarbonization pathway will prioritize investments in these overburdened communities. National policies can build from state climate programs and frontline community leadership, such as enacted climate legislation in both California and New York that requires investments that benefit disadvantaged communities. In addition to requiring investment to benefit designated communities, each of these legislative frameworks prioritizes community engagement to inform and direct investments in zero emission transportation programs that best meet the needs of local populations.

Through strategic use of policy, low-income and other mobility-disadvantaged travelers can see significant improvements via expanded public transportation, more and cheaper pooled transportation network companies (TNC), and more and safer micro mobility options, such as shared bicycle and scooter services. It is important for decarbonization strategies to balance VMT reduction goals with the need to increase mobility and access for individuals and communities, including physically disadvantaged and elderly populations. Rethinking transportation planning to prioritize access to jobs and services (rather than speed of travel or other metrics) can create major decarbonization co-benefits.

The transportation decarbonization pathway must also include low-carbon mobility opportunities for rural communities, including car-dependent low-income populations and an aging population. An increased variety of zero-emission vehicle offerings, including light-trucks and SUVs and models with longer range batteries, will have a significant impact. In addition to personal vehicle transportation, rural microtransit services, inter-city public transit route expansion, and increased availability of rural broadband internet and cellular data to promote telecommuting and telemedicine can provide additional benefits to rural populations and reduce the need to travel longer distances to obtain services.

COVID-19 response

In the era of COVID-19, investments in infrastructure, such as broadband, enable more access to services and economic activity through telecommunications. Transportation has been significantly affected by the pandemic, including dramatic decreases in public transit use and increases in telework. It remains to be seen how long-lasting these impacts will be. Transportation policymakers should design policies accordingly to enable continued access to jobs, healthcare, education, social interactions, and other critical services during and beyond the pandemic.

COVID-19 has also brought increased attention to the impact of air pollution on cardiovascular and respiratory illness, including the racial and socio-economic disparities in how the pandemic is affecting communities and individuals across the U.S. A low-carbon transportation future can have the important co-benefit of reducing air pollution, which exacerbates risk.

Additionally, as we consider economic recovery and stimulus opportunities in the face of a recession and significant job losses, the nation should resist repeating the pattern where we expand capacity on our existing car-dependent system. The decarbonization pathway should include opportunities for investments in low-carbon transportation systems to stimulate job creation and economic development and provide alternative transportation options. These could include investments to enable smart growth, such as redevelopment in urban centers and mixed-use development in suburban settings; EV fast charging along highway corridors; expanded transit systems in high volume corridors; and rural broadband infrastructure. Low-carbon investments, such as upgraded transit systems, are often found to be more effective at long-term job creation and economic stimulus than traditional highway infrastructure projects.[13]

5.2.2 Scenarios and Overall Decarbonization Strategies

Transportation can contribute to deep CO2 reductions in the 2050 time frame through a number of different decarbonization pathways. While achieving an 80 percent reduction in CO2 between 1990 and 2050 has been a common target, here we focus on achieving net-zero emissions (excluding manufacturing and upstream energy emissions) within the transportation sector by 2050 (see Figure 5.2.2) based on Chapter 2. We consider the business-as-usual or *reference scenario* compared to the low-carbon *central scenario* with the results demonstrated in Table 5.2.1.[14] These cases assume that the COVID-19 pandemic does not have any lingering effects beyond 2025.

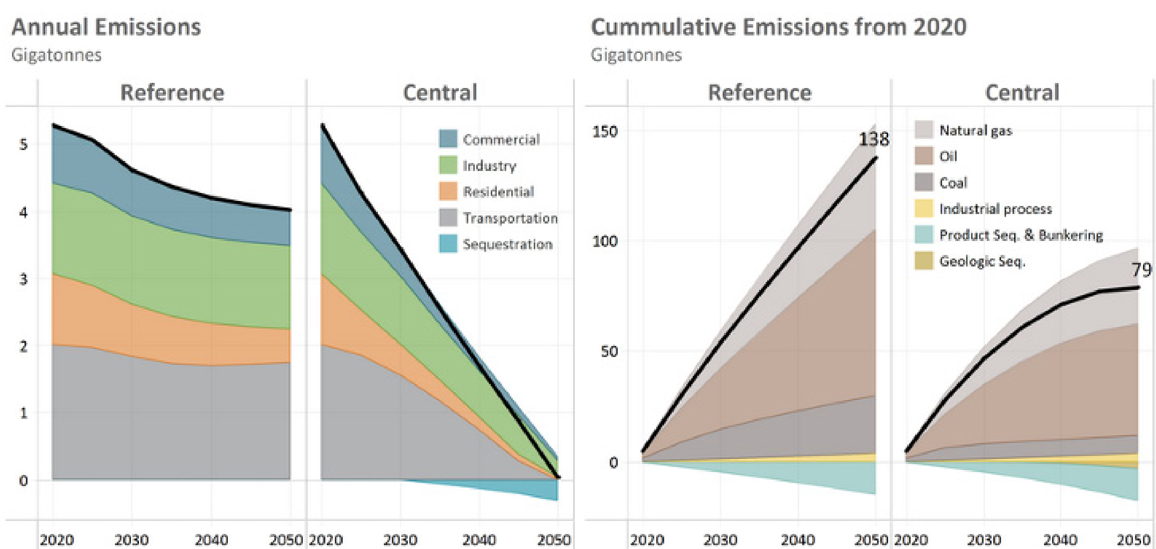

Figure 5.2.2. Emissions from industries across scenarios (Chapter 2).

Table 5.2.1: Assumptions and trends for low-carbon vehicles and fuels by scenario

		Reference Scenario			Central Scenario		
		2030	2040	2050	2030	2040	2050
Zero-emission sales shares	Light-duty Vehicles	10%	15%	20%	50% of sales	100% of sales	100%
	Medium-duty Vehicles	0	0	0	40% of sales	>80% of sales	100%
	Heavy-duty Vehicles	0	0	0	30% of sales	>60% of sales	100%
Zero-emission vehicle stocks	Light Duty Electric Vehicle Stock	5 Million	10 Million	24 Million	>15% of light-duty vehicles are battery electric	>65% are battery electric	95%
Low-carbon fuel share (e.g. advanced biofuels) for ICE vehicles		5%	5%	5%	5%	15%	100%

BAU Reference Scenario

We begin by considering a baseline or *reference scenario*, reflecting current trends and policies, but no new actions to lower CO_2 emissions further into the future. The penetration of low-carbon vehicles and fuels out to 2050 is small in this scenario. The policies undertaken to date spur some uptake but not enough to shift the energy use or CO_2 picture significantly.

Central Scenario

Based on the Chapter 2 model, we consider a low-carbon *central scenario* of near-100 percent reduction in domestic transportation GHG emissions by 2050 there is a strong uptake of zero emission light-duty vehicles with a somewhat slower, but still very ambitious, adoption of zero emission vehicles in the trucking sector. Furthermore, there is a reduction in passenger light-duty vehicle travel relative to the “reference” case. This is achieved from a mix of incentives and disincentives and shifts in transportation funding, resulting in more intensive use of existing modes (mostly light duty vehicles) and some shifting to other modes. We do not do a detailed tracking of these changes in travel but assume a net reduction of 15 percent.

There is an increase in the use of biofuels to replace liquid fossil fuels with advancements in the growth of all biofuels which are to be cellulosic-based, and some algae-based, post-2030. Some electrofuels could also be used. In any case, these fuels would need to provide at least 80 percent well-to-wheels (life cycle) GHG reductions relative to gasoline or diesel fuel. By 2050, transportation-focused fuels such as gasoline and diesel are shown to be largely derived from biomass and (especially) hydrogen conversion in most scenarios apart from the reference. Hydrogen itself is derived from electrolysis and biomass in varying shares depending on the scenario.

The impact of the electric vehicles on grid electricity demand in the *central scenario* is about a 20 percent increase to electricity demand above what would otherwise occur in 2050. There are also liquid and gaseous fuels derived from electricity and used by the remaining internal combustion engine vehicles that add to electric demand. The final energy use in transportation in the *central scenario* is shown in Figure 5.2.3. Energy use drops by more than half to 2050, and electricity accounts for more than half of the energy in that year. Nearly all gasoline has been eliminated and diesel fuel use has been cut by about half.

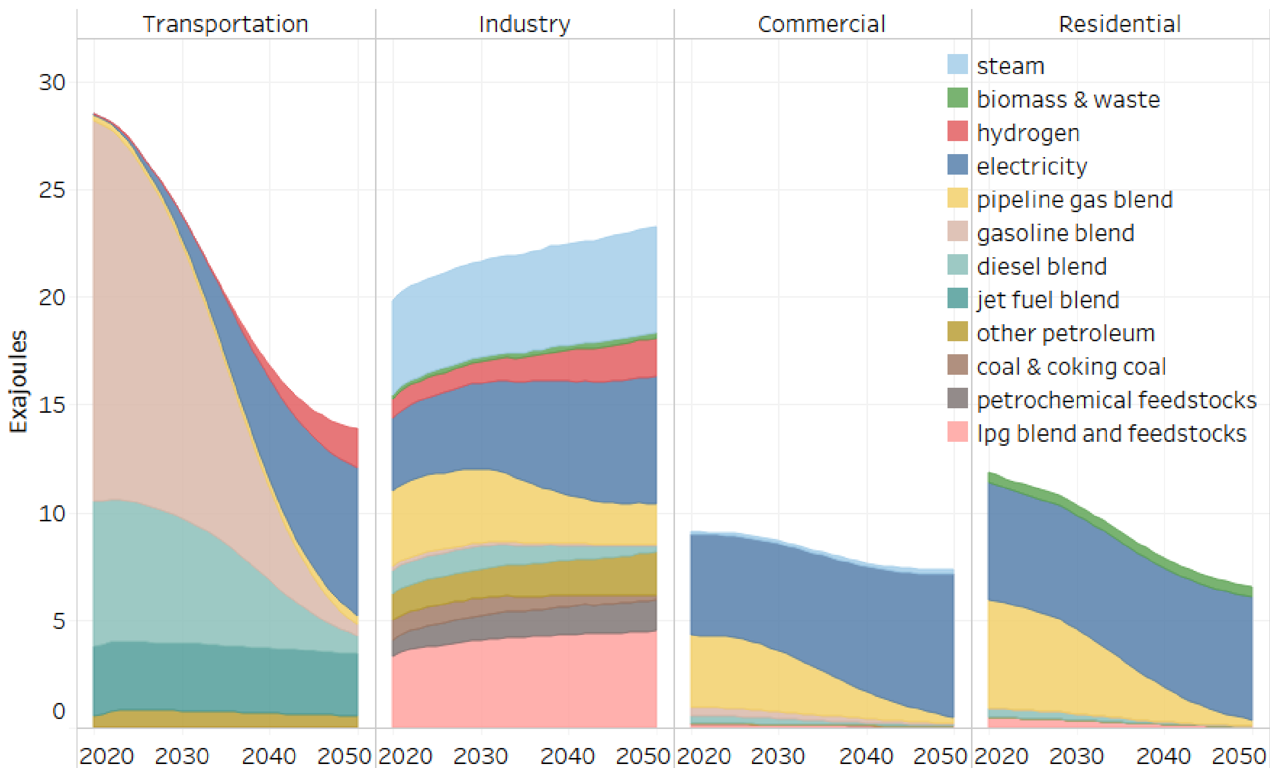

Figure 5.2.3. Final Energy use by sector in the *central scenario*. (Chapter 2)

It may be possible to hit our overall energy and CO_2 targets for 2050 with slower rates of change than shown in this central case, especially in the early years. For example, a 50 percent sales target for light-duty zero-emission vehicles in 2030 may be very challenging to achieve. A lower target such as 30 percent may be reasonable, as long as it is part of a trajectory to approach 100 percent shares by 2040.

5.2.3 Reducing Passenger Travel

Vehicle technology improvements, especially electrification, will dramatically reduce emissions (especially as renewable energy is used for electricity generation and hydrogen production), but substantial emissions will remain from vehicle manufacturing and upstream energy production. Reductions in the amount of vehicle-travel are central to meet GHG reduction goals. This is measured by VMT, representing how far each vehicle travels during a given time-period (e.g., a year). We posit a VMT reduction goal of 25 percent per capita by 2050.

Numerous policies can be enacted to reduce the use of single-occupant vehicles while simultaneously providing additional benefits to communities, including reduction in vehicle crashes, traffic noise, and criteria pollutants, while improving the livability of communities and improving accessibility to opportunities for all, especially disadvantaged communities. Different approaches are needed for different trip purposes and across urban, suburban, exurban, and rural areas.

VMT reductions will be challenging, but are key to achieving deep GHG reductions in transportation. These reductions can be achieved by 1) increasing the occupancy of passenger vehicles, 2) switching to low-carbon modes including active transportation, and 3) replacing trips with telecommunications. Many of these VMT-reducing strategies and policies are under the jurisdiction of local governments, but there is also an important role for the Federal Government, as we highlight in this section.

In urban and some suburban areas, conventional bus and rail transit are compelling solutions if used intensively. They provide an alternative to driving and allow commuters to avoid traffic congestion, improve the economic productivity of transport infrastructure, and provide an important public service by providing access to those who are physically impaired and economically disadvantaged. Public transit accounts for a steadily dwindling share of passenger travel outside of major metropolitan areas. On average today's buses have about the same GHG emissions per passenger mile as cars and light trucks, highlighting the need to fill these vehicles top capacity with passengers, electrify these modes, or convert to less carbon-intensive fuels.

A principal strategy, to reduce VMT and GHG emissions while enhancing the public service benefits of conventional transit, is to focus buses (including Bus Rapid Transit) and rail lines on dense routes and urban centers—and increase their utilization. Land use changes are key to enhancing the economic and environmental performance of transit. Transit performs better when cities focus development around transit stations, increasing utilization and load factors. Various policies can encourage more compact, walkable, and transit-oriented development. These include easing local zoning regulations that restrict denser development and increasing incentives for retail and dense residential development near stations, and creating a more walkable environment so that more people can easily access bus and rail service. As part of any new or expanded transit project, funding incentives should be provided for municipalities to restructure their zoning to allow mixed use and transit-oriented development.

Making streets safer for pedestrians and cyclists will result in a reduction in motorized VMT and GHG emissions, by replacing vehicle trips and providing a feeder service to transit. Funding is clearly an issue, but investments and actions are also frequently hindered by local regulations. For example, even when communities desire safer streets, state Department of Transportations (DOTs) may require expensive studies that only examine the consequences on vehicular traffic flow. Any reduction in the automotive level-of-service may be a roadblock to making a street safer for all users. Relaxing or replacing this arcane but influential policy is important.

Perhaps the most important overarching strategy to reduce VMT is to expand mobility choices. New mobility options include bikeshare, e-bikes, e-scooters, demand-responsive transit (referred to as microtransit), and pooled ride-hailing (especially if automated). More choice means people are not dependent on their personal vehicles, encouraging them to own fewer cars. The result is greater use of low-carbon modes, less cost, more healthy living, less VMT, and less GHG emissions. In urban areas, this less car-centric transportation system provides higher quality service—less time and effort caring for vehicles, fewer parking hassles, and more free time as a result of being "chauffeured."

Federal funding for bicycle, e-bicycle, and e-scooter lanes can lead to safer streets and increased use. These new technologies can also help to extend the reach of existing transit systems, making them more attractive, more efficient, and more equitable, and reduce carbon emissions.[15]

State and local governments make decisions on providing safe infrastructure but this can also be enabled by dedicated federal funding, such as through the Transportation Alternative set-aside program enabled under the Fixing America's Surface Transportation (FAST) Act. Currently some states shift this money to traditional projects; this flexibility should be eliminated and the total funding available should be increased significantly.

Ride-hailing services, including companies such as Uber and Lyft and micro-transit providers such as Via, offer a new mobility option for many travelers. These provide a convenient door-to-door travel option for many trips; they are essentially a cheaper, more convenient taxi. They can serve as a complement to existing high-speed transit services by providing last-mile access and egress, and to replace low quality bus service in suburbs and small cities. In these settings, these services may be less expensive than conventional bus service and can provide higher quality service. A compelling strategy, for transit operators, ride-hailing companies, and travelers, is for these ride-hailing companies to partner with existing transit providers to provide affordable service in suburban, exurban, and rural areas, improving mobility and allowing transit agencies to invest in areas in need of higher capacity and more frequent service.

The promise of vehicle automation could provide greater mobility for many more people. While there was considerable buzz over the last half decade for automated vehicles, automotive and technology companies continue to invest in advancing the technology. It is widely believed that the first lucrative (on-road) application will be food delivery and automated taxis, sometimes referred to as robo-taxis. These robo-taxi services are still under development and while their debut is just beginning (Waymo began operating a sparse commercial service in Arizona in 2019) they build on a strategy of expanded choice; and if shared rides are common could lead to large reductions in VMT.

Another potentially important strategy for reducing VMT is the use of telecommunications to replace travel for work commutes, health services, long distance business trips, shopping and some social interactions. A substantial fraction of jobs can be performed from home, even if only on some days of the week. COVID-19 is demonstrating the feasibility and constraints of a home workforce. One of the constraints is inadequate broadband and hardware; policy can be aimed at increasing broadband connections and subsidizing hardware for homeworkers. Funding can be aimed at subsidizing broadband, especially in rural areas that may have inadequate coverage. Employer tax-credits for providing hardware to employees should be provided.

Likewise, online shopping has surged due to COVID-19, and can be more efficient than having people drive to shops. This trend can be facilitated by increased broadband. One downside is reducing the viability of small-scale retail which is one component of a mixed-use neighborhood and transit-oriented development. These developments already have difficulty attracting a good mix of retail (partly due to competition from big-box stores but also from online retailers). Smaller scale retail in a mixed-use setting allows customers to walk or cycle to the store, or to drive shorter distances. One potential opportunity is to leverage online shopping by converting retail space to centralized delivery locations for customers to pick up products. This could increase the efficiency of online deliveries while maintaining mixed-use and transit-oriented developments.

The Federal Government can play an instrumental role in reducing VMT and GHG emissions, while improving accessibility. Financial actions include altering the distribution of funds from the transportation trust fund and empowering and facilitating local and state actions. Most important is to shift funds, including those in stimulus packages, away from new highway capacity and lane expansions to support transit in dense areas, public-private partnerships between transit operators and ride-hailing providers, bicycle, pedestrian and e-scooter infrastructure, and transit-oriented development. The key mechanism for doing so is to link federal and state transportation funding to per capita VMT reductions. In this way, federal policy can be redesigned to encourage better planning at the local level—by providing funding and incentives to reduce VMT, support walkable and safer streets, and providing residents with alternative modes to avoid driving.

Individually, many of these initiatives would result in small reductions in VMT and GHG. Collectively, they can add up to substantial per capita reductions in VMT and also result in substantial co-benefits of increased accessibility for mobility disadvantaged travelers, reductions in traffic crashes and fatalities, improved air quality, increased walking and physical activity, and an overall better quality of life. It could also result in less costly infrastructure and a more efficient overall transportation system.

5.2.4 Light Duty Vehicle Technology

The overall strategy for decarbonizing light-duty vehicles (LDVs) is quite straightforward: electrify them all and use clean sources of power generation. Electric drivetrain vehicles (EVs), including battery electric, plug-in hybrid, and fuel cell vehicles, all offer large reductions in emissions with today's grid as well as a pathway to net-zero as electricity is further decarbonized. Improved efficiency can reduce emissions, but in and of itself does not offer a pathway to net-zero given the overall constrained supply of low-carbon liquid fuels—in short, fossil-fuel powered vehicles are a technological dead end.

Full electrification of the LDV fleet is therefore both necessary and sufficient to decarbonize this subsector. Getting more specific on how to execute this overall strategy reveals much more complexity and several challenges to deployment. Economics, range and charging, model availability, awareness and attitudes, and lifecycle emissions will all need to be taken into account in developing a comprehensive and effective policy strategy. Because most of the deployment so far has been of plug-in vehicles rather than fuel cells, most of this strategy focuses on these vehicles.

To accelerate the transition to EVs, supportive policy is needed. The first challenge is economics. EVs are currently more expensive to buy than gasoline and diesel vehicles, due mainly to battery costs.[16] However the mean price differential between electric and conventional cars has decreased dramatically in recent years. This is because costs for batteries have dropped by more than 80 percent since 2010. Still EV driving range (and battery size) has grown, the purchase price of EVs has remained higher than conventional vehicles. But within a few years, the total cost of ownership for an EV over its life will tend to become lower than for a conventional vehicle because maintenance is less, due to fewer moving parts, and electricity is generally less costly than the gasoline it replaces. While there were early concerns that batteries would require regular replacement, modern batteries in most applications seem to perform well for over 100,000 miles, with further advances suggesting even longer lives.

While EVs will soon be cost competitive in total costs, the reality is that consumers tend to weigh the initial purchase price of the vehicle more heavily than future maintenance and energy cost savings and thus incentives will be needed for some time, though the need for policy intervention should diminish over time as battery costs continue to drop.

A second challenge is range and charging time. Here is a tradeoff between cost and range, because the simplest way to extend the range of the vehicle is to add a bigger (and therefore more expensive) battery. Ranges of available EVs have increased steadily, with all new models having more than 200 miles of range and some market leaders having more than 400 miles on a single charge. While this is sufficient range for the vast majority of daily travel—since the average car travel per day is less than 40 miles—consumers often consider their most unusual use case when buying a vehicle and so expect a vehicle with long range, fast charging, or a combination of both.[17] This range anxiety issue is addressed in part by providing more fast chargers.

A third challenge is availability of a diverse set of vehicle models. Consumers have come to expect a wide variety of vehicle sizes, shapes and performance, including number of seats, cargo capacity, 4-wheel drive, and power. They want compact or large sedans, small or large pickups with perhaps two rows of seats, minivans with more seats and doors, and SUVs of various shapes and sizes, with different expectations of power, luxury, and style. Over time, a greater variety of EVs will be made available, but for many years, the choice will be much more limited than for conventional vehicles.

A fourth challenge is awareness and perception. Even as sales have increased and a greater diversity of models have become available, general awareness of EVs remains low.[18] Most Americans cannot name a single EV even though more than 50 are now available for sale. Car dealerships often have little to no experience with EVs, and studies of dealers show that many dealers attempt to dissuade potential EV buyers and sell them a conventional vehicle instead. There are also groups of potential buyers who have negative attitudes towards EVs, which may prove challenging to change. On the other hand, people with familiarity with EVs—those who own or have driven them—tend to have positive impressions.

Fifth is social equity and justice. Low income communities, often suffering higher levels of pollution, would benefit from EVs. However, early adopters of EVs have been wealthier, and have benefited from the zero or low emissions of EVs. This pattern is reinforced by more affluent people tending to live in single-family homes where they can easily install home chargers, whereas lower income residents tend to live in multi-family housing and use off-street parking, where charging is more difficult. Public policy should encourage increasing equity in EV ownership as a key goal.

One fact, sometimes questioned, is the net GHG impact of electric vehicles. In virtually all circumstances for all EVs, the lifecycle emissions of EVs, including manufacturing, charging, and disposal, will be significantly less than for conventional vehicles.[19] As electricity generation and industrial processes transition to lower emissions, the gap will grow. Setting policies with the lifecycle in mind can accelerate the greening of electric vehicles.

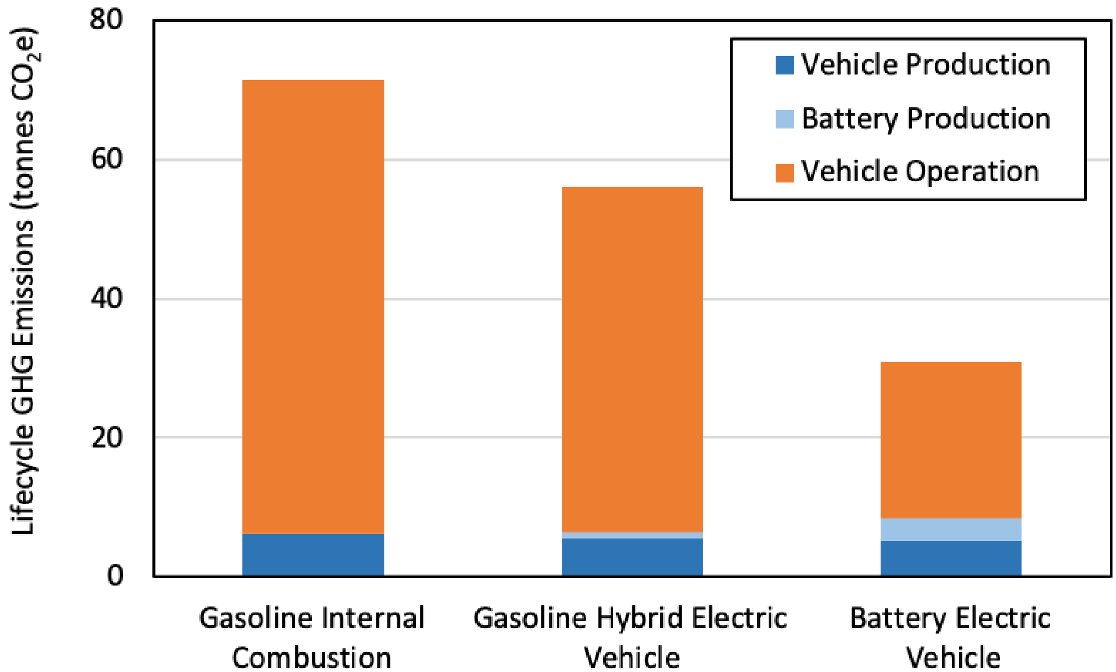

Figure 5.2.4. Life cycle GHG emissions from vehicle production and operation (Kendall et al., 2019). While many factors affect the relative emissions of battery vs. conventional vehicles, under current real world conditions, EVs are much lower emissions. These emissions will decrease as the grid and industrial emissions are reduced.

Policies

While EVs are environmentally superior, and will soon be economically superior, EV market shares will be limited unless the challenges above are addressed. The key elements of policy should include 1) long-term binding rules requiring or motivating automakers to electrify their vehicles; 2) incentives for buyers in the near- and mid-term that improve equity; 3) public investment in charging infrastructure, with a focus on multi-family dwellings and public charging; 4) increased outreach, education, and engagement; and 5) local leadership by cities and regions in support of these aforementioned policies.

EV sales mandates are the single most important policy for decarbonizing transportation. California and nine additional states have a ZEV mandate, which requires automakers to sell an increasing portion of EVs. This mechanism provides a long-term policy signal to manufacturers that they will need to invest in EV development to be competitive in these markets. It also sends a transparent, unequivocal signal to the entire ecosystem of organizations and companies that need to support this transition, including automotive suppliers, dealers, charging companies, electric utilities, public utility commissions, local governments, employers, and more. The current version of the ZEV mandate, adopted by the 10 states, is expected to lead to approximately 10 percent of sales of LDVs in those states being electric by 2025.[20] The mandate will need to be sharply ratcheted up after 2025 if there is to be any hope of deep decarbonization of transportation in the next few decades.

A complementary policy will be the use of greenhouse gas and/or fuel economy performance standards for new vehicles. To accelerate on-going improvements in gasoline and diesel vehicles, these standards will need to be tightened at least 5 percent per year in MPG terms. If tightened even faster, as is happening in Europe, a ZEV mandate might not be needed, since automakers would accelerate their commitment to EVs as a way of meeting these fuel economy/CO_2 performance standards. One advantage of standards is that they could in principle be developed to account for the full lifecycle of the vehicle, encouraging more efficient manufacturing and reuse or recycling as a component of compliance.

Mandates, standards, or a combination should be affirmed in statute to provide policy certainty to automakers. The fact that all other major car markets in the world—China, Europe, Japan, and Korea—have adopted aggressive vehicle fuel economy and electrification policies provides additional market and policy certainty to automakers.

Clean vehicle purchase incentives are a second complementary policy. Incentives are needed to overcome the higher purchase price of EVs in the near term, and the continuing reluctance and resistance of consumers, which may persist for many years, perhaps decades. These incentives could be in the form of rebates, feebates (a revenue-neutral rebate for EVs paid for by a fee on high GHG emitting vehicles), tax credits, or reduced registration fees. In the U.S., many states have had incentives for purchasers of EVs, in addition to the federal tax credit of up to $7,500. Many European countries are providing even larger incentives. Such incentives are highly influential in purchase decisions.[21] Incentives for new vehicles should be limited to either lower income households or subject to a vehicle price cap. High income buyers are less influenced by incentives; these restrictions are effective at improving the equity effects of incentives. Since about two-thirds of all vehicle purchases are used vehicles, usually by lower income households, opportunities to apply incentives to used vehicles should be given high priority.

The costs of funding vehicle purchase incentives need not be imposed on taxpayers. Since subsidies will continue to be needed as the market expands, expanding the magnitude of needed incentives, revenue source creativity is a necessity. For instance, rebates can be included as part of feebate programs, whereby fees would be placed on purchases of bigger, higher fuel-use, and more expensive vehicles. Relatively small fees on these vehicles could, in aggregate, pay for fairly large rebates, at least until the clean vehicle market grows to a sizable share of the total new vehicle market. These feebates can be based on sales taxes or registration fees. Another mechanism is to use revenues from carbon taxes or cap and trade programs to pay for incentives. And still another non-taxpayer mechanism is to package credits generated from sales of electricity to households within a transportation low-carbon fuel standard (LCFS) program, as California is doing. In this case, oil companies are buying credits from electric utilities, in effect creating a subsidy from the oil industry for electric vehicles.

Charging and hydrogen infrastructure support is a third complementary policy. The vast majority of EV charging today occurs at home and at work. Public charging is still important, however, in enabling long-distance trips, providing an occasional emergency charge, and increasing consumer confidence. Public charging will be a mix of medium-power 'level 2 charging', well-suited to situations where vehicles are stationary for extended times, such as at workplaces, shopping malls, overnight at multi-family dwellings. There is no widely accepted single method for estimating the number of needed chargers for a fleet of EVs. EV infrastructure demand depends heavily on the specific geography, fleet mix, and vehicle-use patterns of the scenario in question.

However, one recent analysis from the National Renewable Energy Laboratory (NREL) –based on another NREL report by Wood (2017) –suggests that "on average 0.57 DCFC stations (and 1.85 plugs) and 40 non-residential L2 plugs per thousand [plug-in electric vehicles] (PEVs) [are] needed to provide minimum coverage requirements".[22] This implies that 15,000 DCFC plugs and 320,000 L2 plugs would be needed to support a fleet of 8 million EVs by 2025 (the amount forecast by the U.S. Department of Energy's (DOE) Annual Energy Outlook 2019). This represents approximately five times the number of plugs available in the United States today.

Faster charging is needed to support taxis, work vehicles, ride-hailing vehicles and long-distance trips. The revenue from electricity sales rarely covers costs, and thus support from electric utilities, employers, and others is needed. In the early years, support is also needed for hydrogen stations, until utilization of stations increases. Hydrogen stations can become profitable more quickly since the energy throughput is faster and larger.

Outreach and awareness: Private companies will, in the long run, need to advertise and sell EVs. In the early market, however, there may be a public role in increasing awareness of the benefits and availability of EVs in general. Outreach and partnership with dealers can also improve their awareness of the benefits of EVs.

Local policy: Although the focus of this is federal policy options, many local actions can support the transition to EVs. Several U.S. cities, including Austin, TX, Los Angeles, CA, and Seattle, WA have signed the "Green and Healthy Streets" declaration are moving to adopt zero emission areas, which allow access only to clean transportation modes such as walking, bicycling, transit, and EVs. Other cities and regions allow free or discounted use of priorities lanes and other forms of preferential access.

Summary Policy Recommendation for LDVs:

We recommend a foundational policy of a national LDV ZEV mandate at a minimum of 30 percent by 2030 and 100 percent by 2040. This will provide the long-term policy certainty to allow the automotive industry to invest in EV development with confidence.

This policy should be supported by a suite of other policies, including:

- Incentives as a subsidy or feebate that phases out over time, for example as EVs pass 10 percent of a particular vehicle market segment. Include an incentive for used EVs, avoiding potential for gaming the system through multiple resales.
- Increase Corporate Average Fuel Economy (CAFE)/GHG standards to keep pace with the ZEV mandate and also increase the efficiency of conventional vehicles as a transitional emissions reduction option
- Invest in charging infrastructure through federal investments
- Government fleet EV purchase requirements to demonstrate buy in

5.2.5 Medium and Heavy Duty Truck Technology

While most attention to vehicle electrification has been focused on light-duty vehicles, trucks are increasingly seen as appropriate for using the same technologies. There are many different types of trucks, notably varying in terms of overall weight, driving patterns, and daily driving distances. Given the relatively high efficiency of battery electric vehicles in an urban cycle, most medium duty urban trucks (such as delivery vans and even larger trucks up to class 6), are good candidates for electrification with savings on both operating and energy costs, and short payback times for initial higher cost vehicle investments. These higher costs are also dropping, along with the on-going reductions in battery costs, and many truck types should reach purchase cost parity with diesel trucks within the next 10 years, and have overall “total cost of operation” that is significantly lower.[23]

The bigger challenge is with very heavy (class 7 and 8) trucks, both for long haul and urban “day truck” use. These trucks would need large battery packs to move the heavy loads they typically carry (up to 30 tons of payload). Various studies suggest that it will be possible and even cost effective to run such trucks on batteries up to at least 200 miles per day, especially if their operation allows for some periods of recharge during the day.[24] The use of such trucks in long haul operation (e.g., up to 500 miles or more per day) becomes increasingly problematic without significant periods of recharge or use of ultra-fast charging, such as using one megawatt (or greater) charging power levels, which will be expensive and create energy/power issues for grid power systems. Since trucks traveling such long distances account for a high share of overall trucking fuel use, this is an important issue.

For such long haul trucks, as well as other types of vehicles with long range requirements, fuel cells are expected to be an attractive option, given their potential for much longer range driving per refueling, and much faster refueling. However these trucks are currently expensive, as is the retail cost of hydrogen (such as is used for light duty vehicles in California). It is widely estimated that the cost of fuel cell trucks will continue to decline to where, at high volumes, they will be competitive with diesel trucks in the 2030-2035 time frame; the bigger question is the cost of hydrogen. In theory, use of electrolytic hydrogen from renewable power generation could eventually provide very low production costs, with a final retail price of hydrogen dropping to as low as $5/kg, compared to typical prices of $15/kg today.

At $5/kg (about equivalent on an energy basis to $5/gallon gasoline), and with the efficiency advantage of fuel cells, fuel cost per mile could eventually be competitive with diesel or gasoline fuel. But this also is unlikely to be achieved before 2030. More RDD&D and much investment is needed to reduce the costs and improve the efficiency of fuel cells, hydrogen storage tanks, and electrolytic (green) hydrogen production—similar to what happened with batteries over the past decade. Policies that accelerate the commercialization of fuel cell vehicles will play a large role in inducing the needed investments.

Finally, an important low-carbon fuel strategy for existing gasoline and diesel trucks is advanced biofuels and synthetic liquid fuels. It is feasible that either advanced biofuels, with truly low-carbon life cycle emissions, or fuels created from electricity (via production of synthesis gases and then long-chain hydrocarbons as “drop in” fuels), can provide essentially net-zero GHG emissions operation. However, in the case of biofuels, the challenge is scaling up technologies that allow production from biomass such as grasses, other cellulosic materials, and algae, and moving away from starches and oil-seed crops that do not perform as well from either a carbon nor general environmental impact perspective.

Determining the quantities of any biofuels that can be produced sustainability is an additional challenge, suggesting that any biofuel used in transportation be allocated to their most valuable applications (including aviation).

In the case of electro fuels, a pathway from electricity to liquid fuels, building molecules with CO_2 captured from exhaust gases or the atmosphere, can provide zero emissions, but the issue is cost. Currently these technologies can cost on the order of $10/gallon or more to produce; eventually, at large scale and with learning, and done in certain locations, it is believed this cost could come down to below $5. But even then, unlike an equivalent price for hydrogen, there is no vehicle efficiency benefit from these fuels and the fuel cost would thus be significantly higher than for hydrogen.

There are a range of changes that could be considered in our freight systems that could be coupled with the technology solutions, and some that would help enable these solutions. For example, some freight truck systems could be restructured to facilitate use of (shorter range) battery-powered trucks—such as relocating distribution centers closer to final destinations, using more, smaller trucks on shorter routes, and shifting some delivery to micro-systems such as e-bikes or even drones. Achieving an overall electric urban freight system should not require trucks that can travel more than 100 miles per day, and system adjustments to allow this should be possible—the challenge as always will be to reconfigure systems in a cost-effective manner.

For long haul shipments, there is a long, on-going discussion of moving more freight to rail, where it is viable and cost effective. Rail is already a major mover of bulk raw materials around the country, though shipments of coal have declined substantially in the past 10 years, possibly increasing capacity for other goods. One challenge in the U.S. is the shift in recent years to “just in time” delivery, which reduces the attractiveness of (more circuitous and slower) rail systems. Still, moving entire containers from trucks onto rail, and back to trucks again is common and probably could be expanded if pricing systems incentivized this. Most studies suggest that the effects of such policies might be small without strong price signals, which may be problematic for other reasons but is worth exploring. Finally, if rail is to take on a greater role and provide substantial GHG reductions over trucks, rail would need to be fully decarbonized, which means either widespread catenary systems or shifting to fuel cell locomotives, neither of which is currently being widely pursued. If trucks achieve very low CO_2 emissions by transitioning to electric propulsion and low-carbon biofuels, then the advantages of switching freight to rail mostly dissipates.

5.2.6 Intercity Passenger Travel: Aviation, Coach, Rail and Personal Vehicles

While decarbonization of daily travel within communities and metropolitan areas is critically important, approximately 30 percent of the passenger miles of travel in the United States are estimated to be long-distance or intercity.[25] Intercity, including international, travel is undertaken by personal vehicle, motor coach, rail, and aviation. Long-distance travel, both personal and business, was projected to significantly increase before the COVID-19 pandemic and may again as growth is driven by disposable income, the large global tourism industry, wide-spread social networks, and globally dispersed manufacturing and business operations. Aviation and rail account for 9 percent and 2 percent of transportation emissions in the U.S.[26]

Much of the future growth in passenger aviation was projected for international travel, requiring coordinated policy actions. The US Department of Commerce estimates that only about 15 percent of international trips were for business purposes, which suggests lingering COVID-19 impacts on business travel might not have significant effects on GHG emissions.[27]

The length of intercity trips and shipments vary significantly. Policy solutions vary by distance range and here we focus on passenger travel on “intra-regional” as less than 400 miles one-way and “inter-regional” as greater than 400-miles one-way. Note that in many cases “inter-regional” trips are 1000s of miles or even intercontinental in length. Ultimately, different modes incur different levels of energy and embody different efficiencies per passenger mile but ultimately trip length and how full the vehicle is. The longer the trip the more energy and thus emissions and therefore the vehicles should be operating with as close to capacity of passengers as possible.

Significant replacement of liquid petroleum-derived jetfuel upon which the inter-regional trips rely will be a challenge due to energy density. Airplanes have steadily improved efficiency since the 1970s, reducing energy use per passenger mile by 3 percent per year since 1970, and 2.6 percent annually since 2007.[28] Through 2050, researchers expect a net improvement of 2 percent per year in energy per passenger mile but most of this improvement is attributable to fleet turnover and operational improvements not merely aircraft design. Sustainable aviation fuel (SAF) or bio-jet is being tested in several markets but the generation of the quantities needed for complete, or even substantial, substitution is not feasible with expected fuel stocks. Policies to incentivize reasonable levels of SAF for use in flight for trips over 400-miles is recommended. This effort should include an international low-carbon jet fuel standard. For interregional long-distance travel above 400-miles (or travel across water, to Hawaii for example) airlines have little modal competition and there are no time-effective alternatives. In this range, reducing travel demand (or holding it constant without growth) through significant increased ticket fees and allocation of these resources based on efficiency-based metrics to airlines and airports is a viable policy option. Given that flying is needed for national and international communities and economies, the decarbonization solution for long-haul passenger aviation (>400-miles) is based on the assumption that these aircraft will remain legacy users of petroleum. Although the policy goal should be reducing short-haul segments (<400-miles) even when the overall trip is longer, in total we must aim to hold passenger flight miles constant at pre-COVID-19 levels. Note as well some shorter flights in places without alternatives will remain such as for Alaska, Puerto Rico and Hawaii, especially for freight. Fees on international arrivals may be a reasonable way to raise revenue for green airport infrastructure.

Miles flown on petroleum fuel for trip lengths or segment lengths less than 400 miles must be minimized if not completely eliminated. This goal can be accomplished through a combination of investment in alternative modes, reduction of travel demand and both electric flight and electric surface vehicles. This diversion of inter-regional travel from air to surface will require fees of a substantial level and incentives for development of higher passenger capacity for reasonable range electric flight. In the 120 to 400 mile range there must also be incentives and infrastructure investment where demand is high for reliable rail service and electric coach service. Travelers should be encouraged to use flying for trips where efficient surface alternatives are not viable.

The needed modal substitution in intercity travel will include switches from airlines to automated electric coaches and vans.[29] Incentivizing multi-person commercial vehicle services, including motor coaches, will be critical especially in congested corridors. To achieve decarbonization, long-distance automated vehicle travel must be via electric vehicles.

While high-speed rail, similar to what is available in other countries is desirable, there are other lower cost solutions that can improve rail service. Selective upgrading of current infrastructure that allow higher average speeds (above 120 mph) and more reliable speeds can be beneficial in high volume corridors. Exploration of more effective high capacity rail or coach service potentially along interstate highway corridors with airports as multimodal mobility hubs is advisable. In short, policies to discourage short-haul flights, even those that are part of longer trips, will be necessary replacing these with electric ground transportation that is better integrated with air scheduling. Finally, trips generally under 120 miles should most often be ground-based and can be converted to EVs but require regional coordination to ensure access to those who may be transit-captive especially in rural areas. There will be a need to develop more efficient ground-based services for essential air service routes.

There is the need for an expanded role of the USDOT and Federal Aviation Administration (FAA) in national mobility and infrastructure system planning for long-distance travel. The aviation system operates on a large geographic scale within which only the USDOT has jurisdiction for coordinated system-wide planning. An optimized national aviation system (including the expanded use of electric ground equipment, flight path optimization to reduce emissions, increased renewable energy generation at airports, use of underutilized airports to reduce induced driving and reduce infrastructure investment and coordination of surface mode connections including rival heavy and light rail systems) requires data, modeling and strong vision-based decision-making. Airlines and private actors should be expected to optimize for their own system, but they require strong national public policy and robust international agreements to set system-wide objectives and operating rules. Federal policy, largely driven by funding, should be balanced between modes to provide the best solutions. Currently aviation funding is separate from ground transportation funding, leading to non-optimal investment decisions. There should be one unified transportation trust fund, instead of one for highways and one for aviation.

In general, airport infrastructure expansion should be limited with an emphasis on improving the environmental performance of existing airports and using existing capacity. Moreover, national travel data and a demand forecasting model is needed to guide a potential re-alignment of the hub and spoke routing patterns which may be resulting in more passenger air miles than required to meet actual passenger origins and destinations.

In short, for intercity travel (including any part of a trip) under 400-miles, modal substitution to electric surface vehicles is necessary. In rural areas, this will include electric motor coaches and in urban corridors rail, light rail, and motor coaches. Policies to accelerate conversion to these systems will be needed. For travel or segments over 400-miles in length, shorter legs must be eliminated and ground transportation and total passenger miles flown must be held constant powered by liquid petroleum fuel and where feasible limited biofuel stocks encouraged by international low-carbon fuel standards.

5.2.7 Conclusions and Policy Recommendations

To reduce GHG emissions in the transport sector, one strategic initiative stands out: the transition from combustion engines to electric propulsion for virtually all cars, trucks, and buses and a limited number of airplanes—including the use of battery, plug-in hybrid, and hydrogen fuel cell electric vehicles. But even in this transition to electric propulsion, a suite of policies is needed, including aggressive GHG vehicle performance standards, vehicle sales requirements, incentives for vehicle purchase (especially during the next decade), and incentives and subsidies for public charging and hydrogen stations.

The cost of this transition will be relatively modest in the context of our massive expenditures for vehicles and fuels. Indeed, in most vehicle segments electric vehicles will eventually be less expensive in terms of total cost of ownership—eventually generating large cost savings to the economy and society. If one adds reductions in external costs, especially health and climate, then the savings to society become quite large.[30]

The second most important strategy is reduction in vehicle use and filling vehicles to passenger capacity, but with an understanding that greater accessibility is desired for mobility disadvantaged groups such as those with low incomes, those with mobility disadvantages, and elderly travelers. In simple terms, this means improving services that carry more passengers and discourage those that serve single occupants or drivers, including zero occupants (as could be the case with automated vehicles). The types of services to be incentivized include conventional buses and rail, pooled ride-hailing services, and bicycles, e-bikes, and e-scooters. Reducing VMT and improving accessibility for mobility disadvantaged travelers is especially challenging, but the number of co-benefits is large, including cleaner air, improved public health, less land for parking and roads, lower road infrastructure costs, and more equitable access to jobs, school, health services, recreation, and more.

Overall, the top priority policies to reduce emissions from the transport sector are the following:

- Make ZEVs a high share of vehicles
- National ZEV sales requirements for cars as described in chapter 4:
    - National LDV ZEV mandate at a minimum of 30 percent of new sales by 2030 and 100 percent of new sales by 2040.
    - National medium duty vehicle (MDV) and HDV ZEV mandate at a minimum of 20 percent of new sales by 2030 and 80 percent of new sales by 2050.
- National ZEV sales and fleet purchase requirements for trucks
- Incentives for ZEV vehicle purchases and support for investments in needed ZEV infrastructure
- Tightened fuel economy/GHG standards for all new cars and trucks
- Low-carbon fuel standards covering all fuels for road vehicles and airplanes

- Reduce passenger travel and vehicle dependence—while increasing access for walking, bicycling, new micro mobility modes, telecommunications, transit, pooled ride-hailing services, and other low-carbon choices, especially for disadvantaged travelers, via:
  - Altering distribution of funds from the federal transportation trust fund and stimulus packages away from new highway capacity and lane expansions, and toward bicycle, pedestrian and new micro mobility modes infrastructure; transit in dense areas; and public-private partnerships between transit operators and ride-hailing providers.
  - Supporting local and state actions to increase low-carbon travel and investments, reduce single-occupant vehicle use, and support transit-oriented development.
  - Pricing policies that create incentives and generate funds for investments in low-carbon alternatives

Other priorities include investment in and support of low-carbon biofuels for aviation, ships, and long haul trucks, and the use of automation for electric, pooled vehicles. Automated vehicles (AVs) are desired, from an environmental (as well as an economic and equity) perspective, only if they are used in commercial mobility services that feature pooled services (versus single passengers)—and not individually owned. If individually owned they will likely lead to large increases in VMT, largely offsetting emission reductions from electrification. When used in commercial pooled services, this new technology provides the opportunity to reduce vehicle use, provide low-cost accessibility to mobility disadvantaged travelers, reduce the cost of travel to individuals and society, and sharply reduce the amount of land devoted to transportation.

Transportation is generally seen as the most challenging sector to decarbonize, but it may also prove one of the least costly—even eventually providing large economic saving. It is also the sector with the greatest opportunity to provide a large number of associated co-benefits to travelers and society and to create a more environmentally sustainable and equitable society.

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