PART II

Advancing the Next Generation of Transportation Technology
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In the last few years, autonomous and connected vehicles have emerged as a technology with the potential to spur enormous social change. Public interest has grown steadily since late 2010, when Google first publicly disclosed its self-driving car project, and grew dramatically during 2015.1 Autonomous vehicles are stoking the public’s imagination by offering the promise of hassle-free, more productive travel, increased safety, broader access to mobility options for underserved populations, and other benefits.

Additionally, autonomous vehicles offer enormous potential energy security benefits.2 The widespread availability of autonomous vehicles would trigger the greatest revolution in transportation since the invention of the automobile. Specifically, autonomous technology represents an opportunity to fundamentally reshape the transportation system, and mobility more generally, by eliminating inefficiencies in how vehicles are owned, used, sized, and fueled.

Change will not be easy or proceed in a predictable fashion. The vast expanse of the U.S. transportation system, with its hundreds of millions of vehicles and millions of miles of roads, will resist rapid transformation. Entrenched consumer behaviors, the unpredictable evolution of technology, and the limitations of policy levers inhibit the ability to project with full confidence the impact and trajectory of autonomous vehicles. Still, the inefficiencies of the current system and the potential for autonomous vehicles to offer significant and rapid improvement merits vigorous effort from society and policymakers to realize their full potential.

SAFE modeling demonstrates that economic realities are likely to encourage the rapid adoption and heavy utilization of shared, autonomous vehicles once they are available. Although shared, autonomous vehicles will likely induce greater demand for travel, modeling shows that the vast majority of such vehicles will be advanced fuel vehicles (AFVs) (Figure 44), and therefore petroleum use will decline substantially.3 The availability of shared, autonomous vehicles should encourage accelerated adoption of AFVs which share design synergies and are a more economic choice for heavily utilized vehicles. These factors have the potential to drive transportation oil use from current levels of over 11 million barrels a day to under 4 million barrels a day by 2040, even as road travel increases by 30 percent.4

Although autonomous vehicles will generate substantial benefits, there are several obstacles that could slow deployment. While significant technological development is still required for deployment, regulatory risk remains the largest unknown factor: existing rules governing motor vehicles generally do not contemplate autonomous vehicles. This could dramatically slow or even prevent marketplace innovation of autonomous technology. Urgent action is required at all levels of government to ensure that private-sector research, development, and deployment does not needlessly lag as a consequence of inadequate or obsolete regulation.

1 Note: Public interest is measured by volume of Google searches (Figure 43).
2 Note: For brevity, the term “autonomous vehicle” is used to refer to vehicles with both autonomous and connected capabilities.
3 SAFE modeling assumes that shared, autonomous vehicles are available from 2019.
4 SAFE modeling.
Public Interest in Autonomous Vehicles

Source: Google Trends

Light Duty Fleet Composition with Shared, Autonomous Vehicles

Note: Model assumes supportive policy environment for AFVs.

Source: SAFE modeling

Connected and Autonomous Technologies Work in Concert

Source: SAFE analysis
Autonomous Vehicles and AFVs

Under current conditions, the adoption of AFVs will continue to be incremental. The Energy Information Agency currently projects continued slow adoption of EVs and other AFVs. In essence, AFVs do not yet offer most consumers a sufficiently compelling value proposition. Given the realities of well-established consumer preferences in the United States, even a rapid decrease in the cost of advanced fuel technologies might not spur significant increases in adoption.

In important ways, the strategic value of autonomous vehicles is the mirror image of AFVs. The autonomous vehicle technology platform is intrinsically neutral in terms of fuel type, but, based on a compelling consumer value proposition, it offers the most significant opportunity to reshape personal transportation since the invention of the automobile.

The current transportation system is vastly inefficient. For example, on average only 4 percent of household vehicles are in use at any given time, and peak utilization is about 11 percent. The vast majority of vehicle trips take place with just one or two passengers onboard and several empty seats. Limited road infrastructure leads to system congestion and wasted time and fuel. More fuel and space is wasted in the search for parking, which also contributes significantly to urban congestion. Most of the fuel burned in motor vehicles is lost to friction and engine inefficiencies; even the fuel converted to forward motion is mostly used to propel the vehicle and not the passengers riding inside. On average, only 1 percent of the energy in gasoline is used to move passengers. Generally speaking, time spent driving vehicles, especially when commuting for work, is unproductive compared to time in an office, at home, or as a vehicle passenger.

Autonomous vehicle technology can address these inefficiencies while also providing safe, reliable, and on-demand transportation. This shift would change the economic calculus of personal vehicle ownership, choice of transportation mode, and vehicle technology platforms. Driven by compelling consumer benefits across multiple areas, the rapid adoption of autonomous vehicles powered by electricity and other fuels would set the stage for a rapid decrease in oil consumption.

However, even with a compelling economic rationale and consumer value proposition, the need for further technological development and the lack of a regulatory framework will delay the transition to autonomous vehicles. Given the potential for significant energy security benefits, removing regulatory obstacles preventing the deployment of autonomous vehicles should be a priority for policymakers and regulators.

“Think big, start small, scale quickly” should be the guiding principle used to inform both commercial endeavors and public policy on autonomous vehicles.

Think Big. Energy security benefits do not accrue incrementally with the deployment of autonomous vehicles, but result from a broad transformation of the transportation system. Governments should adopt flexible policies and remove obstacles to autonomous vehicle innovation.

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5 EIA, Annual Energy Outlook 2015.
7 Id.
9 SAFE analysis.
12 SAFE interview with Lawrence D. Burns, March 2016.
Start Small. One of the lessons of early deployment efforts for EVs is that deployment is best stimulated through targeted, local efforts to install necessary infrastructure such as charging stations. Therefore, initial consumer deployment of autonomous vehicles should occur within a limited number of deployment communities. This will build comfort with the technology, demand for further deployment, and political support for necessary actions.

Scale Quickly. An iterative policy framework should be established to promote rapid scaling of autonomous and connected transportation systems incorporating the lessons of early deployment trials. This will allow governments to avoid the difficult task of regulating pre-commercial technologies.

Autonomous and Connected Vehicles

Autonomous vehicle technology does not intrinsically reduce petroleum usage, but can promote greater efficiencies in the transportation system through higher utilization and better aligning supply and demand; this transformation, in turn, promotes the usage of more efficient vehicles and those with advanced propulsion technologies.

Public discussion of autonomous vehicles often conflates the “autonomous” and “connected” aspects of the technology. While these technologies are highly complementary and have the greatest impact when working in concert, each technology set has a distinct boundary and raises an independent set of issues. A car can be highly connected without being autonomous, and the reverse can be true as well.

Connected Vehicle Technology

Connected vehicles are collectively enabled by a broad range of communication technologies. Satellite connectivity is used for GPS devices, for satellite radio entertainment, and for emergency connectivity through programs such as OnStar. On-vehicle cellular connections are used to create “hot spots” for vehicle passengers and, in the case of at least one OEM, download software upgrades to improve the car’s capabilities. Control over connected vehicle content, bandwidth, and software is a relatively mature, competitive market which is projected to be worth $47 billion by 2020.

Connectivity plays a key role in integrating individual vehicles into the broader transportation system and enables a shift to “transportation as a service.” Connected vehicle technologies allow for real-time traffic updates, which enables more efficient routing. Information about vehicles is already transmitted to manufacturers, consumers, and fleet managers, allowing more effective maintenance and fuel consumption management. On-demand ridesharing, such as by Uber and Lyft, is facilitated by connected technology.

Two prominent connected vehicle technology platforms are vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), collectively called V2X. V2X uses transponders installed in vehicles and key infrastructure to enable communication between elements of the transportation system, preventing crashes and enabling more efficient traffic flow. Thus far, the development of these technologies has primarily focused on safety applications, such as alerting a driver to the presence of other cars at a blind intersection. It uses Dedicated Short Range Communications, a wireless communications technology.

At present, there is little commercial deployment of V2X technology in the United States. Since two cars on a collision trajectory would both need to be equipped with V2V for it to be effective, V2X will be most impactful once a significant percentage of vehicles are equipped with the technology. This reasoning has led NHTSA to begin the process of mandating that all new vehicles be equipped with V2V.

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V2V based on short-range communication in the 5.9 GHz band differs from other connected vehicle technologies due to its low “latency” or ability to exchange messages with very short lag time (several milliseconds). This feature positions V2X technology for important uses, such as preventing crashes, particularly those resulting from vehicles that are not in each other’s direct line of sight, and vehicle platooning, which will improve fuel efficiency. V2V and sensor-based approaches to autonomy are complementary and will likely be pursued in concert to maximize safety and other benefits.

One unresolved issue is whether the spectrum band for this technology can be opened up for sharing with unlicensed devices such as Wi-Fi without degrading V2X performance and endangering the important benefits offered by V2X. Efforts are ongoing to develop and test a method for robustly sharing the band while maintaining the integrity and reliability of V2X.

**Autonomous Vehicles**

Discussion of autonomous vehicle technology uses a broad range of descriptive terms, including “autonomous vehicles”, “self-driving cars”, “robocars”, and “highly automated vehicles.” NHTSA has established a 5-level definition for “automated vehicles”, ranging from level 0 (“no automation”) to level 4 (“Full Self-Driving Automation”). Generally speaking, “automation” refers to machines that independently “step through pre-determined processes,” even if they utilize highly sophisticated algorithms. An “autonomous” machine has a “broader sense of self-determination than simple feedback loops” and “incorporates a panoply of ideas imported from artificial intelligence and other disciplines.”

A vehicle is “automated” if some of its functions can be conducted without human input. These functions are considered “automated” and a car with automated features is an “automated car” (NHTSA Levels 1-2). Vehicles with high degrees of automation, usually combining the automation of several driving features, begin to take over much of the driver’s role. These vehicles are “highly automated” or “partially autonomous” cars (NHTSA Levels 2-3). “Autonomous vehicles” or “self-driving vehicles” are capable of fully taking over for the driver, letting the driver disengage, or not be present in the car (NHTSA Level 4). It is possible for a vehicle to function as an autonomous vehicle under some circumstances, and as a partially autonomous vehicle under others. The Society of Automotive Engineers has created its own autonomous vehicle classification system with a special category for a vehicle that can always operate autonomously.

Certain vehicle functions have been automated for decades such as cruise control and anti-lock brakes. Relatively new entrants to the auto industry have been influential. Google began its autonomous vehicle work in 2009, and as of March 2016, the company has “driven” more than 1.5 million miles in autonomous mode on public roads. Tesla Motors has provided a suite of automated features known as “Autopilot,” which enable almost completely autonomous highway driving if necessary conditions are met.

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Automotive companies have not ignored this important trend. Most have announced autonomous vehicle development activities, although they differ in whether they are aiming for “full automation” where the driver is rendered unnecessary, or using autonomous technology as a “backup driver” to improve safety and reduce accidents. Some automakers are also experimenting with new business models such as ridesharing and other mobility-on-demand services, while others believe that personal vehicle ownership will remain the near-exclusive paradigm for decades to come.

Growing commercial interest in autonomous vehicles can be seen through the increased generation of intellectual property, especially by the private sector. This is reflected in the soaring rates of patent applications related to autonomous driving (Figure 46). Additionally, the last few years have seen considerable startup activity in automotive technology, a space historically viewed as inhospitable to venture capital. Taken together, these trends indicate that companies active in the autonomous vehicle space and the funders who perform due diligence on investments in early-stage technology are increasingly confident in the future of autonomous vehicle technology.

As autonomous vehicle technology matures, related regulatory and legislative activity is accelerating. In 2011, Nevada became the first state to pass a law regulating autonomous vehicles. As of March 2016, 33 states had considered legislation related to self-driving cars; laws have been enacted in four states and the District of Columbia (Figure 57). In 2013, NHTSA adopted a preliminary policy framework and plans to issue guidance on deploying autonomous cars in mid-2016. DOT and NHTSA have signaled potential flexibility in allowing autonomous vehicles on the road, and have identified key issues with the current Federal Motor Vehicle Safety Standards (FMVSS) that need to be resolved. The state of California began the process of regulating autonomous vehicles for testing in 2012, with finalized regulations for the commercial deployment of these vehicles expected sometime in 2016. To date, officials in Sacramento have declined to create a path towards the certification of autonomous vehicles and proposed prohibiting the operation of an autonomous vehicle without a licensed driver in the vehicle. California’s position has raised concerns that a patchwork of incompatible regulations may emerge and underscores the need for the federal government to play a leading regulatory role.

New Mobility Options: The Next Few Years

The traditional trajectory of new technology adoption in the light-duty vehicle market is through the gradual adoption of features, first in luxury vehicles and gradually diffusing to less costly models. The product cycle for a vehicle model is five to seven years. Together, these trends usually mean that new technologies take several decades to penetrate across the entire fleet.

One potential deployment trajectory for autonomous vehicles is the “Iterative Autonomy” paradigm. The current generation of vehicles has significant uptake of automated features such as automatic emergency braking (AEB), adaptive cruise control (ACC), and lane keeping assist (LKA). The next generation will have more advanced autonomous features, and, in a number of product generations, full autonomy would be possible.

The second potential autonomous vehicle deployment trajectory is not evolutionary through Iterative Autonomy, but rather “revolutionary” by including the introduction of fully autonomous vehicles immediately. Even if it is not feasible in the near future to deploy fully autonomous vehicles on all roads...

Source: SAFE and Ryan Koppelman (Alston & Bird LLP) analysis

Autonomous Vehicle Development Trajectories

Source: SAFE analysis

Concentration of Population, Vehicles, and Land in the Largest 25 Metropolitan Areas

Source: SAFE analysis based on data from Census Bureau
and in all conditions without human supervision, this does not mean that the vehicles should not be deployed at all. Instead, deployment of fully autonomous vehicles may occur in limited areas and with limited functionality, such as lower maximum speeds. A likely initial deployment would be in areas such as private developments, limited-access highways or, more ambitiously, an urban core where most traffic flows slowly. Vehicles could be deployed initially in cities with more favorable climates if, for example, the technology to handle autonomous driving in snow requires further development. As the technology improves, more and more areas will be made accessible to autonomous vehicles. Eventually, autonomous vehicles will be able to navigate nearly any road at any time and at any lawful speed with virtually no human supervision. The “Autonomous First” paradigm deploys autonomous vehicles in the areas and under the conditions in which they can operate safely, without waiting for autonomous vehicles to work everywhere.

The two potential autonomous vehicle deployment trajectories are illustrated in Figure 47. The vertical axis represents the range of transportation tasks that a vehicle can execute. Vehicles lower on this axis cannot travel at full speed or may be unable to operate on certain roads or under certain conditions. The horizontal axis represents increasing automation. The Iterative Autonomy approach gradually increases the autonomy of today’s cars until they are fully autonomous. The Autonomy First approach takes today’s state-of-the-art autonomous vehicles, which are limited in their functionality, and gradually broadens the operating domain in which they can safely operate.

The Iterative Autonomy approach will take significant time given the slow pace of implementing a new technology across a manufacturer’s product line. Additionally, even a partially autonomous vehicle will require a driver at all times, as their autonomous functions will not be robust enough to eliminate the driver. Consequently, private household ownership of multiple vehicles and the use of the oil-dependent internal combustion engine will likely remain the dominant paradigm for the foreseeable future under the Iterative Autonomy pathway.

The Autonomy First approach would build upon some of the fully autonomous vehicles that are currently in use or nearing deployment, traveling fixed routes or in geographically limited areas. These vehicles would then be deployed commercially at a neighborhood or city level. Because preparing an area for the deployment of autonomous vehicles will be resource-intensive, likely requiring the preparation of expensive high-definition maps and careful coordination with local officials, small scale deployment is a likely initial scenario. This approach can reach many Americans rather quickly, however—the 25 most populous metropolitan areas contain 42 percent of the population and 44 percent of vehicles, even though they represent just 5 percent of U.S. land area (Figure 48).

Both of these approaches offer societal benefits, and the market will ultimately guide the progression to fully autonomous vehicles; both may co-exist for some time. The Autonomus First pathway, however, offers a more immediate route to the benefits of autonomous vehicles. However, it is more difficult to implement from a legal, regulatory, and according to some, technological perspective, as it would represent a significant departure from current vehicle functionality. A broad range of national, state, and local level regulations would need to be altered or streamlined to allow for this deployment trajectory. These changes will be discussed later in this section.

Heavy-Duty Truck Automation

The freight industry will likely be an important early adopter of autonomous vehicle technology. Most freight transportation occurs on limited-access roads such as the Interstate Highway system, which presents a less complex environment than urban roads. This reduces the technical requirements to provide high degrees of automation; much of the necessary technology to support basic highway

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36 Note: According to Lawrence D. Burns, about one half of the world’s vehicles never encounter snow during their operational lifetime.
automation is already available.37 In 2013, heavy trucks consumed 22 percent of U.S. petroleum usage, even though they represented only 9 percent of highway travel (Figure 49) and 4 percent of the vehicles on the road.38 Additionally, freight vehicles are often managed in large fleets by owners who are highly sensitive to economic efficiencies at the vehicle level—and automation provides significant opportunities to save on fuel, time, and labor costs.39 Perennial driver shortages, increasing demand for freight shipment, and pressure to reduce costs will incentivize fleet owners to rapidly adopt autonomous technology once it becomes economically rational to do so.

One early application of automation that has already seen significant on-road testing is platooning, where two or more trucks closely follow each other to reduce fuel normally lost to aerodynamic drag for both vehicles, with the trailing truck enjoying an efficiency boost of 10 percent in some cases.40 Extensive on-road trials of platooning are ongoing.41 In addition, highly automated trucks are being tested in both the United States and Europe.42

**Autonomous Vehicles and Energy Transformation**

The impact of autonomous vehicles on energy usage likely will happen in two phases. In the first wave, additional autonomous capabilities will impact vehicle energy consumption—both positively and negatively. In the second wave, significant market penetration of autonomous vehicles will allow for changes in vehicle design, performance specifications, and ownership patterns. At this point, the first wave effects will deepen as well. Collectively, these changes will have a deep impact on the energy use profile of the transportation sector. Some developments will promote efficiency, but there is also the potential to increase travel, as well promote less efficient driving patterns.43 If autonomous vehicles can drive the rapid adoption of electric vehicles, that will be more important than any other factor, reducing petroleum dependence by as much as 75 percent.44 Under all cases, however, autonomous vehicles likely will reduce oil intensity and generate significant economic gains. Figure 50 captures some of the efficiency-related impacts of vehicle autonomy and the range of potential impact. It focuses mainly on shifts in individual autonomous vehicle energy use, rather than systemic impacts.

**First Wave Impacts**

- Mitigation of congestion through improved traffic flow and reduced accident frequency (accidents cause congestion and fuel waste). This effect has begun with connectivity (better traffic directions), but will accelerate with autonomous vehicles.

- Smoother braking/acceleration and other driving maneuvers leading to reduced energy consumption. This impact results from high degrees of automation (e.g. highway autonomy) and accelerates with autonomous vehicles.

- Vehicles may be allowed to safely follow one another at short distances, reducing fuel losses to air resistance, increasing highway throughput, and reducing congestion. This is already feasible and may be further enabled by high degrees of automation, such as highway autopilot. Early adoption of this practice is being closely studied in the freight system.

37 Reuters, “Daimler’s self-drive trucks are going to be tested in Nevada,” May 6, 2015; and Roland Berger, “On the road toward the autonomous truck,” January 2015.
38 Oak Ridge National Laboratory, Transportation Energy Data Book, Edition 34; and Federal Highway Administration, Freight Management and Operation.
39 David Morris, “In trucking, a little automation saves a lot of money,” May 2015.
40 Peloton Technologies, “How It Works.”
42 Reuters, “Daimler’s self-drive trucks are going to be tested in Nevada,” May 2015.
44 Austin Brown, et al., 2014.
Second Wave Impacts

- As accidents become less common, vehicle weights could safely decrease, improving fuel efficiency.

- As humans spend less time in control of the driving experience, consumers may be more likely to purchase cars that are optimized for fuel efficiency.

- As autonomous vehicles become more common, they may be allowed to travel at higher maximum speeds on freeways, reducing fuel efficiency.

Transformational Impacts

The previous section discussed how vehicle efficiency may evolve as autonomous vehicles are deployed. These changes focused on the efficiency of a single vehicle. However, most of the opportunity for altering energy usage resides in the potential for autonomous vehicles to transform the transportation system.

Today, personal vehicle ownership is the dominant transportation paradigm. In 2014, over 90 percent of U.S. households owned (or leased) a vehicle, and the average household owns 1.75 cars. Car ownership is even higher outside the dense cities where few viable alternatives to personal ownership exist.\(^45\) The convenience of using a single vehicle for multiple purposes motivates individuals to make purchasing decisions based on their most intense use case (e.g. purchasing a high-powered SUV for the few times a year it is used to haul a boat and using it primarily for a short commute). 53 percent of light-duty vehicle sales in early 2015 were either SUVs or pickup trucks.\(^46\) Vehicles typically carry enough fuel for over 300 miles of driving, even though the average vehicle trip is under 10 miles, and the average vehicle travels less than 30 miles in a day.\(^47\)

As of January 2015, there were just under 1.2 million U.S. members in paid carsharing services (e.g. ZipCar, Car2Go).\(^48\) The total population of licensed drivers in the U.S. is just over 210 million.\(^49\) Carsharing, without autonomy, does not appear well positioned to significantly impact vehicle purchase and usage habits in the foreseeable future.\(^50\)

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45 Census Bureau, 2014 American Community Survey.
46 Tom Libby, “SUVs Climb to 40% of U.S. New Vehicle Sales,” IHS Automotive Blog, October 2015.
47 DOT, National Household Travel Survey, 2009.
However, there is already evidence of a market for a more efficient alignment of transportation needs with on-demand supply. Uber was founded in 2009 and has provided more than one billion rides and facilitates 2 million rides per day globally. A recent study showed that, in all but the most saturated markets, cars participating in on-demand ridesharing were far more efficient at picking up passengers and reducing empty miles than conventional taxis.

Autonomous vehicles can reduce the inefficiencies inherent in personal ownership. Autonomous technology offers a consumer proposition in the form of easier, safer, more accessible trips. Combined with connected vehicle technologies that better sync transportation supply and demand, this may provide, for many Americans, a viable—and in many cases economically preferable—alternative to private ownership. This is especially true in urban areas, where the cost of maintaining private vehicle ownership is greater and levels of vehicle ownership are lower. As illustrated in Figure 56, households tend to own fewer—or even zero—vehicles in areas of higher population density. This is because of the alternatives to private vehicle ownership offered in dense cities and the higher cost of vehicle ownership in these areas. Studies have found that individuals in urban areas who use ridesharing, car-sharing, and bike-sharing services are more likely to use public transportation, own fewer vehicles, and spend less on transportation. This suggests that if autonomous vehicles offer a compelling functional and economic alternative to private vehicle ownership, consumers will choose to own fewer vehicles.

Some observers are skeptical that the transportation system will pivot away from family-owned vehicles. Many experts believe that Americans are attached to their cars and will not forego personal ownership. Others believe that economics inexorably points toward either a partially or almost fully shared future for personal transportation.

SAFE modeling shows that significant private ownership of vehicles will persist even with the emergence of autonomous, shared vehicles (Figure 51). Governments should not force a particular type of transportation service on the public, but the compelling economic proposition of cheap, reliable, on-demand service will encourage many consumers to reduce the numbers of vehicles per household to about one. Today, most households have two or more cars.

SAFE’s model tested how consumers would react to the commercialization of shared, autonomous vehicles. The model showed that if autonomous vehicles never become available, the car parc would
Modeled U.S. Car Parc

Note: Model does not account for effects of duty cycle matching ("right-sizing").
Source: SAFE modeling

Virtuous Cycle Between EVs, Autonomous Vehicles, and Ridesharing

Source: SAFE analysis
Modeled Impact of Autonomy on VMT

Source: SAFE modeling

Projected Population Growth, 2015-2050, and Personal Travel By Age

Source: Census Bureau and NHTS

Disabilities and Labor Pool Participation

Source: Census Bureau
grow slowly over time. However, if autonomous, shared cars become available, consumers significantly utilize these vehicles. Each shared, autonomous vehicle replaces about 10 personally-owned vehicles, and the total number of light-duty vehicles in the United States goes down by 75 million, from a baseline of about 250 million. This would represent a massive realignment for the auto industry.

Still, the vast majority of the car parc would remain personally owned vehicles. This entire change occurs rapidly, in a period of about 10 years. After that period, individual households increasingly buy autonomous vehicles for their individual use, but the number of vehicles in the fleet stays nearly constant. Any prediction of the future of the car parc has a high degree of uncertainty, but the persistence of personal ownership in SAFE modelling is a manifestation of the power of personal vehicle ownership in the United States. Personally owned autonomous vehicles can find their own parking, serve as storage for families, give rides to multiple family members, and run errands. A key factor will be the cost differential between shared and owned vehicles; a large differential may drive personal ownership even lower.

Beyond the efficiencies introduced at the vehicle level, a system which dynamically matches mobility needs with on-demand autonomous vehicles will allow for a matched duty cycle. For example, a solo rider would be placed in a small, single-occupancy vehicle. Groups that wish to travel together would order a vehicle that could accommodate them. Similarly, the fuel capacity of the vehicle might be matched to the task. A car with a smaller battery might be dispatched to meet the demand for short trips, whereas a larger battery might be used for longer trips. This would avoid expensive battery overcapacity. As a whole, such a system would produce two important impacts:

As 90 percent of personal trips have one or two passengers, most travel demand will be filled by small, light vehicles which consume less fuel. In addition to being intrinsically more efficient, a light car can go farther on a battery or other advanced fuel, making electric vehicles an increasingly attractive choice.

Shared vehicles will have higher rates of utilization, which flip the economics of ownership to favor electric or other advanced fuel vehicles which typically have lower operating costs. If an electric vehicle (or other AFV) costs an additional $5,000 in up-front costs, but has operating costs that are lower by 10 cents per mile (a conservative estimate), the EV becomes economically advantageous at about 50,000 miles. SAFE modeling showed that a shared, autonomous vehicle can reach this mileage in several months, making EVs a rational investment for fleet managers.

A recent study from the Lawrence Berkeley National Laboratory modeled what a shift to fully autonomous taxis would do to national energy consumption. The results of the study: *Oil consumption
would... be reduced by nearly 100 percent." The "virtuous cycle" between EVs, autonomous vehicles, and Mobility on Demand is illustrated in Figure 52. The convergence of these trends have the potential to create a positive feedback loop and transform the transportation system.58

SAFE’s model showed that even though total travel soars by about 30 percent with the availability of shared, autonomous cars (Figure 53), there is a rapid adoption of AFVs, which reduces overall petroleum use in the transportation system. Autonomous vehicles also increase the use of shared vehicles by a factor of ten relative to a world with autonomy, further increasing the proportion of miles driven by AFVs.

Mobility Access for the Underserved

By removing the need for a driver, autonomous vehicles have the potential to offer accessible mobility for many who do not have it today – groups such as Americans with disabilities, older Americans, children, and low-income Americans who struggle with the current cost of transportation.

Individuals with Disabilities. The disabilities community could be transformed through better access to mobility. The American Association for People with Disabilities reports that 31 percent of people with disabilities have insufficient transportation compared to 13 percent of the general population. As a result, many individuals with disabilities cannot reliably vote, work, attend medical appointments or otherwise enjoy full independence. According to the U.S. Census Bureau, the labor force participation rate for individuals with an ambulatory disability is only 25 percent, compared to 75 percent for the broader population (Figure 55). With the cost of a paratransit trip far outstripping the cost of fixed route transportation—and rising quickly—access to autonomous vehicles would help this population better integrate into society.59

Older Americans. By 2050, the number of Americans older than 65 will approach 90 million, more than double today’s number.60 A recent survey found that as Americans enter their 70s and 80s, they sharply reduce travel, largely due to age-related factors (Figure 54).61 Autonomous vehicles can provide mobility and dignity to older Americans; better integrating seniors into the economy through autonomous vehicles will contribute significantly to economic growth.

Low-Income Americans. Access to efficient, quick, and reliable transportation significantly helps individuals escape poverty by allowing access to a broader range of jobs and opportunities.62 One transportation policy expert stated that, in New York City, “it’s far more important to have a MetroCard than a college degree” for economic mobility.63 For the vast majority of cities that have been unable to sustain the expense of a broad, reliable public transportation network, autonomous vehicles will increase economic mobility and help low-income Americans access better employment.

Health-Care Cost Savings. Studies have shown enormous potential for health-care cost savings by improving the availability of transportation. The National Academies estimated in 2005 that 3.6 million American miss or delay non-emergency medical care each year because of transportation issues. This population contains a high proportion of individuals with chronic diseases for whom the lack of non-emergency care can lead to expensive hospitalizations.64 Autonomous vehicles have the potential to significantly improve quality of life and decrease health costs for the significant population without access to transportation for non-emergency medical treatment.

60 Census Bureau, “Population Projections.”
61 Federal Highway Administration, Summary of Travel Trends: 2009 National Household Travel Survey, June 2011.
64 Transportation Research Board, Cost Benefit Analysis of Providing Non-Emergency Medical Transportation, 2005.
Improved Safety

The impact of motor vehicle accidents is staggering. In the United States, there are more than 6 million crashes, causing more than 2 million injuries each year. In 2015, accidents caused 38,300 fatalities, a sharp increase from the year before, which is partially blamed on an increase in distracted driving. The death toll is the equivalent of a fully-loaded Boeing 747 crashing each week. A recent estimate for the total annual costs of accidents amounted to $836 billion.

Driver-assist technologies already deployed in the marketplace demonstrate the impact of partial autonomy on safety. Adaptive cruise control systems, a NHTSA Level 1 feature, automatically regulates the speed of motor vehicles. AAA estimates that this feature helps prevent 13,000 crashes per year. Higher levels of automation where a combination of safety systems work in unison have even greater impacts. The Insurance Institute for Highway Safety estimates that if all vehicles on the roads today incorporated Level 2 features, such as dynamic brake support, forward collision and lane departure warning, blind spot assistance, and adaptive headlights, nearly one-third of accidents could be prevented. In 2013, NHTSA found that 93 percent of accidents resulted from human error, and an autonomous vehicle would be able to mitigate or eliminate the vast majority of those crashes.

Potential Obstacles

Technology Development

Currently, autonomous vehicles capable of travelling on public roads are not broadly available for commercial use, and there are diverging opinions as to when this will change. The technology requires further development for the sensors which “see” the world, the algorithms that “fuse” together input from multiple sensors and plan a safe trajectory for the autonomous vehicle, the high-definition maps that may be required for navigation, and the computational power required to manage driving-related tasks.

Some autonomous vehicles are currently in or close to commercial deployment, although they are vehicles with considerably less functionality than a typical car. Driverless “pods” capable of low-speed travel in small areas will be deployed in several British cities later this year. A driverless bus is currently being tested, with passengers on public roads in the Netherlands, travelling on a fixed route. As of March 2016, 12 entities had been issued permits to test autonomous vehicles on public roads in California. A number of companies have demonstrated autonomous vehicles over long distance trips.

A major challenge in bringing autonomous vehicles to market is understanding when they have sufficiently demonstrated enough safety for commercial deployment. One metric proposed for measuring the reliability of autonomous vehicles is “miles between failures” of the autonomous vehicle; as the technology becomes more robust, failures will become increasingly rare. Early research suggested that reaching one million miles between safety failures would take until at least 2025. The difficulty is...
determining what constitutes a failure, especially when an accident between an autonomous vehicle and a conventional vehicle is often not the fault of the autonomous vehicle.

California has required that autonomous vehicles tested on its roads report miles between “disengagements,” which is defined as when a human driver must manually take over the car because of safety concerns. While capturing some information about the state of autonomous technology, the broad definition of “disengagements” limits its utility as a metric, as it allows companies to choose and report different interpretations. Additionally, variations in the disengagement rate are driven by factors aside from the maturity of the autonomous technology, such as the choice of testing conditions and whether the autonomous vehicle is learning new operational maneuvers. A disengagement does not mean that the autonomous vehicle would have crashed had the safety driver not taken over; Google claims that its software simulations demonstrate that only a tiny proportion of disengagements would have resulted in accidents had the driver not intervened.

Based on publicly released data covering September 2014 to November 2015, Google’s autonomous vehicle fleet improved during this period from several thousand disengagements per million miles to about 100 disengagements per million miles. As noted, changes in the disengagement rate are not a full measure of technological progress, as other factors can impact the rate. Even so, the rapid decrease in the disengagement rate is evidence that rapid improvement of autonomous vehicle technology is both possible and currently ongoing.

**Level 3 versus Level 4**

An area of ongoing discussion is the proper role of the human-vehicle interface and whether the driver should be given the responsibility of re-engaging in certain circumstances, or removed from the system entirely. Studies show that effectively handing over control can take about 10 seconds, in which a car at highway speeds can travel nearly 1000 feet. This has long been recognized as an issue in aviation; the National Transportation Safety Board found that improper monitoring of automated functions causes the overwhelming majority of plane crashes. Early experiences in testing their self-driving cars with volunteers convinced Google that inattention is unavoidable in partially autonomous vehicles and that fully autonomous vehicles were the only safe development pathway. The deployment of autonomous vehicles will require either skipping Level 3 or finding a solution to mitigate some of the dangers of “The Handoff Problem.”

**Cybersecurity**

Cybersecurity is broadly recognized as an important vulnerability for networked systems, which increasingly includes vehicles. Development of cybersecurity defenses will be important for the deployment of autonomous vehicles. As electronic control units (ECUs) became more common in vehicles in the 1980s, the Controller Area Network (CAN) bus protocol was developed to carry messages from point to point within the car. For decades, it has proven to be a relatively robust and secure technology. However, as connected vehicle technology offered the ability for external actors to access internal vehicle communications, cybersecurity concerns have become more prominent, highlighted by recent incidents in which security researchers have demonstrated the capability to gain remote access and control of vehicles.

Vehicle connectivity, which is present in many of today’s cars and will be ubiquitous on new cars in the near future, creates vulnerability to hacking. Although autonomous vehicles may have additional vulnerabilities relative to non-autonomous vehicles if hacked, cybersecurity is a major present-day

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77 California Department of Motor Vehicles, “Autonomous Vehicles in California.”
79 Alex Davies, “Ford’s Skipping the Trickiest Thing About Self-Driving Cars,” November 2015.
Concern for automakers and should be addressed regardless of the pace of autonomous vehicle development.

In July 2015, automakers announced the formation of a voluntary Information Sharing and Analysis Center (ISAC) to serve as a “central hub or intelligence and analysis, providing timely sharing of cyber threat information and potential vulnerabilities in motor vehicle electronics or associated in–vehicle networks.” The ISAC has potential to convene automakers to promote common industry cybersecurity standards and updating them as needed.

Some have advocated legislation to mandate cybersecurity and privacy standards for vehicles. While setting mandatory standards guarantees full and uniform adoption by automakers and suppliers, such standards will necessarily be formulated through the regulatory process which takes a long time relative to the pace at which new cyber threats and defensive technologies emerge. Any standards would likely be obsolete by the time that they are deployed.

Regulations Patchwork
The task of regulating autonomous vehicles requires addressing a complex set of issues. Already, 33 states and the federal government (Figure 57) have considered legislation related to autonomous vehicles, with 4 states and the District of Columbia passing legislation.

Already, differing standards have emerged. In California, legislation mandated that the state DMV create regulations for the deployment of autonomous vehicles. In December 2015, the CA DMV proposed draft regulations that did not permit the operation of vehicles without a licensed driver who would be able to assume control at any time. On the other hand, Florida’s legislature recently passed a bill explicitly allowing the operation of an autonomous vehicle with no operator inside. The potential

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86 Stanford Center for Internet and Society, “Legal Aspects of Autonomous Driving.”
87 California Department of Motor Vehicles, “Express Terms.”
88 Florida Senate, “House Bill 7067.”
emergence of varying regulations in different states have led to calls for the federal government to take
the lead on establishing national-level standards for autonomous vehicle regulations.89

Autonomous vehicles, like conventional vehicles, fall under the authority of the federal government
to regulate the "instrumentalities of interstate commerce."90 A key issue is whether federal standards
for permitting an autonomous vehicle should pre-empt state-level positions that establish different
standards or prohibit autonomous vehicles entirely.

At the federal level, it is unclear whether the Department of Transportation and NHTSA have the legal
authority necessary to permit autonomous vehicles, or whether doing so will require Congress to grant
DOT new authorities.91 Additionally, several issues may need to be addressed at different levels of
government (Figure 59).

Researchers at the Emory University School of Law identified several broad areas of law and policy
where sustained research will be necessary to create viable options for lawmakers before the
widespread commercial use of autonomous vehicles.92 They include:

Privacy. What data is collected from an autonomous vehicle, and how can the autonomous vehicle
owner use the data?

Criminal Law. Is information gleaned from autonomous vehicles protected by the 5th amendment?

Crimes Against Autonomous Vehicles. Are existing cybersecurity laws appropriate for
prosecuting those who compromise autonomous vehicles through hijacking or other interference?

Tort Liability. How must traditional tort liability standards based on human conduct be updated for
autonomous vehicles?

Road Infrastructure Standards. Should legislation be specific as to infrastructure standards
necessary for smooth autonomous vehicle operations? This will likely include the significant
information technology infrastructure required by autonomous vehicles.

89 Chris Urmson, Testimony of Dr. Chris Urmson, Director, Google Self-Driving Car Project, Google [x] Before the Senate Committee on Commerce,
Science and Technology, March 2016.
90 Interview with Mark Goldfeder of Emory University.
92 Mark Goldfeder, Katherine Sheriff, Vaibhav Sharma, and Mason Raphaelson, Emory University School of Law Autonomous Vehicle Legal Project.
Legal Issues for Autonomous Vehicles

| International | The 1949 Geneva Convention on Road Traffic, to which the United States is a party, may prohibit vehicles without a driver in control. It is likely that the Convention is not enforceable against private companies, but the federal government might play a role in international efforts to modify the convention. |
| National | The Department of Transportation has noted that there are significant elements of the FMVSS Code that present compliance challenges for autonomous vehicles. NHTSA has attempted to mitigate some of these challenges by interpreting any reference to a driver as referring to the software “driver” of the vehicle. However, many of the provisions of the vehicle code explicitly disallow new designs that one would expect in autonomous vehicles (e.g. no steering wheel or brake pedals) and may not be changeable without new Congressional authorities. |
| State | Necessary insurance levels and liability frameworks are governed by a combination of state-level tort and financial responsibility laws. These differ from state to state, although groups such as the Uniform Law Commission and other advocacy groups may attempt to harmonize laws by creating and promoting model legislation across different states. Driver permitting and licensing issues, as well as many traffic laws, have traditionally been the purview of the states. Some states may use this authority to regulate who may or may not be licensed to “drive” an autonomous vehicle, but the federal government has the ability to discourage states which, for example, exclude certain groups from the benefits of autonomous vehicles. |
| Local | Municipalities often have their own traffic laws, particularly around parking. Signage often varies from state to state as well. A move towards uniform design and laws will help the smooth deployment of autonomous vehicles in broader areas. Mobility-on-demand business models will need to comply with local regulations on rides-for-hire, which differ in nearly every locality. Ridesharing services have spent considerable resources working to change for-hire regulations on a city-by-city basis. Unless this is addressed, autonomous vehicle operators who wish to use a mobility-on-demand business model may have to repeat this extended battle, which may delay the deployment of autonomous vehicles or even prevent autonomous vehicles from operating in some areas. |

**Tax.** If autonomous vehicles lead to the rapid uptake of AFVs, how will revenue from the gas tax be replaced?

**Emergency Vehicles.** Standards will be necessary for autonomous emergency vehicles.

**Vehicle Insurance.** Will requirements and insurance models need to change?

**Consumer Acceptance**

Autonomous vehicles offer potential benefits that include safer driving, enhanced productivity, more access to driving for underserved groups, a more enjoyable riding experience, and cheaper mobility. Despite these advantages, there is some evidence that consumers may resist autonomous vehicle adoption. AAA found that only 20 percent of U.S. drivers would trust an autonomous vehicle to drive them around, with women less likely to trust an autonomous vehicle than men. However, individuals who have had experience with semi-autonomous features are more likely to trust autonomous vehicles, consistent with the idea that consumers tend to be resistant to technology before they have experienced it. A recent focus group on autonomous vehicles found considerably more consumer interest in the technology after being educated about self-driving car technology. Recently, a survey by the Boston Consulting Group found significant enthusiasm for autonomous vehicles, but also suggested that high initial costs would slow adoption. Focus groups by KPMG revealed significant

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96 Anita Kim et al., March 2016.
98 Goldfeder et al., 2016.
102 KPMG, Self-driving cars: Are We Ready?, 2013.
103 Xavier Mosquet et al., Revolution in the Driver’s Seat: The Road to Autonomous Vehicles, Boston Consulting Group, 2015.
interest in using autonomous vehicles and mobility-on-demand to create new options for children and older Americans unable to drive themselves.\textsuperscript{104}

Consumer exposure to autonomous vehicles and the value proposition they offer may stimulate additional demand, but there will continue to be some uncertainty around predicting the adoption of a technology that has not yet been deployed. Therefore, early testing of autonomous vehicle technology will be important, not just for engineers to learn more about the technology, but for the public to gain exposure as well.

**Workforce and R&D Issues**

Autonomous vehicles are one element in a broader discussion of how automation impacts the labor market and contributes to increased productivity. Some economists argue that technology raises earnings for both high- and low-skilled workers—the latter due to induced demand for low-skilled labor.\textsuperscript{105} Other economists believe that new technologies are eliminating jobs faster than they are created.\textsuperscript{106} Within the auto industry, some analysts have predicted a significant reorientation of jobs away from incumbent auto manufacturers to new players, as fewer mass-market cars are produced for private sale.\textsuperscript{107} There would be broad social ramifications of such a shift, given the 1.6 million direct jobs provided by automakers in the United States.\textsuperscript{108} Additionally, according to the Bureau of Labor Statistics, 3.8 million Americans work as motor vehicle operators, with an annual mean wage of $36,460, with potentially up to $140 billion of driver wages at risk.\textsuperscript{109} Autonomous vehicles could contribute to the continued erosion of middle-class and manufacturing jobs, an issue which is an increasingly prominent element of current political discourse.

The United States has previously undergone major industrial shifts. At the beginning of the 20\textsuperscript{th} century, nearly half the labor force worked in agriculture. As machines increased productivity, jobs shifted to manufacturing and other industries. Despite sharp reductions in farm employment, total U.S. employment grew robustly. Figure 58 shows the last few decades of this trend. Even though a major industry, agriculture, now employs a tiny fraction of the workforce it once did, increasing labor productivity has allowed agricultural output to grow, and other industries have absorbed the displaced labor. Vehicle automation has the potential to greatly increase worker productivity through freeing time

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\textsuperscript{104} KPMG, *The Clockspeed Dilemma*, 2015.
\textsuperscript{109} Alliance for Automobile Manufacturers, *Auto Jobs and Economics.*
and reducing productivity-sapping injuries. Still, even if the economy continues to grow in other areas, replacing wages lost to autonomous vehicles, the large-scale displacement of jobs increases the risk of social disruption.

New technologies such as autonomous vehicles and their associated productivity gains can become a major source of national economic competitiveness and employment. As countries such as Singapore or South Korea have taken an active interest in autonomous vehicle development, the productivity gains offered by the technology will confer competitive advantage to countries leading in this space. Additionally, as autonomous vehicles sit at the nexus of multiple industries (i.e., technology, automotive, telematics), leadership in this area will attract a hub of activity with significant employment benefits.
Policy Recommendations

Organizing Principles

**RECOMMENDATION**

The federal government should remove regulatory obstacles to the deployment of autonomous vehicles.

Autonomous vehicles have the capability to provide on-demand transportation, driving down costs, boosting productivity, enabling access to mobility for underserved groups, and reducing petroleum usage (Figure 60). These benefits will not be fully realized if the car requires a driver to be engaged and ready to take over; non-autonomous vehicles could not self-relocate to pick up the next passenger, which would be necessary to allow for shared, autonomous mobility-on-demand. Individuals who could not serve as a suitable driver, including many in the disability or elderly communities, would not be able to ride in a vehicle that required a driver’s supervision.

As illustrated in Figure 47, autonomous vehicles may not develop through the incremental automation of today’s conventional vehicles, but by operating fully autonomously in increasingly complex, but still limited, domains. Both trajectories face challenges from the current regulatory framework. Without concerted and deliberate action, autonomous vehicles might be stymied or limited because of regulatory roadblocks.

Despite dramatic improvements in safety over the course of decades, motor vehicles remain far from perfectly safe. Autonomous vehicles should not be held to a standard of perfection applied to no other comparable technology, including current motor vehicles. Autonomous vehicles should be allowed to operate, without the need for a licensed driver, under any circumstances in which they have been demonstrated to be at least as safe as today’s non-autonomous vehicles.

The government should neither require nor limit differing levels of automation or technology development trajectories. It is likely that most of the safety benefits of autonomous vehicles are accessible to NHTSA level 3 autonomous vehicles. Regulators should allow industry to deploy its choice of autonomous vehicle technology, and let the marketplace choose which technology best meets consumer needs.

**Role of the Federal Government**

Regulating autonomous vehicles presents a challenge because the technology does not exist yet in the form of a commercialized product, the pace of adoption is uncertain, and the delivery model (private, shared, or private and shared) to consumers is still unknown.

Government action to advance specific technologies is often justified on the grounds of internalizing societal benefits that are not easily captured by private markets. In the case of autonomous vehicles, the vast amounts of capital being spent by a broad range of companies suggests that there is limited room for government action to accelerate the deployment of autonomous vehicles through traditional "market pull" mechanisms such as subsidies or substantial investments in R&D.

However, there are a broad range of obstacles to the commercial deployment of autonomous vehicles that will be impossible to solve without coordinated national, state, and local government action. The federal government is best positioned to marshal the resources required to create model regulations...
and coordinate deployments across multiple states and cities. Federal action is required to modify or waive the FMVSS which currently do not allow autonomous vehicles to operate on the road.

Most states have considered autonomous vehicle legislation, threatening to impose a patchwork system of regulations and delay deployment. A pressing issue is whether autonomous vehicle standards established by the federal government should pre-empt state level standards or decisions to entirely prohibit autonomous vehicles. Today’s model is a hybrid: states are allowed to set their own rules regarding driver licensing requirements. For vehicle safety, however, federal standards pre-empt state positions. Vehicle emissions are regulated using a hybrid national/state level system. National level standards are set by NHTSA and the EPA, but states are allowed to require the more stringent standards set by California.

Autonomous vehicles represent a conflation of vehicle and driver because the “driver” is the vehicle itself. Therefore, regulating autonomous vehicle certification is far more like creating a safety code for vehicles than it is like licensing a driver. Federal vehicle safety codes pre-empt state standards because of the compelling interest in not requiring different cars in each state. If autonomous vehicles were just vehicles with an “autonomous” switch, it would still be onerous to have differing requirements for turning on autonomy in neighboring states. However, since the design and ownership model of autonomous vehicles will differ from conventional vehicles, varying state standards likely would require distinct vehicle models. Avoiding this outcome is the exact reason why federal pre-emption for safety standards was upheld by the Supreme Court in Geier and Williamson, where state tort claims were disallowed because the design in question was permitted by the FMVSS. If existing law does not give NHTSA sufficient authority to pre-empt state laws obstructing the deployment of autonomous vehicles, Congress should grant such authority.

On other matters, such as tort actions, for-hire regulations, and on-road regulations, the traditional division that allows states and localities control over these issues could remain in place, as they do not directly impact the autonomous vehicle platform. The federal government should help create voluntary model frameworks for state and local adoption to encourage uniformity, but may choose not to pre-empt. If differing state regulations in this area prove to be a roadblock for the adoption of autonomous vehicles, the federal government should use incentives such as the withholding of federal highway funds to encourage the adoption of uniform standards. This approach was used to great effect in the past to encourage states to raise the drinking age, lower speed limits, and require motorcycle helmets.

RECOMMENDATION

The federal government should “learn through doing” by facilitating autonomous vehicle deployment communities to inform any necessary regulation.

Just as technology is developed through real world testing, regulations for autonomous vehicles should be created iteratively. To take a recent example, ridesharing services provided by companies such as Uber and Lyft have grown dramatically in recent years. These services began in the absence of a regulatory framework, or in some cases, despite contrary regulation. Today, these companies are actively working with municipalities to craft legislation and regulations. Several years of experience have helped states and municipalities identify the need these services fill, mitigated concerns that

111 Note: This argument is not fully applicable to vehicles with Level 3 autonomy or lower.
may have been initially present, and identified concerns that may not have been anticipated, putting local governments in a far better position to regulate effectively. Market experience informs a better framework and context for regulation.

This is true of product engineering as well—technologies develop iteratively, gradually improving through testing. New technologies are not created in a vacuum—they are often tested before production to gauge and stimulate market demand.

The same lesson applies to regulation of autonomous vehicles. The state of California has drafted regulations for the deployment of self-driving vehicles and was not able to formulate clear specifications for certifying the safety of autonomous vehicles. This is a difficult question to answer without considerable commercial experience with autonomous vehicles. How will the public interface with autonomous vehicles? Will consumers choose to rely on these products in lieu of private ownership? Can the technology capture significant societal benefits? It is difficult to anticipate the answers to these questions before significant consumer deployment.

An example of an ineffective solution was offered by California, which chose to offer generalized guidelines that testing data must be turned over to expert third parties for testing and verification, and prohibited the operation of an autonomous vehicle without a licensed driver in the vehicle and maintaining responsibility at all times. This effectively placed a ceiling on autonomous vehicle technology at essentially current levels—California actually had to clarify that certain popular cars were not prohibited by the regulations. California's approach risks significantly setting back the deployment of autonomous vehicles.

Sometimes, regulators do not create the necessary framework for a new technology because they misjudge its utility. For example, AT&T approached regulators for help in deploying early mobile phone technology as early as the late 1940s, but the Federal Communications Commission preferred to allocate the necessary spectrum for other uses. Actual consumer experience with autonomous vehicles will prove far superior to expert theories on deployment in informing action by legislators and regulators.

NHTSA has the authority to exempt autonomous vehicles from standards that are incompatible with the technology. This authority is currently limited to 2,500 vehicles, but Congress should increase this number to at least 10,000, enough to allow for several large scale demonstrations. The federal government should coordinate with local and state governments on lining up a diverse range of deployment communities where autonomous vehicle technology can be provided to the public on a trial basis. These deployment experiences should be used to inform necessary safety, business model, and liability regulations.

**Foster State-Level Innovation**

The significant progress that has been achieved to date on autonomous vehicle development reflects the critical role of states as innovation laboratories. The millions of real-world miles traveled by autonomous vehicles have occurred almost entirely under state regulatory regimes. Even as federal action should be pursued to avoid an unmanageable patchwork of state and local rules, states should retain the autonomy to experiment with autonomous vehicles. This blended approach will encourage a broad range of experimental deployments to help expose the public to the benefits offered by autonomous vehicles while mitigating risk associated with possible regulatory uncertainty at the federal level.

Specifically, Congress should ensure that states have the ability to authorize a limited number of autonomous vehicles for deployment without requiring federal approval. To allow each state to conduct a meaningfully sized deployment experiment, this number should be set at approximately 500
vehicles per state. State-level exemptions should be provided in addition to, and not in lieu of, NHTSA's exemption authority.

**Spectrum Sharing**

V2X technology will contribute to autonomous vehicle functionality once there is widespread deployment, or sooner in areas targeted for use of V2X-enabled vehicles and infrastructure. The federal government should not endanger the potential benefits of this technology by allocating the necessary 5.9 GHz spectrum to other uses without first ensuring that the spectrum can be shared safely and not cause harmful interference.

**Legal Issue Roadmap**

Experience gained through test deployments of autonomous vehicles can best inform the regulatory process if they are designed to address specific knowledge gaps. A recent call to perform a “legal audit” of the status of autonomous vehicles underscore the need to create a road map of legal and policy issues to solve before the deployment of autonomous vehicles. Legal scholars have already begun the process of analyzing proposed and enacted state-level legislation on autonomous vehicles to create a legal road map for issues requiring attention from regulators before the deployment of autonomous vehicles. Additionally, research should be initiated on a range of legal issues, such as privacy and tort liability, which will come to the fore as autonomous vehicles begin to reach widespread commercial use.

**Recommendation**

Create an alternative liability framework for early autonomous vehicle deployment.

Today, motor vehicle accident insurance is carried by individuals who own vehicles, broadly spreading out the cost of insurance. The minimum required insurance coverage for each vehicle varies by states, but is usually less than $100,000. However, proposed legislation in many states has called for significantly higher insurance coverage for the testing of autonomous vehicles, often around $5 million per vehicle.

Similar insurance requirements for the commercial deployment of autonomous vehicles would represent a serious obstacle. Especially in the early stages of deployment, autonomous vehicles will likely be operated in fleets rather than sold to consumers. If one company wished to deploy a fleet of 2,000 autonomous vehicles, this would require an insurance policy of $10 billion dollars. Insurance companies may refuse to issue such a policy, or may charge a very high rate, until the risk levels of autonomous vehicles are fully understood. Very few companies can afford to set aside funds for a self-insurance policy of many billions of dollars.

Even if reasonable insurance policies were available, companies may be reluctant to deploy autonomous vehicles because their liability would be both large and uncertain, as there is little case law or precedent related to manufacturer liability for autonomous vehicles. There have been a range of proposed solutions to this issue.

Some have pointed to earlier federal programs to address situations where societal welfare is harmed by liability concerns. In 1988, the National Vaccine Injury Compensation Program was created to compensate those injured by childhood immunizations in response to a small number of adverse reactions to the pertussis portion of the DPT vaccine. Concerned that manufacturers of vaccines would stop production because of the threat of lawsuits, Congress created an alternative claims process funded by a fee on all vaccines. The claims process was part of broader legislation requiring

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116 Goldfeder et al.
the reporting of all adverse events to a national database and the establishment of a federal, no-fault system for adjudicating claims of harm from a vaccine. Not only has this structure preserved U.S. vaccine manufacturing capability, but the Fund has run at a surplus.117

A similar case might be made for the manufacturing of autonomous vehicles, where liability concerns will delay deployment and the significant resulting safety and health benefits. The terms governing the earliest public deployments of autonomous vehicles will likely be the product of a negotiation between the company manufacturing the autonomous vehicles, and federal, state, and local governments. Even after all efforts are made to ensure that autonomous vehicles meet a satisfactory safety standard, autonomous vehicle manufacturers will still require safeguards to limit their liability in order to proceed with deployment. The federal government should prepare for this eventuality by studying and considering alternative liability arrangements, including an analogue of the Injury Compensation Program. Such arrangements should be designed to retain a strong financial incentive for companies to deploy only autonomous vehicles that have been tested and rigorously certified as safe, but, at the same time, remove a significant obstacle that disincentivizes the deployment of autonomous vehicles and delays benefits.

The federal government should promote pilots of automated trucks; all levels of government should maintain flexibility and openness to innovative urban delivery approaches.

Despite representing only 4 percent of the U.S. vehicle fleet, heavy trucks account for about 22 percent of U.S. petroleum consumption. The disproportionate energy consumption results from trucks’ heavy weight and long distances, high-speed travel pattern. At the same time, this usage pattern and the economics of fleet operation represents an opportunity: highway automation is relatively easy to achieve and fleet managers are highly incentivized to seek even minor improvements in efficiency, quickly adopt technology that improves safety for their workers and the public, reduce labor costs and find ways to mitigate truck driver shortages.

Some savings can be gained through technology that is already available, such as using GPS data to better manage acceleration on stretches of highway with elevation changes. Platooning is a technology which is being extensively tested. These technologies should be incentivized by inclusion in fuel efficiency standards. Additionally, roadblocks, such as rules about vehicle following distances, should be removed.

At least one trial deployment of autonomous vehicles should center on truck automation. This would require designating a specific interstate highway corridor for testing automated trucks. This could be accomplished by the Federal Highway Administration in coordination with states and municipalities. The Federal Motor Carrier Safety Administration should participate in these pilots to explore how vehicle automation can reduce driver fatigue. Driver work hour rules should be updated to account for autonomous features and incentivize the deployment of technologies that will make drivers safer.

Innovative autonomous vehicles might offer a solution to the “last-mile” problem where much of the cost to ship a package across the country is accrued in the last leg from a central depot to its final destination in the same city. Several companies are testing innovative autonomous vehicle designs specifically for this purpose. Some of them are radical departures from the idea of a motor vehicle, such as a small, slow-moving box that travels on the sidewalk alongside pedestrians. These innovative

117 National Vaccine Information Center, “FAQ.”
designs may present challenges for regulation as they represent a novel class of devices. Local governments should maintain flexibility and openness towards new delivery vehicle concepts.

**Policies to Maximize Autonomous Vehicle Benefits**

**RECOMMENDATION**

Incentivize ridesharing and autonomous vehicles in addition to the current emphasis on vehicle-level efficiency.

**Autonomy and Ridesharing Reduce Petroleum Usage**

The advent of autonomous vehicles has the potential to reshape the transportation system through the adoption of shared, electric, and autonomous vehicles. This can dramatically drive down the cost of travelling a mile ($0.76 per mile today for today’s personal cars versus $0.15 per mile for future custom-built shared, autonomous vehicles), allow currently underserved groups more access to travel, and reduce petroleum dependency. These are all highly desirable policy outcomes, but some have raised concerns that cheap and accessible travel will cause a sharp increase in the total volume of travel, with negative impacts.

However, petroleum reduction induced by the adoption of shared autonomous vehicles, in combination with policy support for AFVs, is quite dramatic, even with a projected 30 percent increase in VMT. In 2016, the U.S. transportation system, excluding aviation, produced about 700 miles of travel for every barrel of oil consumed (Figure 62). The increase in shared, autonomous, electric vehicles drives this number to around 3,400 miles per barrel by 2040, close to a five-fold increase.

The model found that the shift of the transportation system from petroleum-based to an increased reliance on shared, autonomous, and electric vehicles will rapidly reduce petroleum usage compared to a baseline case. Although VMT would rise, the share of miles driven by electric vehicles or other AFVs would increase dramatically as well (Figure 63).

With respect to energy security and petroleum use, the net impact of shared autonomous vehicles would be strongly positive, with the increase in VMT more than outweighed by the shift to AFVs. Additionally, it is important to separate the distinct policy objectives of improving mobility by making it cheaper, more accessible, safer, and less fuel intensive per “mile of transportation” from the question of mitigating impacts from increased travel. In a transportation system with significant shared autonomy, the ability to drive down the cost of each mile of service and expand to new markets by increasing access to mobility will produce enormous benefits that should be encouraged. There is little justification for the idea that VMT should be limited to current levels by denying mobility to underserved groups.

Some have raised concerns that increased travel/VMT may cause negative impacts, such as congestion and strain on infrastructure. However, given the relatively poor understanding of what autonomous vehicles will do to land use patterns, commuting habits, and the distribution of populations between urban, suburban, and rural areas, it is almost impossible to make the case that the impacts of increased travel would outweigh the positive benefits of autonomous vehicles. This is an important area for further study, but should not hold up deployment.

In the interim, any autonomous vehicle policy framework should have the goal of improving consumer choice, safety, cost, energy security, and access to mobility; this is more reliably accomplished through removing and avoiding barriers to innovation and consumer choice. Issues stemming from increased

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mobility made possible by autonomous vehicles, however important to address, would be challenges associated with tremendous advancements in standard of living.

**Update Fuel Efficiency Standards**

Fuel economy and zero-emission vehicle mandates have been powerful policy levers for reducing U.S. oil consumption, and the design of these policies have significant impact on how manufacturers design their vehicles. These standards, however, are not designed in a way that accounts for the broader efficiencies that will result from ridesharing and autonomous vehicles.

By law, a vehicle’s efficiency under Corporate Average Fuel Economy (CAFE) regulations is determined by its performance on two cycles or simulated conditions: a “city” cycle and a “highway” cycle. The tests are performed on a dynamometer (essentially a treadmill for cars) and do not account for variations in driver behavior.

This means that the CAFE standards do not, for example, incentivize increased efficiencies in the design of automated braking systems. The behavior of these systems in “stop and go” situations are not captured in the testing cycles. Since low-speed travel with frequent braking is very common in urban driving, algorithms optimizing efficiency can decrease urban fuel use by 10 percent. Algorithms that are poorly designed could actually increase fuel usage significantly, making it important to incentivize efficiency in autonomous vehicle software design.\(^\text{119}\) However, the two-cycle test is codified into law by a 1975 law that requires that the EPA continue to use the exact same procedure to rate vehicles as it did at the time of the law’s passage.\(^\text{120}\)

Additionally, as discussed earlier, autonomous vehicles induce other efficiencies that will not be captured in a test of individual vehicles. Some efficiency impacts will result from accident reduction, which will mitigate congestion, and platooning, which are “off-cycle” benefits and are not currently accounted for. Longer term positive impacts include shifting the transportation system from its reliance on low-utilization personally owned vehicles to a highly utilized, shared system that will accelerate AFV adoption. Currently, there are no mechanisms to encourage either ridesharing or vehicle autonomy in current ZEV and fuel economy regulations.

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Congress should require agencies to update fuel efficiency standards to do the following:

**Incentivize more efficient autonomous vehicles.** Just as fuel efficiency standards have led to more efficient engines, they should incentivize software developers to create more efficient algorithms for vehicle automation.

**Account for the “off-cycle” benefits of autonomy such as reduced congestion resulting from better traffic routing and reduced accident frequency, once such benefits are quantifiable.**

**Recognize the different use profile of shared vs. privately owned vehicles.** A shared autonomous vehicle can easily drive more than ten times as many miles in a year as a privately owned, non-autonomous car. Additionally, SAFE modeling predicts that by 2040, with the availability of autonomous vehicles and even without policy support for AFVs, all sales to shared fleets will be battery or plug-in electric vehicles (Figure 61). Fuel efficiency standards should recognize the increased impact of shared autonomous vehicles and increase their representation in calculating fleet-wide average fuel economies. This might be accomplished by including a credit multiplier for vehicle sales to a fleet operator.

As discussed in greater detail in Part I, there is an ongoing and important debate on midterm fuel economy standards review and the long-term trajectory of these policies after the National Program concludes in 2025. The rapid pace of technological change and the growing opportunities presented by autonomous vehicle technology require that these ideas be taken into consideration as soon as possible—ideally for the midterm review. This should not be about providing loopholes to OEMs to meet fuel economy standards, but rather a serious, cost effective means of increasing efficiency and lowering greenhouse gas emissions in the context of California and EPA fuel efficiency regulations.

The greatest impact autonomous vehicles can have on fuel efficiency is through transforming the transportation system once they are deployed in significant numbers. Fuel efficiency policies should be updated to recognize and reward the positive impact that new technologies and business models offer. New policies should be put in place as soon as possible, and certainly no later than the end of the current National Program in 2025.

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**RECOMMENDATION**

State and federal governments should encourage the utilization of autonomous vehicles to expand mobility options for underserved groups.

**Identification of Benefits**

Identifying potential benefits in the early stages of autonomous vehicle deployment encourages adoption. For example, the National Council on Disability (NCD) identified numerous obstacles that may delay or prevent the availability of autonomous vehicles for use by Americans with disabilities. This allowed the NCD to issue policy recommendations and raise awareness of the need to make autonomous vehicles accessible to all Americans; this may accelerate benefits to the disabilities community.121

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A study should be commissioned to create a comprehensive list of societal benefits that could be realized by autonomous vehicles. Potential benefits should be assessed for their feasibility, likelihood of realization, and whether government actors have the necessary policy levers to encourage the benefits.

**Coordinated and Demonstration on Benefits**
The near-term availability of Level 4 autonomy carries the potential for transformative benefits. However, unless there is a concerted effort to shape autonomous vehicle deployment to meet the needs of all Americans, it is possible that the technology and services will be designed in a way that does not fully realize these benefits or require retroactive integration; this would likely be more expensive and less effective. For example, an autonomous vehicle will still require modification to fully accommodate individuals with disabilities. Consumers may need demonstrations before adapting to a mobility-on-demand paradigm.

The federal government should work with state and local governments, as well as relevant stakeholders and advocates, to create and test a diverse set of autonomous vehicle use cases. The tests should be closely monitored and the results published so that autonomous vehicle developers can incorporate lessons into further autonomous vehicle development and deployment plans.

Early stage pilots for autonomous vehicles should be designed to demonstrate and validate potential social benefits. The Minnesota State Senate is considering legislation that would set up a pilot test using autonomous vehicles to serve individuals with disabilities. Developers are looking to set up an autonomous vehicle system within a retirement community in Florida. Early test deployments should carefully record data that can offer insight into how autonomous vehicles can impact energy and private vehicle usage. These projects have the capability to demonstrate the feasibility and commercial viability of socially beneficial autonomous vehicle use cases.

The potential for autonomous vehicles to increase mobility is immense, but given the state of the technology, largely unproven. Piloting the use of autonomous vehicles for underserved populations will set the stage for capturing these societal benefits by demonstrating benefits and economic value to government actors and the private sector. If some states hold out and do not take necessary steps to include underserved groups in autonomous vehicle deployment, the federal government has effective levers to encourage compliance, such as withholding highway funding.
Update Regulatory Structures for Autonomous Vehicle Technology

RECOMMENDATION

Federal regulation of automotive safety should evolve to a more flexible and collaborative model based on performance-based standards.

A complete regulatory framework for a technology requires detailed perspectives on two issues: One, the requirements for demonstrating its safety and, two, how the results of the safety demonstration are verified. To be certified as safe, motor vehicles are required to meet a long list of highly specific component specifications. These requirements must be updated and regulators must be more responsive to changes in technology. At the same time, the current method for verifying that vehicles meet requirements—manufacturer self-certification of compliance—should not be replaced.

NHTSA currently regulates vehicles by requiring them to adhere to the FMVSS. These standards include many highly detailed specifications for dozens of vehicle components such as brakes, seat belts, steering wheels, and windshields. The vehicle standards are enforced through manufacturer self-certification.

Much of NHTSA’s regulation is reactive. Recalls are initiated after the discovery of safety defects. New safety technologies are usually in the market for several years before NHTSA begins the process of creating a rule to require its use throughout the fleet. Recent rules have required as much as eight to ten years from the start of the process.

Given the rapid change currently underway in the auto industry, a regulatory model based on fixed component specifications can prevent useful new technologies from being deployed if not already fully compatible with the FMVSS. Elements of the FMVSS have not been updated in several decades, and updating the FMVSS requires a time-consuming and expensive rule-making process. The pace of adoption of new auto technologies has rapidly increased, software is an increasingly important component of vehicles, and over-the-air updates can continually change vehicle functionality. Additionally, autonomous vehicles will likely bring extensive changes in both the hardware (for example: removal of mirrors, rear-facing “driver” seats) and performance of vehicles. Together, these changes have forced a rethinking of the relevance of the current vehicle regulatory structure and its prescriptive requirements for how a vehicle must look and the equipment that must be included.

Regulating autonomous vehicles will require a nimble, iterative regulatory framework. While it is premature to promulgate a full regulatory framework, as autonomous vehicle technology improves and is deployed broadly, a better understanding will allow for more effective regulation. Creating such a framework may require appropriating regulatory elements from other industries.

A shift to performance-based standards would position the government to avoid committing to specific technologies as autonomous vehicles rapidly evolve. For example, the Federal Aviation Administration (FAA) recently overhauled its certification processes for small aircraft so that safety innovations were able to be quickly adopted without going through years of evaluations. It accomplished this by writing safety objectives broadly enough to cover future unanticipated technologies and eliminating many prescriptive and technology-dependent elements from of the regulatory text. Applying these principles to the auto industry would accelerate the adoption, not just of autonomous vehicles, but of other important safety technologies as well.

Performance-based standards for software reliability and licensing limited to a subset of operational conditions are the norm at the FAA. The FAA requires that different hardware and software components, such as autopilot, be highly reliable (requiring tens of thousands or even millions of hours between failures of specific components), without prescribing exactly how the hardware and software systems should work. This regulatory framework could work well for autonomous vehicles. NHTSA could require certain levels of reliability from the component systems of autonomous vehicles such as sensor hardware, software fusing sensor data, or motion planning software.

The aviation industry has a reputation for working proactively with regulators to educate them on reasonable test procedures necessary to assure the safety of new technologies. This includes the ability for industry players to share safety failures such near-misses in an anonymous fashion and without fear of negative consequences such as litigation. This has led to valuable information sharing and increased safety. A similar process should take place in the auto industry. Currently, regulators do not understand how to determine if an autonomous vehicle is reliable. This undermines public trust and opens the door to poorly conceived regulatory schemes. Manufacturers should work with regulators to craft reasonable performance-based standards that are achievable and promote confidence in the safety of autonomous vehicles. NHTSA has recently sought to engage in more industry collaboration and consensus building, which is an important step in this direction. Some examples include the recent voluntary industry compact to standardize automatic emergency braking on most vehicles by 2022 without a government mandate and industry agreements to proactively share information to identify safety issues in the earliest stages.\(^\text{125}\)

The aviation industry uses an operational licensing model that restricts the use of some technologies to conditions for which it is proven safe. For example, an autopilot functionality might not be allowed at night or during foggy conditions until further data is gathered to validate uses under those conditions. This concept would be valuable for autonomous vehicles, whose functionality might be limited initially to certain areas, conditions, or types of roads. This iterative model for regulation will dovetail with the iterative deployment advocated earlier in this chapter.

However, it is vital to emphasize the importance of maintaining the current practice of manufacturer self-certification of vehicle compliance. This method allows for automotive companies to bring a broad range of models to market (in 2015, 222 different models were sold in the United States)\(^\text{126}\), while reducing the cost of regulatory compliance. Manufacturers may need to allow government to audit the results of tests proving compliance with performance standards, but there should not be a shift to

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126 Statista, “Total number of existing and new car models offered in the U.S. market from 2000 to 2015.”
a regulatory model where the government engages in continual surveillance of companies to monitor compliance.

**RECOMMENDATION**

A single office at a restructured Department of Transportation and an interagency working group with special hiring authorities should lead federal action on autonomous vehicle policy and necessary regulations.

**Department of Transportation Restructuring**

The vast majority of the Department of Transportation’s budget is organized around transportation modalities (e.g. highways, vehicle safety, transit, aviation, railroads). Regulatory activity and research agendas around each modality are controlled by agencies within the Department.

The entire DOT budget in FY2016 was just under $76 billion. Approximately $43 billion is allocated to the Federal Highway Administration (FHWA), $870 million to NHTSA, and $12 billion to the Federal Transit Administration. Additional agencies include the Federal Aviation Administration ($16 billion), the Federal Motor Carrier Safety Administration ($580 million), the Federal Railroad Administration ($1.7 billion), and others. Each agency effectively serves as an advocate for the transportation modality it sponsors.

The regulatory and technology issues surrounding autonomous vehicles do not fit neatly into the modal agencies that currently compose the DOT. Autonomous vehicle technology has relevance to urban transit, individual and shared light-duty passenger vehicles, and the heavy-duty and motor coach fleet. This presents two issues: not only does the use case of autonomous vehicles significantly overlap with several of the DOT agencies, but the scope of autonomous vehicle technology leans heavily on computer science disciplines and does not fit neatly into the current domains of expertise housed either at the DOT or its associated research facilities (such as the Volpe Center in Cambridge, MA).

Although the current Secretary of Transportation and Administrator of NHTSA are in the process of a major effort to advance the policy discussion around autonomous vehicles, ensuring long-term progress toward effective regulation will require restructuring the DOT. Additionally, a better regulatory framework will require funding that is better aligned with the scope of the new mission—NHTSA is not funded at a level which would allow it to assume greater responsibilities in a restructured DOT or enable it to significantly update its regulatory approach.

A reorganization should be an extension of steps Congress has already taken. In the Consolidated Appropriations Act of 2014, Congress consolidated the activities of the Research and Innovative Technology Administration (RITA) into the Office of the Assistant Secretary for Research and Technology (OST–R), which coordinates R&D across the modal agencies. Autonomous vehicle-related regulation could be centered in the office of a new Assistant Secretary, or NHTSA could be expanded appropriately with resources and autonomous-related regulatory functions from the other modal administrations. This office would also be well positioned to respond rapidly to industry inquiries on new technologies, a process which currently takes too long and holds back innovation.

The Department of Energy has taken several steps to reorganize away from its traditional, discipline-based approach to organizational structure and given greater emphasis to interdisciplinary and challenge-based innovation models. These moves are based on studies of effective innovation management and blue ribbon panel recommendations. They should be emulated by the Department of Transportation.
Need for an Interagency Working Group

At present, NHTSA is the agency at the center of autonomous vehicle regulation. NHTSA’s mission centers on saving lives and reducing motor vehicle accidents, which are important metrics, but do not capture the full rationale for autonomous vehicle deployment. The potential benefits of autonomous vehicle technology go well beyond reduced crashes and improved safety, and include numerous other social benefits which have been discussed in detail earlier in this section.

To ensure that the benefits of autonomous vehicles are captured in any decision-making, the Executive Office of the President should establish an interagency working group to be funded through the budget of participating agencies. Today, ad hoc collaborations between agencies exist on autonomous vehicle-related issues, but a more formal approach is needed. Agencies with missions that intersect with autonomous vehicles and have relevant expertise should be included. Agencies will include the Department of Energy for its perspectives on capturing energy security benefits, Health and Human Services for mobility access for older and disabled Americans, the National Science Foundation for access to scientific expertise, the Department of Defense to help deal with security issues, including cyber attacks, that could make autonomous vehicles a tool for terrorists or other groups with ill intentions, and the Department of Housing and Urban Development for economic mobility.

Special Hiring Authorities for the Working Group

Robust autonomous vehicle policy development requires expertise that is highly valued in the private sector and will be hard to accumulate within the constraints of agencies’ civil service structures. The DOT and interagency working group must seriously engage academic and industrial actors with the expertise to inform the autonomous vehicle regulatory process. Given that almost the entirety of an autonomous vehicle policy framework will be created—and repeatedly iterated—in the next several years, it is unlikely that an infrequently meeting advisory committee is the right mechanism for private sector and academic involvement in this process. The interagency group should use contracting mechanisms to bring on experts with relevant private sector and academic experience on at least a part-time basis. Flexible contracting mechanisms make it easier to pay experts an appropriate salary for their services and make hiring or firing decisions quickly.

To minimize conflict-of-interest risk, non-government participants of the working group should be limited to providing technical, neutral advice to government agencies on autonomous vehicle technology and the likely impacts of any policy measure. Congress should grant any relevant hiring authorities.