The Future of Mobility

A Report by the Mobile Sources Technical Review Subcommittee

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- Technology Work Group: Amy Bunker, Susan Burke, Bill Charmley, and Christy Parsons
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Executive Summary

Since its inception in 1996, the EPA Mobile Sources Technical Review Subcommittee (MSTRS) has provided the U.S. Environmental Protection Agency and its Clean Air Act Advisory Committee (CAAAC) with independent advice, counsel, and recommendations on the scientific and technical aspects of programs related to reducing air pollution from motor vehicles and other mobile sources.[2]

In recent years, the agency has been assessing the impact of a wide array of new technologies, fuels, and transportation trends on the air pollution, climate, and other environmental impacts of the transportation sector. Some of these mobility trends include, without limitation:

- the accelerating electrification of light-duty passenger cars and certain segments of the medium-duty and heavy-duty truck and bus market;
- the increasing use of renewable, alternative fuel, and/or other low-carbon fuels in today's vehicles and future vehicles that will continue to operate on liquid fuels;
- changes in personal mobility that stem from the emergence of micro-mobility and the intersection of transit, land use, and community development; and
- shifts in last-mile goods movement as retail goods increasingly are bought and sold online, a trend that has accelerated during the Covid-19 pandemic.

From September 2019 until June 2021, at EPA's request, the MSTRS met regularly to develop a series of insights and recommendations that sought to address a series of questions arising from these topics. The 35 members of the MSTRS self-selected into one of four work groups that explored a series of questions that were designed to consider a range of future mobility paradigms in each of the following four categories: Vehicle Technology, Fuels, Personal Mobility, and Goods Movement. These meetings and discussions, along with additional research and analysis throughout the process, enabled the Subcommittee's experts from state, local, and regional government, the automotive and related industries, fuel and energy companies, environmental and other public interest organizations, and academia to develop the work presented in this Future of Mobility report.[3]

This Future of Mobility report summarizes the research, analysis, discussions, and recommendations of these work groups. In addition to this executive summary, this report includes a chapter for each work group, which provides detailed insights and recommendations related to their respective topic. Each chapter addresses questions and topics that aim to help guide EPA's ongoing near-, mid-, and long-term work. In addition, each chapter discusses important equity, accessibility, and other considerations that will help ensure that our future transportation systems are safer and more equitable for all. Last but certainly not least, each chapter discusses possible new approaches to EPA's work, with respect to its many collaborations with other federal agencies, state, tribal, and local air pollution officials, and the full range of industry, environmental organizations, community groups, and other stakeholders that have interest in the topics discussed in this report.

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[2] https://www.epa.gov/caaac/mobile-sources-technical-review-subcommittee-mstrs-caaac

[3] This report represents the work of each work group and the discussions of the entire MSTRS and does not necessarily represent the views or opinions of each of the entities represented on the MSTRS.

The following table presents the initial questions posed to each of the work groups:

Technology "Zero Emissions"	In a world where the majority of new light-duty and heavy-duty fleets are zero tailpipe emission technologies (e.g., battery electric, hydrogen fuel cell), describe EPA's work and role in reducing emissions from transportation while maintaining mobility.
Personal Mobility "Share a Ride"	In a world where the majority of people in the U.S. get from Point A to Point B using a transport mode other than a personally owned vehicle, describe EPA's work and role in reducing emissions from transportation while maintaining mobility/accessibility.
Fuels "Future Fuels"	In a world where alternative fuels such as electricity and hydrogen are used to meet a significant percentage of the light-duty and heavy-duty onroad fuel demand, describe EPA's work and role in reducing emissions from the fuel pool.
Goods Movement "I Want My Stuff!"	In a world where goods delivery primarily happens through on-line orders and by direct-to-household-and-business deliveries, describe EPA's work and role in reducing emissions from transportation options in the supply chain (e.g., between the final distribution site and a household or business).

In addition, each work group was asked to consider the following questions:

What are the opportunities and challenges that may arise in each scenario?

- What factors are most important for positive environmental outcomes?
- What type of information would EPA need?
- What tools, skills, or authority would EPA need to continue reducing transportation emissions in the given scenario?
- What role would state, tribal, and local government, industry, environmental organizations, and other stakeholders play in this evolving landscape?
- What other new concepts are emerging that EPA needs to consider, i.e., what is the next disruptor?

Over the course of the MSTRS's Future of Mobility work, ten themes emerged:

1) To meet the nation's greenhouse gas (GHG), criteria pollution, and other Future of Mobility goals, EPA should adopt a comprehensive approach to decarbonizing the entire transportation sector – which will mean accelerating the use of zero-emission vehicles (ZEV), decarbonizing the liquid fuels and the engines that will continue to be used in many applications, and finding ways to move people and goods in as sustainable and equitable a way as possible.
    - Certain vehicle classes and applications will move to electrify or adapt other zero-emission technologies relatively quickly (e.g., passenger vehicles, transit buses, school buses). However, even in the best-case scenario, EPA will need to adopt strategies to

reduce emissions from the millions of cars, heavy-duty vehicles, nonroad engines, marine vessels, locomotives, and aircraft that will still use internal combustion engines and liquid or gaseous fuels throughout the 2030 – 2050 timeframe.

- Recent research from the Intergovernmental Panel on Climate Change underscores the critical importance of the next ten years. Strategies that accelerate rapid deployment at scale will bring cleaner air, improved health, and reduced GHG emissions faster in the short-run and in the long-run.

2) Good data and analysis will be critical to meeting our Future of Mobility goals.

- EPA should consider a wide range of better, updated, more nimble databases, emissions models, and monitoring, as well as new analytic tools designed to answer the questions that the MSTRS has been addressing. EPA should also take steps to ensure all fuels, technologies, and strategies are evaluated in ways that maximize decarbonization while meeting other important policy goals.

- Examples of areas for EPA to consider include an updated MOVES model (e.g., for ultrafine PM and aerosols, emissions from brakes and tire wear, etc.), life-cycle analyses, personal and community exposure in environmental justice and near-highway environments, telematics data, consumer choices for both personal mobility and their package delivery, logistical/operational improvements in goods movement, more holistic fuel/vehicle systems approaches (e.g., vehicle-to-grid integration), fleet averages that consider ZEVs accurately, land use models that consider pedestrian and bicyclist safety, community mapping to understand environmental justice impacts, evaluating the impact of Covid-19 on transportation, cost-benefit analyses, better understanding of grid, infrastructure, model availability and related issues, and more.

3) EPA should consider ways to integrate and prioritize principles of social equity, environmental justice, and mobility justice in ways that have never been done before.

- EPA should consider ways to prioritize investments and programs in a manner that increases social equity, affordability, accessibility, and mobility justice to create economic opportunity.

- EPA should consider how to use Diesel Emissions Reduction Act (DERA) funding and other tools to prioritize pollution hotspots, reduce disproportionate burdens, increase transportation justice, expand opportunities for workforce development (e.g., ZEV maintenance), and increase scrappage of the oldest, dirtiest vehicles.

- EPA should consider adopting new approaches to longstanding environmental justice issues, including compliance and enforcement (e.g., consider ports as stationary sources; new ways for its Office of Transportation and Air Quality (OTAQ), Office of Air Quality Planning and Standards (OAQPS), Office of Enforcement and Compliance Assurance (OECA), and other EPA offices to coordinate).

- EPA should consider ways to improve real-time and other emissions monitoring to better understand personal and community exposure.

4) EPA will need to identify and pursue ways to increase collaboration across agencies and levels of government.

    - EPA should continue to assert the leadership role on fuel and vehicle issues.

    - As EPA moves from regulating tailpipe emissions to broader, more holistic approaches to moving people and goods sustainably, increased collaborations with federal agencies (such as the Department of Energy (DOE), the Department of Transportation (DOT), the Department of Housing and Urban Development (HUD), the Department of Labor, and others), state, tribal, and local governments, standard-setting bodies, industry, environmental organizations, community groups, and others will become more important than ever before.

5) EPA should consider solutions that are outside its traditional regulatory authority.

    - Additional or new regulatory, non-regulatory, and other strategies will be necessary to mitigate the externalities that the MSTRS has already foreseen, such as upstream stationary source emissions, battery mining, end-of-life recycling issues that arise from increased use of ZEV technologies, the need to reduce disproportionate impacts on communities of color, and other environmental impacts related to personal mobility mode choices and shifts in last-mile goods movement.

6) Fuel-neutral, technology-agnostic performance standards will continue to be critical for both fuels and vehicles.

    - Examples include the Clean Trucks Plan, announced on August 5, 2021, which will include a rulemaking, to be finalized in 2022, that will apply to heavy-duty vehicles and engines starting in model year 2027, and an additional rule to reduce GHG emissions from new heavy-duty vehicles and engines that would go into effect as soon as model year 2030.[4]

    - Other examples include future low-carbon fuel performance standards, low-carbon biofuels standards, other fuel quality standards for gasoline or diesel fuel, and any other fuel, vehicle emission, or efficiency standards that may be promulgated.

7) Incentive, public education, and outreach programs will continue to be critical to accelerate deployment.

    - Existing partnerships, such as SmartWay, the 21st Century Truck Partnership, Energy Star, and other partnerships to promote sustainable communities, will play a vital role, especially if new sources of funding can be identified and secured.

    - EPA should consider ways to coordinate with the DOE, the DOT, charging entities (e.g., Electrify America, utilities), and others to increase funding, visibility, and consumer education.

8) EPA will need to consider new approaches to solve new problems <u>and</u> old problems (e.g., legacy vehicles), some of which are beyond EPA's traditional role.

[4] www.epa.gov/regulations-emissions-vehicles-and-engines/clean-trucks-plan

- Examples of ideas to consider beyond traditional tailpipe emission standards include a ZEV efficiency standard; new roles for high-octane, renewable, and other low-carbon liquid or gaseous fuels; evaluating the use of hydrogen for biofuel production; strategies to increase vehicle occupancy; shifts towards shared vehicles, "right-sized" vehicles, micro-mobility, and more active transportation modes; integrating automated vehicles; California's Clean Mile Standard; transit, land use, and related issues that impact congestion, mobility and vehicle-miles traveled (VMT); and others.
- EPA will need to consider how to integrate transportation issues that are not directly emissions-related but are part of a holistic approach to transportation, such as safety, affordability, reliability, access to jobs, and other issues.

9) EPA should consider additional strategies that will be needed for hard-to-electrify components of the legacy and future fleets.

    - EPA will need to consider strategies to reduce emissions from agricultural, construction, marine, locomotive, aviation, and other nonroad engines and equipment to complement its strategies for highway vehicles, as well as from long-haul trucking and other diesel sectors that will be slower to electrify.
    - Research and development support and other strategies will be needed to explore new low-carbon, carbon-neutral, or even carbon-negative fuels, such as hydrogen, e-fuels, or advanced biofuels.

10) There is no "silver bullet"

    - Meeting our near-term, mid-term, and long-term climate, health, and equity goals will require an integrated, holistic, data-driven, approach that uses new and existing tools, approaches, and strategies.

Detailed insights and recommendations from each of the work groups are included in the remaining chapters of this report. The MSTRS looks forward to continuing the important discussions about the range of Future of Mobility topics that it began in 2019, and towards further dialogue with EPA and its Clean Air Act Advisory Committee.

Chapter 1: Technology

1.1 Executive Summary

The Mobile Sources Technical Review Subcommittee (MSTRS) is a subcommittee of EPA's Clean Air Act Advisory Committee (CAAAC) and provides the latter with independent advice and perspective on scientific and technical aspects of programs related to mobile source air pollution and motor fuels. Through a variety of work groups, the MSTRS addresses a wide range of developments and transportation emissions-related policy issues. The MSTRS is composed of approximately 30 technical experts drawn from an array of stakeholder organizations, including individuals from the automotive industry, energy companies, academia, public interest groups, and state, tribal, regional, and local governments.

The MSTRS initiated a study to explore how EPA (the agency) can best ensure reduced emissions from the transportation sector, while increasing mobility access in a future world where the majority of new vehicles are comprised of zero tailpipe emission technologies (e.g., battery-electric, hydrogen fuel cell).

As a primary task[5] for EPA's request, a "Technology" work group[6] was convened to offer suggestions for agency consideration under this majority-ZEV-sales future. As a secondary task, the group also provides suggestions for the "transition" period between today and the majority-ZEV-sales future. These recommendations are provided in no particular order. We start with the primary task considerations.

1.1.1 Agency Considerations in a Future where the Majority of New Vehicle Sales are Zero-Tailpipe Emission Technologies

In this future, the Technology work group assumes that ZEV sales are increasing rapidly, consistent with the market entering the "late majority" phase of a typical technology diffusion curve. At this stage, the majority of new vehicle buyers are adopting ZEV technologies in lieu of internal combustion engine vehicle (ICEV) alternatives. While decarbonization and emissions reductions of the light-duty fleet will be well underway, continued agency diligence will be important. The work group recommends maintaining a robust and science-based understanding of transportation air quality issues, including (but not limited to) emissions monitoring, impacts to frontline communities, inventory modeling, vehicle technology cost and effectiveness, market adoption of technologies and barriers to technology adoption.

The work group also recognized that the ZEV-majority-sales scenario has structural implications on existing regulations, such as fleet average requirements for criteria pollutant emissions. For example, under a fleet averaging approach that includes a large portion of ZEVs, there is at least a mathematical potential for some degree of ICEV emissions performance backsliding. The work group suggests that

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[5] Technology work group EPA assigned task considers: "In a world where the majority of new light-duty and heavy-duty fleets are zero tailpipe emission technologies (e.g., battery-electric, hydrogen fuel cell), describe EPA's work and role in reducing emissions from transportation while maintaining mobility."

[6] The work group representatives interpreted this to apply to light-duty vehicles and focused on "majority" as to referring to new car sales rather than the on-road fleet of light-duty vehicles.

EPA investigate pros and cons of fleet average compliance schemes, particularly as they relate to forecasted zero-emission technology market share.

Another element of the ZEV-majority-sales scenario is that it could coincide with substantial growth in car-share and ride-hailing (or ride-share) services due to the fact that electrification, automation, and connectivity could make these services financially and socially very attractive. To reduce emissions from fleets and catalyze the broader market's transformation, EPA could explore opportunities for a national fleet standard modeled upon the innovative Clean Miles Standard, a transportation network company (TNC) regulation pioneered by California. Data show that these fleets have the potential to offset transit use and increase vehicle trips, raising vehicle miles traveled. It will be important for the agency to analyze the impacts such transformations could have on the trajectory of GHG and criteria emissions.

The Technology work group strongly believes that equity—and equitable mobility—should be key considerations in EPA's efforts to protect public health and welfare. In the context of the ZEV-majority-sales future (and during the transition to it), EPA should support availability of ZEV technologies to all, as a means of ensuring equitable protection of the public. The work group provides several suggestions for ways to make new and used ZEVs easier to use and own in underserved communities. The work group recommends the agency develop metrics to establish and identify high priority populations and underserved communities that would benefit the most from equity driven programs, as well as to identify potential barriers to accessing such technologies or programs.

1.1.2 Agency Considerations During the Transition Toward a Zero-Tailpipe Emission Technology Future

The transition to ZEVs is nascent, characterized by the innovators phase of adoption, though some areas of the country are also seeing early adopters. The pace of growth toward a majority-sales adoption stage will depend on a range of factors, including industry investment decisions and consumer adoption behavior. The work group delved into some of the key challenges and opportunities associated with this transition. It is the work group's view that equity considerations elevated in the ZEV-majority-sales scenario are largely relevant during this period as well, though for brevity the discussion is not repeated. In the transition section, challenges associated with consumer adoption are summarized, along with suggested policies (regulatory and otherwise) that can promote continued and accelerated ZEV technology development and deployment.

Several challenges to consumer ZEV adoption are identified, including higher technology cost, limited access to charging (or hydrogen fueling) infrastructure, limited consumer awareness, limited product offerings in certain vehicle categories, low gasoline prices and continued (albeit more modest) efficiency gains in conventional ICEVs. EPA's approach to low-carbon transportation policy will have a notable effect on the speed of this transition. Thoughtfully designed policies can provide incentives, and support industry actions that will prove necessary for meeting low-carbon transportation goals. The work group recommends that EPA consider, analyze, and advise on policies complementary to vehicle emissions standards that can help foster ZEV adoption. Finally, the work group notes that transportation and/or economy-wide carbon pricing mechanisms have the potential to enhance consumer signals for choosing the cleanest vehicle options.

The work group recognizes that the transition to ZEV technologies means that the main transportation contributions to emissions will shift from the vehicle tailpipe to upstream power (electricity or hydrogen) production. Increasingly, as power plant emissions clean up, the emissions associated with the production of materials that make up a vehicle will become a larger share of total vehicle lifecycle emissions. EPA support in the areas of lifecycle assessments will be valuable in helping ensure that a holistic approach to emissions reductions is taken, one that considers not only exhaust emissions, but also upstream emissions, materials-based emissions, and emissions from other sectors, with prioritization that considers abatement costs and benefits while targeting full turnover of the transportation sector to low- or zero-carbon options.

EPA should also evaluate the potential for emissions performance standards in transportation fuels to drive innovation toward the lowest emissions sources. A low-carbon or clean fuel standard would both encourage the reduction in the carbon intensity of existing liquid fuels while helping to fund the development of zero emission fuel technologies. These will be particularly important for aviation, marine and other portions of the transportation sector that have limited electrification potential. Some work group members also highlight the potential for new gasoline-biofuel blends to offer near-term reductions in ICEV technology emissions during the transition to ZEVs. In all cases, EPA should continue activities supporting the agency's analytic understanding, as well as public communications, of the full lifecycle emissions impacts of vehicles and their fuels.

Similarly, there is an ongoing need to educate policymakers and the general public to increase awareness and knowledge of the benefits of low-carbon transportation, taking into account varying community needs and backgrounds. These efforts will be fundamental to realizing the future low-carbon world being considered by MSTRS and the agency more broadly.

Many of these actions can be taken now to achieve immediate reductions and lay the foundation for achieving full and necessary decarbonization in line with long-term climate and clean air goals. Even still, the path toward these goals includes challenges. The pace at which the costs of low- and zero-carbon technologies achieve parity with conventional combustion technologies – while, importantly, providing consumers and businesses with the seamless functionality they have come to expect – will be a dominant factor in determining the speed at which this transition occurs. Similarly, resource management and production capacity of batteries, fuel cells, motors and related components will be important factors in the transition from liquid-based fuels to electrification. It is critical that EPA take a holistic approach to regulation, giving proper attention to these and other issues as the agency considers appropriate regulatory frameworks.

1.2 Agency Considerations in a Future where the Majority of New Vehicle Sales are Zero-Tailpipe Emission Technologies

The set of items EPA will need to consider under a future ZEV-heavy environment are fundamentally different from the types of considerations the agency has deliberated over the past five decades. While the past (and by most accounts, near-future) regulatory playbook has and will largely involve cost-effective performance-based standards ratcheting down tailpipe pollution over time, such an approach will be less meaningful under a ZEV-heavy future.

1.2.1 Alternative Regulatory Structures

It is expected that the domain of further environmental improvements will shift from mobile sources to stationary sources, from vehicle tailpipes to powerplant smokestacks, from carefully controlled aftertreatment and on-board diagnostics (OBD) systems, to the extraction, refining and transporting of key minerals needed for batteries, motors, and power electronics. The vast majority of "cleaning of the fleet" will occur through stock turnover, as older ICEVs on the road are replaced with clean, zero-emission technology. Vehicle emissions will predominantly be a conversation about powerplant emissions. As to the vehicles themselves, today's attention on powertrains is likely to shift to other environmental impacts of mobility, such as tire wear, brake dust, cabin air quality, and materials-based emissions.

As in-use emissions diminish due to greater electric vehicle (EV) market share, the significance of upstream emissions (i.e., the extraction, refining and transporting of fuel) and the emissions associated with materials used in vehicles will increase. Regulators will need to recognize the importance of mitigating these emissions where they are generated. The agency may wish to consider reforms in areas beyond emissions certification/compliance, such as validation of environmentally sound supply chains.

As the Chair of the UN ECE GRPE, EPA is well positioned to develop and define characteristics of a "normal EV."[7] As part of this process, specific analyses can better define usage and driving patterns on the path to a global regulation considering region-specific driving patterns. Part of this process also involves developing a global technical regulation on battery durability including original equipment manufacturer (OEM) certification of range or battery energy and in-service confirmation of retained range or retained energy after specified operational time, mileage, and age of vehicle, with the goal of maintaining minimum EV performance standards. EPA could play a more proactive role and allow OEMs to develop traction battery state of health metrics that are based on field data over a period of time. Battery state of health metrics may possibly be based on initial usable battery energy rather than range.

Though it is likely out of OTAQ's purview, upstream emissions and the emissions associated with materials in vehicles will take on significant relevance. Ongoing innovation in the areas of connected, automated and shared mobility will require special consideration by the agency to ensure that the future of mobility is more "heaven" than "hell" in its environmental impact. While the respective paces of the coming "Three Revolutions"[8] are not yet clear, the auto industry's committed investments in these areas strongly suggest they will arrive. The agency should continue to familiarize itself with this transition to ensure it is prepared to regulate accordingly.

At the same time, it is critical that the agency continue its core activities, including monitoring, collecting data, and understanding the evolving emissions inventory. These efforts are fundamental to knowing where the agency should focus its attention, and how aggressively to regulate. Similarly, understanding the distribution of transportation emissions, and the impacts they have on underserved communities and other populations, remains critical. Even with a shift toward greater relevance of upstream and embodied emissions in the transportation sector, it will be important for EPA to maintain a robust understanding of the inventory, markets, and science, given the evolving broader mobility landscape.

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[7] See "Higher Level Information Needs on Charging / Electrical Grid," p.23, for additional items that could impact normal usage characteristics.

[8] Sperling, D. (2018). Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future. Island Press: Washington. This work examines how automated, shared, and electric vehicles are transforming the mobility landscape, and how policymakers can steer this technology in a sustainable, equitable direction. A more detailed discussion of this can be found in the Personal Mobility section of the report."

1.2.2 Approaches to Emissions Averages

One of the regulatory items that EPA will likely need to grapple with sooner rather than later is the issue of fleet average criteria emissions. This approach, which has historically been implemented to provide automakers flexibility to comply, presents a different set of challenges in a future where the majority of new vehicle sales are ZEVs.

California Air Resources Board staff and environmental non-governmental organizations (NGOs) have recently expressed concern that as a higher fraction of new vehicle sales become electric, an overlaid fleet average requirement could allow "backsliding" from the remaining ICEVs sold in the new car fleet. (Figure 1)

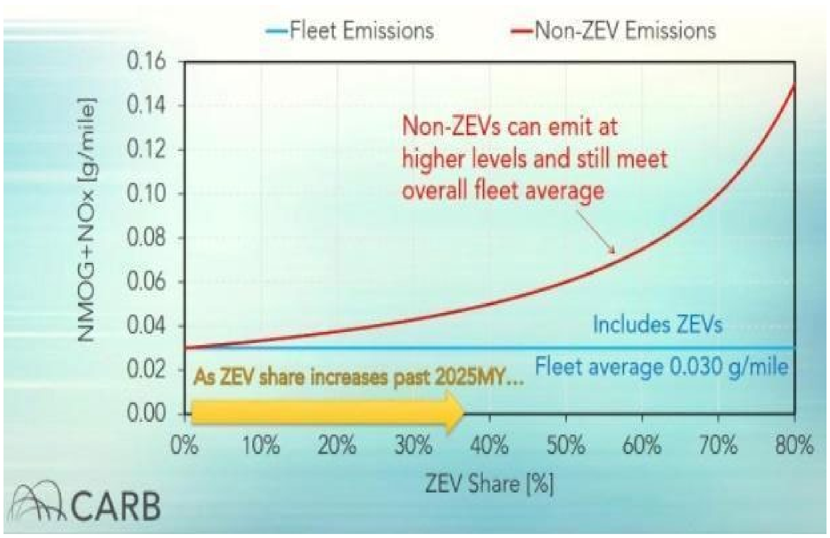

Figure 1: CARB presentation illustrating NMOG+NOx "backsliding" concept. (California Air Resources Board, 2020).

Automakers regard this scenario as highly unlikely, given the investment and effort required to reverse course and seek cost recovery on a smaller and smaller share of product. Nevertheless, one potential solution could include placing a ceiling on non-methane organic gases (NMOG) and NO_x emissions, effectively creating an ICEV emissions backstop. Agency monitoring of ICEV emissions would ensure total fleet emissions are appropriately controlled. ICEVs and ZEVs could continue to be part of a combined (ICEV & ZEV) fleet average standard—set as usual on a cost-benefit basis. This approach of having an ICEV + ZEV fleet average with an embedded standard for ICEVs would encourage continued development of ZEVs while ensuring that ICEV emissions are improved as needed to meet air quality goals.

1.2.3 Electric Vehicle Efficiency Standards

As the number of grid-based EVs on the road grows, it will be important to understand the implications that onroad vehicles will have on grid-based emissions and the power sector writ large. From the perspective of quantifying the emissions inventory, it is important that EPA continue to refine its understanding of the demands plug-in EVs (PEVs) place on the grid which, by extension, requires understanding vehicle efficiency. This awareness will allow the agency to quantify regional emissions, as well as inform public consideration of the potential need for additional powerplants and related infrastructure, as the fraction of grid-based vehicles in the onroad fleet grows.

From a consumer adoption standpoint, it is beneficial for customers to understand the monetary impact that a vehicle's electricity consumption will ultimately have. EPA investigated this issue more than a decade ago and concluded that customers' lack of familiarity with electricity metrics such as kilowatt-hours (kWh) limits their comprehension of this issue. As such, the agency today includes miles per gallon (MPG)-equivalent (MPGe) estimates on vehicle window labels, using the vehicle's efficiency and a conversion factor of 33.7 kWh per gallon of gasoline-equivalent to yield MPGe estimates that better allow customers to cross-compare on showroom floors. Vehicle window labels also include overall efficiency estimates on a kWh/100mi basis for those seeking a more detailed assessment of a vehicle's electricity consumption.

A question raised within the work group was whether PEVs should be regulated based on their overall electric efficiency. The group found that there was no clear answer to this question. On one hand, ensuring higher efficiency would put downward pressure on PEVs' grid demands. On the other hand, there is strong governmental interest in increasing the fraction of renewables on the grid in a very short period of time, promising to reduce the environmental impact of PEV charging regardless of vehicle efficiency. If the U.S. succeeds in decarbonizing the power sector by 2035, as currently proposed, the grid consequences of high rates of PEV usage will be felt largely as an infrastructure need (i.e., increased electricity demand could prompt the need for more renewable generation) rather than an emissions impact (i.e., increased electricity demand causing greater emissions from fossil-fueled power generation).

Grid impacts aside, EV efficiency standards could serve to reduce materials-based environmental impacts. Efficiency standards could be achieved by advances in materials, power density, recharging efficiency, minimizing electrical losses and thermal management of battery systems, while reducing battery and vehicle weight, all serving to minimize overall lifecycle emissions.

Over the past four decades, improvements in the fuel efficiency of vehicles were accompanied by trends towards greater vehicle power, acceleration, size, and weight. These same trends are apparent in recent EV announcements. It is worth noting that in many of these cases, increases in EV size, weight, and battery capacity are a function of diversification into new segments and the pursuit of broader consumer adoption. Regulators themselves have been calling for greater market segment diversification, suggesting that broader availability will yield increased adoption rates. In considering whether there is a need for EV efficiency standards, the agency should do so in a way that recognizes the need for continued customer choice that furthers zero emission technology adoption.

Some work group members observed that manufacturers are already highly motivated to improve the efficiency of grid-based EVs. Range anxiety has proven to be one of, if not the most important impediment, to consumer adoption of EVs. There is already significant market incentive to improve vehicle efficiency as a means of providing adequate range without undue cost associated with the need for additional batteries. In considering whether there is a need for EV efficiency standards, EPA should evaluate the impact of this key market driver.

A final question raised, but not answered by the work group, was whether EPA is indeed even best suited to address this issue. In the near term, EPA's experience with vehicle regulations makes it the right place to continue tracking the emissions consequences of increased electrification. In the longer term, particularly after the grid has decarbonized, the DOE – which already implements minimum efficiency standards for a wide range of appliances and has longstanding experience in this arena – may be better suited to monitor and, if needed, take on this issue. The statutory authorities of the respective agencies in this space would also need to be considered.

1.2.4 Electrification, Automation, and Connectivity

The introduction of electrified, automated, and ride-sourcing mobility options has the potential to revolutionize mobility in the coming decades.[9] Ride-sourcing services, coupled with driverless technology, could reduce the cost of commercial services, which in turn could lower costs of travel. As an example, Figure 2 shows a scenario[10] of future costs, illustrating the potential attractiveness of electric automated rideshared vehicles in 2035. These revolutions in transportation may combine in various ways that result in very different travel behaviors, vehicle occupancy, urban traffic patterns, parking, infrastructure, energy use and GHG emissions.

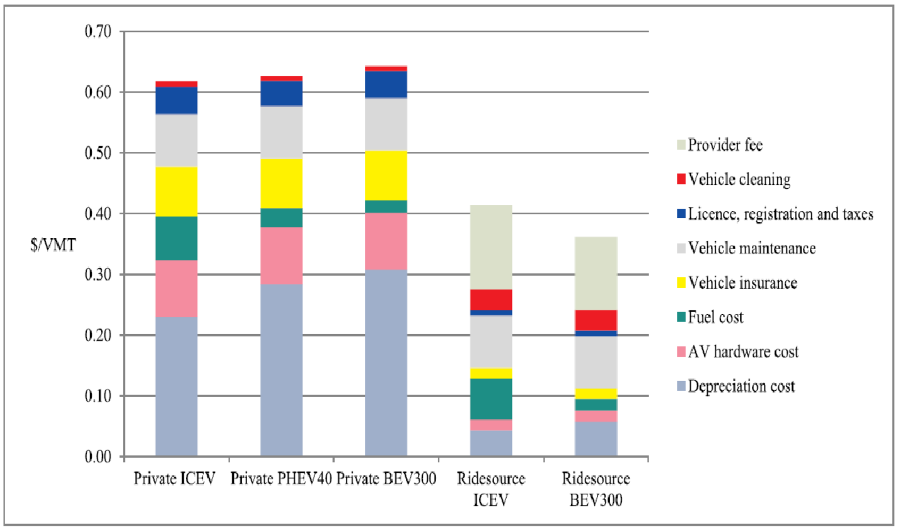

Figure 2: Example illustrating the potential economic attractiveness of electric automated rideshared vehicles in 2035 (Compostella et al., 2020).

Regulators should consider opportunities to leverage the enormous growth potential of these new mobility options, as well as conventional fleets, to accelerate transportation electrification and address community needs. Vehicle fleets—including government, corporate, utility, and TNCs—account for a large share of the vehicles and miles driven on America's roads. In fact, corporate fleets represent 18 percent of U.S. light-duty vehicle registrations, and light-duty federal government fleet vehicles drove 1.8 billion miles in 2019.[11] At the same time, TNC ridership is growing quickly, and such services now carry billions of riders each year. In some cities, TNCs are now responsible for as much as

[9] Sperling, D. 2018. Three Revolutions: Steering Automated, Shares, and Electric Vehicles to a Better Future. pp 14, 15. Island Press: Washington.

[10] J. Compostella, L.M. Fulton, R. De Kleine, H.C. Kim, T.J. Wallington, Per-mile cost estimates for automated vehicle and shared mobility in the United States in the near and long term, Trans. Policy, 85, 54 (2020). Figure 5.

[11] https://www2.deloitte.com/content/dam/Deloitte/us/Documents/consumer-business/us-cp-fleet-leasing-and-management-in-north-america.pdf; https://www.gsa.gov/policy-regulations/policy/vehicle-management-policy/federal-fleet-report.

13 percent of all vehicle miles traveled (VMT), alongside traditional taxi fleets.[12] Vehicle automation will only add to these trends, growing the fleet vehicle population and its VMT.

Fleets are well-suited for early and accelerated electrification because they often perform a large share of stop-and-go urban driving or defined routes. In ride-hailing fleets, each vehicle provides rides to numerous passengers, and can act as a mechanism to increase public exposure to the technology.[13] There is an opportunity for rideshare companies to facilitate education and outreach about ZEVs, which can have secondary benefits of informing non-TNC vehicle owners. To reduce emissions from fleets and catalyze the broader market's transformation, EPA could explore opportunities for a national fleet standard modeled on the innovative TNC regulation pioneered by California, known as the Clean Miles Standard. This regulation sets emissions standards on a per-passenger mile basis, emphasizing the need to reduce VMT relative to passenger miles traveled.

The regulatory community needs to also consider regulations for a highly automated, connected, and shared mobility ecosystem. For example, using a gram of CO_2 per passenger mile metric would be appropriate for such fleet regulations. However, the ability to collect accurate vehicle occupancy data is a challenge that should be addressed.

Electrification, Automation, and Connectivity Recommendations

- Maintain a robust and science-based understanding of transportation air quality issues, including (but not limited to) emissions monitoring, impacts to frontline communities, inventory modeling, vehicle technology cost and effectiveness, market adoption of technologies and barriers to technology adoption.
- Annually evaluate and report on the pace of transportation "revolutions" that are likely to impact transportation air quality, including (but not limited to) connected, automated, shared, and electric mobility. Use the opportunity to communicate advance/draft agency thinking and raise issues of potential regulatory significance.
- Annually evaluate and report on the pace of transportation "evolutions" that are likely to impact transportation air quality, including micromobility, public transit, goods movement, and livable communities. Use the opportunity to communicate advance/draft agency thinking and raise issues of potential regulatory significance.
- Evaluate whether there is a need for EV efficiency standards. In doing so, the agency should consider the impact of existing market drivers, including consumers' demand for adequate vehicle range, as well as the role of continued customer choice in furthering zero emission technology adoption.
- Explore pros and cons of fleet average compliance schemes, particularly as they relate to forecasted zero-emission technology market share.

[12] https://drive.google.com/file/d/1FIUskVkj9lsAnWJQ6kLhAhNoVLjfFdx3/view
[13] ICCT, Emerging policy approaches to electrify ride-hailing in the United States (https://theicct.org/sites/default/files/publications/EV_ridehailing_policy_approaches_20190108.pdf)

- During the transition to carbon neutrality, explore creative and targeted approaches to particular segments—such as fleets, including ride-hailing operations—to accelerate transportation electrification.

1.2.5 Equity

According to the EPA, environmental justice is the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies."[14]

However, the environmental justice gap for underserved populations is growing as historical injustices continue to disproportionately impact communities of concern. The Intergovernmental Panel on Climate Change (IPCC) Fourth National Climate Assessment Report[15] found that underserved populations such as low-income communities, older adults, people with diverse abilities and some communities of color (e.g., Black, Latino/a/e, and Indigenous) are more exposed to environmental hazards and pollution and thus, have a harder time recovering from the impacts of climate change. These populations may also have less access to—and therefore less familiarity with—new technologies that aim to resolve negative environmental impacts.

To increase access to clean transportation and mobility options for underserved populations, the following actions should be considered, in alignment with the DOT's Pillars for Mobility Access and Inclusion.[16] The work group has included a list of actions that it believes should be considered. However, the group also recommends soliciting more direct input from the environmental justice community.

1) Help increase awareness and access through engagement with new technologies:

    - Vehicles and their fuels: through ride-and-drive events, new mobility services based on zero emission vehicles (e.g., carsharing, ride-hailing), and new or used personally owned zero emission vehicles.
    - Integrate design elements into technologies that allow better access to new technologies for underserved communities. Design considerations could include (but not be limited to):
        - Payment methods for un/under-banked;
        - Multi-lingual features;
        - Cognitive/physical abilities support; and
        - Geographic proximity to natural community gathering locations such as churches and schools.

[14] https://www.epa.gov/environmentaljustice
[15] https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf
[16] https://www.transportation.gov/accessibility

2) Increase access to clean transportation and mobility options and services:

- Promote policies that expand the use of zero emission vehicles in new mobility services, including autonomous vehicles, ride-hailing, and carsharing.
- Promote policies that deploy shared micromobility services, such as scooters and bikes, near underserved populations.
- Promote policies that foster inclusive design elements related to cognitive and physical accessibilities for shared mobility and services.
- Encourage car dealerships to stock new and pre-owned ZEVs.
- Deploy safe and well-lit refueling infrastructure in low-income communities and those with multi-unit dwellings, and ensure they use payment methods that are widely accessible to low-income or un/under-banked individuals.
- Couple closely with expanded education to build awareness and understanding. For example, with respect to clean transportation and mobility services, how to reserve and use them, and the types of options available.
- Provide federal, state, and tribal incentives to individuals for the purchase of pre-owned, as well as new, ZEVs.

3) Help increase awareness of clean transportation options and make them more affordable:

- Educate individuals of varying income levels and backgrounds about affordable ways to transition to cleaner technologies and the benefits they offer relative to their cultural, geographic, and socio-economic circumstances, including the potential savings in fuel and maintenance costs.
- Implement a federal ZEV incentive program for consumers with diverse levels of income, considering:
    - Vehicle Replacement – Program for lower-income individuals to replace their highly-polluting vehicles with a more efficient new or used option (ex. Plug-in hybrid, fuel cell vehicle, EV).
    - Refueling – Within the vehicle replacement program, include incentives for an optional home charger or credit to access public charging or refueling, as well as charging pathways that accommodate placement at rentals or multi-unit dwellings.
    - Hydrogen: Consider possible avenues for alleviating high hydrogen cost in the early market, especially for those facing greater environmental justice challenges.
    - Alternative Mobility Options: Provide awareness of and access to multiple mobility solutions that meet community needs, including carsharing, ridesharing, bikes, scooters, public transportation vouchers, trip planning, reservation systems, etc.
    - Dealerships: Encourage dealerships to properly train staff on EV technology and use (potentially through incentives), and broadly disseminate information on new and used EV incentive programs to consumers in an equitable manner.

- Organize campaigns to educate consumers, and specifically underserved populations, on the benefits of zero emission transportation and incentive programs.

Equity Recommendations

- Identify high priority populations and underserved communities that would benefit the most from equity driven programs.
- Develop metrics to measure the benefit from equity driven programs. Construct metrics that consider both mobile and stationary sources, based on community pollution monitoring.
- Identify potential barriers to accessing such technology or programs (cost, infrastructure, etc.).
- Foster and maintain relationships with companies and manufacturers that reliably and cost-effectively provide services to those located in these communities.
- Incentivize practices that would promote and enable consumers in these target populations to use secondary programs, such as single driver high-occupancy vehicle (HOV) lane access.
- Consider methodologies, such as those being developed by the United Nations Working Party on Pollution and Energy - Electric Vehicles and the Environment (GRPE-EVE) discussed above, aimed to ensure that the technology is reliable and safe to protect investments made on behalf of the consumer.
- Provide continual outreach and support to community-based organizations and non-profits for consumer education and advocacy.
- Work with local and tribal agencies to provide reliable funding opportunities to various communities who will assist in electrifying or decarbonizing their communities.

1.3 Agency Considerations During the Transition Toward a Zero-Tailpipe Emission Technology Future

Notwithstanding the agency charge to consider a majority-ZEV-sales future, the Technology work group felt strongly that consideration of future clean transportation and mobility needs remains important, along with understanding the pace and scope of the transition between today and tomorrow's future low-carbon world. The following sections highlight this transition period, and relevant topics of consideration.

1.3.1 Equity

The environmental justice issues noted in Section I above are systemic in nature, and not limited to a future where the majority of new vehicle sales are ZEVs. One would hope, in fact, that some of these challenges will seem less daunting in the future by the fact that they have been identified and addressed in a more immediate time frame. As such, this document strongly urges near-term consideration of the Equity recommendations specified above.

1.3.2 Steering an Industry Transformation

While most if not all automakers have stated aggressive electrification and/or decarbonization goals, their approaches in the near-term vary. Some automakers have stated an intention to pursue ongoing improvements to internal combustion engines during the transition time needed to develop and commercialize ZEVs. Other automakers have expressed concerns about the need to balance resources between further ICE development and development toward ZEV technologies. To date, regulatory emission standards have been a foundational driver of the pace of technology to reduce pollution from vehicles. As the industry drives toward carbon neutrality, it will be important for EPA to consider how potential changes in the passenger vehicle market could require additional or new regulatory approaches.

1.3.2.1 Upstream Emissions

ZEVs' contribution to emissions are largely a function of their demand for electricity from the grid or hydrogen production for use in fuel cells. Vehicle manufacturers' limited control over these upstream emissions suggests the need for commensurate regulation on fuels and electricity generation. While vehicle manufacturers can seek to improve the efficiency of ZEV technologies through battery durability and energy utilization improvements of the vehicle, they have little to no control of the production of electricity or hydrogen, which dominates the overall share of emissions on a per-vehicle basis.

To date, EPA has excluded upstream emissions associated with EV charging in the regulatory accounting of ZEV tailpipe emissions. Many automakers believe continued "0 g/mi" accounting for grid-based upstream emissions reflects an important understanding of where and how those emissions can be mitigated, while preserving a regulatory signal supporting accelerated deployment of ZEVs into the fleet. Nonetheless, it is appropriate for EPA to track progress toward emissions reductions from stationary sources to comprehensively understand the transportation sector's well-to-wheels footprint.

1.3.2.2 Criteria Emissions Trends

Starting in the early 1990s, successive light-duty vehicle (LDV) emission standards have lowered the regulated emissions intensity (g/mi or g/km) of non-methane hydrocarbon and NO_x (NMHC+NO_x) emissions by 98% in the U.S. (Tier 1 to Tier 3). Heavy duty vehicle (HDV) emission standards for NMHC+NO_x decreased by 95% or more since 1988 in the U.S. As shown in Figure 3, such standards have had a profound effect on the resulting emissions inventory.[17]

[17] Particulate matter emissions from modern ICEVs vehicles are dominated by non-tailpipe emissions (brake- and tire-wear); this too applies to ZEVs.

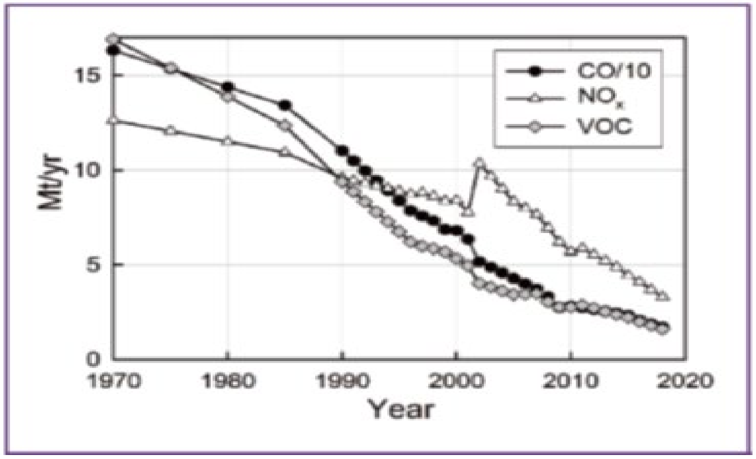

Figure 3: U.S. highway vehicle (LDV, HD, commercial vehicle, and motorcycle) NOx, VOC, and CO emissions in millions of tons (Mt). Source: U.S. Environmental Protection Agency (EPA).

Given progress made to date in criteria emissions reductions, diminishing returns of successive vehicle emission regulations are anticipated. For example, peak ozone in the U.S. declined by 1-13% from 2008 to 2018 (Tier 1 to Tier 2) but is projected to only decrease by 1-4% from 2018 to 2030 (Tier 2 to Tier 3).

It is expected that the most meaningful reductions in criteria emissions moving forward will come not from further incremental ratcheting of standards, but rather from the ongoing process of fleet turnover: the routine replacement of old (dirty) vehicles with new (clean) vehicles. Recent research supports this understanding.[18] It is conceivable that a thoughtfully designed scrappage program could accelerate emissions reductions associated with fleet turnover. However, evaluations of the most recent vehicle scrappage program (the 2009 program under the Car Allowance Rebate System, commonly known as “Cash for Clunkers”) suggest it yielded decidedly mixed results.[19]

With tailpipe emissions from modern ICEVs decreasing to very low levels, at least one automaker has suggested that establishing a suitably low criteria emissions ‘floor’ could help address the concern of resource management, allowing the industry to focus investment and resource allocation on ZEV development, while prioritizing continued CO_2 improvements in a rapidly dwindling ICEV portfolio. The pros and cons of such an approach were robustly discussed among the MSTRS Technology work group. For example, setting a cap on vehicle emissions would ensure future vehicles meet a per-vehicle threshold, while continued introduction of ZEV models would allow the overall fleet average to continue declining. The existence of a cap would bound any potential emissions backsliding. Requiring a fleet average of ZEV and non-ZEV technologies combined would incentivize further electrification, though standards would need to be regularly re-assessed to ensure that standards remained consistent with vehicle electrification market adoption rates.

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[18] CRC Report E-101 http://crcsite.wpengine.com/wp-content/uploads/2019/05/FINAL-E101-Report-SR-20160810-w-CRC-Cover-and-Appendices.pdf
[19] See, for example, https://www.brookings.edu/wp-content/uploads/2016/06/cash_for_clunkers_evaluation_paper_gayer.pdf; https://www.gao.gov/assets/310/303722.pdf; https://crsreports.congress.gov/product/pdf/R/R46544/2.

1.3.2.3 Increasing Reductions Towards the Goal of Carbon Neutral Mobility

Global warming through 2020 has been approximately 1.1°C and looks set to exceed the thresholds of 1.5 and 2°C identified in the Paris Agreement as levels above which dangerous anthropogenic influence on climate effects (e.g., sea level rise, extreme weather, wildfires) becomes more likely. As such effects become widely recognized, public pressure for further carbon reduction actions can be expected to climb. Urgency in addressing climate change underscores the need for large reductions in GHG emissions from vehicles and other sources.

All stakeholders recognize that the transportation sector will need to achieve zero emissions. Many automakers are reorienting their internal investments and resources now to deliver substantial volumes of battery EVs (BEVs) into the market. At the same time, advancements in non-BEV technologies will lead to further reductions in GHG emissions. Advanced combustion engine technologies, including Atkinson or boosted Miller Cycle engines with electrified powertrains and modestly sized batteries, might play a role for some automakers in delivering carbon reductions. Strong hybrids and plug-in hybrids in the marketplace today have also demonstrated meaningful tailpipe GHG reductions, offering as much as 40-70% reductions in CO_2 emissions, relative to conventional counterparts.[20]

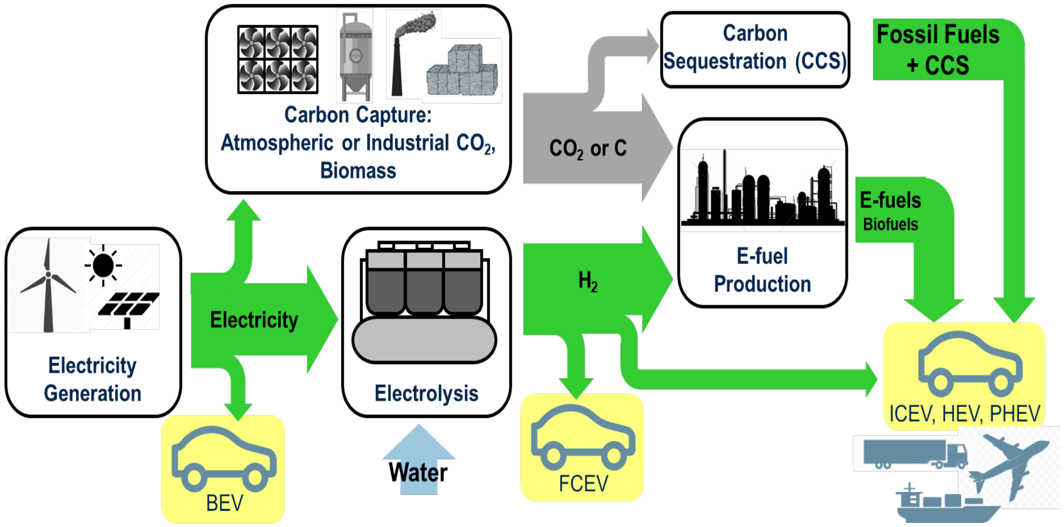
Investment in hybrid EVs (HEVs) and plug-in hybrid EVs (PHEVs) can deliver benefits to the broader market—including a diversity of vehicle offerings for the driving public, emissions reductions, and relatively low-barrier entry points for consumers to become familiar with EVs—but there are trade-offs. One is the opportunity cost involved for automakers with finite resources making long-lead-time investments. Supporting robust HEV, PHEV and BEV options across the full breadth of a manufacturer's line-up is unlikely to be feasible, and choices will need to be made—especially if industry will be expected to achieve 100 percent ZEV sales, or something approaching that goal, as soon as 2035. Consumer acceptance of HEVs and PHEVs also remains uncertain. While several models have enjoyed mainstream success in some segments of the U.S. auto market, that experience is far from universal (in 2020, HEVs and PHEVS represented less than 10% of new U.S. light-duty vehicle sales.[21]

Ultimately, each automaker will need to make its own investment and portfolio decisions on the road to a zero-emissions future, within the confines of a guiding regulatory framework. Greater deployment of HEVs and PHEVs will represent one strategy that offers parallel emissions reduction benefits as industry embarks on the larger transition to ZEVs. However, it will likely not be the only one. It will be important and appropriate for EPA to play a role in supporting a variety of approaches that deliver benefits to the environment by continuing its practice of developing and justifying vehicle emissions regulations through thorough, stakeholder-informed cost-benefit analyses.

The development of low-carbon fuels represents another transitional parallel path for the in-use legacy fleet to yield lower CO_2 emissions. The four fuel-related options for further carbon reductions towards the goal of carbon neutral mobility are illustrated in Figure 4. While BEVs and hydrogen-based fuel cell vehicles are often considered as carbon-neutral mobility, the use of e-fuels and petroleum combined with direct air capture of CO_2 and carbon capture and storage (CCS) have the potential to

[20] Emissions reduction potential varies based on, among other things, battery capacity and plug-in capability.
[21] EPA, 2021. The 2020 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975. Figure 4.10.

also be carbon neutral mobility options. A technology neutral regulatory framework, including low-carbon liquid fuels and electrification as parallel paths, could help enable the development of a portfolio of climate-friendly options, offering consumers more flexibility in meeting mobility needs.



Source: Adapted from http://pubs.awma.org/flip/EM-Apr-2020/wallington.pdf

Figure 4: The four primary options for zero/lower-carbon transport include: (1) BEV; (2) H2 FCV; (3) E-fuel; (4) Continued use of petroleum combined with direct air capture of CO_2 and carbon capture and storage (CCS).

Given the magnitude of the task of addressing climate change, the most cost-effective approaches to reducing carbon emissions should be pursued. While it can make for difficult politics, an economy-wide escalating price on carbon could provide a powerful price signal to steer businesses and consumers towards a low-carbon future.[22] Carbon pricing coupled with cross-sector carbon trading may facilitate the most efficient, cost-effective methods to reduce carbon across the economy. A Low-carbon Fuel Standard[23] is one such method that could be designed to transfer benefits to consumers for choosing zero-carbon vehicle technologies.

During the transition toward a zero-tailpipe emission technology future, it can be expected that one technology pathway will result in greater carbon reductions than another, that one geographic region will benefit more from one approach than another, or that different end uses will benefit more with one technology approach than another. Collaboration across industry, government and academia is needed to chart the most cost-effective pathways towards decarbonization. Creating specific strategies for the now, near, and far timeframes can help focus limited research and investment resources towards lower- and zero-carbon transportation technologies.

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[22] See, for example, https://clcouncil.org/our-plan/

[23] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

1.3.2.4 Recommendations

- Conduct cost-benefit analyses of the additional criteria emissions reduction benefits of future (Tier 4) tighter tailpipe standards, versus business as usual (BAU) reductions delivered from comprehensive fleet turnover transition from Tier 2 to Tier 3 standards
- Conduct cost-benefit analyses of the additional parallel GHG emissions reduction benefits that could be obtained from the greater market penetration of existing electrified vehicle technologies such as HEVs and PHEVs.
- Study opportunities for accelerated vehicle retirement to contribute to transportation emissions reductions. Such a study should consider how a scrappage program might maximize emissions reductions in a cost-effective manner, affect the used vehicle market, and grow the ZEV market with a particular focus on expanding access within underserved communities.
- Leverage agency expertise in the evaluation of opportunities and drawbacks to controlling carbon via carbon pricing mechanisms, with particular attention to ensuring benefits in underserved communities.

1.3.3 Understanding Consumer Adoption

The ZEV market, while modest today, has the potential to grow tremendously to include a much more diverse and varied customer base. Clear and aligned public policies are needed to support consumer adoption. Vehicle purchase incentives have proven to be very effective in the United States, and while not directly in the EPA's policy lever toolbox, the agency can indirectly influence broader market conditions.

1.3.3.1 To Reach More than Half of New Car Sales, ZEVs Must Reach Beyond Early Adopters

Today, ZEVs make up approximately 2% of new vehicle sales: in 2019, roughly 330,000 BEV or PHEV models and 2,089 fuel cell EVs (FCEVs) were sold in the United States.[24] The ZEV market is growing but too slowly to be assured that 100% of the onroad fleet will be zero emissions by 2050. Current modest growth can be attributed to several factors, including:

- **Higher purchase cost:** ZEVs can be several thousand dollars more to purchase than comparable ICEVs. However, projected reductions in ZEV technologies, particularly battery costs, may lead to purchase price parity for many ZEV classes by 2030. Vehicle standards that promote continued technology innovation and development can help ensure that technology costs meet the projected declines. While ZEVs can be cheaper to operate because of lower fueling costs (particularly for PEVs) and maintenance costs, upfront costs are still a significant barrier. In the near-term, vehicle purchase incentives can help overcome the purchase price difference.
- **Limited access to widespread charging (or hydrogen fueling) infrastructure:** For many—if not most—vehicle trips, adequate charging can be accomplished while a car is stationary at home or at work. However, longer-duration trips will require more widespread charging and

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[24] https://insideevs.com/news/343998/monthly-plug-in-ev-sales-scorecard/; https://insideevs.com/news/392360/2019-sales-hydrogen-fuel-cell-cars-us/

fueling stations. Charging access must also address car owners who today lack access to a private, plug-equipped parking spot, such as people living in multi-unit dwellings or people dependent on street parking.

- **Limited consumer awareness:** Many consumers are unfamiliar with ZEV technology and have not had an opportunity to experience it directly. Common with many new technologies, lack of familiarity creates a challenge for making ZEVs a serious consideration in a car purchase, new or used. Used ZEVs, particularly BEVs and PHEVs, have the added challenge that a consumer cannot easily assess the health of the battery—a major cost component—in a short test drive.
- **Limited offerings:** While ZEVs are growing into new market segments each year, there are still some classes of ICEVs that have no ZEV counterpart widely available yet, such as pickup trucks and large SUVs.

At the same time, ZEVs present many attractive attributes to consumers, including lower emissions, increased performance (improved handling, reduced noise, instant torque, etc.), lower per-mile fuel costs, more convenient fueling options, and lower maintenance costs. With concerted public policy efforts to address the challenges described above, ZEV adoption is poised to accelerate.

1.3.3.2 Understanding Vehicle Parity

Market analysts have suggested that technology cost reductions in the coming years are likely to bring about a tipping point for EV adoption, as ZEVs reach purchase price parity with conventional internal combustion engine vehicles. While such a point is likely to bring increased consideration for ZEVs on showroom floors, purchasing decisions are based on numerous factors. As the market unfolds, it will be important that parity assessments considered (or even conducted) by the agency include not only purchase price, but also performance/functionality/convenience, technology cost and total ownership cost.

Greater Market Offerings and Infrastructure Buildout are Key for Expanding the ZEV Market

To reach more than half of new car sales, current market conditions and other external factors that directly affect consumer behavior will need to change. These changes include increasing the number and variety of vehicles in the market, making more ZEVs available at dealerships, and improving ZEV-supporting infrastructure.

Increasing the number of vehicles on the market will expand EV options that meet the varied cost and utility expectations of the U.S. population. In 2019, just 8 percent of auto market nameplates represented ZEV offerings, but by 2025 this figure is expected to roughly triple and include ZEV entries in the popular and versatile SUV and truck segments.[25] Continued progress in the capability and battery range of these vehicles will accompany the expanded offerings. With more and varied ZEV nameplates available, it is hoped that a larger share of the car-buying public will find a vehicle that meets their needs in the ZEV fleet—creating some of the market conditions necessary for broader adoption.

Improved market conditions also rely on enhanced ZEV infrastructure, which can support greater ZEV uptake by addressing range anxiety. Increasing the number and density of public EV charging and

[25] https://www.autosinnovate.org/initiatives/energy-and-environment/electric-drive

hydrogen fueling stations, as well as home and workplace charging, will require clear regulatory support and both coordination and sustained investment across the public and private sectors. Experience to date suggests that tax credits for alternative fuel infrastructure installation—such as the federal "30C" tax credit—and utility-led investments are key enablers, but much more will be necessary, including significant retrofitting and renovating of existing homes to facilitate home charging of plug-in vehicles. Relying on building codes and new construction alone will be insufficient to meet electrification levels called for in today's policy dialogue.

1.3.3.3 Supportive Public Policies Play a Central Role in Growing ZEV Sales

Financial Incentives and Disincentives for Purchase. Because of the cost premium associated with ZEVs, policies that reduce the purchase price of a ZEV significantly increase sales. Conversely, evidence shows that policies that effectively increase the cost of a ZEV further depress sales.

In the United States, a variety of policies aim to reduce the purchase costs of ZEVs at the federal, tribal, and state levels. These policies include:

- *Rebates.* Eleven states currently offer a rebate—some as high as $5,000—to consumers buying a ZEV, though income restrictions apply in some places.
- *Tax Incentives.* Two states partially or fully exempt ZEV sales from sales taxes, and two others, plus the federal government, provide an income tax credit to ZEV buyers.

Several European countries have also adopted *feebates*, imposing fees on vehicles sold with high CO_2 emissions or fuel consumption and providing rebates for those with low CO_2 emissions or fuel consumption. Evidence from Europe suggests that feebates can be effective in encouraging the market to transition to lower-emissions vehicles; thoughtful design would be needed to ensure that administrative, fairness and equity-based pitfalls are avoided during implementation.[26] Implementation in the U.S. may prove particularly challenging on fairness and equity bases. For example, the policy would have to adequately address fairness and equity associated with rural communities and the vehicles and infrastructure upon which they depend.

Studies have clearly documented the benefits of incentive programs. Between just 2010 and 2014, approximately a third of all EV sales nationwide stemmed directly from the federal EV tax credit.[27] More generally, every $1,000 offered as a rebate or tax credit increases the average sales of EVs by 2.6 percent.[28] Just as the presence of incentives supports sales, their absence can chill the market. When Georgia eliminated its state income tax credit of $5,000 per EV purchase, sales of EVs fell approximately 80 percent in the following year and a half.[29] (Both Denmark and the Netherlands also experienced similar effects after restricting their incentives.[30]) Durable and robust financial incentives

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[26] https://theicct.org/blog/staff/practical-lessons-vehicle-efficiency-policy-10-year-evolution-frances-co2-based-bonus

[27] https://www.niskanencenter.org/evaluating-the-case-for-the-electric-vehicle-tax-credit/

[28] https://www.sciencedirect.com/science/article/abs/pii/S0301421518302891; https://phev.ucdavis.edu/wp-content/uploads/2017/09/purchase-incentives-literature-review.pdf

[29] https://www.utilitydive.com/news/georgia-electric-vehicle-sales-shrink-80-in-wake-of-tax-credit-repeal/434092/#:~:text=Sales%20of%20electric%20vehicles%20in,with%20a%20new%20registration%20fee.&text=The%20Atlanta%20Journal%2DConstitution%20reports,expired%20to%20less%20than%20250.

[30] https://its.ucdavis.edu/wp-content/uploads/Credits-and-Rebates-Gil-Tal.pdf

for much of the coming decade will be important for accelerating the ZEV market and ensuring advanced vehicles enter the mainstream.

Additionally, public officials should avoid sending mixed messages to consumers by implementing financial *dis*incentives. This includes the whipsaw effect of sunsetting and reinstated tax incentives, and disproportional registration fees levied upon ZEV owners. These fees fail to meaningfully address transportation infrastructure funding shortfalls while also often penalizing ZEV drivers, charging them more than a typical ICEV driver pays in gas taxes annually.[31] Such actions deter prospective ZEV buyers. Researchers at the University of California at Davis find that imposing registration fees could reduce ZEV sales by as much as 24 percent.[32]

Fuel Prices. Data show that the opportunity to save money on fuel motivates many prospective ZEV buyers, and that higher conventional fuel prices could serve as a "push factor" in decisions to purchase an EV. In one AAA survey, about two-thirds of respondents pointed to "lower operating costs" as a reason they would consider buying a ZEV.[33] The reverse is also true. Lower fuel prices could serve as a "pull factor," inducing consumers to buy relatively less efficient vehicles. Historically, higher gasoline prices have been associated with the purchase of more efficient cars.[34] As gasoline prices fell around 2015, Edmunds found evidence that HEV and EV owners traded in their vehicles for conventional SUVs at higher rates than previously recorded, suggesting weak loyalty to EVs in times of low gasoline prices.[35] Importantly, fleet owners and operators are more likely than individual consumers to account for total cost of ownership considerations in their vehicle purchase decisions, and thus respond more sensitively to changes in fuel prices.

Policy choices regarding taxation of fuel have the potential to directly influence the choices of the car-buying public. Evidence suggests that sustained periods of low gasoline or diesel prices will work against a sustained market shift toward ZEVs. While EPA does not possess the authority to levy taxes, the agency could consider how durable market-based policies for emissions reductions, including carbon taxes and cap-and-trade programs, can influence fuel prices and the context in which consumers and fleets will make vehicle purchase decisions. An agency recommendation endorsing the benefits of carbon pricing could build momentum for such policies in the United States (and perhaps abroad), helping accelerate mainstream ZEV adoption.

Other Policies Supporting Vehicle Electrification. Many states are finding other ways to encourage consumer (and fleet) adoption of EVs, creating either alternative or indirect sources of financial incentives for EV ownership, or providing ancillary ownership benefits. These policies include:

- *Low-carbon Fuel Standard (LCFS).* Two states (California and Oregon) currently impose a LCFS, a market-based and technology-neutral approach to reducing the carbon intensity of the entire portfolio of transportation fuels. Several other states and regions are considering adopting similar policies. With credit/deficit trading mechanisms, such programs can generate revenue that states

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[31] https://www.consumerreports.org/hybrids-evs/more-states-hitting-electric-vehicle-owners-with-high-fees/

[32] https://calmatters.org/commentary/2019/12/electric-vehicle-fees/; https://www.greencarcongress.com/2019/01/20190104-ucd.html.

[33] https://money.cnn.com/2018/05/08/technology/aaa-electric-car-consideration/index.html

[34] https://conference.nber.org/conferences/2009/IOs09/busse.pdf

[35] https://www.edmunds.com/about/press/hybrid-and-electric-vehicles-struggle-to-maintain-owner-loyalty-reports-edmundscom.html

can use to further accelerate decarbonization of the transportation sector. The benefits of LCFS policies for ZEV adoption are discussed at greater length in the "Fuels" section of this report.

- *Single-Occupant Access to HOV and High-Occupancy Toll (HOT) Lanes.* Twenty states offer designated HOV lanes on some portion of their highway network, and a subsection of those—including California, Maryland, and New York—exempt ZEVs (or in some cases, only plug-in EVs) from the typical occupancy restrictions on those lanes, allowing access at all times even when occupied by just a single individual.[36] Survey results indicate that, at least in the early years of the last decade, large shares of PHEV consumers—and up to a majority of owners of one vehicle model, in particular—cited HOV lane access as their primary motivation for purchasing the vehicle.[37] The "value" of such incentives, however, depends on traffic densities and the availability of lanes, which vary significantly by state.

Given their powerful benefits for ZEV buyers, these policies will likely play a key role as the ZEV market expands. Exploring possibilities for a national LCFS would likely fall under EPA's purview and represent an opportunity to build on demonstrated success at the state level. Similarly, as states weigh instituting or continuing HOV lane access policies, EPA might consider further refining both the public's and research community's understanding of the benefits of this tool for ZEV adoption, as well as leveraging its public education role to enhance consumer awareness of these policies.

1.3.3.4 Recommendations

- EPA should consider routinely analyzing ZEV sales patterns over the coming years to understand if there are gaps in uptake in certain vehicle segments, geographic regions, or buyer groups. This information could inform future ZEV education and policy efforts.
- EPA should leverage its tremendous influence on consumer adoption of ZEVs and play a convening or educating role by continuing to gather and synthesize data on the impact of financial incentives on ZEV sales. This could be accomplished through its own studies, formal literature reviews, or even consumer focus groups or other means of collecting primary data from vehicle buyers themselves. EPA's regional offices could play unique additional roles here by considering the distinct policies and adoption trends evident in the states and tribal areas in their regions.
- EPA should consider how durable market-based policies for emissions reductions, including carbon taxes and cap-and-trade programs, can influence fuel prices and the context in which consumers and fleets will make vehicle purchase decisions. Such an assessment could provide valuable context to the ongoing policy dialogue on pathways toward carbon neutrality.
- EPA should study how a national LCFS could be implemented in support of ZEV uptake and continued decarbonization of the transportation sector, even after ZEVs become the predominant vehicle sold in the United States.

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[36] https://afdc.energy.gov/laws/state

[37] https://www.researchgate.net/publication/269694497_Exploring_the_Impact_of_High_Occupancy_Vehicle_HOV_Lane_Access_on_Plug-in_Vehicle_Sales_and_Usage_in_California

- EPA should consider further refining both the public's and research community's understanding of the benefits of HOV lane access as an incentive for ZEV adoption and leverage its public education role to enhance consumer awareness of these policies.

1.3.4 Public Education

Strengthening widespread receptivity to vehicle electrification will require education strategies that address the diverse needs of public segments, including underserved communities. EPA should draw upon agency, industry, consumer, and academic resources to better understand the likely pathways of technology adoption. Focus groups could be used to help identify specific education strategies and their timing to accelerate technology adoption. As EV adoption rates increase, EPA should engage marketing experts to conduct periodic surveys and market analyses to identify the gaps in EV penetration based on vehicle type, demographics, and other criteria, to target the information and education strategies to those segments of the population that have yet to embrace ZEV technologies.

Given the breadth of stakeholders, the agency should utilize the expertise of vehicle manufacturers, related companies (i.e., rental car fleets, electric utility companies, etc.) and consumer organizations to identify mutual educational programs and broaden their reach. For example, EV rental programs could be established with automotive dealerships, car share and rental car fleets could offer consumers (such as general rental car customers, or curious new car buyers) EV rentals to gain exposure, understanding and familiarity with EVs. Overall, the agency can fill a critical role in providing factual, unbiased technical information to the various public segments, businesses, commercial car and truck fleets, school educators and students, as well as state, tribal, and local policymakers.

Information should be provided employing concise, easy-to-read text with supporting visual graphics in fact sheets, reports, and webpages with links to other reputable information sources, including the websites of government and state, tribal, and local agencies, national laboratories, universities and select third parties.[38] Other communications-related tools, including news releases, fact of the week, and social media posts could be employed to reinforce awareness of the website and legitimacy of the information.

An existing website[39] may be suitably extended for these educational purposes, or the agency may wish to create an entirely new website specific to the educational effort on electric and electrified vehicles. Either way, it will be important to capture a robust set of basic information, including:

- ZEVs 101: Basic information about EVs; where and how to refuel / recharge; incentives lookup based on ZIP code.
- Breakout of vehicle electrification types, features, and emissions comparisons regarding the attributes of conventional ICEVs, HEVs, PHEVs, BEVs, and FCEVs.
- Information on evolving battery and fuel cell technologies.
- Searchable lists of available new and used models and vehicle types.

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[38] See, for example, Veloz's Electric for All campaign, www.electricforall.org

[39] such as U.S. EPA/DOE www.fueleconomy.gov or www.epa.gov/greenvehicles.

- Consumer assurance measures (battery health monitoring, OBD, available repair information to support proper vehicle maintenance) and durability information showing key mileage thresholds.
- Key EV-related information which should also be included on new vehicle labels. While some of this information is legislated, these requirements do not adequately address newer electrified vehicles (i.e., Level 1, 2 and 3 charging times, etc.)

1.3.4.1 Real-World Performance

The various public segments would benefit from a trusted information source regarding the real-world performance of EVs, including the impacts of hot and cold weather, cabin climate control, road terrain, traffic volumes and consumer driving habits. Other aspects could include recognition of underserved communities, suburban and rural lifestyles, as well as typical first and subsequent ownership considerations, such as primary vs. secondary family vehicles, used car repair histories and the needs of long-distance travel and towing.

As much as BEVs are unfamiliar to consumers, FCEVs are even less well understood. Additional content to explain the differences in technologies, the respective strengths of BEVs and FCEVs, and information that can help consumers make informed purchase decisions should be included.

Further, there is an educational need to reinforce awareness that EV manufacturers have already developed and deployed battery technologies that are intended to last typical vehicle lifetimes. Consumers should be educated on how their charging decisions can affect the battery performance and lifetime. For example, exclusively using direct current (DC) fast charging or keeping vehicles at a high or low state-of-charge may accelerate the deterioration of a vehicle's all-electric range.

1.3.4.2 Consumer Information on Charging

The DOE reports that 80% of electric car drivers charge at home, but as EV penetration increases there will be a need for a variety of private and public charging options. Although EPA and DOE websites contain some information on charging, consumers still lack awareness and a convenient, central source of information on charging options including charger types (i.e., 120V/240V/fast chargers), charging locations (including the level of available public chargers), plugs, adaptors, installation requirements and access to local and tribal utilities or other organizations that may offer discounts on their purchase, installation, and repair.[40]

Consumers also lack knowledge of base and peak load grid periods, which impact the cost of vehicle charging at different times of the day, as well as the environmental benefits of charging at off-peak periods. This is especially true for public chargers, which may presently lack billing transparency. Such information directly impacts the total cost of ownership of EVs and the magnitude of environmental benefits they provide.

Owners and residents living in multi-unit dwellings (i.e., apartments, condos, etc.) also need awareness and reassurance that charging options are commercially available that will allow the

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[40] Examples of websites containing such information are www.chargehub.com, www.goelectricdrive.org and www.atlasevhub.com.

simultaneous charging of many EVs.[41] On a related note, municipal governments are looking to provide charging options for urban residents with access only to street parking. Municipalities are also looking for best practices for siting commercial destination charger locations on streets and at nearby shopping centers, businesses, and other common destination locations.

By providing information about EV charging in the languages and formats that are easy to understand and resonate with communities, including underserved communities, in addition to increasing access to EVs and supporting infrastructure, consumers will gain increased awareness and acceptance of EVs. This in turn should help accelerate their adoption and the accompanying environmental benefits they deliver.

Consumers who drive FCEVs also have similar information needs, especially real-time station availability information. This can be critical information in the early market stages when few stations are available in a region, and FCEV drivers must plan their fueling more carefully. In addition, clear and accurate communication of ongoing development and projections for hydrogen fueling station network development can help consumers make informed decisions about FCEVs. California has made significant steps to address this need for consumer information, through semi-annual reporting of the status and projections of FCEV and hydrogen station deployment and the consumer-facing real-time Station Operational Status System (SOSS) and Hydrogen Station Map managed by the California Fuel Cell Partnership.

1.3.4.3 Higher Level Information Needs on Charging / Electrical Grid

There is a need for more detailed educational information and resources for federal, state, tribal, and local policymakers regarding the electricity supply mix and related emissions intensities in regional grids. This includes but is not limited to renewable vs. non-renewable electricity, integration of renewables, and broader understanding of the grid to support local, tribal, and regional decisions regarding vehicle purchase incentives. Indeed, today the environmental value of electrifying the fleet is greater in some parts of the country than others. To the extent that areas with cleaner grids can accelerate the earlier adoption of EVs, a more optimized path toward emissions reductions may be possible. It will be important to update the grid and reduce its carbon intensity to help inform progress in reducing overall CO_2 emissions from the light-duty fleet.

1.3.4.4 Vehicle-Grid Integration

Although the electricity grid is not a mobile source of emissions, there are vehicle and refueling technologies that can greatly assist with barriers associated with a 100% carbon-free grid, upon which the promise of a ZEV is dependent. A fleet of ZEVs can enable further renewable grid investments by providing energy storage and other grid services, and/or providing a market for hydrogen production at renewable source locations during periods of curtailment. These two strategies combined on a large scale can help address renewable grid barriers. However, in the case of a ZEV providing energy storage and other grid services, new technology is required: vehicles and charging infrastructure need to incorporate common communication protocols and two-way electricity flow capability. This collaboration between vehicles and fueling infrastructure technology is often referred to as vehicle to

[41] An example of such information is available from Plug-in NC (https://pluginnc.com/wp-content/uploads/2016/06/Multifamily_Handbook_PluginNC.pdf).

grid integration (VGI) and should be included in ZEV adoption planning and available public information.

EVs represent a flexible load with charging that can be managed to match grid needs. Beyond this, advanced bi-directional charging systems, known as "V2G," could be used to support grid needs. While some V2G pilot programs exist today, V2G at scale remains a work in progress. V2G-DC could avoid the uncertainty of third-party certification processes required by the utilities to satisfy grid needs. The customer would just plug into the charge port of the vehicle for both charging and discharging into a wall unit, which makes the entire V2G much simpler to manage on a daily basis.

The Agency may wish to consider a self-certification system similar to the National Highway Traffic Safety Administration (NHTSA)'s established precedence, allowing for more streamlined approvals as well as limiting unnecessary vehicle cost increases at this critical stage of EV penetration. Incentives or credit mechanisms for GHG abatement for key stakeholders to participate in V2G could drive grid adoption and deliver a strong signal for widespread deployment.

There is also a need to quantify and communicate the potential to accelerate total GHG emissions reductions through energy storage deployment. Hydrogen and battery energy storage may both play a role in enabling faster deployment of renewable energy resources to the grid. At the same time, these energy storage devices can serve as a link between the grid and ZEV deployment. Battery storage of renewable electricity may interact in real-time with BEV charging. Conversion of renewable electricity to hydrogen enables longer-term energy and larger-volume energy storage and distribution, while offering opportunity to supply FCEVs with low-carbon hydrogen. The opportunities for deploying these resources and optimizing their use to reduce overall system costs may need individual regional consideration. Information gained by studying, quantifying, and characterizing these opportunities could prove useful in policy deliberations.

As electric vehicle populations grow, there will be a need for local and tribal utilities to track the density of chargers to properly plan infrastructure investments, as well as account for expanded charging and local and tribal grid stabilization at peak times of the day. Moreover, it will be important to provide ongoing, up-to-date information to policymakers on the true full build-out costs of transitioning to 100% ZEV, including both electric infrastructure to support BEVs and hydrogen infrastructure to support FCEVs. This is critical information that EPA can help provide, in coordination with other agencies such as the DOE.

1.3.4.5 Regional Issues

State, tribal, and local policymakers may be looking for federal input as they consider a hierarchy of national, state, tribal, and regional strategies targeting various local communities. An EPA-produced roadmap would be a valuable addition in providing direction to the various levels of policymakers. Such a document could share proposed strategies, grid updates, consumer incentives (i.e., rebates, HOV access, etc.) and available funding sources. The roadmap could also identify the types of state, tribal, and local regulations that can accelerate (or impede) electrification strategies.

There is also considerable discussion at present regarding the need for the national standardization of EV charging plugs and charging infrastructure to reduce redundant investment in the build-out of a national charging network. Information is needed to inform regional building codes, including consideration of mandates that new construction includes standardized wiring requirements to facilitate the installation of chargers for single family and multi-unit dwellings. Educating policy makers on the most effective and efficient use of building codes in local and tribal permitting standards, as well as the most critical transportation needs of local and tribal consumers, can support thoughtful expansion of charging infrastructure in public, private and multi-unit dwellings and buildings.

1.3.4.6 Recommendations

- Leverage focus groups to assist the EPA with the identification of public education strategies that can address evolving consumer understanding of, and receptivity toward, vehicle electrification.
- Provide educational materials on electric, electrified vehicles and V2G in the form of fact sheets, social media, and websites to educate consumers, educators, and students, as well as federal, state, tribal, and local policymakers.
- Provide educational materials on charging options for different types of dwellings and public areas. Work with utilities to ensure the availability charging in every community segment, the transparency of charging rates and preferred times to recharge EVs.
- Working with constituents and community leaders, provide tailored information that addresses the diverse needs of various public segments on evolving battery, fuel cell and other vehicle technologies based on testing that EPA will be generating through their own internal evaluations of EVs.

1.3.5 Driving Neutral and Low-carbon Fuels

For conventional internal combustion powertrains (gasoline, diesel, and natural gas), the actual combustion process required for vehicle operation accounts for 80-90% of the lifecycle emissions associated with global warming potential, while for electric propulsions, such as BEVs and PCEVs, the overall emission impacts vary widely depending on how energy carriers are produced and regional variances in electrical grids.

1.3.5.1 Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways

A recent analysis conducted as part of the DOE's US Drive program, the Integrated Systems Analysis Tech Team leveraged the GREET model[42] to conduct a thorough study of current (2020) and future (2025-2030) technologies for midsized light-duty vehicles.[43] This cradle-to-grave (C2G) assessment examined the full lifecycle of a product including raw materials, manufacturing, operation, and disposal.

Figure 5 below depicts assessments of both upstream (energy production) and downstream (energy consumption) GHG emissions across the various technology options.

[42] The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model is recommended for use by EPA (see Appendix A for additional background).
[43] Elgowainy, A., Han, J., Ward, J., Joseck, F., Gohlke, D., Lindauer, A., Ramsden, T., Biddy, M., Alexander, M., Barnhart, S., Sutherland, I., Verduzco, L. & Wallington, T. J. *Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies*. (Argonne National Laboratory, 2016). at https://greet.es.anl.gov/files/c2g-2016-report

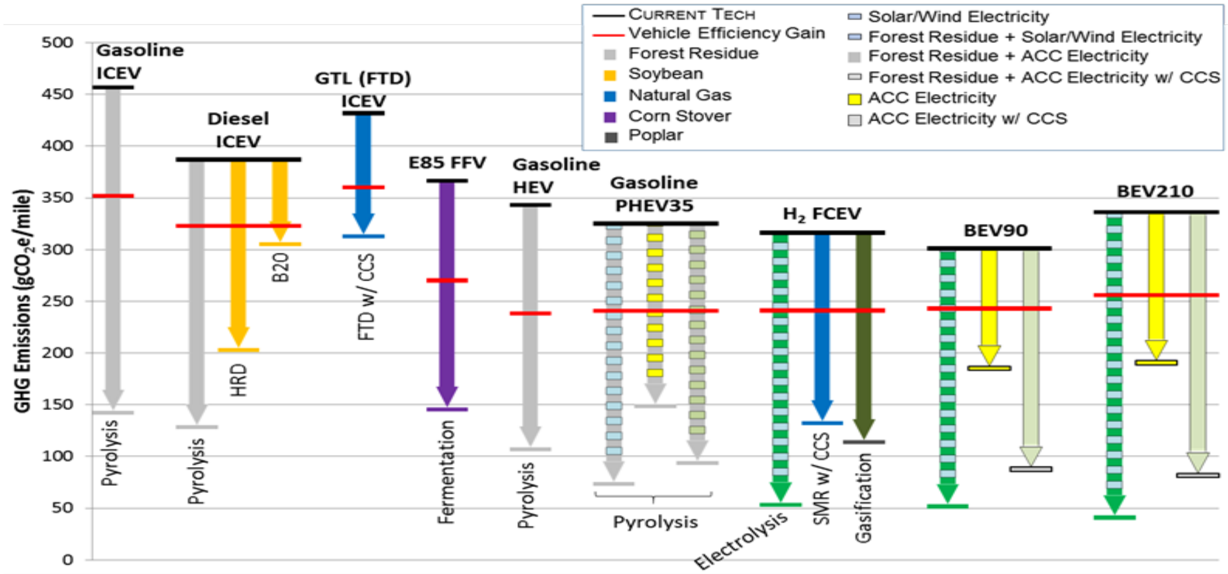

Figure 5: Lifecycle GHG emissions for different vehicle-fuel pathways.[44]

For current technology vehicles (indicated with black bars), the emissions from vehicle manufacturing represents a small fraction of the total emissions associated with the operation of the vehicle over its lifetime, which can range from ~300 to ~450 g CO_2 eq./mile. The downward arrows (from the black line) indicate the potential for further reduction opportunity, given different vehicle-fuel pathways. Ultimately, the total carbon footprint can be lowered through the incorporation of fuels using highly renewable energy sources, carbon-neutral fuels, and/or carbon capture utilization and storage technologies.

Historically, past GHG reductions were achieved primarily by increasing fuel efficiency and by imposing increasingly stringent emissions standards. While there is still opportunity for further efficiency gains, the largest reduction opportunity remains with lowering the carbon intensity of fuels used for combustion. Reducing the well-to-tank emissions across all transportation fuels is a critical step and necessary to achieve significant decarbonization across the entire transportation sector. Concurrent with transitioning ICE to carbon neutral technologies, emissions associated with the electric grid is just as critical to achieve the transition to carbon-neutral emissions in support of BEV. Figure 6 below provides a high-level illustration of selected vehicle-fuel pathways.

[44] *Id.*

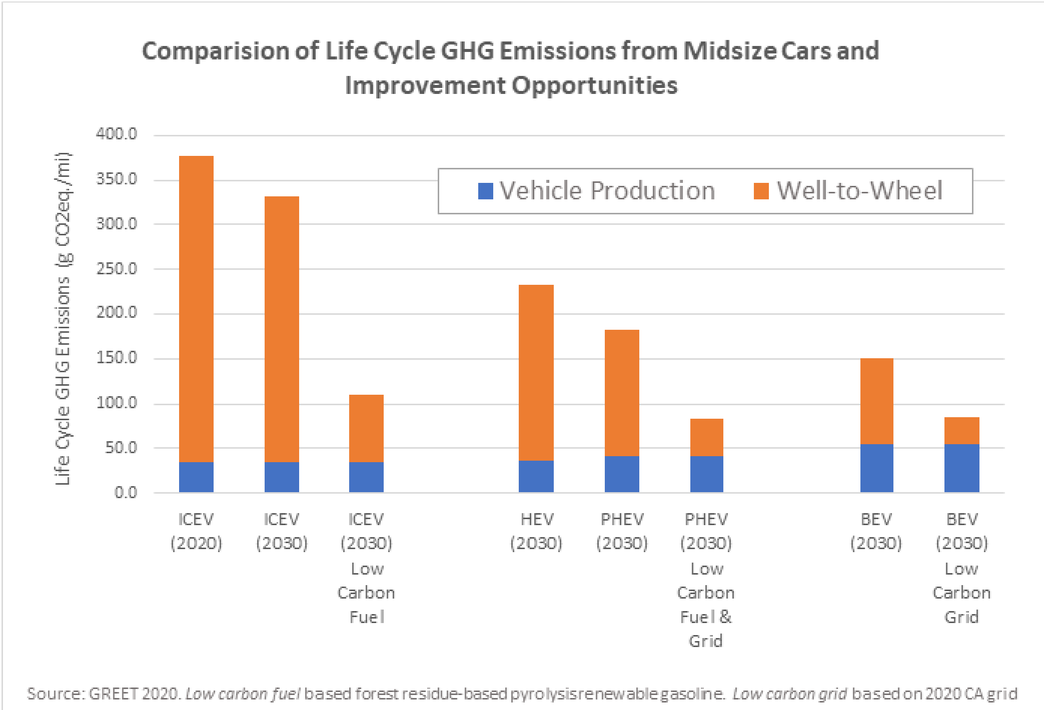

Figure 6: An Illustrative Lifecycle GHG Example of Vehicle Trends and Policy Needs. Source: Ford Motor Co.

Today, conventional vehicles' use phase (the actual combustion for vehicle operation) is dominated by fossil fuel combustion. As such, significant opportunity for carbon reductions exists by lowering the carbon intensities of those liquid fuels being consumed. A low-carbon intensity liquid fuel could theoretically be consumed by the entire onroad, 280 million vehicle fleet, yielding substantial GHG reductions.

To achieve rapid decarbonization of fuel and energy, new measures would be needed. Transforming the existing Renewable Fuel Standard into something more akin to a LCFS has the advantage of being able to promote the production and use of low-carbon liquid fuels, while also providing incentives for the adoption and use of ZEVs that use hydrogen or low-carbon electricity. Complementary measures could include biofuels in conjunction with carbon dioxide mitigation techniques, such as carbon capture utilization and storage. It should be noted that expanded renewable power supplies and carbon capture utilization and storage are likely to be necessary to make widely available zero-emission fuels.

The technology exists to produce low-carbon liquid and gaseous fuels (including carbon neutral fuels), but investment, expansion in production facilities, and confidence in long-term access to raw materials or sources to produce such low-carbon fuels would need to be expanded to yield meaningful carbon reductions. As a first step, for example, fuel suppliers would need proper signals to have confidence to initiate efforts to bring such low-carbon fuels to the market.

As the transportation industry shifts from 2020 to 2050 on pathways toward carbon neutrality, improvements to all three legs of the proverbial "three-legged stool" (vehicles, fuels and vehicle miles traveled) should be included.[45] While technologies and time horizons are far from static, it is critical to provide certainty and clarity to fuel and technology supply industries, OEMs, and research efforts, which are all competing for limited investment resources during the transitional phases. An example of the possible evolution of vehicle and energy technologies is shown in Table 1 below.

Table 1: Possible Evolution of Vehicle and Energy Technologies.

Time Period	Potential Vehicle Technology	Potential Energy Sources
NOW	Advanced ICE	Increases in Octane rating
	Hybridization	Shift from E10 to E15 (inc. low carbon content)
	BEV Introductions	Low Carbon Electricity Introductions
	Fuel Cell Introductions	
NEAR	Further Advances in ICE	Continued Renewable Electricity
	Expanded Vehicle capability	Higher levels of Low Carbon (ethanol) Dominate
	Additional BEV Models	Renewable Hydrogen Introductions
	Additional Fuel Cell Models	
	BEV Models Dominate	Renewable Electricity Expands
	Fuel Cells Expand	Renewable Hydrogen Expands
		e-Fuels Introduction
	Advanced BEV Models	Renewable Electricity dominates
	Advanced Fuel Cell Models	Renewable Hydrogen dominates
	Lower # of LD ICE Models	
FAR	BEV and FCEV Dominate	e-Fuels dominate
	BEV Models ONLY for LD/MD	Renewable Electricity ONLY
	Fuel Cell Models ONLY for MD/HD	Renewable Hydrogen ONLY
		e-Fuels ONLY

Policymakers should use a balanced mix of tools to regulate, support and stimulate improvements to vehicle, fuels, and usage (VMT). Cross-sector stakeholders should have clearly defined targets – for example, for vehicles (CO_2 grams per mile standards) and energy/fuels (carbon intensity of electricity or the liquid/gaseous fuel).

During the transition to a zero-carbon onroad fleet, it is critical to support the development and commercialization of low-carbon liquid fuels, renewable electricity, and renewable hydrogen, each playing its role on the pathway to decarbonization.

One possible pathway to accelerate carbon emission reductions (in liquid fuels for ICE) now, during the transitional phase to electrification, includes the use of increased ethanol content to increase gasoline octane rating and enable engine efficiency improvements. This approach is only possible with agency collaboration and by sending the correct signals to manufacturers to build such capability to advance ICE efficiency technology and to fuel providers to apply measures to supply, as well as distribute, such cleaner and more efficient gasoline formulations. Again, stressing the importance of such transitions can result in emission reductions for decades to come. With respect to

[45] Similarly, reduced traffic congestion through improved traffic efficiency could bring additional benefits.

biofuels, specifically ethanol, the agency may wish to consider alternative regulatory approaches that would incentivize the use of sustainable biofuels during the transitional period.

Regulatory measures such as carbon pricing and a LCFS could accelerate the development, production, and deployment of lower-carbon fuels. LCFS policies are especially attractive by creating markets for advanced low-carbon liquid fuels—whether biofuels or perhaps even synthetic fuels — driving emission reductions in the existing onroad ICEV fleet. LCFS also offer unique benefits for ZEV adoption by encouraging the deployment of alternative fueling infrastructure, including hydrogen fueling stations and public EV chargers, easing ZEV consumer concerns. California's program provides a successful example of the country's most mature LCFS policy.

As EPA considers future fuels policy, it will be important for the agency to maintain a robust dialogue with other agencies working in these areas, including the following DOE offices that conduct work in low-carbon fuels and related projects: Bio-Energy Technologies Office, Vehicle Technologies Office and the Hydrogen and Fuel Cell Technologies Office. EPA can play a critical role in convening key stakeholders and helping develop policies that support infrastructure expansion, carbon pricing, and broader reconsideration of regulations for future carbon-neutral mobility. Transportation and the fuels/energy they consume are a system and should be treated as such.

1.3.5.2 LCA in State-Based Analyses

Lifecycle assessments (LCA) can serve as a valuable policy guide in identifying significant contributions to the full lifecycle emissions of powertrains. EPA might consider using an LCA to understand, for example, the contribution from electricity and fuel generation on a state level. The analysis could incorporate the latest version of the GREET model and other published fuel and electricity surveys to understand the carbon intensity of the grid and facilitate point source CO_2 reduction by states. EPA and DOE should collaborate and share information to continue to populate the model with the latest information on pathways and inputs. Setting CO_2 reduction goals for the power and fuel sectors through a revised powerplant GHG regulation (CPP 2.0) and LCFS would be one approach to ensure that the electricity generating units (EGUs) and fuel refiners continue to increase the renewables fraction and reduce the carbon footprint of the fuels and electricity they supply to transportation. The transportation contribution could be modeled by the broad categories of vehicles based on the state fleet of ICEV, HEV, PHEV, BEV, and FCEV. This would provide for parallel carbon reductions from vehicles and upstream energy sources. To address downstream carbon emissions, EPA could use LCA analysis to understand the impact of recycling on lifecycle emissions and coordinate with other EPA offices to develop incentives for states to receive emission reduction credits for battery recycling efforts implemented within their state.

One concept posed by a member of the Technology work group was a policy framework based on LCA that could engage states or tribes to regulate stationary point source CO_2 emissions in their territory, modeled on the National Ambient Air Quality Standards (NAAQS) established for criteria pollutants. Under the concept, EPA would first need to set national ambient climate pollutant goals that would include CO_2 and methane, for example a CO_2 NAAQS. States or tribes could then use the GREET model and LCA to estimate their stationary point source contribution of their climate pollutant inventory and take steps to reduce those transportation upstream emissions from their total state inventory. This could then be combined with CO_2 emissions from vehicle operation using the MOVES model to give a state or tribe an estimate of the full LCA of their motor vehicle inventory.

1.3.5.3 Socially Equitable Carbon Pricing

There are significant opportunities with the energy use side of the LCA equation, as shown by the tables and figures above. The energy sector directly influences the carbon intensity of the fuel/electricity being consumed by transportation, and consumers are directly linked to the transportation choices they make when traveling. Economists have long advocated that an escalating carbon fee could offer an efficient, cost-effective climate policy solution, sending a powerful price signal to steer businesses and consumers towards a low-carbon future. As policymakers seek dramatic carbon emissions reductions, such policies need to be given new and serious consideration. Still, it will be important to incorporate mechanisms to defray carbon pricing for lower income segments of the population to ensure equitability and allow everyone to contribute positively toward a low-carbon future.

1.3.5.4 Recommendations

- Ensure commensurate carbon reductions from transportation, energy/fuels, and infrastructure, treating fuels and vehicles as a system.
- Promote low-carbon fuels and establish a low-carbon fuel standard (LCFS) as mechanisms to reduce the carbon intensity of fuels and open pathways to further improvements in fuel efficiency (i.e., increased gasoline octane rating).
- Consider and, if appropriate, implement socially equitable carbon pricing.
- Until carbon price signals are effective, focus aggressively on regulations to decarbonize liquid fuels, electricity, and hydrogen.
- Consider using LCA modeling as a tool to periodically review the progress of decarbonization from transportation based on a cradle-to-grave analysis, including the carbon intensity of fuel and energy production, vehicle operation and battery recycling.
- Consider a mechanism to monitor and address CO_2 reductions at the state or tribal level through the NAAQS process that incorporates stationary and transportation sources and helps states or tribes to identify and prioritize the CO_2 inventory budget that could be tightened over time in order to meet long-range national goals.
- Map out a long-term plan with interim updates; include concrete plans to enable a renewables-dominant grid.
- Implement policy encouraging utilities, vehicle manufacturers, and energy providers to coordinate on implementing VGI technologies and markets, in coordination with the Federal Energy Regulatory Commission.

1.3.6 Issues Specific to Medium- and Heavy-Duty (MD/HD) Zero Emission Vehicles

Though largely out of scope for this section of the report and the discussions that informed it, MD/HD vehicles represent a critical target market for emissions reduction.[46] Despite making up just 6 percent of California's on-road fleet, for example, MD/HD vehicles represent 21 percent of transportation GHG emissions and nearly half of transportation NOx emissions. These vehicles operate near ports,

[46] See the Goods Movement section the report for related information.

warehouses, and other freight hubs that are typically located within or adjacent to underserved communities, further compounding the issues faced by these communities.

Policymakers are now looking to act. California's adoption of the Advanced Clean Trucks regulation, the signing of the Memorandum of Understanding between 15 states and District of Columbia regarding medium- and heavy-duty electrification, and California Executive Order N-79-20 all signal a clear intention to push for electrification of this market segment.

Many barriers exist for electrification of the MD/HD segment. While a detailed discussion of these barriers is needed, this committee did not comprehensively consider these issues in its deliberations. EPA could potentially encourage different vehicle/powertrain technologies that result in the lowest emissions/energy consumption. Using LCA analysis of regional grid emissions could help in directing states and tribes to apply relative incentives toward the cleanest technologies on an annual basis. As a foundation for further discussion, the following provides a summary of the main barriers to consider in greater depth in the future:

- Functional Capability – Current BEV technology doesn't provide the energy capacity needed for the heavy hauling/towing requirements of some MD/HD customers. Fuel cell technology may resolve this issue, but further research and development is needed to apply to these vehicles.
- High purchase price for vehicles – While ZEVs are anticipated to have a lower total cost of ownership than conventional options, vehicle prices are higher due to the cost of ZEV components such as batteries and fuel cell stacks. These prices could decline with increased vehicle production and economies of scale.
- Infrastructure – ZEV infrastructure development presents costly new challenges that may be unfamiliar to fleets. Operators will need to learn new technology requirements, adjust logistics and fueling operations, and might face permitting challenges. Fleet depots might also face power draw challenges—charging several MD/HD vehicles simultaneously requires substantial electrical power potentially in excess of a building's or local or tribal grid's existing electrical capacity.
- Electricity rates – Generally, electricity is cheaper than diesel for heavy-duty fleets, which is a major reason fleets are interested in pursuing electrification. However, to maximize these benefits, stakeholders will need to develop new rate structures that lessen or avoid demand charges, which can make charging cost prohibitive.
- Hydrogen fuel costs – In today's market, hydrogen fuel remains more expensive than conventional fuels in most applications, but this is anticipated to change if demand for hydrogen fuel significantly grows in future years, especially given the potential advantages of fuel cell vehicles. Some estimates point to cost parity with conventional fuels as early as 2030, even for renewable hydrogen.[47]
- Limited model availability – There are currently limited models of zero-emission MD/HD vehicles. In addition, the current models are often produced by smaller start-up manufacturers that lack broad dealer networks or regional service facilities, nor are they able

[47] https://efiling.energy.ca.gov/GetDocument.aspx?tn=233292&DocumentContentId=65781

to deliver large orders for major fleets. This is expected to change over time as larger manufacturers bring increased models to market due to market demand and regulation. Vehicle manufacturers have suggested a targeted approach to rapidly electrifying vehicles in certain market segments that make the best business case. This includes municipal and tribal school bus fleets as well as shuttle fleets that have a centralized charging location and travel limited distances from their base of service.

Chapter 2: Personal Mobility

2.1 Review: Our Scenario to Optimize Personal Mobility to Maximize Social and Environmental Outcomes

In a world where the majority of people in the U.S. get from Point A to Point B using a transport mode other than a personally owned vehicle, describe EPA's work and role in reducing emissions transportation while maintaining mobility and accessibility.

Personal mobility is poised to be transformed by much greater use of context-sensitive shared mobility strategies, vehicle electrification, and the emergence of connected and automated vehicles[48]. As this happens, EPA must enrich and integrate its strategies with those of other federal agencies (especially DOT, DOE and HUD) and state, tribal, and local partners to better protect public health, safety, and reduce emissions, while expanding access to jobs and opportunities for the transportation disadvantaged. EPA should have a critical seat at the table with a focus on emission reductions. As such, EPA must continue vital work that supports tailpipe emission regulations, as these integrate with the Clean Air Act's larger mobile source emission control framework. This could include focusing on defining new metrics, emphasizing higher occupancy levels and accessibility, providing credits and incentives, and developing other creative strategies (e.g., developing new strategies like the California Air Resources Board's SB 1014 or Clean Miles Standard aimed at multi-modal transportation, electrification, higher occupancy levels, and modal shift to active transportation modes) for advancing personal mobility in the short- and long-term. With an eye toward the longer term, EPA should play a complementary role to other agencies to ensure the scaling and financial sustainability of new business models and approaches, which has been a notable challenge with pilot projects. Fostering social equity[49] and mobility justice[50] across personal mobility strategies must also be top priority moving forward. In considering advanced technologies and emerging mobility services, it is essential that EPA ensure it is not leaving people behind (e.g., digital and income divide). Thus, a critical eye to the social equity and mobility justice impacts of mobility alternatives (e.g., incentives, credits) to private vehicle ownership/use is needed. But EPA must go beyond regulating tailpipe emissions to ensure timely reductions in motor vehicle GHGs and criteria pollutant emissions while

[48] Please note this chapter is not intended to advocate for a particular mobility strategy or policy response (e.g., incentives, credits) to shared mobility modes without closer analysis of their social and environmental impacts. There is growing literature on the social and environmental impacts of the strategies featured in this chapter. Further, it is well documented that some may have negative environmental impacts and others may have more positive ones (e.g., carsharing, active transportation). This chapter encourages a critical eye toward deploying personal mobility strategies, including developing new metrics, data collection techniques, and analysis methods to better understand where emerging technologies and services can reduce emissions and improve mobility outcomes (e.g., access to jobs, healthy food, health care, etc.), particularly for underserved populations. This chapter argues that a focus on personal mobility alternatives could lead to less personal auto reliance/use and potentially foster energy and environmental benefits.

[49] Social equity focuses on fairness and justice. This means distributing resources to people in a just and impartial way. It does not give everyone the same thing (i.e., equality) but rather it focuses on giving everyone what they need today.

[50] Mobility justice applies a wider lens than transportation equity. It calls for recognition, participation, deliberation, and procedural fairness with discussions, adjustment, and repair. It goes beyond the traditional notion of accessibility by focusing on cultural meaning and the hierarchies surrounding mobility infrastructure by addressing power issues (e.g., valuation and who determines value). It focuses on intentional inclusion by putting underserved and historically marginalized groups at the center of mobility debates, data collection, and analysis (Sheller, 2018). See: https://www.versobooks.com/books/2901-mobility-justice

driving progress towards greater equity and mobility justice. EPA should develop EV incentive programs in the context of OTAQ's GHG emission standards to maximize the societal and environmental benefits of active transportation and shared mobility services. In this personal mobility transformation, EPA must ensure its strategies support development of robust bus and rail public transit services, that in turn support more compact development patterns and integrate with a wide array of low-carbon motorized and non-motorized travel modes. EPA should provide incentives to ensure EVs and shared EV services substantially expand affordable and practical access for transportation disadvantaged individuals.

Toward this end, EPA has a role to play in monitoring, evaluating, and incentivizing wider use of low-carbon micromobility and shared micromobility devices, such as bikes, e-bikes, and e-scooters which substitute for more polluting motor vehicle modes and support less car-dependent development of towns, cities, and suburbs. EPA has a role to play in monitoring, evaluating, and incentivizing for-hire vehicle and fleet operators to design services that will accelerate GHG mitigation and improve affordable access for those now poorly served.

As EPA focuses on micromobility and shared mobility incentives that encourage right-sizing vehicles for the trip type, DOT should develop new pilot initiatives, funding programs, and technical assistance to support, test, evaluate, disseminate, and take-to-scale improved micromobility infrastructure. These should be developed in a range of built environments and typologies, from urban to rural, to showcase slow mobility and its potential to reduce emissions, energy use, and improve quality of life and social equity. Federal funding should offer opportunities for user-friendly direct aid to local and tribal governments and public-private partnerships and should be stripped of needlessly burdensome state and federal reviews and red tape.

This document uses terminology consistent with the SAE J3163A standard, as defined at the end of this document, to describe the various elements of the micromobility and shared mobility ecosystem.

Highlights of key near-term recommendations for immediate EPA action in the next two years:

- EPA should prioritize social equity and mobility justice across personal mobility strategies moving forward in all its actions.
- EPA should focus on providing micromobility and shared mobility incentives that encourage right-sizing vehicles for the trip type and land-use and built environment context (urban to rural) to showcase slow mobility and its potential to reduce emissions, energy use, and improve quality of life and social equity.
- EPA must ensure its strategies support the development of robust bus and rail public transit services (including microtransit, first and last mile connections, mobility wallets, mobility on demand (MOD), and mobility as a service (MaaS)), which reinforce more compact development patterns and integrate with a wide array of low-carbon motorized and non-motorized travel modes (e.g., bikes and scooters).
- EPA should adopt new incentive programs, such as the ZEV "transportation system" credits or CARB's SB 1014 (Clean Miles Standard) aimed at multi-modal transportation, electrification, higher occupancy levels, and modal shift to active transportation modes (walking, bicycling, and scooter use). Incentives and credits could support the purchase of active transportation modes, e.g., e-scooters and e-bikes.

- EPA should define new metrics (e.g., higher occupancy levels and accessibility to jobs, health care, education, and healthy food) that prioritize active transportation modes and pooled vehicle services, including public transit, in meeting emission reduction goals.
- EPA should reinvent and update its past work promoting sustainable communities and smart growth, working in partnership with state, tribal, and local governments, transportation agencies, and other stakeholders in the private and public sector.
- EPA should support research, documentation, and local uptake of best practices to encourage walkable, bikeable, and transit-oriented development supported by complete streets that are designed and operated with safety as a top priority. This should include how innovative mobility services can be designed to best support accelerated goals for mitigation of transportation GHG emissions, as well as conventional criteria pollutants.
- EPA should work with DOT and HUD to provide incentives for electric vehicles (EVs) and shared EV services to improve access for low-income communities to jobs and services.
- EPA should shape federal standards for AVs, noting the potential for AVs to undermine active transportation modes and low-carbon urban development patterns, prompting an explosion in vehicles miles traveled (VMT), if not managed with sound pricing and regulation.
- EPA should work with NHTSA to shape rules so AVs will be designed and programmed to comply with state, local, and tribal traffic laws and operated in ways designed to avoid or mitigate adverse impacts on public health and the environment.
- EPA should support research on how connected and automated vehicles may impact emissions, examining vehicle and traffic operations, driver behavior under various scenarios for road user charging and rules for traffic law compliance and modal shifts.
- EPA should work with relevant stakeholders to promote consistent, complete, and open data access to on-board telematics and roadway infrastructure sensor data and other data enabling evaluation of personal mobility and a suite of state, tribal, local, and federal policies needed to reduce emissions and promote key public health and social equity and justice goals.
- EPA should continue to develop and improve the MOVES model, focusing not only on tailpipe and evaporative emissions, but also on the modeling of brake and tire wear, accounting for secondary organic aerosol (SOA)-precursors and ultra-fine particles, which are not currently counted.
- EPA should ensure consideration of upstream and downstream GHG emissions when evaluating transportation actions with a potential to affect the number, type, and patterns of use of various types of motor vehicles and zero polluting modes in use under different scenarios over time.
- EPA should foster widespread measurement and reporting on community and personal exposure to pollutants (e.g., California's SB 617, Community Air Protection Program), highlighting how near-roadway concentrations of PM, NOx, and other pollutants still lead to increased morbidity and mortality for millions of Americans. EPA also should ensure timely action to mitigate these adverse health impacts and the disproportionate burdens they

impose on low-income individuals and black, Indigenous, and people of color (BIPOC) communities.

- EPA and NHTSA need to collaborate to advance vehicle traffic safety technologies like automated braking, pedestrian and cyclist recognition systems, and Intelligent Speed Assistance that can reduce emissions, while improving the safety of zero-carbon walking, cycling, and micromobility modes.
- EPA must enrich and integrate its strategies with those of other federal agencies (especially USDOT, USDOE, HUD) and state, tribal, and local partners to better protect public health, safety, and reduce emissions while expanding access to jobs and opportunities for the transportation disadvantaged.
- EPA staff should host a multi-stakeholder workshop (USDOT, USDOE, HUD) to explore strategies for maximizing flexibility and creativity in the context of existing regulations, such as the Clean Air Act (CAA).
- EPA should actively engage community-based organizations and communities in addressing environmental justice[51] and disproportionate health and other impacts through co-creation of strategies.

2.2 "First Principles" to Guide our Work

EPA should ensure its regulations, initiatives, policies, and engagements with stakeholders and other agencies:

- Integrate principles of social equity and justice, affordability, accessibility, and mobility to create economic opportunity
- Actively engage community-based organizations and communities in addressing environmental justice and disproportionate health and other impacts
- Create an efficient transportation system that integrates safety and health concerns to holistically reduce risks to all people
- Pay heed to not just direct, but also indirect, secondary, induced, cumulative, and disparate impacts of actions and mobility sector development strategies.
- Reduce tailpipe and lifecycle GHG and criteria emissions through mode shift and effective design and operations of emerging vehicle technology and intelligent transportation systems.
- Emphasize slow mobility modes, such as walking, cycling, and scooters to foster low-carbon modes, modal shift, reduced emissions, social equity, and quality of life.

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[51] Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (US EPA website). See: https://www.epa.gov/environmentaljustice

- EPA could develop new metrics that focus on occupancy, accessibility, and critical social outcomes (e.g., job access, access to healthy food, education, and health care) to advance these principles.
- EPA could provide credits and incentives to encourage the public and private sectors to advance principles of mobility justices, maximize environmental and energy benefits, and help to scale and support financial sustainability of personal mobility strategies in the short- and longer-term.
- OTAQ staff should be empowered to work creatively and think outside the box in advancing personal mobility strategies and principles in the context of the CAA and other regulatory mechanisms. Staff consider hosting a multi-stakeholder workshop to explore strategies for maximizing flexibility and creativity in the context of existing regulations, such as the CAA.

2.3 EPA Should Consider How Various Factors May Impact our "First Principles"

2.3.1 Examples of Factors That EPA Will Want to Consider

Land use, transportation infrastructure, urban design, pricing, and other drivers have shaped—and will continue to shape—the built environment in which people and firms make transportation choices. Many communities are desperate for federal support to help them recover and rebuild in the wake of the COVID pandemic. In coming years EPA should consider ways it can encourage and accelerate uptake of more sustainable transportation systems. The emergence of new transportation technologies offers opportunities for EPA to develop new and more effective integrated transportation emission control strategies that also improve safety.

- EPA should reinvent or update its past work promoting sustainable communities and smart growth, working in partnerships with state, tribal, and local governments, transportation agencies, and other stakeholders in the private and public sector. EPA should collaborate with USDOT in shaping guidance for federal stimulus or Infra/TIGER style funding to encourage "shovel worthy" state, tribal, and local initiatives that will provide a short-term recovery with long-term benefits for sustainability.
- EPA should support research, documentation, and local uptake of best practices to encourage walkable, bikeable, and transit-oriented development supported by complete streets that are designed and operated with safety as a top priority.
- EPA should support initiatives that consider how transportation options like bikesharing, e-bikes, Mobility on Demand, Mobility-As-A-Service, and automated vehicle services can be designed best to support accelerated goals for mitigation of transportation greenhouse gas emissions as well as conventional criteria pollutants.

Improving the customer experience and usability of public transit services, seamlessly integrated with shared mobility services, would have benefits for dependent transit riders, who are often from marginalized communities. Public transit data from across the US suggests that the majority of current riders (since COVID-19) are essential workers and low-income individuals. The majority of "choice riders" have shifted away from public transportation due to work-from-home/telework policies and virus transmission concerns. Immediate attention should focus on public transit dependent riders who rely on public transit for accessing jobs and other services, along with enhancing the network of shared mobility services to complement public transit. Services should embrace equitable access and address unbanked and underbanked populations to address the digital and income divide.

Census data show that people of color have lower household incomes than white households, and that in US cities over 100,000 people, up to 48% of residents do not have access to an automobile. To further compound this, as those with more resources have moved back into cities, many people of color and low-income individuals have been able to find affordable housing only in suburbs where absent changes in street design, walking and biking are hazardous. Access to affordable transportation choices is critical to the quality of life of all Americans. Middle- and low-income American households spend, on average, nearly 20 percent of their income on transportation and 41 percent on housing (and are thus rent burdened). Limited access to affordable housing near employment centers—or to affordable and reliable transportation options to and from employment centers—creates the high burden of transportation costs for many families due to spatial mismatch.

Outside of urban areas, it is important to consider how various shared mobility services could enhance social equity and transportation justice. This could include providing integrated intercity rail and public transit access for rural communities, particularly those who do not own a private vehicle.

- In close collaboration with US DOT and other agencies, EPA should consider how transit service and shared mobility system changes affect public transit dependent riders who rely on public transit to access jobs and other services. This should include examinations of how public-private partnerships might contribute to filling gaps in transit coverage to reduce emissions while boosting access for transportation disadvantaged people.
- In close collaboration with US DOT and other agencies, EPA should consider how shared mobility services could better advance equitable access and address access for the unbanked and underbanked populations to address the digital and income divide.
- Access to affordable transportation choices is critical to the quality of life of all Americans. EPA should work with US DOT and other agencies to create incentives that make shared, electric, automated, and micromobility transportation options more affordable. This could include bike and scooter purchase and use incentives, infrastructure funding, and pilot programs to document lessons learned and provide technology transfer.
- Limited access to affordable housing near employment centers—or to affordable and reliable transportation options to and from employment centers—creates a burden of high transportation costs for many families due to "spatial mismatch." EPA should work with DOT and HUD to provide incentives for electric vehicles (EVs) and shared EV services to fill these gaps, including means-targeted incentives and subsidies.
- Any initiative developed by USEPA (and sister agencies) should be sensitive to the social equity/environmental justice implications of service changes and public-private partnerships. Reallocation of services or funding should not decrease accessibility for communities of color or other marginalized groups.

2.3.2 *Shared Mobility*

Shared mobility is the shared use of a vehicle, bicycle, or other mode that enables users to have short-term access to transportation modes on an “as- needed” basis (please see definitions at the end of this paper). It includes carsharing, personal vehicle sharing (PVS, including peer-to-peer [P2P] carsharing and fractional ownership); scooter sharing; bike- sharing; transportation network companies (TNCs, also known as ridesourcing or ridehailing); ridesharing (i.e., carpooling, vanpooling); microtransit; and courier network services. The figure below categorizes these key areas of shared mobility. Carsharing, scooter sharing, and bikesharing are services that enable vehicle sharing. Ridesharing (carpooling and vanpooling), on-demand ride services, and microtransit (see figure, middle) facilitate the sharing of a passenger ride. Lastly, courier network services (see Figure 7, below) allow for the sharing of a delivery ride (i.e., a ride for cargo).

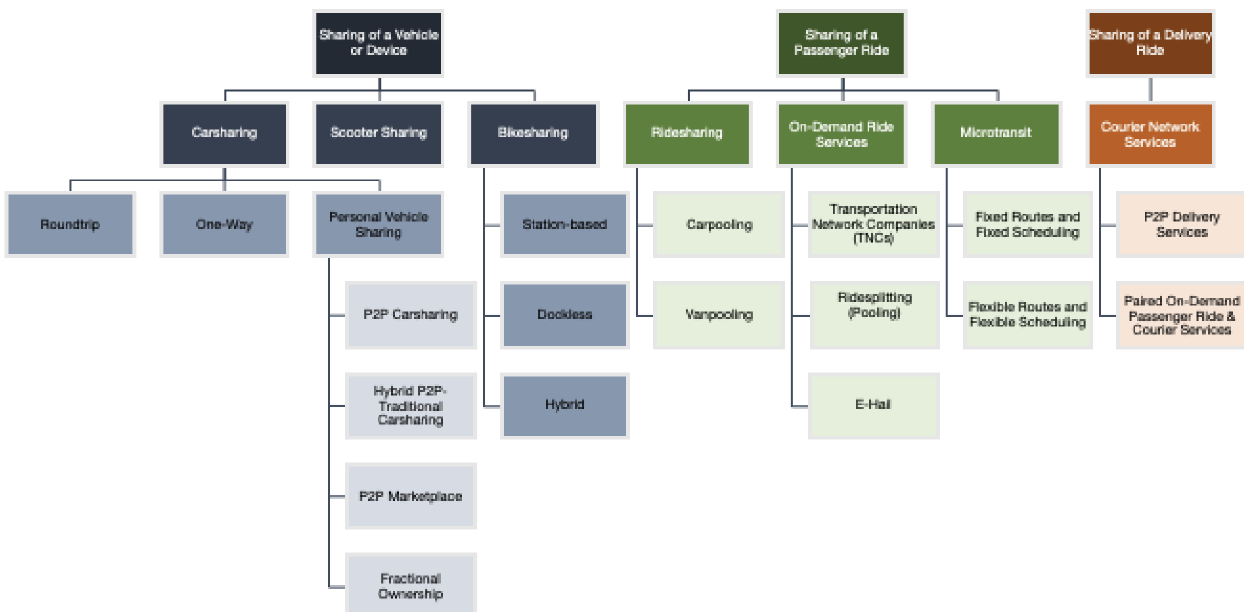

Figure 7: Key Areas of Shared Mobility.[52]

Mobility as a Service and Mobility on Demand platforms are beginning to link mobility services on an integrated multi-modal platform in regions across the globe. Many studies have documented the impacts of shared mobility in numerous global cities with respect to cost savings and convenience, reduced personal vehicle ownership and vehicle miles traveled (VMT)/vehicle kilometers traveled (VKT), which can translate to greenhouse gas (GHG) emission reductions. As the private sector innovates and the menu of shared mobility options grows, it is important for the public sector,

[52] Shaheen, Susan, Nelson Chan, Apaar Bansal, and Adam Cohen (2020). “Chapter 13: Sharing Strategies: Carsharing, Shared Micromobility (Bikesharing and Scooter Sharing), and Innovative Mobility Modes,” *Transportation, Land Use, and Environmental Planning*. ISBN 9780128151686, pp. 237-262. http://dx.doi.org/10.1016/B978-0-12-815167-9.00013-X. https://escholarship.org/uc/item/0z9711dw.

including EPA, to not only respond with appropriate regulations and incentives to protect public safety but also to provide guiding policies to maximize the social and environmental benefits.

In 2001, the California Air Resources Board (CARB) approved a revision to the ZEV mandate allowing for additional incentives for placing EVs in "transportation systems" or carsharing and station car fleets.[53] This policy was phased out on January 1, 2018. A later study documented some of the impact of the ZEV transportation system credits in terms of education.[54] The data from user surveys across several carsharing programs suggests that carsharing programs with hybrid vehicles and EVs within their fleets played a role in promoting greater adoption of these technologies. This is in addition to the other favorable impacts of carsharing, such as facilitating reduced vehicle ownership, overall driving, and reduced GHGs. Shared mobility programs provide exposure to a demographic that otherwise has a lower propensity to own such vehicles. The result of this access is an improved impression of ZEVs and a stronger affinity toward ZEV technology. Thus, such an incentive program should be considered by EPA in the context of its GHG emission standards. EPA should consider adopting new incentive programs, such as the ZEV "transportation system" credits or CARB's SB 1014 (Clean Miles Standard) aimed at multi-modal transportation, electrification, higher occupancy levels, and modal shift to active transportation modes

There is an opportunity for EPA to incentives right-sized vehicles and clean propulsion vehicles in shared mobility systems to help scale these services and provide subsidies to ensure their long-term financial sustainability in a wide range of land use and built environments. EPA should consider introducing creative incentive programs and pilot projects, exercising flexibility within the CAA, to test and advance concepts around right sizing and clean propulsion, which complement emerging personal mobility strategies, to maximize the social/environmental good and support financial viability and scaling.

2.3.3 Vehicle Automation and Connectivity

In the last decade, there has been significant interest how vehicle connectivity (i.e., vehicles communicating with each other and with the infrastructure) and vehicle automation (aka autonomous driving, self-driving cars, etc.) will reshape personal mobility.[55] There have been many reports that have predicted that vehicles could be fully automated (i.e., not requiring a driver) by as early as 2025, however as we approach that date, we are finding that full automation will likely be tightly bounded in areas that consist of easy driving conditions.

Nevertheless, we are seeing significant progress in terms of partial automation capabilities, and for scenarios where limited vehicles are taking advantage of communications. In terms of impacts on energy and emissions, connected and automated vehicles could have both positive and negative implications. Wide deployment of connected and automated vehicles could lead to reduced emissions, due to congestion reduction (for example, crash avoidance, platooning), traffic smoothing

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[53] Shaheen, Susan, John Wright, and Daniel Sperling (2002). "California's Zero Emission Vehicle Mandate--Linking Clean Fuel Cars, Carsharing, and Station Car Strategies," *Transportation Research Record*. No. 1791, pp. 113-120.
[54] Shaheen, Susan, Elliot Martin, and Apaar Bansal (2015). *Zero- and Low-Emission Vehicles in U.S. Carsharing Fleets: Impacts of Exposure on Member Perceptions*. September, 19 pages. http://innovativemobility.org/?project=zero-and-low-emission-vehicles-in-u-s-carsharing-fleets-impacts-of-exposure-on-member-perceptions.
[55] See, *e.g.*, Sperling Three Revolutions book; M. Barth and D. Sperling (2019), "Environmentally Sustainable Transportation", in Bending the Curve: Climate Change Solutions, Regents of the University of California. Editor: V. Ramanathan; Regents of the Univ of California. pp. 14-1 – 14-31.

(for example, cooperative adaptive cruise control, advanced intersection management), and better speed management (for example, speed harmonization). These benefits could be significantly bolstered by the potential parallel transition to road user charges (such as VMT-fees) that may vary based on time, place, occupancy, and emissions vehicle class.

In contrast, connected and automated vehicles could potentially increase emissions by increasing overall vehicle travel (i.e., VMT). Due to their increased capabilities and convenience, people might use their connected/automated vehicles for additional purposes or choose a more distant place to live. Further, connected and automated vehicles could be used by a wider range of users, including youth and elderly. "Drop-off" errands might increase, resulting in new empty vehicle relocation trips, such as returning home without any passengers. These negative outcomes become highly likely if road user charging is not adopted in parallel with automation.

Thus, EPA needs to fully participate with other agencies and automotive OEMs on how connected and automated vehicles are developed and deployed, particularly as the National Highway Traffic Safety Administration (NHTSA) moves to adopt standards related to motor vehicle fuel economy, motor vehicle traffic safety, and vehicle automation technologies which will have a very large cumulative impact on motor vehicle emissions for decades to come.

- EPA should support research to better determine how connected and automated vehicles will impact fuel economy and emissions, examining not just vehicle and traffic operations, but also driver behavior under various scenarios for road user charging.
- EPA should participate in shaping federal standards for AVs, taking note of the potential for AVs to undermine active transportation modes and low-carbon urban development patterns, prompting an explosion in Vehicles Miles Traveled, if not managed with sound pricing and regulation.
- NHTSA and EPA should require that AVs be programmed to comply with state. local, and tribal traffic laws and operate in ways designed to avoid or mitigate adverse impacts on public health and the environment.
- EPA should encourage and incentivize the use of connected and automated vehicles in shared mobility scenarios, where VMT can be closely managed and pooling can be more easily encouraged, particularly with occupancy-based emission and road use fees.
- EPA should help promote the combination of connectivity and automation rather than a purely autonomous vehicle approach, since vehicle communication will promote better coordination with other vehicles and infrastructure, leading to greater improvements in fuel economy and reduced emissions.

2.3.4 Improving Collaboration and Coordination Among Different Levels of Government

Given the novel nature of many of the personal mobility options and the way in which they have entered the market, a range of government actors have already begun to think about how to regulate these services. Moreover, many of these actors have authorities and priorities differing substantially from EPA's authority under the Clean Air Act. Thus, while actions to date may provide EPA with substantial opportunity to learn "best practices" and take advantage of established networks as is most effective, the differing goals of the various governmental bodies will require significant coordination. This coordination will not just come at the federal level (e.g., DOT and DOE), but through municipalities, state, tribal, and regional government entities, including metropolitan planning organizations (MPOs).

Collaborative activity is ongoing, with many different subgroups forming to define best practices, etc.—for example, the National Association of City Transportation Officials (NACTO), the American Association of State Highway and Transportation Officials (AASHTO), and the American Public Transit Association (APTA) all have their own work groups targeting shared mobility and MaaS. However, it is the interaction of partners crosscutting these siloes where linkages need to be made and fostered in order to transform the transportation sector in a coherent way.[56] Early efforts show both the promise and need for coordination but also its challenges, including delays and reductions in scope for pilot efforts.[57]

One critical factor limiting the potential for collaboration could center on data availability and privacy. This itself represents both a factor around which coordination will be required and a potential central challenge to coordination among entities operating under different regulatory paradigms.[58] While EPA will only be one of many stakeholders in any such process, ensuring consistent, complete, and open data sources for the wide range of public-private interactions will be critical to data-based regulation and planning for personal mobility consistent with the first principles laid out above.[59]

- EPA should work with relevant stakeholders to develop consistent, complete, and open data sources for personal mobility, which can better enable the suite of state, tribal, local, and federal policies needed to reduce emissions and promote the first principles laid out above.

2.3.5 Engagement Is Critical, Regardless of Specific Regulatory or Policy Frameworks

There are many forms by which coordination can take shape, but in order for partnerships to be consistent with the values and objectives of EPA, EPA must have a seat at the table. Whether that means engaging directly with standards-setting bodies, formal funding and/or memoranda of understanding with appropriate partners, or joining established task forces, EPA should become more engaged well in advance of establishing any regulatory activity to better ensure that actions taken in the interim will not undercut future action(s). It should also learn from and partner with agencies like the DOE who already have experience with initiatives in this space (e.g., Systems and Modeling for

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[56] *See* McCoy, K., Andrew, J., Glynn, R., and Lyons, W. (2018). Integrating Shared Mobility into Multimodal Transportation Planning: Improving Regional Performance to Meet Public Goals. Report for Federal Highway Administration, February 12, 2018. FHWA-HEP-18-033. https://www.planning.dot.gov/documents/SharedMobility_Whitepaper_02-2018.pdf.

[57] *See e.g.,* City of Columbus. (2020). Performance Measurement Plan (PfMP) for the Smart Columbus Demonstration Program. Reporter, updated August 2020. https://d2rfd3nxvhnf29.cloudfront.net/2020-08/SCC-C-PfMP-Update-v1.pdf. and McCoy, K., Glynn, R., Lyons, W., and Andrew, J. (2019). Integrating Shared Mobility into Multimodal Transportation Planning: Metropolitan Area Case Studies. Report for Federal Highway Administration, May 2, 2019. FHWA-HEP-19-036. https://www.planning.dot.gov/documents/regional_shared_mobility_planning_caseStudies.pdf.

[58] Stantec and Ara. (2020). Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #1—Models for Data Sharing and Governance for Automated Vehicles and Shared Mobility. Prepared for the Transportation Research Board Forum on Preparing for Automated Vehicles and Shared Mobility on September 21, 2020. http://onlinepubs.trb.org/onlinepubs/AVSMForum/products/1-NCHRP_Data_Sharing_and_Governance_FINAL.pdf.

[59] Shaheen, S., Cohen, A., Randolph, M., Farrar, E., Davis, R., and Nichols, A. (2019). Shared Mobility Policy Playbook. Retrieved from https://escholarship.org/uc/item/9678b4xs

Accelerated Research in Transportation [SMART] Mobility Consortium)[60] and through established interagency partnerships (e.g., the Coordinating Council on Access and Mobility [CCAM]).[61]

There is no reason for EPA to reinvent the wheel—however, it cannot help guide a better-informed process from the sidelines. Owing to the breadth of local, tribal, and regional work, as well as its expertise and research in transportation technologies, EPA is in a strong position to engage with both new and existing partnerships while providing a different perspective from that of the federal, state, tribal, and local departments of transportation and other government agencies already engaged in this space.

- EPA should engage with federal partnerships and cross-agency task forces in order to ensure that emission reductions, environmental justice, and other agency values are represented in the work conducted by these working groups, including as it relates to standards-setting and funding.

2.4 New Research Tools Will Be Needed

2.4.1 Research, Data Collection, Modeling, and Analysis

Estimating accurate mobile source energy and emissions inventories is critical for understanding and managing our air quality and climate. In developing a mobile source energy and emissions inventory, there are typically three general components that have to be considered: 1) *energy and emission factors* (i.e., how many units of energy or emissions are used per unit distance or time); 2) *vehicle activity* (i.e., how often are vehicles driven in terms of unit distance or time, and at what loads); and 3) *fleet composition* (i.e., what types of vehicles are being used). All three of these components continue to become increasingly complex due to a larger variety of vehicles utilizing different fuels, as well as an overall increased vehicle activity both in volume and type of trips being carried out.

As a result, it is important to continue to collect appropriate data sets for all three components listed above, perform extensive data analysis to support rule making, and improving our modeling capability to predict future scenarios.

2.4.2 Specific Data Collection Recommendations

- EPA should continue to collect the best data available to estimate on-road vehicle populations and technologies; in addition, data needs to be collected for nonroad equipment;
- EPA should work with US DOT and other stakeholders to ensure better national, state, tribal, and local accounting for changes in travel activity for all modes, including walking and cycling, shared transport, and vehicle occupancy;
- EPA should maximize use of emerging on-board telematics data wherever possible, as well as roadway infrastructure sensor data sets, to better estimate vehicle activity;

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[60] EERE (Office of Energy Efficiency and Renewable Energy). (2020). EEMS SMART Mobility Capstone Reports. Collection, released August 28, 2020. https://www.energy.gov/eere/vehicles/downloads/eems-smart-mobility-capstone-reports-and-webinar-series.

[61] CCAM (Coordinating Council on Access and Mobility). (2020). "Coordinating Council on Access and Mobility Report to the President." https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-09/CCAM-Report-to-the-President.pdf.

- EPA should continue to collect real-world energy and emissions data through on-board sensing and reporting; this is particularly important in the heavy-duty sector;
- EPA should enhance its ability to estimate energy and emissions implications of tampering, malfunction, and mal-maintenance.

2.4.3 Specific Modeling Recommendations

- Continue to develop and improve the MOVES model, focusing not only on tailpipe and evaporative emissions, but also on the modeling of brake and tire wear;
- Improve modeling of alternative fuels and technology (ethanol, biodiesel, natural gas, electric vehicles, hybrid electric vehicles, gas direct injection, flex fuels), for both tailpipe and evaporative emissions;
- Better account for secondary organic aerosol (SOA)-precursors and ultra-fine particles, which are not currently accounted for;
- Improve modeling capabilities for analyses at the microscale *project level*; this can be accomplished by considering the incorporation of a true modal emissions model and improved linkages with traffic models;
- Continue to integrate models such as MOVES with other critical modeling tools, such as Life-Cycle Energy/Emissions models, a variety of transportation/travel demand models, and air quality models; developing a unified modeling suite and effective users guide would be highly beneficial.
- Continue to develop synthetic population models to support evaluation, disclosure, and design of remediation strategies to reduce disparate impacts and community exposures.

Improve accounting and monitoring of transportation life-cycle environmental impacts including GHGs, considering upstream vehicle and fuel production and distribution and downstream vehicle disposal.

2.4.4 Research, Data Collection, And Analysis Is Needed in Critical Areas

- EPA should support more use of lifecycle analysis of major systems and investments to inform better-grounded decisions by stakeholders in the public and private sector. This should take account of secondary and indirect impacts and consider alternative scenarios.
- EPA should ensure consideration of upstream and downstream transport sector greenhouse gas emissions when evaluating actions with a potential to affect the number, type, and patterns of use of various types of motor vehicles and zero polluting modes in use under different scenarios over time.
- EPA should support efforts to ensure timely widespread measurement and reporting on community and personal exposure to pollutants, highlighting how near-roadway concentrations of PM, NOx, and other pollutants still lead to increased morbidity and mortality for millions of Americans more than 50 years after the Clean Air Act was passed (e.g., California's SB 617, Community Air Protection Program). EPA should support data collection, analysis, and ensure timely action to document and mitigate these adverse health impacts

and the disproportionate burdens they impose on low income individuals and communities of color.

- EPA should support development of more sketch tools that help communities, stakeholders, and professionals consider integrated pollution remediation strategies and the costs and benefits of shifting investment priorities in local, regional, tribal, and state budgets and plans.

Collaboration with universities, national labs, other federal agencies, etc. will be needed because EPA will not be the lead agency for many relevant actions.

2.5 Every Policy Tool Will Be Needed

The EPA Has Numerous Policy Options to Drive Emissions Reductions from Personal Mobility. Because a low-emission transportation system built on personal mobility would be truly a systems-wide transformation, the vehicle-focused regulatory approach currently implemented is likely to prove increasingly inadequate to achieve by itself the goals of the Clean Air Act. Because of the breadth of potential regulated entities, establishing new paradigms for regulatory action will be necessary, but the Clean Air Act gives EPA latitude to advance new approaches.

2.5.1 Adapting Current Regulations

Given the long-established history of regulating vehicle manufacturers, EPA may seek to build on its greenhouse gas emissions regulations for light- and heavy-duty vehicles. However, this raises three chief issues: 1) enforcement of vehicle use; 2) disparity between service providers (which are consumers of the products of manufacturers) and the manufacturers themselves; and 3) incompleteness.

On the first point, regulation of the same vehicle based on different use cases would be fairly novel. While EPA has approached this in its heavy-duty greenhouse gas emissions regulations for vocational vehicles (81 FR 73719-73725), in that case it is done because the incomplete vehicle must be certified on a unique test procedure in advance of a non-regulated third-party (so-called "upfitters"). Were EPA to shoehorn use into its light-duty regulations based, for example, on extra credits for the sale of so-called "high-utilization" applications (e.g., see GM 2018, p. 24), it has now shifted the burden for enforcement, creating issues around how the agency would ensure compliance with such utilization. Moreover, it would beg the question around such practice for non-commercial consumers, since emissions make no distinction between private and commercial vehicle use, and it is even less clear how to hold automakers accountable for their consumers' use.

Shifting the responsibility for emissions from the manufacturer to the end-user would be a significant shift in responsibility, and this would create a potentially disparate field of regulated entities—since manufacturers would likely remain the regulated entity under the light-duty vehicle greenhouse gas regulations, those with a parent relationship between the OEM and the service provider (e.g., General Motors and Cruise) would have more direct ability to take advantage of any crediting program, as opposed to a manufacturer that sells to a variety of service providers. Such inequity would likely create indirect, haphazard incentives that are unlikely to fully realize the emissions gains needed.

Finally, because existing regulations only cover the light- and/or heavy-duty vehicles, there is a broad swath of mobility uses which would likely be excluded from any such system. For instance, the idea of crediting General Motors for Cruise better integrating public transit into its mobility usage is enough to make one's head spin, let alone how the agency would actually go about operationalizing this in the case of a service provider like Uber that uses vehicles manufactured by all automakers.

A vehicle-specific requirement makes sense in some instances -- for example, requiring all driverless, autonomous vehicles to be electric and requiring them to be designed to support compliance with state, local, and tribal traffic laws. However, it would be generally preferable for EPA to directly regulate the providers of the end product (passenger-miles) resulting in the direct emissions rather than indirectly regulate the emissions by regulating vehicle production. Such an approach to directly regulate mobility service providers may require additional authorization from Congress.

While not an EPA regulation, NHTSA's New Car Assessment Program (NCAP) provides a regulatory opportunity for the agency. NCAP can be used to regulate the safety outcomes of new motor vehicles, including conventional and automated technologies that may impact systemwide emissions. The European Union (EU) has mandated all new motor vehicles sold in the EU after 2022 have automated braking, pedestrian and cyclist recognition systems, and Intelligent Speed Assistance. A push by NHTSA to adopt similar regulations on all new motor vehicles sold in the U.S. could promote a systemic shift in mobility by improving safety for all road users, reducing hazards to walking, cycling, and micromobility choices, and producing reductions in criteria pollutants, GHGs, and motor vehicle fatalities and injuries. Studies for the European Commission estimate that Intelligent Speed Assistance alone could cut motor vehicle CO2 emissions by 8 percent while preventing 30 percent of collisions and 20 percent of road deaths. Deaths of vulnerable road users - cyclists and pedestrians - have been increasing in the U.S. due to wider adoption of SUVs and light trucks with high grills and poor visibility. EPA needs to work with NHTSA to ensure changes in vehicle design make walking, cycling, and micro-mobility modes safer and more attractive.

- In the near-term, EPA should maintain the vehicle-specific focus of its light-duty passenger vehicle emissions standards, in order to ensure that manufacturers are providing the cleanest and most efficient vehicles to its customers, regardless of end use.
- In the longer term, EPA should focus on particular use cases (e.g., first- and last-mile connectivity), right sizing of vehicles by trip type, increasing occupancy levels through pooling strategies, and reducing VMT (e.g., work-from-home policies and active transportation) by employing incentives and credits to maximize social/environmental benefits and support pilot scaling and long-term financial sustainability of personal mobility strategies, along with social equity and mobility justice.
- EPA should require that driverless automated vehicles be electric, in order to negate as much as possible the large potential increase in vehicle miles traveled.
- EPA should work with NHTSA to assess the net emissions impacts of vehicle safety systems--particularly those which impact vulnerable road users, especially pedestrians, cyclists, and operators of slower and more slowly accelerating light vehicles--in order to ensure (to the extent possible) that NCAP and other vehicle safety programs are incentivizing systemwide efficiencies and lower-emission mobility choices.
- EPA and NHTSA need to collaborate to advance vehicle traffic safety technologies like automated braking, pedestrian and cyclist recognition systems, and Intelligent Speed Assistance.

2.5.2 New Regulatory Approaches

States and tribal lands which are not compliant with NAAQS must file implementation plans with EPA. As part of those SIPs/TIPs, EPA provides guidance on different control strategies. EPA could develop a roadmap for incorporating emissions reductions from mobility service providers as an emissions control strategy. Numerous different pathways can be identified for emissions reductions, including reducing emissions of the vehicles themselves or shifting usage to transit through integration. Given the widely varying nature of emissions reductions options for various locales, this could create a financial incentive for service providers due to the higher costs of emissions reductions from certain industrial point sources.

One risk is that some share of these emissions reductions may have happened regardless of their inclusion as a control strategy -- by explicitly crediting them as a control strategy, any incidental reductions from the status quo could thus be lost. However, by defining a robust program in the limited jurisdictions in non-compliance under NAAQS, EPA could create models for reductions that could be deployed by other locales for emissions reductions that may be outside the scope of NAAQS, including greenhouse gas emissions.

An additional risk of such an approach is concerns around equity—point source emitters disproportionately impact low-income and BIPOC communities, and any SIP/TIP guidance around a new reduction strategy should consider any such transfer as part of the process to uphold the “first principles” identified above.

- EPA should use its authority under the Clean Air Act (CAA) to adopt Transportation Control Measures (TCMs) that states could adopt in State Implementation Plans (SIPs) to meet NAAQS. Clearly defining emissions assessments and reduction pathways would provide incentives in non-attainment areas but could also provide clearer guidance on reducing emissions even in regions already in attainment.

2.5.3 Dynamic Mobility Management

Another paradigm that EPA should consider investigating and further developing, is the continuous monitoring of a vehicle’s emissions performance in real-time, and potentially managing vehicle and traffic operations to minimize the impacts of emissions on local air quality. In recent years, a new generation of on-board sensors and communication technology has emerged, allowing for development of a real-time emissions inventory for traffic in specific regions. Given this information, it is feasible to dynamically manage the operation of vehicles, traffic infrastructure, and traveler behavior to minimize air quality impacts at the local level. Examples may include switching hybrid vehicles to all-electric mode in sensitive areas (e.g., dynamic geo-fencing), changing traffic signalization to minimize total traffic emissions, and have travelers choose different routes to avoid exposure to local residents.

- EPA should investigate the potential for real-time emissions monitoring as part of an in-use emission regulation program.
- EPA should conduct pilot projects to assess benefits and efficacy of these in-use-oriented regulatory paradigms and protocols, so that they are consistent, fair, and reliable. This should include exploration of the impacts on travel behavior and emissions of road use charges that vary by time, place, emission class, and occupancy.

- EPA should encourage dynamic mobility management in shared mobility options, such as carpooling, TNCs/ridesourcing, carsharing, and microtransit systems to improve their overall efficiency.

2.5.4 Voluntary Programs

In lieu of direct regulation, EPA could establish a voluntary program around certification of emissions reductions. In the case of SmartWay, EPA certified technologies to specific benchmarks, which allowed entities to have a more rigorous guarantee of expected emissions reductions. They also worked with end users (fleets) to use these operational and technology improvements to reduce emissions. This model could be adapted to personal mobility as well, providing a key service to not just mobility providers, but municipalities and others looking to understand how to incorporate personal mobility options into their own plans.

There are a number of different clear value-adds for EPA in this space. For example, developing a set of clearly defined test procedures for scooters, e-bikes, etc. would better enable apple-to-apple comparisons among different vehicle services. Requiring full lifecycle analysis using a common protocol could aid this as well, allowing localities to better consider service providers' products as part of local emissions reductions strategies, including the impact of potential shortfalls in operational life. EPA could also work with transportation officials to develop clear metrics around the emissions benefits of modal switching and clear methods for assessing and attributing any such benefits to service providers—this could provide more robust assurance of emissions reductions for locales working with service providers to reduce transportation emissions, just as under California's Cleans Mile Standard.[62]

- EPA should establish a voluntary program for mobility service providers to incentive the adoption of an appropriate set of emissions reduction strategies, modeled on its successful SmartWay program.
- EPA should develop and standardize lifecycle assessment tools for all types of personal mobility vehicles, including scooters, e-bikes, and light-duty vehicles.
- EPA should work with local, tribal, and state transportation agencies and transit providers to develop clear metrics and best practices for emissions reductions related to modal shifts.
- While voluntary programs can be beneficial, EPA should also consider mandatory approaches, such as California's Clean Miles Standard (SB 1014), as noted above.

2.5.5 Financial Incentives

New technologies and services open up the potential for large public or private fleet operators, mobility service providers, or transportation infrastructure operations and management organizations to measure, monitor, incentivize, and shape the emissions characteristics of the portion of the mobility systems they control.

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[62] https://ww2.arb.ca.gov/events/public-workshop-clean-miles-standard

- EPA should establish and fund an innovation platform to pilot test means of measuring and incentivizing smarter, safer, and more equitable traffic operations and mode shift strategies, documenting the distributional impact of costs and benefits.
- EPA should employ incentives and credits to scale and support financial sustainability of personal mobility strategies to test new ideas and ultimately scale them in the longer term. This should be done in partnership with other agencies (e.g., USDOT, HUD, etc.). It is critical that these incentives and credits align with new metrics and emphasize social equity and mobility justice, going beyond traditional metrics of energy efficiency and emission reduction.

2.6 Education and Outreach

2.6.1 Guidance to State, Tribal, and Local governments, MPOs, and Regional Efforts

Guidance, support, and outreach is needed to address the often poor coordination and integration of transit and shared mobility across regions, operators, and the public and private sectors. For public transit riders, this means they have less access to jobs, education, healthcare, family, friends, and all the other elements of life to which public transit connects them, either due to the expense of transfers between systems or trip travel times are too long to be a realistic option. This lack of coordination can mean lower ridership on the public transit system as a whole.

Furthermore, the public transit systems are at risk of substitution by TNCs and other mobility providers that can provide a better customer experience. If lost potential ridership is replaced by more private autos on the road, that means more congestion, more emissions, and greater numbers of traffic crashes. More reliance on private autos also puts an unfair financial burden on marginalized households who already face budgetary constraints including rent, food, and health care. Affordable housing can often be distant from jobs, which further burdens marginalized populations with longer and more costly commutes (in both time and money).

- EPA should work with USDOT and other agencies to create pilot programs to assist metropolitan regions, cities, and towns interested in integrating public transit systems and shared mobility services within their region. This could include the integration of fare policy and payment platforms, schedule coordination, wayfinding information, and digital information, with the goal of improving the usability and customer experience of their public transit systems. EPA has a role incentivizing and supporting the evaluation of travel behavior, mode shift, and related emissions changes flowing from various system designs and incentives as well as dissemination of lessons learned.
- Shared mobility services have the potential to complement existing public transit options and fill key gaps for low-income families. To foster a more robust mobility ecosystem, EPA incentives (e.g., EVs, scooters, bikes through credit systems such as CARB's transportation system credits (ZEV mandate) and SB 1014 (Clean Miles Standard) and other policy mechanisms (e.g., mobility wallets) should be tested and applied, along with integrated fare payment, seamless routing, service platforms (e.g., MOD/MaaS), etc. EPA could partner with US DOT on infrastructure and pilot program/evaluation opportunities to support these initiatives.
- Guidance is needed to develop pilot projects, including third-party evaluations to document lessons learned and best practices that can lead to long-term financial sustainability and

scaled networks in a wide range of land use and built environments, ranging from rural to suburban to urban.

- EPA, DOT, and DOE should develop new metrics for measuring success in concert with marginalized populations and community-based organizations to ensure we are measuring the right things. Objectives should include energy efficiency, emission reductions, and social equity/environmental justice.

2.6.2 Other Public Education Efforts

To successfully deploy/test public transit/shared mobility pilot programs that advance integrated MOD/MaaS platforms, incentives, pricing, and mobility wallets, it is critical to ensure that the public understands how to use these services and the value of them. Further, these services need to be equitably accessible to all travelers--based on the land use and built environment context, physical disability, income, socio-demographics, and social context, etc. (i.e., STEPS framework for transportation equity).[63]

- EPA should support user-focused education efforts with USDOT, service providers, industry suppliers, and state, tribal, and local partners to ensure a wide understanding of how to safely and responsibly use e-bikes, e-scooters, shared mobility services, and new platforms (e.g., MOD and MaaS).[64]

- EPA and sister agencies should enhance service quality and customer satisfaction, along with public outreach campaigns. This could include training opportunities (e.g., mobility fairs, workshops, etc.) and mobility counseling services. These campaigns should emphasize the critical role that public transportation plays in our society, overall.

- EPA could join forces with sister agencies to develop and fund these campaigns that couple investments, incentives, policy initiatives (e.g., pricing) and pilot programs in a wide range of land use and built environment contexts (i.e., suburban, rural, urban, and small to medium sized cities). Once key lessons learned are amassed, EPA should provide long-term credit and incentive programs to ensure that personal mobility efforts can scale and are financially sustainable in the longer term (e.g., right-sizing clean vehicles in personal mobility services and providing credits to ensure public transit linkages and complementarity, higher occupancy levels, and multi-modal systems).

2.7 Definitions

Shared Mobility: The shared use of a travel mode that provides travelers with access to a transportation mode on an as-needed basis.[65]

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[63] *See* Shaheen, S., Bell, C., Cohen, A., and Yelchuru, B. (2017). "Travel Behavior: Shared Mobility and Transportation Equity." U.S. Department of Transportation. Report # PL-18-007. https://www.fhwa.dot.gov/policy/otps/shared_use_mobility_equity_final.pdf.

[64] *See* Shaheen *et al*., 2015

[65] Taxonomy and Definitions for Terms Related to Shared Mobility and Enabling Technologies, SAE. J3163_201809 (2018). https://www.sae.org/standards/content/j3163_201809/

Shared Micromobility: The shared use of a bicycle, scooter, moped, or other low-speed vehicle that provides travelers with access on an as-needed basis.

Mobility on Demand (MOD): A concept based on the principle that transportation is a commodity where modes have distinguishable economic values. MOD enables customers to access mobility, goods, and services on demand.[66]

Mobility as a Service (MaaS): An integrated mobility concept in which travelers can access their transportation modes over a single digital interface. MaaS primarily focuses on passenger mobility allowing travelers to seamlessly plan, book, and pay for travel on a pay-as-you-go and/or subscription basis.[67]

Advanced Air Mobility (AAM): A broad concept focusing on emerging aviation markets and use cases for urban, suburban, and rural operations. Advanced air mobility includes local use cases of about a 50 mile (80 km) radius in rural or urban areas, and intraregional use cases up to a few hundred miles.

Bikesharing: A service that provides the traveler with on-demand, short-term access to a shared fleet of commercially-owned bicycles typically for a fee. Bikesharing mobility providers typically own, maintain, and provide charging (if applicable) and insurance for the bicycle fleet.

Carsharing: A service that provides the traveler with on-demand, short-term access to a shared fleet of commercially-owned motor vehicles typically through a membership and the traveler pays a fee for use. Carsharing mobility providers typically own and maintain the vehicle fleet and provide insurance, gasoline/charging, and parking.

Car Rental: A service that provides the traveler with medium-term access to a shared fleet of commercially-owned motor vehicles typically for one day to a few weeks for a fee for use. Gasoline and insurance may be provided for an additional fee. Car rental mobility providers typically own and maintain the vehicle fleet.

Personal Vehicle Sharing: A service that provides the traveler with on-demand, short-term access to a fleet of privately-owned motor vehicles for a fee for use. Vehicle hosts own and maintain the vehicle fleet. Vehicle hosts and drivers broker transactions using an online-enabled application or platform (i.e., smartphone app) provided by a personal vehicle sharing company. The personal vehicle sharing company may provide resources and services to make the exchange possible (e.g., an online platform to facilitate the transaction, customer support, etc.). Personal vehicle sharing companies do not own or maintain a fleet of vehicles.

Scooter Sharing: A service that provides the traveler with on-demand, short-term access to a shared fleet of commercially-owned standing or seated scooters for a fee for use. Scooter sharing service providers typically own, maintain, and provide fuel/charging (if applicable) and insurance for the scooter fleet.

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[66] Shaheen, S., & Cohen, A. (2020). Chapter 3 - Mobility on demand (MOD) and mobility as a service (MaaS): early understanding of shared mobility impacts and public transit partnerships. In *Demand for Emerging Transportation Systems: Modeling Adoption, Satisfaction, and Mobility Patterns*. Location: Elsevier. UC Berkeley: Transportation Sustainability Research Center. Retrieved from https://escholarship.org/uc/item/5030f0cd

[67] *Id.*

Taxi: A service that provides the traveler with pre-arranged and/or on-demand access to a ride service in a motor vehicle for a fee for use. The traveler can typically access this ride service by scheduling trips in advance, by street hail or by e-hail.

Transportation Network Company (TNC) / Ridehailing/ Ridesourcing: A service that provides the traveler with pre-arranged and/or on-demand access to a ride for a fee using a digitally-enabled application or platform (e.g., smartphone app) to connect travelers with drivers using their personal, rented, or leased motor vehicles. Digitally-enabled applications are typically used for booking, electronic payment, and ratings.

Ridesplitting / Ridepooling: A concurrently shared commercial ride service in a motor vehicle where the traveler is matched with other riders traveling along a similar or identical route.

Informal Ride Service: A concurrently shared unlicensed commercial ride service.

Microtransit: A transportation service operated by, or provided exclusively on behalf of, a government entity or nonprofit organization that offers multi-passenger/pooled rides, typically in on-demand and dynamically routed shuttles or vans. Variations include using fixed routes, fixed schedules or pre-scheduling, and larger or smaller vehicles.

Shuttle: A service typically employed using vans or buses that connect travelers from a common origin or destination to public transit, retail, hospitality, or employment centers. Human-driven shuttles are typically operated by professional drivers, and many provide complimentary services to the travelers.

Pedicab: A for-hire ride service in which a cyclist transports traveler(s) on a tricycle with a passenger compartment. Service may be concurrently or sequentially shared.

Carpooling: The formal or informal sharing of rides between drivers and travelers with similar origin-destination pairings using vehicles of 2 to 6 passengers.

Vanpooling: The formal or informal sharing of rides between drivers and travelers with similar origin-destination pairings using vehicles of 7 to 15 passengers who share the cost of a van and operating expenses and may share driving responsibility.

Courier Network Services (CNS): A commercial for-hire delivery service for monetary compensation using an online application or platform (such as a website or smartphone app) to connect freight (e.g., packages, food, etc.) with couriers using their personal, rented, or leased vehicles, bicycles, or scooters.

On-Demand Air Mobility: Enables consumers access to air mobility, goods delivery, and emergency services by dispatching or using advanced air mobility and enabling technologies through an integrated and connected multimodal network.

Water Taxi: Any vessel for hire on-demand that is operated between a point of origin and a destination point different from the point of origin.

Ferry: A boat or ship for conveying passengers and goods as part of a regularly scheduled service, typically over a relatively short distance.

Mobility Hub: Public transportation access points with frequent transit service, connections to shared and on-demand modes, services, and enabling infrastructure such as bikesharing, carsharing, microtransit, carpooling, urban air mobility, taxis, TNCs, electric vehicle charging, high capacity bicycle parking, etc.

Mobility Zones: Geographic areas with a network of shared mobility options that include either 1) predefined set of boundaries (e.g., neighborhood boundaries, school zones, etc.) or 2) a radius around a point or anchor location (e.g., mobility hub, public transit station, shared mobility station, government center, or a land use with high trip generation). While sizes may vary based on local context, typically most mobility zones are approximately of three to five square miles (five to eight square kilometers).

Key industry benchmarks exemplify developments in this emerging sector:

- **Carsharing** - As of January 2017, there were 21 active carsharing programs in the United States (U.S.) with over 1.4 million members sharing more than 17,000 vehicles.[68]
- **Bikesharing** - As of the end of 2017, the U.S. had more than 200 bike-sharing operators with more than 100,000 bicycles (Russell Meddin, unpublished data). More than 84 million trips were taken on micromobility (bikesharing and scooter sharing) in the U.S. in 2018 (NACTO, 2018).
- **Transportation network companies (TNCs, also known as ridesourcing and ridehailing)** - As of the end of 2018, Lyft reported 18.6 million active riders and more than 1.1 million drivers operating in more than 300 markets throughout the U.S. and Canada (based on SEC filings). Uber operated in 63 countries serving an estimated 82 million users as of December 2018 (based on SEC filings).
- **Pooling** - As of December 2017, Uber POOL and Lyft Shared rides, a pooled version of for- hire TNCs, were available in 14 and 16 U.S. markets, respectively (Paige Tsai, personal communication; Peter Gigante, personal communication). Innovative carpool apps, such as Scoop and Waze Carpool, also are enabling on-demand higher occupancy commuting.

[68] Shaheen *et al.*, 2018

Chapter 3: Fuels

3.1 Introduction and General Recommendations

In a world in which EPA will be overseeing the environmental performance of alternative fuels such as electricity and hydrogen, which will be used to meet a significant percentage of the light duty and heavy duty on-road fuel demand, the Agency will continue to have a role in reducing emissions from the combustion engines that continue to operate on liquid fuels. As tasked by EPA at the March 2020 MSTRS meeting, this paper examines actions, both regulatory and non-regulatory, EPA could undertake to address emissions from liquid fuels in the near (5 years), mid- (10 years) and long-term (30 years) timeframes. Such emission reduction efforts should include transportation sub-sectors where liquid fuels are likely to remain critical into the long-term notwithstanding net zero achievements. In order to understand how EPA's role may evolve, it is important to consider the size of the market that would be subject to such activities.

To put the future market into context, two bookend scenarios were contemplated – a low plug-in electric vehicle (PEV) uptake scenario and a high PEV uptake scenario. These are represented in Figure 8 below. The low PEV scenario builds upon the U.S. Energy Information Administration's Annual Energy Outlook 2020 in which sales of PEVs are projected to represent 10% of light duty vehicle sales in 2040. The high PEV scenario is derived from Bloomberg New Energy Finance's projection that 60% of sales would be PEV by 2040. Given the historic rate of fleet turnover included in EIA's AEO, these scenarios would result in converting between 6% and 27% of the light duty vehicle fleet to PEVs by 2040. The rate of PEV expansion within the heavy-duty sector is expected to lag behind that of the light-duty sector and the share of vehicles that remain combustion powered should be higher. While these rates may change depending on market conditions and policy decisions, the continued presence of combustion engines and liquid fuels is anticipated though the mid- to long-term.

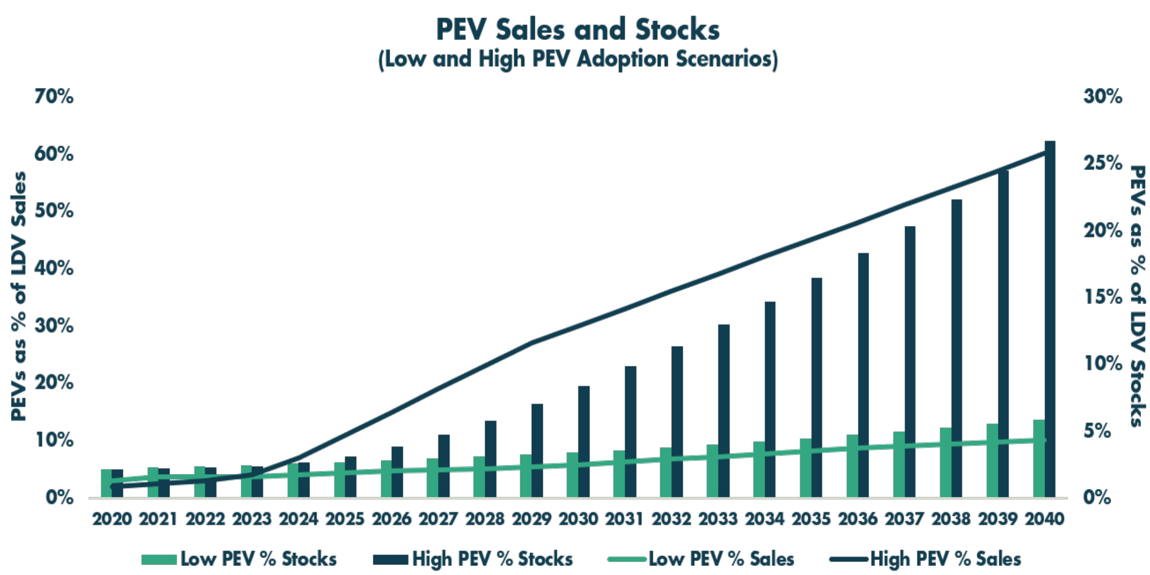

Figure 8: Light Duty PEV Sales and Stocks.

Assuming internal combustion engines and liquid fuels could continue to comprise a significant portion of, and potentially as much as two-thirds of the light-duty vehicle fleet in 20 years, it is incumbent upon EPA to remain focused on its approach to regulating the liquid fuels transportation sector. Yet, its focus should evolve. For example, criteria pollutant emissions from light-duty vehicles have largely been eliminated through existing regulations. Therefore, EPA should narrow its focus to address life-cycle greenhouse gas (GHG) emissions from the light-duty vehicle sector, while addressing GHG and criteria emissions from the heavy-duty sector.

General Recommendations

In addition to the specific topics detailed on the following pages, the subgroup identified the following general recommendations that EPA should pursue regardless of specific policy considerations. It is the strong opinion of the subgroup that these three recommendations will greatly enhance the effectiveness of the Agency and assist the transportation sector to reduce its impact on the environment.

Leadership

EPA should adopt a stronger leadership position relative to regulatory and standards setting organizations. The topics presented in this paper will affect multiple industries and will rely upon other authorities having jurisdiction and organizations who establish industry standards. Without some guidance and coordination, the market could experience significant inconsistencies, which will impede achieving improved emissions. As the federal authority with the greatest reach and broadest perspective, EPA should engage pro-actively with regulated industry stakeholders, other federal agencies including DOT and DOE, and regulatory bodies and organizations such as ASTM and the National Conference on Weights and Measures to promote collaboration and coordination.

Collaboration

EPA has achieved great success in pursuit of its mission when it has adopted regulations that incentivize achievement, as opposed to mandating specific solutions. This approach provides a framework through which the transportation sector can develop solutions that are realistic and viable in the market. To further foster collaboration between the Agency and the market, educating stakeholders regarding new requirements or programs is essential. Working with industry to host educational workshops, including compliance training programs, has been extremely successful in the past and should be part of any new regulatory program.

Integration

EPA should evaluate its myriad of regulatory programs that operate independently to determine if they could be more effective working in tandem with others. For example, there might be opportunities to integrate the objectives of the Corporate Average Fuel Economy program with those of the Renewable Fuel Standard to incentivize more creative strategies to reduce carbon emissions. It is feasible that coordination between these two programs could create a viable market opportunity for higher octane fuels and optimized engines that would improve compliance with both programs. By enabling such programs to build off one another, the Agency could provide the market with tools and opportunities that may not be viable independently.

Coordination

EPA should seek to coordinate with other federal, state, tribal, (and where necessary local) regulatory agencies in order to promote consistency in fuels regulations across jurisdictions. Liquid fuels are primarily a fungible commodity which are produced in certain regions of the nation and efficiently distributed throughout. However, when certain jurisdictions impose requirements incompatible with those of other jurisdictions the system can experience disruption, which can result in economic and environmental harm. By seeking to coordinate policies to the greatest extent possible, such disruption can be minimized.

Equity and Energy/Environmental Justice

Access to reliable and affordable transportation is essential for all people, and not all communities are equally equipped to accommodate new developments. As policies are considered to reduce emissions from the transportation sector, consideration must be given to understand how such policies might affect disadvantaged and rural communities that may not have advanced infrastructure or means to fully benefit from new policies, as well as communities that may be disproportionately impacted by legacy inequities with existing infrastructure. Policies must be developed in such a way as to prioritize infrastructure and societal costs, facilitate public involvement, and mitigate any potential negative implications for such communities.

Finally, we recognize that some of the recommendations presented in this paper may fall outside the scope of the Agency's current authority. In such circumstances, we encourage the Agency to be transparent about that challenge and indicate how its authority would have to evolve to enable adoption of such recommendations.

3.2 Specific Recommendations

The subgroup has identified eight areas in which EPA should focus for regulating the liquid fuels market. These are presented in Table 2 by order of priority and categorized for those that can or should be achieved in the near-, mid-, and long-term time periods.

Table 2: Possible Recommendations for EPA.

	Near Term 0 to 5 years	Mid Term 5 to 10 years	Long Term 10 to 30 years
Life-cycle Analysis Criteria			
Database of Emissions Sources			
Low-Carbon Performance Standard			
Low-Carbon Biofuels			
Harmonize Gasoline Specs			
Non-Fuel/non-Tailpipe Emissions			
Emissions from Legacy Vehicles			
Hydrogen and E-Fuels			

The first two recommendations presented in Table 2 are considered necessary direction from the Agency to enable effective assessment of the other recommendations. These are listed as Category 1 recommendations below:

Category 1 Recommendations

The subgroup recommends EPA establish the baselines for evaluating options so that all stakeholders understand what is under consideration and how it shall be measured. This should take the form of:

- Working with stakeholders to establish a consensus-based methodology for life cycle analyses (LCA), to eliminate different models and versions that are subject to bias. A consensus-based model should conform to academic standards for sound science, peer review, and transparency. Such model should be used by EPA to evaluate and publish fuel and vehicle emissions pathways for all types of fuels. (See LCA Section 4.0 for more details.)
- Develop a comprehensive database of all sources of emissions to ensure attention is paid to those sources which present the greatest opportunity to reduce emissions and to ensure that transportation-focused regulations are appropriate and proportional

Category 2 Recommendations

A robust low-carbon liquid fuel program can deliver significant near term and ongoing carbon reduction benefits, while other fuel and vehicle platforms transition into the market. Therefore, the subgroup recommends EPA pursue the following strategies to promote a liquid fuels market with the lowest environmental impact possible:

- Establish a low-carbon performance standard for fuels and vehicles
- Facilitate development and introduction of low-carbon fuels
- Harmonize gasoline specifications to facilitate improved vehicle-fuel performance
- Develop a plan to address non-fuel/non-tailpipe emissions
- Develop a plan to address criteria and GHG emissions from legacy vehicles
- Explore the role of low-carbon hydrogen and electricity in the production of future liquid fuels

3.3 Current and Future Transportation and Fuel Systems

Before presenting the subgroup's recommendations, it is important to first establish a baseline understanding relative to the existing fuel systems. In 2019, the transportation sector consumed 28% of the total U.S. energy consumption.[69] Currently, this energy largely comes from petroleum fuels, representing 91% of transportation energy use (transportation represents 70% of the total U.S. petroleum use) and biofuels, representing 5% of transportation energy use. Virtually all of transportation final energy today is supplied by liquid fuels. These energy-dense fuels have unquestionably provided reliable and convenient mobility options to power the modern global economy. However, petroleum fuels have also created challenges associated with geopolitics, energy security, price volatility, and environmental impacts. Today, the transportation sector is responsible for the largest share of U.S. greenhouse gas emissions (28% of the total 2018 6,677 Million Metric Tons of CO_2 equivalent).[70]

[69] https://www.eia.gov/totalenergy/data/annual/
[70] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Approximately 215 billion gallons of four major fuels are used by the hundreds of millions of vehicles moving people and good in the U.S.: motor gasoline, diesel fuel, jet fuel, and residual oil (see Figure 9).[71] This translates to ~28 quadrillion BTU of energy. The largest transportation fuel use is for gasoline light-duty personal vehicles (57%, or approximately 125 B gallons), with ~90 billion gallons being used by larger vehicles, mostly gasoline and diesel trucks (~25%) and airplanes (~10%).

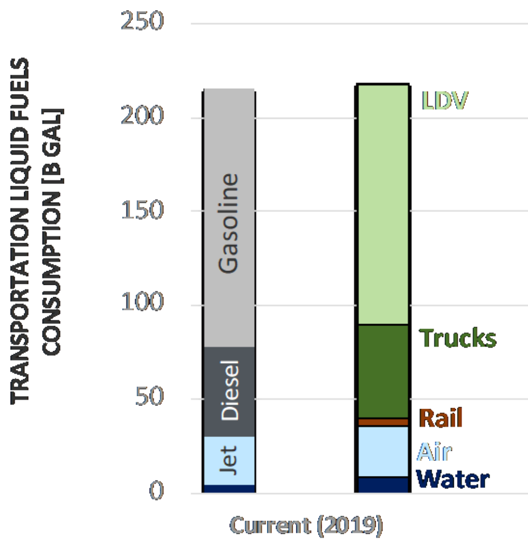

Figure 9: US Transportation liquid fuels consumptions in 2019 (data from EIA).

These different fuels match different vehicle requirements and the first step to understand future needs for different fuel types is understanding future mobility needs, vehicle adoption and use. Several trends will influence the future transportation energy use and fuel requirements (additional detail regarding the four trends identified below can be found in Appendix B):

1) Growth in mobility demand for passenger and freight;
2) New technologies and business models and system-level structural changes impacting travel and modal choices and energy use;
3) Vehicle efficiency (fuel economy) improvements; and
4) Technology adoption, especially adoption of electric vehicles that are rapidly becoming cost-competitive and are poised to replace liquid fuels for on-road transportation.

The following recommendations should be considered within the context of the existing system and the applicable trends that may affect its development.

[71] https://www.eia.gov/totalenergy/data/annual/

3.4 Recommendations

3.4.1 Life Cycle Analysis and Emissions Database

3.4.1.1 Life Cycle Analysis Criteria

LCA is a very useful tool in assessing the overall environmental effects (particularly GHG emissions) of current and future vehicles and fuels as the transportation sector moves forward with different powertrain systems and different fuel types. LCA-based regulations and policies may help create a level playing field that encourages various powertrain technologies and fuels to play a role in GHG reduction from transportation. In order for LCA to serve this role, a standardized LCA model with consistent LCA methods and system boundaries and up-to-date data, such as Argonne's GREET model, which has already been used for LCFS compliance, is needed. The standardized LCA model needs to be publicly accessible and well documented with respect to input parameters and assumptions of vehicle manufacturing and operation performance, and associated fuel production technology pathways. The LCA results should be transparent and be subject to verification. In addition, the vehicle manufacturing cycle and end-of-life processes should be integral parts of LCA of various vehicle/fuel systems. This will allow for a complete carbon footprint assessment (CFA) of competing vehicle/fuel systems.

In pursuing this objective, it seems appropriate for EPA to prepare and issue a comprehensive report that documents and explains their historical methodology and assumptions in determining CI values of various fuel pathways and the current state of LCA models, methodologies, and results among key regulations. For example, since the 2010 EPA LCA efforts, CARB LCFS, EU RED, and the Canadian Clean Fuel Standard (to be finalized in 2021) all use standardized LCA methodologies with a process-based, attributional LCA approach supplemented with economic modeling of land use changes. Standardized models used within these approaches (such as GREET) are transparent and accessible. They minimize inconsistencies of LCA methodologies and system boundaries, among other factors, so that agencies and stakeholders can concentrate on technology potentials instead of creating confusion and debate of models and LCA methodologies. EPA may also elaborate how new technologies and pathways are to be addressed in its new LCA efforts. Examples of such future fuels include renewable natural gas (RNG), renewable diesel fuel (RD), renewable fuels produced from pyrolysis oils, renewable fuels produced from gasification and Fischer-Tropsch (FT) processes, and E-fuels.

Additionally, classifying renewable fuels into specific GHG reduction bins, as required under RFS, does not incentivize improvements in feedstocks or processes that would further reduce the carbon footprint of the fuel below the threshold for each bin – unless the changes are large enough to move from one bin to another. An approach that focuses on quantifying the carbon intensity (CI) of a given pathway, and incentivizing meaningful, incremental improvements in CI, such as California's LCFS program does, is likely to provide greater overall GHG reductions than the current RFS approach.

Finally, although the RFS program (and the LCA modeling to support it) was focused on incentivizing growth of renewable fuel volumes, the main concern today is GHG reduction. Thus, it is critical to assess the life cycle GHG impacts of alternative systems, which goes far beyond determining a CI value for a given fuel pathway. For example, with increased electrification of the vehicle fleet, variabilities in the source of grid power by region become important. Similarly, variability in sources of H_2 for fuel cell vehicles must be understood. For plug-in electric vehicles (PEVs), it is also important to know what fraction of power is derived from the grid.

Thus, the true carbon footprint of a particular vehicle depends upon how, where, and when the fuel is produced, in addition to the lifecycle of the vehicle itself. A holistic approach that considers the LCA of a vehicle and its associated energy source as a system is essential. In completing such a holistic evaluation, it would be necessary to fully account for the different components and processes involved in the production of various fuels. Such an approach could require significant modifications to existing programs but would provide the necessary benchmarks to drive low-carbon fuel choices. (Additional commentary on the process for determining LCA is included in Appendix C.)

3.4.1.2 Database of Emissions Sources

As onroad mobile sources move towards increasing electrification, the nonroad sectors will become increasingly more significant users of liquid fuels. EPA should ensure that all sources that may impact the total contributions of primary emissions into the atmosphere (including non-transportation related emissions) are measured and included in a comprehensive catalogue of emissions. This will provide the necessary information to develop regulations that are appropriate, those that will provide the greatest benefit and, especially with regards to the transportation sector, those that are proportional to the emissions contributions of subject sector.

More details regarding regulations pertaining to on-road and non-road transportation emissions are presented in section 8. This general recommendation, however, encourages the development of a comprehensive database that extends beyond the transportation sector. Only by accurately identifying the myriad sources of emissions can EPA develop strategies to effectively reduce emission in the most efficient manner possible while not overly and disproportionately burdening one source of emissions.

3.4.2 Low-carbon Transportation Performance Standards

When considering emissions regulation, it is important to view the transportation sector holistically. Fuel producers and engine manufacturers should be developing new transportation models in a manner that most efficiently reduces emissions. However, both industries have very different performance standards that are either based upon fuel economy or a percent reduction in GHG emissions, which complicates efforts to collaborate for the most efficient solutions.

EPA should pursue a more unified approach to setting overall standards for engines and fuels, one that includes life cycle analysis and identical methodologies for both components of the sector. As noted above, EPA should determine and standardize the LCA methodology to be used when evaluating performance and this same methodology should be applied across all vehicles and all fuels. As described here and in section 6.0, EPA should consider developing a performance-based metric, using LCA methodology and based on carbon intensity (CI) targets, that could be applied to both engines/vehicles and fuels, without overlapping requirements. The CI targets should provide industry flexibility to achieve the objectives.

Performance standards have been an effective policy tool to reduce emissions from the top-down. National approaches such as fuel efficiency standards (CAFE) and renewable fuel standards (RFS) allow industry to innovate and reach goals without overly prescriptive rules which often create unintended consequences and impede innovation. Performance standards often align with industry's competitive nature if those standards are consistent and predictable.

Considering the fact that electrification and internal combustion engines will co-exist in the transportation sector for a long time, a new holistic approach is needed, beyond today's regulations that mandate reduced CI values for transportation fuels. While CI values for fuels help incentivize fuel production GHG emissions, fuel economy of vehicles is key to reduce per-mile GHG emissions. Thus, per-mile GHG emission ratings that take into account per-MJ fuel CIs and fuel economy of vehicles provide more complete picture of GHG reduction potentials of powertrain/fuel combinations. (An assessment of such a system using the GREET model is presented in Appendix C.)

This suggests that a new type of vehicle/fuel carbon footprint assessment (CFA) model may be required to correctly assess the GHG impacts of future fuel/vehicle systems on a new basis such as per mile driven, so that low-carbon fuels and vehicle efficiency will work together for GHG reductions in the transportation sector. In addition, the LCA should be expanded from fuel cycle (or well-to-wheels cycle) to include vehicle manufacturing processes so that the environmental effects of new vehicle components can be considered to prevent unintended consequences. Argonne National Laboratory (ANL) has recently conducted such assessments for a variety of current and future generation vehicles and fuels, which could serve as a valuable resource as EPA considers such an approach. (Additional details on ANL's model are presented in Appendix C.)

3.4.2.1 Incompatible Regulatory Approaches

To illustrate the disparity in regulatory approaches, it is helpful to review the manner in which the RFS and CAFE programs are structured.

Performance standards should include most-current building blocks and emission variables that may be applied to varying industries and fuels. As an example, the current EPA RFS program determines percent reductions in GHG emissions by modeling the factors below:

1) the processes required to produce feedstocks, convert them into fuel, and deliver the fuel to the end-user;

2) the emissions from the vehicle itself; and

3) any direct or indirect changes in emissions not attributable to fuel production or use, including changes in land use.

The first two components are often referred to as "well-to-tank" and "tank-to-wheels" emissions; both taken together are referred to as "well-to-wheels" emissions.[72]

It is understood that implementing the massive RFS program required certain assumptions and generalizations on fuel production. Where possible, these assumptions should be minimized, and a fuel's actual carbon intensity be modeled transparently. This includes consideration given to all energy inputs used in the production of biofuels/alternative fuels. EPA should coordinate and streamline the pathways assessments for all fuels and be fuel agnostic. This new focus will create an environment that inspires innovation in future years as organizations recognize the financial benefits to reducing emissions during production. (See Appendix F for additional information on Advanced Low-carbon Fuel Development, including barriers and potential resources.)

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[72] CRS Report R40460, Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard (RFS) (updated March 2010), https://crsreports.congress.gov/product/pdf/R/R40460/9.

By contrast, CAFE standards are a strict tailpipe performance standard (MPG to gCO_2/mile) but lack the overall LCA approach found in liquid fuel modeling. Because emissions determination is the endgame, the MSTRS fuels group suggests that EPA approach fuel economy more directly via a standardized model that reflects similar metrics as liquid fuel modeling.

Modeling vehicles and fuels on the same plane will create a higher understanding of emissions stemming from transportation. It will also solve the inaccuracies that come from a simple conversion of averaged tailpipe emissions. Such an approach would be equally viable when assessing new vehicle technology (electric, hydrogen, etc.).

EPA should combine knowledge and efforts with DOE and other applicable agencies to apply LCA principles to automobile production and mileage. (Additional commentary on the process for determining LCA is included in Appendix C.) Once the model has been constructed, it may also be applied to aviation and marine applications where there is currently no performance standard.

3.4.2.2 Policy Suggestion Timeframe

The suggestions above are substantial, require legislative action, and run the risk of creating policy gaps and/or over-regulating industry with redundant policies. The following is a suggested sequencing of events that may reduce these two unwanted scenarios.

Near Term (0-5 years)

The current Renewable Fuel Standard should be modified to be fuel agnostic and steps taken to transparently account for each fuel's GHG lifecycle contributions. The majority of these modifications can be completed by EPA and should be ready for implementation by 2022. DOT and EPA should begin discussions on harmonizing future CAFE and tailpipe GHG standards.

Mid Term (5-20 years)

The RFS, as written, should be fully modified to measure a fuels carbon intensity. New goals should be set for a national fuel carbon intensity standard to be phased in under new reporting requirements that utilize existing EPA reporting tools. Via legislative action, CAFE standards should begin reflecting LCA and report on a per mile or per vehicle basis. During this period, CAFE standards should be phased out.

Long Term (20+ years)

Overall transportation emissions should reflect a holistic "cradle-to-grave" analysis once the fuel and vehicle standards are merged. This will be a living model that reduces built-in early assumptions over time. New fuel and vehicle registrations, under this schema, should be expedited and not hinder new technological advances. The new overarching model must be agnostic to fuels and vehicles, allowing the fuel and vehicle market to develop with the greatest level of innovation. Once the EPA has standardized the modeling for fuels and vehicles, these same models may be applied to all modes of transportation.

3.4.3 Low-Carbon Biofuels

Decarbonizing the existing and future non-electric U.S. fleet of vehicles will best be accomplished by reducing the carbon intensity (CI) of traditional fuels. To achieve the necessary levels of emission reductions in the near and mid-term, auto manufacturers, fuel supply chain sectors, and policy makers/regulators will have to intensify coordinated efforts to limit unintended consequences on the consumer and to unlock potential new opportunities related to new low-carbon advanced biofuels that are not currently in the market. The application of a consistent LCA methodology will enable the efficient identification of viable options and guide market development. In addition, there are key things the Agency can implement to accelerate the pace of reducing the CI of the liquid fuels market.

Establish High Level Policy Objectives on Carbon Reduction from Transportation Sector

Carbon reduction policies should be applied at the highest level across a broad section of the economy, rather than on individual sectors. Such policies should be technology and fuel neutral and market based, to avoid an unlevel playing field and predetermination of favored options. They should target the lowest marginal abatement cost for reducing carbon and should be large in scale for maximum cost effectiveness. When sector specific policies (like transportation) are considered, they should focus on market-based solutions and avoid subsidies and mandates. Such sector specific programs should be based on a full life cycle assessment of all fuel pathways on a technology neutral basis. Transportation specific programs should consider all elements including fuels, vehicles, and infrastructure.

Modifications to RFS to Incentivize Carbon Reductions

The current structure of the RFS uses four biofuel categories, or "buckets", with fixed thresholds for GHG reduction. Fuel pathways do not receive credit for their full lifecycle value for carbon reduction. While there are statutory requirements in the RFS that further limit effectiveness for carbon reduction, including the use of renewable biomass for feedstock and the use of biofuels to displace transportation fuels (gasoline and diesel), EPA has the requirement to establish new volume mandates for each of the four buckets for 2023 and future years. This presents an opportunity to increase the effectiveness of the RFS for carbon reduction. Discussions regarding a post-2022 RFS must commence immediately.

While EPA cannot change the statutory buckets or the minimum GHG reduction for each bucket, they could consider incentives for carbon reduction to stimulate the growth of advanced and cellulosic biofuels. One example would be to generate additional renewable identification numbers (RINs) for fuels that have a full LCA carbon intensity below the statutory thresholds. This is not without precedence – RFS1 included the option to generate 2.5 RINs per gallon when production energy input is renewable. Current RFS requires 1) feedstocks be renewable and 2) end use is transportation fuel, heating oil, or jet fuel in order to fulfill the RIN generation. EPA should consider all waste feedstock as meeting #1 if LCA provides a 50% or greater GHG reduction. EPA should also recognize all combustion scenarios as an opportunity to reduce emissions and expand on #2 whenever possible.

EPA must develop streamlined processes that are capable of approving or denying new pathways within 60 days and remove the current backlog of pending pathway approvals.

Consideration for a National Low-carbon Fuel Standard

The concept of a national LCFS has been proposed by some to provide GHG reduction beyond the current RFS. A national LCFS would provide additional incentives for use of low CI biofuels. Arguments in favor of a national LCFS would include: fuel and technology neutral structure (not a volume mandate); full credit allowance for fuel pathways based on LCA carbon intensity; and ability to extend program benefits beyond current limitations of the RFS program (consider other non-biomass feedstocks, other carbon reductions related to fuel production and distribution, etc.).

A key question would be whether a national LCFS would coexist with a modified RFS or if the LCFS would replace the RFS (post 2022), which would require new legislation. Also, a national LCFS should preempt state, tribal, and local programs to avoid double regulation and to simplify compliance and enforcement. If an LCFS would exist in parallel with the RFS, the programs would need to be coordinated to maintain feasible compliance pathways. An aggressive LCFS program combined with a restrictive RFS volume mandate could result in an infeasible compliance requirement and an unlevel playing field for obligated parties. The MSTRS Fuels group strongly suggests no duplicative GHG policies or overlapping regulations should exist, other than a state's fuel excise tax benefit, or similar state tax incentive, to the extent applicable.

An LCFS provides certain benefits that may be more consistent with the high-level policy objectives stated above. However, establishing a new national carbon reduction program would be extremely complicated and could result in unintended consequences. A national LCFS would need to be closely coordinated with the RFS and would likely need to preempt additional state. tribal, and regional programs for GHG reduction. Should existing state LCFS remain during a national LCFS policy, EPA should coordinate with such states to create a more fungible credit system between state and federal programs.

Development of "Drop-In" Hydrocarbon Biofuels

While corn-ethanol, biodiesel and renewable diesel have significant production capacity and market penetration, they are constrained by market forces. Ethanol is limited by the "blend wall" in the motor gasoline market. Between 2017 and 2050, aviation and heavy-duty vehicle use is projected to grow considerably faster than for light-duty vehicles. Air passenger miles are projected to double, and freight truck miles traveled are projected to grow by nearly 50%, compared with an 18% increase in light-duty vehicle miles traveled.[73]

Due to anticipated increases in vehicle fuel economy and penetration of electric vehicles, demand for gasoline—and thus fuel ethanol—is expected to face greater competition for market-share. Biodiesel and renewable diesel production are limited by feedstock availability, and biodiesel also faces similar blending limitations particularly due to concerns over cold-weather performance. Both ethanol and biodiesel are subject to infrastructure compatibility concerns with pipelines, fuel storage, distribution, and dispensing infrastructure.

Due to these constraints, as well as potential to deliver biofuels with improved environmental and lifecycle greenhouse emission benefits over first generation biofuels, domestic and international biofuels industries have increased focus on the production of "drop-in" hydrocarbon biofuels. While there are myriad feedstocks and production technologies—or pathways—the constant is the production of fuels that are compatible with existing infrastructure and fleets, whether for aviation, marine vessels, light-duty vehicles, or heavy-duty trucks. Thus, these fuels would avoid the market barriers referenced above, and provide a means to reduce the carbon footprint of legacy fleets.

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[73] "Annual Energy Outlook 2018, Table 7: Transportation Sector Key Indicators and Delivered Energy Consumption," U.S. Energy Information Administration, last modified February 6, 2018, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2020&region=0-0&cases=ref2020~noace~rpstranche_50tx~norps~carbonfee15~carbonfee25~carbonfee35&sourcekey=0.

EPA should consider policies that support the development of such fuels and facilitate their registration and introduction into the market. (A more exhaustive analysis of the methodologies and opportunities for producing drop-in hydrocarbon fuels is presented in Appendix F.)

Electricity and Biofuels

Certain stakeholders have advocated to establish RFS pathways for RIN generation from electricity used to charge EVs (eRIN). The EPA has established a RIN pathway for electricity from biogas (2014), but it has not completed the administrative process necessary to fully implement this pathway. Electricity from renewable sources like solar or wind would not be eligible for RIN generation due to the RFS requirement for biomass-based feedstocks. The eRIN pathway would generate the much-needed cellulosic RINs required to meet the overall RFS goal of 36 billion gallons. This influx of RINs (eRIN) would likely reduce the per RIN values and may decrease the cost of compliance.

Other stakeholders have argued that the RFS should be focused on liquid fuels and should not be expanded to include electricity. The California LCFS does allow for generation of credits for the electricity to EV pathway, without the restriction of using biomass as a feedstock for generating the electricity.

Expanding the RFS and LCFS to incentivize electricity credits should be balanced with other policies and incentives that exist to promote EVs and electricity use. There are multiple programs that support electrification of the fleet, including: ZEV mandates; ICE bans; EV tax credits; and incentives and mandates for charging infrastructure investments.

EPA should coordinate with industry stakeholders to determine the practicality of approving the eRIN pathway, under RFS, and make a final determination on this pathway.

Coordination

New fuel policies for low-carbon biofuels would require regulatory changes for fuel pathways and fuel registration. Changes in state regulations and fuel standards (ASTM, NCWM, etc.) would be required. EPA should consider how to streamline the processes for fuel pathways and registration to eliminate confusion and to avoid multiple layers of regulation and exercise the recommendation to lead standards-setting organization in a united effort to achieve a lower-emissions transportation sector. It must also recognize that preemption of certain state, tribal, and regional programs may be required.

New fuel pathways need to be considered for vehicle compatibility and coordinated with auto manufacturers. These must also consider limitations of fuel distribution infrastructure. There will be limited time and resources available to modify the distribution system to accommodate unique fuel formulations during the transition period where gasoline demand is declining.

EPA should coordinate fuels registration, equipment compatibility, vehicle compatibility, and necessary fuel standards for new high efficiency engines. Once EPA takes on this coordinating role, EPA will be positioned to assist with new innovation and technology funding to assure any federal dollars are well utilized. Such a process will expedite the move towards significant GHG reductions in a timely manner.

Conclusions

All transportation policy options should be evaluated based on market based, full LCA, low-cost attributes for maximum effectiveness. The requirement to establish new RFS volumes in 2023 presents an opportunity to drive further carbon reductions from the existing regulatory program.

The addition of a national LCFS could be an option to reduce GHGs, consistent with the high-level policy objectives. However, this would be a very complicated regulatory program. It would need to be coordinated with the RFS and possibly preempt state, tribal, and regional GHG programs. It is premature to endorse a national LCFS without further consideration of these external factors.

Expanding fuel programs to incentivize electricity for EVs would need to be balanced against the other significant incentives that exist in this space. Adding yet another incentive could create an unlevel playing field.

3.4.4 Harmonizing Fuel Specifications

With the very recent promulgation of the Regulatory Streamlining standards, EPA has achieved a high degree of harmonization between Federal Reformulated Gasoline (RFG) and Conventional Gasoline (CG). (For a summary of the history of fuels regulations, see Appendix D) There are limited opportunities for further harmonization in this particular segment of the fuels market. EPA should monitor the impact of the Regulatory Streamlining requirements to determine if additional standards would be beneficial in the future.

CARB gasoline still exists with regulatory requirements that differ from RFG and CG, in a segregated market with dedicated production and distribution within California. The state is essentially a "fuel island", where most CARB gasoline is produced inside the state with limited imports from other states or foreign refiners. It is unlikely that CARB would consider relaxing the CARB gasoline standards simply to harmonize with the federal gasoline standards, which would be viewed as backsliding by state regulators and environmental groups.

Suggestions have been made to consider moving RFG and CG standards to more closely align with CARB standards. In theory, this would represent further harmonization of a national gasoline specification. However, it would be extremely expensive to apply CARB standards nationwide. With the significant improvements in RFG and CG quality, it would not be cost effective to adopt a national CARB gasoline standard. This would impose an unacceptable cost on the market for limited air quality benefit during the transition period when gasoline demand will naturally decline.

High Octane Fuels

Recently, several studies have considered whether higher octane fuels could enable new internal combustion engine vehicles to meet higher fuel efficiency standards and reduce GHG emissions. Many auto manufacturers have identified high octane fuels as an important performance characteristic that would improve the overall GHG performance of the vehicle/fuel system, especially in boosted spark ignition engines. EPA should continue to engage with stakeholders on the benefits of high-octane fuel and explore opportunities to leverage its associated benefits for vehicles brought to market in the next 10–15 years; such an approach would deliver GHG reduction benefits for several decades as the fleet transitions to new technologies.

Changing the octane standard for the nationwide gasoline pool would be extremely challenging for both the fuel and vehicle markets. The introduction of a new fuel standard would need to be coordinated with the design of new high compression ratio vehicles to improve overall fuel efficiency.

Investments in fuel manufacturing would be required, either by producing a higher-octane base gasoline blendstock or by blending higher percentages of ethanol. Modifying refineries to produce a higher octane blendstock could cost billions of dollars and would require a multi-year timeline for investment. Similarly, increases in ethanol blending would require additional renewable feedstock and production capacity, and increased infrastructure to deliver and store the higher volumes of ethanol. A 2019 report published by the Fuels Institute[74], found that converting the entire refining capacity of the United States to produce only 95 RON gasoline would increase the average price of gasoline by about 5 cents per gallon but could take as long as 20 years to complete. For the much of the transition period, such fuels would likely resemble the current market for premium gasoline, which is essentially 95 RON and is typically priced significantly higher than regular grade gasoline (sometimes by as much as 60 cents per gallon). Therefore, requiring new vehicles to operate only on 95 RON could significantly increase consumer fuel expenses to a level not offset by improved fuel efficiency. An option for lowering the production cost, and thereby the retail price, of 95 RON includes increasing the percent of ethanol blended into the fuel to 20% or 30%. Doing so, however, would require the replacement of most of the existing fuel storage and dispensing equipment which is not listed as compatible with these fuels and would require complex misfuelling mitigation measures to ensure new vehicles could only purchase the higher octane fuel, enabling greater vehicle efficiency, while preventing legacy, non-compatible vehicles from purchasing the fuel. Neither option would be easy to implement nor inexpensive.

Changes in octane standards would also require upgrades in retail fueling stations to handle multiple grades of fuel and to prevent misfueling of lower octane legacy fuels in new vehicles that require high octane fuel. Again, this would result in significant investment and close coordination between fuel providers, vehicle manufacturers, and fuel retailers.

New regulations would be required to establish a high-octane fuel standard which would be extremely complex at both the federal and state level. Fuel regulatory experts at EPA and CARB have estimated that the timeline for establishing the technical basis for an octane standard and implementing new regulations could easily be 5-10 years. Ideally, the introduction of high-octane fuel would also be coordinated with the regulatory programs for CAFE and vehicle GHG emissions and with the RFS, to maximize the environmental benefits and to ensure that all programs would be consistent with each other.

Assuming that all of the above fuel, vehicle, infrastructure, and regulatory challenges could be met, an extensive customer education effort would be required to ensure that the benefits of high-octane fuel could be realized in the market.

Conclusion

EPA should continue to implement the very successful fuel regulatory program which has generated significant reductions in criteria pollutants from the light duty fuel/vehicle sector. Further opportunities for harmonization and pollution reduction may exist but are likely reaching the point of

[74] Fuels Institute, "Transitioning the U.S. Gasoline Pool to a Single High-Octane Fuel: A Baseline Analysis" (Feb. 2019), https://www.fuelsinstitute.org/Research/Reports/Transitioning-the-U-S-Gasoline-Pool-to-a-Single-Hi.

diminishing returns. Performance standards, like higher octane fuels, may present new opportunities for greater GHG reduction. Any further regulatory or performance changes will need to be managed for cost-benefit effectiveness, considering the declining demand of gasoline during the transition to a future low-carbon state.

Consistent with the recommendation above to apply similar methodology to fuels and vehicles regulations and to consider the transportation system from a holistic perspective (i.e., consider fuels and vehicles as a system), EPA should increase coordinated efforts with engine manufacturers and producers of fuels to assure fuels do not impede the effectiveness of an engine's performance and emission control devices. For example, the DOE's Co-Optimization of Fuels and Engines initiative leverages the expertise of the national laboratories to explore engine designs and fuel properties that together would deliver the greatest benefits to emissions reductions. By engaging with stakeholders in a similar manner, to ensure programs affecting vehicles and fuels support each other, EPA could greatly improve the effectiveness of its efforts.

3.4.5 Nonroad Sources and Emissions

Nonroad mobile sources use diesel, gasoline, CNG, and other fuels and include agricultural equipment, construction equipment, lawn and garden equipment, aircraft ground support equipment, aircraft, locomotives, and recreational and commercial marine vessels. As onroad mobile sources face more stringent emissions requirements and increasing electrification, nonroad sources are expected to comprise increasingly greater portions of transportation-related fuels use. While some nonroad sources may be poised for electrification or alternative fuels, a significant portion of new and legacy nonroad sources are expected to continue to use liquid fuels into the foreseeable future. Consequently, EPA must consider emissions from aviation, marine and other nonroad sectors and make these a priority for future emissions inventories, taking into consideration and collaborating with international efforts in these sectors, and consider potential additional regulations and low-carbon liquid fuel deployment. (For details regarding nonroad sources of emissions and regulations, see Appendix E.)

Need for Continued Data Collection and Refinement to Reassign Regulatory Priorities

As onroad mobile sources move towards increasing electrification, the nonroad sectors will represent a larger share of consumed liquid fuels. EPA should ensure that all sources that may impact the total contributions of primary emissions into the atmosphere are appropriately reflected in inventory estimates. This provides the necessary information to develop regulations that are appropriate and proportional to the emissions contributions of the transportation sector.

Currently, within the US, nonroad source and equipment classifications are not consistent. Notably, EPA MOVES-NONROAD model and the various California ARB models[75] separate nonroad sources according to different categories and applications.[76] Inconsistency in engine size classification and nonroad applications can inhibit assessment of data and evaluation of potential regulation.

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[75] See CARB, Mobile Source Emissions Inventory Website: Off-Road Documentation (accessed Dec. 2020) (https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/msei-road-documentation-0).
[76] See Zhenying Shao, *Non-road emission inventory model methodology*, ICCT Working Paper 2016-4 (Feb. 24, 2016), at https://theicct.org/sites/default/files/publications/ICCT_nonroad-model-method_20160224.pdf, for more information about nonroad emissions inventories.

EPA's current MOVES3 model, released in November 2020, allows for the estimation of emissions from 12 different sectors of nonroad equipment containing 88 equipment types at the county level based on default assumptions of county-level nonroad equipment populations and activity extrapolated from state, tribal, and regional population growth estimates.[77] The MOVES3-NONROAD model includes both nonroad and marine diesel fuel supply sources, as well as gasoline, CNG and LPG nonroad sources, but does not include locomotive, aircraft or commercial marine vessels.[78] While the MOVES model has limitations and estimating local data for nonroad equipment populations and activity can be challenging, relying on MOVES default nonroad population and activity data is acceptable for SIPs and other regulatory purposes.[79]

EPA's National Emissions Inventory (NEI) estimates air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from various air emissions sources. The NEI is released every three years based primarily upon data provided to the Emissions Inventory System (EIS) by State, Local, and Tribal air agencies for sources in their jurisdictions and supplemented by data developed by the US EPA.[80] The NEI includes various nonroad sources, though they are defined and categorized in different ways. The NEI "nonroad sources" only include the MOVES3 model nonroad sources, as described above. The NEI point source data include other nonroad sources, such as aircraft emissions at airports (during takeoff and landings) and locomotive emissions at rail yards, while the NEI nonpoint source data include other locomotive and marine commercial vessel emissions at ports. The NEI also includes data provided on event sources, including reported wildfires and prescribed burns, for which EPA estimates emissions. As with the MOVES model, the NEI has limitations, including that the nonroad inventory is not uniformly categorized, not complete, and data provided by state, local and tribal agencies is not always consistent.

Recommendations

Onroad-related emissions represent a decreasingly significant sector of the transportation-related emissions inventory, particularly for criteria emissions. Nonroad sources, however, comprise a significant portion of transportation-related emissions and are expected to grow in percentage as onroad sources are increasingly regulated and electrified. Emissions from nonroad sources, including from the aviation, marine and locomotive sectors, must be considered and become a priority going forward, particularly in the mid- to long-term.

- In the near term, EPA should consider mechanisms to develop a comprehensive and consistent emissions inventory for nonroad sources, including aviation, locomotive, and marine sources. EPA should identify a model that should be used consistently to inventory nonroad sources.

- In the mid-to long term, nonroad sources, to the extent feasible, should be a priority for low-carbon fuel solutions (as discussed in other sections of this report) and advanced

[77] EPA, MOVES3 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity at 59-61, EPA-420-B-20-052 (November 2020) (https://www.epa.gov/sites/production/files/2020-11/documents/420b20052.pdf) (listing nonroad equipment types in Appendix C).
[78] EPA, *Fuel Supply Defaults: Regional Fuels and the Fuel Wizard in MOVES3* at 22, EPA-420-R-20-017 (November 2020) (https://www.epa.gov/sites/production/files/2020-11/documents/420r20017.pdf).
[79] MOVES3 Technical Guidance at 59.
[80] EPA, National Emissions Inventory: Data and Documentation (updated September 2020) (https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei).

technologies, including hybridization, for applications where complete electrification may not be feasible or cost effective.

Recognizing that low-carbon fuel solutions may not be feasible, available, or cost effective for certain sources, including marine and aviation as well as some construction and agricultural applications, EPA should consider potential for additional emissions regulation to continue to reduce the impact of legacy equipment.

- In the mid-term, EPA should consider a comprehensive strategy to review and control emissions from nonroad mobile sources. Such strategy should address both new and in-use vehicles and engines and should be performance based to allow for multiple technological solutions among varied applications.

Non-exhaust/non-combustion contributions of vehicles (including electric vehicles) to PM emissions, such as tire and brake wear may not be properly accounted for in existing emissions inventories and models.

- In the near-term, EPA should consider the contributions of tire and brake wear (among other components) to air quality and conduct or commission further research to assess the impact of such emissions. EPA should consider collaborating with CARB in work being conducted in these areas.
- In the mid-term, EPA should evaluate the results of such research to determine whether non-exhaust emissions, such as from tire and brake wear, should be the subject of further requirements, including for EVs.

3.4.6 Legacy Vehicle Fleet

As the transportation sector evolves and new technologies enter the market, EPA must direct appropriate attention to regulating emissions from the legacy fleet portfolio. Given the diversity of the applications and vehicles, the recommendations are designed to address the unique needs of the legacy fleet, including the light-, medium-, and heavy-duty on-road fleets. For the purposes of this report, the legacy fleet in the context of 2050 consists of today's current vehicle fleet as well as all vehicles sold and operated over the next 10-20 years.

The vehicle fleet is expected to evolve as newer technology vehicles, such as BEVs and hybrids, are introduced into the market. The average light duty vehicle lifetime or retirement age in the US is 16.6 years (Figure 10).[81] Assuming, that the vehicles remain within the fleet for their full useful life, it is estimated that it will take 19.6 years for new technology (assuming it is included in 100% of new vehicles sold) to be able to account for 90% of the on-road fleet. This means that it will take some time for newer technologies to become a meaningful fraction of the fleet.

[81] Keith et al. (2019), Vehicle fleet turnover and the future of fuel economy, Environmental Research Letters, 14(2).

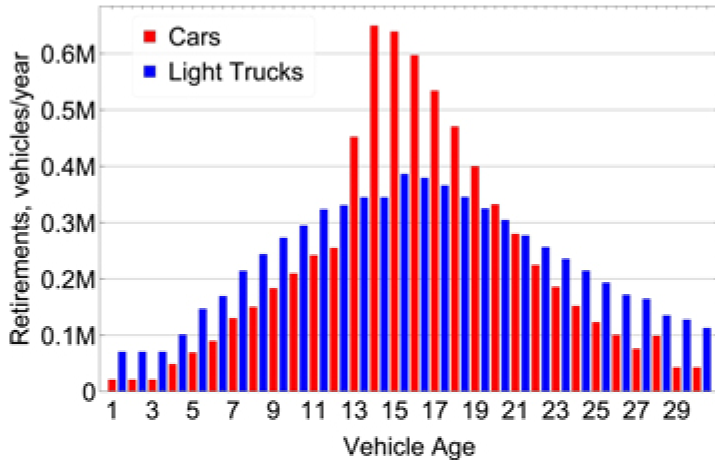

Figure 10: Distribution of vehicle retirement ages in the US.

Medium- and heavy-duty vehicles make up a smaller fraction of the overall US fleet compared to light-duty vehicles. Less is known about the average retirement age (by year) of the U.S. MD and HD fleet, but the average lifetime is longer than that of the light duty fleet from a miles driven perspective. They will continue to play a large role in the energy consumption of the transportation sector; EIA projects that commercial light trucks and freight trucks will make up approximately 25% of the transportation energy use in 2050.[82] Because the average lifetimes of a MD or HD truck can be longer than the average LDV, any changes that occur today have the potential for near term as well as long term benefits. Suggestions for addressing the legacy fleet are listed below.

Re-Evaluation Of Existing Programs

Inspection and maintenance (I/M) programs were originally put into place as a way to help maintain the effectiveness of vehicle emissions controls by identifying malfunctioning vehicles. Since its start in 1990, these programs have been shown to reduce emissions from the LD fleet, especially for pre-1985 model year vehicles.[83] However, as vehicles continue to transition towards more advanced technologies, fewer high-polluting vehicles remain in use, thereby making the programs less effective at reducing local air pollution. There is evidence that emission levels and frequency of occurrences of high emitting vehicles are similar between I/M and non-I/M cities; where emissions reductions are occurring at similar levels and rates. [84] To understand whether or not reductions are meaningful enough to justify continuation of the current program or the introduction of any new programs, the emissions benefit impact of these I/M programs requires further study. Overstating emissions or using outdated methodologies may lead to ineffective or unnecessary regulations as well as an underestimation of the true cost of the emissions reductions.

Fuel Economy (FE) Benefits

Fuel efficiency standards have significantly impacted U.S. gasoline demand and CO_2 emissions and are expected to continue to do so as they continue to migrate towards a more efficient low-emitting

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[82] https://www.eia.gov/outlooks/aeo/tables_ref.php
[83] Sanders and Sandler (2017), Working Paper: Technology and the Effectiveness of Regulatory Programs over Time: Vehicle Emissions and Smog Checks with a Changing Fleet.
[84] Bishop, G. (2020) CRC Report No. E-123-4. Inspection and Maintenance Evaluation using Historical U.S. Remote Sensing Measurements.

vehicle fleet.[85] Much of the vehicle fleet turnover with regards to CO_2 reduction is projected to be driven by technology advancements resulting from stringent fuel economy standards; first, the CAFE standards put into place under the Obama administration and more recently, the SAFE rule.[86] Previous work investigating the potential impact of the two different rules with continued stringency over time on annual fleet emissions, indicated automotive GHG reductions in the range of 60 to 75% by 2050.[87] Both versions of the standard yield significantly reduced annual emissions; automakers are driven to further advance the FE of the internal combustion engine (ICE) as well as diversifying their sales by introducing new technologies over the next decade to meet the more stringent requirements. In addition to improved vehicle FE standards, low-carbon fuels and pre-existing tier 3 technologies are expected to yield substantial long-term emissions reductions.

For the Medium Duty / Heavy Duty vehicle classes, there remains potential for substantial fuel economy improvements. Additional benefits are possible from heavy trucks by advancements in autonomous driving via platooning, packaging efficiencies, route optimization, etc.

Fuels Diversification – Cleaner Fuels and Advanced Alternative Fuels

There is significant potential for cleaning up today's legacy fleet through the use of low-carbon alternative fuels. Since the start of the RFS fuels program, the use of biofuels in the transportation sector has reduced GHG emissions by several million metric tons and the expanded RFS2 rule has resulted in cumulative CO2 savings of nearly 600 million metric tons over the implementation period.[88] This was achieved without adverse air quality impacts as noted in the anti-backsliding determination and study conducted by EPA.[89] Additional suggestions include:

- Expediting the transition of gasoline and diesel-powered vehicles to operate on lower CO_2-emitting alternative fuels such as RNG or low-carbon biofuels for heavy-duty fleets. Drop-in renewable diesel is convenient, as it does not require new fueling and maintenance infrastructure, like it would for a NG fleet, which would require that the fleet is centrally located.

- Due to the economic and environmental benefits of natural gas, a shift toward natural-gas powered trucks has already been observed for fleets that are centrally located. South Coast AQMD has provided funding to install CNG and LNG fueling stations and production facilities within their 4-county jurisdiction.[90]

- Low-carbon performance standards should be incentivized to further improve the overall emissions footprint of various fuels. Details of a potential low-carbon performance standard as well as a low-carbon biofuel recommendations are highlighted in their respective sections of the report.

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[85] Greene et al., (2020) Two Trillion Gallons: Fuel Savings from fuel economy improvements to US light-duty vehicles, 1975-2018, Energy, 147.
[86] EPA Fact Sheet. NHTSA and EPA Proposed SAFE Vehicle Rule: Overview of the Alternatives Analyzed, EPA-420-F-18-902, August 2, 2018.
[87] Keith et al. (2019), Vehicle fleet turnover and the future of fuel economy, Environmental Research Letters, 14(2).
[88] Unnasch. S. (2019) GHG Reductions from the RFS2 – A 2018 Update. Life Cycle Associates Report LCA. LCA.6145.199.2019 Prepared for Renewable Fuels Association
[89] https://www.epa.gov/renewable-fuel-standard-program/anti-backsliding-determination-and-study
[90] http://www.cleantransportationfunding.org/

- As noted above, EPA should remove silos that exist between various programs that have similar objectives, such as fuel efficiency and the RFS. Doing so could enable these programs to build off one another, creating incentives for more effective strategies to reduce carbon emissions.

Voluntary incentive-based approaches

A relatively small number of legacy vehicles are responsible for a relatively large fraction of total criteria pollutants. EPA can place a greater emphasis on the retirement of the oldest and most polluting vehicles on the road. For example, EPA could work with state and tribal authorities having jurisdiction to evaluate legacy fleets and facilitate evaluations and corrective measures to either improve existing vehicles or incentivize a fleet turn-over to tier 3 or 4 vehicle standards. This helps build a fleet that is efficient and low emitting. As an example, continue developing research via demonstration and feasibility test programs related to the use of diesel "retrofit" solutions for HD vehicles (e.g., engine or vehicle replacement, advanced after treatment technologies, advanced alternative fuels, etc.) which have shown some success.[91]

Congestion Management

In many parts of the country, traffic congestion continues to increase in severity and duration. Information specifically related to the impacts of traffic congestion on air pollution remains limited as air monitoring stations are not spatially refined enough to capture such data. Although, it may not be directly correlated to congestion, many studies have indicated increased emissions in areas located near high traffic highways.

As populations continue to increase, cities are required to find solutions to move more people and their vehicles efficiently in a fixed amount of space. Multiple options are available, ranging from smaller low-cost solutions to large scale projects that are costly and require infrastructure modifications, as well as emerging technologies including intelligent transportation systems (ITS). The EPA can work with the DOT to educate localities on appropriate congestion mitigation strategies and help develop programs to assist with achieving these goals as a means of managing congestion and thereby, lowering emissions in high traffic regions.

Summary

Not a single technology option, but a diversification of technologies and programs are essential to achieve reductions that fulfill the various needs of the transportation sector. There is potential for alternate fuels, trends in vehicle efficiency and fuel economy, and alternative programs that can address the emissions reduction requirements of our legacy fleet.

- Further evaluate the benefits of ongoing technology programs and publicize the results.
- Encourage aggressive coordinated leadership between states and trade associations in order to implement programs that will require high levels of funding

[91] Dallmann et al. (2011), Effects of DPF Retrofits and Accelerated Fleet Turnover on Drayage Truck Emissions at the Port of Oakland, Env. Sci. Tech., 45(24).

- Further work with the DOE on exploring new fuel economy and emissions reduction technologies and fuels technologies for the legacy fleet (e.g., refer to hydrogen and e-fuels section)
- Work with the DOT to educate localities on congestion mitigation to help reduce emissions from existing vehicles.
- EPA should commit significant attention to identifying strategies for reducing emissions from legacy vehicles, which will remain on the road for many years.

3.4.7 Hydrogen and E-Fuels

Following historical trends, demand for passenger and freight mobility (passenger-miles, ton-miles of freight) will grow as both U.S. population and economy expand.[92,93] However, demand growth is not uniform across all fuels and applications, and the extent of demand growth will be different for different travel modes, with aviation and freight trucks projected to grow the fastest in the U.S. (see Figure 11).[94] This will change the requirement for liquid fuel, with jet fuel and diesel powering large vehicles such as airplanes and heavy trucks growing faster than gasoline powering smaller on-road vehicles.

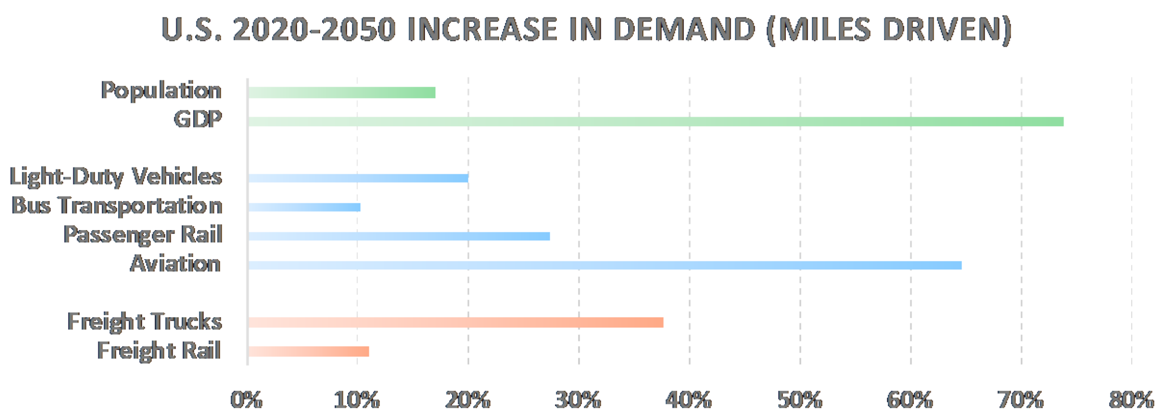

Figure 11: 2020-2050 increase in population, GDP, and vehicle miles traveled by model as projected by AEO2020.

Difficult to Electrify Sectors (Aviation; Long-haul Trucks, Maritime, Rail) Will Continue to Require Low-Carbon Liquid Fuels

Considering expected growth in mobility demand, transportation system-level structural changes, fuel economy improvements, and adoption of alternatives to liquid fuels, especially electric vehicles, the U.S. liquid fuel demand is expected to decrease drastically compared to today's 215 billion gallons, mostly as a result of widespread electrification of on-road transportation vehicles. However, uncertainty remains on the extent of electric vehicle adoption, especially for heavy trucks, which in turn influences the requirements for liquid fuels and other alternatives, like hydrogen. Moreover, the transition to electric or alternative fuels will take time to allow the entire fleet to turn over, and there

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92 https://www.sciencedirect.com/science/article/pii/S0967070X1200008X
93 https://pubs.acs.org/doi/abs/10.1021/acs.est.6b04515
94 https://www.eia.gov/outlooks/aeo/

will be a long transition with legacy vehicles in all sectors for decades to come sustaining demand for liquid fuels during this time.

Even in the long run (~2050), after a complete fleet turnover and assuming widespread success of electric vehicles technologies, there are sub-sectors of transportation that will be hard to transition to direct electrification (i.e., aviation, maritime, rail, and long-haul trucks). These sub-sectors are projected to grow faster than light-duty vehicles in the next decades.

In the long run (~2050) large vehicles that are unlikely to electrify are projected to account for about a third of the total transportation energy demand (~8 Quadrillion BTU). As a result, even with widespread electrification of on-road vehicles, the need for energy-dense, carbon-based liquid fuels is projected to remain, especially in long-distance travel and transport, whether on-road long-haul, maritime, air, or rail.

A number of alternatives to liquid petroleum or biofuels are also being explored, especially hydrogen (e.g., compressed or liquid hydrogen, ammonia), and while these solutions are not yet commercially competitive today, they could play a larger role in the future and displace more liquid fuel demand. If all of these large vehicles were to be powered using liquid fuels, approximately 70 billion gallons of fuel will be required in 2050 in a scenario that does not account for major mobility disruptions and is aligned with the EIA AEO (but assumes full electrification of light-duty and short-haul on-road commercial vehicles). Although this would be a 67% decrease in liquid fuel use in transportation compared to 2019, it still represents a substantial demand. Moreover, the type of fuels will be different: while motor gasoline (including ethanol) represents 64% of current liquid transportation fuels the future could be dominated by jet fuel and a combination of diesel and heavy fuel for long-haul trucks, ships, and trains.

Low-carbon liquid fuels from biomass and other waste carbon sources can satisfy a significant portion of this demand. The DOE Billion Ton Study estimates the U.S. could produce ~50B gallons of low-carbon liquid fuels, which roughly aligns with the expected demand for these hard-to-electrify modes.[95] That amount could grow if carbon capture allows for low-cost CO_2-to-fuels pathways in the future. For aviation, long-haul trucks, rail, and maritime applications, that have limited alternatives to energy-dense carbon-based liquid fuels, biofuels might offer a viable solution in line with the resource potential.

CO_2 to Fuels Requires Huge Amount of Electricity

There has been significant recent interest in developing "efuels" by using electricity to power the conversion of CO_2, either via renewable H_2 or direct carbon electroreduction. Such fuels have the potential to effectively "electrify" portions of the transportation system that remain difficult for battery technologies to serve. The inherent greenhouse gas mitigation benefit of these fuels lies in the fact that they are derived from waste carbon that otherwise would have been emitted to the atmosphere or could even be made from CO_2 capture from ambient air.

Since the energy input for creating efuels comes from the electricity, the carbon intensity of that power becomes the overall driving force in determining their life cycle carbon footprint. Similarly, the technoeconomic feasibility of efuels are also heavily dependent on the price of the electricity used to perform carbon reduction. Thus, the viability of efuels is heavily dependent on the availability of low

[95] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

cost renewable electricity. To ensure a solid framework for valuing the carbon intensity reduction of efuels, acceptable guidelines should be developed for assessing the carbon intensity of point sources of CO_2 as well as the electricity used.

Key Pathway Considerations

There are many possible pathways for generating efuels, each with their own unique advantages and challenges to achieving scale. Arguably the most common pathways being examined today for producing efuels from CO_2 processed through an intermediate, followed by an upgrading strategy. The overall technoeconomic and carbon intensity implications of these fuels are heavily dependent of the intermediate chosen. The production of the intermediate from CO2 is the most energy-intensive and technically difficult part of the process. As demonstrated in Table 3, the choice of intermediate is crucial to understanding the overall technology readiness level of the pathway

The most common intermediate studied today for producing efuels is carbon monoxide. The generation of CO can be achieved through roughly two avenues:

- Thermocatalytic conversion of CO_2 using hydrogen via reverse water-gas shift
- Electrocatalytic reduction of CO_2 using an electrode assembly.

For thermocatalytic CO_2 reduction, a major barrier to feasibility at scale lies heavily in access to low-cost renewable hydrogen and the carbon intensity implications of the heat required to carry out the reaction. For electrocatalysis, major challenges exist in improving electron efficiency, lowering cell overpotential, controlling pH and carbonate crossover, and determining electrolyzer design.

Table 3: Qualitative evaluation of the ease of formation of several intermediates produced from CO_2.

Species	Rate of Formation[a]	Selectivity[b]	Energy Efficiency[c]	Current TRL[d]
Carbon Monoxide	High	High	High	High
Ethylene	High	Medium	Low	Low
Formate	Medium	High	Medium	Low
Methane	High	High	Medium	High
Acetate	Low	High	Medium	Low
Methanol	High	High	High	High

[a] High: >200 mA/cm^2 (or commercial TC), Medium: 200 >/>100 mA/cm^2, Low: <100 mA/m^2
[b] High: >80%, Medium 80% > FE > 60%, Low: < 60%
[c] High: >60%, Medium 60% > EE > 40%, Low: < 40%
[d] High: Operated at TRL > 6, Medium: Operated TRL 4-6, Low: Operated TRL 1-3

Once an intermediate is produced, there are several upgrading strategies available that have been demonstrated at scale, such as CO fermentation or Fischer-Tropsch synthesis. Though both have been demonstrated at scale, there are still many challenges to their deployment for generating efuels. To ensure success at scale, research and development is needed in integrating and rightsizing downstream strategies with CO_2 reduction technologies as well as understanding how these technologies would be integrated with a renewable electricity system that favors flexibility.

The Role of Hydrogen in This Process

To meet the proper specifications, many renewable fuel pathways require hydrotreating to remove heteroatoms and to saturate carbon-carbon bonds. Oxygen removal through hydrotreating is required for stabilizing bio-oil intermediates from pyrolysis or hydrothermal liquefaction. Hydrotreating is also an essential part of converting free fatty acids and esters from used cooking oil, animal fats, and oil crops into fuels. This process is similar to the hydrotreating used in petroleum refining, however oxygen removal on the scale required for converting bio-oils is much less developed. Several ongoing R&D efforts are aimed at efficient hydrogen use to overcome the reactivity of bio-oil and preventing catalyst coking.

Hydrogen is also essential to many efuels processes for converting CO_2 to fuels. The need for hydrogen in the conversion process varies depending on the technology used, however generally the more external hydrogen provided, the higher the single-pass carbon efficiency. Arguably the largest commercial demonstration of CO_2 utilization in the world is via direct hydrogenation of CO_2 in a thermochemical process; an Icelandic company (Carbon Recycling International) leverages the region's geothermal power to generate green hydrogen and uses that to convert CO_2 to methanol for sale onto the European market at a scale of approximately 4,000 tons/year. As stated above when discussing efuels broadly, the critical factor to the feasibility of using hydrogen to generate renewable carbon fuels at an acceptable carbon intensity lies in ensuring that the electricity used is simultaneously low cost and renewable.

Chapter 4: Goods Movement

4.1 Introduction

Emissions from the trucks, trains, ships, aircraft, and cargo-handling equipment associated with the goods movement sector are substantial contributors to air pollution and greenhouse gases (GHGs). As demands from the expansion of e-commerce fuels the rapid growth in goods movement, addressing emissions from this sector is of paramount importance.

The Mobile Sources Technical Review Subcommittee (MSTRS) was tasked with providing input to the U.S. Environmental Protection Agency (EPA) about its role in four future mobility paradigms. One of those scenarios was "Goods Movement – I Want My Stuff." In a world where goods delivery primarily happens through on-line orders and through direct-to-household-and-business deliveries, EPA should play a major role in reducing emissions from transportation options in the supply chain (e.g., between the final distribution site and a household or business). Transportation options may include but are not limited to trucks, drone delivery, wheeled robot delivery, new delivery business models and processes, connectivity and improved intelligent routing software, 3D printing, etc. The goods movement subcommittee evaluated the following questions and provided recommendations.

- What is needed to deploy technology in a manner that achieves emission reductions most efficiently? Consider both overall transportation emissions reductions and sector specific emissions reductions. Are there differences in technology applications under the different use cases? What could that look like?
- What would an efficient low-emissions goods delivery system look like? Who are the major players? What is EPA's role in this space?
- How can EPA best utilize, or encourage utilization of, data to enable and optimize low-emissions deliveries (e.g., real-time activity info, intelligent routing software, etc.)?

4.2 Executive Summary

This document provides robust recommendations across a variety of sectors within the EPA Office of Transportation and Air Quality (OTAQ), and highlights some key themes to guide agency action and achieve real GHG emission reductions, including the following:

1) The Clean Air Act (CAA) authority to regulate tailpipe emissions is the most powerful incentive available and should be fully exercised to eliminate truck, marine, and locomotive GHG emissions. A credit system, such as the one that Tesla has used, could be employed to make $518 million in emission reduction credits and this same credit system should be used to support zero-emission trucks, vessels, and locomotives.
2) Goods movement initiatives, grants, policies, and regulations should be targeted to reduce emissions in overburdened environmental justice communities. Ports, railyards, and truck routes disproportionately impact these neighborhoods and should be a top priority.
3) While the Diesel Emission Reduction Act (DERA) and SmartWay have been tremendously successful, OTAQ needs to reinvent and refocus these programs to support zero-emission

trucks, vessels, locomotives, and equipment. In the future, the Environmental Defense Fund, the Natural Resources Defense Council, the Clean Air Task Force, and the American Lung Association will only support DERA funding for Zero-Emission Vehicles (ZEVs) and equipment.

Note that references throughout this document to zero emission or vehicle electrification apply equally to battery electric as well as fuel cell electric. For some use cases, battery electric technology is market ready whereas for other use cases, fuel cell technology is more appropriate. Thus, the recommendations herein are "fuel agnostic"; zero tailpipe emissions are the goal.

4.3 Analysis and Recommendations

4.3.1 Engage in Strategic Planning and Coordination

EPA should take the lead in developing a dedicated, comprehensive federal strategy for electrifying the transportation sector that outlines policy actions and provides funding, with priority given to environmental justice areas.

As atmospheric levels of carbon dioxide (CO_2) and other GHGs increase, states will experience changes to their environment including increases in temperature, variability in precipitation, frequency and intensity of storms, and sea-level rise. Fossil fuel combustion is a key contributor to climate change as it results in GHGs and short-lived climate pollutants such as black carbon. Shifting the transportation and energy sector to zero carbon emissions is essential to mitigating the short- and long-term impacts of climate change (although black carbon will likely continue to be released through brake and tire wear). Organizations like the U.S. Climate Alliance, a bipartisan coalition of 25 governors committed to reducing GHG emissions consistent with the Paris Agreement, have made transportation electrification one of their key priorities.[96] A comprehensive effort to produce, sell, and deliver electric vehicles (EVs) in all shapes and sizes, deploy sufficient associated charging infrastructure, and eliminate idling by installing electrical outlets at warehouses and other locations where trucks gather, are among the strategies needed to tackle climate change. Success will depend on the bold participation of stakeholders at all levels of government as well as the private sector.

It is imperative that there be a dedicated, comprehensive federal strategy for electrifying light-, medium-, and heavy-duty vehicles as well as nonroad equipment used in goods movement that lays out policy actions and provides funding. EPA must be a lead player in developing and implementing this strategy, including near-term criteria pollutant and GHG emission goals and milestones, which could include legislative and regulatory components as well as executive directives and stakeholder commitments. Zero-carbon strategies could include green hydrogen and fuel cell electric in addition to battery electric.

For example, with respect to medium- and heavy-duty vehicles, this "roadmap" should also be used to help establish funding priorities for programs like DERA to fund deployment of both near zero-[97] and zero-emission (criteria pollutants, GHGs, and short-lived climate pollutants) vehicles. Each component will require coordination with appropriate parties. The EPA regional offices should also prioritize this overall "roadmap" strategy in their partnerships with the states.

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[96] http://www.usclimatealliance.org/

[97] The term "near-zero" emissions refers to 90% or cleaner NO_x emissions compared to the 2010 standard of 0.2 g/bhp-hr for heavy-duty trucks.

Fifteen states and jurisdictions signed a Memorandum of Understanding in the Summer of 2020 committing to work together to ensure 30% of medium- and heavy-duty truck sales are electric by 2030 and 100% are electric by 2050. A National Academy of Sciences Committee recommends that national standards be set for medium- and heavy-duty vehicles so that 30% of sales in 2030 are ZEVs.[98] California recently passed its Advanced Clean Trucks regulation, which requires manufacturers to sell increasing numbers of zero-emission trucks in Classes 2b to 8 starting in 2024.[99] Achieving this goal will require, as noted above, a suite of strategies and engagement by all levels of government and private stakeholders, including EPA.

It is also important that EPA expand its role and work with respect to deploying EV charging and hydrogen (H_2) fueling infrastructure and participating in the development of policies and practices for efficient build-out. EPA should engage on EV charging/H_2 fueling interoperability, which is an essential aspect of infrastructure deployment, and contribute to the creation of standardized, open charging/H_2 fueling systems to enhance both consumer-facing interoperability and systems management interoperability. As work on this continues, EPA should coordinate with charging/H_2 fueling equipment providers, operators, and users, EV charging/H_2 fueling network software providers, app developers, Original Equipment Manufacturers (OEMs), and others to provide input and recommendations.

Through the January 20, 2021 Executive Order 13985, "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government," President Biden committed to make environmental justice a part of the mission of every agency by directing federal agencies to develop programs, policies, and activities to address the disproportionate health, environmental, economic, and climate impacts on disadvantaged communities.[100] Thus, EPA's strategic plan should necessarily incorporate this direction and integrate environmental justice considerations into all the action items listed below.

Action Items

Planning and Goal Setting

- Establish a Federal Goods Movement Working Group with the DOT and DOE to develop a comprehensive federal strategy for decarbonizing and improving the energy efficiency of the transportation sector. EPA OTAQ should identify the DOT and DOE activities that could potentially provide beneficial impacts on air quality and public health and engage in discussions to further those activities. Similarly, EPA OTAQ should identify DOT and DOE projects that could potentially have an adverse impact on air quality, especially in overburdened communities, and take steps to ensure those harms are mitigated. As an example, infrastructure projects involving diesel construction equipment operating in a concentrated geographic area for an extended period may cause significant local impacts. EPA should also identify actions that other agencies can take to accelerate medium- and heavy-duty vehicle (MHDV) electrification in public and private fleets (MHDVs are typically greater than 8500 pounds Gross Vehicle Weight Rating). EPA OTAQ should brief the Assistant

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[98] National Academies of Sciences, Engineering, and Medicine 2021. Accelerating Decarbonization of the U.S. Energy System. Washington, DC: The National Academies Press. https://doi.org/10.17226/25932.
[99] https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet
[100] https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government

Administrator for EPA's Office of Air and Radiation (OAR) and the OAR leadership should brief the EPA Administrator on this concept so establishment of bi-lateral and tri-lateral discussions and decision-making is endorsed and established at, and the offices and divisions that should participate are identified by, the highest levels of the agencies.

- Work with the General Services Administration to:
    - Implement aggressive medium- and heavy-duty ZEV federal fleet purchase targets designed to achieve 100% ZEV purchases by 2050; and
    - Transition the U.S. Postal Service delivery fleet to zero-emission in nonattainment areas by 2025, and nationally by 2030, and mail tractors (carrying loads to distribution centers) to 100% zero-emission by 2030.
- **Work with DOT and DOE through the 21st Century Truck Partnership** and SuperTruck to ensure that heavy-duty ZEV technology is incorporated into the program (program efficiency targets and technology demonstrations).
- **Prioritize EV deployment to goods movement "hotspots,"** such as ports, where air quality benefits can be maximized to the most vulnerable communities.

Education

- Sponsor conferences and technical workshops for public and private sector MHD ZEV stakeholders, including at conferences, workshops, or forums focused on goods movement, including the Council of Supply Chain Management Professionals and North America's Corridor Coalition.
- **Advocate for creation of an interagency workforce development program** for a clean transportation future for applicants who reside in underserved or disadvantaged communities with a focus on training a diverse manufacturing, assembly, operations and maintenance, grid integration, and/or driver workforce. This program should follow standards such as those put forth by the Electric Vehicle Infrastructure Training Program and hire from certified, registered apprenticeship and pre-apprenticeship programs.[101]
- Work with the U.S. Department of Labor on educating the workforce on operation and maintenance of EVs (both hydrogen and battery electric).

Data & Research

- **Lead a cross-agency effort to identify MHD ZEV research needs** and conduct research to support MHDV electrification (e.g., support establishment of an Advanced Research Projects Agency for transportation (ARPA-T) and an electrification task force focused on MHD ZEVs). This could include studying different approaches to MHD ZEV charging, including catenary and centralized/overnight, and make recommendations for optimal route/charging approaches.
- **Work with DOE to enhance the Alternative Fuels Data Center** (**AFDC) to collect usage data** and other parameters from light-duty EV charging stations. This would enable states to

[101] https://evitp.org/

analyze energy impacts, future siting options, charging trends, etc. The National Renewable Energy Laboratory maintains the AFDC and corresponding Alternative Fueling Station Locator for DOE, which includes a comprehensive listing of EV charging stations across the U.S.

- **Advocate for single point of contact at DOE** to streamline coordination with interagency partners to provide technical assistance for MHDV electrification infrastructure planning and implementation. This point of contact should proactively coordinate with other DOE offices, such as DOE's Vehicle Technology Office (VTO) and Fuel Cell Office, to provide guidelines and robust assistance to EPA transportation and climate offices, state energy offices, public utility commissions, regulated utilities, rural electric cooperatives, tribal electric authorities, public and private fleets, and other partners on all issues related to zero-emission MHDVs.
- **Study MHD ZEV electric charging and hydrogen fueling infrastructure needs** and produce a report on where infrastructure should be placed that evaluates the structural environmental justice implications of EV infrastructure, the number of chargers/fueling stations needed to support clean mobility, optimal locations for charging/fueling infrastructure, and recommendations for a phase-in schedule of charging/fueling infrastructure needed to meet an equitable and just transition to MHD ZEV.

4.3.2 Enhance Incentive Programs

Refocus partnership programs, such as the SmartWay program, on zero- and near zero-emission medium- and heavy-duty vehicles and equipment with priority given to environmental justice areas.

Since 2004, the SmartWay program has played a historic role reducing criteria pollutant and GHG emissions from the freight sector, largely through the development and deployment of advanced aerodynamics, auxiliary power units (APUs), and single-wide tires. It is now time to declare "mission accomplished" for diesel engine fuel efficiency improvements and refocus/reinvent the program to support the development and deployment of electric medium- and heavy-duty trucks. When SmartWay started, many trucking companies were paralyzed by a lack of credible information about the effectiveness of advanced aerodynamics, APUs, and single-wide tires. SmartWay, through collaboration with industry stakeholders, fixed this problem. The freight transportation sector is now confronted with the same confusion and uncertainty as numerous companies introduce near zero- and zero-emission medium- and heavy-duty trucks. SmartWay has the credibility and industry trust to provide trucking companies with the critical information they need to purchase and deploy these new zero-emission trucks.

Action Items

- **Enhance and update SmartWay to include near zero- and zero-emission components.** While the SmartWay program acknowledges zero-emission technology through the Carrier, Logistics, and Shipper Performance Models, there are no specific programs around near zero- and zero-emission equipment. Elements of this strategy may include developing graduated specifications for SmartWay-designated near zero- and zero-emission vehicles (similar to the SmartWay designation for Class 8 sleepers and day cabs); award programs for adopting near zero- and zero-emission technologies; providing SmartWay with a "seat at the table" during goods movement education and outreach; funding programs to help develop and implement the chosen strategy; and funding programs to encourage and assist SmartWay partners in adopting near zero- and zero-emission technologies, with greater incentives offered for zero emissions compared to near zero.

- Working with current partners and affiliates, as well as others who have a stake in the supply chain and its impacts, **EPA should explore ways to expand SmartWay partnerships** beyond shippers, freight carriers, and logistics providers and promote additional participation.
- **Promote truck and bus electrification through the 21st Century Truck Partnership** (which EPA co-leads with DOT and DOE). EPA should work with DOE and DOT through the 21st Century Truck Partnership and Super Truck to ensure that heavy-duty ZEV technology is incorporated into the program (program efficiency targets and technology demonstrations).
- Develop scoring rubric for federally funded projects that gives greater weight to use of near zero- and zero-emission equipment on the project. As an example, DOT and the Army Corps of Engineers projects using Congestion Mitigation and Air Quality Improvement (CMAQ) funds or federal transportation funds should incorporate zero-emission technologies wherever possible.
- Expand Energy Star to DC fast chargers (currently only applies to Level 2).

4.3.3 Identify Sustainable Funding

Identify additional and sustainable sources of funding for strategies and programs that reduce emissions from goods movement, including through the advancement of new technologies, with priority given to environmental justice communities.

One of the major coordination roles EPA can play on the issue of reducing and eliminating emissions from goods movement is on funding. The scope of this role is broad, starting within the agency and extending out to other federal agencies, the Administration, Congress, and other potential funders. Within the agency, EPA OTAQ, through OAR, can advocate for EPA to make commitments to prioritize federal funding for an array of initiatives necessary to reduce and eliminate emissions from goods movement, such as by including such funding in OAR's annual federal budget requests and identifying it as a priority in annual National Program Guidance.

Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," signed on January 27, 2021, creates a government-wide Justice40 Initiative with the goal of delivering 40% of the overall benefits of relevant federal investments to disadvantaged communities and tracks performance toward that goal through the establishment of an Environmental Justice Scorecard.[102] By strategically targeting new and existing funding sources, the goals of this Executive Order can be achieved.

Working with Congress, EPA should target key bills under development that will authorize funding that could be used for initiatives to reduce and eliminate emissions from goods movement and 1) provide technical recommendations for legislative provisions, 2) provide guidance on how the authorization of funds (including to EPA) for priority initiatives would reduce emissions, and 3) provide guidance on how authorized funds are appropriated and/or used (including by other federal agencies) and related provisions are implemented. Near-term bills include the transportation authorization and infrastructure bill(s). On July 1, 2020, the House of Representatives approved the Moving Forward Act, sponsored by Rep. Peter DeFazio (D-OR), Chairman of the House

[102] https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad

Transportation and Infrastructure Committee. Examples of provisions of the bill are $1.5 billion for EV charging and a requirement that "next generation" vehicles purchased by the U.S. Postal Service using funds appropriated under the bill "shall, to the greatest extent practicable, be an electric or ZEV, and the Postal Service shall ensure that at least 75 percent of the total number of vehicles purchased using such funds shall be electric or zero emission vehicles." Transportation infrastructure legislation is a high priority for the 117th Congress.

Additionally, technology is an important tool in managing and improving air quality. As such, care needs to be taken when prioritizing or adopting technologies within policy or funding initiatives. In our age of seemingly unlimited technology, which oftentimes has to be modified (through software downloads, for example) it can appear that implementation of new technologies is simple and straightforward. In reality, however, technological change is rarely simple or straightforward and seldom assured of success. The following recommendations include suggestions on how EPA should consider new technologies and their implementation.

Action Items

- **Seek a prime role in implementation of the Biden-Harris Administration's "Build Back Better"** plan, which provides for, among other things, 500,000 charging stations. EPA should offer recommendations and also seek a seat at the table for further development and implementation of relevant portions of the plan.
- **Coordinate with Electrify America,** the organization established by Volkswagen under the terms of its consent decrees with the federal government and California to settle violations of the Clean Air Act, to evaluate projects focused on goods movement, specifically on MHD engine replacements. With $2 billion that must be spent by the end of 2026, Electrify America is primarily funding electric charging stations across the country to boost the EV market, but the organization is also spending some money on consumer education. Electrify America has sought input on Cycle 3 of its four-cycle ZEV investment plan and EPA should collaborate with Electrify America on Cycle 3 as well as on Cycle 4, when appropriate. EPA should also conduct an analysis of projects funded through the VW settlement dollars for the purpose of evaluating and promoting the most successful and cost-effective projects.
- Besides taking steps to preserve and expand existing incentive programs such as DERA, EPA should **explore potential international collaboration and partnerships** that could serve to stretch the power of financial incentives. For example, a concept that the South Coast Air Quality Management District has been exploring is a collaboration with Pacific Rim environmental authorities to provide joint incentives to attract cleaner ocean-going vessels to their area.[103]
- **Provide guidance on how the U.S. Department of Agriculture's Electric Programs could be expanded** through loans and grants to rural communities for grid modernization, electric vehicle charging, and electric farm vehicles.
- **Work with DOT and DOE to enhance the use of their grants for air quality improvement projects.** DOT has CMAQ funds that can be used for vehicle electrification projects and DOE has innovation grants that can apply to transportation projects such as Vehicle-to-Grid

[103] http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/AgendaItems/4_primer.pdf?%20

Demonstration projects or battery storage. Grant eligibility criteria can be changed to allow state and tribal air agencies to apply directly to DOT and DOE for funding to reduce transportation emissions. Currently, only EPA money can flow directly to an air agency; funding from non-air federal agencies must flow through state DOT state Boards of Public Utilities (BPUs), etc. before going to the air agency actually implementing the project. Another option would be to dedicate a percentage of each grant to air quality improvement projects or require concurrence by state air agencies on the allocation of the funds or structure of the competitive solicitation.

- **Provide funding for development, commercialization, and implementation of cleaner technologies.** Current EPA incentive programs focus on verified ("commercial") technologies through the DERA and Targeted Airshed Grant (TAG) programs. The Emerging Technologies program, run by OTAQ, should be resurrected and reinvigorated with additional funding, as a complement to the existing DERA and TAG programs. Although pre-commercial on-road technology development has been the focus at DOE as part of its VTO (e.g., the SuperTruck and the Zero Emission Cargo Transport projects) there are only limited funds available for near zero- and zero-emission technologies commercialization essential to achieving attainment of the health-based NAAQS. Region 9, for example, has the Clean Air Technology Initiative (CATI), which provides up to $500,000 per year to advanced technology demonstrations, but these Section 105 funds are not specifically designated for pre-commercial technology advancement. Similarly, as indicated in the "barriers" section, such a pre-commercial fund could assist in the requisite testing for establishing the technology longevity and durability. Finally, as previously recommended, EPA should closely coordinate with the other federal agencies and investigate opportunities to combine funding support. There have been related goods movement funding efforts at DOT (LoNO), FRA (ZERO), and FRA (VALE) to name a few. Combining these efforts for larger or sustained multi-year funding could help accelerate commercialization of these technologies.
- **Provide funding for sector-specific technologies.** EPA should consider directed support to sectors which contribute the greatest emissions, such as on-road trucks, off-road equipment, marine vessels, and locomotives. These projects currently all compete for limited funding but are in different stages of commercialization and have different development needs (as shown in Technology Readiness Timelines). EPA could combine resources as suggested above as well as prioritize projects based on greatest emissions benefit, involvement of a major manufacturer, potential for both criteria and GHG benefits and cost-share.
- **Ensure that incentive programs are well funded but not at the expense of funding for grants to state, tribal, and local air agencies.** Incentive programs provide important non-regulatory ways to get cleaner engines into fleets in the near to medium term, and often work best in conjunction with regulations to provide a push/pull towards cleaner technologies. The conventional EPA mechanisms for incentives have been through DERA and TAG programs, which require congressional authorization every year. A constant challenge is to separate these programs from state, tribal, and local air agency funding that is provided via grants under CAA Sections 103 and 105, so that funding for these programs (i.e., DERA and TAG) does not come at the expense of funding for air agencies, which has been the case in the past. Since incentives have been shown to reduce emissions while also aiding the economy, **DERA and TAG funds should be increased to $150M and $75M respectively, prioritizing nonattainment regions.** Likewise, funding to state, tribal, and local air agencies under

sections 103 and 105 should also be increased – in the near term, at least to keep pace with inflation. EPA OAR should consult with the National Association of Clean Air Agencies to learn more about historic funding of air agencies and current needs. Funding for incentives and for state, tribal, and local air agencies must not be a zero-sum proposition. Although EPA may not lobby Congress for appropriations, EPA may make recommendations to the Administration for inclusion in the President's budget requests to Congress and, regarding the recommendations above, related to DERA, TAG and grants to state, tribal, and local air agencies, should do so. President Biden's May 28, 2021 FY 2022 budget proposal includes appropriate and welcome increases for DERA and grants to state, tribal, and local air agencies, and EPA should encourage the Administration to advocate for these proposed funding levels as it engages in appropriations discussions with Congress.

- Provide voluntary incentives to encourage development and early introduction of new technologies and increase collaboration with key industry organizations to better understand the mindset of ultimate purchasers and how to attract them to new technologies. Incentivize manufacturers to design new zero-carbon solutions buy providing incentives such as Averaging, Banking, and Trading across all mobile transport sectors.
- **Fund manufacturers' products validation to ensure implementation that is reliable and dependable**. New technologies require substantial testing by manufacturers prior to deployment. The larger the equipment, the more significant reliability and dependability become but the lower the sales volume. Improved product validation can help provide ultimate purchasers better confidence of new equipment. Helping fund manufacturers' validation efforts for low-volume, high capital-cost equipment, such as railroad locomotives and marine tugboats, would help to improve new technology perception and successful uptake.

4.3.4 Implement Regulations to Further Reduce Emissions from the Goods Movement Sector

Under the Clean Air Act, states are largely pre-empted from regulating emissions from mobile sources such as cargo handling equipment and trucks used in goods movement and thus must rely on EPA and the California Air Resources Board (CARB) to take a leadership role by promulgating regulations that reflect the best available emission control technology.

Action Items

- **Establish performance-based standards** to harmonize the Phase 2 GHG regulations with the impending highway heavy-duty low-NO_x initiative such that the regulated entities can develop technologies, including electrification, that achieve both GHG and NO_x reductions.

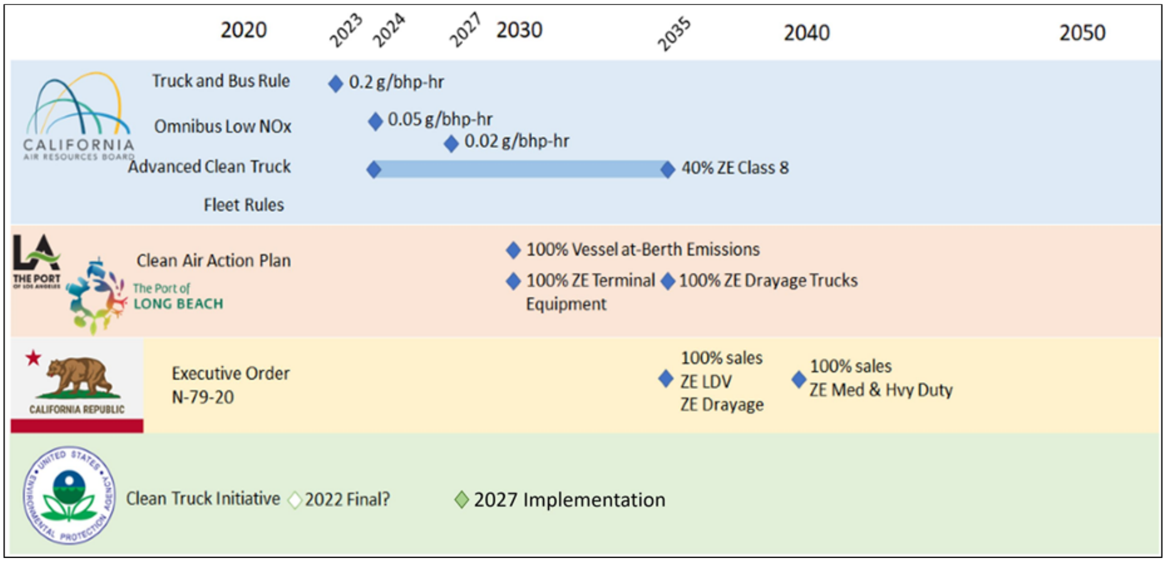

Figure 12: Regulatory Framework for Trucks.

As an example of the concerted efforts at the local (ports). tribal, state and federal levels, Figure 12 above shows the related regulatory timeline for on-road heavy-duty trucks.

- **Establish the Phase 3 GHG regulation stringencies** to progressively drive greater adoption of zero-emission medium- and heavy-duty vehicles over time, initially targeting accelerated adoption in urban and community applications to maximize early benefits. This would drive the advancement of new technologies, as referenced in Section IV.
- To ensure new diesel vehicles are as low emitting as possible, **in the highway heavy-duty low-NO_x initiative**, establish emission standards for idle and low-load conditions based on the CARB Omnibus regulation. Additionally, replace the existing Not-to-Exceed standards with a newly established in-use emissions test that measures idle and low-load NO_x. Research new NO_x sensor technology that can measure NO_x emissions at low load and idle.
- Knowing that diesel engines are long lasting and durable, EPA should implement additional regulations to encourage turnover of the fleet, thus ensuring that the medium- and heavy-duty fleet is as clean as possible (e.g., is subject to the new low-NO_x standards) during the transition to full electrification. CARB's rules can serve as a blueprint.
- Explore opportunities to increase the use of renewable/cleaner fuels.
- EPA should work cooperatively with the railroads, locomotive and engine manufacturers, and fuel supply industry to perform testing and modification of existing locomotive engines using higher blends of lower-carbon alternative fuels (such as renewable diesel, biodiesel, low-carbon natural gas, etc.). This ultimately could reduce emissions of GHGs and especially particulate matter much faster than any wholesale new technology replacement of the more than 25,000 U.S. diesel locomotives. An initial program target would be to raise the allowable and acceptable (i.e., avoiding engine deterioration) biodiesel blend rate from 5% (B05) to 20% (B20), likewise for renewable diesel fuels. The testing would include engine laboratory testing but also dedicated in-service "field fleet testing" under real-world operating conditions to assess impacts on engine components, determine engine component material, and/or design

changes to accommodate the higher blend rates, and then modify the engines. EPA should revise emission standards for locomotives, which have not been revised in over 12 years.

- **EPA should strengthen its recently adopted federal aircraft CO_2 standard**[104] **that is based on the standard adopted by the International Civil Aviation Organization** (ICAO) in 2016 and apply it to domestic flights and to flights all over the world. The ICAO standards fall short of what is necessary and feasible. EPA is not bound by the ICAO standards and should adopt GHG emission standards for new type airplane designs and in-use production models that are more stringent than ICAO's – that are technology forcing rather than technology following – to ensure adequate and appropriate regulation of airplane GHG emissions rather than just business as usual.
- **EPA should work with the International Maritime Organization** to adopt a Phase 4 Energy Efficiency Design Index of 50-70% by 2035-2040 (Phase 3 is 30% by 2025).
- Collect and evaluate data on Vehicle Miles Traveled (VMT) associated with cargo delivery pathways in order to understand emission profiles of cargo delivery pathways to drive delivery pathways to lowest emission options, specifically focused on urban, intermodal, and pollution hotspot areas. With an increasing array of modes for delivering cargo, there will be many options for transporting goods. Depending on the modes used, these options will have different emission profiles. For example, a combination of modes that transport a unit of cargo may involve more VMT than other combinations and would therefore be associated with more emissions. But current business models place a premium on delivering goods as quickly as possible and would select the higher cargo ton/VMT option if that option provides the fastest delivery pathway.

4.3.5 Promote Sustainability in Goods Movement

Globally, there is growing demand for a transition to a low- or zero-carbon economy. Along with current issues surrounding climate change, many companies are seeing the various risks impacting their current business. Acting on climate change is good for the Planet and a smart business strategy. Companies that include carbon reductions in their business strategies reduce risks and realize the benefits around increased innovation, competitiveness, and growth.

The latest science is clear that reaching net-zero carbon emissions by 2050 is possible and necessary to achieve the Paris Agreement's 1.5 °C goal. The Paris Agreement sets out globally agreed goals for action on climate change, aiming to keep the global surface temperature rise well below 2 °C, and preferably to no more than 1.5 °C, above pre-industrial levels.

Many companies are setting carbon neutrality goals by 2050 with some interim goals (in the 2030 timeframe) that support their long-term goal. This is common practice for the more aggressive companies to align with the Paris Agreement. As of September 2020, 989 companies are taking science-based climate action and 467 companies have approved science-based targets.[105]

With carbon reduction goals set, companies and various industries have committed to implementing strategies to reduce energy and carbon emissions in their own operations or supply chains. Some

[104] http://airlines.org/news/a4a-applauds-international-civil-aviation-organization-committee-on-aircraft-emissions-standards-decisions/
[105] https://sciencebasedtargets.org/

focus on renewable energy investments such as wind or solar power, while others focus on efficiently producing and transporting their own goods and services. Along with that, power providers are changing the fuels used to generate electricity, auto providers are manufacturing more EVs, and high technology companies are producing more energy efficient devices, as some examples.

Setting a carbon-reduction goal is trending toward the norm or standard practice for governments, industries, and businesses. Those without a carbon-reduction plan and strategy are at risk to fall behind the competition.

Action Items

- Identify emission-reduction and efficiency strategies currently used in goods movement and key barriers holding back adoption of newer strategies (see Appendix II). Provide consumer methods to track the environmental impact of their choice of delivery method (perhaps similar to the efficiency ratings on vehicles). Identify how the evolution of new strategies has progressed, how organizations have overcome near term challenges, and how wider scale adoption can be accomplished. Illustrate how consumer choice can impact adoption of technologies.
- In addition, there is an opportunity for **EPA to serve as a clearinghouse for improvements that could be made through logistical efficiency/routing or mode shifting.** For example, UPS is testing e-bikes as a delivery option in Europe, something that could be replicated in the U.S., particularly in dense urban hubs.[106] Similarly, while the example of package delivery drivers not taking left turns is well known,[107] there are constant improvements in routing efficiency. Some of this is captured under SmartWay, but it could become part of a future regulatory system if data collection and verification is improved, and DOE's SmartTruck metric is actually freight efficiency, which includes "advances in connectivity and automation."[108]
- Gain an understanding of the entities, their business relationships, and ultimately business models that exist in the goods movement sector. This may be helpful as EPA looks to build knowledge and engagement, design public education strategies and tools, and ultimately develop non-regulatory and regulatory approaches for the goods movement sector over the near, medium, and long term. For example, discussions with a manufacturer and shipper may be helpful in identifying a third-party logistics provider they partner with. Discussions with the third-party logistics provider may be helpful in identifying the air, rail, or truck providers they partner with, and so on. With this potential approach, the various business models that exist between the entities should become evident. Additionally, it will be important to identify the various critical-to-quality items on which each of the partners is focused (e.g., on-time, capacity to meet specified windows, first-time delivery success, visibility, total cost per package, emission reduction, etc.) and what strategies each one implements to achieve its goals. This may give guidance on focus areas these organizations are evaluating to address the medium and future state including, but not limited to, the use of artificial intelligence, 5G,

[106] https://www.ups.com/us/en/services/knowledge-center/article.page?kid=art173481832bc&articlesource=longitudes
[107] https://www.ups.com/us/en/services/knowledge-center/article.page?kid=aa3710c2
[108] https://eere-exchange.energy.gov/Default.aspx#FoaId2f6fb61b-71a1-447c-a009-a4c460d08457

traffic integration, drones, platooning, autonomous transportation, and accelerating automation

- Characterize the phases of the goods movement sector, then identify potential key organizations in each sector for further engagement. One method may be to group the entities into categories:
  - Manufacturers/Shippers – organizations responsible for making the goods (manufacturers) or organizations that ship or receive freight (shippers), including the Engine Manufacturers Association and the American Trucking Association
  - Storage and Distribution – warehouse, cross dock, port, or other similar operations where goods are stored prior to delivery to ultimate destination
  - Transportation – organizations involved in moving the goods (air, rail, truck, drone, ship, etc.)
- Stay abreast of the role 5G mobile networks are having on the accelerating deployment of autonomous transportation, platooning, and drones, and their impact on transportation emissions. Artificial intelligence, 5G, traffic integration, drones, platooning, autonomous transportation, accelerating automation and other technology enhancements have promise to deliver economic and efficiency gains in the goods movement sector. Efficiency gains can have a positive impact on emissions.

The fifth-generation mobile network is currently being deployed nationwide. While not widely available as of now, the faster connection speeds, wider bandwidth, lower latency, and ability to allow mobile devices to connect to multiple networks simultaneously open opportunities to reshape supply chains. Distribution and warehousing will be able to leverage 5G's enhanced network to obtain instant updates on cargo movement, which will, in turn, enhance productivity. Internet of Things (IoT) sensing devices using 5G can achieve greater capabilities (location, speed, temperature, etc.) and be deployed on more items. Quicker transmission of complex data sets, goods movement visibility, and network communication improvements will allow for more sophisticated analytics ultimately resulting in more opportunity to enhance efficiency. 5G may also support smart cities with the promise of providing greater visibility and control to traffic monitoring. As with all technology, there are challenges to overcome. For example, the faster and larger data transmission 5G may require new systems to process. Additionally, network security and data privacy issues will need to be addressed. However, 5G is forecast to be a leading network technology, and as technology evolves, new methods and innovation are expected.

- **Evaluate how goods movement changed under the COVID-19 pandemic.** Have practices developed that result in lower goods movement impacts that are transferable in this industry? How can packaging for home deliveries be optimized to minimize space taken in goods movements and create less solid waste? Create a forum for manufacturers touting best practices, perhaps as an extension of SmartWay.

4.3.6 Address Pollution Hotspots & Health Disparities

We now know that levels of air pollution can vary by up to eight times within one city block and that living in areas with the most elevated levels increases heart attack risk in the elderly by 40%, similar to a history of smoking. Also, new satellite data show that 24 million more Americans — twice as many as previously thought — live in areas with unhealthy air, making it more important than ever to address the problem.

Based on evidence of air pollution problems especially impacting vulnerable communities, we recommend that the agency implement a series of actions to address health disparities and equity issues:

Action Items

- Prioritize zero-emission projects for areas identified by environmental justice Screen or locally developed screening tools as being high priority based on vulnerability or health risk indices. Provide guidance on how to incorporate transportation equity elements into guidance on scoring of transportation projects using screening tools.
- The Assistant Administrator of EPA OAR, in consultation with state, tribal, and local agencies, should develop, make public, and implement an asset management framework for consistently sustaining the national ambient air quality monitoring system. Such a framework could be designed for success by considering the key characteristics of effective asset management described in our report, such as identifying the resources needed to sustain the monitoring system, using quality data to manage infrastructure risks, and targeting resources toward assets that provide the greatest value.
- The Assistant Administrator of EPA OAR, in consultation with state, tribal, and local agencies and other relevant federal agencies, should develop and make public an air quality monitoring modernization plan to better meet the additional information needs of air quality managers, researchers, and the public. Such a plan could address the ongoing challenges in modernizing the national ambient air quality monitoring system by considering leading practices, including establishing priorities and roles, assessing risks to success, identifying the resources needed to achieve goals, and measuring and evaluating progress.
- Promote community engagement in measuring emissions. Coordinate with EPA's Office of Air Quality Planning and Standards (OAQPS) on development and deployment of guidance on how low-cost community monitors may support regulatory monitoring framework. It is already established that current modes of goods movement in the U.S. supply chain contribute excessively to air pollution levels that harm human health and the environment and, that without further action to address this issue, these contributions will only continue to grow in the future. Community involvement in understanding the impact of goods movement, by employing low-cost sensors, may lead to productive dialogues and collaboration that help bring about solutions. Compared to conventional air pollution

management, which commonly relies on a few sparsely located monitors and modeling, hyperlocal monitoring allows for a more holistic picture of air quality at a high spatial resolution (with different concentrations every 30 meters, for example) and frequency (different concentrations every minute or few minutes, rather than on an hourly or daily basis). Hyperlocal monitoring can fill a gap in places where modeled or regional monitoring data are not available. Additionally, measuring on-the-ground pollution allows for a better understanding of the true exposure and health impacts of air pollution, which can then result in targeted solutions. While low-cost sensors cannot be used for determining compliance with the health-based NAAQS, they can be used to provide community members with a better understanding of air quality in their neighborhoods. With increasing community interest in air quality and the evolution of monitoring technology, residents can now use low-cost sensors to evaluate air quality in their neighborhoods. The accuracy of the data gathered by the monitors is largely dependent on the way the data are collected and the level of quality assurance procedures in place. In October 2020, the Environmental Law Institute released a set of three reports that examine the ways in which environmental agencies are using citizen science in their programs, exploring "best practices", and identifying strategic steps that can be taken to support the use of citizen science for environmental decision-making. The reports are the product of a multi-year project conducted by ELI under contract with EPA.[109] As a next step, EPA should look to apply these recommendations particularly to the goods movement sector

- Using the definition of ports as adopted by EPA's Port Initiative Work Group, EPA should designate ports as stationary sources of pollution and require mitigation for the activities derived from port activities.
- EPA OTAQ should review the Energy Policy Act of 2005 to determine if a certain percentage of DERA funding (e.g., 80%) can be earmarked for mitigation efforts in areas identified as vulnerable communities. Vulnerable communities should be designated using environmental justice Screen coupled with additional information and data from local jurisdictions.
- EPA OTAQ should renew efforts to address emissions from borders, including by engaging with Mexico to encourage a request to IMO to designate an Emission Control Area and efforts to address border crossing issues in areas like Laredo and Brownsville.
- For significant national enforcement cases, maximize the use of Supplemental Environmental Projects to ensure violative emissions are mitigated. Develop recommendations for supplemental environmental programs that could be implemented at the state level to support existing EPA opportunities such as DERA as well as develop EPA guidance/best standards/decision-making tool for highest use of available public funds like grants, VW, etc.
- Assess the potential for "local policy matching" requirements akin to financial matching to receive grant funding, demonstrating local policies in place that will assure best practices to reduce exposure to pollution.
- EPA should develop environmental best practices to reduce emissions impacts and policy options that lead to more equitable and mitigating land uses and built environments, like:

[109] https://www.eli.org/sites/default/files/eli-pubs/eli-citizen-science-best-practices-report.pdf

- Local zoning with buffer distances from busy freeways and industrial-transportation hot spots
- Setting up funds to provide window replacements and air filtration in homes in hotspot areas (doing in Detroit)
- Establish an EPA-Council on Environmental Quality work group requiring Health Impact Assessments as part of EIS processes and logistics/trucking operations of a specified size in residential areas; and for developments requiring ongoing air quality permits.

Use of the monitors can range from very sophisticated monitoring, which is resource intensive, to general educational purposes. For illustrative purposes, some possible use categories/tiers are explained below.

- Low-cost air sensors can be used to supplement network monitoring, that is, they can complement an existing network of state-operated air quality monitors in two ways: they can be used in areas that are far away from current network monitors; and 2. They may identify potential pollution sources of interest or areas of high pollution levels that state-operated monitors may have missed.
- Low-cost air sensors can be used for identifying potential air pollution hotspots, where levels may be higher than expected. Because these sensors are typically portable, users can use them in a fixed location or as mobile sensor systems to map pollutants and determine emission sources. The proximity of the sensors' measurements to the source is a key factor because the aim is to measure at a location where the pollutant concentrations may be unusually high.
- Low-cost air sensors can be used to measure the air pollution a person is exposed to during their daily routine. Typically, in personal exposure studies people wear devices that measure air quality as they go about their day. Many low-cost sensors estimate personal exposure levels using a color-coded air quality index scale. Individuals or community groups can use these sensors to: Assist in making personal health decisions; measure personal exposure indoors or at a workplace; determine differences in exposure at home, during a commute to work, while outside gardening, or while exercising; and estimate exposures for individuals in areas that are disproportionally affected by negative environmental factors.
- Low-cost sensors can be used to educate students and the public. The measurements from these monitors can show whether a pollutant is present in different environments and at different times. They can be used to learn about air pollution, the scientific method, and how to operate and use air monitoring equipment.

- While monitoring and other data-collection actions should be evaluated routinely, EPA should increase enforcement penalties on companies that fail to comply with required engine upgrades and replacements. For example, many tug engines are bypassing requirements to meet newer engine standards during re-builds. EPA's OTAQ should work with EPA's Enforcement office to penalize those skirting new standards.
- **Conduct emissions mapping of environmental justice communities** to better understand the local impact of freight transportation on over-burdened communities
- Evaluate least-distance transit policy incentives that incentivize buying/dealing locally, creating relationships for manufacturing inputs and local customers to reduce emissions and other impacts by reducing miles traveled.
- Continue to promote the guidance and continued conversation with communities and other stakeholders to enable a better understanding of the impact of goods movement and identification of opportunities to minimize that impact.
- Collaborate with state, tribal, and local air agencies to ensure that rules, policies, and programs related to goods movement achieve emission reductions sufficient to achieve and sustain clean air and environmental goals and protect public health in all areas of the country, and particularly in overburdened communities.

Over the past several decades, several unique partnerships have developed between communities and ports that validate the importance of ongoing coordination and communication. One example is the Baltimore Port Alliance, a working group led by the Maryland Department of Transportation and the Maryland Port Administration with many neighborhoods and community organizations throughout the Port of Baltimore. The Baltimore Port Alliance informs, engages, and invests in port neighborhoods and communities to enhance the environment and quality of life around Baltimore. EPA should promote similar community collaboration models and offer resources to navigate the sometimes difficult conversations.

Appendix A. Technology: Background Information

GREET

The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed by the DOE, Argonne National Laboratory (Figure A-1) focuses on the energy use and emissions associated with specific fuel pathways. A significant benefit of the GREET model is its transparency and the ability for users to explore the inputs and parameters used in the model at a very detailed level. As such, the GREET model serves as a scientifically recognized methodology for attributional lifecycle studies of vehicles and fuels in the literature for analysis to support policy such as California's (and Oregon's) Low-carbon Fuel Standard.

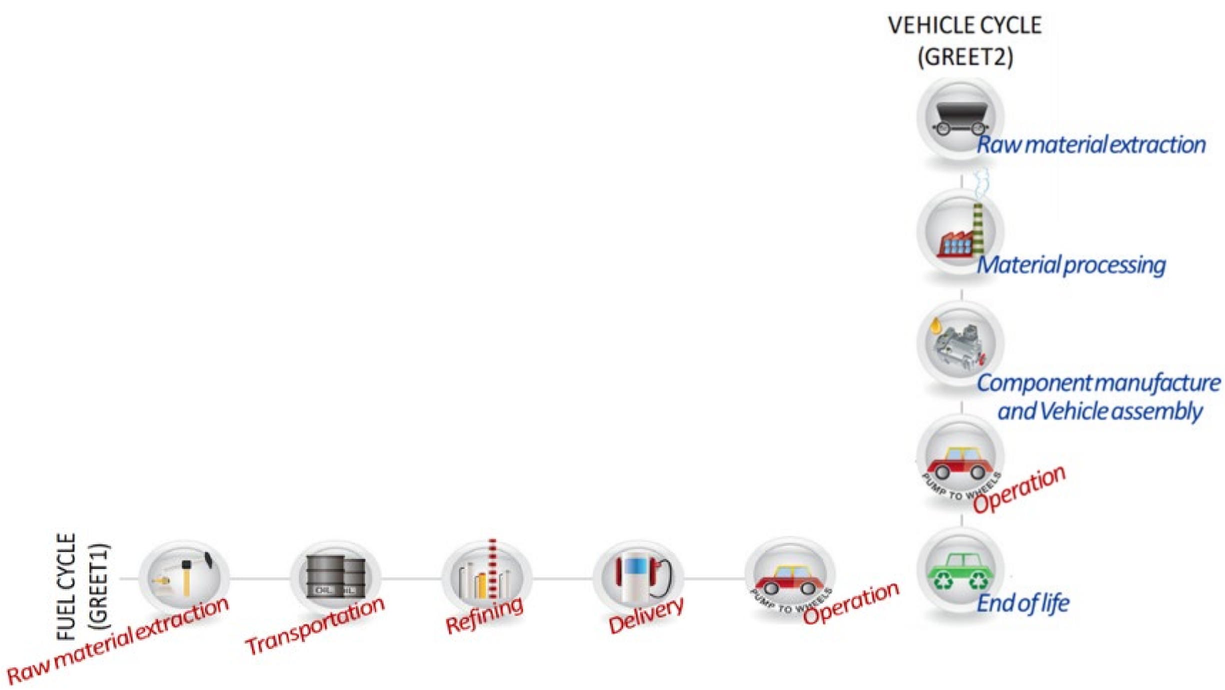

Figure A-1: GREET1 (Fuel Cycle) and GREET 2 (Vehicle Cycle)

LCA Value in Vehicle Studies

A typical automotive lifecycle consists of vehicle production and operation, often called well-to-wheels (WTW). The vehicle production phase includes raw material extraction, material processing, and part and vehicle manufacturing, while the use phase consists of well-to-tank (WTT), from energy feedstock extraction to the final provision of the fuel, and tank-to-wheel (TTW), which is the vehicle operation stage. LCAs and LCA-based approaches are deemed essential to compare sustainability performance across powertrain and fuel options, enabling fair comparisons taking into consideration the upstream energy demand, material inputs and associated carbon emissions that are not captured in typical fuel economy or tailpipe emissions measures.

For conventional internal combustion powertrains (gasoline, diesel, and natural gas), the operation or TTW-stage accounts for 80-90% of lifecycle WTW primary energy demand and global warming potential, while for electric propulsions such as battery electric vehicle (BEV) and hydrogen fuel cell electric vehicle (FCEV), the WTW impacts vary widely depending on how energy carriers are produced in the WTT stage and regional variances in electrical grids.

Appendix B. Fuels: Trends Influencing Future of Transportation Energy Use

Growth In Mobility Demand

Following historical trends, demand for passenger and freight mobility (passenger-miles, ton-miles of freight) will grow as both U.S. population and economy expand.[110,111]

However, demand growth is not uniform across all fuels and applications, and the extent of demand growth will be different for different travel modes, with aviation and freight trucks projected to grow the fastest in the U.S. (see Figure B-1).[112]

This will change the requirement for liquid fuel, with jet fuel and diesel powering large vehicles such as airplanes and heavy trucks growing faster than gasoline powering smaller on-road vehicles.

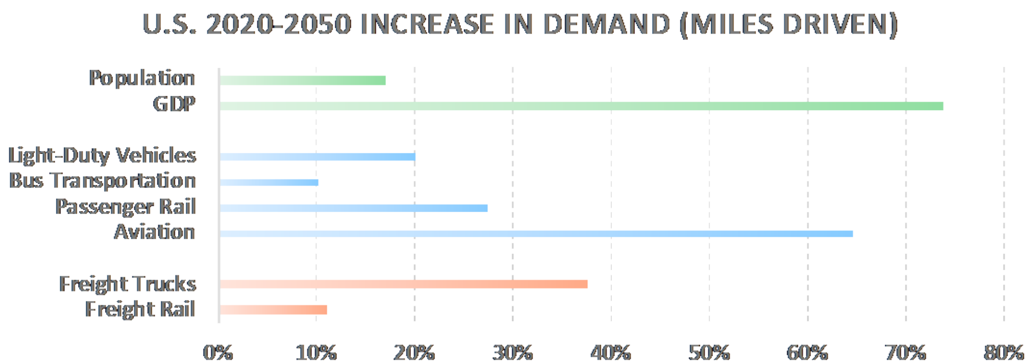

Figure B-113: 2020-2050 increase in population, GDP, and vehicle miles traveled by model as projected by AEO2020.

New Technologies and Business Models and System-Level Structural Changes Are Impacting Travel and Modal Choices and Energy Use

Several emerging trends, technologies, and business models are emerging that can profoundly change the future mobility systems, impacting travel demand, and modal choice, ownership decisions, technology adoption, and in turn fuel requirements.[113]

New ride-hailing business models are rapidly being adopted and could disrupt passenger mobility, but their final effect remains uncertain. For example, ride hailing could complement and enhance or

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110 https://www.sciencedirect.com/science/article/pii/S0967070X1200008X
111 https://pubs.acs.org/doi/abs/10.1021/acs.est.6b04515
112 https://www.eia.gov/outlooks/aeo/
113 https://www.energy.gov/sites/prod/files/2020/08/f77/SMART-Workflow_Capstone_07.28.20_0.pdf

replace public transit, with major energy use implications.[114] Ride pooling is also critical in assessing the impact of ride hailing on energy use.

Recent trends such as e-commerce and just-in-time business and issues around drivers' retention have caused a significant shift away from long-distance inter-regional or national hauls in favor of decentralized hub-and-spoke distribution models. This resulted in an increase in the share of short-haul operations and a decrease in the average length-of-haul from 800 to 500 miles between 2000 and 2018, making electrification easier for freight trucks.[115]

Vehicle automation and connectivity is also posed to disrupt both passenger and freight travel, and its impact could lead to major rebounds in vehicle-miles-travelled (VMT) and energy use. At the same time, these technologies can improve system-level efficiency and fuel economy (e.g., via better traffic management). The net impact of these factors remains highly debated and uncertain.[116] As a result, energy use in a future dominated by automated vehicles could be significantly lower or significantly higher compared to a baseline case without automation.

Vehicle Efficiency Improvements

Vehicle fuel efficiency has improved significantly in the past and can continue to improve in the future, balancing the expected growth in demand and reducing demand for energy.

- For example, the fuel economy of new light-duty vehicles in the US almost doubled from 1975 to 2018, mostly as a result of fuel economy and emissions standards that drove about 4/5 of the fuel savings.[117]
- Airplanes have also experienced significant energy efficiency improvements with a compound annual reduction in energy use for new aircraft of 1.3% between 1968 and 2014,[118] even though significant differences exist for different airlines.[119]
- Further energy efficiency improvements are expected across all modes and technologies. These improvements are expected to more than offset mobility demand growth in the U.S. As a result, transportation energy use in business-as-usual scenarios (such as the EIA AEO Reference Scenario) is projected to slightly decrease over time. Also, the share of energy consumed by light-duty vehicles is expected to decrease due to faster growth of other transportation modes (see Figure B-2).

[114] https://escholarship.org/uc/item/82w2z91j
[115] https://truckingresearch.org/wp-content/uploads/2019/02/ATRI-Impacts-of-E-Commerce-on-Trucking-02-2019.pdf
[116] https://link.springer.com/chapter/10.1007/978-3-319-94896-6_10
[117] https://www.sciencedirect.com/science/article/pii/S0301421520302627
[118] https://theicct.org/publications/fuel-efficiency-trends-new-commercial-jet-aircraft-1960-2014
[119] https://www.sciencedirect.com/science/article/pii/S1361920920307987

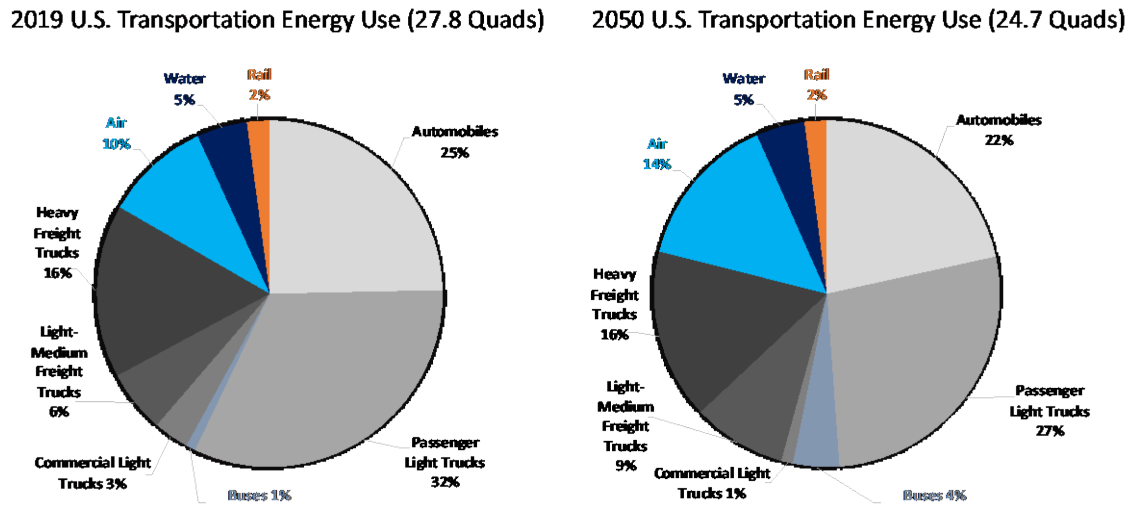

Figure B-2: Energy use by transportation sub-sector in 2019 and 2050. Data from EIA AEO2020.

Technology Adoption, Especially Adoption Of Electric Vehicles And Other Alternative Fuels

- Widespread electrification of light-duty vehicles will drastically reduce the demand for gasoline, with several studies projecting major adoption of battery electric vehicles over the next decades.[120]
- Electrification is expected to also affect other on-road modes, especially buses and short-haul freight commercial vehicles (~60% of trucking energy use). As a result of widespread adoption of electric vehicles, a recent NREL study projected that electricity demand could increase by 1,400 TWh by 2050 (increasing the share of transportation from 0.2% today to 23% of total electricity demand in 2050) while demand for gasoline and diesel drops rapidly.[121]

[120] Muratori et al. “The Rise of Electric Vehicles – 2020 Status and Future Expectations. Forthcoming.
[121] https://www.nrel.gov/docs/fy18osti/71500.pdf

Appendix C. Fuels: Life Cycle Assessment Considerations

The U.S. Renewable Fuel Standard (RFS) was established by the Energy Policy Act (EPACT) of 2005 and was modified to RFS2 under the Energy Independence and Security Act (EISA) of 2007. While recognizing that renewable fuels could reduce GHG emissions, the primary purpose of RFS and RFS2 was to promote greater volumetric usage of renewable transportation fuels within the U.S. to reduce transportation's reliance on petroleum fuels, not to achieve a particular GHG emissions goal. To qualify as a renewable fuel under the RFS program, fuels must be produced from renewable biomass and meet statutory GHG emissions reduction threshold requirements in four fuel groups, as compared to a 2005 baseline (i.e., GHG reduction thresholds). The threshold requirements are 20% lower carbon intensity (CI) for fuels categorized as "Renewable Fuel," 50% lower CI for "Advanced Biofuels" and "Biomass-Based Diesel Fuel," and 60% lower CI for "Cellulosic Fuels." The required GHG reductions are assessed on a life-cycle basis, "including direct emissions and significant indirect emissions such as emissions from land use changes." In determining compliance with RFS, EPA considers the impacts of economy-wide effects as well as the entire renewable fuel pathway for a given fuel (which consists of three components: feedstock, production process, and final fuel use). EPA adopted the so-called consequential LCA approach, in place of the process based, attributional LCA approach. In doing so, EPA relied on two economic models (one covering domestic economic sectors and the other covering international economic sectors). EPA used process based LCA models such as the GREET model (greet.es.anl.gov) to provide emission and energy use data for certain activities in the economic models.[122] The economic models link different economic activities based on co-relationships, instead of causalities. While the models' coverage of the entire, global economy is extensive, they lack technology details, especially for new technologies. They are not transparent and are not available to stakeholders to verify and use. To date, EPA has quantified lifecycle GHG results for over 150 renewable fuel pathways, many of which are shown in Figure C-1.

On the other hand, a process-based, attributional LCA of a biofuel includes energy inputs and other requirements for feedstock planting, growth, harvesting, fuel production, distribution, and combustion – as well as all intermediate transportation steps. Impacts of co-products generated throughout the life-cycle are included. With the so-called allocation method in these models, a fraction of the total GHG emissions over the fuel pathway are assigned to the co-products, thereby impacting the net GHG emissions attributed to the biofuel. With the displacement method, emission credits of co-products are determined on the basis of their displacement of conventional products (also known as the system boundary expansion method). The choices made in dealing with co-products in LCA can have major impacts on the final, computed CI values.[123] By using a consequential LCA model, EPA used the displacement method by default. The California Air Resources Board (CARB), by adopting Argonne's GREET model, has used mainly the displacement method for co-product credits in biofuel pathways. On the other hand, the EU Renewable Fuels Directive has been using the energy content based-allocation method.

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[122] Wang, M. et al., 2020, Summary of Expansions and Updates in GREET® 2020, ANL/ESD-20/9, Systems Assessment Center, Argonne National Laboratory, Oct.

[123] Wang, M., H. Huo, and S. Arora, 2011, "Methods of Dealing with Co-Products of Biofuels in Life-Cycle Analysis and Consequent Results within the US Context," *Energy Policy 39*: 5726–5736.

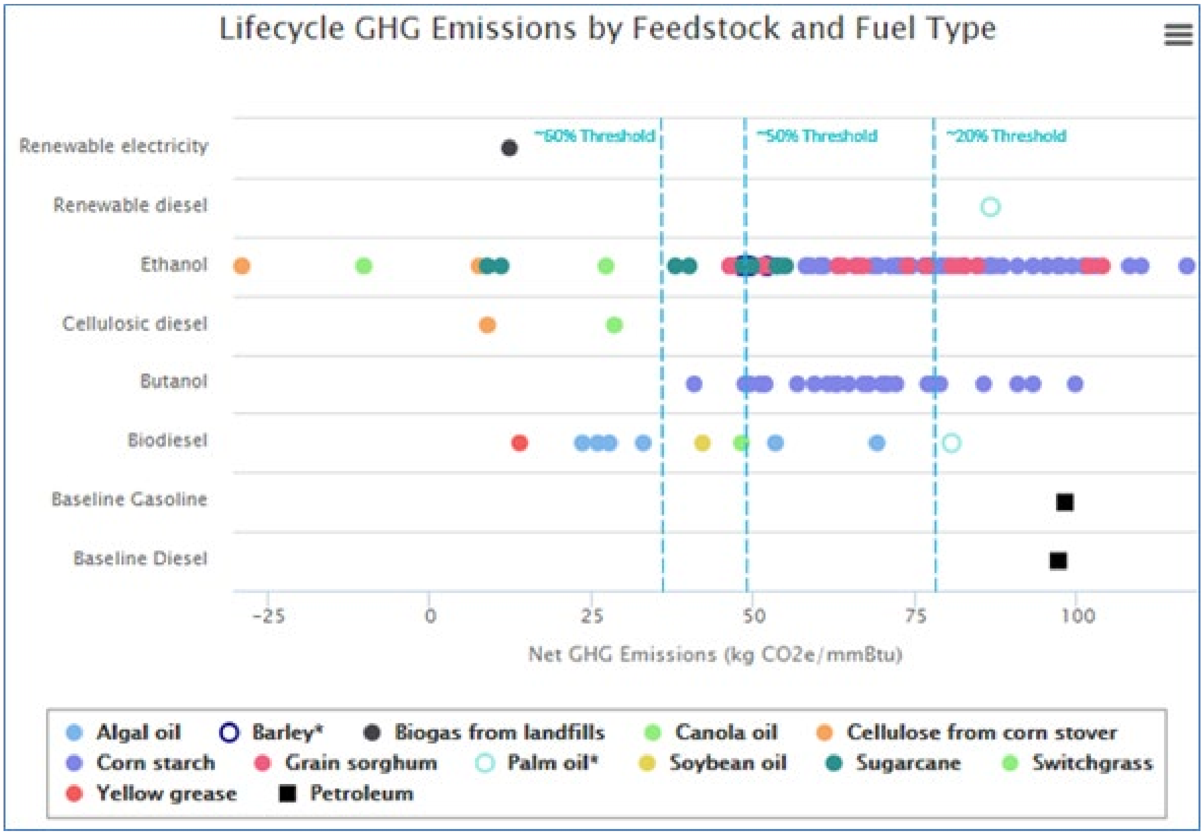

Figure C-1: CI values determined by EPA for various fuel pathways. Presented by Aaron Levy (EPA) at 6th CRC Workshop on Life Cycle Analysis of Transportation Fuels, October 15, 2019.

For agricultural-based biofuel feedstocks, land use change (LUC) and its impacts on life cycle GHG emissions are important considerations. Increasing agricultural output to satisfy a growing demand for biofuels can occur by higher cropping intensification, expansion into new agricultural lands, reduction in existing demand for food items, and changes in land use from one type of crop to another – all of which have GHG implications that affect a fuel's CI value. In addition, large changes in agricultural production in one region of the world can affect other regions, through global economic effects. Thus, increased demand for U.S. biofuels can cause global agricultural expansion to satisfy the market demands of a feedstock that was displaced to produce the biofuels. Such indirect land use change (ILUC) also results in GHG emissions, some of which may be attributed to the U.S. biofuel.

In assigning the total CI value for a given biofuel, EPA sums the contributions of direct and indirect emissions under its consequential LCA approach. On the other hand, CARB uses the process-based, attributional LCA approach to determine CIs of specific fuel production pathways for its LCFS program. In particular, CARB adopted Argonne's GREET model to develop a CA-GREET model for the LCFS program. Direct emissions along a fuel's pathway are determined with CA-GREET that accounts for agricultural activities, transportation, fuel production processes, and vehicle usage. Indirect emissions from LUCs are determined by the agro-economic model GTAP in combination with emission factors of a variety of domestic and international land conversions. These LUC emissions are added to the pathway direct emissions.

The basic LCA modeling methodology employed by EPA in assessing whether a given renewable fuel pathway satisfies the GHG reduction requirements under RFS was established over 10-years ago. Because of improved understanding of market behaviors, LUC patterns, GHG impacts of LUC, advances in fuel production processes, and other factors, many improvements in application of LCA to estimate a fuel's CI value have occurred. In addition, the diversity of fuel pathways has expanded, and this is expected to continue into the future. For example, issues such as co-processing of renewable and non-renewable feedstocks, production of E-fuels using various sources of electricity, and incorporation of renewable electrical power into conventional fuel production processes are all of growing interest. The standard LCA methodologies employed to support the RFS program may not be suitable for addressing these situations. Furthermore, the consequential LCA approach used by EPA is time-consuming to update and expand for new data and new technologies.

In light of these developments over the past decade, it seems appropriate for EPA to prepare and issue a comprehensive report that documents and explains their historical methodology and assumptions in determining CI values of various fuel pathways and the current of state of LCA models, methodologies, and results among key regulations. For example, since the 2010 EPA LCA efforts, CARB LCFS, EU RED, and the Canadian Clean Fuel Standard (to be finalized in 2021) all use standardized LCA methodologies with a process-based, attributional LCA approach supplemented with economic modeling of land use changes. Standardized models used within these approaches (such as GREET) are transparent and accessible. They minimize inconsistencies of LCA methodologies and system boundaries, among other factors, so that agencies and stakeholders can concentrate on technology potentials instead of creating confusion and debate of models and LCA methodologies. EPA may also elaborate how new technologies and pathways are to be addressed in its new LCA efforts. Examples of such future fuels include renewable natural gas (RNG), renewable diesel fuel (RD), renewable fuels produced from pyrolysis oils, renewable fuels produced from gasification and Fischer-Tropsch (FT) processes, and E-fuels.

Additionally, classifying renewable fuels into specific GHG reduction bins, as required under RFS, does not incentivize improvements in feedstocks or processes that would further reduce the carbon footprint of the fuel below the threshold for each bin – unless the changes are large enough to move from one bin to another. An approach that focuses on quantifying the carbon intensity (CI) of a given pathway, and incentivizing meaningful, incremental improvements in CI, such as California's LCFS program does, is likely to provide greater overall GHG reductions than the current RFS approach. This can be seen in Figure C-2, which shows a continuum of CI values for several alternative fuels used in California.

Finally, although the RFS program (and the LCA modeling to support it) was focused on incentivizing growth of renewable fuel volumes, the main concern today is GHG reduction. Thus, it is critical to assess the life-cycle GHG impacts of alternative systems, which goes far beyond determining a CI value for a given fuel pathway. For example, with increased electrification of the vehicle fleet, variabilities in the source of grid power by region become important. Similarly, variability in sources of H_2 for fuel cell vehicles must be understood. But electricity and hydrogen are not even considered in RFS. For plug-in hybrid electric vehicles (PHEVs), it is also important to know what fraction of power is derived from the grid. Thus, the true carbon footprint of a particular vehicle depends upon how, where, and when the fuel is produced.

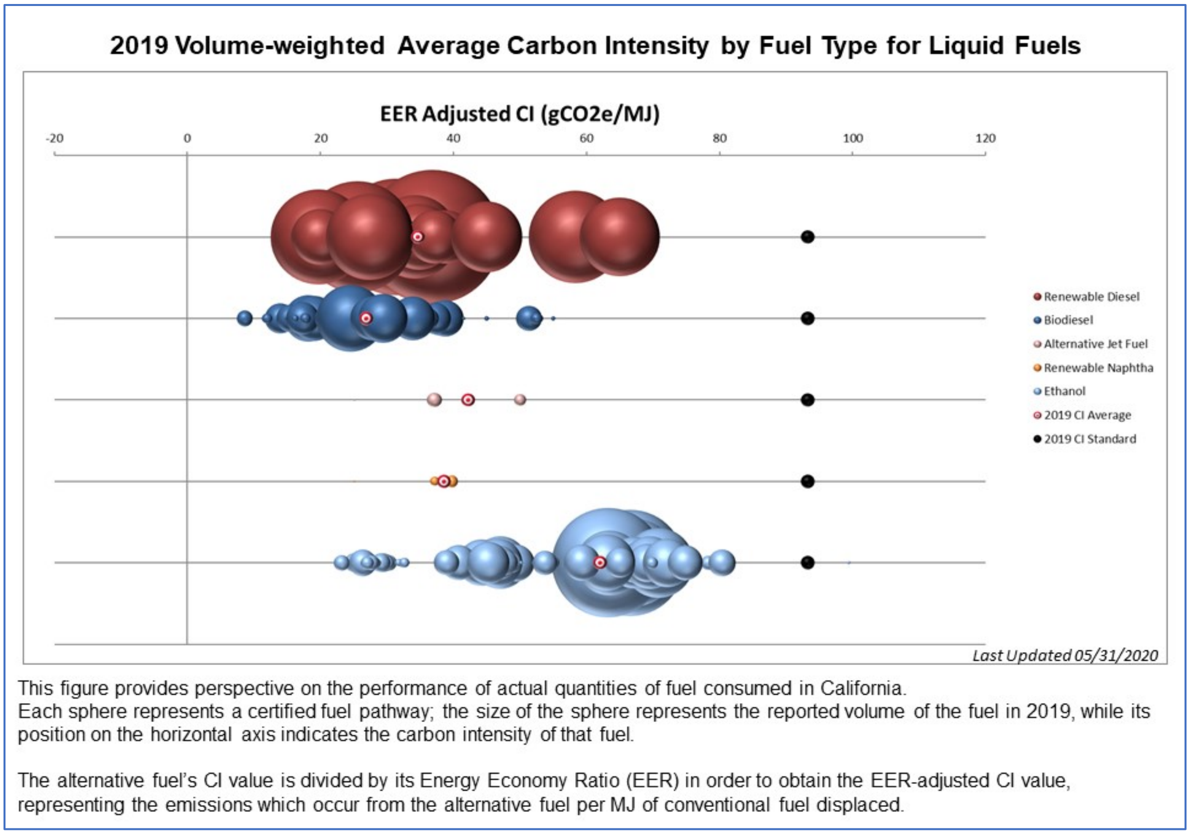

Figure C-2: Energy Economy Rate (EER) adjusted carbon intensity (CI) of California fuels in 2019. Source: https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

Considering the fact that electrification and internal combustion engines will co-exist in the transportation sector for a long time, a new holistic approach is needed, beyond today's regulations that mandate reduced CI values for transportation fuels. This suggests that a new type of vehicle/fuel carbon footprint assessment (CFA) model may be required to correctly assess the GHG impacts of future fuel/vehicle systems on a new basis such as per mile driven, so that low-carbon fuels and vehicle efficiency will work together for GHG reductions in the transportation sector. In addition, the LCA should be expanded from fuel cycle (or well-to-wheels cycle) to include vehicle manufacturing processes so that the environmental effects of new vehicle components can be considered to prevent unintended consequences. Argonne National Laboratory (ANL) has recently conducted such assessments for a variety of current and future generation vehicles and fuels, with the results summarized in Figure C-3. In this figure, the horizontal black line at the top of each bar cluster indicates the life-cycle GHG emissions per mile for current generation (2015) vehicles and fuels. The red horizontal lines indicate the lower anticipated GHG emissions from the same vehicle/fuel types in the future (2025-2030) due to vehicle efficiency gains. The bottom of the colored arrows show anticipated future GHG emissions from the same vehicles, but when operated on lower-carbon fuels. Important conclusions from this LCA modeling work include the following:

Anticipated efficiency gains over the next 10-15 years will significantly reduce GHG emissions per mile from all vehicle types.

Even with the lowest carbon fuels imaginable (such as electricity from solar and wind), future life-cycle vehicle emissions are far from zero. There is no such thing as a ZEV when considering transportation activities, infrastructure build up and vehicle manufacturing cycle.

When operated on low-carbon renewable fuels, life-cycle GHG emissions from ICEs can be similar to emissions from EVs with recent US grid mix. This highlights the naivete of calls to "ban ICEs." Instead, performance based, technology neutral policies should be established to achieve GHG reduction goals.

Vehicle manufacturing processes may constitute the bulk of CI as conventional fuels are replaced by low-carbon fuels.

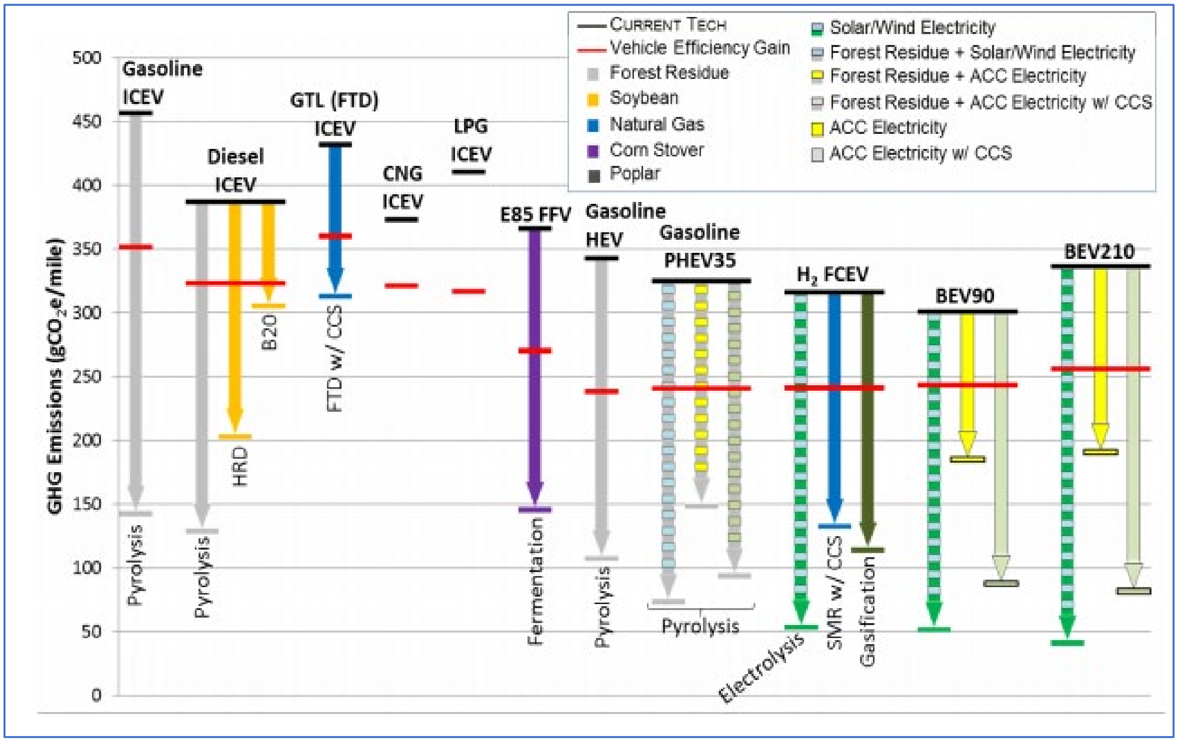

Figure C-3: Life-cycle GHG emissions from current (2015) and future (2025-2030) vehicle/fuel technologies.[124]

More recently, ANL utilized the consistent LCA modeling methodology and framework of the GREET2020 model to determine the CI value of selected fuel production pathways for the year 2035. The WTW results, expressed as g CO2-eq/MJ, are shown in Figure C-4. Note that the gasoline CI is for E10 with 10% of corn ethanol by volume. On the other hand, the CI of gasoline blending stock is about 95 gCO2/MJ. The CIs for corn ethanol, soybean biodiesel (BD) and renewable diesel (RD) include GHG emissions from land use changes simulated with Purdue University's GTAP model and ANL's CCLUB model. RD from algae and sludge with hydrothermal liquefaction (HTL) and renewable gasoline (RG) from woody biomass (75% forest residues and 25% pine) with catalytic fast pyrolysis (CFP) reflect

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[124] Elgowainy, A., Han, J., Ward, J., Joseck, F., Gohlke, D., Lindauer, A., Ramsden, T., Biddy, M., Alexander, M., Barnhart, S. and Sutherland, I. (2018) "Current and Future U.S. Light-Duty Vehicle Pathways: Cradle-to-Grave Lifecycle Greenhouse Gas Emissions and Economic Assessment." *Environmental Science and Technology*, DOI: 10.1021/acs.est.7b06006.

DOE's on-going R&D efforts. Electro-fuels (e-fuels) are with CO2 streams such as those from corn ethanol plant fermentation and hydrogen from renewable electricity such as solar and wind power. The per-MJ results are the basis for determining RFS qualifications and LCFS compliance (with fuel economy ratio adjustments for hydrogen and electricity under the LCFS).

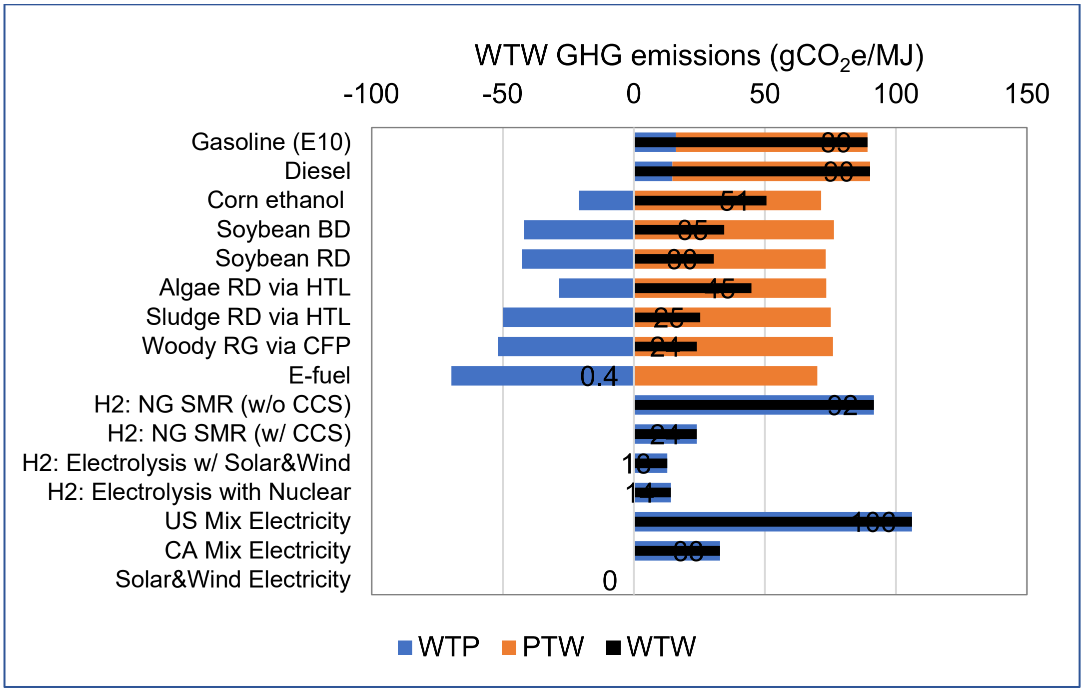

Figure C-4: Life-cycle GHG emissions of selected fuel production pathways in 2035 (simulated with GREET2020)

Besides CIs of fuels to help incentivize fuel production GHG emissions, fuel economy of vehicles is key to reduce per-mile GHG emissions. Thus, per-mile GHG emission ratings that take into account per-MJ fuel CIs and fuel economy of vehicles provide more complete picture of GHG reduction potentials of powertrain/fuel combinations. Figure C-5 below presents per-mile results of powertrain/fuel combinations for LDVs (mid-size cars), Class 6 delivery vans, and Class 8 long-haul trucks using GREET. As the charts show, relative fuel economy performances of different vehicle/fuel combinations for a given vehicle class affect per-mile GHG results significantly. Eventually, standards based on WTW per-mile GHG emissions will be able to consider both fuel pathway CIs and vehicle fuel efficiencies. Of all current vehicle fuel consumption regulations, only the Japanese standards for 2030 fully adopt this WTW approach.

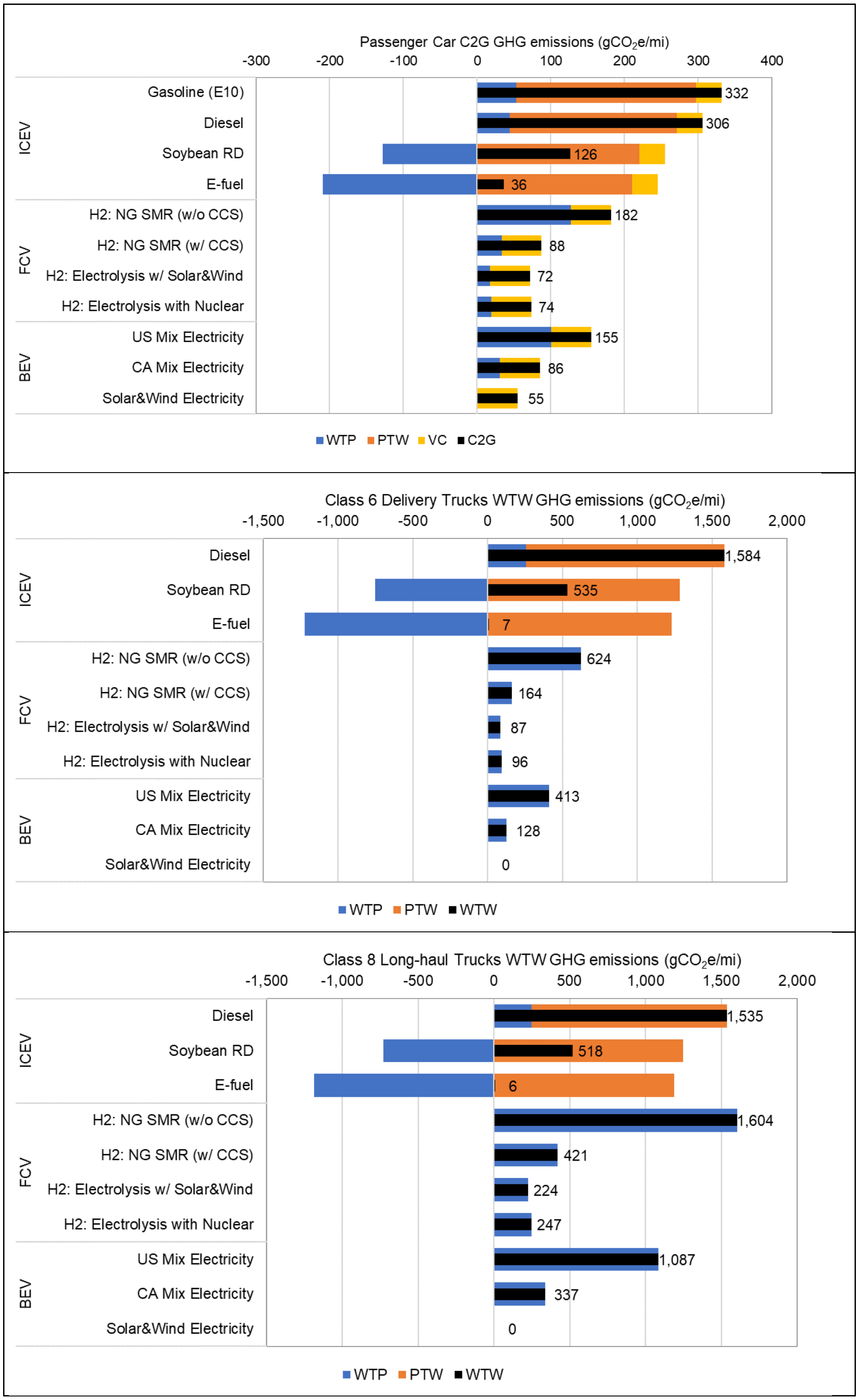

Figure C-5: Per-mile GHG emissions for passenger cars (top), Class 6 delivery trucks (middle), Class 8 long-haul trucks in 2035 (bottom)

The simulations above were based on GREET2020 with Autonomie 2016 results for passenger cars and Autonomie 2019 results for Class 6 and 8 trucks. Note that LDV results include the vehicle cycle (VC) GHG emissions (C2G), while Class 6 and Class 8 results present WTW GHG emissions.

In conclusion, LCA is a very useful tool in assessing the overall environmental effects (particularly GHG emissions) of current and future vehicles and fuels as the transportation sector moves forward with different powertrain systems and different fuel types. LCA-based regulations and policies may help create a level playing field that encourages various powertrain technologies and fuels to play a role in GHG reduction from transportation. In order for LCA to serve this role, a standardized LCA model with consistent LCA methods and system boundaries and up-to-date data, such as Argonne's GREET model, which has already been used for LCFS compliance, is needed. The standardized LCA model needs to be publicly accessible and well documented with respect to input parameters and assumptions of vehicle manufacturing and operation performance, and associated fuel production technology pathways. The LCA results should be transparent and be subject to verification. In addition, as presented in Figure C-5, the vehicle manufacturing cycle should be an integral part of LCA of various vehicle/fuel systems.

Appendix D. Fuels: Evolution of Fuel Regulations

A Brief Regulatory History

The Clean Air Act Amendments (CAAA) of 1990 established a new federal regulatory program targeting emissions from light duty vehicles. Since then, significant improvements have been made in reducing criteria pollutants from transportation sources, which in turn have improved air quality across the United States.

The CAAA established a Reformulated Gasoline (RFG) standard which was required for use in the metropolitan areas with the most severe air quality problems. Along with the RFG program, an anti-dumping baseline was established for Conventional Gasoline (CG) to prevent a deterioration of air quality in the non-RFG areas. Volatility limits were established to minimize volatile organic compound emissions, which contribute directly to smog formation.

During the same period, the California Air Resources Board (CARB) established new gasoline regulations under the CaRFG Phase 2 (1996) and CaRFG Phase 3 (2003) programs. The CARB gasoline standards were designed to address the unique air quality problems in California and were applied uniformly across the entire state. The CARB gasoline standards exceeded the federal RFG standards under the provisions of a California specific waiver granted by EPA.

EPA has issued subsequent regulations that established new gasoline requirements on both RFG and CG, further reducing criteria pollutant emissions and improving air quality. These programs include the Tier 2 and Tier 3 gasoline sulfur standards, and the Mobile Source Air Toxics (MSAT) and MSAT 2 benzene content standards.

The 2005 Renewable Fuel Standard (RFS) and 2007 RFS2 programs established the widespread use of ethanol and virtually eliminated MTBE blending from both the RFG and CG gasoline pools. The RFS programs introduced the concept of GHG reduction and climate change into federal fuel regulations. Prior to the RFS, fuel regulations were focused on reducing criteria pollutants and improving air quality for health benefits rather than addressing climate change. Similarly, California implemented the Low-carbon Fuel Standard in 2010 to reduce the carbon intensity of transportation fuels in the state.

Most recently in 2020, EPA promulgated a revised set of fuel regulations under the Fuels Regulatory Streamlining program, which eliminated several obsolete legacy requirements and further minimized the differences between RFG and CG.

Current Regulatory State

Following the 2020 Regulatory Streamlining program, RFG and CG have the same standards for sulfur and benzene content. During the summer months, RFG has an additional volatility constraint which is more stringent than that of CG. During the non-VOC winter months, RFG and CG are essentially equivalent and can be used interchangeably.

Ethanol use is ubiquitous in RFG and CG at the 10 volume percent level, with provisions that allow blends up to 15 volume percent. Both RFG and CG are produced at the distribution terminals by blending ethanol with a sub-octane gasoline blending component which is produced by refineries.

CARB gasoline still has unique requirements that are slightly more stringent than RFG and CG, although the sulfur and benzene standards are comparable. CARB regulations limit ethanol blending to 10%. The difference in criteria emissions between CARB gasoline and RFG/CG has narrowed significantly over the last 15 years.

Appendix E. Fuels: Overview of Nonroad Sources and Regulations

In general, the "nonroad" category consists of a wide range of fuels, technologies, and uses. The common characteristic is simply that the engines are not used to drive on roads, meaning these engines are used everywhere else, from construction sites to the sea to the sky, and for all sorts of purposes other than on-road driving. Currently, both EPA and CARB regulate various nonroad mobile sources to varying degree. With the nonroad regulations enacted in 2004 and 2008 for the categories described below, EPA anticipated a reduction in criteria exhaust emissions by up to 90 percent by 2030, in particular for NOx and PM emissions from nonroad diesel engines, on top of the decrease in sulfur emissions by up to 99 percent resulting from fuels requirements for nonroad diesel engines, locomotives, and marine vessels.[125] Greenhouse gas emissions from most nonroad sources, however, remain notably not as regulated as onroad sources. In addition, practical limitations exist for regulation of in-use emissions, as well as emission-related maintenance and repair, for nonroad equipment in the field. Lastly, monitoring of nonroad sources is currently limited and robust requirements are lacking. Overall, regulation of nonroad mobile sources, including tailpipe emission standards and in-use compliance, lags behind that of onroad mobile sources, including those nonroad diesel sources with similar technologies and designs as onroad heavy-duty engines and vehicles.

Regulated Nonroad Engine Types

Nonroad Compression Ignition (Diesel) Engines**.** Compression ignition engines are powered by diesel fuel that is ignited with mechanical compression. For regulatory purposes, there are three primary categories of nonroad compression ignition engines: land-based diesel engines, most often used in construction and agricultural equipment; marine diesel engines, used in marine vessels ranging in size from small recreational boats to large ocean-going ships; and compression ignition locomotive engines.

Nonroad Spark Ignition Engines**.** Spark ignition engines are powered by the combustion of an air-fuel mixture (most often involving gasoline) that is ignited by a spark. The EPA regulates nonroad spark ignition engines in three categories: marine spark ignition engines, used in personal watercraft, jet-skis, outboard engines, and inboard engines; large nonroad spark ignition engines, which are gasoline and propane powered equipment such as forklifts and generators; and small nonroad spark ignition engines, used primarily in small lawn equipment such as lawnmowers.

Recreational Vehicles**.** EPA defines recreational vehicles as snowmobiles, off-highway motorcycles, all-terrain vehicles (ATVs), and off-road utility vehicles with power less than or equal to 30 kW and a

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[125] See EPA, Fact Sheet: Clean Air Nonroad Diesel Rule, EPA420-F-04-032 (May 2004) (https://nepis.epa.gov/Exe/ZyPDF.cgi/P10001RN.PDF?Dockey=P10001RN.PDF). See also EPA, Fact Sheet: EPA Finalizes More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines, EPA420-F-08-004 (March 2008) (https://nepis.epa.gov/Exe/ZyPDF.cgi/P100094D.PDF?Dockey=P100094D.PDF) (estimating reductions in PM by up to 90% and NOx by up to 80% by 2030 for locomotive and marine diesel engines subject to Tier 4 standards).

maximum speed higher than 25 miles per hour.[126] These vehicles are powered by two-stroke or four-stroke engines.

Aircraft Engines**.** In addition to the nonroad mobile sources described above, EPA regulates emissions from gas turbine aircraft engines pursuant to CAA authority; such engines, however, are not subject to the same level of requirements as nonroad diesel engines.[127]

Methods of Regulating Nonroad Engine Emissions

For the most part, nonroad emissions regulations are designed to control the release of particulate matter, hydrocarbons, carbon monoxide, nitrous oxide, ozone, volatile organic compounds, sulfur, and other criteria pollutants.

a. *Engine Certification*. The regulation of nonroad engines is most similar to onroad engines at the certification stage. As with onroad engines, before engines from any nonroad category may be sold in the US, the manufacturer must apply for and receive a certificate of conformity from EPA (and the California Air Resources Board (CARB), if the engine will be sold in California).[128, 129] To be certified, engines must undergo regulation-mandated testing to prove the engine meets emissions standards. Auxiliary emission control devices (AECDs) must be disclosed in the certification application for all categories except aircraft engines.[130] For spark ignition engines, evaporative emissions components must also be certified before an engine can be introduced on the US market.[131]

b. *Vehicle and Engine Registration*. Unlike onroad vehicles that are registered by state governments, the many types of nonroad vehicles and engines are not registered. Lacking a registration system makes it difficult to track emissions compliance during the life of nonroad engines, which for many nonroad sources is a much longer useful life than onroad mobile sources. California's Diesel Off-Road On-Line Reporting System (DOORS) is an outlier: California regulations require registration of engines in fleets of certain nonroad diesel engines in order to ensure compliance with the California off-road fleet rules.[132] The DOORS system calculates fleet size, fleet average emissions, and other compliance metrics.

c. *In-Use Testing*. In-use testing allows regulators to assess whether vehicles continue to comply with emissions standards after they have been sold and been used in the real world. Although manufacturer-run in-use testing is utilized by both EPA and CARB to track compliance of heavy duty on-road vehicles and engines throughout their full useful lives,[133] such in-use testing programs exist in a comparatively limited capacity for nonroad sources and only for some

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[126] 40 C.F.R. § 1051.1(a).

[127] 40 C.F.R. § 87; § 1068.

[128] See, e.g., 40 C.F.R. § 89, Subpart B (emissions standards and certification provisions of nonroad compression ignition engines); 40 C.F.R. § 91, Subpart B (emissions standards and certification provisions of marine spark ignition engines); 40 C.F.R. § 92, Subpart C (certification provisions for locomotives).

[129] *In-Use Off-Road Diesel Fueled Fleets Regulation*, California Air Resources Board (last visited Dec. 7, 2020), https://ww2.arb.ca.gov/our-work/programs/use-road-diesel-fueled-fleets-regulation.

[130] See, e.g., 40 C.F.R. §89.115(d)(2) (AECD disclosure requirement for nonroad compression ignition engines); 40 C.F.R. § 91.107(d)(2) (AECD disclosure requirement for marine spark ignition engines).

[131] See, e.g., 40 C.F.R. § 1048.105 (Large Spark Ignition Engine evaporative emission standards).

[132] For California nonroad fleet rules, see generally 9 C.C.R. § 2449.

[133] 40 C.F.R. § 86, Subpart T.

locomotives, marine spark ignition engines, and large nonroad spark ignition engines.[134] EPA promulgated rules giving itself the right to conduct in-use testing on land-based nonroad compression engines but has not yet implemented any such program.[135] Thus, for the most part, nonroad mobile sources are not subject to regular in-use testing.

d. *On-Board Diagnostics Requirements*. On-board diagnostics (OBD) systems allow vehicles or engines to perform self-diagnostics and report findings to a vehicle owner or repair technician. EPA and CARB both require OBD systems with specified functions for on-road vehicles, including heavy duty vehicles.[136] Conversely, diagnostic requirements for nonroad engines vary, and for many categories are basic in comparison to on-road requirements: nonroad diesel engines are only required to have a diagnostic system that monitors reductant quality and tank levels,[137] while marine diesel engines must monitor reductant and NOx and store some records of reductant levels.[138] Recreational vehicles and small spark ignition engines have no diagnostic requirements. Locomotives have the most involved diagnostic requirements, which are used during in-use testing in addition to system monitoring.[139]

e. Warranty & Useful Life Requirements. All categories of nonroad engine are subject to federal warranty requirements.[140] Small spark-ignition engines, marine compression ignition engines, locomotives, and construction and agricultural engines are also subject to federal useful life requirements.[141] Additionally, all nonroad regulated mobile sources (except aircraft) are subject to emissions defect reporting and recall requirements.[142]

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[134] See, 40 C.F.R. § 92, Subpart G (Locomotive In-Use Testing Program); 40 C.F.R. § 91, Subpart I (Marine Spark Ignition Engine In-Use Testing); 40 C.F.R. § 1048, Subpart E (Large Spark Ignition In-Use Testing).
[135] 40 C.F.R. § 1039.401 (provision which reserves the right of EPA to perform in-use testing on nonroad compression ignition engines, but no mandate or procedure has ever been enacted).
[136] See generally, 13 C.C.R. § 1971.1; 74 Fed. Reg. 8,309 (2009).
[137] 40 C.F.R. 1039.1100.
[138] 40 CFR 1042.110(a).
[139] 40 C.F.R. 1033.110; 1033.112.
[140] See, e.g., 40 C.F.R. § 1048.120 (large spark ignition); 40 C.F.R. § 1042.120 (marine compression).
[141] 40 C.F.R. 1033.101 (locomotives); 40 C.F.R. § 1042.104 (marine compression); 40 C.F.R. §91.105 (marine spark); 40 C.F.R. § 1054.107 (small spark).
[142] See 40 C.F.R. § 1068, Subpart G.

Appendix F. Fuels: Advanced Low-carbon Fuel Pathway Development

U.S Ethanol, Biodiesel, and Renewable Diesel Production

The U.S. biofuels industry started to gain market penetration in the 1980s as corn-based ethanol emerged as oxygenate replacement for methyl-tertiary-butyl ether (MTBE), a petroleum-derived oxygenate that was heavily scrutinized and regulated since this time. Figure F-1 demonstrates feedstock properties and shows that corn ethanol--primarily produced via fermentation of corn starch—still dominates the U.S. biofuels market with domestic production of almost 16 billion gallons/year in 2019. Approximately 14 billion gallons is blended into gasoline for use in light duty vehicles at rate of 10% ethanol (E10). The remaining 2 billion gallons/year of ethanol was blended into domestic E15 and E85 markets or exported. However, production of ethanol in 2020 is anticipated to drop precipitously due to COVID-19 pandemic and resulting decline in gasoline consumption.

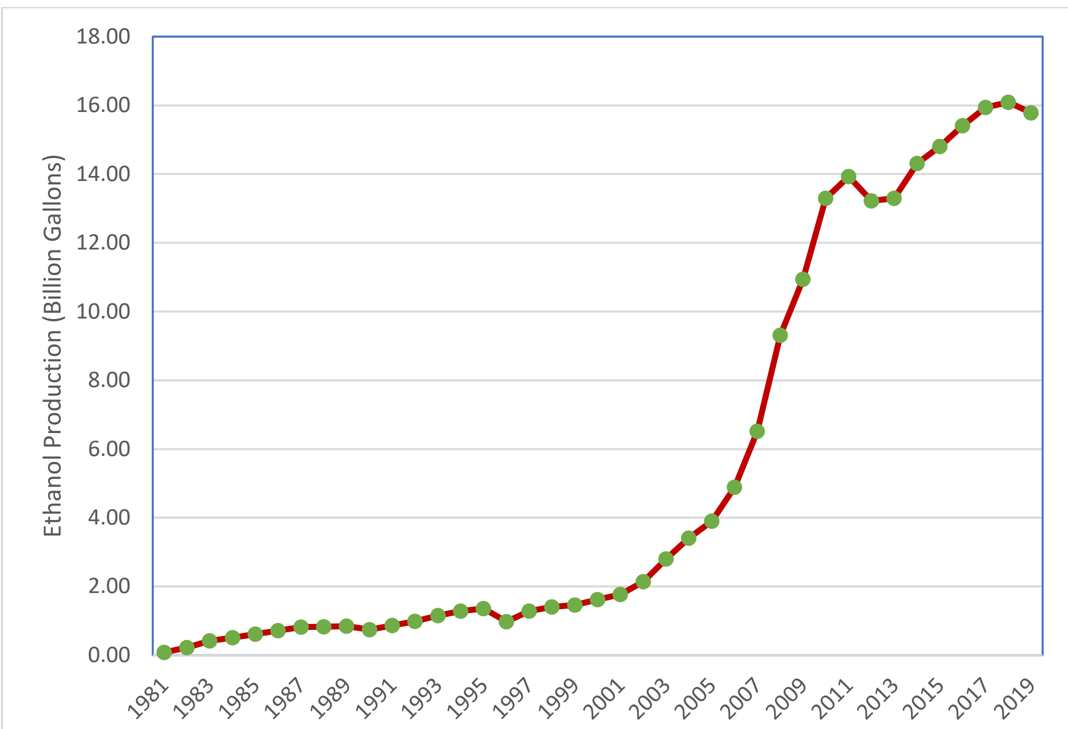

Figure F-1: Historical US Ethanol Production. Source: Energy Information Administration

In the early 2000s, biodiesel (fatty acid methyl esters, or "FAME", produced by transesterification of fats, oils, and greases) and more recently renewable diesel (hydrocarbon fuel, produced by hydrogenation of fats, oils, and greases) started to gain market penetration. As Figure F-2 indicates, biodiesel is typically blended into diesel at rates of 5% to 20% (B5 to B20, respectively). As of 2019, U.S. biodiesel and renewable diesel production reached 2.8 billion gallons/year, or 4% of diesel demand in heavy duty vehicles. Nearly half of this volume is produced using soybean oil as a feedstock, with distillers corn oil, canola oil, yellow grease animal fats each comprising 10-15%.

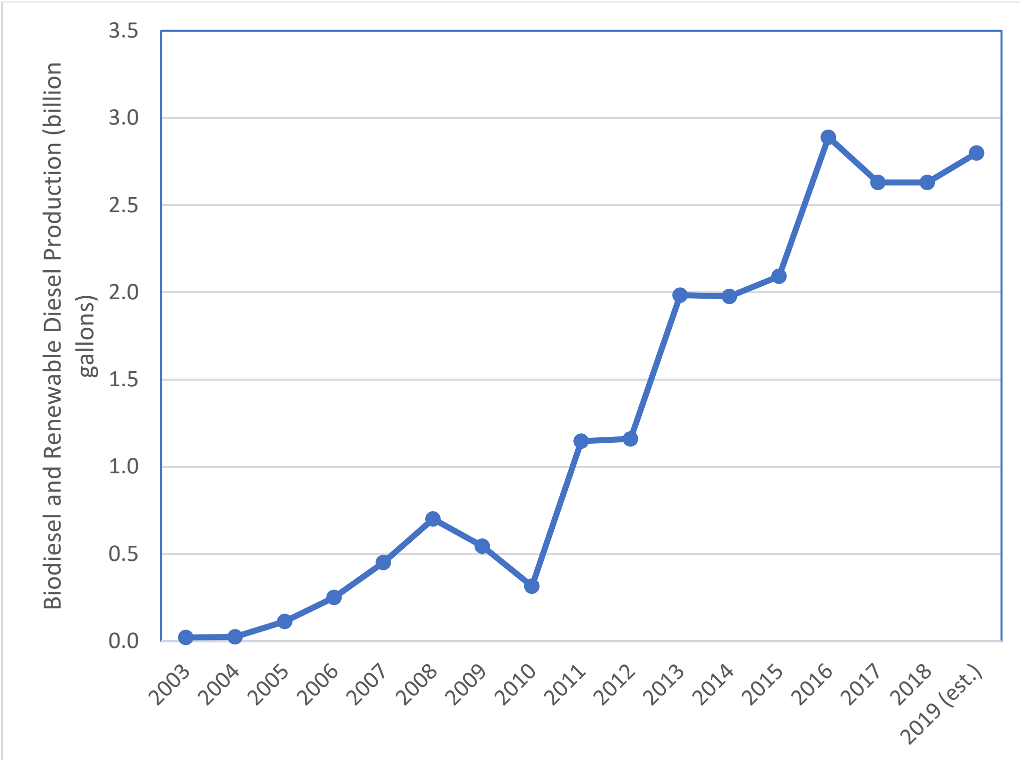

Figure F-2: Historical U.S. Biodiesel and Renewable Diesel Production.

Volumes reported under the RFS in the D4, D5, and D6 categories.[143]

Development of "Drop-In" Hydrocarbon Biofuels

While corn-ethanol, biodiesel and renewable diesel have significant production capacity and market penetration, they are constrained by market forces. Ethanol is limited by the "blend wall" in the motor gasoline market. Between 2017 and 2050, aviation and heavy-duty vehicle use is projected to grow considerably faster than for light-duty vehicles. Air passenger miles are projected to double, and freight truck miles traveled are projected to grow by nearly 50%, compared with an 18% increase in light-duty vehicle miles traveled.[144]

Due to anticipated increases in vehicle fuel economy and penetration of electric vehicles, demand for gasoline—and thus fuel ethanol—is expected to face greater competition for market-share. Biodiesel and renewable diesel production are limited by feedstock availability, and biodiesel also faces similar blending limitations particularly due to concerns over cold-weather performance. Both ethanol and biodiesel are subject to infrastructure compatibility concerns with pipelines, fuel storage, distribution, and dispensing infrastructure.

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[143] EPA EMTS, and National Biodiesel Board (NBB), http://www.biodiesel.org

[144] "Annual Energy Outlook 2018, Table 7: Transportation Sector Key Indicators and Delivered Energy Consumption," U.S. Energy Information Administration, last modified February 6, 2018, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2020&region=0-0&cases=ref2020~noace~rpstranche_50tx~norps~carbonfee15~carbonfee25~carbonfee35&sourcekey=0.

Due to these constraints, as well as potential to deliver biofuels with improved environmental and lifecycle greenhouse emission benefits over first generation biofuels, domestic and international biofuels industries have increased focus on the production of "drop-in" hydrocarbon biofuels. While there are myriad feedstocks and production technologies--or pathways--the constant is the production of fuels that are compatible with existing infrastructure and fleets, whether for aviation, marine vessels, light-duty vehicles, or heavy-duty trucks. Thus, these fuels would avoid the market barriers referenced above, and provide a means to reduce the carbon footprint of legacy fleets.

Biofuels also can provide benefits and performance advantages that increase their value. Bioenergy crops such as perennial grasses and woody crops have the potential to provide multiple ecosystems services, such as increased farm productivity and profitability, more efficient nutrient utilization, improved water quality, soil conservation, and enhanced wildlife habitat.

Products

Up to 16% of U.S. crude oil consumption by volume is used to make chemicals and products, such as plastics for industrial and consumer goods,[145] contributing $812 billion revenues annually to the U.S. economy and about 40% of the value derived from crude oil. Currently, because of costs and technology uncertainty, less than 4% of U.S. chemical sales are bio-based.[146] Biomass and waste resources represent an important (and, in some cases, the only) option for creating additional sustainable options to augment many petroleum-derived chemicals, plastics, and products relied upon today.[147]

Many products derived from biomass are equivalent to, or even better than, those made from petroleum-derived materials. For example, some bio-derived chemicals, like 1,3-propanediol, are lower cost and use substantially less energy than those derived from petroleum.[148] Additionally, bottles and packaging made from bio-derived polyethylene terephthalate can be made thinner and more cheaply. Other biomass- and waste-derived chemicals can be used in applications as diverse as anti-freeze, cosmetics, and pet food; however, the cost and quality of the feedstock, in combination with the conversion efficiency, determines whether the product can be cost competitively produced.

The global, bio-based non-fuel platform chemical[149] market was valued at over $4 billion in 2018 and is expected to reach nearly $8 billion by 2023 with the U.S. portion of that market estimated to grow from $456 million to $804 million.[150] Organic chemicals such as plastics, solvents, and alcohols

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[145] American Chemistry Council, *Guide to the Business of Chemistry—2014* (Washington, DC: American Chemistry Council, 2014).
[146] J. S. Golden, R. Handfield, J. Daystar, and E. McConnell, *An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America* (Washington, DC: U.S. Department of Agriculture, 2015), http://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf.
[147] U.S. Department of Energy, edited by M. H. Langholtz, B. J. Stokes, and L. M. Eaton, *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks* (Oak Ridge, TN: Oak Ridge National Laboratory, ORNL/TM-2016/160, 2016), https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.
[148] M.J. Biddy, "Performance-advantaged products from biomass: State of the market and opportunities for innovative products," presented at the Biomass Research and Development Initiative Technical Advisory Committee Meeting, August 22–23, 2018, https://biomassboard.gov/pdfs/MBiddy%20Bioproducts%20Presentation%202018-08-22.pdf.
[149] Platform chemicals are intermediate chemicals used to produce bioproducts such as polymers, solvents, and pharmaceuticals.
[150] Market Research Future, *Global Bio-Based Platform Chemicals Market Research Report – Forecast to 2023* (Maharashtra, India: Market Research Future, 2018), https://www.marketresearchfuture.com/reports/bio-based-chemicals-market-5706.

represent the largest and most direct market for bioproducts.[151] Due to this potential, bioproduct manufacturing represents an interesting near-term market opportunity to support the development of the biorefining industry. Higher valued bioproducts manufactured from cellulosic biomass are expected to establish feedstock supply chains, overcome materials handling challenges, and reduce costs of key processes that are applicable to both bioproducts and biofuels. Further, bioproducts offer opportunities to explore new chemical properties that could offer performance advantages over traditional products, due to the structural differences from their petroleum-derived counterparts.[152] Higher-value bioproducts coproduced with biofuels should improve the commercial viability of a biorefinery.

Basic Approaches to the Production of Drop-In Hydrocarbon Biofuels

Traditional Terrestrial Cellulosic Biomass to Fuel

Figure F-3 demonstrates a variety of conversion technologies are being explored that can be combined into pathways from feedstock to product (Historically these pathways have been roughly classified as either biochemical or thermochemical to reflect the primary catalytic conversion system employed as well as the intermediate building blocks produced. Generally, biochemical conversion technologies involve pathways that use sugars and lignin intermediates, while thermochemical conversion technologies involve pathways that use bio-oil and gaseous intermediates. Moving forward, however, the traditional division between biochemical and thermochemical conversion technologies does not encompass the diversity of innovative technologies being developed and deployed around the world.

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[151] A. B. Lovins, E. K. Datta, O.-E. Bustnes, J. G. Koomey, and N. J. Glasgow, *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security* (Snowmass, CO: Rocky Mountain Institute, 2005), http://www.rmi.org/Knowledge-Center/Library/E04-07_WinningTheOilEndgame.

[152] U.S. Department of Energy (DOE), *Moving Beyond Drop-In Replacements: Performance-Advantaged Biobased Chemicals* (Washington, DC: DOE, 2018), https://www.energy.gov/sites/prod/files/2018/06/f53/Performance-Advantaged%20Biobased%20Chemicals%20Workshop%20Report.pdf.

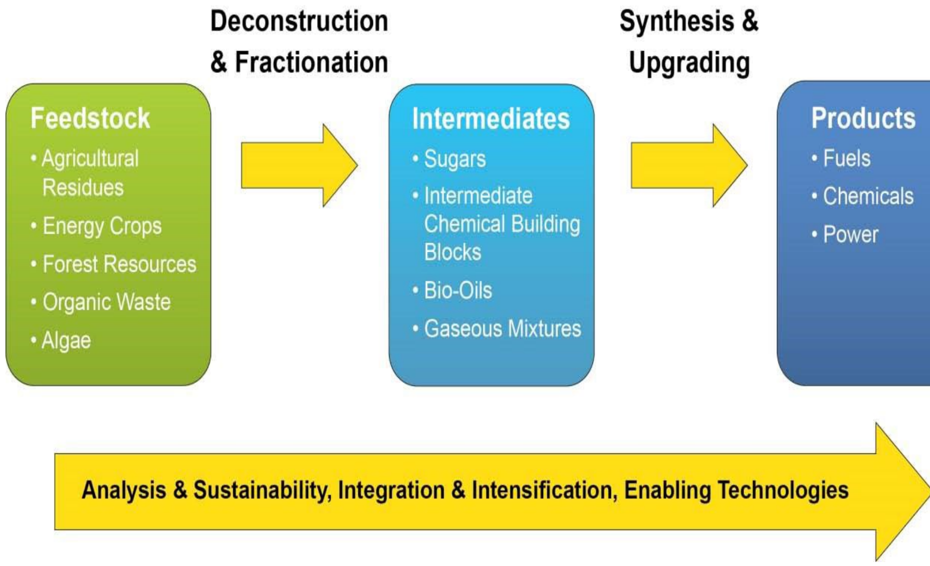

Figure F-3: Generalized conversion route for biomass-derived feedstocks to renewable products

The conceptual block flow diagram in Figure F-4 outlines the main process steps and materials in the feedstock-to-end products process. This figure depicts a high-level view of the primary unit operations to create desired biomass-derived products including fuels. Each conversion technology involves at least two main steps: deconstruction of feedstock into relatively stable chemical building blocks through the breaking of chemical bonds followed by the controlled recombination of those building blocks into a slate of desired products.

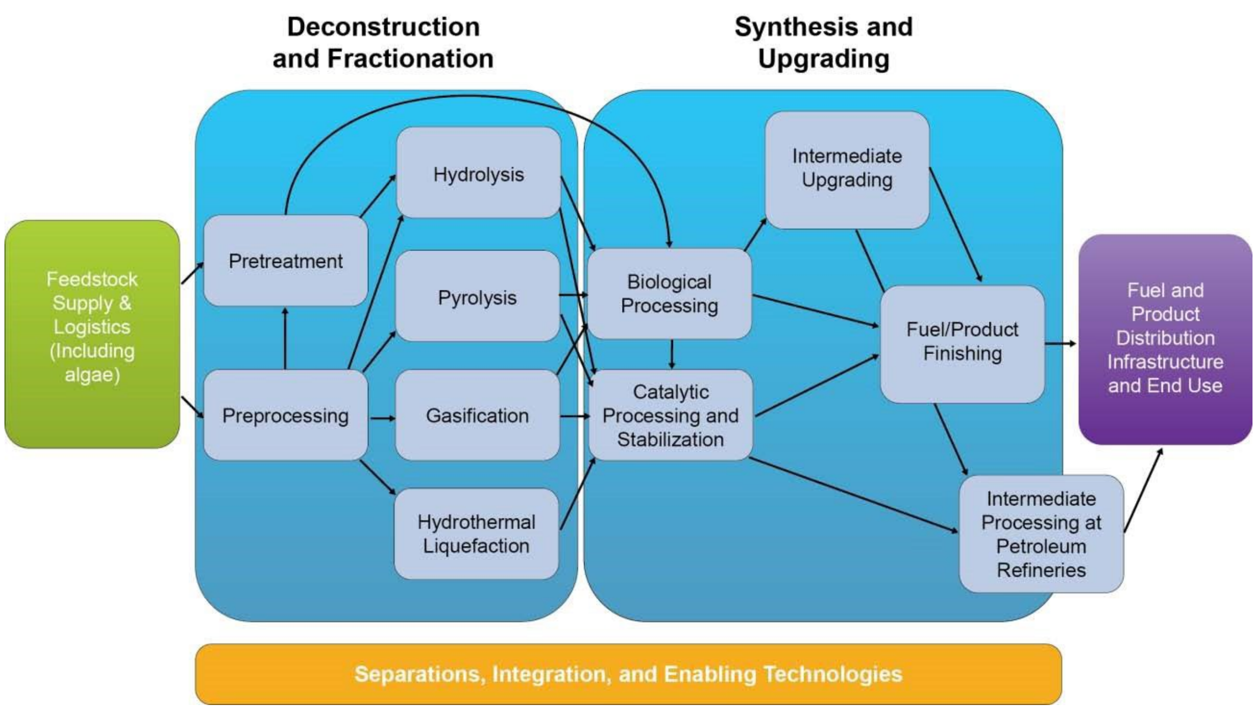

Figure F-4: Conversion pathways from feedstock to products

These renewable products can include finished fuels, fuel precursors, high-quality intermediates, such as sugars, syngas, or stabilized bio-oils, and high-value, bio-based chemicals that enable fuels production. Specific process operating conditions, inputs, and outputs vary within and between each step. These process variations impact key performance outcomes (such as titer, rate, selectivity, and yield), which in turn determine economic viability. Potential environmental impacts are also assessed for conversion pathways by evaluating sustainability metrics and conducting life-cycle assessments.

Conversion Process

Conversion processes can be broken down into two areas: Deconstruction and Fractionation, and Synthesis and Upgrading. Figure F-4 highlights key technologies within Deconstruction and Fractionation as well as Synthesis and Upgrading, which can be linked to form a complete conversion pathway from feedstock to products. The arrows represent the transition of organic matter from feedstock to intermediates to end products, showing the diversity of accessible conversion options. Multiple technologies along several pathways are under development to address the broad range of physical and chemical characteristics of various feedstocks and to reduce the risk that any specific technology could fail to reach commercial viability. Additionally, each linked set of conversion technologies results in the production of a unique product slate with value that will vary depending on market size and demand.

Many combinations of unit operations can result in conversion strategies that have the potential for commercial success. Not all possible permutations can be pursued by any entity, and ultimately, a company or industrial entity will select the technology combinations that provides the strongest market advantage.

The following section provides a high-level overview of processing steps.

Preprocessing: Development of a variety of conversion technologies is necessary to address the broad range of physical and chemical characteristics of various biomass feedstocks. Depending on the conversion strategy, a variety of feedstock preprocessing and handling steps may be employed.

High-Temperature Deconstruction: High-temperature deconstruction encompasses pyrolysis, gasification, and hydrothermal liquefaction (HTL).

Pyrolysis is the thermal and chemical decomposition of feedstock without the introduction of oxygen to produce a bio-oil intermediate. The bio-oil produced contains hydrocarbons of various lengths but contains more oxygenated compounds than petroleum crude oils and must undergo upgrading before it can be finished into a fuel or used in a refinery. There are several pyrolysis variations that require different catalysts and reaction conditions.

Hydrothermal liquefaction is a deconstruction process that utilizes a wet feedstock slurry under elevated temperature and pressure to produce a HTL bio-oil. The feedstock is treated with water before entering the reactor and is particularly applicable to algal feedstocks and diverse blends of wet waste feedstocks, such as wastewater and bio-solids; other variations include solvothermal liquefaction where a non-water solvent, such methanol, is used to make the feedstock slurry.

Gasification is the thermal deconstruction of biomass at high temperature (typically > 700°C) in the presence of sub-stoichiometric air or an oxygen carrier and sometimes steam followed by gas cleanup and conditioning. In these processes, feedstock is partially oxidized to form a synthesis gas (syngas), which contains a mixture of light gases such as CO_2, CO, H_2, CH_4, as well as heavier species.

Low-Temperature Deconstruction: Low-temperature deconstruction is the breakdown of feedstock into intermediates by pretreatment followed by hydrolysis. Pretreatment is the preparation of feedstock for hydrolysis via chemical or mechanical processing and separation of feedstock into soluble and insoluble components. This process opens up the physical structure of plant and algae cell walls, revealing sugar polymers and other components. Hydrolysis is the breakdown of these polymers either enzymatically or chemically into their component sugars and/or aromatic monomers.

Anaerobic Digestion: Anaerobic digestion is a series of biological steps where a diverse population of microorganisms breaks down organic material in an oxygen-free setting to produce biogas, which is a mixture of primarily CH_4 and CO_2. Alternatively, the conditions within a digester can be altered such that methanogenesis is suppressed; *arrested methanogenesis* then leads to the accumulation of other, more readily convertible molecules such as volatile fatty acids. These techniques can be used to valorize wet waste streams.

Synthesis and Upgrading

Intermediates can include crude bio-oils, gaseous mixtures such as syngas, sugars, and other chemical building blocks as outlined in Figure F-3. These intermediates are upgraded using various techniques to produce a finished product. These finished products could be fuels or bioproducts ready to sell into the commercial market or could be stabilized intermediates suitable for finishing in a petroleum refinery or chemical manufacturing plant.

Biological Processing: Microorganisms (including, but not limited to, bacteria, yeast, and cyanobacteria) can convert sugar or gaseous intermediates into fuel blendstocks and chemicals. Metabolic engineering of these microbes allows for maximum sugar utilization, robustness, and selection of the product slate. Syngas, biogas, and waste carbon monoxide can also be upgraded into biofuels and bioproducts using microbial methods.

Catalytic Processing and Stabilization: Sugars and other intermediate streams such as bio-oil and syngas are generally upgraded to minimize the effect of reactive compounds to improve storage and handling properties. Liquid sugar streams are filtered and concentrated and can then be catalytically upgraded in an aqueous phase reforming process to generate a range of hydrocarbons. For bio-oil, stabilization may involve hydroprocessing such as hydrodeoxygenation to transform oxygen-rich biomass into a mix of compounds more similar to hydrocarbon-rich petroleum. It may also involve separation and fractionation steps to remove water, coke, catalyst, char, and ash particulates, or metals and oxygenated species. For syngas streams, stabilization involves removal of contaminants from crude biomass-derived synthesis gas. Gas cleanup and conditioning involves the removal of problematic heteroatom compounds, metals, and particulates as well as adjusting the hydrogen-carbon monoxide ratio. Gaseous intermediate upgrading is the conversion of clean gaseous intermediates to fuels or mixed oxygenates via biological organisms (e.g., syngas fermentation) or catalytic processes (e.g., Fischer-Tropsch synthesis or fuel synthesis of mixed alcohols).

Intermediate Upgrading: Intermediate upgrading involves a variety of technologies to transform intermediate streams into crude product streams. Actual upgrading and separations processes will vary greatly according to the identity of the intermediate streams. Streams with tight chemical distributions such as algal lipids, fatty acids, or other products from biological processing may require less complex processes than streams involving more varied compounds. Chemical rearrangement into the final fuel blendstock or product can involve biological or chemical processing.

Fuel/Product Finishing: After upgrading, final product streams must conform to standards for off-take agreements. This may involve removing problematic contaminant compounds and further finishing to attain correct product specifications. For complex bio-oil mixtures, the finishing process may involve balancing various hydrocarbon components, whereas for single compound products the process may only involve removing impurities.

Intermediate Processing at Petroleum Refineries: Certain product streams may be transported to refineries at a cruder stage for upgrading. Placement of this box on the edge of Synthesis and Upgrading and Products in Figure F-4 represents the interface of conversion technologies with refiners.

Figure F-5 below shows modeled current and projected fuel costs for a variety of biomass conversion processes with and without co-product credits.

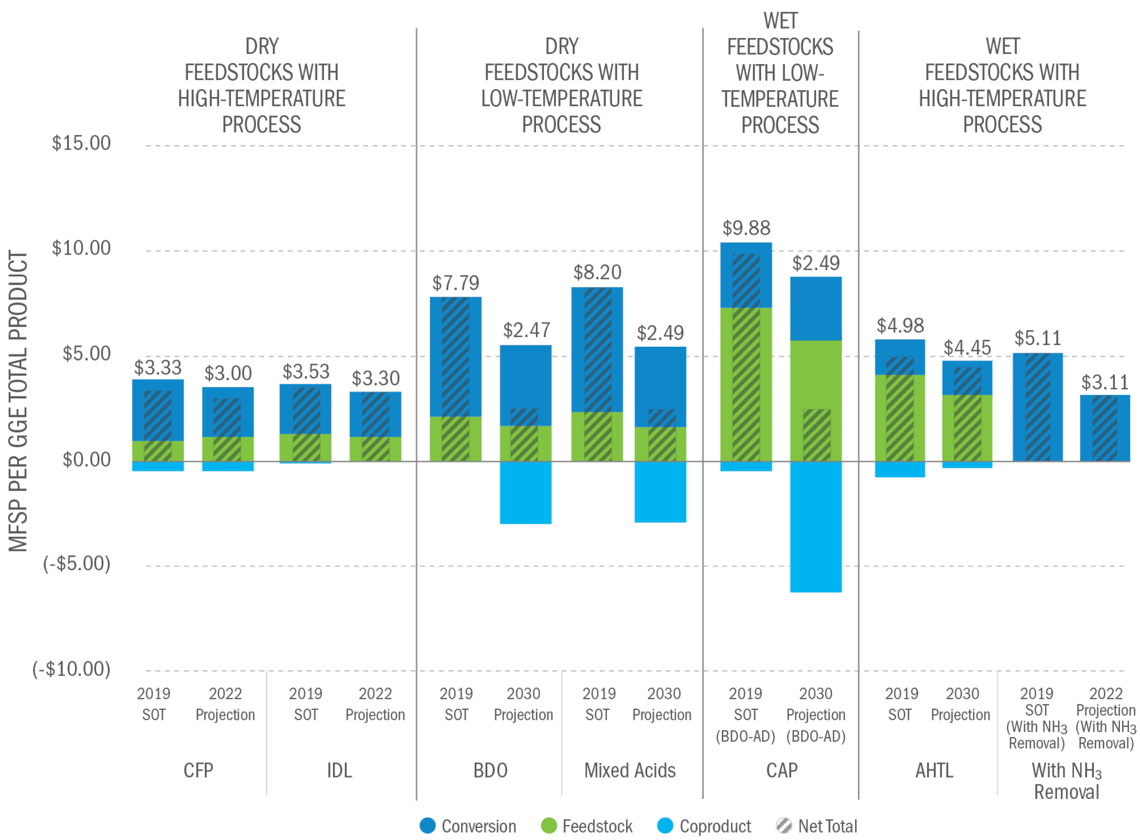

Figure F-5: Modeled current and projected fuel costs for a variety of biomass conversion processes with and without co-product credits

Major cost contributions and technical barriers for example processes are illustrated in Figure F-6, Figure F-7, and Figure F-8.[153]

[153] Additional information on technical barriers can be found in the DOE Bioenergy Technologies Office multi-year program plan (https://www.energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf) and strategic plan (https://www.energy.gov/sites/prod/files/2017/09/f36/beto_strategic_plan_december_2016.pdf).

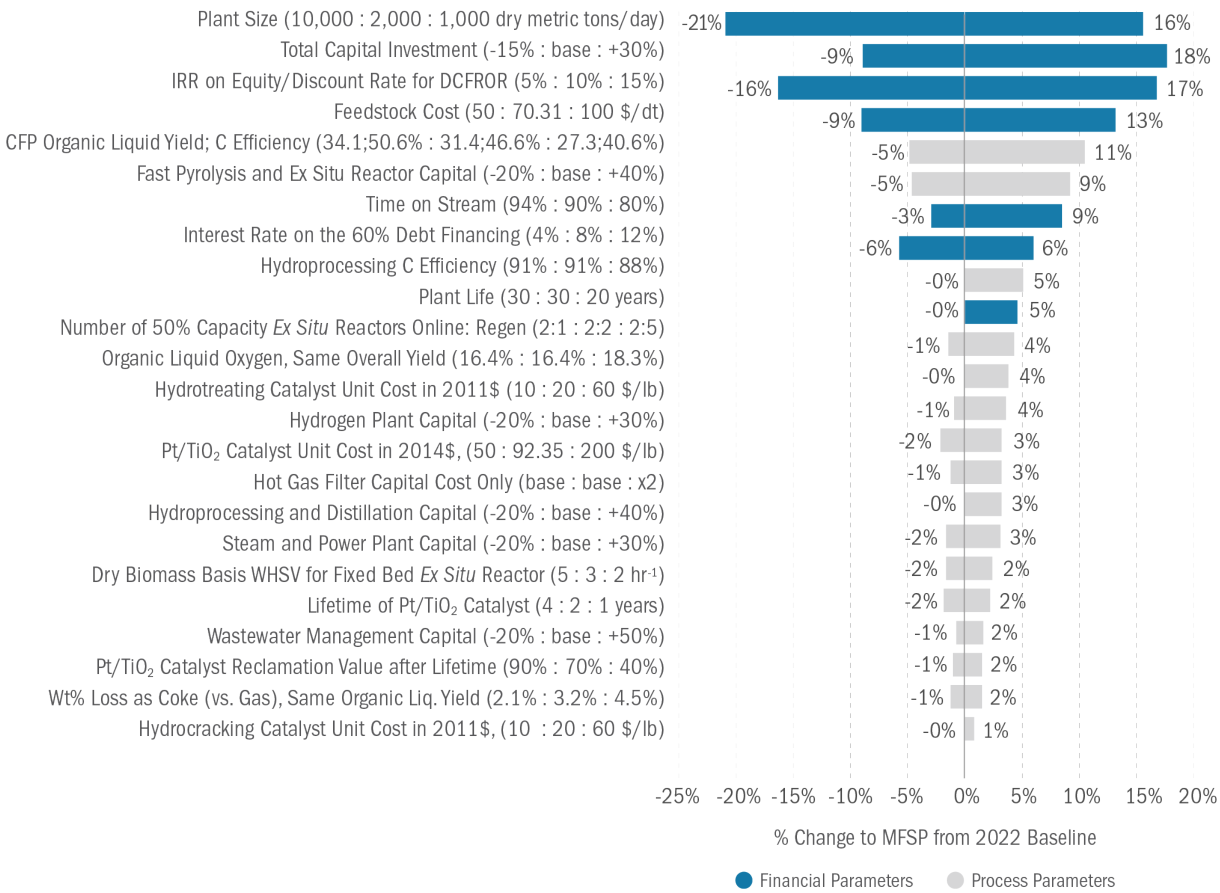

Figure F-6: Factors influencing conversion costs relative to the catalytic fast pyrolysis design case 2022 projection.

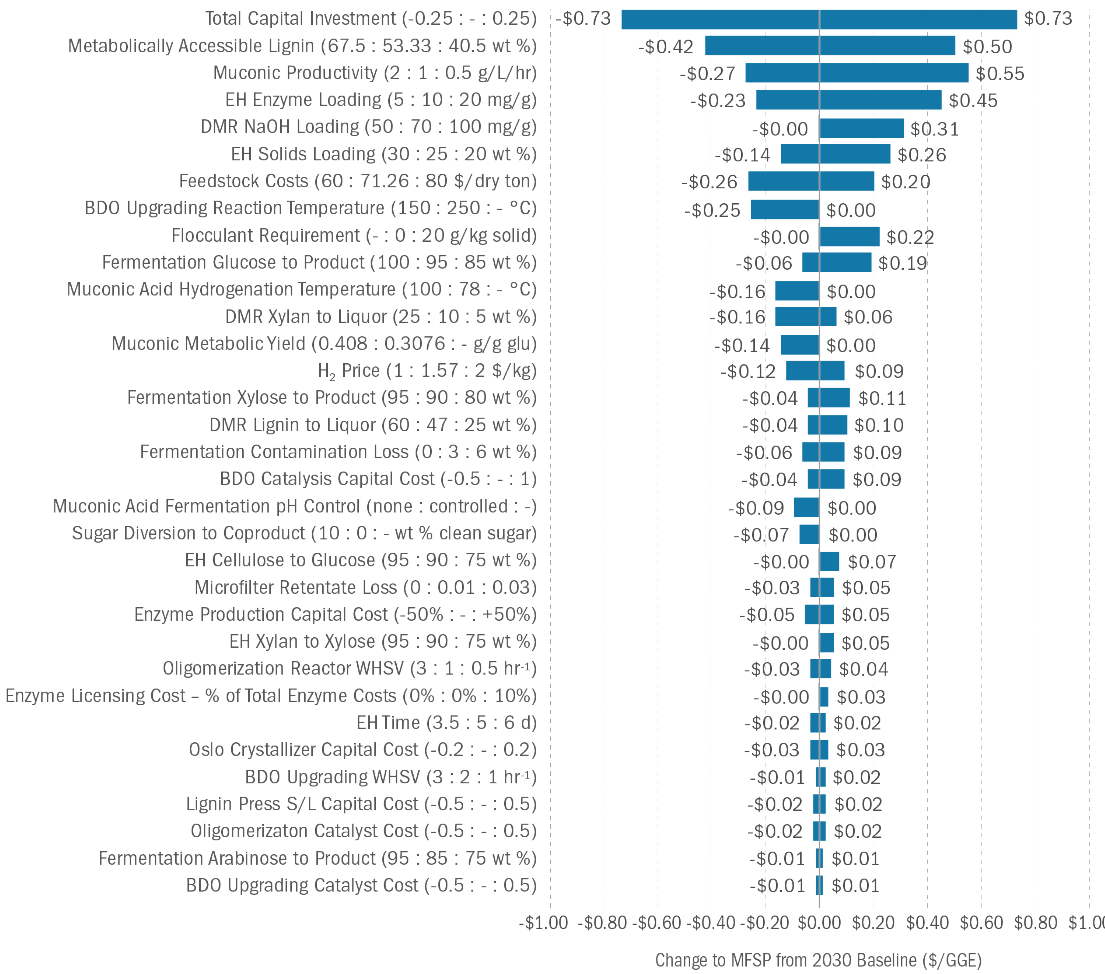

Figure F-7: Major cost factors in the production of hydrocarbon biofuels via biochemical conversion with a 2,3-BDO intermediate

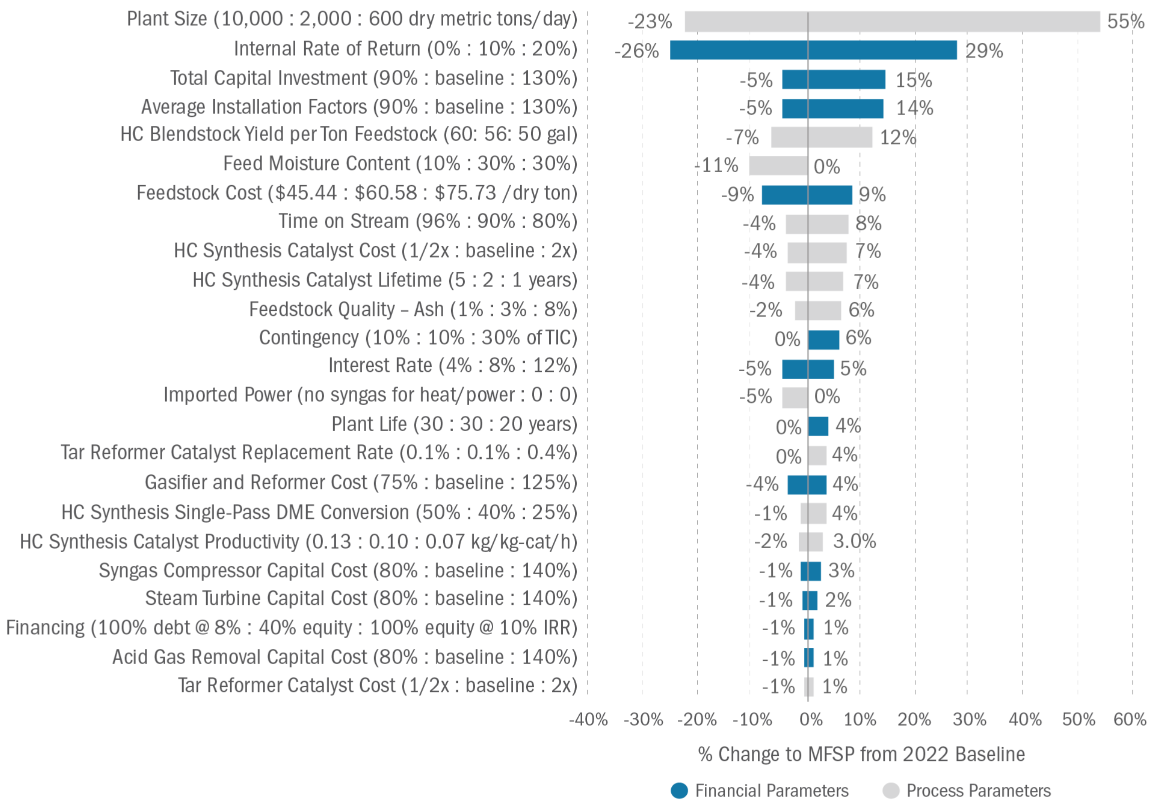

Figure F-8: Key conversion factors impacting MFSP for the biomass gasification design case

Waste (MSW, Municipal Sludge, And Other Organic Waste) to Fuel

Hydrothermal liquefaction, described above in Section 3a is a process that is capable of converting organic feedstocks into a biocrude. The process operates with high levels of water in the system which makes it well suited for organic waste feedstocks that contain high levels (>70%) of moisture such as food waste, sludge from municipal wastewater operations, and manure. After upgrading, the biocrude produces a mixture of renewable diesel, jet fuel, and gasoline. Engine tests to-date have demonstrated no reductions in performance on gasoline and diesel engines (sufficient volumes have not yet been produced to evaluate jet engine performance or ASTM qualification). There has been considerable R&D on this pathway both in the United States and abroad, and the technology has matured to the pilot phase as noted in Table F-1. Without tipping fees or accounting for avoided costs of disposal, the cost of finished fuel is currently projected under $5/gallon of gasoline equivalent (gge). Factoring these costs in, projected costs of finished fuel are approaching $3/gge.

Table F-1: Selected pilot-scale (or larger) hydrothermal liquefaction units worldwide

Project Location	Project Status	Input Feed Rate	Primary Feedstock(s)
PNNL, Washington	Operational	36 kg/day	Municipal sludge, food waste, manure, algae, forestry residues
Aalborg, Denmark	Operational	1.4 ton/day	Municipal sludge, algae, forestry residues
Vancouver, British Columbia	Design complete, Commissioning ~2023	10 tons/day	Municipal sludge
Central Contra Costa, California	Design phase	15 tons/day	Municipal sludge
Tofte, Norway	Design phase	30 tons/day	Municipal sludge, agricultural, forestry residues
Calgary, Alberta	MOU signed	TBD (commercial scale)	Municipal sludge, food waste, forestry residues
Queensland, Australia	Design phase	TBD (commercial scale)	Municipal sludge, waste tires

Remaining technical and research barriers include:

- Impacts of mixed waste blends on biocrude and final fuel quality
- Long-term demonstration of biocrude upgrading catalysts
- Handling/homogenization/preprocessing of feedstock(s) prior to conversion (esp. at-scale)
- Management and efficient separations of by-product streams such as the aqueous and solid phases
- Evaluation of co-products or nutrient recovery from these by-product streams

Key considerations:

- Hydrothermal liquefaction is an appealing process because of its ability to process multiple waste streams simultaneously (See examples above). From this perspective it can solve both waste diversion and renewable fuel production goals. Therefore, the economic/environmental value proposition will vary for each municipality (e.g., landfill diversion requirements, availability/infrastructure for handling of mixed wastes). This will present challenges to potential Renewable Fuel Standard (RFS) pathways associated with this technology due to definitions used for waste feedstocks versus cellulosic feedstocks and associated RIN type.
- A key environmental value proposition of hydrothermal liquefaction (and other technologies that divert organic waste from landfills) is that it prevents the release of fugitive methane emissions. The counterfactual scenario for the waste being processed will vary based on local regulatory and infrastructure factors. This has resulted in favorable metrics for similar pathways under existing carbon intensity accounting systems such as the California Low-carbon Fuels Standard (LCFS). However, current RFS approval approach has disincentivized

this approach by de-rating RINs produced by wastewater digesters from a D3 cellulosic RIN to a D6 RIN if they introduce food waste. As a result, some municipalities no longer accept food waste, which instead is being sent to landfill and may actually increase emissions.

- While Hydrothermal Liquefaction shows promise, there is not going to be a single pathway for renewable fuel from waste. Other technologies that can process mixed or multiple feedstocks, such as gasification of municipal solid waste or co-digestion of food waste with other waste streams, will encounter similar policy considerations with regard to feedstock definitions and lifecycle accounting issues.

A Combination of Approaches is Likely Needed

To produce larger quantities of low-carbon biofuel, a combination of approaches and feedstocks will be necessary. Biomass is highly variable both spatially and temporally which has major implications in the development of a national scale industry. Figure F-9 shows how by combining multiple resources (in this example, corn stover and municipal solid waste), the cost of delivered material to make feedstock[154] can be driven down. Raw carbon resources to produce biofuel feedstocks comes from forest and agricultural residues, waste, waste gases, and the production of dedicated energy crops.

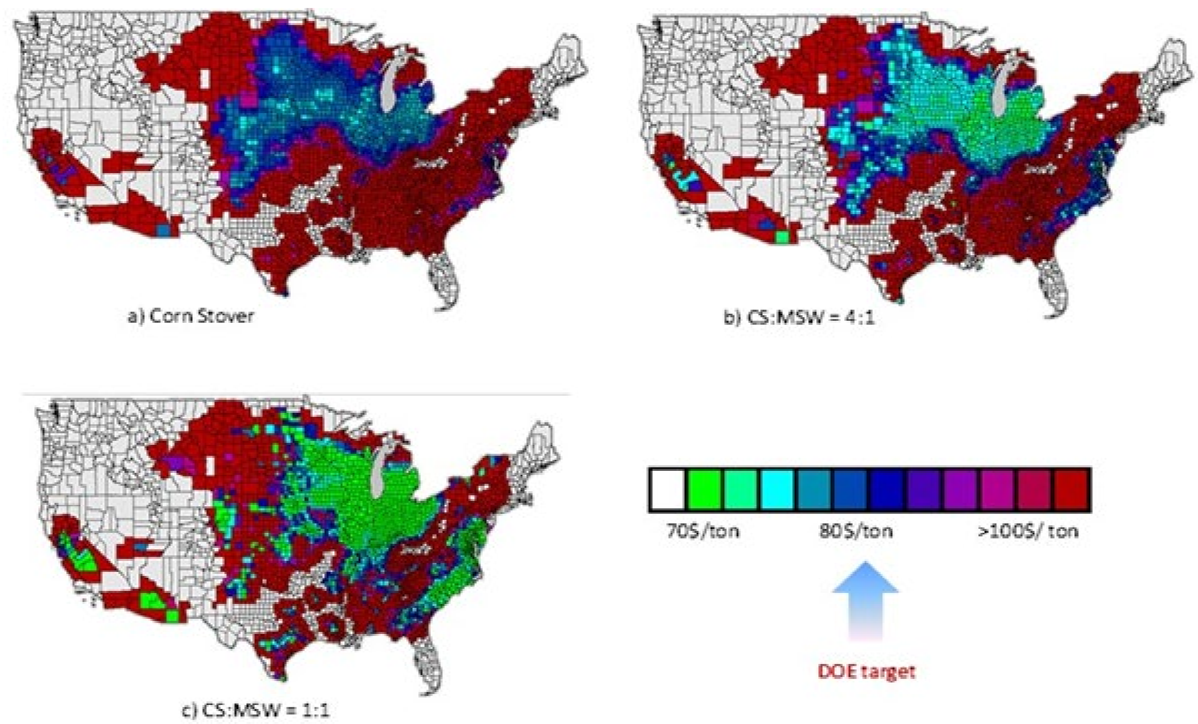

Figure F-9: Sun, Ning et al. Blending municipal solid waste with corn stover for sugar production using ionic liquid process. Bioresource Technology 186 (2015) 200-206.

[154] Feedstock has undergone preprocessing to convert the raw carbon resource into an on-specification feed to be converted to a biofuel.

In addition to the obvious differences in these biomass and waste resource's physical characteristics, they have their own supply and value chains that dictate the amount available at a particular price point for a given conversion technology. Early in the development of a biofuel industry, the cost of feedstock entering the reactor throat is determined by numerous factors unique to each biorefinery location such as local supply and demand dynamics and the preprocessing required for the raw biomass or waste to be converted into an on specification feedstock.

As a biofuel industry matures so will the feedstock supply system. A mature biomass system will produce a commodity-type feedstock that has consistent characteristics that meet the specifications dictated by the conversion technologies no matter the biomass or waste source.

Biomass and waste resources have characteristics that can make them more amenable to one conversion technology over another. For example, woody resources tend to be easier to convert to biofuels using high temperature thermal conversion technologies while herbaceous materials are more convertible to biofuels using low temperature biological based technologies.

Factors that contribute to the type of conversion technology include the characteristics intrinsic to the biomass or waste such as moisture content, inorganic content, contaminants, and particle size distribution created by response to milling. At a future biorefinery, the biomass and waste resources will be converted to a biofuel feedstock at a processing facility that takes in multiple biomass and waste sources and converts them into multiple products. This transfers the feedstock risk from the conversion facility to the feedstock processor and reduces construction cost by removing the need for a sophisticated feedstock processing front end.

Biomass and waste resources with adequate supply and few, if any, markets will be the first resources available for a biofuel industry. These consist of:

- Woody material from forest harvest, forest thinning, and tree processing
- Herbaceous material from corn stover, small grain straws, and grain processing
- MSW and other waste material from paper/cardboard, textiles, yard waste, and animal manures
- Waste CO_2 from fermentation at grain ethanol facilities and other point sources.

Locations where these biomass, waste, and waste gas resources have high concentrations will be sites for early biorefineries. Thus, these biomass/waste resources will be mobilized first. As a biofuel industry develops all the plant sites with easy access to large biomass and waste supplies will be taken and continued expansion will require the development of a commodity type biomass/waste based feedstock. Feedstock processing facilities will be able to scale differently and increase the access to geographically isolated resources.

In addition, the increase in biomass demand will spark the use of dedicated energy crops. Dedicated energy crops are specifically grown herbaceous and woody crops that can be produced on crop and pasture lands. These dedicated energy crops can be grown in conjunction and rotation with existing commodity crops. To reach a billion tons of annual biomass supply about half the biomass will have to come from dedicated energy crops.

Analysis on current resources estimate that sustainable collection of forest derived wood to be 154 million dry tons, agricultural herbaceous material at 144 million dry tons, MSW at 68 million dry tons, and 45 million tons of CO_2 from grain ethanol plants.[155]

Figure F-10 indicates that the delivered cost of these biomass and waste resources is from less than $20 up to $120 a dry ton with an average cost of $46.12 a dry ton. These costs do not include the preprocessing costs that are included in the cost projections in the figure.

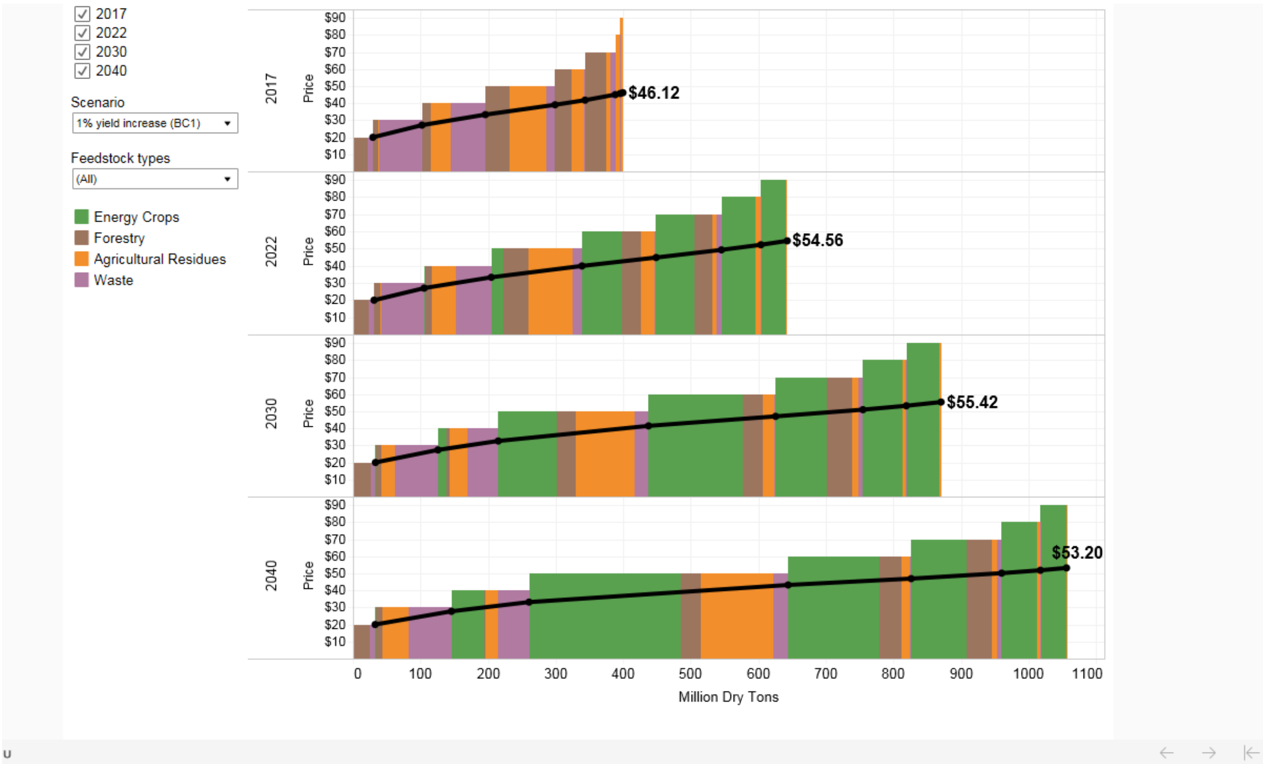

Figure F-10: Billion Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks. M. H. Langholtz, B.J. Stokes, and L.M. Eaton (Leads), Oak Ridge National Laboratory, Oak Ridge, TN 448; doi: 10.2172/1271651

The location of most forest based resources are the southeastern, Northeastern, Great Lakes, and Pacific Coast (Figure F-11). Agricultural residues from commodity crops are generally located in the Midwest, Great Plains, and Mississippi River Delta. However, there are agricultural residues from various sources located across the country. MSW resources tend to be located around major metropolitan areas. Ethanol plants which will most likely be the first resource for relatively clean CO_2 are located primarily in the corn belt and regions where there are large dairy and cattle production. Analysis of density of currently available biomass and waste resources indicates that biorefineries using wood will most likely be developed in the southeastern US. Biorefineries requiring herbaceous materials will be developed in the corn belt, and biorefineries that use some fraction on the MSW

[155] Billion Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks. M. H. Langholtz, B.J. Stokes, and L.M. Eaton (Leads), Oak Ridge National Laboratory, Oak Ridge, TN 318; doi: 10.2172/1271651

stream will be located near major metropolitan areas across the country. Biorefineries using CO_2 gas will be located in the corn belt.

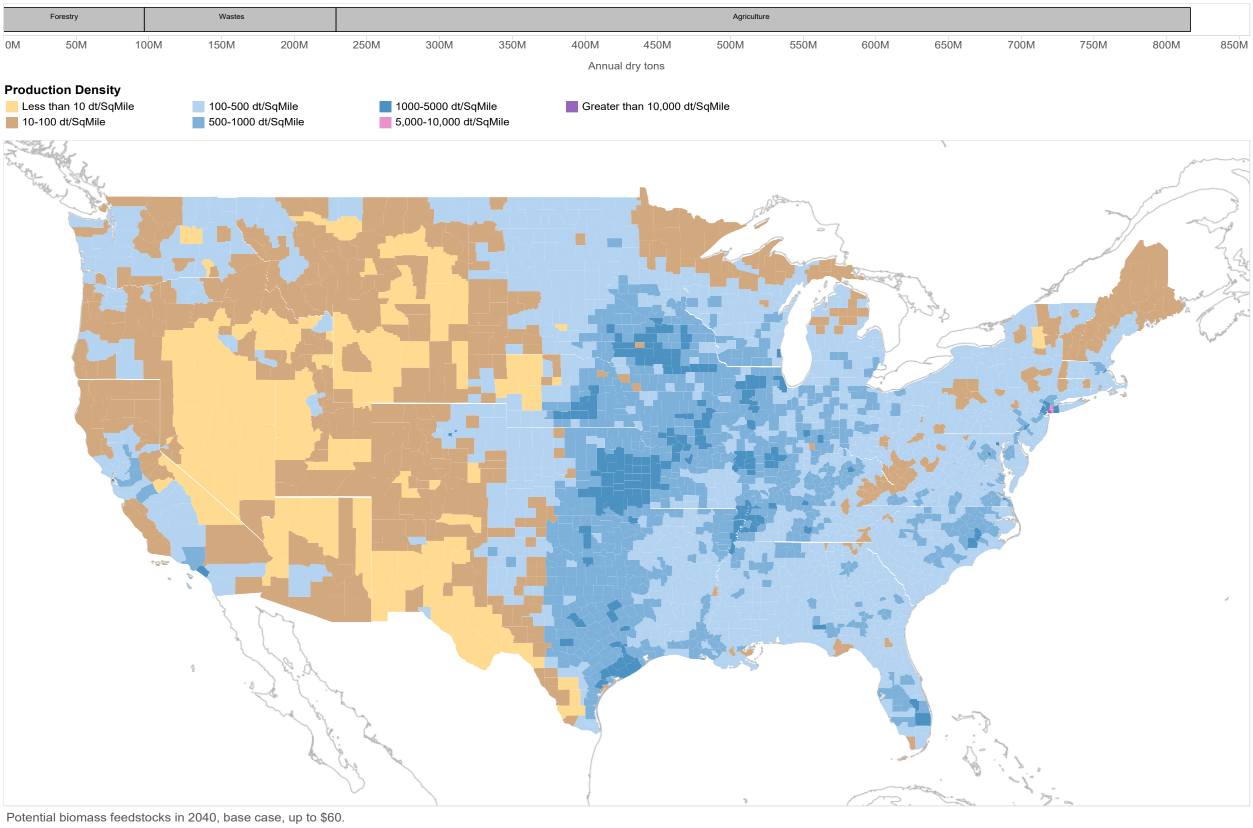

Figure F-11: Billion Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks. M. H. Langholtz, B.J. Stokes, and L.M. Eaton (Leads), Oak Ridge National Laboratory, Oak Ridge, TN 329 p.; doi: 10.2172/1271651

Progress to Date

To successfully compete in the fuels market, biofuel must be produced at low enough cost to compete with petroleum-derived fuels or provide performance advantages that offset any price premium. A minimum fuel selling price (MFSP) of $3 per gasoline gallon equivalent (GGE) can compete, without incentives, with fuels derived from petroleum costing $105–$113 per barrel. Technologies capable of producing fuel with an MFSP of $2.5 per GGE could compete with fuels derived from petroleum crude costing $84–$92 per barrel. While incentives from the Renewable Fuel Standard, California Low-carbon Fuels Standard, and other policies impact the economic viability of biofuels, analyzing the MFSP without incentives serves as a useful and consistent means of assessing technological progress.

Researchers and industry have made significant progress in lowering the MFSP of drop-in biofuels. As noted above in Section 3, there are number potential pathways however the DOE's Bioenergy Technologies Office tracks progress across eight example pathways that use various combinations of feedstocks and process technologies. Each pathway must produce fuels and coproducts that result in lifecycle GHG emissions at least 60% lower than a petroleum baseline. Figure F-12 illustrates technology development progress and projections of future improvements for one such example technology pathway,[156] woody biomass via catalytic fast pyrolysis (CFP) with upgrading to hydrocarbon fuel. R&D on this pathway has reduced the MFSP by over 50 percent between 2014 and 2020. This figure also demonstrates the importance of higher-value coproducts to meet MFSP targets that are more competitive with current oil prices. Progress and projections of future improvements for other technology pathways are published in the DOE's *Bioenergy Technologies Office, 2019 R&D State of Technology*.

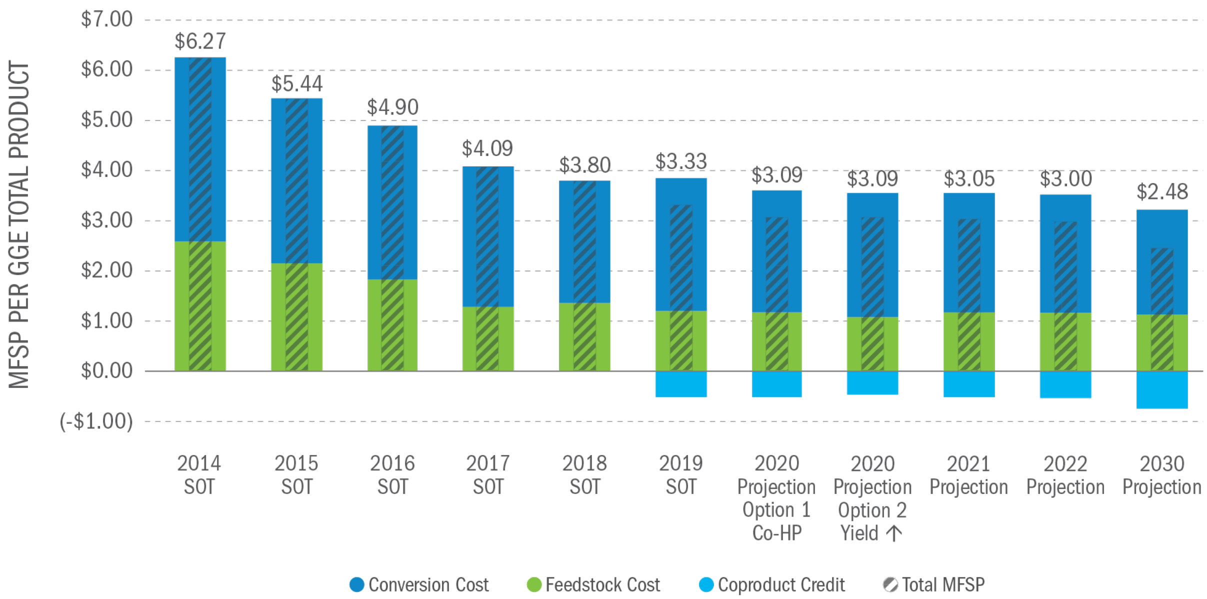

Figure F-12: Illustrative biofuel pathway progress toward $3/GGE (woody feedstocks via CFP pathway)[157]

[156] Additional example technology pathways are included in BETO's *MYP Technical Addendum*, which further details BETO's R&D portfolio. https://www.energy.gov/sites/prod/files/2020/07/f76/beto-2019-state-of-technology-july-2020-r1.pdf

[157] U.S. Department of Energy, *Bioenergy Technologies Office Multi-Year Plan 2020 Technical Addendum* (Washington, DC: U.S. Department of Energy, DOE/EE-1385, 2020), URL.

Appendix G. Goods Movement: Near-Term, Medium-Term, and Long-Term Recommendations

Opportunity/Recommendation	Near Term (1-3 years)	Medium Term (3-5 years)	Long Term (5+ years)
ENGAGE IN STRATEGIC PLANNING AND COORDINATION			
Establish a Federal Goods Movement Working Group with DOT and DOE to develop a comprehensive federal strategy for decarbonizing and improving energy efficiency of the transportation sector	X	X	
Work with the General Services Administration to: • Implement aggressive medium- and heavy-duty ZEV federal fleet purchase targets designed to achieve 100% ZEV purchases by 2050 • Transition the U.S. Postal Service delivery fleet to zero-emission in nonattainment areas by 2025, and nationally by 2030, and mail tractors (carrying loads to distribution centers) to 100% zero-emission by 2030	X	X	
Work with DOT and DOE through the 21st Century Truck Partnership	X		
Prioritize EV deployment to goods movement “hotspots”	X	X	X
Sponsor conferences and technical workshops for public and private sector MHD ZEV stakeholders, including at conferences, workshops or other forums focused on goods movement	X		
Advocate for creation of an interagency workforce development program	X		

Opportunity/Recommendation	**Near Term (1-3 years)**	**Medium Term (3-5 years)**	**Long Term (5+ years)**
Work with U.S. Department of Labor on educating the workforce on operation and maintenance of EVs (both hydrogen and battery electric)	X		
Lead a cross-agency effort to identify MHD ZEV research needs	X		
Work with USDOE to enhance the AFDC to collect usage data	X		
Advocate for single point of contact at USDOE			
Study MHD ZEV electric charging and hydrogen fueling infrastructure needs	X		
ENHANCE INCENTIVE PROGAMS			
Enhance and update SmartWay to include near zero- and zero-emission components	X		
Promote truck and bus electrification through the 21st Century Truck Partnership	X		
Explore ways to expand SmartWay partnerships	X		
Develop scoring rubric for federally funded projects that gives greater weight to use of near zero- or zero-emission equipment on the project	X		
Expand Energy Star to DC fast chargers (currently only applies to Level 2)	X		
IDENTIFY SUSTAINABLE FUNDING			
Seek a prime role in implementation of the Biden-Harris Administration's "Build Back Better"	X		
Coordinate with Electrify America	X		

Opportunity/Recommendation	**Near Term (1-3 years)**	**Medium Term (3-5 years)**	**Long Term (5+ years)**
Explore potential international collaboration and partnerships	X		
Provide guidance on how the U.S. Department of Agriculture's Electric Programs could be expanded		X	
Work with DOT and DOE to enhance the use of their grants for air quality improvement projects	X	X	X
Provide funding for development, commercialization, and implementation of cleaner technologies	X	X	X
Provide funding for sector-specific technologies.	X	X	X
DERA and TAG funds should be increased to $150M and $75M respectively, prioritizing non-attainment regions.	X-elec only		
Provide voluntary incentives to encourage development and early introduction of new technologies and increase collaboration with key industry organizations	X		
Fund manufacturers' products validation to ensure implementation that is reliable and dependable.	X		
IMPLEMENT REGULATIONS TO FURTHER REDUCE EMISSIONS FROM THE GOODS MOVEMENT SECTOR			
Establish performance-based standards	X		
Establish the Phase 3 GHG regulation stringencies	X		
In the highway heavy-duty low-NO_x initiative, establish emission standards for idle and low-load conditions based on the CARB Omnibus regulation			

Opportunity/Recommendation	**Near Term (1-3 years)**	**Medium Term (3-5 years)**	**Long Term (5+ years)**
Implement additional regulations to encourage turnover of the fleet, thus ensuring that the medium- and heavy-duty fleet is as clean as possible (e.g., is subject to the new low-NO_x standards) during the transition to full electrification; CARB's rules can serve as a blueprint	X		
Explore opportunities to increase the use of renewable/cleaner fuels		X	
Work cooperatively with the railroads, locomotive and engine manufacturers, and fuel supply industry to perform testing and modification of existing locomotive engines using higher blends of lower-carbon alternative fuels (such as renewable diesel, biodiesel, low-carbon natural gas, etc.)	X		
EPA should strengthen its newly adopted CO_2 standard, which mirrors the ICAO standard adopted in 2016, and apply it to domestic flights and to flights all over the world	X		
Collect and evaluate data on VMT associated with cargo delivery pathways in order to understand emission profiles of cargo delivery pathways to drive delivery pathways to lowest emission options, specifically focused on urban, intermodal, and pollution hotspot areas		X	
PROMOTE SUSTAINABILITY IN GOODS MOVEMENT			

Opportunity/Recommendation	Near Term (1-3 years)	Medium Term (3-5 years)	Long Term (5+ years)
Identify emission-reduction and efficiency strategies currently used in goods movement and key barriers holding back adoption of newer strategies (see Appendix II). Provide consumers with methods to track the environmental impact of their choice of delivery method (perhaps similar to the efficiency ratings on vehicles). Identify how the evolution of new strategies has progressed, how organizations have overcome near term challenges, and how wider scale adoption can be accomplished. Illustrate how consumer choice can impact adoption of technologies.	X		
Serve as a clearinghouse for improvements that could be made through logistical efficiency/routing or mode shifting	X		
Gain an understanding of the entities, their business relationships, and ultimately business models that exist in the goods movement sector	X		
Characterize the phases of the goods movement sector, then identify potential key organizations in each sector for further engagement	X		
Stay abreast of new methods and innovation to understand the positive impact they can have on emission reduction	X	X	X
Evaluate how goods movement changed under the COVID-19 pandemic		X	
ADDRESS POLLUTION HOTSPOTS & HEALTH DISPARITIES			
Prioritize zero-emission projects for areas identified by EJ Screen or locally developed screening tools as being high priority based on vulnerability or health risk indices; provide guidance on how to incorporate transportation equity elements into guidance on scoring of transportation projects using screening tools	X		

Opportunity/Recommendation	Near Term (1-3 years)	Medium Term (3-5 years)	Long Term (5+ years)
The Assistant Administrator of EPA OAR, in consultation with state, tribal, and local agencies, should develop, make public, and implement an asset management framework for consistently sustaining the national ambient air quality monitoring system	X		
The Assistant Administrator of EPA OAR, in consultation with state, tribal, and local agencies and other relevant federal agencies, should develop and make public an air quality monitoring modernization plan to better meet the additional information needs of air quality managers, researchers, and the public	X		
Promote community engagement in measuring emissions Coordinate with EPA OAQPS on development and deployment of guidance on how low-cost community monitors may support regulatory monitoring framework	X		
Using the definition of ports as adopted in EPA's Port Work Group, EPA should designate ports as stationary sources of pollution and require mitigation for the activities derived from port activities	X		
OTAQ should review the Energy Policy Act of 2005 to determine if a certain percentage of DERA funding (e.g., 80%) can be earmarked for mitigation efforts in areas identified as vulnerable communities; vulnerable communities should be designated using EJ Screen coupled with information from local jurisdictions	X		
OTAQ should renew efforts to address emissions from borders; including engage with Mexico to encourage a request to IMO to designate an Emissions Control Area and efforts to address border crossing issues in areas like Laredo and Brownsville	X		

Opportunity/Recommendation	**Near Term (1-3 years)**	**Medium Term (3-5 years)**	**Long Term (5+ years)**
For significant national enforcement cases, maximize the use of Supplemental Environmental Projects to ensure violative emissions are mitigated; develop recommendations for supplemental environmental programs that could be implemented at the state level to support existing EPA opportunities such as DERA as well as develop EPA guidance/best standards/decision-making tool for highest use of available public funds like grants, VW, etc.	X		
Assess the potential for "local policy matching" requirements akin to financial matching to receive grant funding, demonstrating local policies in place that will assure best practices to reduce exposure to pollution	X		
Develop environmental best practices to reduce emissions impacts and policy options that lead to more equitable and mitigating land uses and built environments	X	X	X
While monitoring and other data-collection actions should be evaluated routinely, EPA should increase enforcement penalties on companies that fail to comply with required engine upgrades and replacements. For example, many tug engines are bypassing requirements to meet newer engine standards during re-builds. EPA OTAQ should work with EPA OECA to penalize those skirting new standards.	X		
Conduct emissions mapping of environmental justice communities	X		
Evaluate least-distance transit policy incentives and incentivize buying/dealing locally, creating relationships for manufacturing inputs and local customers to reduce emissions and other impacts by reducing miles traveled	X		

Opportunity/Recommendation	**Near Term (1-3 years)**	**Medium Term (3-5 years)**	**Long Term (5+ years)**
Continue to promote the guidance and continued conversation with communities and other stakeholders to enable a better understanding of the impact of goods movement and identification of opportunities to minimize that impact	X		
Collaborate with state, tribal, and local air agencies to ensure that rules, policies, and programs related to goods movement achieve emission reductions sufficient to achieve and sustain clean air and environmental goals and protect public health in all areas of the country, and particularly in overburdened communities	X		

Appendix H. Goods Movement: Research and Technology

Although mostly from a southern California perspective, many of the goods movement challenges being faced in the region, due to two largest ports in the nation of Los Angeles and Long Beach and the extreme non-attainment status of the South Coast Air Basin, are harbingers to the issues that will face other goods movement areas. Heavy-duty trucks, off-road equipment, marine vessels, and locomotives are the largest contributors to NOx emissions, particulate emissions, and smog, and due to these issues, the state of California has established a suite of goods movement-related regulations to curb those emissions.

Largely due to these impending regulations and policies, industry has responded with large and concerted efforts to develop and commercialize cleaner technologies for these vocations. A snapshot in time of the current status of technologies and anticipated early commercialization are shown in Figure H-1 below. Technology readiness level (TRL) 9 indicates the cusp of pre-commercial capability but may still require additional testing, verification, and warranty level information before a product is ready for the market.

Figure H-1: Technology Readiness Timelines

Barriers to Technology

Technology is an important tool in managing and improving environmental air quality. "Technology" can be defined as being *the study and knowledge of the practical, especially industrial, use of scientific discoveries*.[158]

Technological change is the focused application of technology to achieve goals. Such change doesn't just "happen," it must be carefully implemented and managed.

This section:

1) discusses some common barriers to technological change,
2) recommends several tools for assessing and successfully managing change, and
3) makes specific recommendations for U.S. EPA actions in support.

Managing and implementing technological change is critical to achieving goals. The risks of failing to properly manage technological change include:

1) time lost pursuing technologies and/or projects that ultimately fail,
2) wasting private and/or public funds, and
3) failing to achieve environmental improvements.

Barriers to Change: The Dilemma of Cost v Demand

Supply and demand, in economics, is the relationship between the availability of something and the price that users or consumers are willing to pay. Generally, when the price of something wanted by users or consumers declines, sales (and production) will increase. New technologies (and new products) also have a supply versus demand relationship, but supply and demand can be intertwined barriers. This is especially prevalent in the world of vehicles (automobiles, trucks, and locomotives) and machinery (mining trucks and excavators, cranes, etc.).

The first barrier is high cost of components (particularly in emerging technologies), and the second is low sales volume. This relationship can be found in markets using electric and hybridized transmissions, new types of fuels and advanced vehicle powertrains. Lithium-ion batteries for zero-emission cars, for example, are becoming increasing less expensive (and better performing) as technology has improved but especially as both demand and supply have increased. Another industrial example was the introduction of locomotives with alternating current (AC) motors in the mid-1990s, offering greater pulling power and lower maintenance, but at a cost premium compared to traditional locomotives with direct current (DC) motors. Now, however, 25 years later, only AC-motored locomotives are newly manufactured, the result of a shift in customer preferences and changes in both supply and demand. Over time, the manufacturing costs (and sales price) of AC and DC motored locomotives converged.

Costs and volumes are intertwined because low demand means low production, and low production means higher costs per unit. Initially high prices damp down product demand, and low product

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[158] Definition of "technology," https://dictionary.cambridge.org/us/dictionary/english/technology

demand limits production. During early stages of a technology, supply and demand become especially intertwined.

When new products (or new technologies) enter the sales stream, various markets will respond differently. Underground mining, for example, exhibits some willingness to absorb higher prices for advanced machinery offering increased productivity and environmental improvements. Other industries may have more elastic demand and are less tolerant of higher prices. It is likely that supply and demand for (and, therefore, the price of) lithium-ion batteries will always be dominated by the electric automobile market. Industries with lower total demand (such as electric trucks and possibly locomotives) will likely never dominate battery demand.

Low supply and initially high prices are significant headwinds to making technological change. In general, it can take as many as 3 generations of products for costs (and therefore selling prices) to become normalized. Another headwind is the pace of new technology. In general, only computing power has increased tremendously over the past several decades. A Northwestern University economist has studied American innovation and economic growth and concluded that the key technologies of our modern life (except computing power) were all created by 1970: safe drinking water and sanitation; electricity (indoor lighting, powered machines, improved heating and air conditioning, and refrigerated foods); mechanized production of food; improved transportation (railroads, automobiles and trucks, highways, aircraft); and modern medicine and drugs.[159]

Barriers to Change: Reliability, Durability & Maintainability

Consumers often experience the same issues with unreliable technology as do industrial users, but the financial penalties for large users of unreliable technology, technology that isn't durable or is difficult to maintain can be extreme. Which is why many industrial sectors are reluctant to become "first movers," acquiring new technology at the risk of discovering something becomes a reliability or maintainability nightmare. This reluctance to become a "first mover" adds a time delay in accomplishing change. The "flip side" of becoming a "first mover" is gaining competitiveness if the "technology bet" is successful.

Reliability is one of the highest valued industrial characteristics, particularly in the transportation sector. Productivity is key, and "down time" due to failures or excessive maintenance directly reduces output which is the amount of operating time multiplied by the per-hour production rate. A machine available 95% of the time can have 5.5% more output than a similar machine available only 90% of the time.

Durability and maintainability are important as industrial users don't acquire machinery or vehicles simply to acquire equipment; they invest in equipment as capital tools to operate their businesses. And the more unproductive time, manpower and expenses needed to keep machinery and vehicles operating safely, the lower the return on the equipment's financial investment.

Equipment downtime costs vary among different industries. In the mining industry, for example, massive haul trucks and excavators that load them can have downtime costs of $15,000 to $20,000 per hour for each machine. This is where wise decisions must be made in designing, manufacturing, acquiring, operating, and maintaining such machines. Acquisition cost may be lowered by avoiding

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[159] Gordon, Prof. Robert, 2017, "The Rise and Fall of American Growth (The U.S. Standard of Living Since the Civil War)," Princeton University Press.

redundant sensors or by using a lower-cost sensor, for example, but the loss of a single NOx sensor on the engine, without a back-up sensor, can force the engine out of service until a technician can arrive with a replacement sensor. And operating conditions for similar engines, for example, can vary widely (installed on mine haul trucks, in locomotives or onboard ships and boats).

There is often great pressure to take new technology and implement it. But unless new technology (and technology-related products) is carefully designed, tested, redesigned and only then commercialized … the risk of failure remains high. Manufacturers of trucks, for example, subject pre-production fleets of new-design trucks to extensive testing to “shakedown” their designs:

“We try to figure out how somebody might use these and maybe misuse them. We can break just about anything,” said Sheldon Brown, chief engineer for research and development, working on the Toyota Tacoma.”[160]

Unfortunately, such “torture testing” of new vehicles cannot always be accomplished as quickly with larger more-expensive equipment like locomotives. (A new heavy-duty truck tractor may cost $125,000; a new locomotive $3.2 million to $7 million.) This is where tools such as “reliability growth testing (RGT)” can make technological change more successful. RGT is discussed later in this section.

The important point here is that “experiments” cannot be considered “ready for mass use”. This is discussed below under “Commercial Readiness Indicator”.

Barriers to Change: Waste Streams, Rare Materials & Infrastructure

Large wind turbine blades (lightweight and often made from single-use reinforced fiberglass) are special-purpose and, at end-of-turbine life, have no secondary use or application, so they are commonly “landfilled.”[161] Most objects eventually “wear out” and when retired they need to be properly disposed. This is a growing issue for batteries. Currently there may be no established industry protocols or standards for disposal of technological waste streams.

Some technologies, especially storage batteries and high-performance lightweight electric motors, depend on the availability of precious or “rare” materials such as elemental platinum, lithium, molybdenum, and their chemical compounds. Availability of these materials directly affects the availability and cost of alternative powertrain products. And global political, environmental, and economic events can introduce material price instability, increasing financial and supply train problems for manufacturers. Research is ongoing to reduce dependence on premium or rare element metals, for example, but increasing demand (and therefore price) for such materials becomes a barrier or headwind to change. The less diversity there are in market solutions the more a supply shock will impact manufacturers and industry.

Infrastructure is a major barrier to technological change. This impacts commercial electricity, renewable natural gas, hydrogen, ammonia or whatever alternate fuel or energy carrier is required or desired. And infrastructure includes production, storage, and transmission facilities. Changing infrastructure is usually never simple, cheap, or quick to happen, and may even involve additional

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[160] “The brutal and extreme tests Ram, Ford Chevy run on trucks,” https://www.freep.com/story/money/cars/2018/11/02/chevy-ford-ram-truck-tests/1809135002/
[161] “Wind Turbine Blades Can’t Be Recycled So They’re Piling Up in Landfills,” https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills

technological change (such as improving the large-sale storage of electricity which has historically been instantaneously produced and used without any "storage buffers").

Barriers to Change: Understanding Technological Change & Development

Developing and maturing new technologies (and applications) involves multiple paths and variations, but consistency of effort is usually best for long term progress. Commercial businesses have limited resources, and there are practical limits to how many different technologies can be examined, tested, vetted, and eventually used. Variability is both an opportunity and a challenge and risk when looking at different fuels and energy carriers (batteries, natural gas, hydrogen, methanol and ethanol, ammonia, etc.). Businesses can get multiple and often competing suggestions from environmental organizations, government agencies, NGOs, and inventors. Evaluation of alternatives requires dedicating limited resources.

Sources of fuels and energy carriers need to be thoroughly researched and discussed. For the foreseeable future, much of the nation's electricity will not be from renewable sources, and electricity generation produces 26% of all GHG emissions (second only to transportation's 27%). Decarbonizing electricity will require a massive effort. Producing ammonia (as a fuel) from natural gas may reduce GHG more than using natural gas as fuel for internal combustion engines. The U.S. Environmental Protection Agency and other agencies and authorities need clear and common understanding of scalability of technologies and the real impacts of alternative fuels.

Managing Technological Change

The first part of this section has discussed "technology" and some of the barriers to effectively developing and using technology. In this section the emphasis shifts to improving the success of technological change.

Technological change generally involves three activities:

1) **Invention** (the discovery or creation of an idea);
2) **Innovation** (experimentation and creating a prototype); and
3) **Commercialization** (mass production of the idea or discovery for actual users).

An idea or discovery for the business world, by itself, is *not* successful change; and an experimental prototype (especially "one of a kind") is usually insufficiently proven or vetted under real world conditions. Therefore, the complete "change cycle", from invention to innovation to commercialization, must be completed.

A goal of technological change may be, for example, introducing a new vehicle for moving people or freight, changing transport or logistics to reducing the time to deliver freight, mail, or packages, or reducing the environmental impact of such activity. However, users of technology (be they investor-owned corporations, government agencies or non-profit organizations) generally do not (and should not) widely embrace, acquire, replicate, and make large investments in experiments solely on a promise of performance. They should expect and demand actual "proof of concept", part of a process known as "due diligence". Therefore, the third step, commercialization of a prototype, is so critical to ultimately avoiding failure to achieve the desired change.

"Successful implementation" is defined here as minimizing the risks and maximizing the beneficial outcomes.

Why Technological Change has to be Properly Managed

There can be extreme costs involved in making "bad choices" with new technology: capital dollars that end up being wasted on projects that have failed; machines or IT systems purchased and put into service that don't meet the requirements for which they were created; and even machines and IT systems that end up being scrapped prematurely. As technological complexity increases, the risks of failing to achieve the goals also increase.

One research paper, for example, cites "complexity" as a root cause in the failure of large-scale very-complex IT projects,[162] and 54% of such failures are caused by "poor management" including having a poorly defined outcome, lack of leadership or accountability and bad project scheduling (time expectations).[163]

Even the worldwide automotive industry has had its share of "technology flops", despite massive investments. One report cites poor marketing expectations that lead to new automotive failures.[164] A UK company invested $500 million designing a battery powered EV automobile and then ended the project when the projected manufacturing cost (i.e., before any sales profit) reached $182,000 per car, an unmarketable price for automobiles.[165]

"TRL" as a Readiness Assessment for Experiments & Prototypes: Valid or Not?

"TRL" is the abbreviation for Technological Readiness Level, a measure created in 1974 by the National Aeronautics and Space Administration (NASA) to assess "readiness" of scientific technologies for NASA's various space missions.[166] NASA's TRL scale has 9 levels (shown below), with the highest (TRL=9) meaning "*actual system 'flight proven' through successful mission operations*."

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[162] "The Root Cause of Failure in Complex IT Projects: Complexity Itself," https://www.sciencedirect.com/science/article/pii/S1877050913010806
[163] "Are These The 7 Real Reasons Why Tech Projects Fail?" https://www.forbes.com/sites/bernardmarr/2016/09/13/are-these-the-real-reasons-why-tech-projects-fail/?sh=50b4b1eb7320
[164] "Top 10 Automotive Failures of the Last 15 Years," https://www.msn.com/en-us/autos/research/top-10-automotive-failures-of-the-last-15-years/ar-AAbAQM4
[165] "Dyson unveils its $500 million electric car that was canceled," https://electrek.co/2020/05/18/dyson-cancelled-electric-car/
[166] "Technological Readiness Level," https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

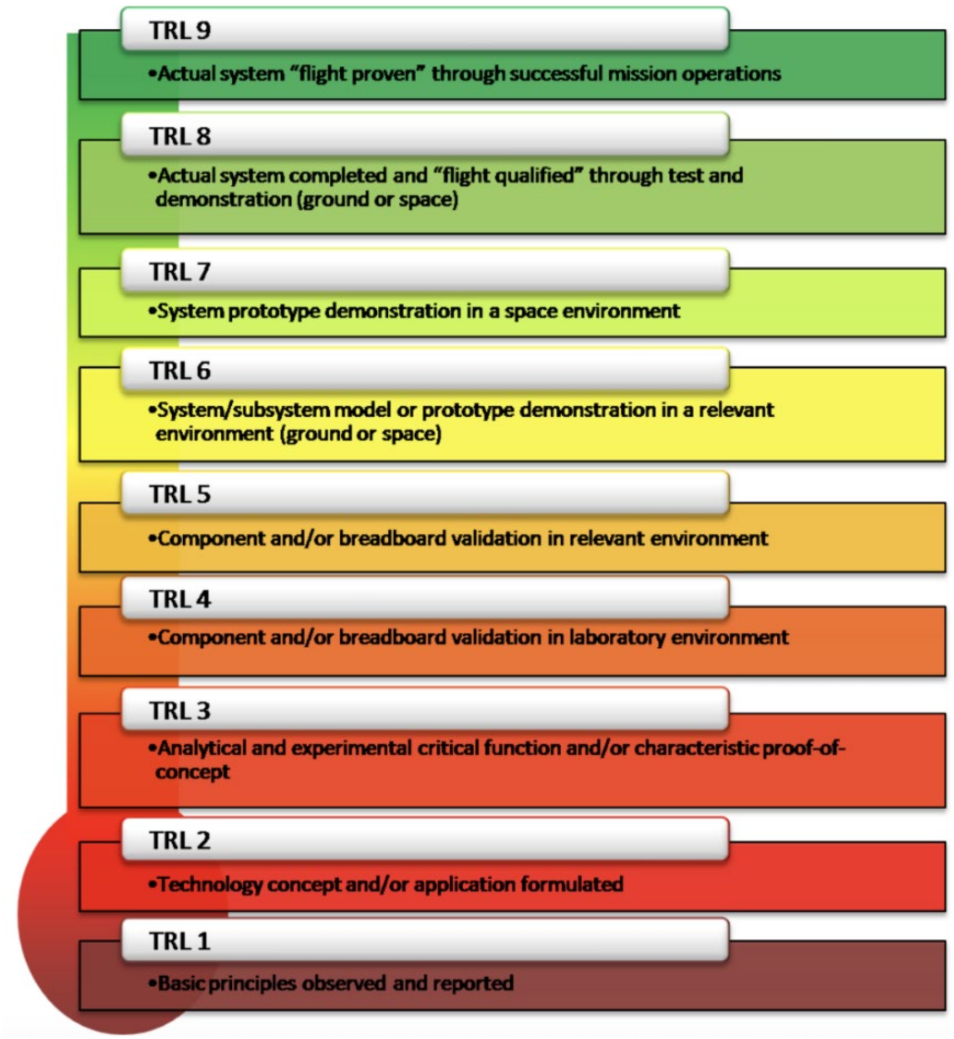

Figure H-2: NASA's TRL Scale

The NASA Space Shuttle, for example, was always rated by NASA as being TRL=9. The Shuttle was a fleet of 5 low-Earth orbit rocket-launched space vehicles, operating between 1981 and 2011, each being partially reusable after launch and recovery. "Partially reusable" meant each Shuttle required extensive inspection, repair, and maintenance after each launch because the thermal tiles that protected the spacecraft body against the heat of re-entry were partially burnt off. The Shuttle was not, importantly, not a commercial venture or technology, comparable to commercial airliners.

And even though NASA assigned level 9 to the Shuttle, in 135 launches 2 of the 5 Shuttles were destroyed with total loss of the spacecraft and both crews.[167,168] This refers to two weaknesses in using the NASA TRL scale to assess readiness of any new technological development.

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[167] "Post-Challenger Evaluation of Space Shuttle Risk Assessment and Management," https://www.nap.edu/catalog/10616/post-challenger-evaluation-of-space-shuttle-risk-assessment-and-management
[168] "Early Shuttle Flights Riskier Than Estimated," https://www.npr.org/2011/03/04/134265291/early-space-shuttle-flights-riskier-than-estimated

- “Maturity” of any technology has no clear definition.
- Even a one-of-a-kind prototype can be ranked as being “flight ready” based on one mission (a launch, a flight, a trip, etc.).

A U.S. airplane manufacturer, in fact, has gone on record cautioning against unbridled use of the TRL scale in assessing technological readiness. Quoting from a published report:[169]

“The modern established metric for technology maturity has been the TRL, or “technology readiness level,” which originated at NASA headquarters in 1974 using a scale from 1 to 9.

“For many in the research and development community a technology is generally “proven” when it reaches Technology Readiness Level 6, at which point it has achieved “System/subsystem model or prototype demonstration in a relevant environment.” And once proven, there should be no reason why the technology isn't available for use in every relevant application, right?

“Well, not really.

“In reality, there is a colossal distance between being technically proven and having a successful implementation. This difficulty in transitioning a new technology or approach is affectionately referred to as “The Valley of Death.”

“In industrial practice, there are many factors threatening the livelihood of technologies that are “ready.” There is an established Manufacturing Readiness Level (MRL) scale, adopted by the U.S. Department of Defense in 2005, that addresses the feasibility and affordability of producing the technology at the required scale and rate. There are also integration maturity metrics used to assess an Integration Readiness Level (IRL) scale. And both of these contribute to a System Readiness Level (SRL).”

Commercial Readiness Indicator (CRI) as a Supplement to TRL

Businesses, government and NGO bodies in Australia and the European Union have also been recognizing the limitations of using TRL in “green lighting” technological developments. The Australian Renewable Energy Agency (ARENA) supplements the TRL scale with a “Commercial Readiness Indicator (CRI)” to more fully assess progress in making technological change.[170]

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[169] “Technological Readiness and the Valley of Death,” https://www.boeing.com/features/innovation-quarterly/may2017/feature-thought-leadership-newman.page

[170] “Technological Readiness Levels for Renewable Energy Sectors,” https://arena.gov.au/assets/2014/02/Technology-Readiness-Levels.pdf

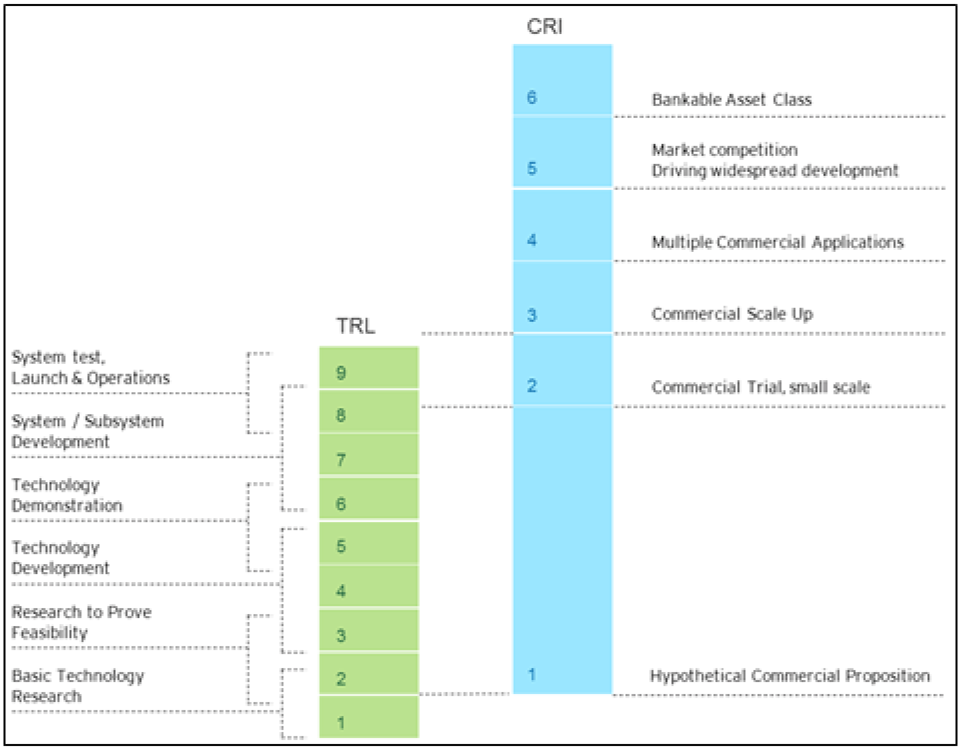

Figure H-3: TRL and CRI

The CRI scale has 6 levels, with CRI level 2 ("commercial trial, small scale") equivalent to TRL level 9 ("system test, launch & operations"). The Australian government CRI scale appears comparable to the "System Readiness Level" discussed in the aircraft manufacturer's paper.[171]

It is only when the development reaches CRI level 6 ("bankable asset class") that a technological development is considered "*ready for commercial deployment*." "Bridging the gap" between the TRL scale (focusing on experiments or prototypes) and the CRI scale is what we referred to at the beginning of this discussion: *innovation*. Innovation means taking an experiment or prototype and transitioning it into a progressive state of commercial readiness.

Before committing corporate, private or government funds to any major technological development, a funding entity should consider and require answers to these questions:

1) Is the current state of the development an "experiment" or a "prototype"? (If the answer is "yes", it may only be at TRL level 9, and not truly ready for production and commercial use.)

2) Have commercial versions been placed into operation on a limited scale in the real world? (If the answer is "yes", it may be at CRI levels 2 or 3.)

[171] *Id.*

3) Has the development seen enough real-world use, been thoroughly evaluated and are funding entities (corporations, banks, government agencies, NGOs) willing to safely commit funds for acquisition? (If "yes" it is a "bankable asset class".)

Does "Verification" Assess Reliability, Durability & Maintainability?

With respect to emissions of mobile devices (automobiles, trucks, construction equipment, locomotives, boats, and ships, etc.) "verification" may or may not encompass the "entire machine", focusing only on emissions performance. As discussed elsewhere in this section, reliability, durability, and maintainability are also key measures of (1) how successful a mobile device will be in performing its intended lifetime mission and (2) the ease or difficulty of mobile device users in operating the device over its intended lifetime mission. Therefore, "emissions verification" may not directly correlate with long-term lifetime reliability, durability and/or maintainability of the entire mobile device.

Reliability Growth Testing (RGT)

The last "tool" to consider in successfully managing technological change is related to 'bridging the gap" between the TRL and CRI scales. Reliability Growth Testing (RGT) is a statistical tool developed for assessing reliability of military machines and systems in the late 1960s.[172]

Prior to the introduction of RGT, the Department of Defense usually purchased ground, flight and naval vehicles based on "prototype demonstrations" and often discovered that reliability was poor and maintenance demands were great, after large-scale expensive acquisitions of equipment. RGT was first used during the Vietnam War to increase the flight time between maintenance events of Blackhawk helicopters by a factor of four.

When transitioning from CRI level 2 (commercial trial, small scale) to CRI level 3 (commercial scale-up), an important tool that should be used is "reliability growth testing" or RGT. RGT is the actual use (and for "machines" their maintenance) in a real-world environment (such as being driven by users, not engineers, and maintained by users, again not engineers) to "shake down" a limited number of machines to identify as many potential failure modes as possible *before* mass production begins.

In simply words, you don't want to mass produce and possibly sell something (even software) unless it has been "shaken down". We don't have time or space in this discussion to fully define how to perform RGT; suffice to say If you are managing "something new" you should consider requiring RGT to be properly performed. And before performing RGT, the user should determine *What is our acceptable limit of failures for the long term?*

In other words, how many times per year of operation or per 100,000 miles travelled or per million packages sorted, are you willing to accept a truck's failure or a sorting systems inability to read shipping labels?

An example of using RGT would be the introduction of a new series of railway locomotives using a radically new propulsion technology. One (or a "handful") of experimental locomotive units may be insufficient to identify the most critical failure modes that could cripple long term performance. An RGT approach would be to accumulate a statistically significant number of "locomotive unit-years" of

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[172] "Reliability Growth for Military Vehicles-Emerging Methodology and Remaining Challenges," https://www.jstor.org/stable/44658084?seq=1

operation and maintenance on commercial railroads, using railroad personnel (a "unit-year" is one locomotive unit operated-and-maintained for one calendar year). Depending on the complexity and the amount of new technology being used, the RGT requirement for a new locomotive technology could be as great as 30-to-50 "unit-years" (achieved by having a pre-production fleet of 15-to-25 locomotive units operated-and-maintained for 2 years). The same process would apply to new truck tractors, as another example.

RGT should demonstrate that your acceptable level of failures (mis-performance) is achievable and will not be exceeded, but it must be done before large investments are made.

Avoid Misconceptions about Managing Technology

Our last comment is a retrospective look at how "managers" typically misunderstand technological change. Lowell Steele, a former vice-president, and chief technology planner for the General Electric Company, published in 1984 the book "Managing Technology" in which he listed the most common misconceptions of managers in making technological change.[173] Steele listed 7 misconceptions, later expanded to 9. Here are Lowell Steele's "managers' misconceptions" (shown on the left) with 9 corresponding "realities" (on the right):

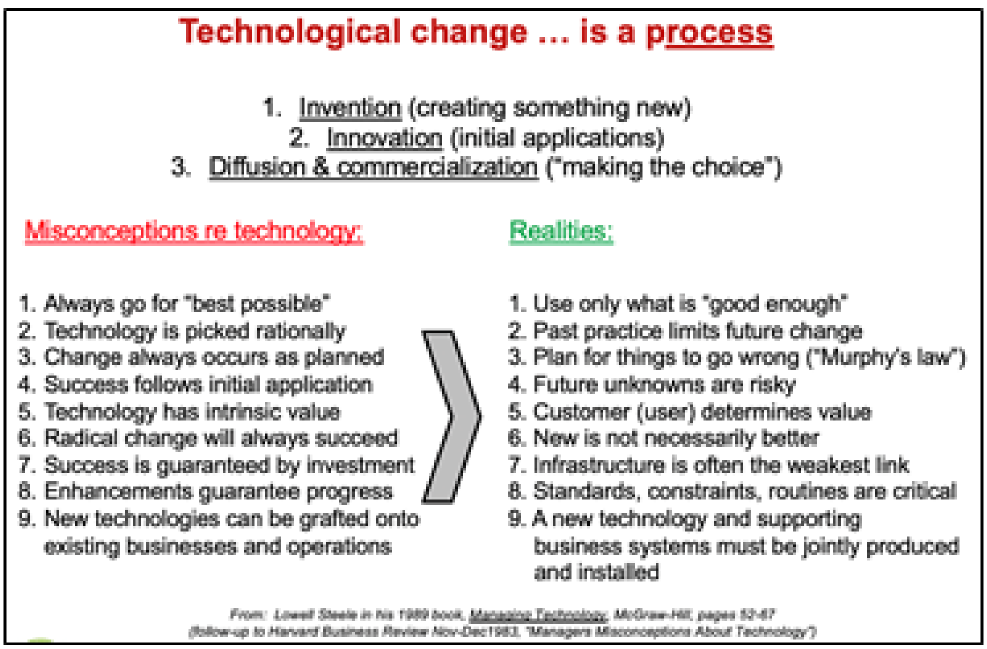


Figure H-4: Lowell Steele's "Managers' Misconceptions"

[173] Steele, Lowell, 1989, "Managing Technology," McGraw-Hill, ISBN13: 9780070608365

Appendix I. Technology Group Presentation

Scenario 1: Technology

I. Agency Considerations in a Future where the Majority of New Vehicle Sales are Zero- Tailpipe Emission Technologies

Alternative Regulatory Structures

- Shift from

Mobile Sources	Stationary Sources
Tailpipe	Powerplant Smokestacks
Aftertreatment/ OBD vehicle systems	Battery Mineral Extraction, Refining and Transportation

- Develop global technical regulations on battery durability including OEM certification of range or battery energy
- Monitor, collect data, and understand the emissions inventory, battery energy and range to guide the agency on key areas of focus

Approaches to Emissions Averages

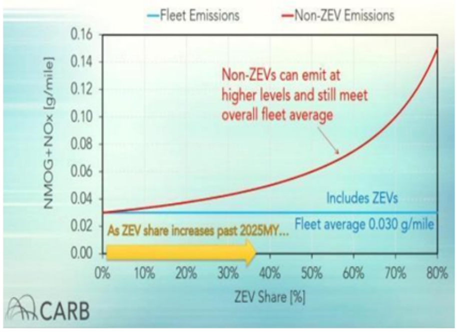
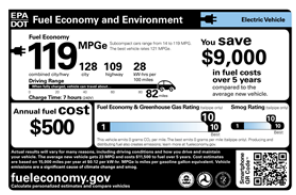


Figure 1: CARB presentation illustrating NMOG+NO_x "backsliding" concept. (California Air Resources Board, 2020).

- Fleet-average emissions reimagination needed to accommodate ZEVs, viable approaches include
  - Placing a ceiling on NMOG+NO_x emissions
  - ICEVs and ZEVs continue as a combined fleet average - standards set using a cost-benefit basis.
- Continuous agency monitoring provides information on total fleet emissions, directing appropriate controls

Electric Vehicle Efficiency Standards



- Understanding PEVs' grid impacts requires understanding vehicle efficiency
- EPA already tracks MPGe and communicates kWh/100mi information on vehicle window labels
- Should PEV electric efficiency be regulated? No clear answer.
  - Ensuring higher efficiency would put downward pressure on PEVs' grid demands
  - However, increased renewables in grid will lower environmental impact of PEV charging, regardless of vehicle efficiency
- Grid impacts aside, EV efficiency standards could materials-based environmental impacts
- OEMs are already highly motivated to improve efficiency, to address range anxiety

<u>Recommendations</u>

- Evaluate whether there is need for electric vehicle efficiency standards. Consider the impact of existing market drivers including consumers' demand for adequate vehicle range, as well as the role of continued customer choice in furthering ZEV adoption
- Consider which agenc(ies) are best suited to address this issue. EPA has longstanding expertise with emissions and vehicle regulations; DOE has longstanding experience setting minimum efficiency standards for a wide range of household appliances

Leveraging Fleets & CASE

- During transition to carbon neutrality, explore creative and targeted approaches to particular segments—such as fleets, including ride-hailing operations—to accelerate adoption
- Fleets are well-suited for early and accelerated electrification because they often perform a large share of stop-and-go urban driving or defined routes.
- Annually evaluate and report on the pace of transportation:
    - "revolutions" that are likely to impact air quality, including (but not limited to) connected, automated, shared and electric mobility
    - "evolutions" that are likely to impact air quality, including micromobility, public transit, goods movement, and livable communities

Ride-hailing in Henri Tudor's electric car (c. 1902)

Equity

- **Identify high priority underserved communities for maximum benefit**
- **Consider both stationary and mobile sources, based on community pollution monitoring**
- **Identify potential barriers to accessing such technology or programs (cost, infrastructure, etc.) and establish programs to address**
- **Foster and maintain relationships with companies, manufacturers and community leaders to identify services needed in communities**
- **Provide continual outreach, support and funding opportunities to community-based organizations and non-profits for consumer education and advocacy focused on sustainable transportation**

Scenario 1: Technology

II. Agency Considerations During the Transition Toward a Zero-Tailpipe Emission Technology Future

Steering an Industry Transformation

- As industry moves toward carbon neutrality, EPA should consider how potential changes in the passenger vehicle market could require additional or new regulatory approaches.
- Track emissions reductions progress from stationary sources, to further understand the transportation sector's well-to-wheels footprint
- Significant criteria emissions reductions have been realized; further reductions can be expected as fleets turn over
- Investment in nearer-term tech can deliver additional benefits, but there are opportunity costs involved for automakers with finite resources making long-lead-time investments.

<u>Recommendations</u>

- Continue cost-benefit analyses of:
  - Criteria emissions benefits of tighter tailpipe standards, relative to reductions from natural fleet turnover
  - GHG emissions benefits of greater market penetration of existing electrified vehicle technologies
- Study potential role of scrappage/retirement programs to accelerate emissions reductions. Such a study should consider effect on the used vehicle market, and potential impacts to underserved communities.

Understanding Consumer Adoption

- Important for EPA to maintain robust understanding of consumer adoption issues:
  - Up-front costs, infrastructure access, consumer awareness and other market barriers
  - Vehicle "parity," including purchase price parity, performance/functionality/convenience parity, technology cost parity and total cost of ownership
  - Impacts of complementary policies, such as LCFS, HOV lane access, etc.

<u>Recommendations</u>

- EPA should play a convening/educating role and leverage its influence on consumer adoption of ZEVs
- EPA should consider how durable market-based policies for emissions reductions – including carbon taxes and cap-and-trade programs – can influence purchase decisions
- EPA should consider establishing a national Low Carbon Fuel Standard, implemented to support ZEV uptake and continued decarbonization of the transportation sector

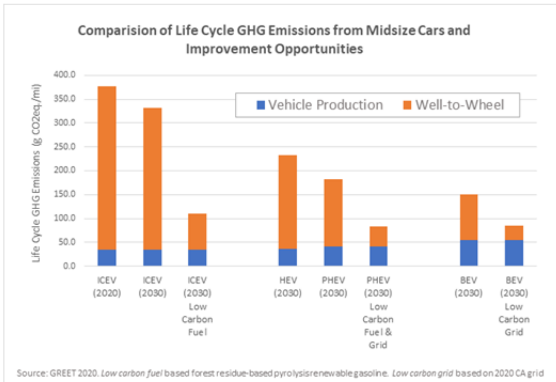
Public Education

- Public education will be critical to fostering greater ZEV adoption
- EPA can fill a critical role in providing factual, unbiased information to businesses, schools and federal/state/local policymakers
- Consumer information on grid emissions, charging considerations, V2G

<u>Recommendations</u>

- Leverage focus groups to help identify public education strategies that address evolving consumer understanding of, and receptivity toward, vehicle electrification
- Provide educational materials on ZEVs, V2G, infrastructure and other critical information
- Working with constituents and community leaders, provide tailored information that addresses the diverse needs of various segments of the public

Driving Neutral And Low Carbon Fuels



- Considerations:
  - Establishing a national Low Carbon Fuel Standard aimed at decarbonize liquid fuels, electricity and hydrogen
  - Implement socially equitable carbon pricing
  - LCA as a tool for reviewing progress while monitoring mobile CO2 reductions at the state level
  - Implement policies to support vehicle to GRID integration

Carbon reductions are needed across the board from transportation, energy/fuels and infrastructure. Continue to treat fuels (energy) and vehicles (transportation) as a system.

Issues Specific to Medium- and Heavy-Duty (MD/HD) Zero Emission Vehicles

- **Functional Capability** – much higher load and energy demands for MD/HD linked to heavy hauling/towing requirements
- **Infrastructure** – ZEV infrastructure (electricity and hydrogen) may be unfamiliar to fleets. New technology, fueling, charging, and operational logistics may pose challenges to fleets.
  - Electricity rates and hydrogen fuel costs need to provide value to fleets to facilitate easier transitions
- **Model availability** – Today's limited zero-emission MD/HD model selection is expected to change.
  - Fleets in market segments that have centralized re-charging/re-fueling and limited travel distances may benefit the most with compelling business cases.
  - Governmental fleets are best positioned to lead by example
- **Equity** – many MD/HD operate near ports, warehouses, and other freight hubs typically located near underserved communities; shifting to MD/HD ZEV provides benefit to these areas as well as to the environment

Appendix J. Personal Mobility Group Presentation

Future Mobility Workgroup Recommendations

June 9, 2021

Review: Our Scenario

- ***In a world where the majority of people in the U.S. get from Point A to Point B using a transport mode other than a personally owned vehicle, describe EPA's work and role in reducing emissions transportation while maintaining mobility and accessibility.***
- Modes considered:
  - All forms of ***Shared Mobility*** (e.g., fixed and flexible transit, TNCs, carsharing and bikesharing, etc.)
  - **Active transport** (i.e., bike/pedestrian)
  - **Micromobility** (e.g., scooters, bikes)

Consider these modes in the context of increasingly smart and automated surface transport systems

2

“First Principles” to Guide Our Work

We want to:

- Reduce tailpipe and lifecycle GHG and criteria emissions via innovative personal mobility options (Note: not all modes reduce emissions, e.g., mitigate externalities)
- Integrate principles of environmental justice by reducing disproportionate health and other impacts, while increasing social equity, affordability, accessibility, and mobility to create economic opportunity
- Create an efficient transportation system that integrates safety and health concerns to holistically reduce risks to all people

3

Definitions

Social Equity focuses on fairness and justice. This means distributing resources to people in a just and impartial way. It does not give everyone the same thing (i.e., equality) but rather it focuses on giving everyone what they need today.

Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (US EPA website). See: https://www.epa.gov/environmentaljustice

Mobility Justice applies a wider less than transportation equity. It calls for recognition, participation, deliberation, and procedural fairness discussions, adjustment, and repair. It goes beyond the traditional notion of accessibility by focusing on cultural meaning and the hierarchies surrounding mobility infrastructure by addressing power issues (e.g., valuation and who determines value). It focuses on intentional inclusion by putting underserved and historically marginalized groups at the center of mobility debates, data collection, and analysis (Sheller, 2018). See: https://www.versobooks.com/books/2901-mobility-justice

4

Questions the Group Wrestled With

- How to integrate social equity and mobility justice in EPA's work
- How to ensure a strong voice for EPA at the table with other federal (and state) agencies in crucial policy and program development related to innovative mobility options, electrification, vehicle automation, and safety concerns
- How EPA might adopt incentives or mandatory approaches to support more multi-modal transportation, electrification, higher occupancy levels, and mode shift to active transport
- How EPA could manage automated vehicles in terms of emissions and VMT growth
- How EPA should work to improve access to data, models, tools

5

We Recommend EPA Should:

- Prioritize social equity and mobility justice across personal mobility strategies moving forward in all agency actions
- Engage with federal and state partnerships and cross-agency task forces to ensure emission reductions, environmental justice, and other agency values are represented in the work, especially related to standard setting
- Continue vital work supporting tailpipe emission regulations within Clean Air Act's mobile source emission control framework, while also considering new regulatory processes
- Continue collecting best data available to estimate on-road vehicle populations and technologies and non-road equipment

6

We Recommend EPA Should:

- Encourage robust bus and rail public transit services (including microtransit, first and last mile connections, mobility wallets, Mobility on Demand, and Mobility as a Service)
- Encourage compact development patterns and policies favoring low-carbon motorized and non-motorized modes (bikes/ scooters) and support related research/metrics/scenario work
- Adapt something similar to CARB's Clean Miles Standard (CA SB 1014) to promote multi-modal transport, electrification, higher motor vehicle occupancy, reduce deadheading, and shift to active transport modes, with credits, incentives, and new metrics

7

We Recommend EPA Should:

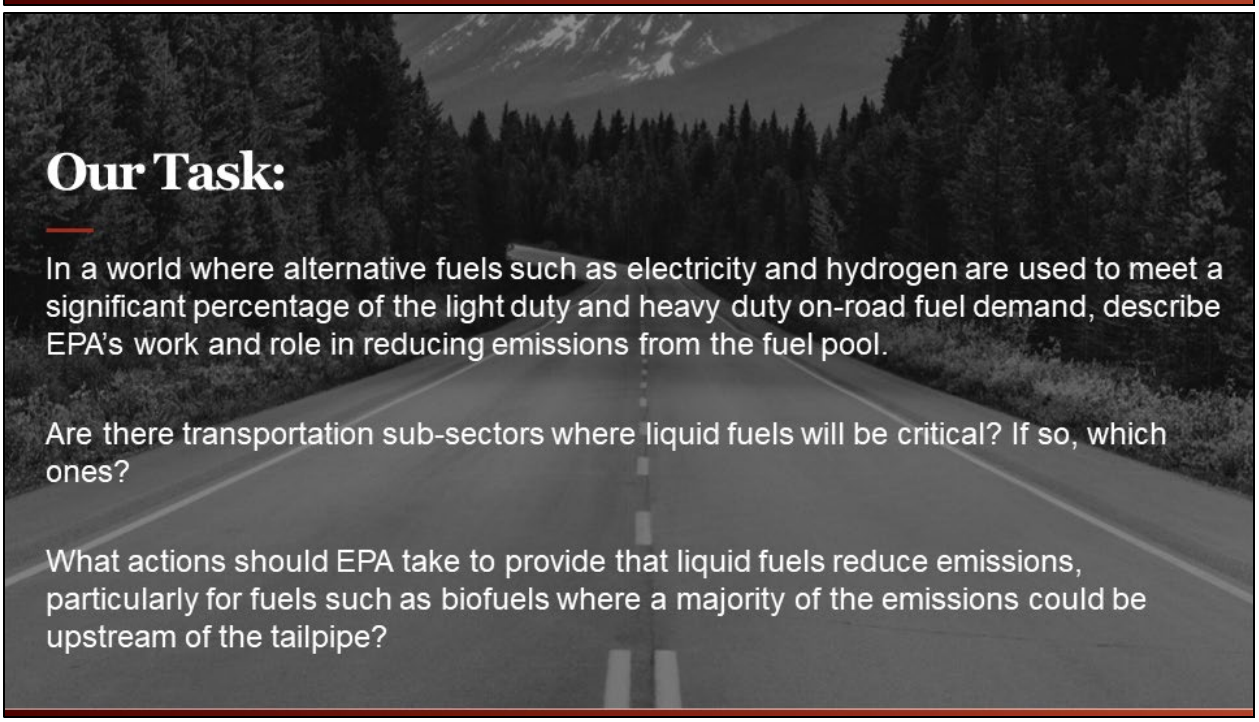
- Reinvent and update past work promoting sustainable communities and smart growth, building partnerships
- Work with DOT & HUD to provide incentives for EVs and shared EV services to improve access for underserved communities
- Shape rules so AVs are electric, programmed to comply with state and local traffic laws, and operated to minimize adverse impacts on health and environment
- Support access by relevant stakeholders to vehicle telematics data to support new methods of emission reductions and promote public health, social equity, and mobility justice goals

8

We Recommend EPA Should:

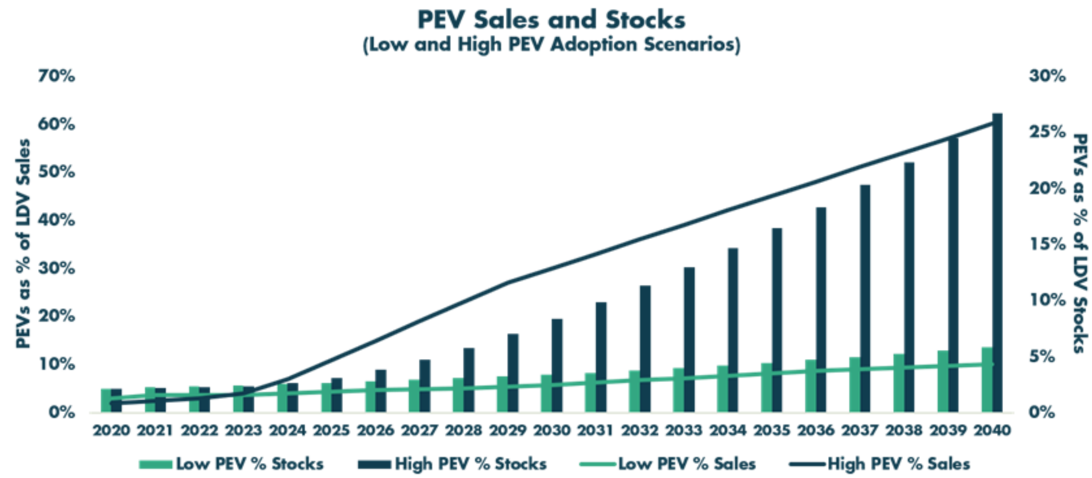
- Continue to improve MOVES model to account for ultra-fine particles and secondary organic aerosol precursors, brake and tire wear, etc.
- Foster widespread measurement and reporting on community and personal exposure to pollutants, with timely action to reduce near-roadway health and disparate impacts
- Work with NHTSA to advance vehicle traffic safety technologies (e.g. automated braking, ped/cyclist recognition systems, intelligent speed assistance) to reduce emissions and boost safety of zero-carbon or low-carbon active transport modes

Appendix K. Fuels Group Presentation



How much liquid fuel may remain?

Two very different forecasts provide insight into how important it remains for EPA to dedicate attention to the liquid fuel and combustion engine sector. In 2040, ICE vehicles may still represent as much as 73% of LDVs on the road and even more MHDVs.



Sources: Bloomberg New Energy Finance, U.S. Energy Information Administration

General Recommendations

The Fuels Subgroup believes there are some over-arching things EPA should pursue regardless of specific policy considerations.

Leadership	EPA should adopt a stronger leadership position relative to **regulatory and standard setting organizations**. EPA should engage pro-actively with regulated industry stakeholders, other federal agencies, and regulatory organizations such as ASTM and NCWM to promote collaboration and coordination.
Collaboration	EPA has achieved great success in pursuit of its mission when it has adopted regulations that incentivize achievement, as opposed to mandating specific solutions. **Working with industry** to host educational workshops, including compliance training programs, has been extremely successful in the past and should be part of any new regulatory program.
Integration	EPA should evaluate its myriad of **regulatory programs** that operate independently to determine if they could be more effective **working in tandem with others**. By enabling such programs to build off one another, the Agency could provide the market with tools and opportunities that may not be viable independently.
Coordination	EPA should seek to coordinate with other federal, state and local regulatory agencies to **promote consistency in fuels regulations across jurisdictions.** When jurisdictions impose requirements incompatible with those of other jurisdictions the fuels distribution system can experience disruption, which can result in economic and environmental harm.
Equity	Access to **reliable and affordable transportation** is essential for all people, and not all communities are equally equipped to accommodate new developments. Policies must be developed in such a way as to prioritize infrastructure and societal costs, facilitate public involvement, and **mitigate any potential negative implications for such communities**.

Specific Recommendations

Subgroup identified eight areas on which EPA should focus and grouped them into two categories: Category 1 (fundamental) and Category 2 (policy specific).

	Near Term 0 to 5 years	Mid Term 5 to 10 years	Long Term 10 to 30 years
Category 1 Recommendations			
Life-cycle Analysis Criteria			
Database of Emissions Sources			
Category 2 Recommendations			
Low-Carbon Performance Standard			
Low-Carbon Biofuels			
Harmonize Gasoline Specs			
Non-Fuel/Non-Tailpipe Emissions			
Emissions from Legacy Vehicles			
Hydrogen and E-Fuels			

Category 1 Recommendations

The first two recommendations will provide fundamental direction from the Agency to enable effective assessment of the other recommendations. The subgroup recommends EPA establish these baselines for evaluating options so that all stakeholders understand what is under consideration and how it shall be measured. This should take the form of:

- **Life Cycle Analysis:** Work with stakeholders to establish a consensus-based methodology for life cycle analyses (LCA), to eliminate different models and versions that are subject to bias. A consensus-based model should conform to academic standards for sound science, peer review, and transparency and be used by EPA to evaluate and publish fuel and vehicle emissions pathways for all types of fuels.

- **Database of Emissions Sources:** Develop a comprehensive database of all sources of emissions to ensure attention is paid to those sources which present the greatest opportunity to reduce emissions and to ensure that transportation-focused regulations are appropriate and proportional.

Life Cycle Analysis

LCA-based regulations and policies may help encourage various powertrain technologies and fuels to play a role in GHG reduction from transportation.

LCA Criteria

- A standardized LCA model with consistent methods, system boundaries and up-to-date data, such as Argonne's GREET model.
- The LCA model must be publicly accessible and well documented with respect to input parameters and assumptions.
- The LCA results should be transparent and subject to verification.
- The vehicle manufacturing cycle and end-of-life processes should be integral parts of LCA of various vehicle/fuel systems to allow for a complete carbon footprint assessment (CFA) of competing systems.

Holistic Vehicle/Fuel Systems Approach

- The true carbon footprint of a particular vehicle depends upon how, where, and when the fuel is produced, in addition to the lifecycle of the vehicle itself.
- A holistic approach that considers the LCA of a vehicle and its energy source as a system is essential.
- It is necessary to fully account for the different components and processes involved in the production of various fuels.

Database of Emissions Sources

Only by accurately identifying the myriad sources of emissions can EPA develop strategies to effectively reduce emissions in the most efficient manner possible while not overly and disproportionately burdening one source of emissions.

EPA should:

- Develop a comprehensive database of emissions sources
- Database should include all sources that may impact the total contributions of primary emissions into the atmosphere, including and beyond transportation.
- This will provide the necessary information to develop regulations that:
  - Provide the greatest benefit
  - Are most efficient and effective
  - Are proportional to the emissions contributions of subject sector
    - Transportation should not be held responsible for offsetting emissions from unrelated sources

Category 2 Recommendations

Specific policy recommendations presented include:

- Establish a low-carbon performance standard for fuels and vehicles
- Facilitate development and introduction of low-carbon fuels
- Harmonize gasoline specifications to facilitate improved vehicle-fuel performance
- Develop a plan to address non-fuel/non-tailpipe emissions
- Develop a plan to address criteria and GHG emissions from legacy vehicles
- Explore the role of low-carbon hydrogen and electricity in the production of future liquid fuels

Low Carbon Performance Standards

Fuel producers and engine manufacturers have very different standards (i.e., RFS and CAFE) which complicates efforts to collaborate for the most efficient solutions. A new holistic approach is needed. Modeling vehicles and fuels on the same plane will create a higher understanding of emissions stemming from transportation and opportunities for more efficiently and effectively reducing emissions.

EPA should:

- Pursue a holistic approach to setting standards for engines and fuels, without overlapping requirements.
- Apply the standard LCA when evaluating performance and apply it to all vehicles and all fuels
- Coordinate and streamline pathway assessments for all fuels and be fuel agnostic to encourage innovation
- Approach fuel economy more directly via a standardized model reflecting similar metrics as fuel modeling
- Combine knowledge and efforts with DOE and other applicable agencies to apply LCA principles to automobile production and mileage.

Low Carbon Biofuels

Lowering the CI of liquid fuels is essential to derive benefits from the long-lived legacy fleet.

EPA Should:

- Apply at the highest levels carbon reduction policies that:
  - Are technology and fuel neutral
  - Are market based
  - Target the lowest marginal abatement cost for reducing carbon
  - Are large in scale for maximum cost effectiveness
- Consider incentives for full life cycle carbon reduction to stimulate the growth of advanced and cellulosic biofuels.
  - Ex: Develop new RIN opportunities for fuels that have a full LCA carbon intensity below the statutory thresholds
- Improve process for approving new fuel pathways to encourage the opportunities for innovation:
  - Streamline process to approve/deny new pathways within 60 days and remove the current backlog of pending pathway approvals
  - Eliminate confusion and avoid multiple layers of regulation
  - Consider vehicle and infrastructure compatibility
- Consider opportunities/challenges of a national LCFS and how it might be integrated with existing programs (RFS)
- Coordinate with stakeholders re: eRIN pathway for RFS, ensure it is balanced with other electricity incentive programs

Harmonizing Fuel Specifications

EPA should:

- Continue it's fuel regulatory program which has significantly reduced criteria pollutant emissions from the light duty fuel/vehicle sector.
- Monitor the impact of the Regulatory Streamlining requirements to determine if additional standards would be beneficial in the future.
- Manage any further regulatory or performance changes for cost-benefit effectiveness
  - Further opportunities for harmonization and pollution reduction may exist but are likely reaching the point of diminishing returns.
  - Performance standards, like higher octane fuels, may present new opportunities for greater GHG reduction but also present significant and potentially expensive challenges.
- EPA should increase coordinated efforts with engine manufacturers and producers of fuels to assure fuels complement the effectiveness of an engine's performance and emission control devices (i.e., Department of Energy's Co-Optimization of Fuels and Engines Initiative)

Non-road Sources and Emissions

Nonroad sources comprise a significant portion of transportation-related emissions and are expected to grow in percentage. Therefore, nonroad sources should be a priority for low carbon fuel solutions and advanced technologies, including hybridization, for applications where complete electrification may not be feasible or cost effective.

EPA should:

- Develop a comprehensive and consistent emissions inventory for nonroad sources, including aviation, locomotive and marine sources.
- Consider a comprehensive performance-based strategy to address both new and in-use vehicles and engines to allow for multiple technological solutions among varied applications.
- Consider the contributions of tire and brake wear (among other components) to air quality and conduct or commission further research to assess the impact of such emissions.
- Evaluate the results of such research to determine whether non-exhaust emissions, such as from tire and brake wear, should be the subject of further requirements, including for EVs.

Legacy Vehicle Fleet

Legacy fleet in context of 2050 consists of today's current vehicle fleet plus all vehicles sold over the next 10-20 years.

Given the expected useful life of vehicles and the slow-turnover of the fleet, EPA should commit significant attention to identifying strategies for reducing emissions from legacy vehicles. Not a single technology option, but a diversification of technologies and programs are essential to achieve reductions that fulfill the various needs of the transportation sector.

EPA should:

- Study effectiveness of inspection and maintenance programs
  - Might be based on dated methodologies that don't take into consideration modern vehicle technology
  - Outdated programs might overstate emissions, leading to ineffective/unnecessary regulations
  - Outdated programs might underestimate of the true cost of the emissions reductions
- Continue fuel efficiency standard program to improve emissions profile of new ICE vehicles entering the market
- Develop pathways and programs to support the use of cleaner fuels and advanced alternative fuels:
  - Accelerate those that lower CI
  - Recognize that different fuel options may be better suited for certain vehicle classes/use cases
- Emphasize retirement of the oldest and most polluting vehicles - a disproportionate contributor of emissions
- Work with the DOT to educate localities on congestion mitigation strategies to lower emissions in high traffic regions

Hydrogen and E-fuels

Even with widespread electrification of on-road vehicles, the need for energy-dense, carbon-based liquid fuels is projected to remain, especially in long-distance travel and transport, whether on-road long-haul, maritime, air, or rail.

- Uncertainty remains on the extent of electric vehicle adoption, especially for heavy trucks, which in turn influences the requirements for liquid fuels and other alternatives, like hydrogen.
- The transition to electric or alternative fuels will take time to allow the entire fleet to turn over, and there will be a long transition with legacy vehicles in all sectors for decades to come sustaining demand for liquid fuels during this time.
- There are sub-sectors of transportation that will be hard to transition to direct electrification (i.e., aviation, maritime, rail, and long-haul trucks). These sub-sectors are projected to grow faster than light-duty vehicles in the next decades.

There has been significant recent interest in developing "efuels" by using electricity to power the conversion of CO_2, either via renewable H_2 or direct carbon electroreduction. Such fuels have the potential to effectively "electrify" portions of the transportation system that remain difficult for battery technologies to serve.

EPA should:

- Support research and development in integrating and rightsizing downstream strategies with CO_2 reduction technologies as well as understanding how these technologies would be integrated with a renewable electricity system that favors flexibility.

Summary

EPA should:

- Assert its leadership position, engage with standards setting bodies, collaborate with industry on education and implementation, integrate programs in a holistic manner, coordinate among regulatory agencies and ensure policies seek to provide all communities with access to affordable and reliable transportation
- Base regulations on a consistent and transparent LCA and consider fuels & vehicles as a holistic system
- Build a database of all emissions sources to help prioritize regulatory attention and ensure regulations are proportional to contribution of emissions
- Develop LCA-based low carbon performance standard, encourage innovation, speed introduction of lower CI fuels
- Monitor the effects of the streamlining rule, evaluate any new changes with a cost-benefits perspective
- Establish performance-based strategy for non-road sources, evaluate non-tailpipe emissions, i.e. tire & brake wear
- Continue improved efficiency of new vehicles, support retirement of oldest vehicles and ensure methods for assessing emissions of legacy fleet reflect modern vehicle technologies
- Support R&D to leverage renewable electricity and H2 to produce zero carbon liquid fuels that can support vehicle classes and use cases that may be extremely difficult to electrify

Appendix L. Goods Movement Presentation

MISSION AND CHARGE OF SUBGROUP

What is needed to deploy technology in a manner that achieves emission reductions most efficiently?

- Consider both overall transportation emissions reductions and sector specific emissions reductions.
- Are there differences in technology applications under the different use cases?
- What could that look like?

What would an efficient low-emissions goods delivery system look like?

- Who are the major players?
- What is EPA's role in this space?

How can EPA best utilize, or encourage utilization of, data to enable and optimize low emissions deliveries? (e.g., real-time activity info, intelligent routing software, etc.)

CHALLENGES & ISSUES THAT CAME TO LIGHT

- Cost effectiveness for individual recommendations were not calculated
- No silver bullet in advising on how to harmonize standards (i.e. CA vs EPA)
- May have fallen short in capturing the latest logistical/efficiency strategies and routing/mode shifting
- Defining short vs mid vs long term strategies
- Distinguishing between ideas that EPA could implement as opposed to other federal agencies
- No consensus on the emission standards for locomotives

6 CATEGORIES OF RECOMMENDATIONS FOR EPA

- Develop comprehensive federal strategy for electrification
- Enhance incentive programs
- Identify new and sustainable funding
- Implement regulations to reduce emissions
- Promote sustainability
- Address pollution hotspots and health disparities

DEVELOP COMPREHENSIVE FEDERAL STRATEGY FOR ELECTRIFICATION

- **Establish a Federal Goods Movement Working Group with USDOT & USDOE**
- Work with DOT and DOE through the 21st Century Truck Partnership and SuperTruck to incorporate heavy-duty ZEV and NZEV technology
- **Prioritize EV deployment to goods movement "hotspots"**
- Work with the General Services Administration to implement aggressive MHD ZEV and NZEV federal fleet purchase targets
- Sponsor conferences and technical workshops for public and private sector MHD ZEV and NZEV stakeholders
- **Advocate for creation of an interagency workforce development program**
- Work with the USDOL on educating the workforce on operation and maintenance of EVs and other new technologies
- Lead a cross-agency effort to identify MHD ZEV and NZEV research needs
- Work with DOE to enhance the Alternative Fuels Data Center to collect usage data
- Advocate for single point of contact at DOE to streamline coordination with interagency partners
- **Study MHD ZEV and NZEV electric charging and hydrogen fueling infrastructure needs**

ENHANCE INCENTIVE PROGRAMS

- **Enhance and update SmartWay to include zero and near-zero emissions components**
  - Explore ways to expand SmartWay partnerships
- **Promote truck and bus electrification through the 21st Century Truck Partnership**
- **Develop scoring rubric for federally funded projects that gives greater weight to use of zero or near-zero emissions equipment on the project**
- **Expand Energy Star to DC fast chargers (currently only applies to Level 2)**

SmartWay®

Partner ship

21st CENTURY TRUCK PARTNERSHIP℠

ENERGY STAR

IDENTIFY NEW AND SUSTAINABLE FUNDING

- **Seek a prime role in implementation of the Biden-Harris Administration's "Build Back Better" Plan**
- **Coordinate with Electrify America**
- Explore potential international collaboration and partnerships
- Provide guidance on expanding USDA's Electric Programs
- **Work with DOT and DOE to enhance use of their grants for air quality improvement projects**
- Provide funding for development, commercialization, and implementation of cleaner technologies
- Provide funding for sector-specific technologies
- Ensure incentive programs like DERA and TAG are well funded but not at the expense of funding for grants to state and local air agencies
- Provide voluntary incentives to encourage development and early introduction of new technologies and increase collaboration with key industry organizations
- Fund manufacturers' products validation to ensure reliable and dependable implementation

IMPLEMENT REGULATIONS TO REDUCE EMISSIONS

- **Establish stringent federal nationwide performance-based standards under existing Clean Air Act authority**
  - Align MHD on-highway Low-NOx initiative with existing Phase 2 Regulations (i.e., finalize in 2022 for implementation in 2027)
  - Include new idle and low-load standards and replace in-use NTE with a new approach that includes idle and low load
- **Establish a Phase 3 GHG regulation**
  - Progressively drive greater adoption of ZEV and NZEV technologies in urban and community applications to maximize early benefits
- **Explore opportunities to increase the use of renewable/cleaner fuels**
- **Consider revising nonroad standards**
  - Locomotive, marine, aircraft

PROMOTE SUSTAINABILITY

- Provide consumers the ability to track the environmental impact of their choice of delivery method
- Serve as a data clearinghouse for improvements made through logistical efficiency/routing, mode shifting etc.
- Characterize the phases of the goods movement sector and identify potential collaboration between key organizations in each sector
- Monitor the role of 5G on the deployment of autonomous transportation, platooning, and drones
- Evaluate how goods movement has changed due to the COVID-19 pandemic

ADDRESS POLLUTION HOTSPOTS AND HEALTH DISPARITIES

- **Prioritize zero-emission projects for areas identified by accepted screening tools as being high priority based on vulnerability or health risk indices. If possible, earmark a certain percentage of DERA funding (e.g., 80%) for mitigation efforts in those areas**
- EPA should develop framework for sustaining and modernizing the national ambient air quality monitoring system to meet the additional information needs of stakeholders
- Coordinate with EPA OAQPS on development and deployment of guidance on how low-cost community monitors may support regulatory monitoring framework
- **Using the definition of ports as adopted in EPA's Port Work Group, EPA should designate ports as stationary sources of pollution and require mitigation for the activities derived from port activities**
- OTAQ should renew efforts to address emissions from borders
- **Maximize the use of Supplemental Environmental Projects to ensure violative emissions are mitigated; develop recommendations for supplemental environmental programs that could be implemented at the state level to support existing EPA opportunities such as DERA**

ADDRESS POLLUTION HOTSPOTS AND HEALTH DISPARITIES, CON'T

- Assess the potential for "local policy matching" requirements akin to financial matching to receive grant funding, demonstrating local policies in place that will assure best practices to reduce exposure to pollution
- **EPA OTAQ should work with EPA OECA to increase enforcement on companies that fail to comply with required engine upgrades and replacements**
- **Conduct emissions mapping of EJ communities and promote the guidance and continued conversation with communities and other stakeholders to enable a better understanding of the impact of goods movement and identification of opportunities to minimize that impact**
- Evaluate least-distance transit policy incentives and incentivize buying/dealing locally to reduce emissions and other impacts by reducing miles traveled
- **Collaborate with state and local air agencies to ensure that rules, policies, and programs related to goods movement achieve emission reductions are sufficient , particularly in overburdened communities**

QUESTIONS?