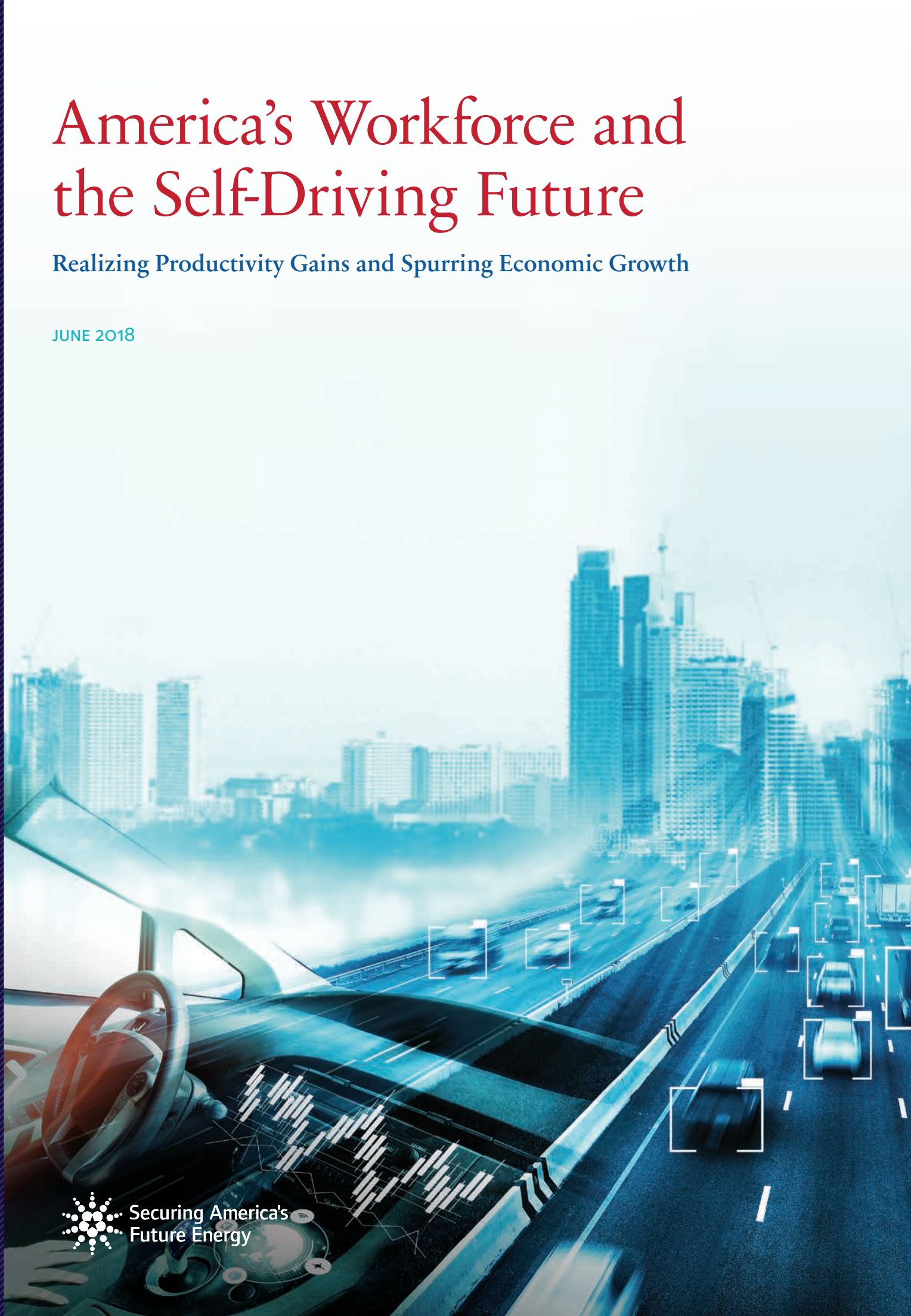
America's Workforce and the Self-Driving Future

Realizing Productivity Gains and Spurring Economic Growth

JUNE 2018



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AUTHORSHIP

SAFE, acting on the guidance of its Energy Security Leadership Council (ESLC), considers the near-term deployment of autonomous vehicles (AVs) a critical area requiring policymaker attention. In particular, the ESLC has identified the potential economic impacts of AVs as well as impacts on U.S. employment and the middle class as an area warranting study. To formulate a strategy to address and contextualize concerns within the broader context of other impacts AVs will have on the economy, SAFE organized a panel of economic experts.

The experts were given a broad mandate to study a set of key questions, including: 1) what precedents can we rely on in thinking about the impacts of AVs?, 2) what is the scale of concrete benefits AVs can offer to the broader population?, and 3) how can we inject rational, well-researched perspectives into the emotionally-charged yet critical conversation around the potential job impacts of AVs?

SAFE convened a team with decades of experience in academia, government, research institutions, think tanks, and the private sector. They include former senior government officials, renowned professors, and experts trusted to make recommendations to a broad range of administrations.

The experts were given technical assistance and were provided access to SAFE and industry expert views on AV technology. Most importantly, they were asked to impartially investigate and report their findings. After several months, the panel delivered three reports comprising over 300 pages of findings, each addressing one of the questions above. The study, including both the brief and the reports, are available separately at www.secureenergy.org/AVLaborImpacts.

This brief, authored by Amitai Bin-Nun, Alex Adams, and Jeffrey Gerlach, represents SAFE's consolidation, integration, and presentation of the three reports. It draws upon, summarizes, and interprets the key findings of these experts' reports within the context of contemporary policy discussions.

The following are the three reports delivered by the panel, with the biographies of their author(s).

1. THE ECONOMIC AND SOCIAL VALUE OF AUTONOMOUS VEHICLES: IMPLICATIONS FROM PAST NETWORK-SCALE INVESTMENTS

Dr. Richard Mudge is President and Founder of Compass Transportation and Technology Inc. This firm specializes in the economics, finance, and policy of transportation, with an emphasis on AVs and shared mobility. He holds a Ph.D. in Regional Economics from the University of Pennsylvania. Dr. Mudge is a nationally-recognized expert in the economics and finance of all modes of transportation. He has held a series of management positions as a transportation consultant. He also directed the transportation policy group for the Congressional Budget Office and worked in applied research at the RAND Corporation.

2. PUBLIC AND CONSUMER BENEFITS OF AUTONOMOUS VEHICLES

Dr. David Montgomery is an expert on transportation policy, fuel markets, and environmental issues. He holds a Ph.D. in economics from Harvard University, was a Fulbright Scholar at Cambridge University, and holds a B.A. in Social Studies from Wesleyan University. His professional experience includes tenures at the U.S. Department of Energy and Congressional Budget Office, he was a Senior Fellow at Resources for the Future, has taught at the California Institute of Technology and Stanford University, and he has received the Association of Environmental and Resource Economists' 2004 award for a "Publication of Enduring Quality" for his pioneering work on emissions trading.

3. PREPARING U.S. WORKERS AND EMPLOYERS FOR AN AUTONOMOUS VEHICLE FUTURE

Erica Groshen served as the 14th Commissioner of Labor Statistics from January 2013 to January 2017, a Senate-confirmed post. The U.S. Bureau of Labor Statistics (BLS) is the principal federal statistical agency responsible for measuring labor market activity, working conditions, and price changes in the U.S. economy. Prior to joining BLS, Dr. Groshen was Vice President in the Research and Statistics Group at the Federal Reserve Bank of New York. Dr. Groshen holds a Ph.D. in economics from Harvard University and a B.S. in economics and mathematics from the University of Wisconsin-Madison.

John Paul Macduffie is Professor of Management at the Wharton School and Director of the Program on Vehicle and Mobility Innovation (PVMI) at Wharton's Mack Institute for Innovation Management. PVMI carries on the work of the International Motor Vehicle Program (IMVP), the research network founded at M.I.T. to study the challenges facing the global automotive industry, which Professor MacDuffie co-directed from 2001-2012. He received his B.A. from Harvard University and a Ph.D. from the Sloan School of Management at M.I.T.

Susan Helper is the Frank Tracy Carlton Professor of Economics at Weatherhead School of Management, Case Western Reserve University. She served as the Chief Economist of the U.S. Department of Commerce from 2013-2015, and as Senior Economist at the White House Council of Economic Advisors from 2012-2013. She received a B.A. from Oberlin College and a Ph.D. in economics from Harvard University.

Charles Carson is a former Program Economist at the U.S. Bureau of Labor Statistics and assistant to the Chief Economist at the U.S. Department of Labor. He holds a B.S. in economics from the University of Alabama.

Advance Praise for "Preparing U.S. Workers and Employers for an Autonomous Vehicle Future"

by Erica Groshen, Susan Helper, John Paul MacDuffie, and Charles Carson

"Groshen, Helper, and MacDuffie provide the most thorough analysis yet of the biggest technological development coming down the road. It deserves widespread attention and to have its recommendations seriously debated."

Lawrence Summers

Charles W. Eliot University Professor and former President, Harvard University; Former Secretary of the Treasury and Director of the White House National Economic Council

"In this paper, Groshen, Helper, MacDuffie and Carson take a historical approach to try to divine the impacts of the transition to Autonomous Vehicles (AV) on workers. The paper is thorough, and draws on a range of earlier waves of disruption, including autopilots in aviation, the industrial revolution, ATMs, globalization, and computer numerically controlled machines. A thorough review of the history of these waves of disruption is used to infer the likely effects of the coming AV revolution. This seems like an eminently plausible way to tackle this question, and one that I expect will have a major impact on the literature and policy discussions."

Alan B. Krueger

Bendheim Professor of Economics and Public Affairs, Princeton University; Former Chairman of the White House Council of Economic Advisers, Assistant Secretary of the Treasury for Economic Policy and Chief Economist of the Treasury Department, and Chief Economist of the Department of Labor

"Autonomous vehicles may be coming soon on a wide scale and will certainly affect the U.S. labor market. Erica Groshen—a former head of the Bureau of Labor Statistics—and her academic colleagues have provided policymakers with a great place to start in understanding the potential effects of autonomous vehicles (AVs) on employment and skills. The study's framework for tracing the labor market impacts of AVs is clear and insightful, and the lessons the study draws from the past—including its case studies of aircraft auto-pilots, ATMs, Engels' pause, and more—are illuminating and important as we consider what the future might hold, and how we can navigate it most successfully."

Michael R. Strain
John G. Searle Scholar and Director of Economic Policy Studies at the American Enterprise Institute (AEI)

"Erica Groshen and her coauthors have produced an ambitious paper that offers a uniquely comprehensive, deeply-sourced, and level-headed assessment of the medium- and long-term consequences of autonomous vehicles for the U.S. economy and the U.S. labor market. Rather than focus on either doomsday or 'it's all good' scenarios, Groshen and her coauthors draw from historical examples, leading scholarship, and a large number of plausible scenarios to paint a picture of the likely pace of change, the probable stress points, the broad benefits, and the concentrated costs faced by a subset of people and places. Complementing this illuminating analysis, the authors offer an agenda for research, experimentation, and policy analysis that can help to guide us towards the best of these scenarios."

David Autor
Ford Professor of Economics and Associate Department Head, MIT Department of Economics

Letter to the Reader from Report Authors

In the last several years, the development and adoption of autonomous vehicles (AVs) has emerged as a central policy subject, both in the United States and across the world. The vision of a future where vehicles drive themselves has captured the imagination of the public, promising the potential for significant improvements in roadway safety, economic productivity, accessibility, and reducing fuel consumption and accompanying emissions.

At the same time, some have expressed concern about the long-term impacts of the technology, most intensely with regard to the question of the potentially far-reaching impacts of the technology on the U.S. labor force. The individual identities of Americans are often intertwined both with the vehicles they drive and their occupations. The potential significant changes on both fronts in the years and decades to come is, understandably, an unsettling prospect for some.

To ensure that policy decisions are made on the basis of solid evidence, SAFE engaged us to answer a series of questions that cut to the core of these issues. The questions were:

1. What precedents should we look to in thinking about the impacts AVs will have on society and the economy?

2. What are some concrete examples that illustrate the nature and magnitude of the economic and social benefits that AVs can offer?

3. What will be the medium- to long-term impacts of vehicle automation on the workforce? Upon what will the scale and timing of those impacts depend? What steps can be taken today to ensure the best outcome for both the public that stands to gain from AVs and the workers whose jobs could be impacted?

These questions were selected because of the importance of improving the social impact of the technology, the potential for impacts on the labor force, and the importance of these considerations to policymakers in weighing AV regulation. A deeper knowledge of the broader economic impacts of AVs will help to encourage constructive choices in a resource-constrained world.

Over the last six months, we divided these questions amongst this group, with a report dedicated to each question. We performed independent and rigorous research utilizing well-accepted methods of economic analysis that culminated in three reports—referred to in this brief as the Compass Transportation report (focused on the question of precedents), the Montgomery AV benefits report (focused on the benefits of AVs) and the Groshen employment report (focused on the employment impacts)—that each addressed one of the questions posed above. The reports are available on the SAFE website at www.secureenergy.org/AVLaborImpacts.

The policy brief that follows draws upon, summarizes, and applies the research findings to broader policy questions. We have reviewed this document and it accurately represents the findings of our own individual reports and applies them in good faith to address the policy questions that concern SAFE. We note that each team worked independently and did not review other teams' research. The combination and application of the three reports was performed by SAFE.

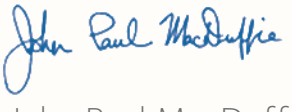
We hope you will read SAFE's policy brief and the broader research reports on which it is based. We look forward to continued dialogue on these critical areas of policy.

Best,

W. David Montgomery

Susan Helper

Richard Mudge



John Paul MacDuffie

Erica L. Groshen

Charles Carson

Executive Summary

Although they are not yet in widespread commercial use, there is intense public interest in autonomous vehicles (AVs).

Much of the focus has been on the broad societal benefits this technology can offer. AVs also have the potential to influence society in a way unseen since the invention of the automobile. In addition to dramatically reducing traffic accidents and roadway fatalities, AVs hold the promise of improved mobility—critical for economic growth and quality of life. AVs can dramatically improve the lives of communities underserved by our current transportation system and those most vulnerable to its inefficiencies, namely Americans with disabilities, seniors, and wounded veterans.

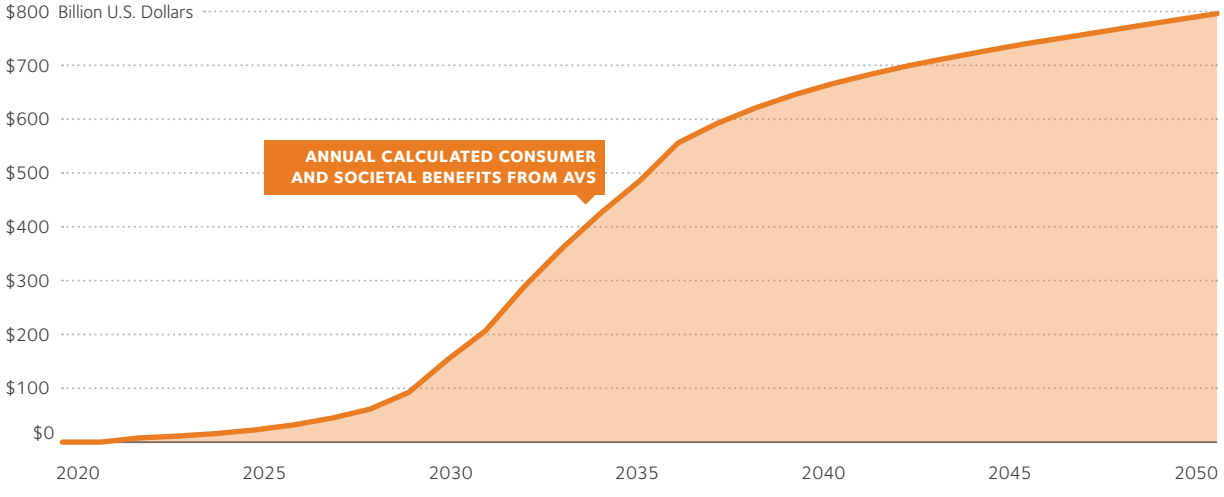
However, some have raised concerns about the potential for AVs to negatively impact workers and exacerbate wealth inequality. SAFE believes that AV-related labor displacement concerns—many of which have been expressed sensationally—must be addressed seriously rather than merely dismissed out of hand or repeated without verification. In response to these concerns, SAFE commissioned a panel of highly regarded transportation and labor economists to conduct a fact-based and rigorous assessment of the economic costs and benefits of AVs, including labor impacts.

The commissioned research painted a detailed outlook for the future economic and labor market impacts of AVs. They found:

- AVs have many of the characteristics of "catalyzing innovations" whose positive impacts are felt broadly throughout the economy.
- Significant economic benefits from the widespread adoption of AVs could lead to nearly $800 billion in annual social and economic benefits by 2050, mostly from reducing the toll of vehicle crashes, but also from giving productive time back to commuters, improving energy security by reducing dependence on oil, and providing environmental benefits.
- A study of traffic patterns and job locations found that some economically depressed regions could see improved access to large job markets for their residents through the deployment of AVs.
- AVs will create new jobs that will, in time, replace jobs eliminated by automation. Strong workforce development infrastructure can both mitigate employment disruption and speed the evolution of worker skill requirements that will contribute to full employment and economic growth.
- There is significant time before the impacts of AVs on employment are fully realized. Simulations of the impact of AVs on employment showed a range of impacts that would be felt starting in the early 2030s but would only increase the national unemployment rate by 0.06–0.13

FIGURE A

Projected Annual Consumer and Societal Benefits from AVs



Source: David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

Quantified Benefits of Autonomous Vehicles

TABLE A

Public Benefits by 2050 (annual)	**$633 Billion**
Congestion Mitigation	$71 Billion
Accident Reduction – Economic Impact	$118 Billion
Accident Reduction – Quality of Life Improvements	$385 Billion
Reduced Oil Consumption	$58 Billion
Consumer Benefits by 2050 (annual)	**$163 Billion**
Value of Time	$153 Billion
Reduction in Cost of Current Taxi Service	$10 Billion
Total Annual Benefits (by 2050)	**$796 Billion**

Source: David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

percentage points at peak impact sometime between 2045 and 2050 before a return to full employment.

- The economic and societal *benefits offered by AVs in a single year* of widespread deployment will dwarf the cost to workers incurred over the *entire multi-decadal deployment of AVs* when measured in purely economic terms. The benefits of AVs are sufficiently large to enable investment of adequate resources in assisting impacted workers.
- By pursuing a rapid deployment of AVs, combined with investments in workforce policies that seek to mitigate costs to workers and policies that address other risks or costs that might emerge alongside greater AV adoption, the United States can enjoy the full benefits of AVs as soon as possible while simultaneously preparing the workforce for the jobs of the future.

Economic and Societal Impact

Many of the most compelling benefits of autonomous vehicle technology will be intangible or undetectable from modeling designed to capture incremental gains. Any economic estimates of these benefits should be understood as an attempt to capture just a portion of gains from AVs. This conservative microeconomic analysis estimates economic benefits of up to $800 billion per year with full deployment of AVs. Utilizing the projections for AV deployment that SAFE developed, the value of AV benefits through 2050 will likely be between $3.2 trillion and $6.3 trillion. This is a partial estimate looking at a narrow set of case studies—a full estimate would likely be significantly higher.

A projection of the annual consumer and societal benefits of AVs is in Figure A. The breakdown of these benefits (upon full adoption) is in Table A.

Accident Reduction: In 2010, the National Highway Traffic Safety Administration (NHTSA) estimated the economic costs of car crashes to be $242 billion per year. When quality-of-life costs are added into the estimate, the total value of societal harm was approximately $836 billion per year. Extrapolating these values based on more recent crash and driving data puts the annual societal cost of crashes at over $1 trillion today. Using a conservative methodology in which we assume AVs would only address crashes resulting from a gross driver error (e.g. distraction, alcohol, and speeding), the annual benefit would exceed $500 billion. Given that human error contributes to over 94 percent of accidents, benefits could exceed this amount.

Reduce Oil Consumption: Oil holds a virtual monopoly on vehicle fuels, with petroleum accounting for 92 percent of the fuel used to power the U.S. transportation system. By precipitating a shift away from petroleum as the dominant fuel source, AVs can substantially reduce America's reliance on oil. An analysis of the energy security and environmental benefits of increased EV uptake as a result of AV deployment supports an estimated $58 billion societal benefit.

Congestion: Crashes are a major source of road congestion and improved safety from AVs and better throughput (e.g. through reduced bottlenecks) could significantly reduce the current costs of congestion: Close to 7 billion hours are lost in traffic and over 3 billion gallons of fuel similarly are wasted every year.

Improved Access to Retail and Jobs: SAFE modelling of road speeds around specific retail establishments found that the increased willingness of shoppers to travel—even by just two minutes each way—could increase a mall's customer base by nearly 50 percent in some instances. Additionally, SAFE modeling identified numerous economically disadvantaged localities

FIGURE B

Improved Transportation Offers Access to Work Opportunities: Gary, IN

Source: SAFE analysis and David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

for whom better transportation options would lead to greater employment opportunities. For a group of four struggling cities (Gary, IN, Benton Harbor, MI, Elmira, NY, and Wilmington, DE), SAFE modeled how increased traffic speeds from AV adoption and greater willingness to travel could impact the number of jobs within reach. An illustrative example is in Figure B.

The Effect of AVs on the U.S. Labor Force

From the automobile to the internet, history has demonstrated time and again that new technologies lead to sizable economic and social benefits in the long run. However, with significant change always comes the specter of potential loss, particularly in the short term. Like many new technologies before it, the public discourse around AVs has witnessed a significant focus on potential downsides, often with considerable exaggeration. However, the potential losses must be balanced with the benefits from highly significant improvements in safety, reductions in vehicle crash fatalities, gains in productivity, reduced congestion and increased fuel efficiency that will result from AV deployment. Indeed, the benefits are sufficiently large to enable investment of adequate resources in assisting those affected.

A study of historical precedents for the impacts of new technologies found a common pattern: Adoption of new technologies improves productivity and increases quality of life. Widely adopted technologies can transform our way of life and improve economic well-being at a national scale. Often, technological progress leads to improved opportunities for workers in the short term; a recent study found that the rise of e-commerce has, on net, improved jobs for high school graduates.[1] However, the impacts of those technologies can also present temporary challenges for the workforce, both for employers needing skilled workers, and for workers whose skills may no longer be as competitive in the labor market.

In the absence of concrete estimates, the media and public have a tendency to concentrate on the worst possible outcome. A recent report claimed that "more than four million jobs will likely be lost with a rapid transition to autonomous vehicles."[2] The methodology used to develop this number was simply to count driving jobs in the United States and assume that they would be rapidly lost as AVs deploy. Such assumptions and conclusions lack context, nuance, or grounding in labor market dynamics and the natural cycle of labor force evolution.

Using the scenarios SAFE provided for the adoption of AVs, the Groshen employment report modeled the technology's impact on the workforce. The study concluded that AVs would not lead to the long-term loss of jobs, although some number of workers could experience unemployment and wage losses. As there are far more professionally employed truck drivers than professionally-employed car drivers, impacts would be tied more closely to the adoption of very high automation in trucks (defined as no driver "in the loop" for most of operation). In contrast, partial automation or teleoperation of trucks is not likely to have significant negative impacts on the workforce.

> Widely adopted technologies can transform our way of life and improve economic well-being at a national scale.

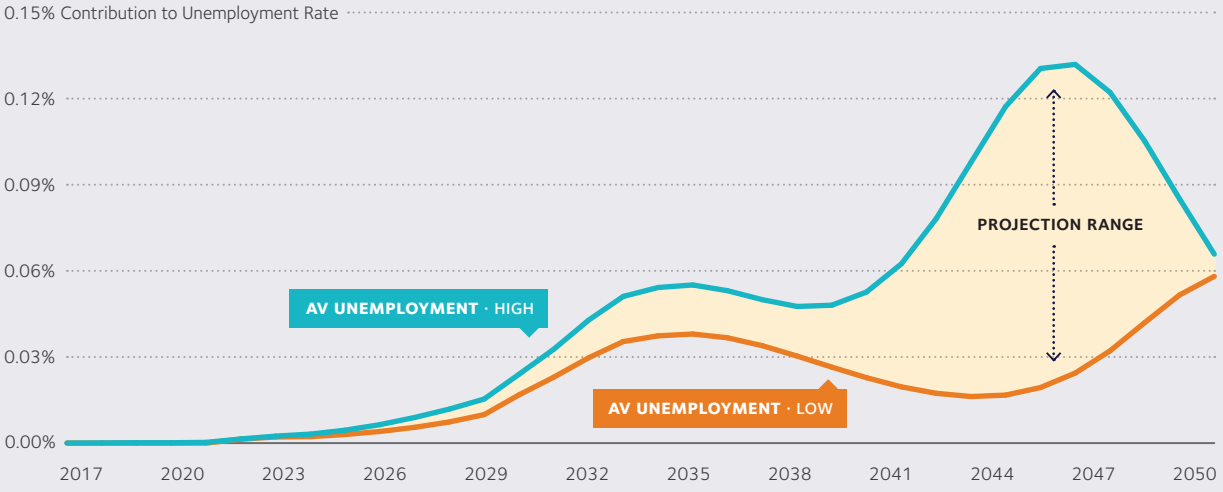
Figure C and Table A contextualize the job loss within a broadly understood metric—the unemployment rate. Relative to a baseline of full employment, the advent of AVs are projected to increase the unemployment rate to a small degree in the 2030s and to a somewhat larger degree in the late 2040s, with a peak, temporary addition to unemployment rates of 0.06–0.13 percentage points. Table A contextualizes the size

1 Michael Mandel: *How Ecommerce Creates Jobs and Reduces Income Inequality* September 2017, Progressive Policy Institute.

2 Algernon Austin et al. *Stick Shift: Autonomous Vehicles, Driving Jobs, and the Future of Work* March 2017, Center for Global Policy Solutions.

Marginal Contribution to Unemployment Rate

FIGURE C



Source: Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

Marginal Contribution to Unemployment Rate in Historical Context

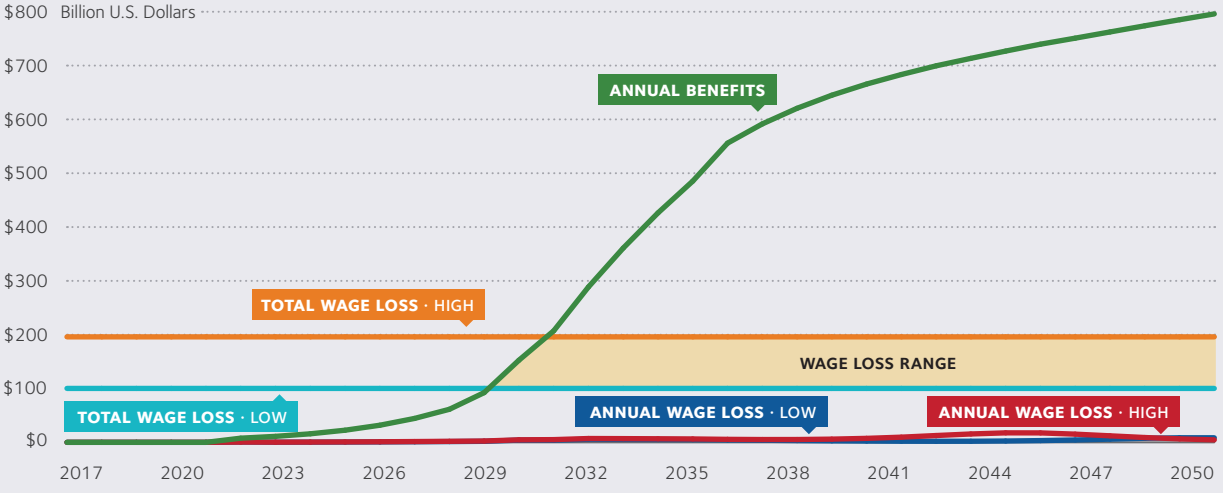
TABLE B

Event	Timing of Peak Impact	Marginal Increase in Unemployment at Peak
Autonomous Vehicle Deployment	Between 2045 and 2055	**0.06–0.13 percent**
Great Recession	2010	**4.9 percent**
Early 2000s Recession	2003	**1.3 percent**

Note: Marginal Increase in Unemployment at Peak assumes a baseline of 4.7 percent unemployment before event impact
Source: Data on AV deployment impacts from Groshen employment report; Data on historical annual unemployment rates from FRED.

AV Benefits and Wage Loss: Broader Context

FIGURE D



Note: Data on annual benefits from Montgomery AV benefits report. Data on wage loss from Groshen employment report. Total Wage Loss is over modeled period (2018 to 2051).
Source: David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018, and Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

of this employment impact with the shock of the recent Great Recession and a previous mild recession.

Policy steps to address the evolution of the labor market must ultimately be placed in the context of the broader impacts of AVs in order to ensure the best outcome. Due to the large-scale societal benefits from the deployment of AVs, policies to address labor force issues must carefully consider their potential impact in delaying the deployment and thus the benefits of AVs. Delaying the deployment of AVs would represent a significant and deliberate injury to public welfare. Rather than delaying the benefits, policymakers could ensure that the interests of the people who may lose jobs are well protected through effective mitigation programs.

Figure D illustrates the importance of balancing these two priorities. It plots both the conservative projected AV benefits and the range of projected wages that will be lost to individual workers due to AV-related unemployment. The range of projected wage loss reaches as high as $18 billion in 2044 and 2045. However, it is essential to note that this goes hand-in-hand with projected social benefits well in excess of $700 billion for each of those years. In fact, not only are the social and economic benefits of AV deployment significantly more than their costs to workers on an annual basis, but the *benefits of AVs each year* are far greater than the total cost to workers *over the next 35 years combined* (illustrated by the middle range of this graph).

POLICY RECOMMENDATIONS

It is highly likely that AVs will revolutionize the American economy in ways that have not been seen since the mid-20th century. In fact, it is hard to foresee any technological or other change on the horizon that can contribute more to economic growth and productivity. The economic and social impacts of deploying safe AVs would be significant and positive. However, these benefits could be accompanied by certain employment dislocations. SAFE strives to take a realistic approach to these risks and propose policies to mitigate them. Those impacts are projected to be unnoticeable before the 2030s, with most impacts in the 2040s. This gives policymakers significant lead time to research, design, and implement workforce development solutions. By committing to this approach, the United States can enjoy the full benefits of AVs as soon as possible while simultaneously preparing the workforce for the jobs of the future.

Although the consensus of opinion on AVs is that the benefits of the technology outweigh the costs, some analysis raises concern that some groups will experience higher costs than others relative to the benefits they receive from the technology. SAFE believes that society does not have to choose between the compelling benefits of AVs and the stable evolution of the workforce. The totality of evidence generated by this study strongly supports the conclusion that the best pathway to broad American prosperity is through the adoption of policies supporting AV deployment while simultaneously laying the groundwork for the workforce of the future.

Introduction

Securing America's Future Energy (SAFE) has long believed that AVs represent arguably the best opportunity to reduce America's oil dependence.

Thirteen years have passed since the Stanford Racing Team achieved victory in the 2005 Defense Advanced Research Projects Agency (DARPA) Grand Challenge. That event, which received widespread attention at the time, was a watershed moment in the evolution of self-driving cars from science fiction theme into market reality. Until recently, however, policymakers at the federal, state, and local levels largely were unaware of the emerging revolution in personal mobility that stood to reshape America's society and economy.

Now, after years of effort and billions of dollars in research and development by both upstarts and incumbents, with innovators testing fully autonomous vehicles (AVs) on the country's roads and preparing to deploy them for consumer use, public officials have begun to think about the technology—and the impacts it may have, including the possibility that AVs may displace some of the jobs of Americans who drive for a living.

This concern is intensified by the struggles of America's working class under years of sub-trend economic growth following the Great Recession as well as severe and concurrent social challenges in this community. These include worsened health and life expectancy and the more than 10 million prime-age men not in the workforce.[3]

Public officials in Washington and state capitals are facing important decisions regarding AV policies and regulation under extraordinary pressure and without a full accounting of likely AV impacts, both positive and negative.

Founded the same year as the DARPA Grand Challenge to advocate for transportation policies that advance American economic and national security, Securing America's Future Energy (SAFE) has long believed that AVs represent arguably the best opportunity to reduce America's oil dependence. while also providing low-cost mobility.

AV deployment portends momentous positive societal change. In addition to dramatically reducing traffic accidents and roadway fatalities, AVs hold the promise of improved mobility—critical for economic growth and quality of life. AVs can significantly improve the lives of communities underserved by our current transportation system and those most vulnerable to its shortfalls, namely Americans with disabilities, seniors, and wounded veterans.

While broader societal benefits are undoubtedly important, SAFE believes that America's wealth and security as a nation, and the upward economic mobility afforded to all Americans as individuals, depends upon broad, equitable access to low-cost mobility. Although oil is both highly energy dense and easily transportable, attributes that together made it the dominant transportation fuel for more than a century, our singular dependence upon it to power most of our transportation needs entails significant costs and vulnerabilities.

First, oil's cost is not determined under the transparent conditions of a free market characterized by price discovery. Rather, oil prices are exposed to significant volatility as a result of the interventions of state-owned actors that share neither America's interests nor her values.[4] These entities have extracted considerable rents from American consumers when they have led oil prices up, and stifled transportation innovation when they have led oil prices down, all the while being protected at significant burden to America's military and taxpayers.

Although SAFE supports expanded domestic oil production, unfortunately, no matter how much oil America produces domestically, OPEC and its associated National Oil Companies (NOCs) will continue to control the largest and lowest-cost reserves in the world and therefore oil's price.[5] Adding insult to injury, many of these very reserves were confiscated from American companies in the 1970s.

3 Nicholas Eberstadt, "Where did all the men go?", *Milken Institute Review*, April 2017. Accessed on March 18, 2018: http://www.milkenreview.org/articles/where-did-all-the-men-go; and Mark Aguiar, *et al.*, "Leisure Luxuries and the Labor Supply of Young Men", NBER Working Paper No. 23552, June 2017.

4 See, e.g., Alex Lawler, Amena Bakr, Dmitry Zhdannikov. "Inside OPEC room, Naimi declares price war on U.S. shale oil. Reuters. November 28, 2017.

5 See, e.g., SAFE, *National Strategy for Energy Security: The Innovation Revolution*, May 2016.

Second, unlike in electric power generation, where energy from natural gas, coal, nuclear, hydropower, wind, solar, and even fuel oil can be utilized depending on market conditions, there currently is no substitute for oil as a transportation fuel available at scale. The result: When OPEC and NOCs succeed in raising the price of oil, consumers cannot currently transform the cars that take them to work and their children to school to run on a less expensive fuel—and the millions of American workers in the auto sector, blue-collar and white-collar, have their livelihoods subjected to the diktats of people living half a world away.

As evidence mounts that AVs are likely to accelerate a transition to advanced fuels, AVs hold the potential to unshackle the transportation sector from the constraints associated with oil dependence and provide—even more so than oil—inexpensive, secure, and scalable mobility.[6] The higher utilization rates of AVs deployed through fleets that will significantly improve on today's conventional vehicles—which sit idle more than 90 percent of the time—means that vehicles powered by advanced fuels, particularly electricity and natural gas, will become more economically viable as substitutes for oil. Over time, as autonomous vehicle operation penetrates the U.S. automotive market, significant energy security gains will be made. These gains will accrue to U.S. families as well as the U.S. government, including our men and women in uniform currently still guarding oil exports from the Persian Gulf region.

AVs hold the potential to unshackle the transportation sector from the constraints associated with oil dependence.

Uniquely, AVs can satisfy the concerns of both *laissez-faire* activists and policy interventionists. If allowed to develop under a coherent regulatory structure, AVs will achieve the potential of private-sector innovators to provide more mobility at lower cost and reduce environmental impacts to segments of the population currently underserved by existing transportation means. To this end, since 2015 SAFE's Autonomous Vehicles and Mobility Innovation program has advocated for a sound regulatory environment for AV development, undertaking extensive research and analysis on the range of public policy questions pertaining to AVs, including but not limited to: reconfiguring fuel economy regulations to account for autonomous technologies; bolstering vehicle testing and safety; accounting for the unique characteristics of heavy-duty trucks; and ensuring access for the disability community.

Given the revolutionary potential of AVs to benefit the country and its economy, SAFE believes that AV-related labor displacement concerns—many of which have been exaggerated or expressed sensationally—must be addressed seriously rather than merely dismissed out of hand or repeated without verification or critical evaluation. Therefore, SAFE commissioned a panel of highly regarded economists to conduct a fact-based and rigorous assessment of the economic benefits and costs of AVs, including labor impacts. Although SAFE funded the economists' work, SAFE did not control the conclusions. This brief draws upon, summarizes, and applies their findings to key policy questions.

Although the benefits calculated in this brief are conservative and likely represent an underestimation, the gains stated here promise to be substantial. Between now and 2050, the cumulative value of AV benefits are projected to be $6.3 trillion. These gains will be realized through benefits to the public, which include fewer crashes, increased productivity and potentially less congestion; benefits to consumers who see greater value in AVs than conventional vehicles; and energy security and environmental benefits.

There are anticipated costs, although these are significantly lower in number than the benefits described above. Modelling projected that the marginal impacts to the unemployment rate, at peak impact in the late 2040s, would be between 0.06 and 0.13 percentage points and the lifetime wages lost to unemployment each year would peak at about $18 billion around this time. For most of the next three decades, impacts would be considerably lower, and mostly unnoticeable before the 2030s. In contrast to the costs, the economic and societal benefits of AVs will approach $800 billion dollars of annual benefits calculated through improvements in mobility, efficiency and safety. Some of these benefits will accrue before the full impacts of AV adoption are felt in the labor market. Furthermore, the long lead time the United States faces before the effects of widespread AV deployment are felt means that governments, employers, and employees will have substantial time to prepare for any displacement AVs will cause.

6 Robbie Diamond and Amitai Bin-Nun, "Self-Driving Cars: Road to Deployment", Written Testimony to the House Committee on Energy and Commerce, Subcommittee on Digital Commerce and Consumer Protection, February 14, 2017: http://docs.house.gov/meetings/IF/IF17/20170214/105548/HHRG-115-IF17-20170214-SD011.pdf

SAFE believes that the very qualities that make the United States the global leader in innovation, including the development of AVs, give it the capacity to take changes in stride. A sclerotic, static society can neither produce change nor tolerate change. But a dynamic, innovative society can both produce change and utilize that change. In this spirit, SAFE offers the following honest accounting of the economic impacts of AVs.

Learning from the Past: Catalyzing Technologies, Network-Scale Changes, and Autonomous Vehicles

Every so often, a new technology or infrastructure project has the potential to create "network-scale" changes in society and reorder our economy by acting as a "catalyzing" technology. AVs have many characteristics of catalyzing technologies that can provide benefits for businesses well beyond the scope of the automotive and technology industries. This is consistent with findings by economists that increases in productivity in the transportation sector have significant follow-on impacts in the remainder of the economy, more so than almost any other sector.[7]

Historical examples abound. For example, investments in the construction of the Interstate Highway System have returned more than $6 in economic productivity for each $1 invested, by cutting journey times for both goods and labor.[8] The internet produced similar productivity gains by making communication and document transfer instantaneous, as well as allowing work to take place anywhere and at any time. For example, by the early 2000s, the internet boosted profitability in companies across a diverse array of countries by 10 percent due to lower administration and production costs.[9]

As examined in the Compass Transportation report, the internet and the Interstate Highway System defied linear economic thinking, as these technologies provided significant benefits far beyond their originally-designed impact that conventional analysis failed to capture. Traditional economic studies for the interstate network showed that only 33 percent of the mileage could be justified based on traffic in 1956 and claimed that at most one road over the Rocky Mountains made economic sense. Eventually, growing demand led to three highways being built.[10] It is remarkable that, despite an average rate of return on public investment of between 50 and 60 percent,[11] economic benefits did not even rank in the top three factors cited by supporters for the highway network's construction when the enabling legislation was passed in 1956.

As early as 1970, for example, the interstate network had reduced journey times by 10 percent on average, a benefit that rippled through the economy.[12] These technologies also help reduce a wide variety of costs associated with traffic and travel. Tractor-trailer operating costs are estimated to be 17 percent lower on interstate highways than other highways, for example,[13] which in turn creates economic benefits for businesses that are passed on to consumers. The broad-based gains provided by these technologies are rarely anticipated in advance—contrary to predictions, logistics companies and vehicle manufacturers were not the main beneficiaries of the Interstate Highway System. More than half of all benefits to private industry were realized in services and non-manufacturing. Indeed, the vast majority of value created by the internet—about 75 percent—was captured by legacy industries that existed before the internet.[14]

Both the Interstate Highway System and the internet, examples of catalyzing technologies, led to a "shrinking of geography" that created broad benefits across a wide range of sectors. These technologies also led to the rapid and dramatic rise of new industries. The most prominent example of this would be the rapid emergence of the FAANG companies—Facebook, Apple, Amazon, Netflix and Google parent Alphabet—which came to make up 10 percent of the U.S. stock market's market capitalization in less than a generation.[15] Of these companies, only Apple existed at the advent of the commercial internet.

We cite these historical examples because the char-

7 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

8 Wendell Cox and Jean Love: *The Best Investment A Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways*, June 1996.

9 Matthieu Pelissie du Rausas et al: *Internet matters: The Net's s weeping impact on growth, jobs, and prosperity*, May 2011, McKinsey Global Institute.

10 Friedlander, Ann "The Interstate Highway System: A Study in Public Investment."

11 Ishaq Nadiri, Theofanis Mamuenas: *Contribution of Highway Capital to Output and Productivity Growth om the United States Economy and Industries* (Summary) August 1998, U.S. Federal Highway Administration.

12 Federal Highway Administration: *Benefits of Interstate Highways*, June 1970.

13 Wendell Cox and Jean Love: *The Best Investment A Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways*, June 1996.

14 Matthieu Pelissie du Rausas et al: *Internet matters: The Net's sweeping impact on growth, jobs, and prosperity*, May 2011, McKinsey Global Institute.

15 Pisani, Bob: *Tech's 'FAANG' Stocks Take A Breather During A Year Of Big Gains*, November 30, 2017, CNBC.

acteristics of AVs are highly suggestive of a catalyzing technology. AVs have considerable potential to reduce the financial and social costs of mobility, which would have significant downstream impacts on sectors other than transportation. Therefore, the deployment impacts of AVs may repeat some of the historical patterns of these predecessor technologies and infrastructure.

Lessons Learned

By examining the network-scale experiences of other catalyzing technologies, particularly the Interstate Highway System and the internet, there are three key points we can apply to future predictions on AVs.

BENEFITS CAN BE SIGNIFICANTLY UNDERESTIMATED

In retrospect, the Interstate Highway System constantly outperformed expectations and had a clear and dramatic positive impact on the U.S. economy. However, the forecasts of the network's impacts significantly under-estimated demand. By 1965, the number of vehicles traveling on the network and the vehicle miles traveled (VMT) served were 11 and 9 percent higher than estimated, respectively. The Interstate Highway System also contributed to a Gross Domestic Product (GDP) that significantly performed above forecasts for that period. In addition, Table 1 shows how the rate of return for investment (ROI) in the Interstate Highway System far exceeds returns on other broad investment classes from 1950 to 1990.

TABLE 1 Returns on Interstate Highway System Investment Compared to Other Asset Classes, 1950-1990

Investment	Annualized ROI
Highway capital	> 30 percent
Private capital	17 percent
Private equity	12 percent
Corporate bonds	8 percent

Source: Richard Mudge, *The Economic and Social Value of Autonomous Vehicles: Implications from Past Network-Scale Investments*, Compass Transportation, June 2018.

Similarly, predictions about the internet in the early 1990s often reflected an inability to comprehend the magnitude of business opportunities opened by the internet. A 1995 Newsweek article, *Why The Web Won't Be Nirvana* has subsequently become infamous because of its dismissive attitude towards the potential of the internet—in particular, lines such as "[some predict that] Stores will become obsolete. So how come my local mall does more business in an afternoon than the entire internet handles in a month?" were notable for missing the transformational impact of online retail giants like Amazon.[16] This is a perfect illustration of the non-linearity of catalyzing technologies: At the outset, it is hard to see the broader implications beyond the core industry of the technology.

The non-linear nature of the network-scale shifts induced by catalyzing technologies—and their significant alteration of supply and demand curves—means that the wider benefits are rarely fully anticipated in advance. With AVs, we can see the broad outlines of future improvements in safety, productivity, energy security and accessibility, which will be examined in greater detail in Section One. The lesson to learn from previous transformational technologies is that even greater impacts may arise than are anticipated today—and that some of the greatest impacts may be completely unanticipated.

WE CANNOT FULLY ANTICIPATE THE BREADTH OF THE IMPACT

Linear thinking about transformative technology often fails. A literature review found that standard modeling exercises have underestimated both the scope and breadth of the impacts of network-scale shifts from catalyzing technologies.

Qualitative analyses of network-scale shifts are also difficult to conduct accurately, because of the non-linear and unpredictable nature of their growth. In the early days of the internet, it would not have been possible to predict the formation and growth of the FAANG companies, as that would have required prophesying what entirely new business models would be enabled by the internet. One study found that the internet accounted for 21 percent of the GDP growth in mature economies over the same time period.[17]

Another illustrative example is the role of the interstate network in enabling significant and unanticipated growth in retailers. When combined with the deregulation of trucking in 1980, the Interstate Highway System allowed the freight industry to meet the needs of the emerging "big box" distribution and retailing models of Walmart and Target, bolstering their national competitiveness in the process.[18]

16 Stoll, Clifford: *Why The Web Won't Be Nirvana* February 26, 1995, Newsweek.

17 James Manyika and Charles Roxburgh: *The great transformer: The impact of the Internet on economic growth and prosperity* October 2011, McKinsey Global Institute.

18 Frederick W. Smith, "Developments in Transportation and Trade Over the Last Half Century" Yale University. Excerpt published in Wall Street Journal, *How Trade Made America Great* March 25, 2016.

AVs are likely to experience network effects, where adoption will proceed rapidly once reasonable performance and cost thresholds are met. This would likely lead to new opportunities and business models that are not anticipated today and will be of considerable value to the public.

BARRIERS TO ADOPTION WILL ERODE OVER TIME

Between 1994 and 2014, relative prices for computer equipment fell by approximately 75 percent.[19] These developments made the technology more accessible and enabled previously unanticipated functionality, fueling rapid growth in internet usage and new and evolving businesses. Similarly, the consumer usability of this technology—both hardware and software—has greatly improved. For example, website creation no longer requires highly specialized skills. There is a striking parallel with AVs; skeptics point to the high cost of initial prototypes and project limited and delayed adoption. The history of previous inventions offers that, with time, significant cost reductions and technology maturation lead to very broad impacts.

In the case of the Interstate Highway System, vehicle operating costs dropped significantly due to reduced maintenance requirements, improved tire wear, lower oil consumption and improvements in depreciation costs. Operating cost savings are estimated to have exceeded $40 billion from 1957 to 1996.[20]

Another important lesson from history is the time scale of change. These catalyzing technologies were developed and then deployed for decades before reaching what we would recognize as maturity. Similarly, full deployment of AVs may not happen overnight, but may well happen on a short timescale compared to, say, the length of a career.

Overall, the lesson of the past is that while some of the costs and downsides of a new technology may be more visible in its early stages, the full scale of its positive impacts rarely are. The experience of previous transformations is instructive of the need to allow new innovations—such as AVs—the regulatory and development space to allow for their full, and strongly positive, impacts to be felt. Further discussion of these benefits is included in Section One.

19 Bachman, David: *Investment In Equipment: From Processing Materials To Processing Information* September 17, 2015, Deloitte Insights.

20 Wendell Cox and Jean Love: *The Best Investment A Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways*, June 1996.

SECTION I

Consumer and Societal Benefits of AVs

Consumer and Societal Benefits of AVs

Although much has been written on the societal and economic benefits that AVs stand to bring, improving our understanding of these benefits is critical to good policymaking.

Introduction

As noted earlier, the deployment trajectory that AVs likely will follow presents some challenges alongside the benefits. Quantifying the economic benefits of AVs will allow for better informed policymaking and a contextualized, proportional response to any challenges.

It is difficult to accurately capture the value of a catalyzing technology, which many attempts have significantly underestimated. This section takes the approach of quantifying some of the benefits through a series of microeconomic, bottom-up case studies. Through this analysis, which uses the passenger vehicle scenarios outlined in the Appendix, we estimate a selection of specific benefits consumers and the wider public can expect. Because this calculation of benefits is far from comprehensive, one can reasonably extrapolate that the overall economic benefits of AV adoption will be considerably greater than this partial projection. A comprehensive macroeconomic analysis is not possible at this nascent stage of the AV industry. Thus, the results of this section's delimited microeconomic approach should be seen as the lower-end, or floor, of potential benefits that would be generated by full AV deployment.

Even in this microeconomic, partial study, the economic benefits promise to be substantial. The consumer and public benefits are estimated to be as much as $800 billion per year.[21] Figure 1 demonstrates the growth of the projected annual AV benefit "dividend" over the next several decades.[22] By 2050, the total cumulative value of AV benefits is projected to be between $3.2–$6.3 trillion. This amount is between twice and four times the $1.5 trillion in value that was created by the Interstate Highway System over a longer 40-year period from 1956 to 1996.[23] In addition, there will be significant quality-of-life benefits for 20 million Americans in the senior and disability communities, with existing SAFE analysis finding that widespread AV deployment could open up 2 million job opportunities for the disability community.[24] These findings are in line with other studies that have sought to define the social and economic benefits of AVs.[25]

This section is further divided into deeper examination of consumer and societal benefits. Consumer benefits capture the level of consumer desire for AVs and the value they anticipate capturing from the technology. Societal benefits reflects gains from AV deployment that do not accrue specifically to the individual consumer, but more broadly to society. These benefits include, but are not limited to, potential improvements in safety, access to jobs, energy security, air pollution and other emissions, and traffic conditions. In this process, these societal benefits make the case for policymakers to act on expediting the responsible deployment of AVs.

Table 2 below outlines the types of benefits captured in this section's analysis. We consider both consumer and societal benefits, as each sheds light on an important aspect of AV deployment. The significant consumer benefits are a leading indicator of rapid AV adoption, demonstrating that consumers can expect compelling value from AVs above the value they would expect to receive from purchasing a conventional vehicle.

21 Note: The range is large primarily because of a debate over whether to include the benefit of reducing the pain and suffering resulting from vehicle accidents. Including these benefits would provide an estimate near the top of the range. Additionally, an informal update of this analysis using more recent data puts the annual benefit above $1 trillion per year.

22 SAFE uses the higher end of AV benefit projections. Essentially the entire difference between the upper and lower bounds of the projections comes from 1) including the loss of quality-of-life from vehicle accidents in benefits, and 2) calculating consumer benefits of AVs based on the value of recouped time rather than existing surveys of what consumers believe they would be willing to pay for a hypothetical AV. We believe both of these more accurately reflect the benefit of AVs.

23 Wendell Cox and Jean Love: *The Best Investment A Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways*, June 1996.

24 Amitai Bin-Nun, Jeffrey Gerlach, Henry Claypool: *Self-Driving Cars: The Impact on People With Disabilities*, January 2017, Securing America's Future Energy.

25 See Lewis Clements, *et al.*, "Economic Effects of Automated Vehicles", Transportation Research Record No. 2602, 2017; Adam Ozimek, "The Massive Economic Benefits Of Self-Driving Cars", Forbes, November 2014; Strategy Analytics, *Accelerating the Future: The Economic Impact of the Emerging Passenger Economy*, June 2017.

Consumer Benefits

The economic benefits of AVs for consumers promise to be substantial. One measure of these benefits is the "consumer surplus," which is the difference between the price of a good and what a consumer is willing to pay for it. This is an important factor for industry to consider, because consumers who derive a large benefit from buying a product are more likely to purchase it. These benefits are poorly captured in standard macroeconomic impact analyses. AVs will provide a value to consumers in many ways, including:

- Reducing stress and providing the ability to engage in other tasks while driving.
- Improving the utilization of household vehicles.
- Making it possible for non-drivers to purchase or access AVs and AV transportation services, including seniors and persons with disabilities.

To create as clear a picture as is currently possible for the scope and scale of the consumer benefits of AVs, it is important to quantify and subsequently extrapolate the consumer surplus. The Montgomery AV benefits report accomplishes this in two ways.

The first—and more conservative—method estimates consumer willingness to pay (WTP) for full automation over and above the price of a conventional vehicle. This is accomplished using the results of a 2017 study conducted by Ricardo Daziano et al. in *Are Consumers Willing to Pay to Let Cars Drive for Them? Analyzing Response to Autonomous Vehicles.*[26]

The findings for these surveys, released in January 2017, found that 40 percent of respondents were unwilling to pay any additional money for AVs. This likely reflects the reality that consumers tend to be skeptical of a new technology before its introduction and significantly undervalue it. Yet even with this caveat, the economic value generated is still quite high. As Figure 2 states, 9.6 million new car buyers, out of a yearly average of 17.5 million, would be willing to pay more for an AV than a conventional vehicle—giving a total WTP of $100 billion per year. It is notable that even in today's early stage of AV development, when public perception of AVs is still lukewarm, that measurable consumer demand is at such a high level.[27]

The second method used to capture these benefits utilized existing estimates of the value of travel time (VOTT) and the consequent benefits of reduced travel time and increased productive time while in transit. Increased travel times have a negative cost to travelers since this time could instead be dedicated to other productive activities, relaxation, or other interests travelers would like to pursue instead of idling in traffic.

The Federal Highway Administration reports the "cost" of driving (or being a passenger) relative to one's

26 Ricardo A. Daziano, Mauricio Sarrias, and Benjamin Leard: *Are Consumers Willing to Pay to Let Cars Drive for Them? Analyzing Response to Autonomous Vehicles* January 2017, Resources for the Future.

27 AAA, *Americans Feel Unsafe Sharing the Road with Fully Self-Driving Cars*, March 2017.

Note on Modeling and Second-Order Impacts

This brief and its policy recommendations lean heavily on the modeling conducted for the Groshen employment report and the Montgomery AV benefits report. As is the case for all modeling, it is important to recognize any limitations which would cause some impacts not to be captured.

The modeling in both reports assumed a mostly static background, balancing the desire to construct an accurate model with avoiding guesswork about future developments to the extent possible. This is a conservative measure reflecting a best practice to improve the applicability of results to today's policymakers.

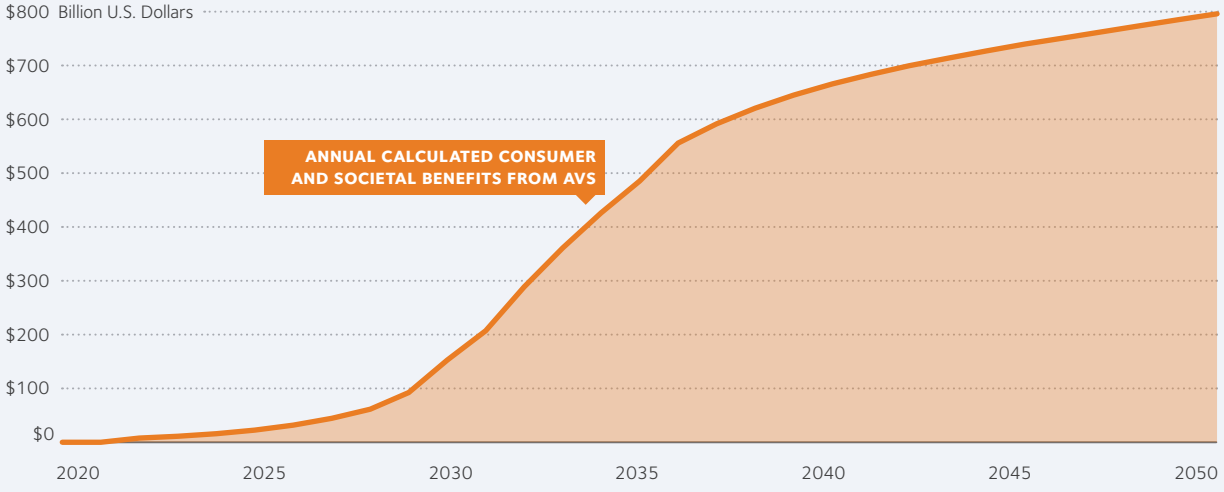
The Groshen employment report assumes static job categories and industry trends. The model does not try to predict the specific job types that will be created by AVs and does not account for the evolution of driving jobs independent of the impact of AVs. For example, the report assumes that the age distribution of long-haul truckers will not change in the future, and that displaced workers will re-enter the workforce at a pace similar to the present.

The Montgomery AV benefits report extrapolates current driving volumes, collisions, and congestion into the future. While this may be the best baseline for a credible analysis, it does not account for the potential for induced demand from AVs to degrade some of the benefits presented. For example, because significant additional volumes of travel are likely in part due to the ease and lower cost of travel and improved access to mobility by underserved populations, this could erode some of the energy use or congestion mitigation benefits of AVs. Comprehensive research should be undertaken now to understand the policies and incentives that can shape deployment in a way that drives energy and environmental benefits.

A treatment of the potential rebound impacts of AVs and the steps policymakers could take to preserve the benefits of AVs while reducing negative second-order impacts is beyond the scope of this study. For further discussion, we direct you to other SAFE analyses on this topic, available at www.secureenergy.org, and in particular the *2016 National Strategy for Energy Security: The Innovation Revolution.* A well-written academic treatment of the energy, equity, and congestion impacts of AVs and a discussion of policy is contained in the book *3 Revolutions* by Professor Dan Sperling of the University of California, Davis.

FIGURE 1

Projected Annual Consumer and Societal Benefits from AVs



Source: David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

TABLE 2

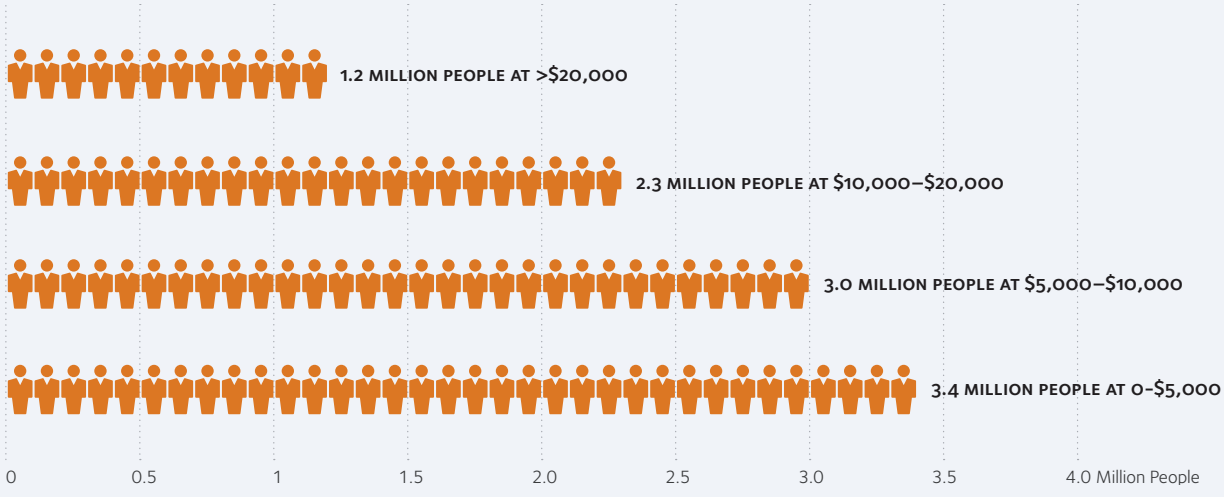
Quantified Benefits of Autonomous Vehicles

Public Benefits by 2050 (annual)	**$633 Billion**
Congestion Mitigation	$71 Billion
Accident Reduction – Economic Impact	$118 Billion
Accident Reduction – Quality of Life Improvements	$385 Billion
Reduced Oil Consumption	$58 Billion
Consumer Benefits by 2050 (annual)	**$163 Billion**
Value of Time	$153 Billion
Reduction in Cost of Current Taxi Service	$10 Billion
Total Annual Benefits (by 2050)	**$796 Billion**

Source: SAFE analysis based on data from David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

FIGURE 2

Current Number of New Car Purchasers Willing to Pay for Level 4-5 Technology



Note: Numbers derived from surveys conductd by Ricardo Daziano et al in January 2017, *Are Consumers Willing to Pay to Let Cars Drive for Them? Analyzing Response to Autonomous Vehicles.*

Source: SAFE analysis based on data from David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

hourly wage. Generally, the cost of being a passenger is considerably less than being a driver, as a passenger has greater ability to engage in other tasks. Level 4 and 5 AVs will turn drivers into passengers, allowing individuals to recapture productive time (although they would still bear the "cost" of being a passenger). Since the number of hours Americans spend driving is known as well as their average wage ($21.48 per hour in 2017), the annual value of "productive time" gained is estimated at about $220 billion once AVs are fully deployed.[28]

MOBILITY BENEFITS

Those previously unable to drive themselves due to a disability, an inability to afford a car, or other mobility issues would also benefit from AVs. Approximately 9 million Americans have a medical condition that affects their mobility, and of these about 8 million have reduced their daily travel. Almost 15 million people have a medical condition that affects their ability to drive, with 11.7 million people reducing their daily travel as a result.[29] This lack of mobility leads to social isolation, reduced economic opportunities, and an inability to participate fully in community life.

Most trips by people with disabilities for medical treatment are by car, with relatively few using alternative modes of transport, including paratransit. In addition, a 2012 survey found that low-income patients who traveled by car were twice as likely to keep appointments than those who traveled by bus.[30]

The relative inaccessibility of public transportation is a persistent problem for individuals with disabilities. A diverse array of problems, from inclement weather to non-functioning elevators at stations can prevent people with mobility limitations from accessing regular public transportation. As a result, almost 90 percent of people with disabilities used a personal vehicle to travel to medical appointments. Less than 4 percent took buses, and less than 2 percent used paratransit.[31] Furthermore, more than 80 percent of employed individuals with disabilities used a private vehicle to commute to work, half the time in vehicles driven by others. Well under 10 percent of people with disabilities used any form of public transport or specialized transportation. Studies have found current paratransit options to be inadequate and have noted that labor costs represent a very large fraction of paratransit operating costs for all public systems.[32]

Consequently, those with limited ability to drive stand to benefit the most from AVs. A real-world experiment providing consumers with a simulated AV (by providing a highly discounted chauffeur) demonstrated that retirees have a high appetite for additional travel if provided with the means to travel. The study found that seniors may consume 175 percent more long trips with AVs, as well as 246 percent more journeys after 6pm.[33]

SOCIETAL BENEFITS

Societal benefits are the gains that non-AV users (conventional vehicle drivers, road users, and others) receive when other consumers purchase AVs. The existence of large societal benefits would build the case for policies to remove barriers to AV deployment. Among the many societal benefits of AVs are four significant external benefits quantified in this report: Improved safety, reduced congestion, enhanced energy security, and improved environmental outcomes.

SAFETY

In 2010, the National Highway Traffic Safety Administration (NHTSA) estimated the economic costs of car crashes to be $242 billion. If quality-of-life costs are added into the estimate, the total value of societal harm was approximately $836 billion.[34] The more conservative number includes medical care, legal costs, emergency services, insurance costs, workplace costs, congestion impacts and property damage. Extrapolating these values based on more recent crash and driving data puts the societal cost of crashes at over $1 trillion today.[35]

The direct economic and quality-of-life costs alone prove to be substantial. In 2010, crashes involving distracted driving, alcohol, or speeding had a cost of $520 billion. Similarly, the indirect costs are also sizable. The cost of congestion due to accidents—including travel delays, excess fuel consumption, and other costs—is estimated to be $28 billion per year.[36]

Accidents caused by distraction, drinking, and speeding are likely to be largely mitigated by the deployment of AVs. These factors are the primary cause of 56 percent of crashes. Further, NHTSA estimates that 94

28 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

29 Cronk, Imran: *When You Don't Have A Ride To The Doctor's Office* August 9, 2015 The Atlantic.

30 Ibid.

31 Marilyn Field, Alan Jette: *Transportation Patterns And Problems Of People With Disabilities*, 2007, National Academies Press.

32 See e.g., Securing America's Future Energy and Ruderman Family Foundation, *Self-Driving Cars: The Impact on People with Disabilities*, January 2017.

33 Mustapha Harb et al: *Projecting Travelers into a World of Self-Driving Vehicles: Estimating Travel Behavior Implications via a Naturalistic Experiment* November 15, 2017. Presented at TRB January 2018.

34 NHTSA: *The Economic and Societal Impact Of Motor Vehicle Crashes*, 2010 (Revised) May 2015.

35 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

36 Ibid.

FIGURE 3 Time and Productivity Savings from Autonomous Vehicles

Michael
Teacher from Columbus, Ohio
Father of three

SALARY	COMMUTE TIME
$56,720	40 mins
DAYS WORKED PER YEAR	COMMUTE COST PER DAY
200	$35.29
HOURLY WAGE	VALUE OF RECOUPED TIME FROM AVs
$31.51	$4,117

Nikki
Lawyer living in downtown L.A.
Single, no dependents

SALARY	COMMUTE TIME
$118,160	23 mins
DAYS WORKED PER YEAR	COMMUTE COST PER DAY
240	$38.05
HOURLY WAGE	VALUE OF RECOUPED TIME FROM AVs
$59.00	$5,327

Note: Calculation assumes that the cost of travel time for an urban commuting driver is 84 percent of hourly wage and that the cost of time for a commuting passenger in light traffic is 35 percent of hourly wage. Salaries are national median for occupation.
Source: SAFE analysis based on data from Bureau of Labor Statistics and Victoria Transport Policy Institute, *Transportation Cost and Benefit Analysis II – Travel Time Costs*, April 24, 2018.

percent of all traffic accidents are caused either wholly or in part by human error, underscoring that AVs have the potential to address an even greater proportion of crashes.[37] Any AV on the road that outperforms a human driver would represent a net benefit to safety.[38]

By 2050, the deployment of AVs is projected to reduce the direct economic toll of accidents by up to $118 billion annually, with quality-of-life improvements of up to $385 billion annually.[39]

Employment and Other System-Wide Benefits

The lower cost of travel provided by AVs has the potential to enable people to travel farther, significantly increasing access to job opportunities as well as a broader range of retail goods and services.[40] This in turn expands customer bases for local stores, increases the job market for workers and widens the talent pool for employers, creating productivity gains in the process. Existing studies have shown that a 10 percent improvement in access to labor increases productivity and regional output by 2.4 percent.[41]

AVs take individuals out of the driver's seat and turn them into passengers. This change alone reduces the cost of traveling for those who would ordinarily drive, as it reduces stress and frees the rider to make better use of their travel time, reducing travel costs. As a result, AVs decrease the time cost of driving for errands and shopping by 30 percent. The 2009 National Household Transportation Survey found that the average length of trips taken for shopping is 6.5 miles. Accounting for the reduced cost of travel time, that trip would be cost-equivalent of a 7.5-mile journey in an AV.

AVs also substantially increase access to employment by commutable range. The average commuting trip in the United States is 9.8 miles and is often conducted at rush hour when traffic is very congested. Additionally, the estimated time value of a driver's lost time during a commute is significantly higher than for shopping trips. Shifting from a driver to a passenger will allow an individual to recoup much of the value of this time, allowing recapture of up to 32.5 percent of the former driver's hourly wage.

Furthermore, if AVs reach their potential for eliminating congestion, they will increase regional travel speeds when broadly deployed. Combining the impact of faster through-speeds on roads with an increasing willingness to spend time in a vehicle means that individuals will be willing to travel significantly farther in search of a job. These improvements also translate into productivity gains. A 1 percent improvement in accessibility to a region's central business district improves regional productivity by 1.1 percent.[42] Similarly, a 10 percent increase in average speed, all other things constant, leads to a 15-18 percent increase in the labor market size, making it easier for enterprises to find the skills they need and for workers to find the job they want. This, in turn, leads to a 2.9 percent increase in productivity.[43]

37 NHTSA: *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey* February 2015.

38 SAFE: *Recommendations of the Commission on Autonomous Vehicle Testing and Safety* January 5, 2017.

39 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

40 Charlie Johnson and Jonathan Walker, *Peak Car Ownership: The Market Opportunity of Electric Automated Mobility Services*, Rocky Mountain Institute, 2016.

41 Remy Prud'homme and Chang-Woon Lee: *Size, Sprawl, Speed, and the Efficiency of Cities* November 8, 2001, Observatoire de l'Économie et des Institutions Locales.

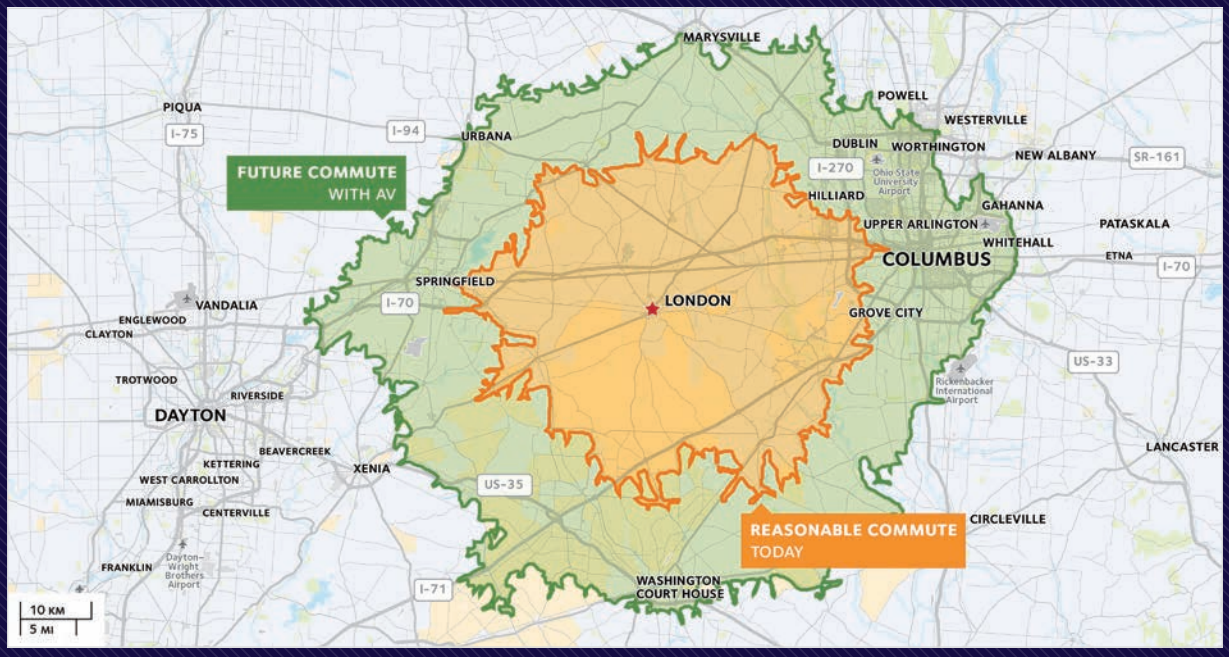
42 David Hartgen and Gregory Fields: *Gridlock and Growth* June 2009, Reason Foundation.

43 Remy Prud'homme and Chang-Woon Lee: *Size, Sprawl, Speed, and the Efficiency of Cities* November 8, 2001, Observatoire de l'Économie et des Institutions Locales.

Improved Transportation Offers Access to Work Opportunities

FIGURE 4

London, OH



Benton Harbor, MI

FIGURES 5, 6

Gary, IN

Elmira, NY

Wilmington, DE

FIGURES 7, 8

Note: Orange represents area commutable in 30 minutes during peak hours today. Green simulates AV travel by representing area reachable today in 40 minutes of travel during off-peak hours. Analysis used Alteryx Analytics and TomTom Traffic dataset; visualized with OpenStreetMaps.

Source: SAFE analysis based on framework from David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

TABLE 3

Employment, Income and Commuting Distance Data for Selected U.S. Communities

City	Peak Unemployment (Great Recession)	Current Unemployment (February 2018)	Median Household Income	Current Jobs in Commuting Distance of City Center	Jobs in Commuting Distance with AV-Enabled Commute	Percent Increase
Niles-Benton Harbor, MI	14.0%	5.8%	$27,520	63,035	206,945	228%
Gary, IN	17.2%	6.8%	$28,895	388,802	1,225,216	215%
Elmira, NY	11.8%	7.6%	$29,955	58,636	123,805	111%
Wilmington, DE	13.3%	6.2%	$40,065	492,500	1,479,969	201%
National	**10.6%**	**4.4%**	**$55,322**	—	—	—

Note: Unemployment figures taken from BLS' Local Area Unemployment Statistics queries, using area type "Cities and towns above 25,000 population" when possible. Niles-Benton Harbor and Elmira uses data for broader metropolitan area.

Source: Bureau of Labor Statistics

The study applied these methodologies across several cities to better illustrate this point. For example, widespread AV deployment in the broader Columbus, OH, metropolitan area would likely lead to better access to jobs for broad swaths of the population. Columbus is a Rust Belt city that is revitalizing after a decline in its industrial base. Taking, for example, the small city of London, Ohio, nearly midway between the larger cities of Dayton and Columbus, SAFE modeled the reach of a commute both today and after the widespread deployment of AVs.

The national average commute is about 30 minutes. From London, OH during peak travel hours, today's commute offer its residents access to 12,000 business establishments employing about 250,000 workers.[44] If the widespread adoption of AVs would reduce congestion to off-peak levels, encourage workers to use their commuting time more productively, and add 10 minutes to their commute each way, a total of 38,000 employers and 800,000 jobs would consequently be within a reasonable commute. AVs have the potential to significantly increase access for many who are currently limited in their job options. Figure 4 demonstrates the extent of the typical commute of today and compares it with the greater reach AVs will provide commuters.

This analysis was repeated for several cities. Figures 5-8 demonstrate the results of this exercise for several Midwestern and Mid-Atlantic communities, many of which currently face high levels of unemployment and/or poverty. As outlined in Table 3, these cities are Benton Harbor, MI, Gary, IN, Elmira, NY, and Wilmington, DE.

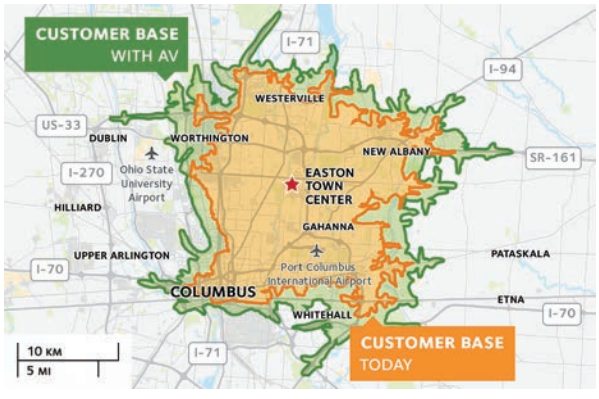
For workers who cannot find a job appropriate for their skills, access to a broader range of jobs can mean the difference between gainful employment and poverty. For employers, access to a broader pool of skilled workers can translate into success and growth. The improved transportation that AVs are expected to bring could allow many in low-income communities access to job opportunities that would have previously been unavailable.

Revitalizing Retail. The retail sector has lost 18 times more workers than coal mining since 2001, although new jobs have been created to support e-commerce. Using the methodology outlined earlier, the study looked specifically at what AV availability might do to improve shopper access to the Easton Town Center, a major mall in Columbus, OH, as an illustrative example. It found that the increased willingness of shoppers to travel—even by just two minutes each way—could increase its customer base by 48 percent (See Figure 9). The other 13 major shopping centers within Columbus would see their consumer base expand by 28-55 percent. In the current challenging environment for the retail sector, AVs could provide an additional tool allowing easier and more convenient access to brick-and-mortar businesses.

44 Note: The location of jobs is taken from the United States Census Bureau's 2014 Zip Code Business Patterns, which tabulates the number of employers and workers on payroll for each zip code.

FIGURE 9

Increased Access to Easton Town Center



Source: SAFE analysis based on framework from David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

ENERGY SECURITY

Oil holds a virtual monopoly on vehicle fuels, with petroleum accounting for 92 percent of the fuel used to power the U.S. transportation system. By precipitating a shift away from petroleum as the dominant fuel source, AVs could substantially reduce this reliance on oil. Considerable analysis and modeling supports the thesis that economic and technology synergies between ridesharing, AVs, and vehicle electrification means that the overwhelming majority of AVs will be EVs. This is supported by mounting evidence: AV developers are using electric and hybrid powertrains for their vehicles,[45,46] and SAFE research demonstrates that 58 percent of current AV test vehicles are based on an EV platform, with a further 21 percent running on a hybrid platform.[47] Shifting away from reliance on oil would bring many strategic benefits to the United States. First, it would help to insulate the American economy from the influence of the OPEC cartel and other petrostates like Russia and Kazakhstan—countries that share neither our strategic interests nor our commitment to market transparency.

The capability of the petrostates to disrupt the world market was graphically illustrated in 2014, when the Saudi-led OPEC group responded to the growth of U.S. shale oil and gas output by announcing in November that it would maintain its high levels of production. The announcement drove prices down dramatically: In June 2014, the price of oil was $140 per barrel, but by February 2016 the price was just $26. In 2018 the price of oil had returned to $70 per barrel. This exaggerated volatility due to Saudi Arabia's actions was damaging to many parts of the oil market.

The precipitous drop in price was felt keenly by the U.S. energy industry. Since January 2015, more than 220 U.S. oil and gas businesses have entered bankruptcy, taking 150,000 jobs with them.[48] Additionally, the low prices forced $1 trillion in upstream investment worldwide to be deferred—capital vital for maintaining a regular supply of oil to meet global demand.[49] The possibility of a continued shortfall of upstream investment is causing concern among some industry analysts who term the coming 2020s as a 'decade of disorder.' Growing global demand is likely to raise prices at the pump steadily over the next decade, and geopolitical tensions continue to make price spikes a strong possibility.

AVs can mitigate this uncertainty by diversifying the energy sources of transportation to include electricity. Unlike oil, electricity is produced from a variety of sources—coal, natural gas, nuclear and renewables—making it a diverse, stable and domestically-produced fuel source. In addition, once at full deployment, AVs are also projected to save 80,000 barrels of oil a day in the United States just from congestion mitigation.[50]

In conjunction with the strategic benefits are significant economic savings generated by improved energy security. Lower gasoline consumption induced by AVs powered by electric drivetrains translates to lower world oil prices as excess oil supply moderates the otherwise likely growth in prices. If the deployment of AVs reduced oil use by 25 percent, that would represent a decrease in U.S. oil demand of 2 million barrels per day (Mbd). Under current market conditions, that drop in demand would drive the world oil price down by approximately $2.15 per barrel.[51]

In addition, the energy security premium—the expected reduction of expected GDP loss from oil supply disruptions[52]—would yield savings of $3.5 billion per year (assuming the same 25 percent reduction in oil use). If AVs replaced gasoline-powered vehicles for 67 percent of passenger miles, U.S. gasoline consumption would fall by 5.5 Mbd and the impacts would be even greater.[53]

In addition to energy security benefits, significant environmental benefits will accrue from a shift from oil to other advanced fuels. The combustion of liquid fuels leads to local air pollution from several "criteria" pollutants and results in increased disease and mortality rates.[54] The Montgomery AV benefits report performs a review of the environmental benefits of reduced consumption of transportation fuels and supports an estimated benefit of $12.11 per barrel of reduced oil consumption. With a 75 percent penetration of electric vehicles in shared fleets, this

45 Fred Lambert: *GM links electric vehicle effort to autonomous driving in attempt to compete with Tesla* November 30, 2017, Electrek.

46 Chris Woodyard: New York Auto Show: *Google's Waymo buying 20,000 electric SUVs for driverless rides* March 27, 2018, USA Today.

47 Robbie Diamond and Amitai Bin-Nun, *Self-Driving Cars: Road to Deployment* Written Testimony to the House Committee on Energy and Commerce, Subcommittee on Digital Commerce and Consumer Protection, February 14, 2017.

48 Haynes Boone: *Energy Bankruptcy Reports and Surveys* October 31, 2017.

49 Wood Mackenzie: *Global Capex Spend Slashed By US$1 Trillion* July 18, 2016.

50 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

51 There would be a small "take-back" effect, as the lower price decreases in U.S. production and increases demand for gasoline and other petroleum products in uses not switched to electric drivetrains. The estimated take-back effect in the U.S. from a $2.15 decrease in the world oil price is just 54,000 barrels per day, less than 3 percent of the savings from a 25 percent reduction in vehicle-related oil use induced by the switch to AVs.

52 Stephen Brown and Hillard Huntingon: *Assessing the U.S. oil security premium* March 2013, Energy Economics.

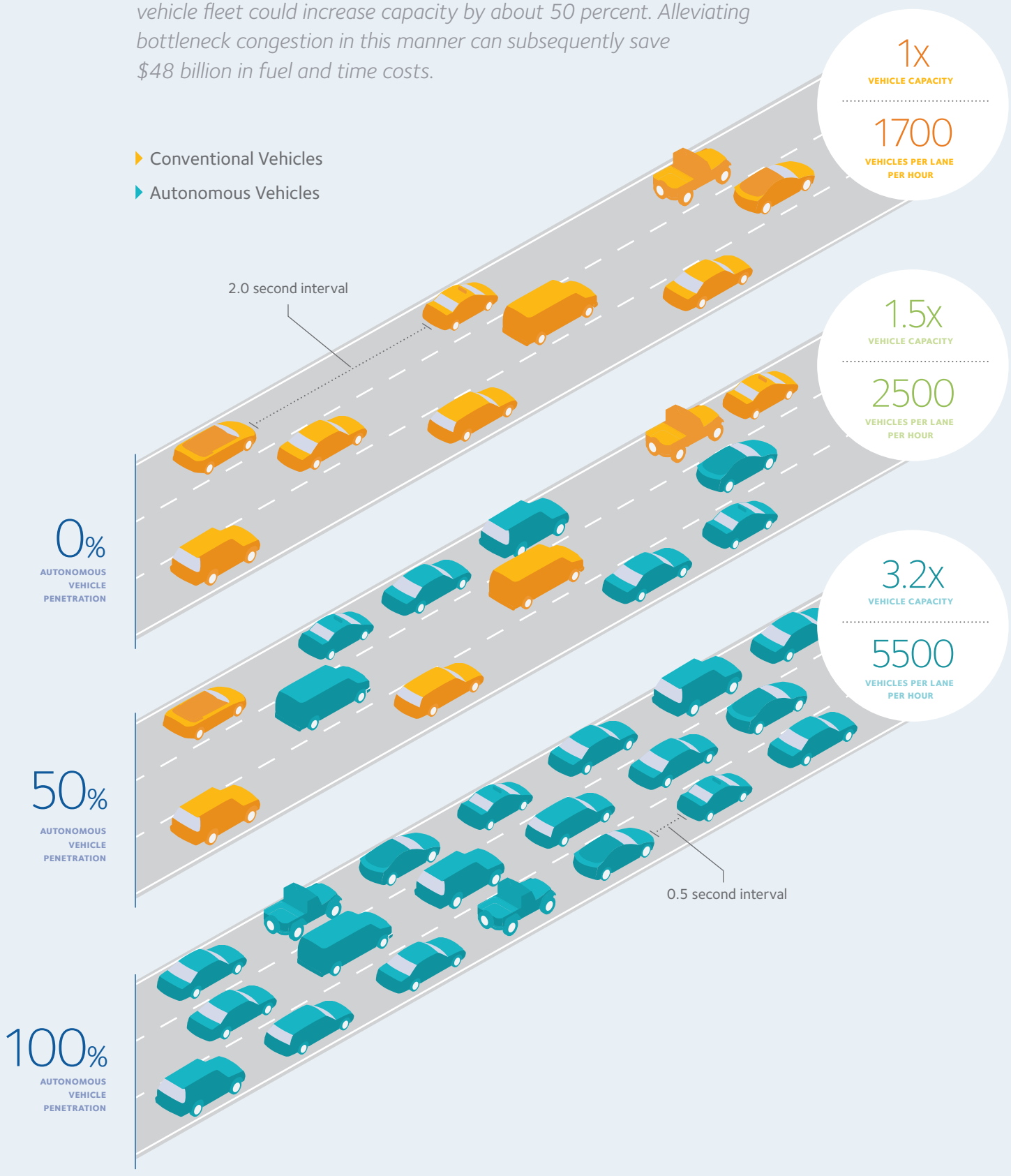
53 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

54 Fabio Caiazzo, et al., "Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005," *Atmospheric Environment*, Volume 79, November 2013.

FIGURE 10

Illustration of Projected Road Capacity Improvements with Broad AV Deployment

AVs make tighter packing feasible: Increasing speeds while shortening vehicle intervals from the two-second standard to 0.5 seconds can increase vehicle capacity three-fold. As a result, a 50–70 percent AV penetration in the vehicle fleet could increase capacity by about 50 percent. Alleviating bottleneck congestion in this manner can subsequently save $48 billion in fuel and time costs.



translates into an additional saving of $15 billion per year.[55]

While these benefits are not tabulated in the Montgomery AV benefits report, a shift to electric vehicles would considerably reduce greenhouse gas emissions. A recent study by the Union of Concerned Scientists highlighted that EVs reduce per-mile greenhouse gas emissions by over 50 percent relative to an equivalent gas-powered vehicle.[56]

CONGESTION

Drivers—and their suboptimal behaviors—cause congestion.[57] Deciding to brake, speed up, or change lanes affects the actions of other drivers, causing them to slow down and create congestion as a result.[58] As AV technology takes the decision-making process out of the hands of drivers, it is likely that the quicker reaction times of AVs coupled with the ability to coordinate movement through connectivity would drastically reduce roadway congestion.

A Texas A&M Transportation Institute study reported that although only 26 percent of trips in 2015 encountered extreme or severe congestion, these trips accounted for 80 percent of all lost travel time due to congestion. The study estimated that in 2015, congestion wasted 6.9 billion hours of driving and 3.1 billion gallons of fuel, at a total cost of $160 billion.[59]

The causes of congestion are varied and can be broken down into non-recurrent and recurrent congestion. Traffic bottlenecks are the primary cause of recurrent congestion, accounting for 40 percent of all congestion. A further 25 percent is attributed to traffic incidents ("crashes"). Bad weather is the cause for another 15 percent of congestion. Both of these are causes of non-recurrent congestion.[60]

Bottlenecks are formed when more vehicles are trying to use a segment of road than its capacity will allow. Therefore, increasing capacity through those segments can alleviate this congestion, as seen in Figure 10. A rule of thumb traffic engineers employ is the capacity of a traffic lane is 2,000 vehicles per hour.[61] Quicker responses by AVs are projected to allow vehicles to negotiate traffic bottlenecks at a much faster rate than human drivers; AVs may also use connectivity to optimize real-time routing, avoiding many of the other traffic incidents composing another 25 percent of congestion. Reducing congestion, in turn, results in traffic flowing faster and shorter journey times, saving fuel and allowing greater ease of travel.

The Montgomery AV benefits report looked at each root cause of congestion and potential avenues for AVs to address each cause. Combined, the study estimated a $71 billion reduction in the cost of traffic congestion from the widespread adoption of AVs.

TRUCKING

The benefits of AV technology are not limited to light-duty vehicles. Demonstrations of autonomy are already underway in the heavy-duty trucking industry, with autonomous technology such as platooning already poised for deployment. This technology is expected to reduce fuel consumption in the trucking sector by as much as 20 percent. If all combination trucks, which account for 38 percent of total truck miles, were platooned, this would create a saving of up to 1.3 billion gallons of diesel fuel per year.[62] At current prices, this represents a saving of up to $3.4 billion dollars per year.

Conclusion

The analysis in the Montgomery AV benefits report uses a partial methodology to establish a floor for AV impacts; even so, it projects that the economic gains of AV deployment will be approximately $3.2 to $6.3 trillion between now and 2050, significantly outstripping the $1.5 trillion in benefits generated by the Interstate Highway System by up to a 4:1 ratio—and over a shorter period of time.[63] Even those who neither buy nor use an AV will experience this welfare improvement, as roadway accident rates fall, traffic congestion declines and U.S. national security is strengthened as the country reduces its dependence on oil.

The significant realizable public benefits mentioned above provide strong reason and support for policies at all levels of government that support the expeditious deployment of AVs by removing barriers to adoption. It is also crucial to consider the intangible benefits—including empowerment and increased mobility to senior citizens and access to new jobs for low-income communities. Together with the very tangible benefits of saving lives through improved road safety, the benefits of AVs create a strong argument that rapid deployment of this technology has a great deal to contribute to the common good.

55 Ibid.

56 Union of Concerned Scientists, *Cleaner Cars from Cradle to Grave*, November 2015.

57 Grewal, San: *How bad driving habits are causing GTA traffic gridlock* September 2, 2015, Toronto Star.

58 Oullette, Jennifer: *Your bad driving is the reason traffic jams exist*, September 3, 2016, Gizmodo.

59 David Shrank, Bill Eisele, Tim Lomax and Jim Bak: *2015 Urban Mobility Scorecard* August, 2015, Texas A&M Transportation Institute, INRIX.

60 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

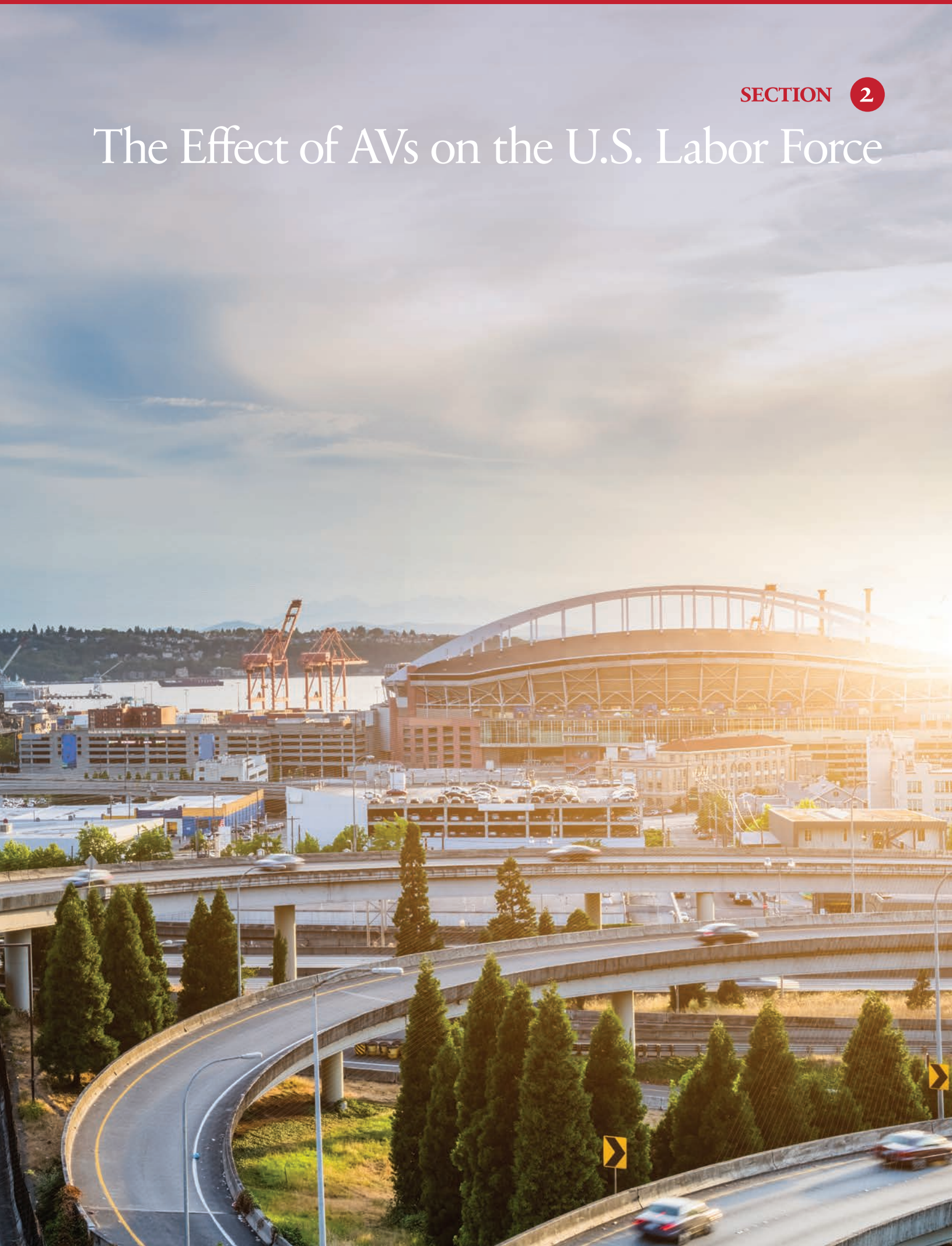
61 Downs, Anthony: *Still Stuck In Traffic* Brookings Institution Press, 2005.

62 W. David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018.

63 Wendell Cox and Jean Love: *The Best Investment A Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways*, June 1996.

SECTION 2

The Effect of AVs on the U.S. Labor Force



The Effect of AVs on the U.S. Labor Force

From the automobile to the internet, history has demonstrated time and again that new technologies can lead to sizable economic and social benefits in the long run.

Introduction

From the automobile to the internet, history has demonstrated time and again that new technologies can lead to sizable economic and social benefits in the long run. However, along with significant change always comes the specter of potential loss, particularly in the short term. Like many new technologies before it, the public discourse around AVs has witnessed a significant focus on potential downsides, often with considerable exaggeration. However, the real potential losses must be balanced with the benefits from highly significant improvements in safety, gains in productivity, reduced congestion, and increased fuel efficiency that will result from AV deployment.

A study of historical precedents for the impacts of new technologies found a common pattern: Adoption of new technologies can significantly improve productivity and increase quality of life. Widely adopted technologies can transform our way of life and improve economic well-being at a national scale. Often, technological progress leads to improved opportunities for workers in the short term; a recent study found that the rise of e-commerce has, on net, improved jobs for high school graduates.[64] However, the impacts of those technologies can also present temporary challenges for the workforce.

Unlocking the potential of technology requires workers with new skills to develop it—a reality that creates a Catch-22. For example, computing technology is not valuable without skilled programmers—a profession that did not exist before computers. When technology evolves rapidly, it stresses the workforce in two ways. First, employers wishing to utilize new technologies may find it hard to find workers with the right skills to take advantage of it. Second, new technologies can reduce demand for certain skills and lead to temporary unemployment and significant earnings losses. Historically, over time, the workforce rebalances and the economy returns to full employment.

A key challenge is to contextualize any challenges and avoid overreacting to unrealistic negative predictions, which have been a constant refrain alongside technological progress since the Industrial Revolution. A technology with the scope and impact of AVs will certainly require workers with new skills and lessen the need for some existing skills, including driving. Policymakers will need to face the challenge of how to upgrade workforce skills and reduce the impact on workers whose jobs may be eliminated. This section examines potential job losses associated with AV deployment, the sectors that will be most affected and when those effects will happen, what happens to people who lose their jobs, and how long it takes those people to return to the workforce.

It is impossible to consider the workforce question independent of the broader impacts of the technology. Given the significant benefits offered by AV adoption—estimated earlier in this brief as potentially approaching $1 trillion a year in value—it is simultaneously in the public interest for AV technology to be deployed at the earliest opportunity and to make significant investments to aid workforce transformation.

However, this nuanced approach is not fully reflected in public discourse. Instead, reports abound of looming catastrophic job loss from AVs specifically, and artificial intelligence (AI) more generally, with one source describing AVs a "one-two punch to America's gut."[65] Others have portrayed it as causing the decline of a core tenet of the American identity,[66] and many more focus on how the job losses they project will affect local industries.[67]

In the absence of concrete estimates, the public has a tendency to concentrate on the worst possible

64 Michael Mandel. *How Ecommerce Creates Jobs and Reduces Income Inequality* Progressive Policy Institute. September 2017.

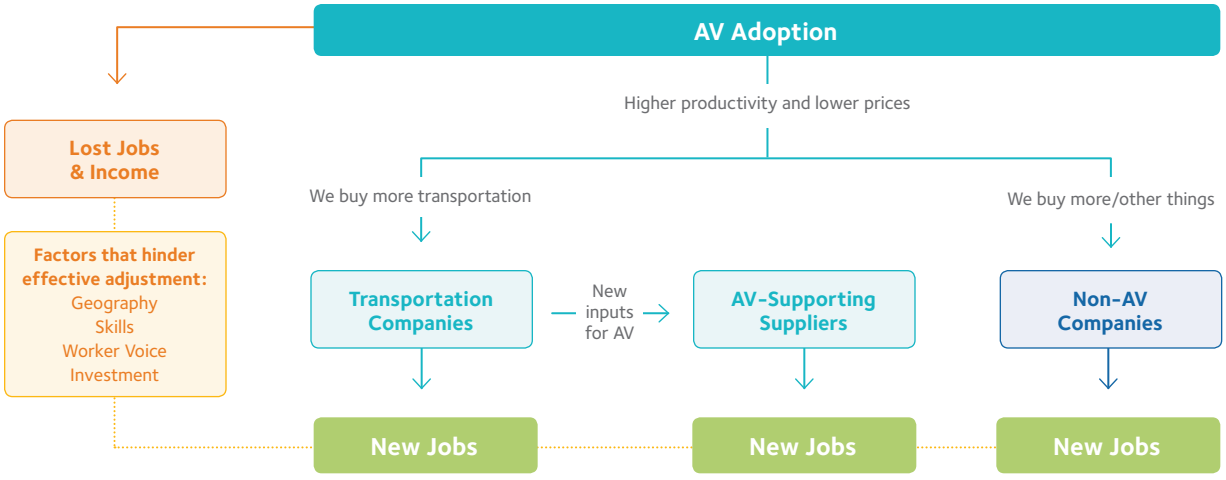
65 Santens, Scott: *Self-Driving Trucks Are Going To Hit Us Like A Human-Driven Truck* May 14, 2015. Medium.

66 Rushe, Dominic: *End Of The Road: Will Automation Put An End To The American Trucker?* The Guardian.

67 Sanctis, Matt: *Could Driverless Tech Mean Thousands Of Ohio Trucking Jobs Lost* November 10, 2017, Springfield News-Sun.

Framework for Labor Market Impacts of AV Adoption

FIGURE 11



Source: Adapted from Erica Groshen et. al, *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

outcome. A recent report claimed that "more than four million jobs will likely be lost with a rapid transition to autonomous vehicles." The methodology used to develop this number was simply to count driving jobs in the United States and assume that they would be rapidly lost as AVs deploy.[68] Such assumptions and conclusions lack context, nuance, or grounding in labor market dynamics and the natural cycle of labor force evolution. To improve policy discourse on the potential job impacts of AVs and ultimately achieve better outcomes, it is necessary to take a more rigorous approach.

Methodology

To examine how AVs may impact employment in the United States, with a particular emphasis on the magnitude and timing of those impacts, Dr. Groshen and her colleagues modeled the potential effects of AV adoption using SAFE's scenarios described in the Appendix. While a modeling forecast always involves uncertainty, broad contours for the potential evolution of the labor market in the coming decades can be instructive in formulating policy and in weighing the benefits of AV deployment against its costs.

It is difficult to separate the impacts of AVs on the labor force from the broader impacts of artificial intelligence (AI); after all, AVs lean on cutting-edge AI and computational techniques and should be seen largely as a particular application of AI. There is some uncertainty about the long-term impacts of AI, but the mainstream view is that as the Industrial Revolution, widespread access to electricity, adoption of the automobile, and the growth of the internet created jobs and did not lead to mass, permanent unemployment, AI is highly likely to repeat this pattern.[69]

AI—and AVs—will create new types of jobs, many of which are likely to be skilled, better-paying jobs. Generally, absent independent conditions in the labor market, whether macroeconomic (such as a prolonged recession) or microeconomic (such as monopsonistic practices by a group of employers), the economy will return to full employment after any disruption from a new technology.

The schematic in Figure 11 illustrates the approach taken by the Groshen employment report to analyze potential workforce effects of the deployment of AVs. AVs have two simultaneous impacts: The first is that labor in some job categories will be automated to some extent and, therefore, the number of jobs in those categories will decrease. At the same time, AVs will improve productivity and create more demand for transportation and goods. This increased demand will create jobs in several categories:

- Firms will add jobs directly associated with AVs, such as fleet service technicians or transportation aides for people with disabilities, as AVs are adopted.
- AV adoption will increase the need for jobs in companies that support AVs, such as parts suppliers or software engineers.
- Falling product and service costs resulting from AV adoption will free up discretionary income in the broader economy. New consumer demand will attract

68 Center for Global Policy Solution: *Stick Shift: Autonomous Vehicles, Driving Jobs, and the Future of Work*.

69 Atkinson, Robert: *False Alarmism: Technological Disruption and the U.S. Labor Market*, Information Technology & Innovation Foundation, 2017.

investment and lead to the growth of entirely new businesses otherwise unrelated to AVs.

To understand how the elimination and creation of jobs will play out and estimate the magnitude, timing, and impact of AVs on the labor market, the Groshen employment report addressed the following questions:

What will be the total impact? AVs will certainly have labor market impacts. Importantly, however, the full impact will take 30 years or more to be felt. The first question the study addressed was, "when AVs are fully available and their impacts absorbed into the U.S. economy, what job skills will be in higher or lower demand?" The economists scanned the entire economy to locate where jobs might transition from their current form. The study began with a list of all job categories in the United States and used expert interviews to estimate how many fewer—or more—jobs there would be in each category once AVs are completely deployed and the market fully adjusts to them. While many impacted jobs would be related to driving, this comprehensive approach captures job impacts in other sectors.

When will these transitions happen? In step 1, the economists determined the total number of jobs whose requirements would change over time, likely resulting in a displaced worker. To understand when and how quickly these changes would occur, the study utilized the AV adoption scenarios developed by SAFE. AV deployment will continue over the next several decades; the timing of impacts on the job market is very strongly tied to the timing of AV deployment.

Will the economy again see full employment? As mentioned earlier, the economists assume that AVs improve the economy, leading to higher productivity for workers and lower prices for consumers, and, therefore, create new jobs for any jobs that are eliminated by AVs. However, just because a job is created somewhere in the economy does not necessarily mean that the job is located conveniently or that a displaced worker has the skills for the available job. Therefore, it will take a period of time before a return to full employment after any job loss resulting from AV adoption.

How long does unemployment persist? To model the labor market impact of AVs, the team modeled what would happen to workers whose jobs are eliminated. The economy, spurred in part because of AV adoption, will create other jobs, but it will take time for workers to transition from one job to another. The researchers used current Bureau of Labor Statistics (BLS) data on job transitions to construct a model for how long it takes workers to find another job after their original position is eliminated. Additional understanding of the characteristics and locations of new jobs would allow improved predictions for the length of time that AV-related unemployment might persist.

What is the impact on displaced workers? The team looked at potential effects on the income of workers displaced by AVs (caused by spells of nonemployment and lower post-layoff earnings), and looked at factors that would affect wage levels in both new and continuing jobs as a result of AV introduction.

Contextual Factors

1. TOTAL JOBS IMPACTED

The skills required to participate in the labor force change over time. At the dawn of the 20th century, more than 40 percent of the U.S. workforce was employed in agriculture.[70] As society and consumer demand evolve, the jobs required to meet these shifts changes in response. Generally, the labor market is resilient to gradual changes in skill requirements. New workers are attracted to growing fields and, generally, existing workers in jobs that are slowly being phased out either stay in their field until retirement or find new employment at some point.

The Groshen employment report asked several experts for an estimate of how employment in various job categories would change in the distant future, which is defined as whenever AV technology is mature and its impacts have been fully felt. For example, the study assumes that once fully autonomous heavy-duty trucks are fully adopted there will only be a need for about 40–45 percent of the drivers required today.[71]

It is useful to note that a considerable number of workers will continue to be employed as truck drivers even after full automation because of the other tasks truck drivers perform aside from driving. The study determined that compared to truck driver positions, a smaller share of school bus driver jobs would be eliminated (50 percent), because non-driving tasks are an even greater portion of a school bus driver's job. This is due to the fact that the study does not assume radical complementary innovation that would automate non-driving tasks that are currently a large part—as much as 50 percent for truckers—of driving jobs (e.g., ensuring care of inventory or performing deliveries).

70 Carolyn Dimitri, Anne Effland, Neilson Conklin: *The 20th Century Transformation of U.S. Agriculture and Farm Policy* U.S. Department of Agriculture, June 2005.

71 Madrigal, Alexis: *Could Self-Driving Trucks Be Good for Truckers?* February 1, 2018, The Atlantic.

Other jobs would be impacted as well.[72] A full list of potential job loss assumptions under "full autonomy" is contained in the Groshen employment report.[73] The study found that the impacts of automation in trucks and cars are distinct and different, and therefore the two are modeled separately to the degree feasible.

The authors present their assumptions and results as a credible and illustrative forecast to guide policymakers, but emphasize that this is not a definitive prediction.

2. TRANSITION TIMING

A key determinant of a technology's effect on the labor market is how quickly a new technology's impact will occur. The elimination of a million jobs may initially sound like it would have a profound impact, but if it occurs gradually over multiple decades, it would be unnoticeable against the background of the natural evolution of the labor market. Therefore, the report uses the AV deployment scenarios in the Appendix to guide modeling of the pace of AV-related job transitions. Generally, new technologies diffuse relatively slowly through the light-duty fleet—as there are over 250 million cars and light trucks belonging to over 120 million households. The trucking fleet has far fewer vehicles in the hands of fewer owners, so rapid adoption of new technology is more common.

While the timetable for deployment of AVs in both the light- and heavy-duty sectors has a high degree of uncertainty, this study illustrates that the pace of AV adoption will be a critical factor on labor market impacts.

3. TOTAL NUMBER OF JOBS

Labor economists generally assume that absent negative macroeconomic conditions (e.g., a recession), the economy is usually at full employment—which is defined as virtually everyone who wants to work has a

72 Note: The economists argue that AV adoption is unlikely to lead to job loss in the supply chain during the time period covered in this report. Vehicle safety standards are not likely to change enough during this time period to allow for substantial lightweighting of current vehicle designs, so the manufacturing content of a vehicle will likely not change significantly. The economists did not consider the imacts of a possible shift to significantly smaller and fewer vehicles, because even if this evolution did occur, there is considerable uncertainty as to whether it would on net significantly impact manufacturing jobs. The potential impact of substantial increases in vehicle electrification—which would likely be stimulated by shared AVs—on the domestic automotive supply chains was first explored in *Economic Impact of the Electrification Roadmap*, published by the Electrification Coalition in 2010.

73 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

SNAPSHOTS FROM THE FUTURE WORKFORCE

Remote Driver

As autonomous vehicles continue to advance and are capable of handling many driving situations independently, some companies may elect to hire remote drivers who can monitor and help AVs navigate some situations. For example, a trucking company may hire those who have obtained a commercial driver's license to remotely monitor one or more heavy-duty trucks simultaneously. This is especially true for situations that might require specialized attention from a remote driver. This could, for example, include a particularly difficult stretch of road that passes through a work zone, or the final mile of delivery in a dense urban area.

Reducing the cost of truck shipments is likely to increase shipping volumes (along with the current strong trend of increasing freight shipments), and, therefore, increase the demand for remote drivers. These drivers would likely not have to spend most of their time away from their families and is likely to be a higher-quality job than employment as a truck driver today.

job.[74] AVs could induce a temporary deviation from full employment but will not fundamentally restructure the economy. Hence, after some time—to be discussed in the long-term results section—the economy will return to full employment. The real question is how many workers will be without a job at a given time and for how long will those workers typically remain unemployed.

Some might argue that AVs, along with parallel advancements in AI, may restructure the labor market permanently below full unemployment. While a full discussion of this potential assumption is beyond the scope of this report, there have been convincing studies that have argued this is unlikely to be the case.[75]

4. UNEMPLOYMENT LENGTH

The Groshen employment report used Bureau of Labor Statistics (BLS) surveys of recently displaced workers to create a model of what happens to the typical worker after job loss. The surveys, and additional analysis conducted by the labor economists, created a curve that predicts how long a displaced worker is likely to remain unemployed and how many would leave the workforce. The curve is available in the Groshen employment report.[76] The study uses data from the last six years because they occured in an environment of high unemployment but strong economic growth which is a good proxy for AVs that would spur considerable economic growth but a temporary spike in sector-specific unemployment.

Labor Market Impact Projections

The study supports the finding that concerns about a large short-term spike in unemployment are unfounded—with most of the labor market impacts projected to arrive after 2040. At the same time, it identified a long-term risk that 1) a number of workers may suffer temporary unemployment; and 2) firms creating and deploying AVs may not have access to the talent they need. The study suggests instituting workforce policies to bridge the gap between current worker skills and the skills that will be needed for the workforce of tomorrow.

As described in the Appendix, the study examined two scenarios each for trucks and for light-duty vehicles. The trucking scenarios were largely differentiated by the pace at which trucking automation becomes available and is adopted. The light-duty vehicle scenarios are differentiated by whether the primary ownership model for AVs is shared, on-demand fleets or household-owned vehicles. Results are presented separately for cars and trucks because the impacts of automation for cars and trucks largely support different jobs.

LONG-TERM RESULTS

The study looked at the time period from the present until 2050. During this 32-year period, 1.1–2.4 million jobs in a total labor market of 160.3 million will be fundamentally changed from their current form. This would include between 700,000 and 1.7 million of the current 3.3 million driving jobs, or 0.7 to 1.5 percent of the broader U.S. workforce. In total, the occupations whose duties are likely to evolve with AV adoption employed 7.7 million people in 2016.

However, context and timing are important. It is normal for the nature of the job skills required for employment to change over a nearly 35-year period. For example, computer skills were required for only 1.2 million jobs just 40 years ago in 1978,[77] which represented a bit over 1 percent of the U.S. workforce at the time.[78] These skills have since become significantly more widespread. By 2010, more than 60 percent of all U.S. jobs required computer skills.[79] U.S. manufacturing has lost 6.7 million jobs since its 1978 peak, equivalent to 1.7 million jobs per decade.[80] In contrast, the Groshen employment report found that AVs would displace an average of 350,000–750,000 workers per decade between now and 2050, which is substantially less. Certainly, this is an important societal concern to address, but the comparison helps contextualize the labor impacts of AVs within other challenges and changes that have occurred in recent history.

The pace of worker displacement—how many workers are displaced at any given time—is arguably more important than the aggregate number in determining how the impacts of AVs will be felt in the labor market. The labor market is very good at reabsorbing

74 Note: Full employment is a somewhat vague concept that recognizes that even in a fully healthy economy, some level of unemployment will occur. Groshen assumes that the starting point for the simulation (e.g. today) is full employment. When required to use a specific value, the SAFE report considers 4.7% unemployment to be full employment, which is the definition used by the Federal Reserve. See: http://money.cnn.com/2017/03/29/news/economy/federal-reserve-us-economy-recovered/index.html

75 Atkinson (2017).

76 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

77 Brown, Warren: *Jobs Growth in '80s Linked to Computer* Washington Post, December 20, 1981.

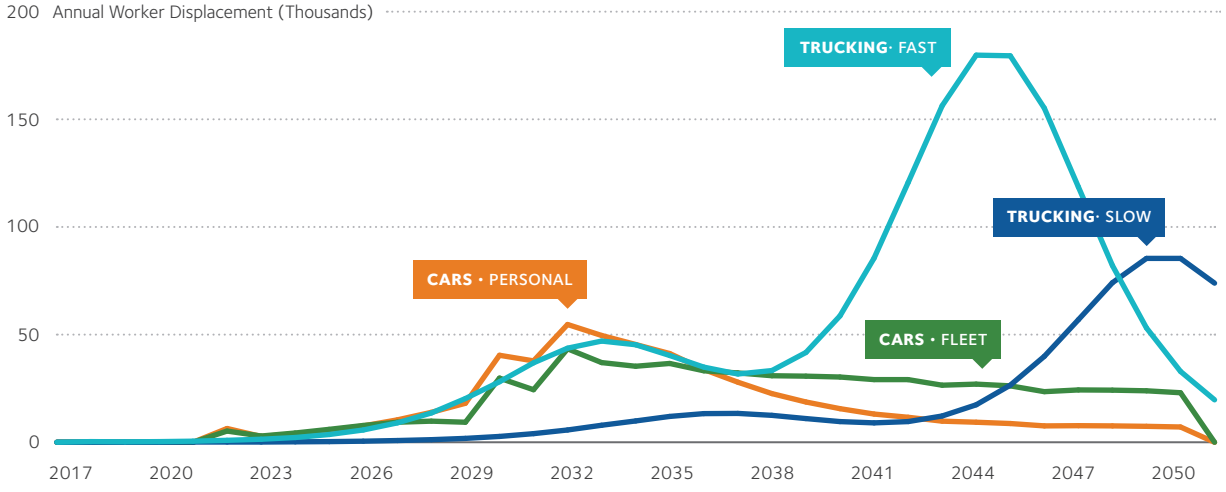
78 Rhode Island Department of Labor and Training: *Labor Market Information*.

79 Anthony Carnevale, Nicole Smith, and Jeff Strohl: *Recovery: Job Growth and Education Requirements Through 2020* Jun 2013, Georgetown Public Policy Institute.

80 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

Total Annual Displacements from AVs, by Scenario

FIGURE 12



Note: See Appendix for more information about scenarios.
Source: Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

small numbers of displaced workers—it is when many workers are displaced in a short time that large-scale unemployment emerges as a possibility.

TIMELINE

The pace of annual worker displacement is displayed in Figure 12. The figure tells us how many workers may be displaced each year due to AV-related innovation, but does not tell us what happens to each worker. The figure illustrates several important points.

First, the displacements induced by AV adoption are predicted to be far larger in the commercial sector—a diverse category, ranging from school bus drivers to long-haul truckers in double tractor-trailers—than in occupations impacted by light-duty vehicle automation. There are simply far more driving jobs in the commercial trucking sector: According to the American Community Survey (ACS), in 2016 nearly 3.3[81] of the 160 million total jobs in the United States were for drivers.[82] Workers whose primary job responsibility is driving fall into several occupation subcategories: Heavy and tractor-trailer truck drivers (1.5 million), light truck or delivery services drivers (781,000), driver/sales workers (383,000), taxi drivers and chauffeurs (300,000), school bus drivers (212,000), transit bus drivers (75,000), and ambulance drivers (10,000). The 300,000 "taxi drivers and chauffeurs," includes drivers on the platforms of transportation network companies such as Uber and Lyft.[83]

Second, even using the more aggressive assumptions about trucking automation, measurable impacts are not seen until the 2030s, with most impacts occurring in the 2040s. This is because the partial automation of trucks (up to Level 3) does not reduce employment—some studies have even projected increases in trucking employment with Level 3 automation.[84] This is particularly true in the context of the current heavy-duty driver shortage estimated at about 50,000 drivers.[85] For these reasons, the study projects minimal, if any, job loss from Level 3 automation of trucks.

Eventually, the study assumes that trucks will be capable of—and permitted to—travel without a driver, initially just for some portion of their route, causing some job loss. A greater wave of job displacement would come with the adoption of a more advanced version of Level 4 automation, which would see trucks capable of operating without drivers at nearly all times. Industry interviews found that few expect trucking automation to progress to widespread commercialization of high automation (Level 4) before 2030.

TRUCKING INDUSTRY CONTEXT

The trucking industry has long been recognized not just

81 Note: Excluding ambulance drivers

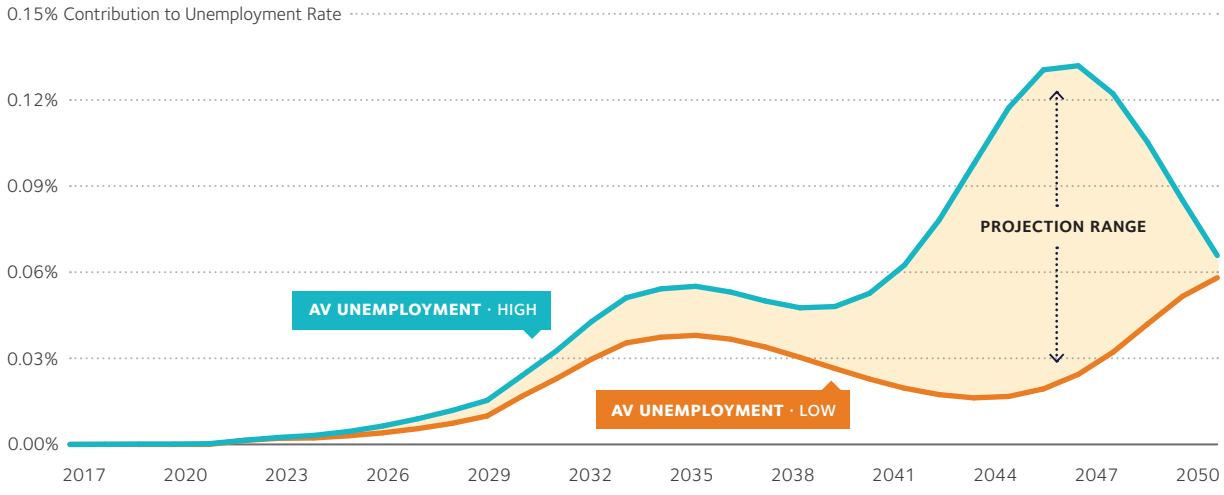
82 See Table IV-1 in Groshen, *et al.*

83 Note: Uber and Lyft each count a larger number of drivers than the figure put forth by ACS. However, many drivers are active on both platforms and many drivers work for only a few hours a week. ACS continues to update its occupational surveys to better track workers in the emerging "gig economy."

84 Madrigal (2018).

85 Evanoff, Ted: *Trucking Firms Offer Up To $8,000 Bonus And Other Deals To Lure Drivers* December 26, 2017, USA Today.

FIGURE 13 Marginal Contribution to Unemployment Rate



Source: Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

TABLE 4 Marginal Contribution to Unemployment Rate in Historical Context

Event	Timing of Peak Impact	Marginal Increase in Unemployment at Peak
Autonomous Vehicle Deployment	Between 2045 and 2055	0.06–0.13 percent
Great Recession	2010	4.9 percent
Early 2000s Recession	2003	1.3 percent

Note: Marginal Increase in Unemployment at Peak assumes a baseline of 4.7 percent unemployment before event impact
Source: Data on AV deployment from Groshen employment study; Data on historical annual unemployment rates from FRED.

as an important source of middle-class jobs, but as an icon representing the independence, resourcefulness, and resilience of the American worker. Indeed, as of 2016, there were 1.5 million workers who are classified as commercial drivers of "Heavy and Tractor Trailer Trucks." The average salary for this group is $44,000.

However, it is not clear that this historic view of the industry continues to reflect reality; the Groshen employment report expressed significant concern about the current state of the trucking industry. The average age of a truck driver is now 55, and the industry has had limited success recruiting younger workers in part because of a lack of real wage increases. While other industries such as construction have experienced labor shortages, the trucking industry is unusual because of the persistence of its labor shortage.

The study found that, over the last 40 years, "truck driver jobs have already undergone a huge transition from good jobs to bad jobs."[86] Automation is, in the short- to medium- term, the most likely pathway for improving trucking jobs, whether by making the driving task less stressful, or by creating jobs that reduce the necessity for long road trips. The economists looked at a variety of ways that the deployment of automation in the trucking sector could impact jobs and analyzed what various interim technological scenarios over the next 10–15 years would mean for truck drivers. It found that the direct job loss impacts are likely to be quite limited during this time period and automation/connectivity technologies actually open avenues for better pay and working conditions for truck drivers.

86 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

Unemployment Rate Impacts

A better way to characterize the labor market impact is to characterize it with a metric that is more broadly familiar: The national unemployment rate. Based on modeling results for worker displacement, reentry and exit from the workforce, the Groshen employment report modeled the contribution of both trucking and light-duty related job displacement to the national unemployment rate.

Figure 13 illustrates the range of potential impacts to the unemployment rate, which under the most aggressive assumptions, would contribute about 0.13 percentage points to the national unemployment rate at peak in the mid-2040s. In the more gradual deployment scenario, peak impacts would be lower—about 0.06 percentage points in the early 2050s when the projection ends. For context, Table 4 compares the unemployment impacts of the Great Recession, which at peak, contributed to an unemployment rate increase of close to 5 percentage points above a base of full employment.[87] It also notes the unemployment impacts of the far more mild recession in the early 2000s, which contributed, at peak, about 1.3 percentage points to the unemployment rate. Looking back further, the unemployment rate has ranged from 2.5 percent to 10.8 percent since World War II.[88] Through 2051, the marginal impacts on the unemployment rate will remain quite low when considered from an economy-wide perspective, below the current uncertainty in the monthly Bureau of Labor Statistics (BLS) unemployment reports.[89]

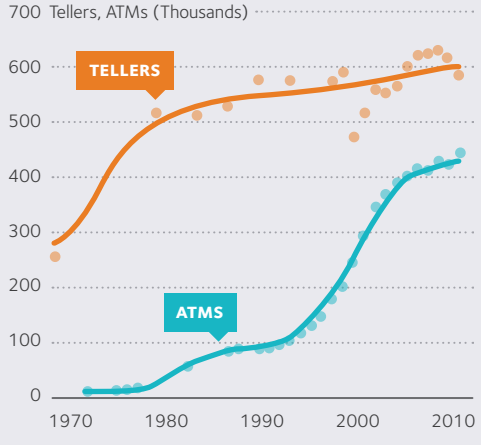
These results are sensitive to the speed of AV deployment. If deployment occurs more rapidly, the impacts will be higher, and if deployment proceeds more gradually, the impacts will be lower. Additionally, while the Groshen employment report has provided national-level statistics, the impact will be felt differently in different regions—understanding where results are most likely to be felt will be helpful in designing the correct policy and business response. The Groshen employment report identified the eight states where truck drivers represent the greatest proportion of workers. When the model examined regional-level impacts in the four Census regions, the lowest impact would be felt in the Midwest, where marginal contributions to the unemployment rate from automation, at peak, would be between 0.06–0.13 percentage points (depending on the scenario). The highest impact would be in the Northeast, where the marginal contribution to the unemployment rate, at peak, would be 0.06–0.14 percentage points.

87 As noted before, we use 4.7 percent unemployment as the baseline for "full employment".

88 St Louis Federal Reserve: *Civilian Unemployment Rate* 1948-2018.

89 Bureau of Labor Statistics, "Employment Situation Technical Note", March 2018. Accessed on March 18, 2018: https://www.bls.gov/news.release/empsit.tn.htm

Automated Teller Machines: An Illustrative Example



Source: Ruggles et al., *Integrated Public Use Microdata Series: Version 5.0*; Bureau of Labor Statistics, *Occupational Employment Survey*, http://www.bls.gov/oes/; Bank for International Settlements, Committee on Payment and Settlement Systems, various publications [see p. 243, note 9].

There are historical examples of how automation technology interplays with jobs that have interesting parallels with vehicle automation. As an example, Automated Teller Machines (ATMs) began growing in availability and popularity in the 1980s, and the direct effect upon bank teller jobs showed up in the employment statistics almost immediately; several thousand bank teller jobs were lost from 1986–96, despite an expanding economy. However, this pattern began to reverse in the mid-1990s to 2014 and the number of bank tellers grew even as the number of ATMs increased. ATMs allowed banks to operate branches at lower cost so banks chose to open more branches for easier access and a stronger community presence. Fewer tellers per branch was offset by the larger number of branches, resulting in net growth for bank tellers.

Source: Teresa Morisi: "Commercial Banking Transformed by Computer Technology."

SNAPSHOTS FROM THE FUTURE WORKFORCE

Transportation Concierge

As new transportation technologies such as on-demand mobility solutions and, in the near future, AVs enter the mainstream they offer significant potential for reducing transportation obstacles for seniors and persons with disabilities. AVs may facilitate travel as they offer door-to-door service and utilizing them will not require the ability to obtain a driver's license. These reduced obstacles will likely lead to greater travel demand from underserved groups. One recent paper estimated that AVs would increase vehicle miles traveled in the United States by roughly 12 percent due to demand from people with disabilities, seniors, and those with travel-restrictive medical conditions.

Many persons with disabilities and seniors may find that while AVs lessen the burden for travel, assistance is still required for navigation or getting in and out of vehicles. Some, for example, may have medical conditions that need to be monitored closely during travel. In order to provide appropriate accommodations, there will likely be a significant increase in jobs for travel aides to accompany these individuals during travel. These transportation aides may require specialized training to deal with such populations, which could include certifications for personal care assistants (PCAs) or certified nursing assistants (CNAs).

New Job Creation

The Groshen employment report predicts that the vast majority of workers whose positions are eliminated because of AVs will regain employment.[90] Many will be reemployed within the AV industry or supply chain and others will gain jobs elsewhere in the economy. As can be seen in Figure 15, job creation may lag worker unemployment and displacement to some extent. The focus of policy recommendations should be to shrink this gap to the greatest extent possible.

New jobs are expected to be created in three broad categories: New transportation jobs; new AV-related jobs; and new jobs providing other goods and services. To the extent that AVs reduce the cost of transportation, people will demand more transportation—requiring greater employment in new transportation jobs. These roles include fleet vehicle dispatchers and repair workers, as well as tasks that are currently bundled with driving, such as package delivery.

AV-related manufacturing will be a prime driver for job growth in the AV-related jobs category. AVs still need to be manufactured, and early indications show that task will fall to the automakers. Other areas of expansion include the hardware and software required for AV operation. Finally, new jobs and services created is an indefinite category, as it is unknown what consumer tastes and business models will emerge after AV deployment. Furthermore, it is not known how consumers will spend their surplus income once AVs reduce cost of travel: For example, consumers could eat out more often, spend more money on healthcare or renovate their homes.

Figure 14 illustrates the process of replacing the jobs changed by AV deployment. The upper line in each pair is the projected cumulative number of workers who will be displaced due to AV adoption, adjusted for retirements. Even as the AV-related displacement occurs, previously displaced workers will continue to be re-employed in new jobs; this quantity is represented by the lower line in each pair. In this model, a new job can only be created to fill a job that has already been eliminated.[91]

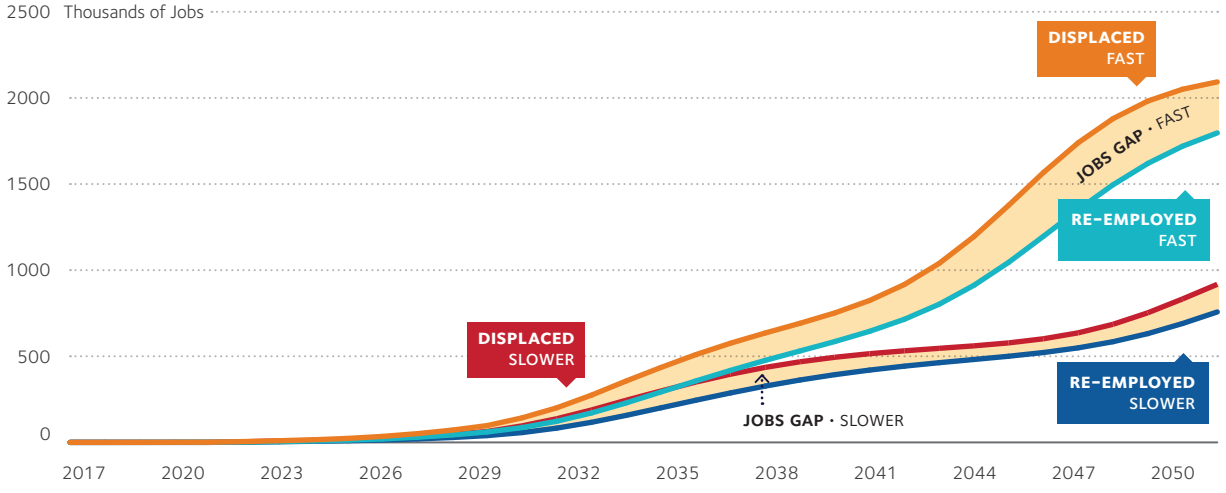
Figure 14 projects that displacement and re-employment rates will be fairly low until about 2040, at which point both rates rise and the gap between displacement and re-employment widens, reflecting the larger number of displaced workers experiencing

90 Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

91 Note: The model does not assume that all displaced workers are hired into new, rather than pre-existing, jobs. Re-employed workers are likely to return to pre-existing jobs as well as fill new jobs created by AV.

Job Displacement and Re-Generation

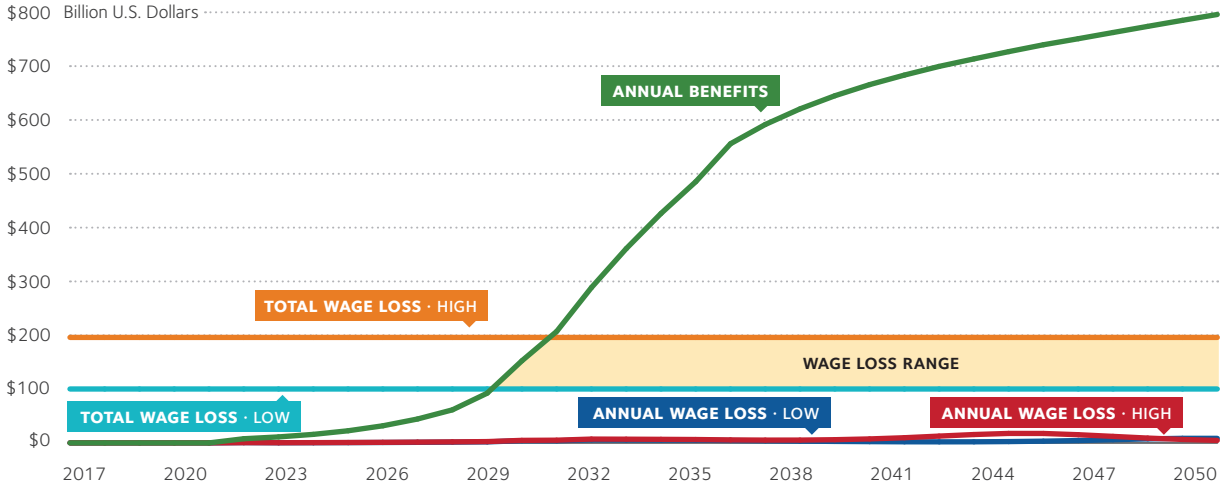
FIGURE 14



Note: Adapted from Groshen employment report.
Source: Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

AV Benefits and Wage Loss: Broader Context

FIGURE 15



Note: Data on annual benefits from Montgomery AV benefits report. Data on wage loss from Groshen employment report. Total Wage Loss is over modeled period (2018 to 2051).
Source: David Montgomery, *Public and Private Benefits of Autonomous Vehicles*, June 2018, and Erica Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, June 2018.

a time lag before they land new positions. The gap will peak at 380,000 in 2047 for the aggressive scenario and 170,000 in 2051 at the lower end of the projected range.[92] After those years, the gap begins to dwindle as AV-related worker displacement tapers off and an increasing number of workers find new jobs. Sometime after 2050, all jobs eliminated by AV deployment will be replaced with new jobs that will be filled with workers.

SAFE INTERPRETATION AND APPLICATION OF THE GROSHEN EMPLOYMENT REPORT RESULTS

Figure 14 illustrates the challenge and goal of policy interventions. It is not necessarily the goal of good labor market policy to reduce the number of jobs that evolve; indeed evolution of worker skill requirements is characteristic of a dynamic, growing economy. Policy instead should focus on narrowing the time required for displaced workers to find new jobs. This is better accomplished through workforce retraining measures rather than slowing technological change.

92 Note: The scenarios do not project past 2051, so it is possible that the gap would grow after that date.

SNAPSHOTS FROM THE FUTURE WORKFORCE

Fleet Manager

As the promise of low-cost, on-demand mobility incentivizes consumers to make the switch from using a conventional vehicle to hailing an AV for a journey, the quality of the fleet will become crucial as AV fleet companies compete for riders. This means ensuring the cleanliness and maintenance of AVs will become paramount, as consumers gravitate toward the fleet provider with the cleanest interiors and the fewest outages. A shift of hundreds of billions of VMT–or more–from privately owned cars to fleets will transform fleet operator into massive operations with employment opportunities to match.

A fleet manager and support staff will be required to clean and maintain the vehicles, as well as take AVs out of service when problems are reported. In an industry where efficiency and convenience are prized, ensuring the fleet is best-positioned to meet the needs of consumers will also become more important. Fleets are likely to employ a broad range of workers to address tasks from maintenance to predictive analytics to stay ahead of consumer demand.

CONTEXTUALIZING JOB LOSS WITHIN THE BROADER BENEFITS OF AVS

Policy steps to address the evolution of the labor market must ultimately be placed in the context of the broader impacts of AVs in order to ensure the best outcome. The large-scale societal benefits from the deployment of AVs suggests that policies to address labor force issues should be considered for the potential to delay the deployment and benefits of AVs. Delaying AV deployment would represent a significant and deliberate injury to public welfare. Rather than degrading the benefits, policymakers could ensure that the interests of the people who may lose jobs are well protected through effective mitigation programs.

Figure 15 illustrates the importance of balancing these two priorities. It plots both the conservative projected AV benefits estimated in Section 1 and the range of projected wages that will be lost to individual workers due to AV-related unemployment. The range of projected wage loss reaches as high as $18 billion in 2044 and 2045. However, it is essential to note that peak wage loss goes hand in hand with projected benefits well in excess of $700 billion for each of those years, as calculated in the Montgomery AV benefits report. In fact, not only are the social and economic benefits of AV deployment significantly more than their costs to workers on an annual basis, but the benefits of AVs *each year* are far greater than the cost to workers *over the next 35 years combined* (illustrated by the rectangle of Figure 15).

The projected discounted earnings[93] that will be forgone due to AV-related unemployment ranges from $54 billion to $101 billion. The cumulative, discounted benefits of AVs are projected to be $5.2 trillion. The very high ratio of projected benefits to job loss damages strongly suggests that policy mechanisms to reduce harm to displaced workers are a better choice than seeking to slow down the technology and risk reducing the economic and social returns it may bring. By the same token, it also suggests that the financial cost of policies to mitigate AV impacts could be well covered from captured benefits of AV adoption.

Workplace Development Infrastructure

The United States has an existing set of workforce retraining and safety net policies that would form a natural foundation for anticipating, mitigating, and minimizing potential negative impacts of AVs on the workforce.

93 Note: SAFE discounted future earnings and benefits at a "risk-free rate" corresponding to the 30 year Treasury Rate, which closed at 3.00% on April 17, 2018.

However, the labor economists concluded that the U.S. workplace development infrastructure has been underfunded and underutilized both historically and in recent years. Budgets for training, employment, and statistical analysis have been falling in recent years, curtailing coverage and modernization. Even well-known policies such as unemployment insurance did not have their full desired impact with more than one-third of those eligible for unemployment insurance from 1989 to 2011 not receiving these payments. While the existence of these institutions allows them to serve as a basis for a better future workforce retraining policy, they are likely not adequate in their current form for the pace and scale of change that AVs will bring.

A broad list of solutions that have been proposed is put forth, without endorsement, in the box that follows; policies include establishing works councils, worker training accounts, wage insurance, public sector employment for infrastructure, universal basic income, flexicurity, and enhanced local economic development. These policies are discussed in more depth in the Groshen employment report.

Additionally, the private sector will have an important role to play in workforce retraining. As illustrated in Figure 11, displaced workers find new jobs more rapidly when those jobs overlap in skill set and are close geographically. To the extent that companies employing workers at higher risk of displacement take steps to restructure jobs rather than eliminate them or to create new jobs within the company and engage in retraining, the transition for workers can be significantly smoother.

While the agenda put forth by the Groshen employment report does not represent a specific proposal for policies to mitigate future workforce displacement, it underscores that this challenge is addressable within the context of workforce policy. Already, policymakers have been discussing potential steps that can be taken. These are by themselves positive steps, as "with advance planning, the task is manageable."[94]

Principles for Labor Market Policy Changes

The study outlined several important criteria for a policy response to mitigate labor market impacts of AVs and other technologies. Policies must be enacted to help both workers and employers prepare for labor market impacts. A comprehensive list is available in Table IV-1 of the Groshen employment report, but four key features of this framework are:

1. Solutions should be comprehensive. AVs are just one example of challenges that will be faced by workers. Change may come from other technologies, as well as the long-term direction of economic policy. Therefore, labor market policy should not focus solely on AVs and their impacts and risk missing these broader, and potentially more significant, developments. What works in one region may also not work elsewhere, as unemployed workers vary substantially in their needs—from income support and job search help, to retraining and other issues—so a single approach will be insufficient. Similarly, adopting a combination of policies is encouraged, given the potential breadth of change.

2. A broad range of policies are needed. Modeling work showed that impacts could be felt across a broad range of regions and demographic groups, impacting workers at different career stages. Unemployed workers, in the present or future, regardless of whether unemployment resulted from AV deployment or another cause, will have a diverse set of needs. This lends credence to the argument that no single workforce policy is a "magic bullet" for solving issues discussed in this policy brief.

3. Strengthen existing workforce development institutions. There are over 2,000 American Job Centers nationwide; offices administered by the U.S. Department of Labor (DOL) to help jobseekers access resources to help them return to work and provide workforce development services to employers and employees. The 2014 Workplace Innovation and Opportunity Act (WIOA) was passed to strengthen the U.S. workforce investment system, including the American Job Centers. Additionally, unemployment insurance is provided through the DOL to support qualifying individuals as they seek re-employment. These institutions could be strengthened by broadening and enhancing coverage, as well as by increasing the range of services provided.

4. Evidence-based solutions. Policies and programs should be continually evaluated for impact and efficacy. The private sector should be engaged and is a key part of the solution. Government should expand labor market data collection efforts and further research should be conducted.

5. Identify areas for additional study. This could include conducting industry-level analyses to identify other jobs that may be affected by AVs; study where unemployed drivers find new jobs by industry and occupation, the duration of unemployment and the wage change; investigating productivity benefits from reduced driving times, and; monitoring the labor market impact of alternative implementation options for AVs.

94 Erica Groshen et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future*, June 2018.

POLICY RECOMMENDATIONS

There are three potential courses of action for policymakers seeking to mitigate the potential impacts of AV deployment on the workforce:

- **The passive option:** Allow AV deployment to occur at a rapid pace, and accept any costs to workers, at the risk of social disruption and heightened public resistance to further technological change, as the price of doing business.

- **The reactionary option:** Impose restrictions on AV technology to artificially slow adoption in an attempt to allow the current workforce system to handle the transition without high costs.

- **The investment option:** Pursue a rapid deployment of AVs, while directing some benefits of AVs to fund investments in policies that would upgrade our ability to mitigate costs to workers.

The first possibility, to promote rapid AV deployment without investing in workforce development, exposes society to significant risk. The specter of significant unemployment can lead to social unrest and political instability, and resistance to innovation. High levels of youth unemployment, for example, were a contributory factor for the Arab Spring.[95] Similarly, unemployment was one of the drivers behind the Occupy movement that sprung up in the aftermath of the Great Recession.[96]

The second option, deliberately throttling AV deployment to match the ability of our current workforce retraining system, does intentional harm to the entire U.S. public by making our roads less safe and accessible, reducing economic growth, and harming U.S. energy security and the environment. It would represent a significant and deliberate injury to public welfare to protect the future interests of a small minority of people who could be more efficiently protected by effective mitigation policies.

The third option, which SAFE prefers, is the investment option. In 2017, SAFE's Commission on Autonomous Vehicle Testing and Safety recommended the deployment of AVs as soon as they offer a net benefit to public safety.[97]

The same principle could be applied here. The immediate economic and social impacts of deploying safe AVs would be significant and positive. Some of these benefits should be directed toward investment in workforce development. SAFE recognizes the potential negative implications for the workforce, but as those impacts are unlikely to be noticeable before the 2030s, with most impacts in the 2040s, the current timeframe offers policymakers significant lead time to research, design, and implement workforce development solutions. By adopting this approach, the United States can enjoy the full benefits of AVs in the near term while simultaneously preparing the workforce for the jobs of the future.

95 International Labour Organization: *Youth unemployment in the Arab world is a major cause for rebellion* April 5, 2011.

96 Gentile, Sal: *Occupy Wall Street: Unemployment is not going away, and neither are we* March 21, 2012, PBS.

97 SAFE: *Recommendations of the Commission on Autonomous Vehicle Testing and Safety* January 5, 2017.

Conclusion

As the technology driving AVs continues to improve, policymakers at all levels will need to make key decisions that will shape the adoption of these vehicles and related services by the general population as well as by industry.

Based on the above analysis, it is highly likely that AVs will revolutionize the American economy in ways that have not been seen since the mid-20th century. AVs promise dramatic increases in mobility to those unable to drive and vulnerable to shortages of current public transit and paratransit options, including seniors, low-income individuals, and persons with disabilities. Fully autonomous vehicle technology will transform possibilities, expanding reasonable commuting distances, and with it, the labor market size for a given area. Concurrently, AVs hold the promise of significant safety, energy security, and environmental benefits. All of these factors combined will likely produce economic growth and increases in quality of life throughout the nation.

AV technology will transform possibilities, expanding reasonable commuting distances, and with it, the labor market size for a given area.

AV technologies will also require newly trained workers and will likely have an impact on employment within driver-based industries—including trucking. SAFE believes that the potential for worker displacement must be addressed seriously and in the context of the many positive impacts of AV technology adoption. As described above, job displacement within driver-based industries likely will not emerge for at least 10–15 years and while those impacts will be painful for certain individuals and their families, it will remain relatively small in the context of the broader economy. Thus, SAFE advises policymakers at the local, state, and national levels to prepare and invest in policies that will develop strong workforce training plans for American workers that may be displaced by AVs or other developments beyond the scope of this study.

Furthermore, envisioning a future without AV technology paints a far bleaker picture for the United States, both socially and economically. High fatality rates on America's roadways would likely continue. Large sections of the population—including people with disabilities, older Americans and injured veterans—would also remain shut off from access to transportation. The United States would also lose its global competitive edge as other nations embrace the efficiencies offered by autonomy, and worldwide leadership in this catalyzing technology would be ceded to America's competitors.

SAFE presents this policy brief, and the reports upon which it is based, as an important step in an evidence-based dialogue on the impact of AVs. We believe that society does not have to choose between the compelling benefits of AVs and the stable evolution of the workforce. The totality of evidence generated by this study reinforces the conclusion that the best pathway to broad American prosperity is through the adoption of policies supporting AV deployment while simultaneously laying the groundwork for the workforce of the future.

APPENDIX: AV ADOPTION SCENARIOS

In order to assist in economic modeling, SAFE developed a series of scenarios informed by industry interviews and background research. This process resulted in the creation of four scenarios, two each for trucks and passenger cars.

Trucking

Both trucking scenarios divide the deployment of automation into three distinct phases. The phases each represent a suite of technology-enabled functions that are described at a high enough level enough to make forecasting tractable, but are specific enough to also be useful in forecasting labor market and economic impacts. The forecasts are consistent with research and modeling performed in earlier SAFE studies.[98]

The first scenario in Figure 16 above shows a slower lead time for the introduction of autonomous technology, with full, driverless autonomy under all conditions expected only to move forward in the 2040s. Figure 17 details a more aggressive deployment, with full automation expected to be in mainstream use by the early 2030s. In both scenarios, Phase 1 consists of technology that still requires a driver, Phase 2 represents a scenario where drivers can be absent for sections or subsets of rides, and Phase 3 does not require a driver for most rides.

Passenger cars

The two light-duty scenarios are mostly similar in projected timeline for the availability and deployment of AV technology, which is denominated in the percentage of vehicle miles traveled (VMT) that is driven autonomously. The scenarios differ most in the mode of AV deployment and test for sensitivity between two oft-cited potential tracks for such deployment: A future where AVs are mostly used in shared fleets, and a future where household vehicle ownership largely continues to prevail.

The first scenario in Figure 18 assumes, based on existing research, that shared, autonomous vehicles will be predominantly electric, as AVs currently being tested are disproportionately using electric or hybrid powertrains, and overarching technological, economic and regulatory trends suggest this will continue.[99] This scenario projects that shared AVs—fleet-owned vehicles that provide on-demand transport access for users—would make up close to 90 percent of travel by 2050. This forecast was made after a review of AV deployment forecasts[100] and consultation with industry experts.

The "personal ownership" scenario, in Figure 19, assumes that shared ownership plateaus at approximately 10 percent of VMT. Once this level is reached in about 2030, new vehicles sold are overwhelmingly AVs, so AVs diffuse through the fleet at the same rate of fleet turnover that we see today. SAFE used data on vehicle survivability and travel mileage schedules to model the adoption of AVs.[101] Additionally, household-bought AVs are no more likely to be electric than a non-AV, so EV deployment is not significantly impacted by the adoption of AVs.

98 SAFE. "Heavy-Duty Innovation: Energy, Automation, and Technology in the Trucking Sector," November 2017. Available at: http://secureenergy.org/wp-content/uploads/2017/11/Heavy-Duty-Innovation_Energy_Automation_Tech.pdf

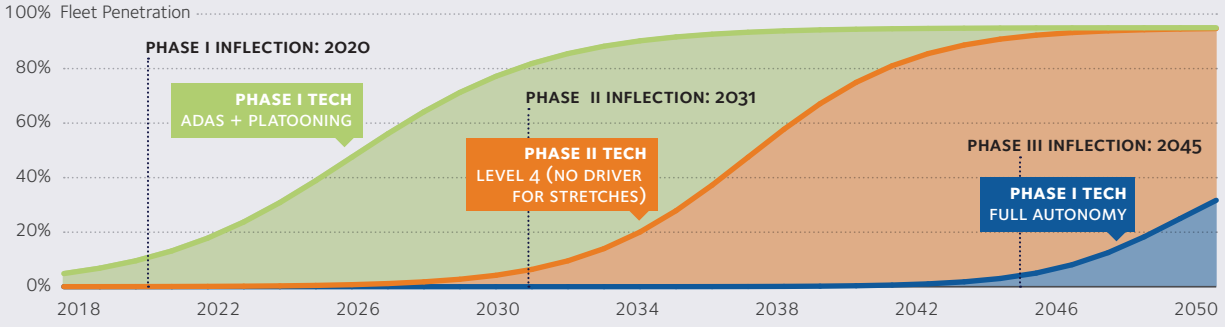
99 Robbie Diamond and Amitai Bin-Nun, "Self-Driving Cars: Road to Deployment", Written Testimony to the House Committee on Energy and Commerce, Subcommittee on Digital Commerce and Consumer Protection, February 14, 2017 http://docs.house.gov/meetings/IF/IF17/20170214/105548/HHRG-115-IF17-20170214-SD011.pdf

100 Energy Information Administration, "Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles" at 28, March 2017. Available at: https://www.eia.gov/analysis/studies/transportation/automated/pdf/automated_vehicles.pdf

101 NHTSA, "Vehicle Survivability and Travel Mileage Schedules", January 2006. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809952

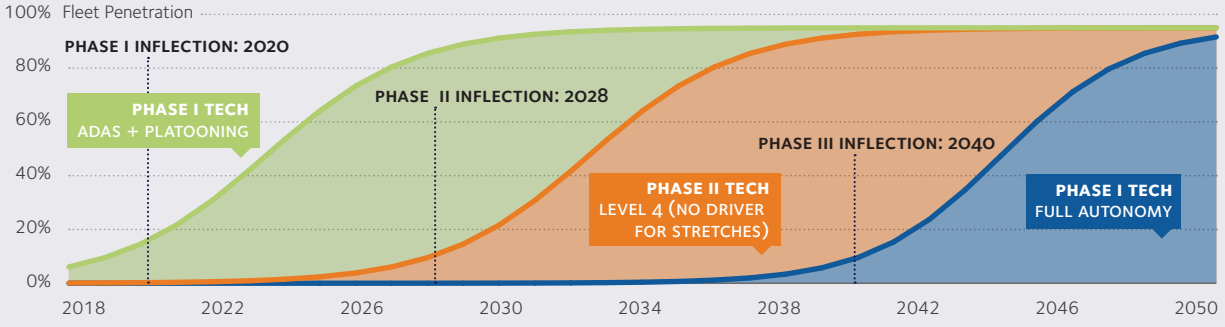
"Slow" Trucking Scenario

FIGURE 16



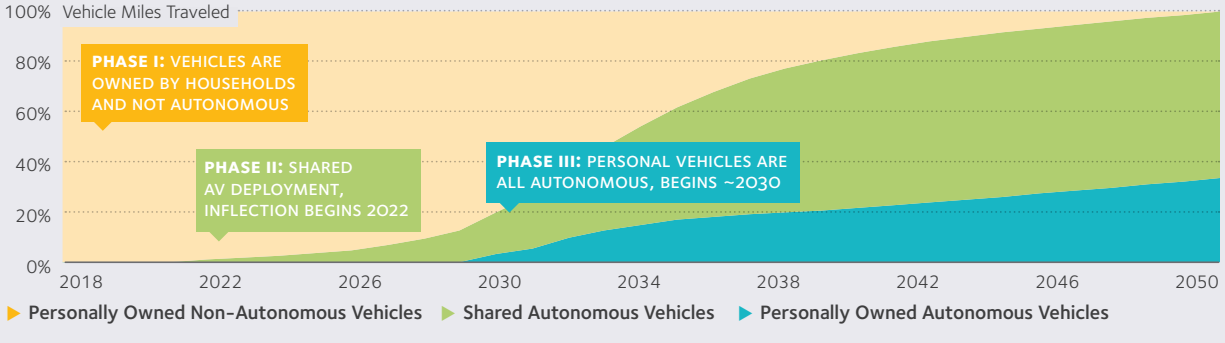
"Fast" Trucking Scenario

FIGURE 17



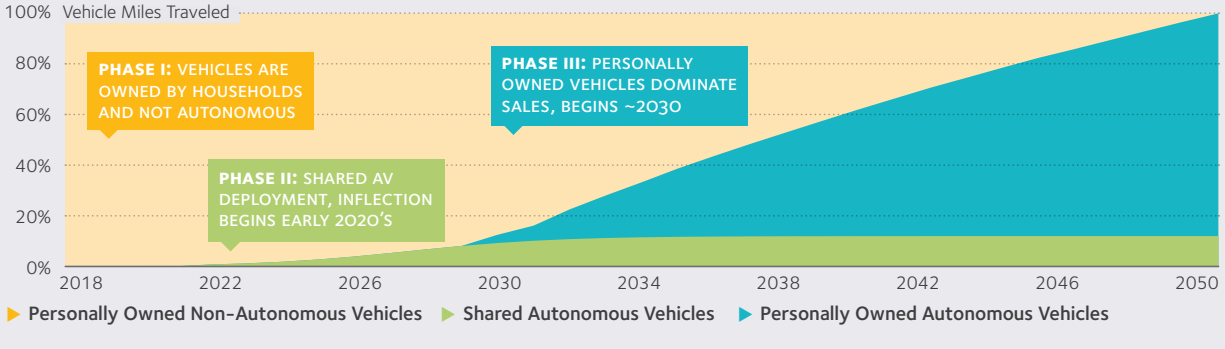
Fleet Deployment Scenario

FIGURE 18



Personal Ownership Scenario

FIGURE 19



Sources: SAFE modeling based on industry interviews and background research

About SAFE

Securing America's Future Energy (SAFE) is an action-oriented, nonpartisan organization that aims to reduce America's dependence on oil. Near-total dependence on petroleum in the transportation sector undermines the nation's economic and national security, and constrains U.S. foreign policy. To combat these threats, SAFE advocates for expanded domestic production of U.S. oil and gas resources, continued improvements in vehicle fuel efficiency, and the advancement of alternative fuels in the transportation sector including electric vehicles and natural gas trucks. In 2006, SAFE joined with General P.X. Kelley (Ret.), 28th Commandant of the U.S. Marine Corps, and Frederick W. Smith, Chairman, President, and CEO of FedEx Corporation, to form the Energy Security Leadership Council (ESLC), a group of business and former military leaders committed to reducing the United States' dependence on oil. More information can be found at SecureEnergy.org.

This report is a project of SAFE's Autonomous Vehicles Task Force, a coalition of automobile manufacturers, technology companies, fleet managers, and thought leaders committed to advancing the future of transportation.

America's Workforce and the Self-Driving Future: Realizing Productivity Gains and Spurring Economic Growth examines the potential societal and consumer benefits of widespread autonomous vehicle (AV) deployment and assesses the impacts of an autonomous, self-driving future on the U.S. labor force. The report provides an outline of the potentially tremendous benefits AVs can bring in terms of mobility and productivity, an appraisal of the potential effects AV deployment could have on some sections of the workforce, and presents potential options for policymakers seeking to maximize the benefits of AVs while minimizing the impacts.