Autonomous Vehicles

Autonomous vehicles (AVs) use technology to partially or entirely replace the human driver in navigating a vehicle while avoiding road hazards and responding to traffic conditions.[1] The Society of Automotive Engineers (SAE) has developed, and the U.S. National Highway Traffic Safety Administration (NHTSA) uses, a classification system with six levels based on the level of human intervention.[2]

SAE Levels of Automation[2,3]

Levels	Description
Level 0	Vehicles equipped with no automated features, requiring the driver to be in complete control of the vehicle.
Level 1	Vehicles equipped with one or more primary automated features such as cruise control, but requiring the driver to perform all other tasks.
Level 2	Vehicles equipped with two or more primary features, such as adaptive cruise control and lane-keeping, that work together to relieve the driver from controlling those functions.
Level 3	Vehicles equipped with features that allow the driver to relinquish control of the vehicle's safety-critical functions depending on traffic and environmental conditions. The driver is expected to take over control of the vehicle given the constraints of the automated features after an appropriately timed transition period.
Level 4	Vehicles equipped with features that allow the driver to relinquish control of the vehicle's safety-critical functions. The vehicle can perform all aspects of driving even if the driver does not respond to a request to intervene.
Level 5	Fully autonomous vehicles that monitor roadway conditions and perform safety-critical tasks throughout the duration of the trip with or without a driver present. This level of autonomy is appropriate for occupied and unoccupied trips.

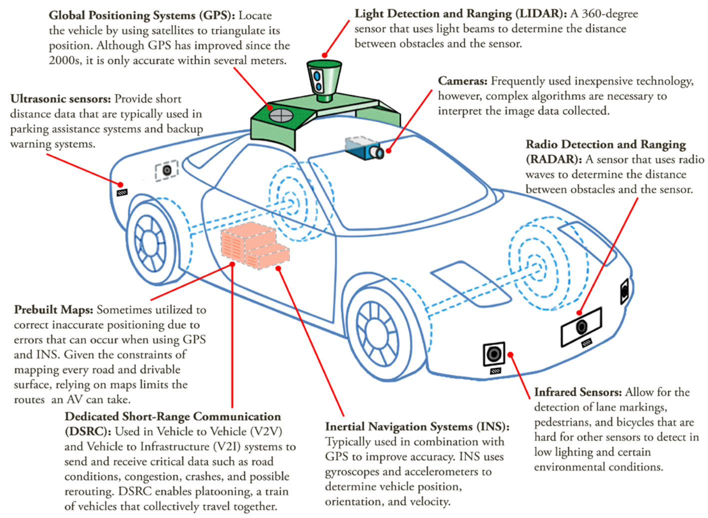
Development of Autonomous Vehicles

AV research started in the 1980s when universities began working on two types of AVs: one that required roadway infrastructure and one that did not.[1] The U.S. Defense Advanced Research Projects Agency (DARPA) has held "grand challenges" testing the performance of AVs on a 150-mi off-road course.[1] No vehicles successfully finished the 2004 Grand Challenge, but five completed the course in 2005.[1] In 2007, six teams finished the third challenge, which consisted of a 60-mi course navigating an urban environment obeying normal traffic laws.[1] In 2015, the University of Michigan built Mcity, the first facility built for testing AVs. Research is conducted there on the safety, efficiency, accessibility, and commercial viability of AVs.[4] Unmanned aircraft systems (UAS), or drones, are being deployed for commercial ventures such as last-mile package delivery, medical supply transportation, and inspection of critical infrastructure.[5]

Autonomous Vehicle Technologies

AVs use combinations of technologies and sensors to sense the roadway, other vehicles, and objects on and along the roadway.[6]

Autonomous Vehicle Technologies[1,7,8,9]



Current and Projected Market

Key Market Leaders

- In 2021, North America was preceived to be leading the AV race ahead of China. In 2023, this perception was evenly split, according to a McKinsey survey.[10]
- Waymo has tested its vehicles by driving over 20M miles on roads and tens of billions of miles in simulation.[11] Teslas have driven over 3B miles in Autopilot mode since 2014.[12]
- Other major players include Audi, BMW, Daimler, GM, Nissan, Volvo, Bosch, Continental, Mobileye, Valeo, Velodyne, Nvidia, Ford, as well as many other OEMs and technology companies.[6,13]

Regulations, Liability, and Projected Timeline

- Regulation will impact the adoption of AVs.[14] In the U.S. there are no national standards or guidelines for AVs, allowing states to determine their own.[14] In 2018, Congress worked to pass the AV Start Act that would have implemented a framework for the testing, regulating, and deploying of AVs. The legislation failed to pass both houses.[15] As of February 2020, 29 states and D.C. have enacted legislation regarding the definition of AVs, their use, and liability.[16]
- Product liability laws need to assign liability properly when AV crashes occur, as highlighted by the May 2016 Tesla Model S fatality. Liability will depend on multiple factors, especially whether the vehicle was being operated appropriately to its level of automation.[17,18]
- Although researchers, OEMs, and industry experts have different projected timelines for AV market penetration and full adoption, the majority predict Level 5 AVs around 2030.[19,20]

Current Limitations and Barriers

- There are several limitations and barriers that could impede adoption of AVs, including lack of buyer demand, data security, protection against cyberattacks, regulations compatible with driverless operation, resolved liability laws, societal attitude and behavior change regarding distrust and subsequent resistance to AV use, and the development of economically viable AV technologies.[6]
- Weather can adversely affect sensor performance on AVs, potentially impeding adoption. Ford recognized this barrier and started conducting AV testing in the snow in 2016 at Mcity, utilizing technologies suited for poor weather.[13]

Impacts and Solutions

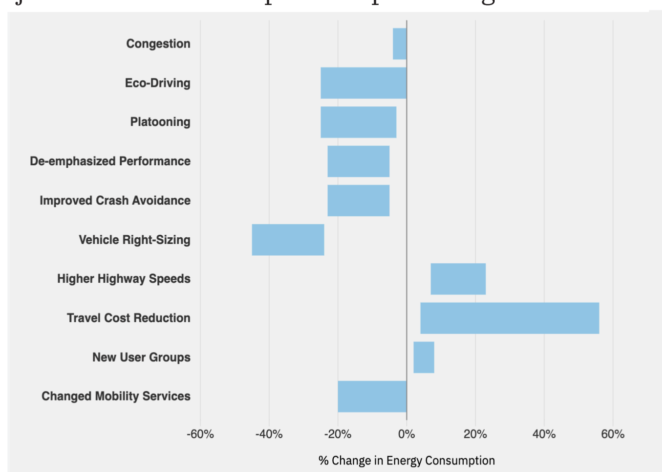
- Although AVs alone are unlikely to have significant direct impacts on energy consumption and GHG emissions, if effectively paired with other technologies and new transportation models, significant indirect and synergistic effects on economics, the environment, and society are possible.[21,22]
- One study found that when eco-driving, platooning, intersection connectivity and faster highway speeds are considered as direct effects of AVs, energy use and GHG emissions can be reduced by 9%.[23]

Metrics and Associated Impacts

- *Congestion* is predicted to decrease, reducing fuel consumption by 0-4%. However, decreased congestion is likely to lead to increased vehicle-miles traveled (VMT), partially offsetting the fuel consumption benefit.[21]
- *Eco-Driving*, a set of practices that reduce fuel consumption, is predicted to reduce energy consumption by up to 20%.[21] However, if AV algorithms do not prioritize efficiency, fuel efficiency may actually decrease.[24]
- *Performance*, such as fast acceleration, is likely to become de-emphasized when comfort and productivity become travel priorities, potentially leading to a 5-23% reduction in fuel consumption.[21]
- *Improved Crash Avoidance,* due to the increased safety features of AVs, may allow for the reduction of vehicle weight and size, decreasing fuel consumption 5-23%.[21]
- *Vehicle Right-Sizing*, the ability to match the utility of a vehicle to a given need, has the potential to decrease energy consumption 21-45%, though the full benefits are only likely when paired with a ride-sharing on-demand model.[21]
- *Higher Highway Speeds* are likely due to improved safety, increasing fuel consumption 7-30%.[21,25]
- *Travel Cost Reduction*, due to decreased insurance cost and improvements in productivity and driving comfort, could result in increased travel, potentially increasing energy consumption 4% to 60%.[21]
- *New User Groups* are likely to increase VMT and fuel consumption by 2-10%.[21]
- *Changed Mobility Services*, such as an increase in ride-sharing could reduce energy consumption 0-20%.[21,26]

Although an accurate assessment of these interconnected impacts cannot currently be made, one study evaluated the potential impacts of four scenarios, each with unknown likelihoods. The most optimistic scenario projected a 40% decrease in road transport energy and the most pessimistic scenario projected a 105% increase in road transport energy.[21]

Projected Fuel Consumption Impact Ranges[21,25]



Potential Benefits and Costs

- 42,795 people died in vehicle crashes in 2022.[27] 94% of crashes are due to human error. AVs have the potential to remove/reduce human error and decrease deaths.[28]
- AVs have the potential to reduce crashes by 90%, potentially saving approximately $190B per year.[29]
- The U.S. AV market is expected to grow to over $75B in 2030, representing an increase of 350% from 2023.[30]
- The last-mile AV energy savings for public transportation were over 33% when compared to private vehicles.[31]
- Potential benefits include: improvements in safety and public health, increased productivity, quality of life, mobility, accessibility, and travel, especially for the disabled and elderly; reduction of energy use, environmental impacts, congestion, and public and private costs associated with transportation; and increased adoption of car sharing.[1,14,32,33]
- Potential costs include increased congestion, VMT, urban sprawl, total time spent traveling, and upfront costs of private car ownership leading to social equity issues; impacts on other modes of transportation; and increased concern with security, safety, and public health.[1,14,25,33,34]

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Sources for this factsheet are here, help with units and abbreviations is here.