NEXTCAR – Next Generation Energy Technologies for Connected and Automated On-Road Vehicles

Chris Atkinson, Sc.D., Fellow ASME
Program Director
Advanced Research Projects Agency-Energy

Introductions – ARPA-E

- Chris Atkinson, Program Director
- Gokul Vishwanathan, Tech. SETA
- Rusty Hefner, Tech. SETA
- Shawn Kimmel, Tech. SETA

- Carlton Reeves, Technology to Market Advisor
- Whitney White, Program SETA

- Pat McGrath, Associate Director for Technology
- Grigorii Soloveichik, Program Director
- Fadl Saadi, Fellow
- Nancy Hicks, Meeting Coordinator

Kickoff Objectives

- What are we are here for –
  - To formally kick off the Program,
  - To establish a technical baseline from which the Program will proceed,
  - To hear from industry, government and policy leaders about the state of the art and future directions in this area, and
  - To start to create an R&D and commercialization ecosystem around the energy efficiency of CAVs.
- Introduce ourselves to each other, get to know what others are doing, get to know the state of the art, and to get a sense of the challenges and the possibilities ahead of us.

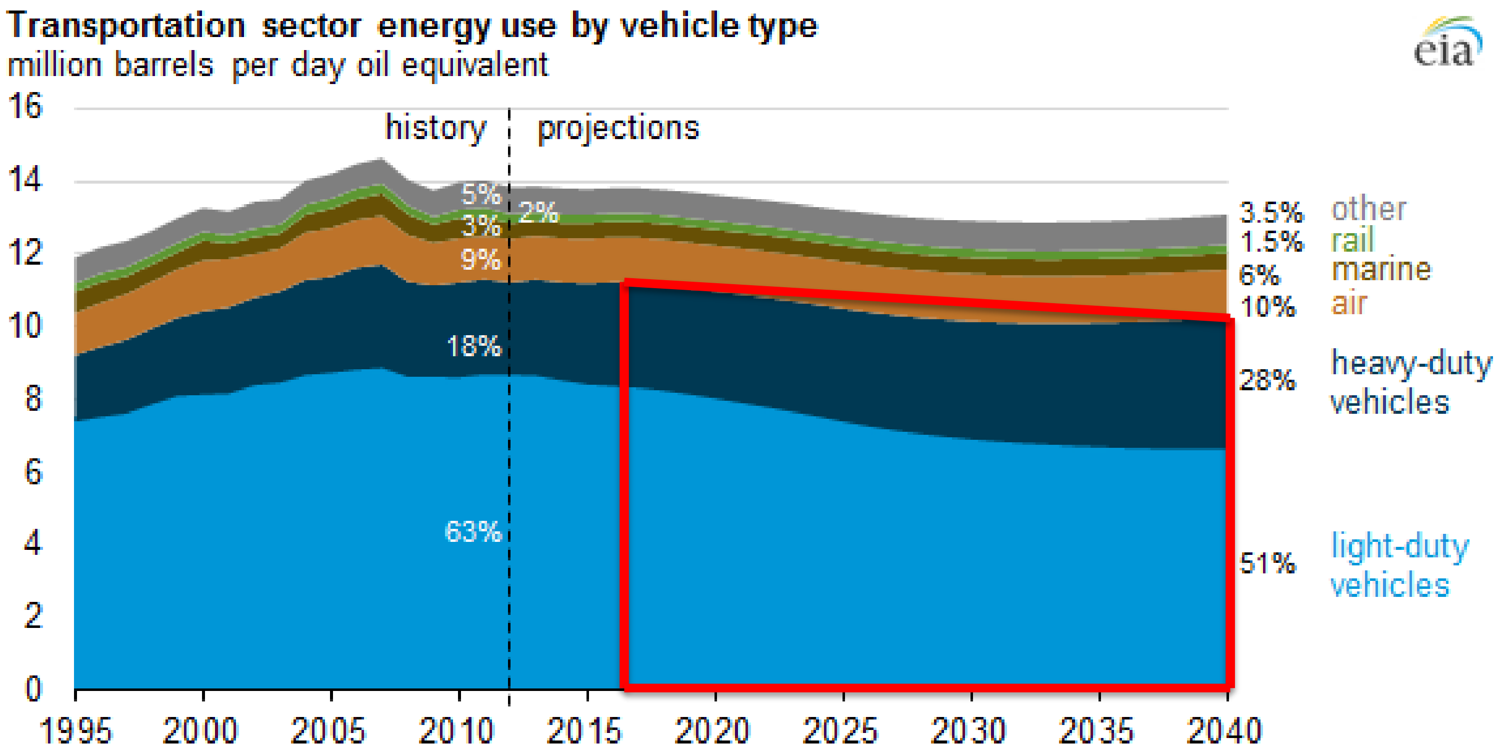
Kickoff Objectives

- What we are NOT here to do
  - Renegotiate the FOA,
  - Renegotiate any project,
  - Rehash the Program assumptions,
  - Talk about the FOA topics specifically not of interest such cybersecurity, safety, or connectivity protocols for example.

Kickoff Objectives

- For the next 2 days this Kickoff is a BUDGET-Free, POLITICS-Free ZONE.
- We will share the challenges of initiating the Program from a purely technical point of view.

Energy Consumed by Transportation in the US



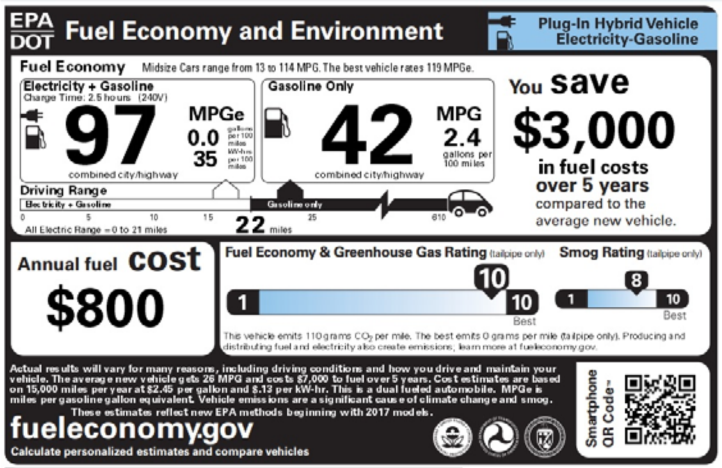
Light-, medium and heavy-duty vehicles consume **~11 million barrels per day** oil equivalent, totaling **81%** of transportation sector energy consumption, or **~23%** of the US primary energy usage.

arpa·e
CHANGING WHAT'S POSSIBLE

3 Significant Trends in Automotive Transportation

Trend 1 – Fuel Economy

- Future **fuel economy** of the **light-duty** vehicle fleet will be required to be significantly higher than today (54.5 mpg CAFE by 2025).

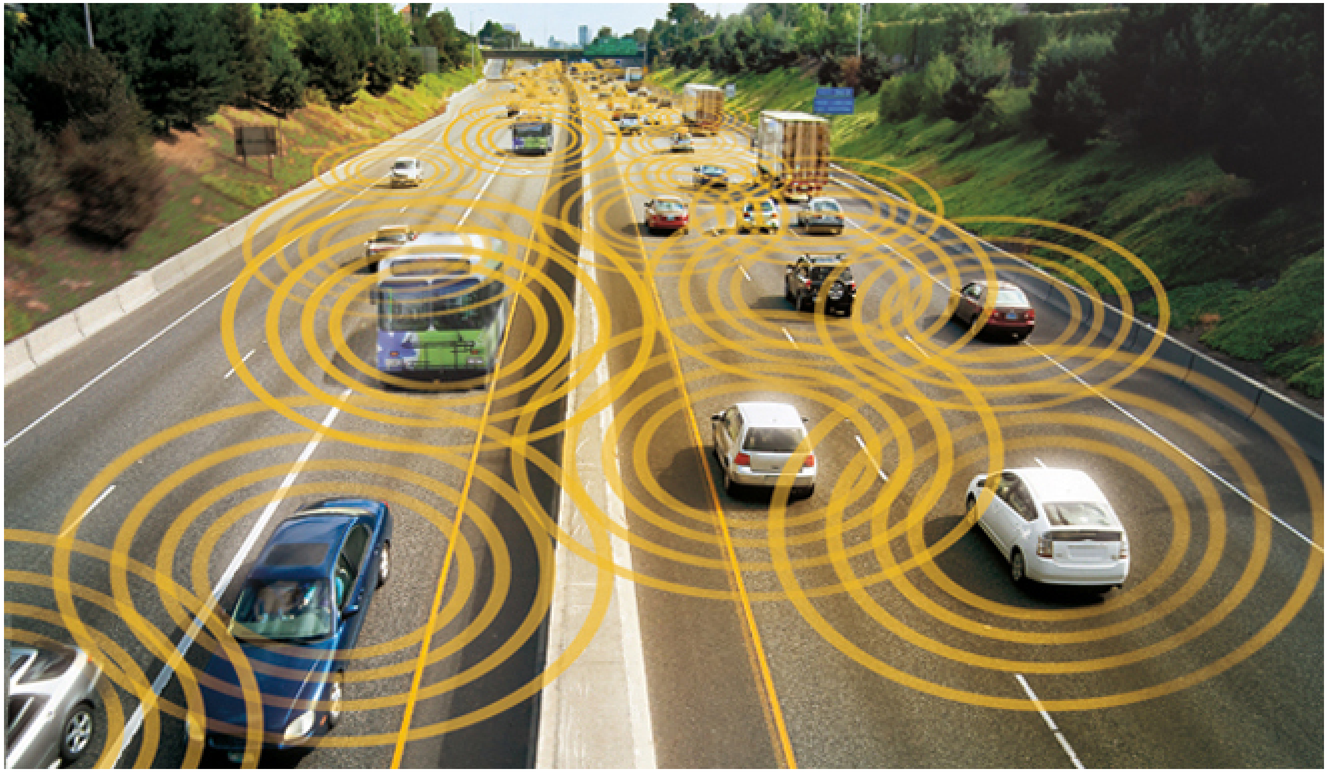


- **Heavy-duty** fuel economy regulated by EPA/NHTSA Phase 2 GHG rules.

Fuel efficiency improvements will be achieved by vehicle light-weighting, reducing aerodynamic drag and tire rolling losses, engine downsizing, boosting, improved transmissions (multispeed, CVT), increased electrification, hybridization, waste energy recovery, and reductions in friction and parasitic losses.

Trend 2 – Vehicle Connectivity

- Future vehicles will utilize greater levels of **connectivity** – V2V, V2I, V2X – this trend is driven primarily by road traffic **safety** considerations.

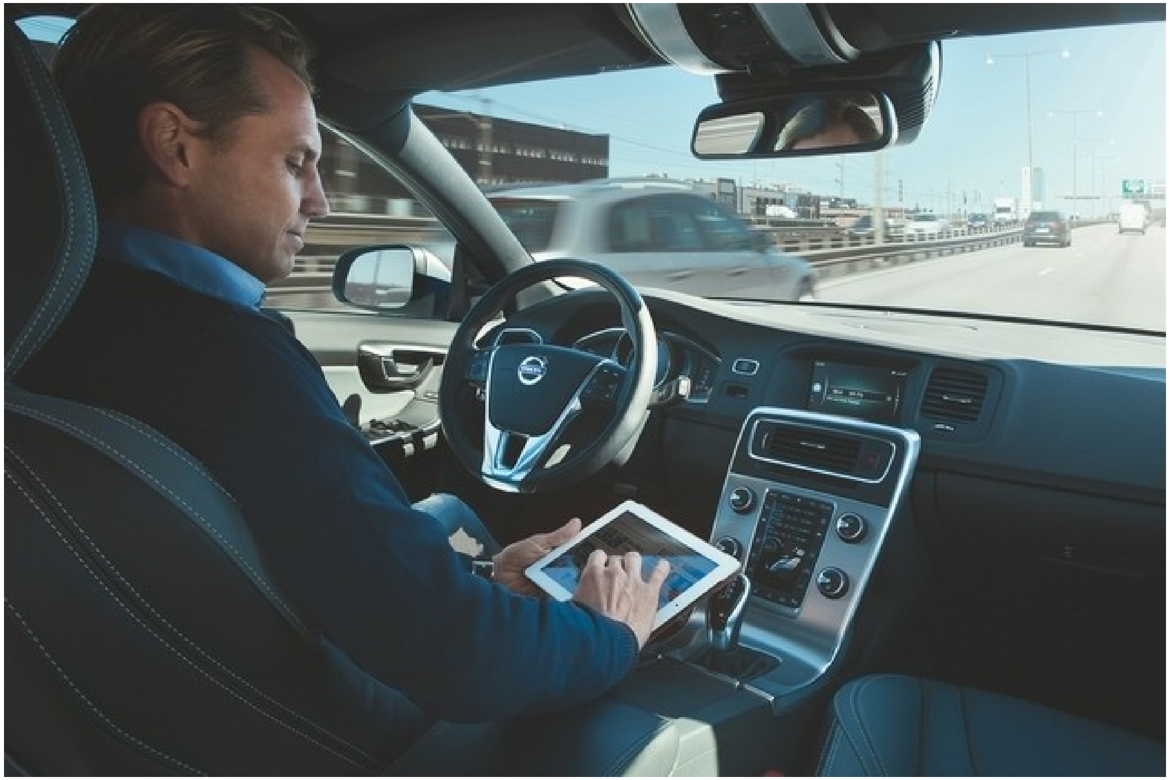


Connected Vehicles – V2V, V2I, V2X.

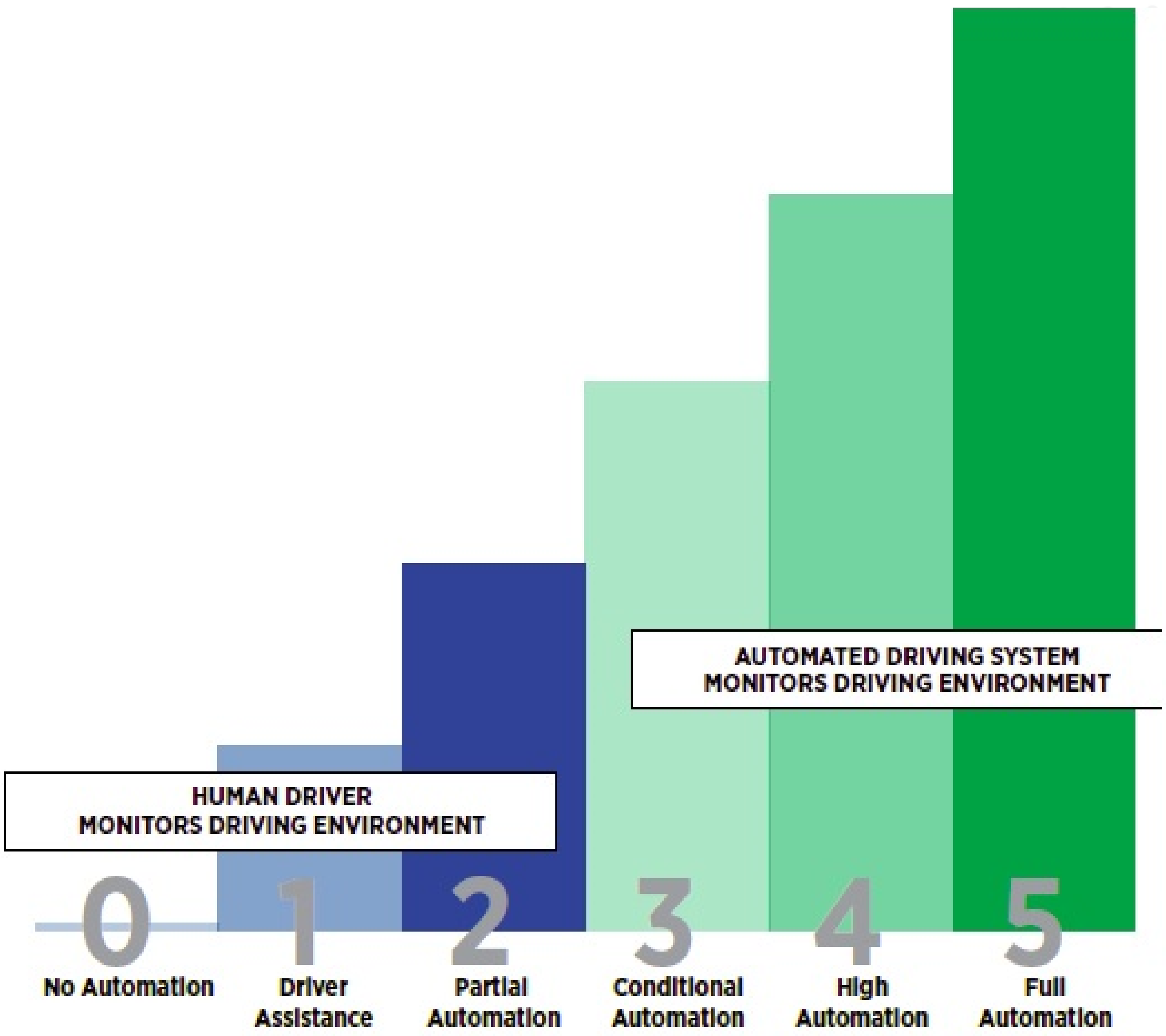
DENSO, 2015

Trend 3 – Vehicle Automation

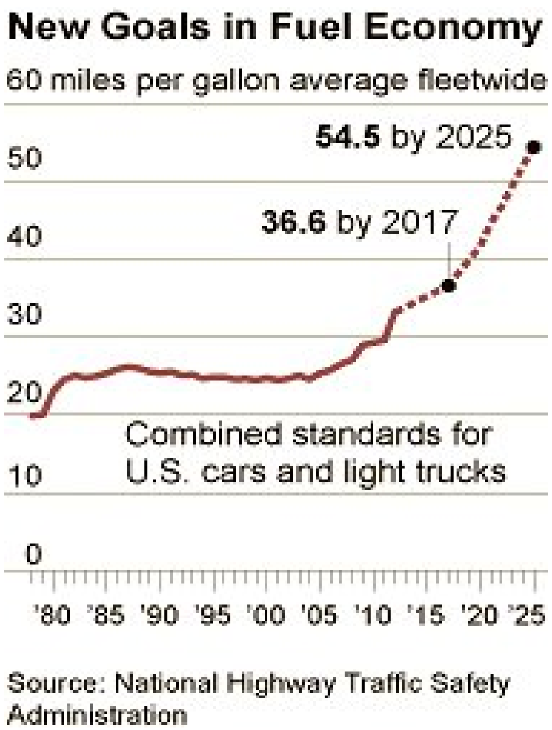
- Future vehicles will display greater levels of **automation** – from **L0** (no automation) to **L1&L2** advanced driver assistance systems (ADAS) to **L3&L4** automation (automated operation with a driver present) and **L5** (full automation – no driver required).



SAE Levels of Automation

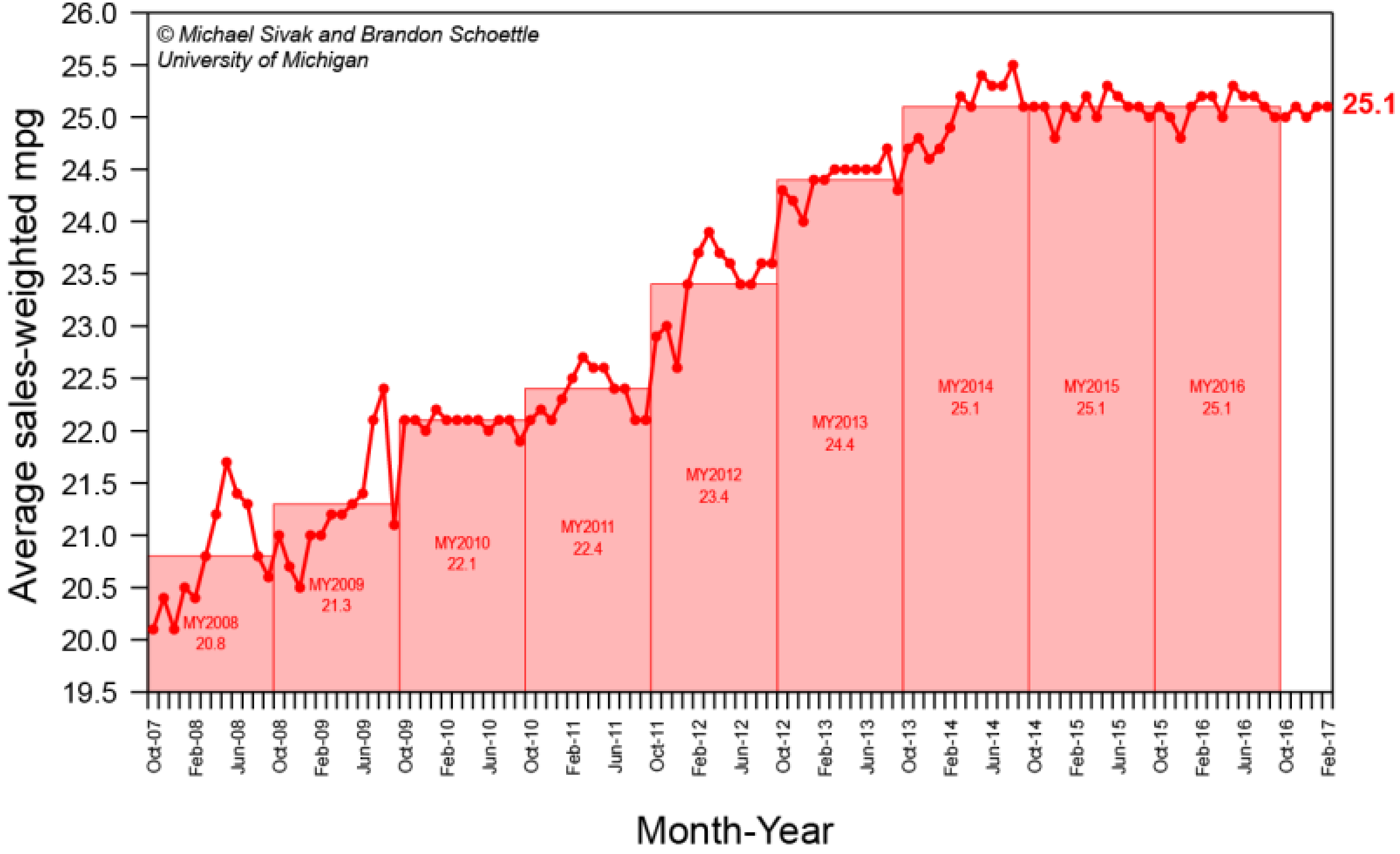


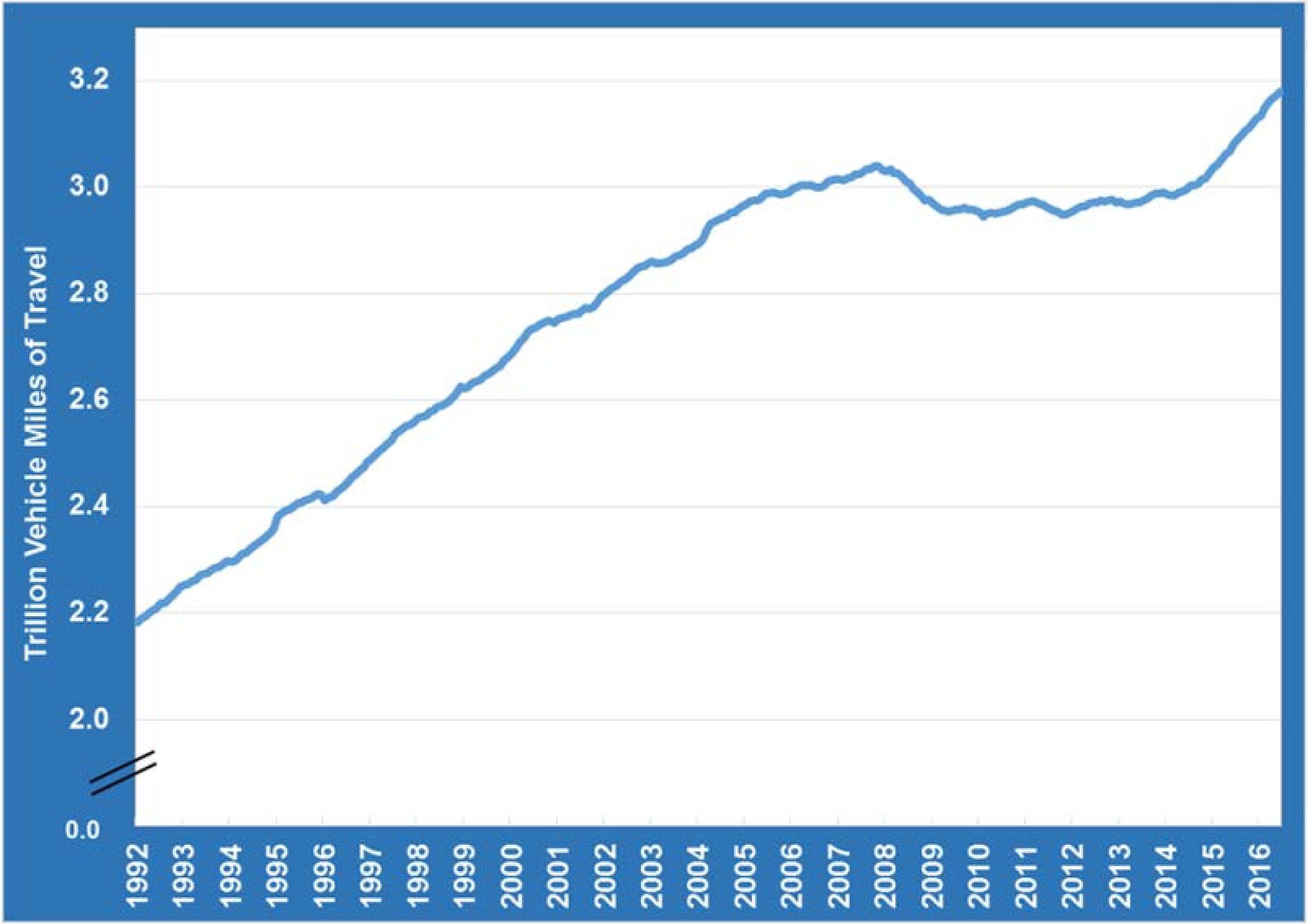
Light-Duty Vehicles – Meeting CAFE in 2025



- OEMs will meet 2025 standards through a combination of technology and fleet mix, adjusting sales of BEVs, PHEVs, HEVs, (FCVs), and conventional cars and light trucks.
- Beyond 2025……..?
- And what about the effect of **connectivity and automated vehicle operation**? This is not reflected in regulations.

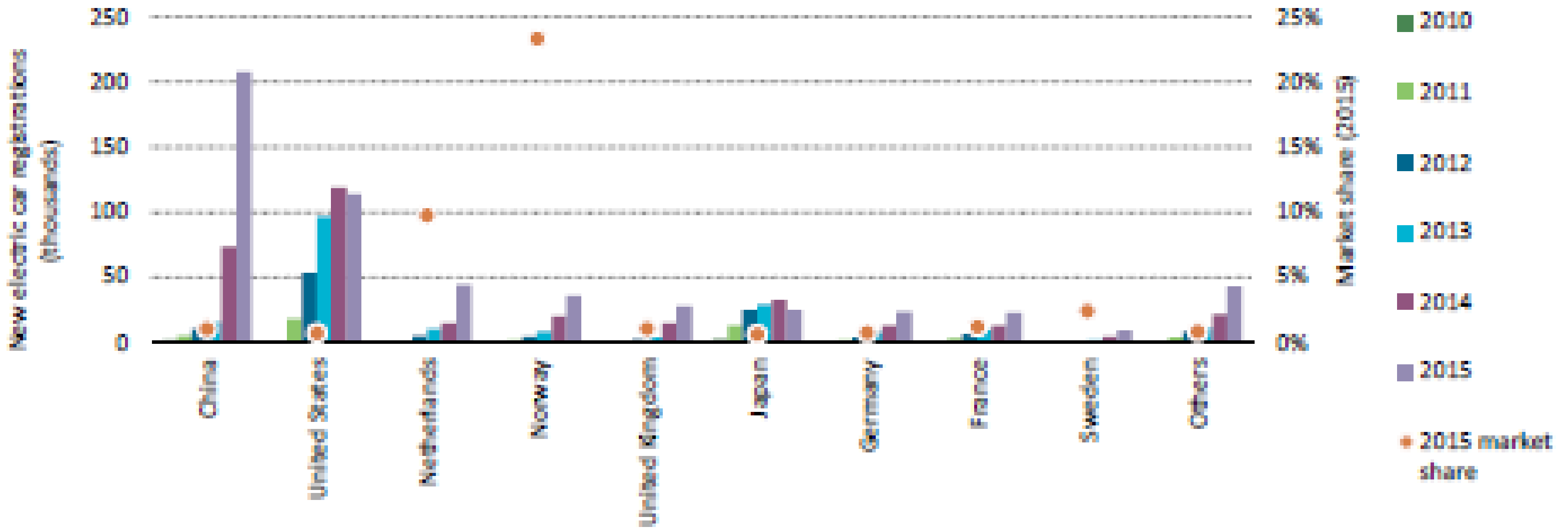
Fleet-Averaged Light-Duty Fuel Economy – Sales Weighted (UMTRI)





VMT in the US (trillion miles), DOE

Figure 6 • EV sales and market share in a selection of countries and regions, 2015



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2016), IHS Polk (2014), MarkLines (2016), ACEA (2016a) and EEA (2015).

Key point • **The two main electric car markets are China and the United States. Seven countries have reached over 1% EV market share in 2015 (Norway, the Netherlands, Sweden, Denmark, France, China and the United Kingdom).**

Vehicle Safety – the motivation for connectivity

- **Road safety** – 32,675 fatalities in 2014 (1.07 per 100M VMT) with 2.31 million injuries in 6.06 million crashes (1.65 million with injuries, or 53 crashes with injury per 100M VMT).
- Has relied to date on **passive safety** – expensive and costly in weight.
- New **active safety** mechanisms – ACC and AEB through radar.
- **Vehicle connectivity** will allow for further advances in safety – DSRC (dedicated short range communications) will broadcast the actions of all vehicles in a 150m radius.
- What will be the effect of **automated vehicles on safety**?

CHANGING WHAT'S POSSIBLE

Sources: NHTSA, industry.

Advanced Driver Assistance Systems (L1-L2)

- ACC – adaptive cruise control (accelerator, brake).
- LKA – lane keeping assist (steering).
- AEB – advanced emergency braking (brake) (standard by 2022).
- FCW – forward collision warning.
- Parking assistance/pilot.
- Alerts – blind spot assist, cross-traffic alerts, rear-view cameras.

- Semi-autonomous (MB, Volvo, Subaru, Infiniti, Nissan, Honda, …) and now essentially autonomous (Tesla Autopilot [L3&L4] and Google car [L5])

L5 Vehicles will demonstrate far higher energy efficiency

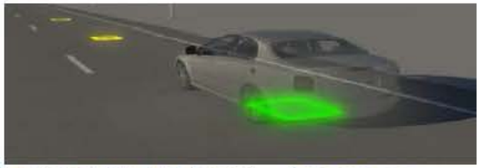
- Intrinsically safe vehicles “won’t crash”.
- Significant reductions in vehicle mass possible due to reduction in safety equipment required.
- Large weight de-compounding effects, also allowing for the use of lighter materials – CF, plastics, light metals?
- Opportunity for xEVs? Reduced energy storage requirements for same vehicle range.
- Automated vehicles will have more/less opportunity for recharging?
- What about the Energy Rebound Effect? The Jevon’s Paradox.
- And what of the interim period? The ‘inefficient medium term’?

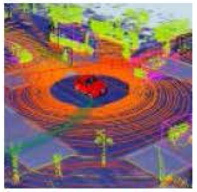
Connectivity and Automation – Effects on Powertrain Control

- For the first time, powertrain control will have full future predictive capabilities – a point of inflection
- Vehicles and powertrains will know (on multiple timescales) what their future power demand will be
- Especially useful for hybrid powertrains due to multiple sources and sinks of energy and power
- Will allow for the use of a whole new class of high efficiency, poor transient response engines
  - Alternative architectures
  - Reconfigurable architectures
  - Alternative combustion regimes
  - Range extenders?

Bringing it All Together in an Integrated Mobility Future

- Electric Vehicles
- Connected Vehicles
- Vehicle Automation





Connected-Automated-Electric Vehicles

- Internet of Things
- Machine Learning
- Big Data
- Mobility on Demand

Smart Cities

Benefits

- Order of magnitude safety improvements
- Reduced congestion
- Reduced emissions and use of fossil fuels
- Improved access to jobs and services
- Reduced transportation costs for government and users
- Improved accessibility and mobility

Source: Adapted from U.S. Department of Transportation

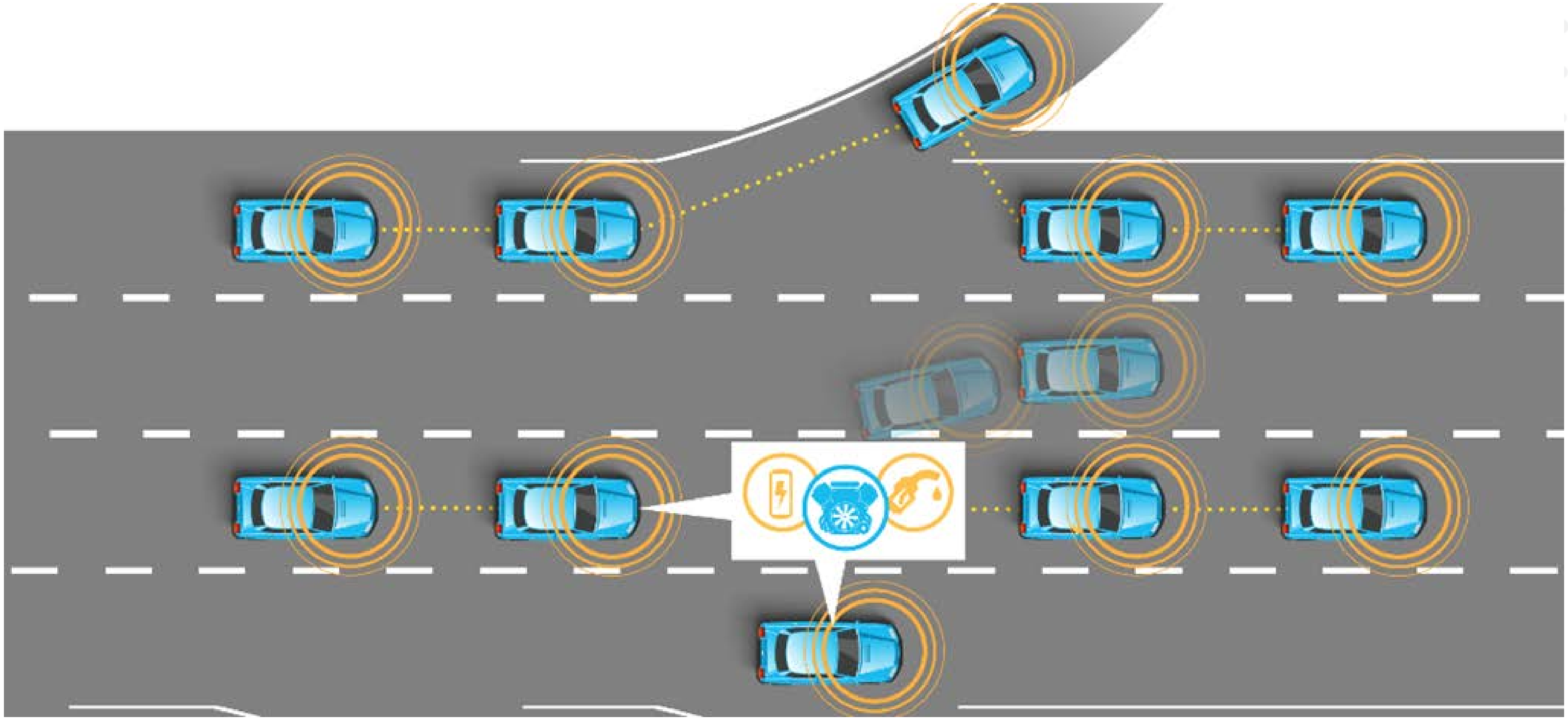
A. Schroeder – R& D Trends and Opportunities in Sustainable ITS, 2016.

CHANGING WHAT'S POSSIBLE

Advanced Research Projects Agency – Energy (ARPA-E)

http://www.arpa-e.energy.gov/

A new program to improve the energy efficiency of the future vehicle fleet through connectivity and automation



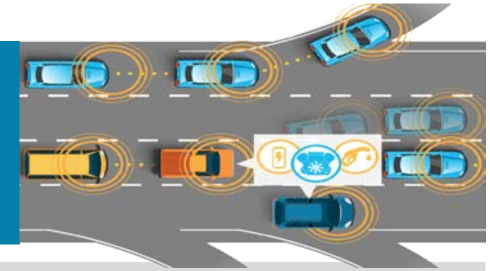
by bringing together experts in powertrains, vehicle dynamics, controls and optimization, and transportation systems.

The Program Focus

- Is on L0-L4 and specifically NOT L5.

NEXTCAR

NEXT-Generation Energy Technologies for Connected and Automated on-Road vehicles



Mission

The ARPA-E NEXTCAR Program will fund the development of new and emerging vehicle dynamic and powertrain control technologies (VD&PT) that reduce the energy consumption of future Light-Duty (LD), Medium-Duty (MD) and Heavy-Duty (HD) on-road vehicles through the use of connectivity and vehicle automation.

Program Director	Dr. Chris Atkinson
Total Investment	$35 Million over 3 years

Goals

- **Energy Consumption:** 20% reduction over a 2016 or 2017 baseline vehicle.
- **Emissions:** No degradation relative to baseline vehicle.
- **Utility:** Must meet current Federal vehicle safety, regulatory and customer performance requirements.
- **Customer Acceptability:** Technology should be transparent to the driver.
- **Incremental System Cost:** $1,000 for LD vehicle, $2,000 for MD vehicle and $3,000 for HD vehicle.

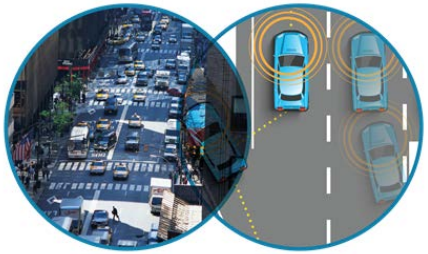
Potential Impact

- **Energy Consumption Reduction:** 4.4 quads/year
- **CO_2 Emissions:** 0.3 GT/year

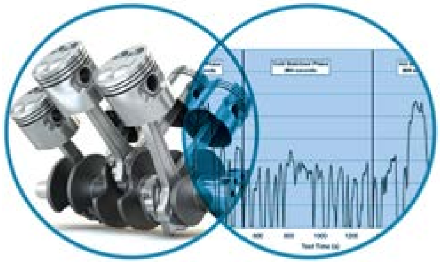
Collaborative Vehicle and Powertrain Solution

STATUS QUO

Two separate and independent efforts for improving vehicle energy efficiency



Independent Vehicle Dynamic Control

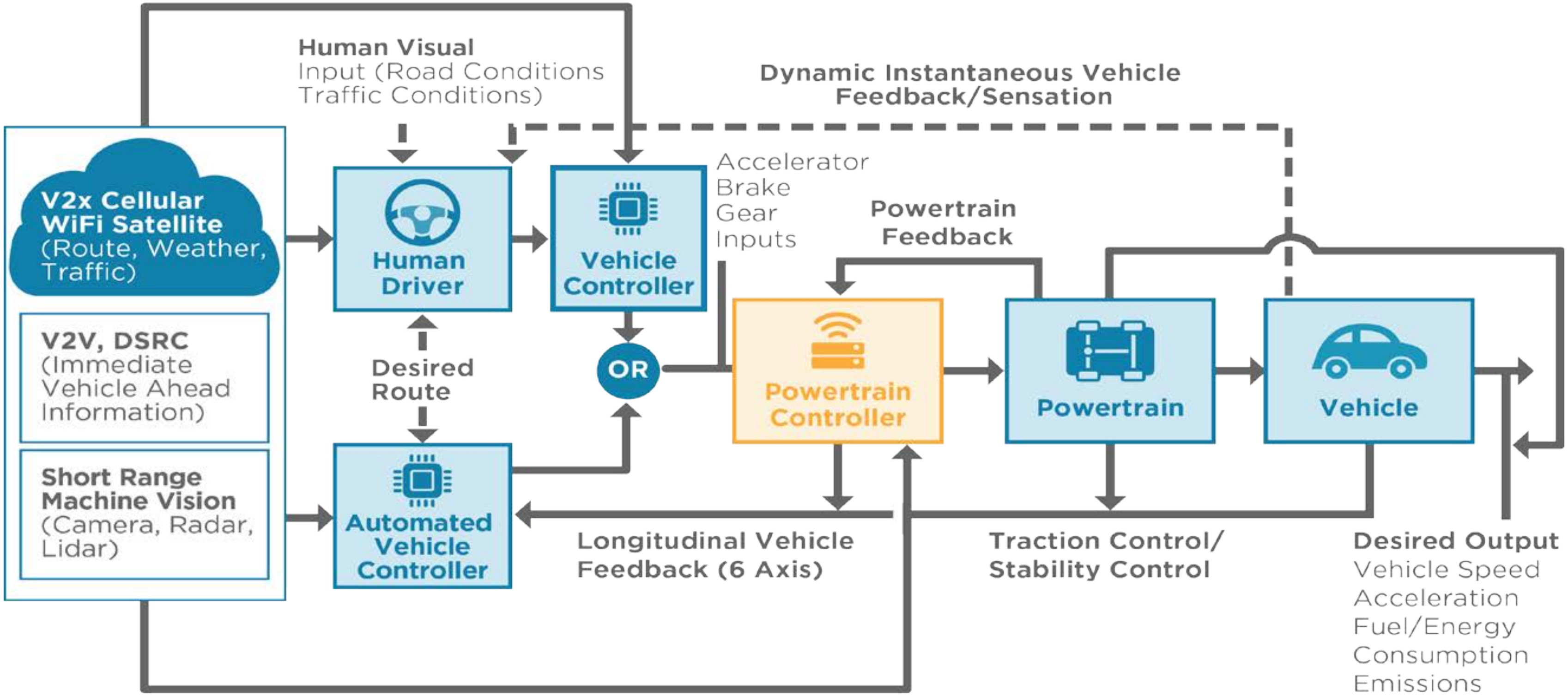


Powertrain Optimization

NEXTCAR

Program vision is to maximize energy efficiency through a cooperative effort from all communities including Transportation, Vehicles and Powertrain

Future Powertrain and Vehicle Control with NEXTCAR

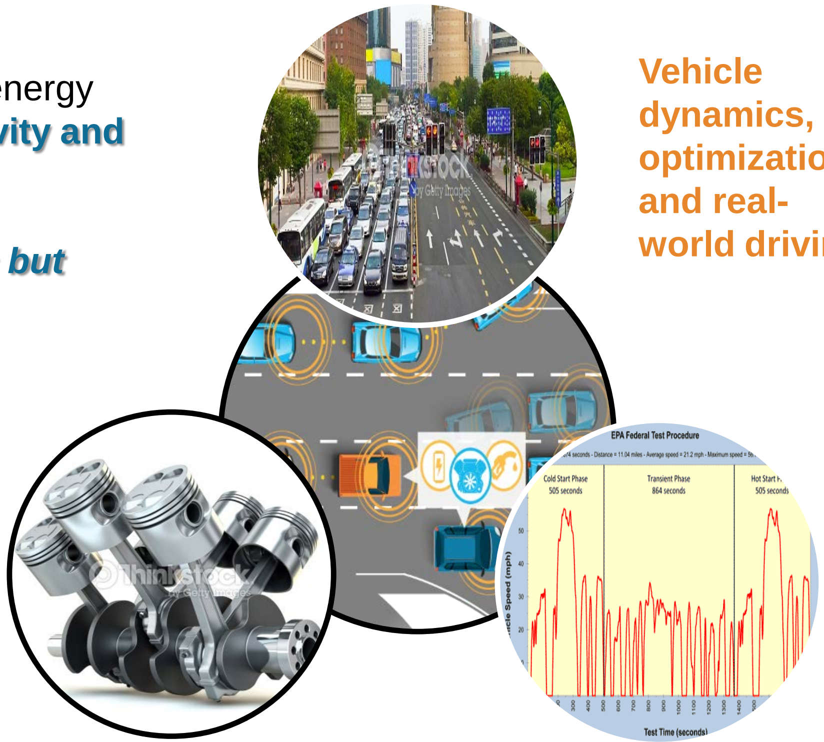


NEXTCAR: Engaging the Powertrain, Vehicle and Transportation Communities

'Bridging the gap' to reduce vehicle energy consumption by harnessing **Connectivity and Vehicle Automation.**

ARPA-E's approach is fuel-agnostic but certainly not energy-agnostic!

Vehicle dynamics, optimization and real-world driving.

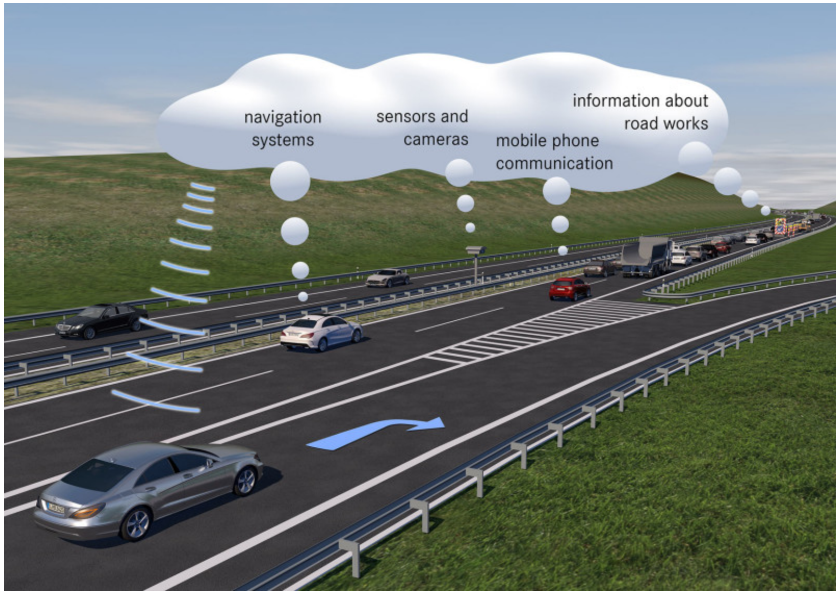


Powertrain control and optimization.

Regulatory fuel economy and emissions.

ARPA-E's NEXTCAR Vision – improving the energy efficiency of our future vehicles through research, development and commercialization.

- What if a vehicle had **perfect information** about
  - Its route and topography
  - Environmental conditions
  - Traffic conditions
  - Traffic behavior
  - Condition of its powertrain and after treatment systems (if any)
  - The quality of its fuel (if used)
  - ……and everything else
- And it **cooperates** with all the vehicles around it in order to reduce its energy consumption,
- With **perfect control** and optimization?



Source: Daimler

ARPA-E strives for towards commercialization of the technologies that it supports – without commercial applications, we will not see the energy efficiency improvements that we seek.

NEXTCAR Awardee Distribution

	ICVs	HEVs	PHEVs	Other
LD	• General Motors	• Ohio State University	• University of Delaware • Michigan Tech. University • University of California – Berkeley • Southwest Research Institute	• University of Michigan
MD		• University of Minnesota	• University of California Riverside	
HD	• Penn State University • Purdue University			

Green - Gasoline
Blue - Diesel
Yellow - Natural Gas

PROJECT DESCRIPTIONS

General Motors LLC – Detroit, MI

InfoRich Vehicle Dynamics & Powertrain Controls – $4,200,000

General Motors (GM) and their team will develop and incorporate innovative, predictive, "InfoRich" vehicle dynamic and powertrain (VD&PT) technologies for conventional internal combustion engine vehicles in four application areas: approach to a stopping event, departing from a stopping event, travel routing to maximize energy efficiency, and intelligent cruising that takes into account upcoming road and speed conditions. The GM team draws on experience in engine technologies and connected and autonomous vehicles to expedite the project development process.

Michigan Technological University – Houghton, MI

Connected and Automated Control for Vehicle Dynamics and Powertrain Operation on a Light-Duty Multi-Mode Plug-in Hybrid Electric Vehicle – $2,801,390

The Michigan Technological University team and its partners will develop a mobile connected cloud computing center, a vehicle dynamics and powertrain (VD&PT) model-based predictive controller (MPC) using real-time connected vehicle (V2X) data, traffic modeling, predictive speed, and eco-routing to improve the energy efficiency of plug-in hybrid electric vehicles (PHEVs). Key innovations include the development and implementation of the MPC controller, a connected and automated traffic simulation system to provide optimal eco-routing and speed profiles, a real-time virtual toolkit for developing and optimizing VD&PT control strategies, and the integration of a mobile laboratory for on-the-fly traffic simulation.

University of Delaware – Newark, DE

Ultimately Transformed and Optimized Powertrain Integrated with Automated and Novel Vehicular and Highway Connectivity Leveraged for Efficiency – $3,357,191

The University of Delaware team and its partners seek to develop and implement control technologies to exploit connectivity between vehicles and infrastructure to optimize concurrently vehicle-level and powertrain-level operations. The project will use a plug-in hybrid electric vehicle (PHEV) to achieve the following: compute optimal routing to bypass bottlenecks, accidents, special events, and other conditions that affect traffic flow; accelerate and decelerate optimally based on traffic conditions and the state of the surrounding roads; and optimize on-board the efficiency of the powertrain.

The Ohio State University – Columbus, OH

Fuel Economy Optimization with Dynamic Skip Fire in a Connected Vehicle – $5,000,000

The Ohio State University team with its partners will develop a transformational vehicle dynamics and powertrain (VD&PT) controls solution that leverages a novel ignition and air-management control technology to significantly improve vehicle energy efficiency. This solution comprises a unique combination of engine controls and hardware, enabling selective fuel-efficient cylinder deactivation at any time. The vehicle will be further augmented with a hybrid-electric system to broaden the engine control technology operating range. The powertrain control system will take advantage of connectivity and level 2 automation by using knowledge of the upcoming driving environment to maximize vehicle energy efficiency for a range of driving conditions. Vehicle demonstration will leverage the Smart City infrastructure in Columbus.

The Pennsylvania State University – State College, PA

Maximizing Vehicle Fuel Economy Through the Real-Time, Collaborative, and Predictive Co-Optimization of Routing, Speed, and Powertrain Control – $3,000,000

The Pennsylvania State University team aims to develop a comprehensive VD&PT system that will operate in a tightly integrated manner to improve vehicle energy efficiency for a heavy-duty diesel truck. Key innovations include using V2V and V2I communications to anticipate traffic congestion and signals; developing technologies for coordinated activities like truck platooning and coordinated intersection arrival and departures; optimizing vehicle routing and speed trajectories; and optimizing powertrain operation including engine start/stop decisions, cylinder deactivation, driveline engagement and disengagement, and gear shifting.

Purdue University – West Lafayette, IN

Enabling High-Efficiency Operation through Next-Generation Control Systems Development for Connected and Automated Class 8 Trucks – $5,000,000

Purdue University, together with its partners, has a multi-pronged approach for the implementation of their heavy-duty diesel truck project, focusing on concepts including: transmission and engine optimization; more efficient maintenance of exhaust after-treatment systems using look-ahead information; cloud-based remote engine and transmission recalibration; cloud-based engine and transmission control; and efficient truck platooning. The most promising strategies will be evaluated and refined using a phased approach relying on a combination of simulations, development and real-world testing.

University of California, Berkeley – Berkeley, CA

Predictive Data-Driven Vehicle Dynamics and Powertrain Control: from ECU to the Cloud – $3,330,000

The University of California, Berkeley team and its partners will develop an innovative VD&PT control architecture based on a predictive and data-driven approach, which will optimize PHEV performance in real-world conditions, and facilitate efficient departure at intersections, predictive cruise and speed profiles, and learning-based eco-routing and tuning. The team's proposed VD&PT control architecture will operate in a coordinated manner over short-, medium-, and long-term targets while being optimized in real time, based on the predicted behavior of the vehicle and inputs from the surrounding environment. The system will also crowdsource real-time and historical data on drivers' origins and destinations, traffic conditions, infrastructure, road grade, and road curvature to improve individual vehicle operating efficiency.

University of California, Riverside – Riverside, CA

An Innovative Vehicle-Powertrain Eco-Operation System for Efficient Plug-in Hybrid Electric Buses – $2,800,000

The University of California, Riverside team will design, develop, and test an innovative vehicle-powertrain eco- operation system for natural-gas-fueled plug-in hybrid electric buses. This system will use emerging connected and automated vehicle applications like predictive approach and departure at traffic signals, efficient adaptive cruise, and optimized stopping and accelerating from stop signs and bus stops. Since stop-and-go operation wastes a large amount of energy, optimizing these maneuvers for an urban transit bus presents significant opportunities for improving energy efficiency. Using look-ahead information on traffic and road grade, the team will optimize the powertrain operation by managing combustion engine output, electric motor output and battery state of charge in this hybrid application.

The University of Michigan – Ann Arbor, MI

Integrated Power and Thermal Management for Connected and Automated Vehicles (IPTM-CAV) Through Real-Time Adaption and Optimization – $1,500,000

The University of Michigan team will develop four technological solutions for their ARPA-E NEXTCAR project that include managing and optimizing propulsive power and auxiliary thermal load, predictive thermal management of electrified connected and automated vehicles, optimizing powertrain and exhaust after-treatment systems by anticipating future conditions, and integrating powertrain and vehicle thermal management systems. The proposed strategies are applicable for a range of vehicles powered by internal combustion engines, hybrid-electric, plug-in hybrid, and all-electric powertrains.

University of Minnesota – Minneapolis, MN

Cloud Connected Delivery Vehicles: Boosting Energy Efficiency Using Physics-Aware Spatiotemporal Data Analytics and Real-Time Powertrain Control – $1,400,000

The University of Minnesota team and its partners seek to improve the energy efficiency of medium-duty delivery vehicles through real-time powertrain optimization using two-way vehicle-to-cloud (V2C) connectivity. Large delivery fleet operators already use extensive data analytics to assign routes for minimizing energy consumption. The project team will further improve the energy efficiency of their series hybrid-electric vehicle by optimizing battery state of charge and engine operating strategy in coordination with intelligent eco-routing. Using cloud connectivity, the vehicle will periodically download the most-efficient powertrain calibrations based on external data like traffic and weather collected while the vehicle is en route.

Southwest Research Institute – San Antonio, TX

Model Predictive Control for Energy-Efficient Maneuvering of Connected and Automated Vehicles – $2,900,000

The Southwest Research Institute (SwRI) team will outfit an internal combustion-engine vehicle with connectivity and automated controls to produce a fuel economy improvement of over 20 percent compared to the baseline vehicle. To do this, the SwRI team will develop a path planning tool that taps into vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) resources to determine future powertrain performance requirements, enabling more efficient control of the engine and transmission. Vectors for improving vehicle efficiency include automated eco-driving, improved thermal efficiency and engine down-speeding using electronic boost, engine start-stop, and powertrain optimization.

Invoicing

- Whitney White will be sending an email about ePIC and invoicing information for all awardees.
- Please pay attention to invoicing requirements!

Modeling and Simulation Software

- Autonomie
- POLARIS
  - Free licenses from Argonne National Laboratory

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Questions?

Chris Atkinson, Sc.D., Fellow ASME

Program Director, ARPA-E

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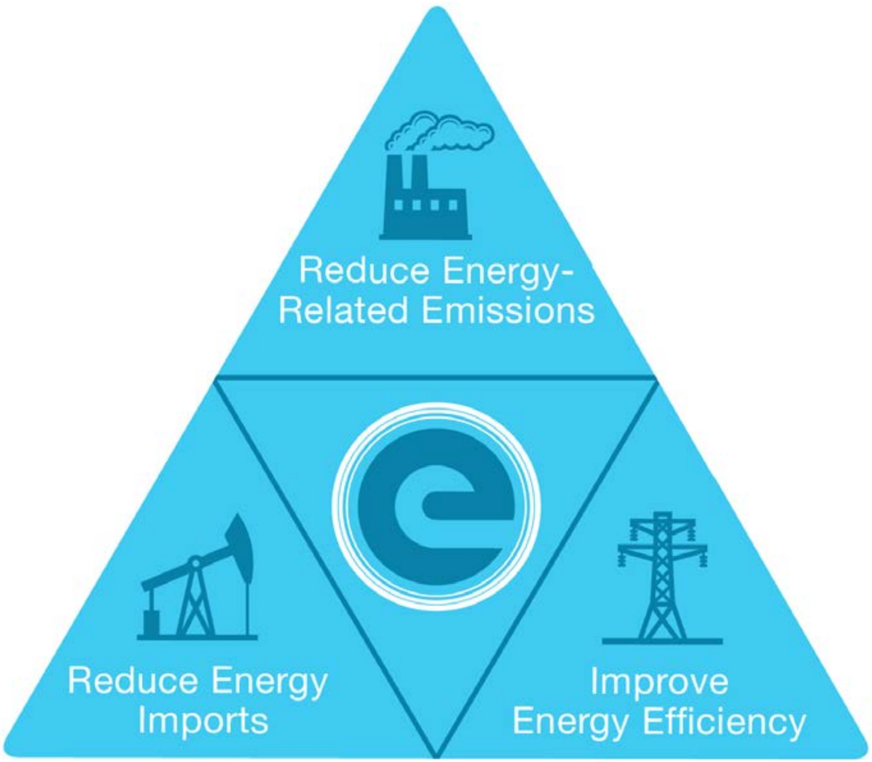
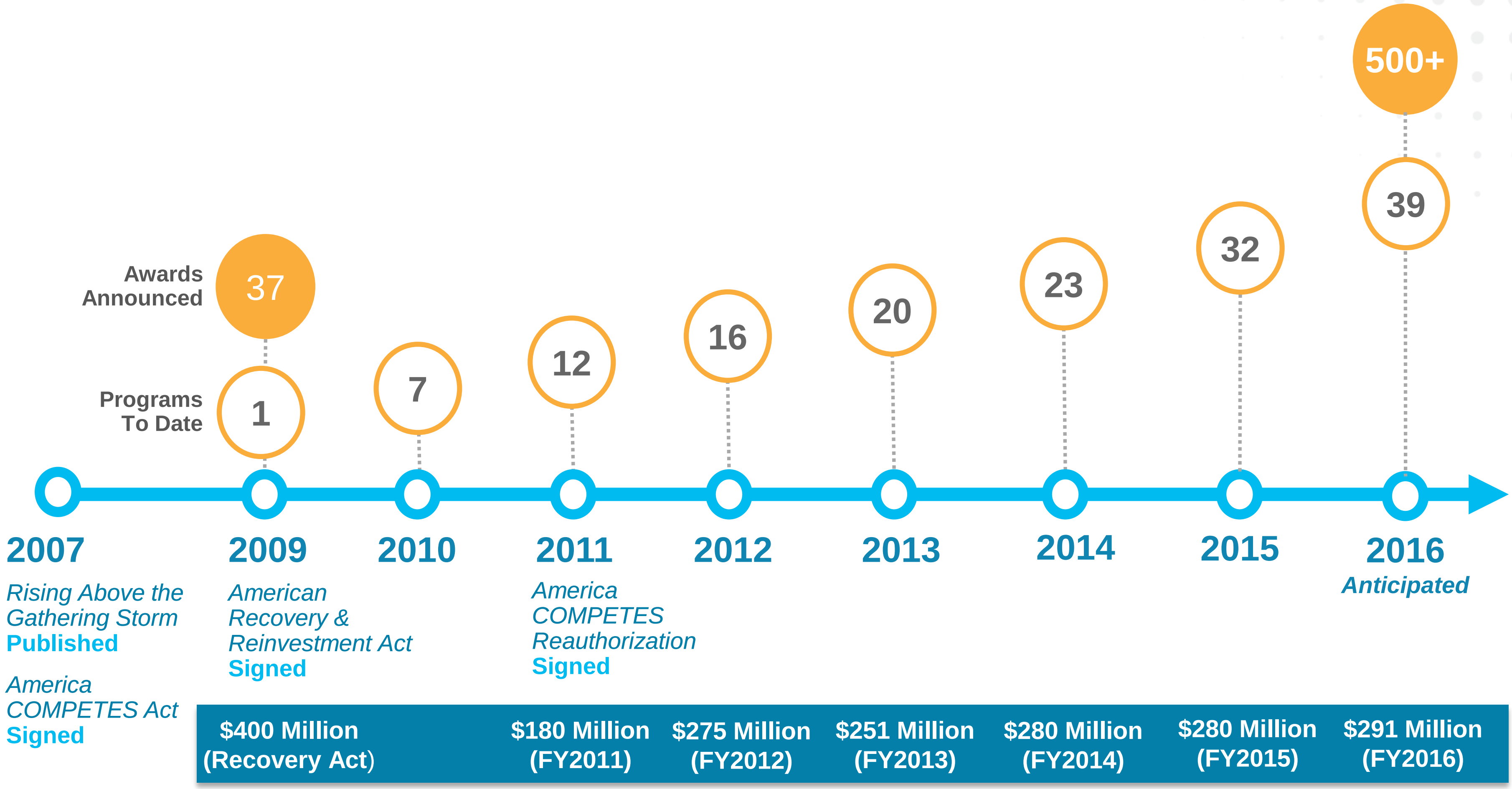
ARPA-E Mission

Catalyze the development of transformational, high-impact energy technologies



Ensure the U.S. maintains a lead in the development and deployment of advanced technologies

Evolution of ARPA-E – $1.3B in funding 500 projects in 7 years



Focused Program Portfolio