The Automotive Industry to 2025 and beyond.

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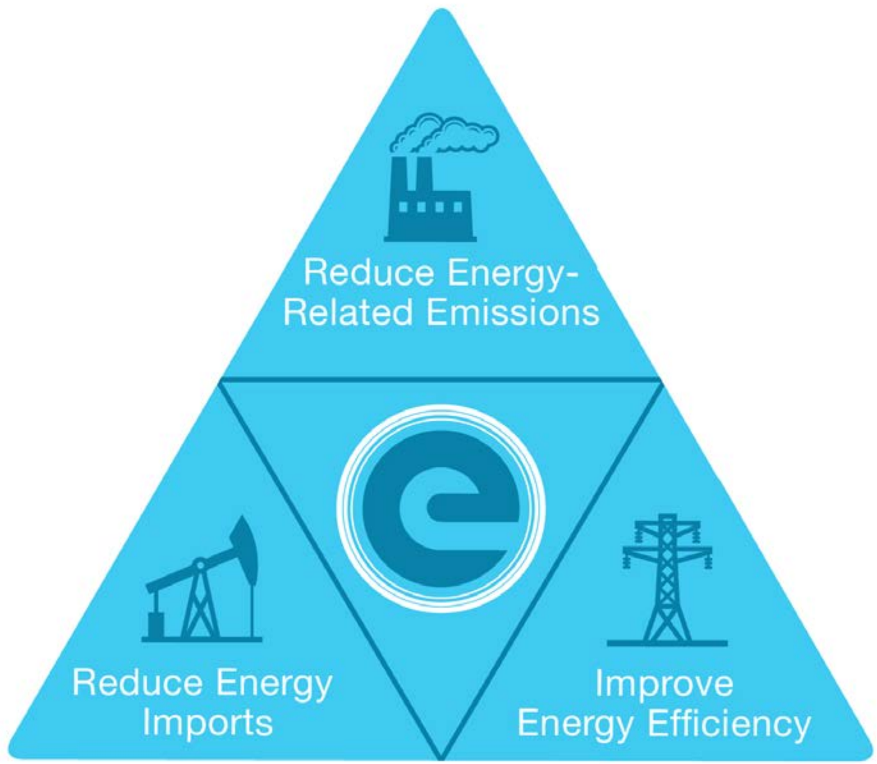
Program Director
Advanced Research Projects Agency-Energy

EPA MSTRS Meeting
October 18, 2016

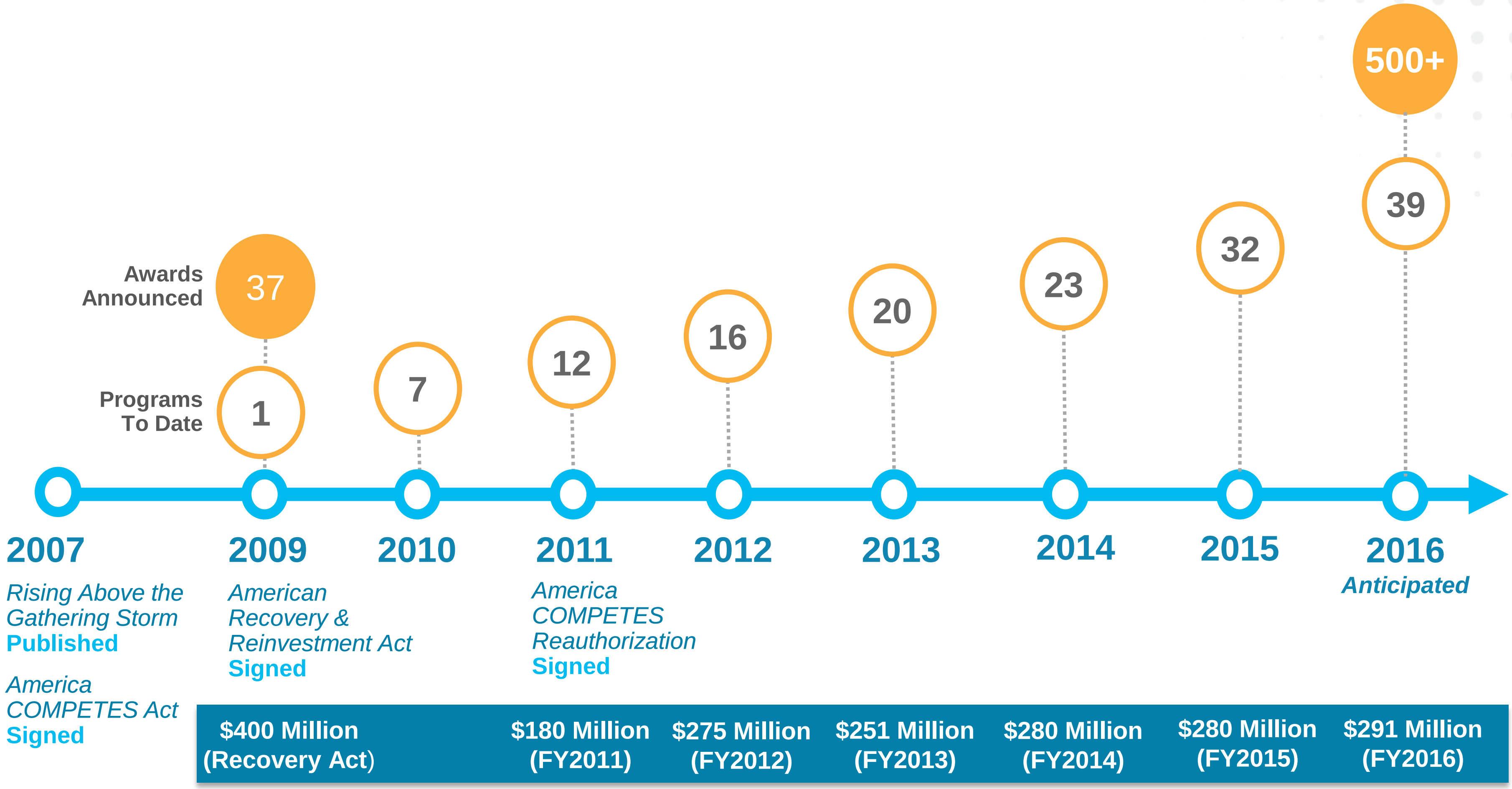
ARPA-E Mission

Catalyze the development of transformational, high-impact energy technologies



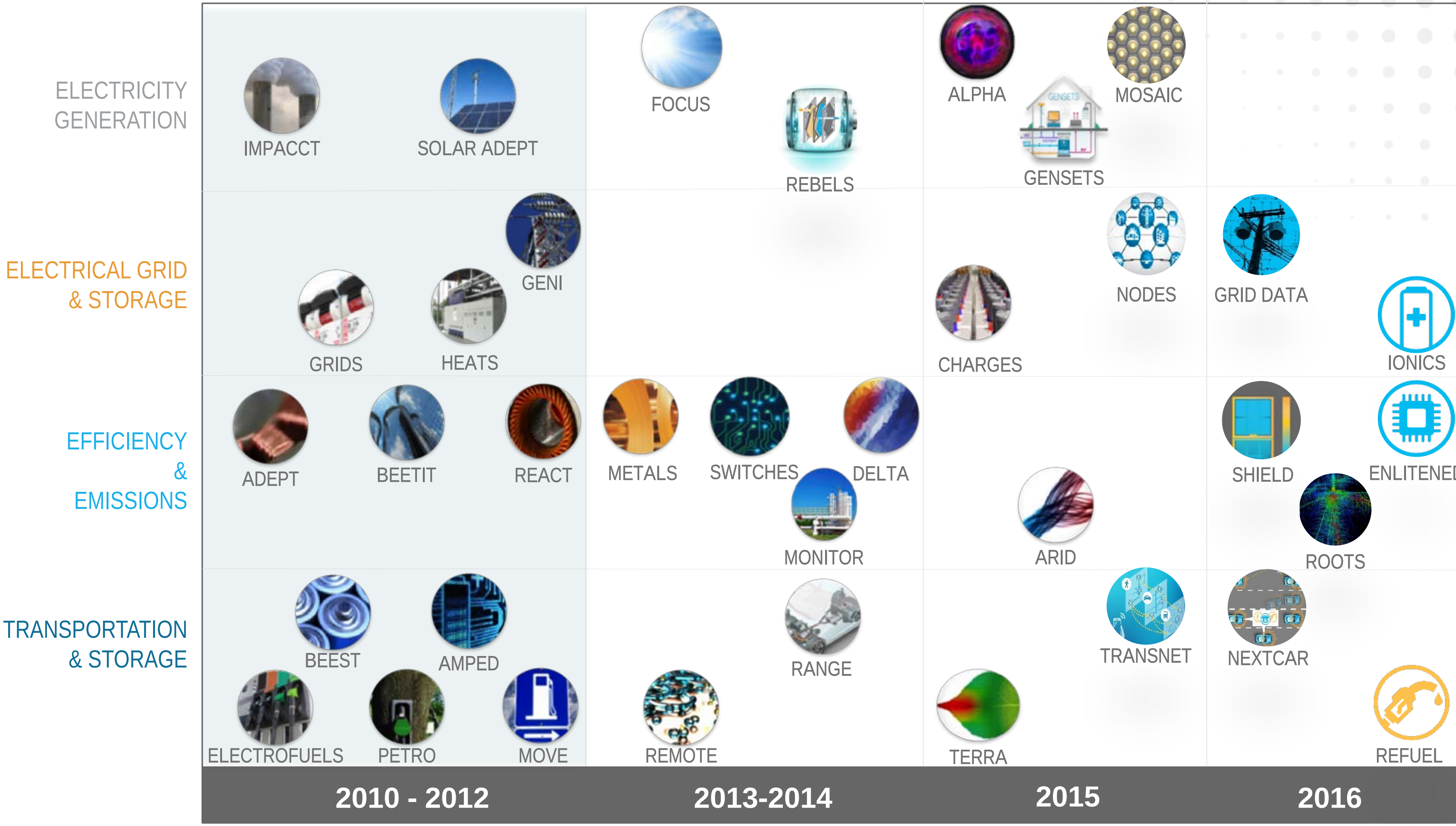
Ensure the U.S. maintains a lead in the development and deployment of advanced technologies

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



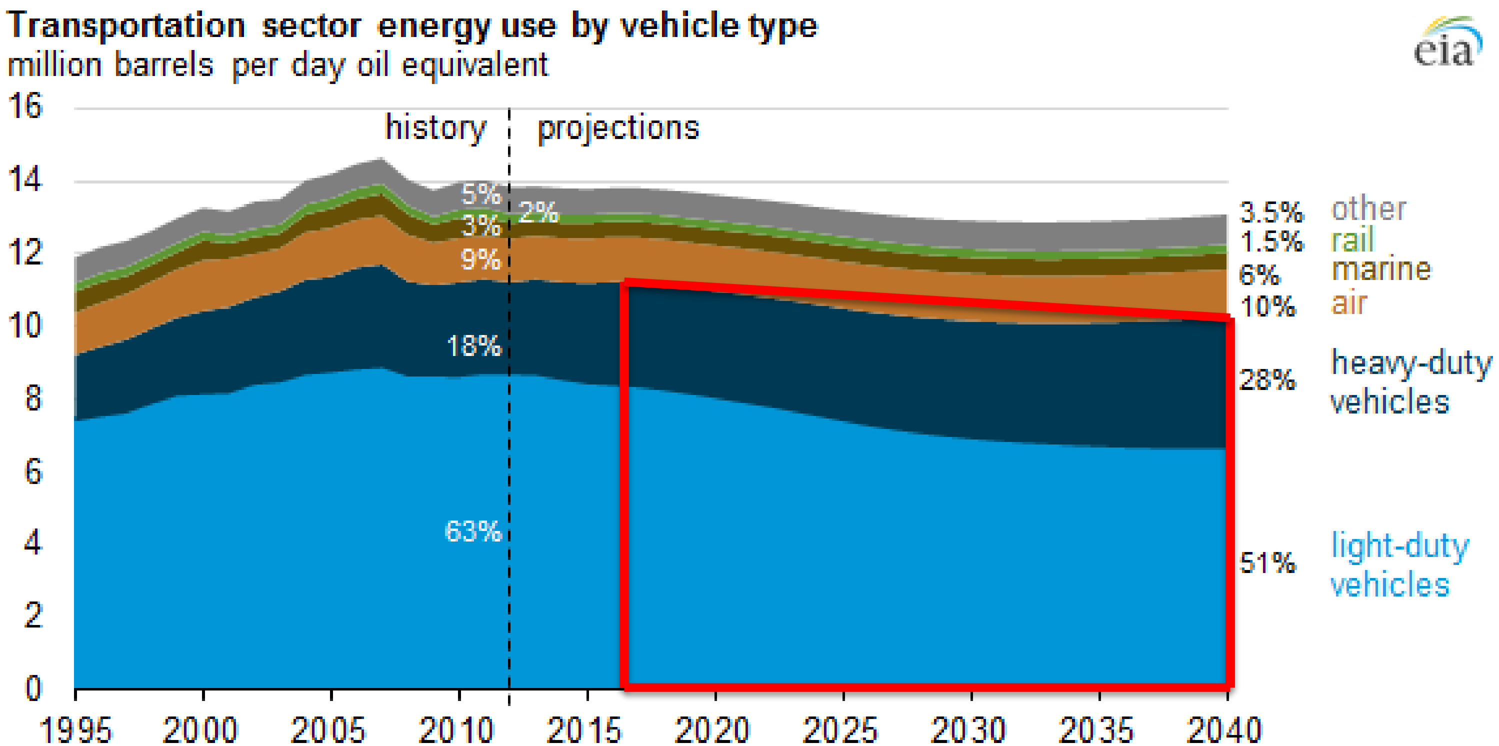
CHANGING WHAT'S POSSIBLE

Focused Program Portfolio



CHANGING WHAT'S POSSIBLE

Energy Consumed by Transportation in the US

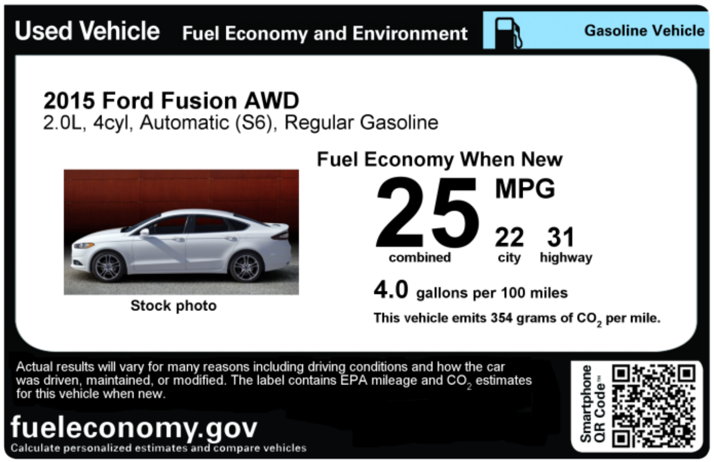


Light-, medium and heavy-duty vehicles consume **~11 million barrels per day** oil equivalent, totaling **81%** of transportation sector energy consumption, or **~23%** of the US primary energy usage.

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).

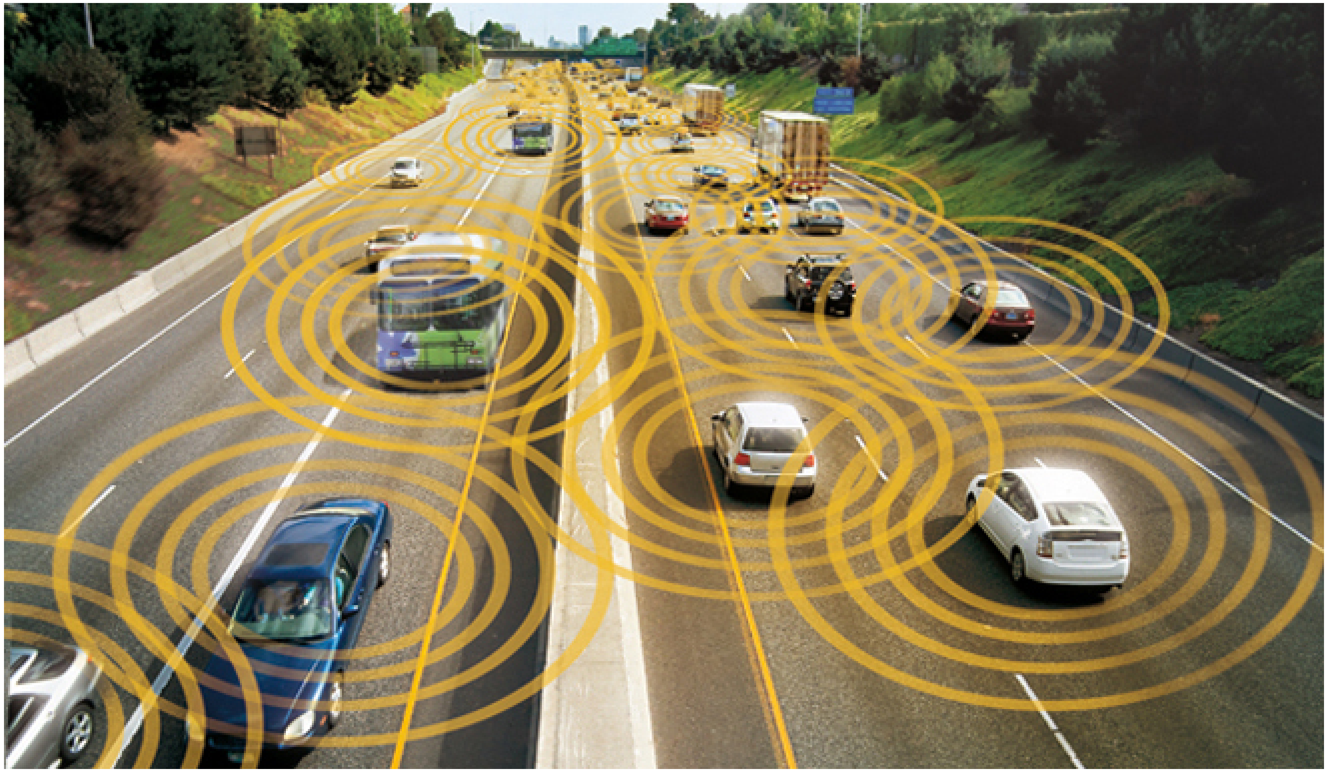


- **Heavy-duty** fuel economy regulated by EPA/NHTSA Phase 2 GHG rules.

Fuel efficiency improvements will be achieved by vehicle light-weighting, reducing aerodynamic drag and tire rolling losses, engine downsizing, boosting, improved transmissions, 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.

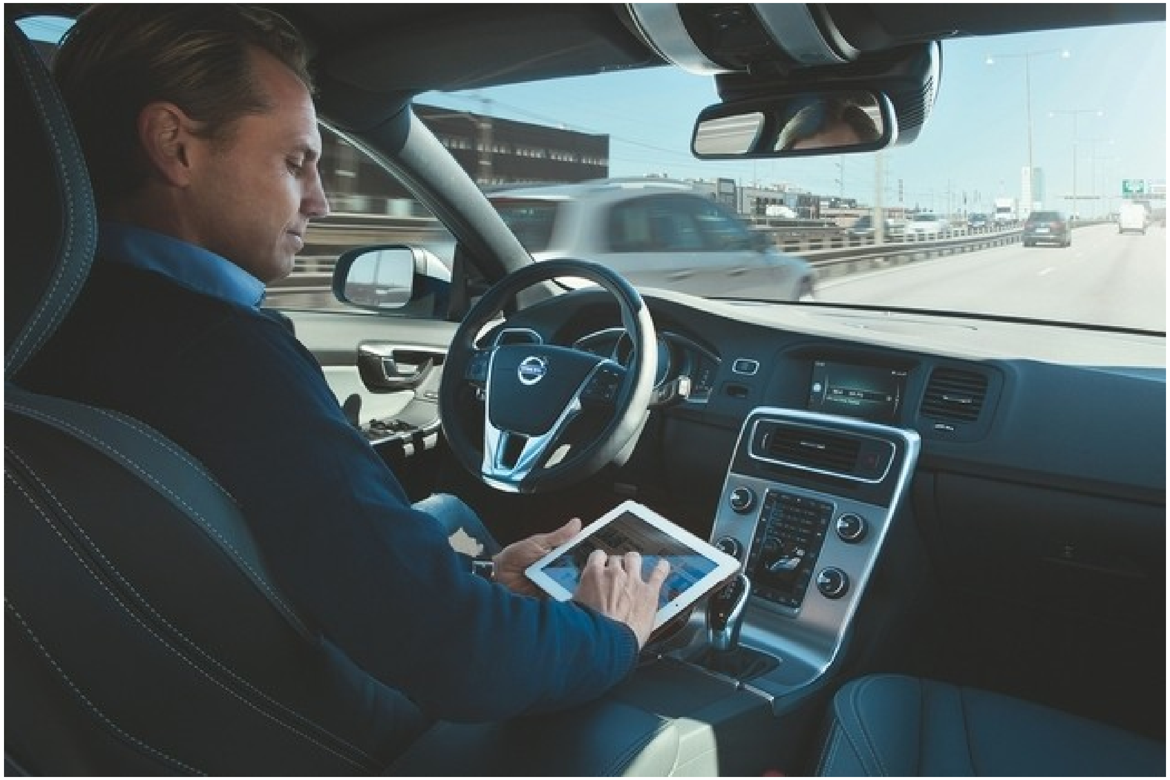


Connected Vehicles – V2V, V2I, V2X.

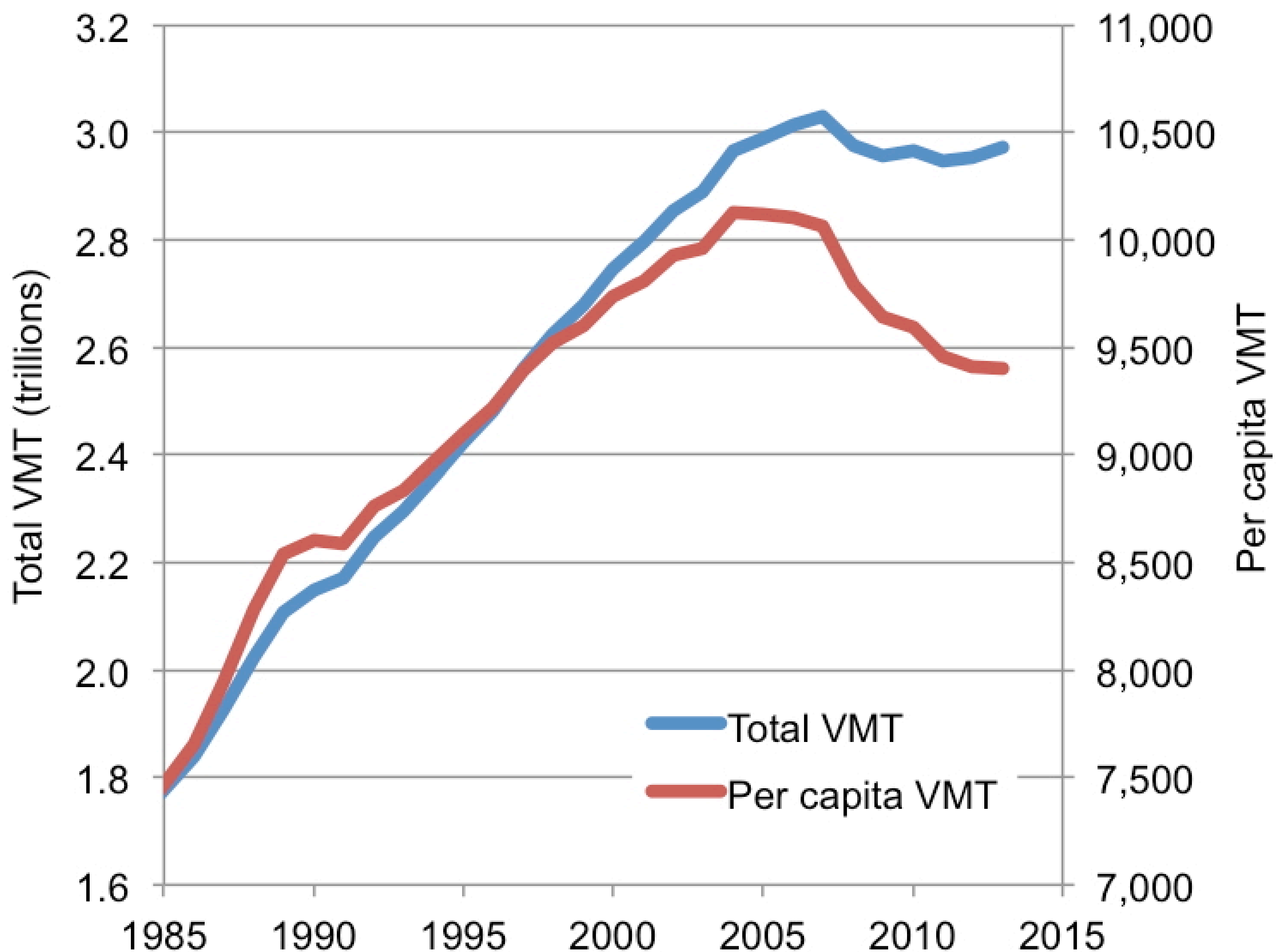
DENSO, 2015

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** automation (automated operation with a driver present) and **L4** (full automation – no driver required).



US Light-Duty Vehicle Miles Traveled – VMT



NHTSA, 2015

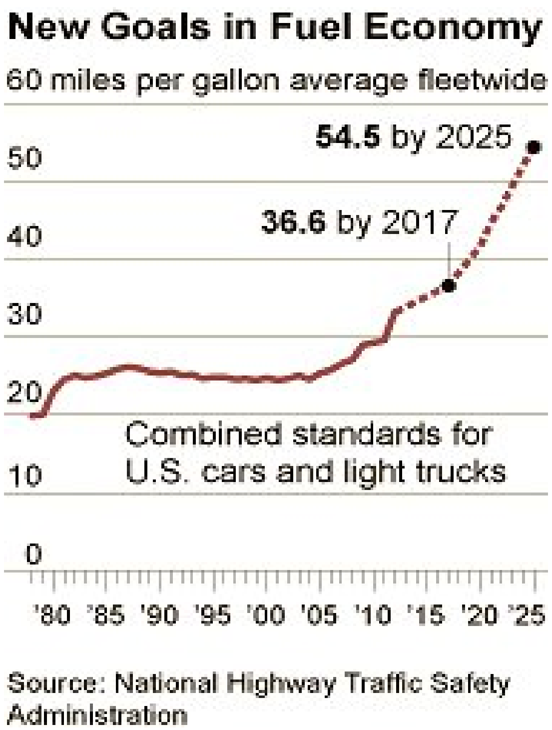
Vehicle Ownership and Economics

- Average vehicle purchase price $34,428 (Dec. 2015) (NADA).
- Average loan term 67 months (30% of all loans are 74-84 months) at $482/month with $28,936 financed (Experian).
- Average vehicle miles traveled (VMT) per year is now 12,700 (per vehicle) and 9,500 (per capita) (NHTSA).
- Car total cost of ownership is on average around **$0.60/mile** (vehicle cost, financing, insurance, fuel cost).
- Total VMT is 3.1T miles (NHTSA).

The road transportation industry is a **$3.0T** per year business in the US alone!

Sources: NHTSA, NADA, Experian.

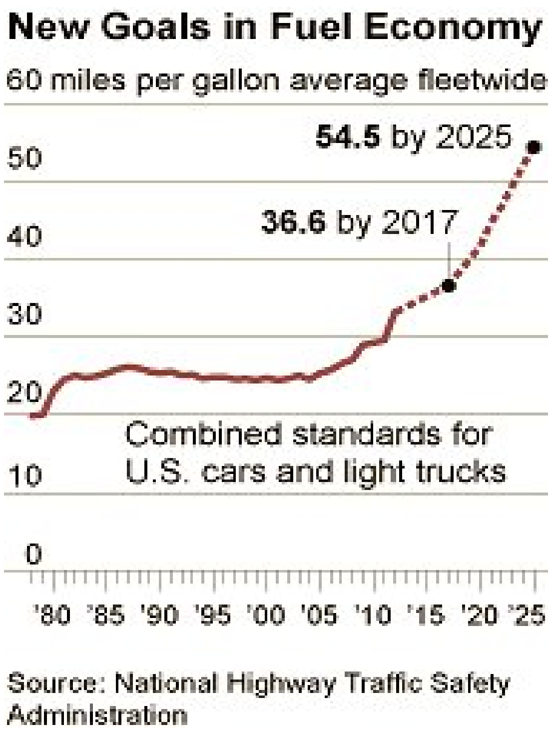
Light-Duty Vehicles – Meeting CAFE in 2025



- OEMs will meet 2025 standards through a combination of technology and fleet mix, adjusting sales of BEVs, PHEVs, HEVs, (FCVs), diesel and conventional cars and light trucks.
- They will also pursue 'extra credits' and ….

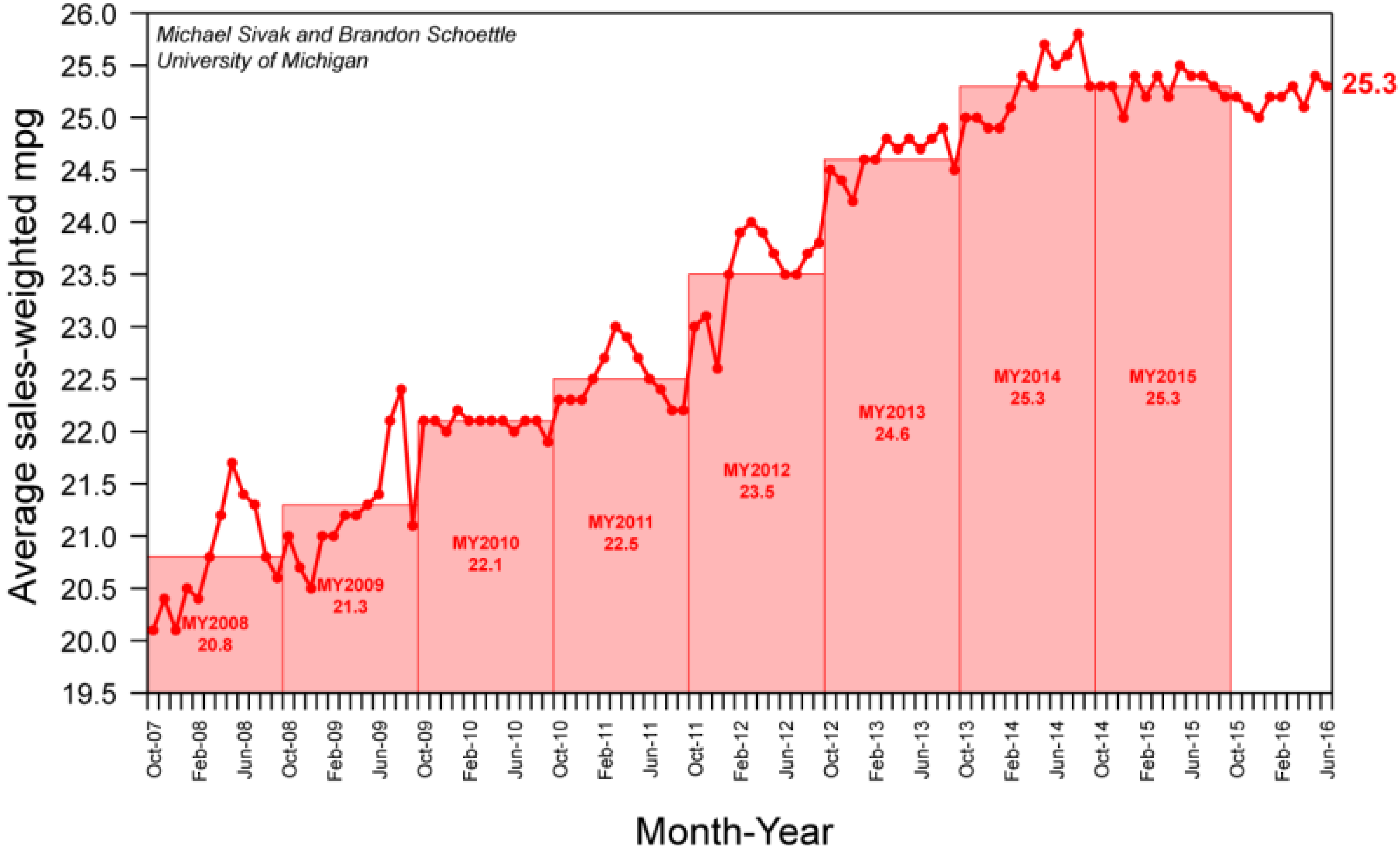
[**Remember:**
Monroney sticker fuel economy ≠ CAFE ≠ Real world fuel efficiency (calculated from fuel use and VMT)]

Light-Duty Vehicles – Meeting CAFE in 2025

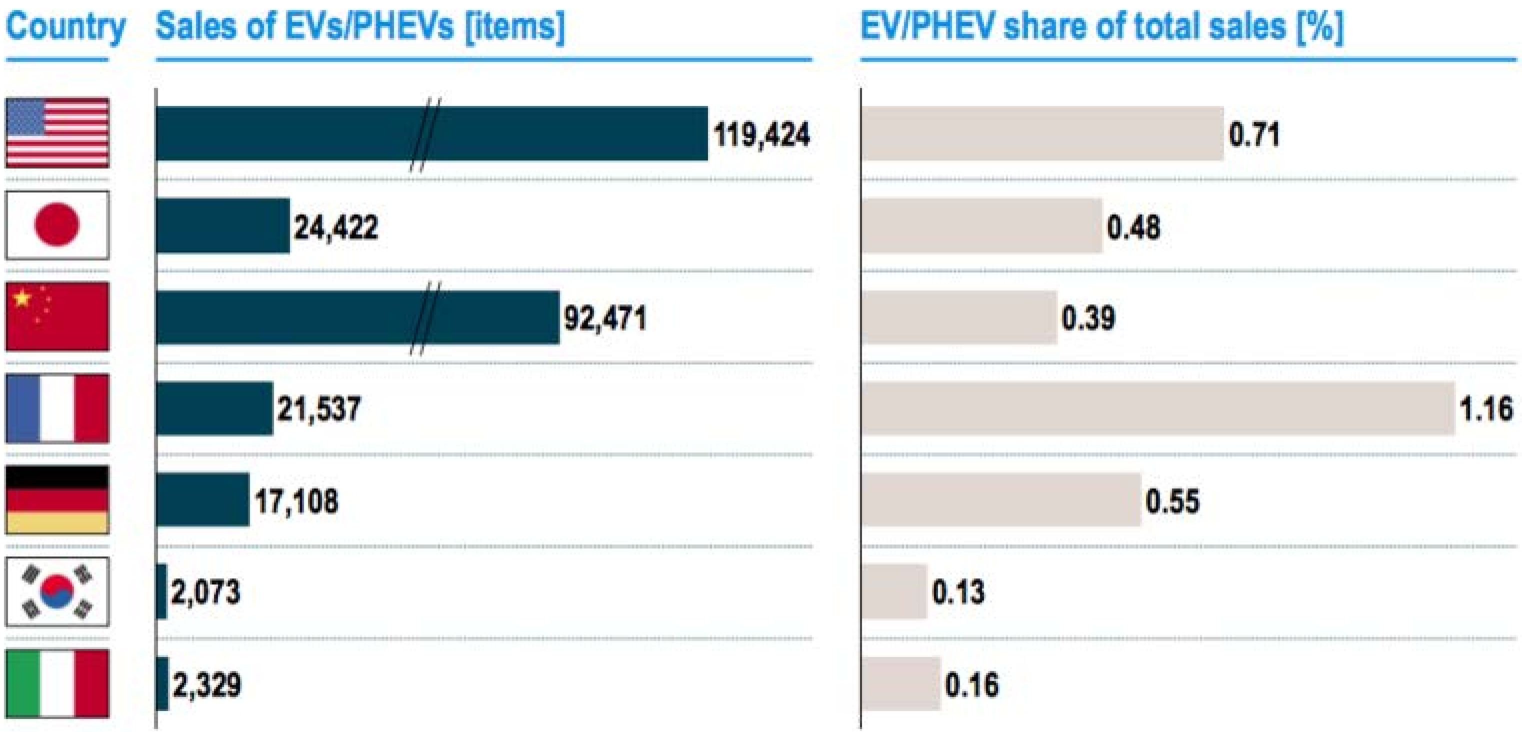


- OEMs will meet 2025 standards through a combination of technology and fleet mix, adjusting sales of BEVs, PHEVs, HEVs, (FCVs), ~~diesel~~ and conventional cars and light trucks.
- Beyond 2025……..?
- And what about the effect of **connectivity and automated vehicle operation**? This is not reflected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

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



Sales figures and market share of EVs/PHEVs, Q3 2014 to Q2 2015



Source: fka; Roland Berger

Vehicle Safety

- **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.
- The effect of **automated vehicles**?

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.

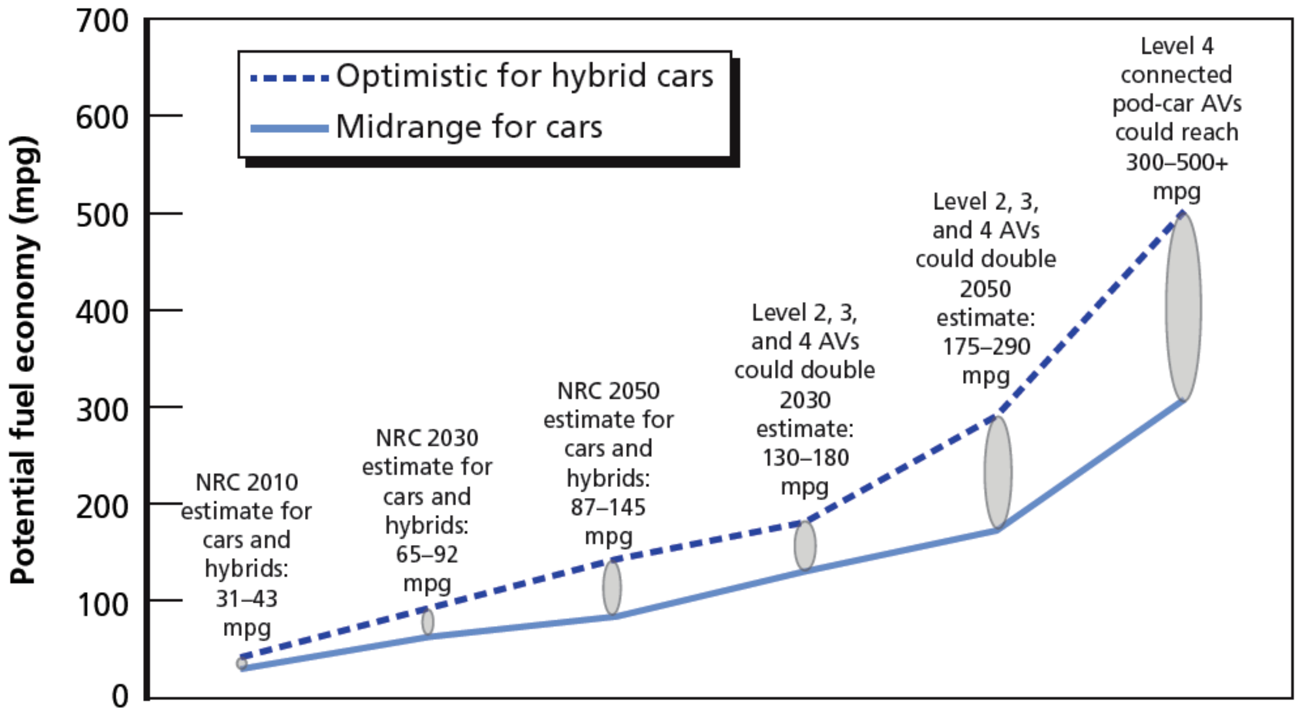
- Semi-autonomous (MB, Volvo, Subaru, Infiniti, Nissan, Honda, …) and now essentially autonomous (Tesla Autopilot [L3] and Google car [L4])

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?

Future Potential with Vehicle Autonomy?

Figure 2.6
Range of Potential Fuel Economy Improvements for Conventional, Hybrid, and Autonomous Cars



SOURCES: Analysis using data from NRC, 2013a; Folsom, 2012.

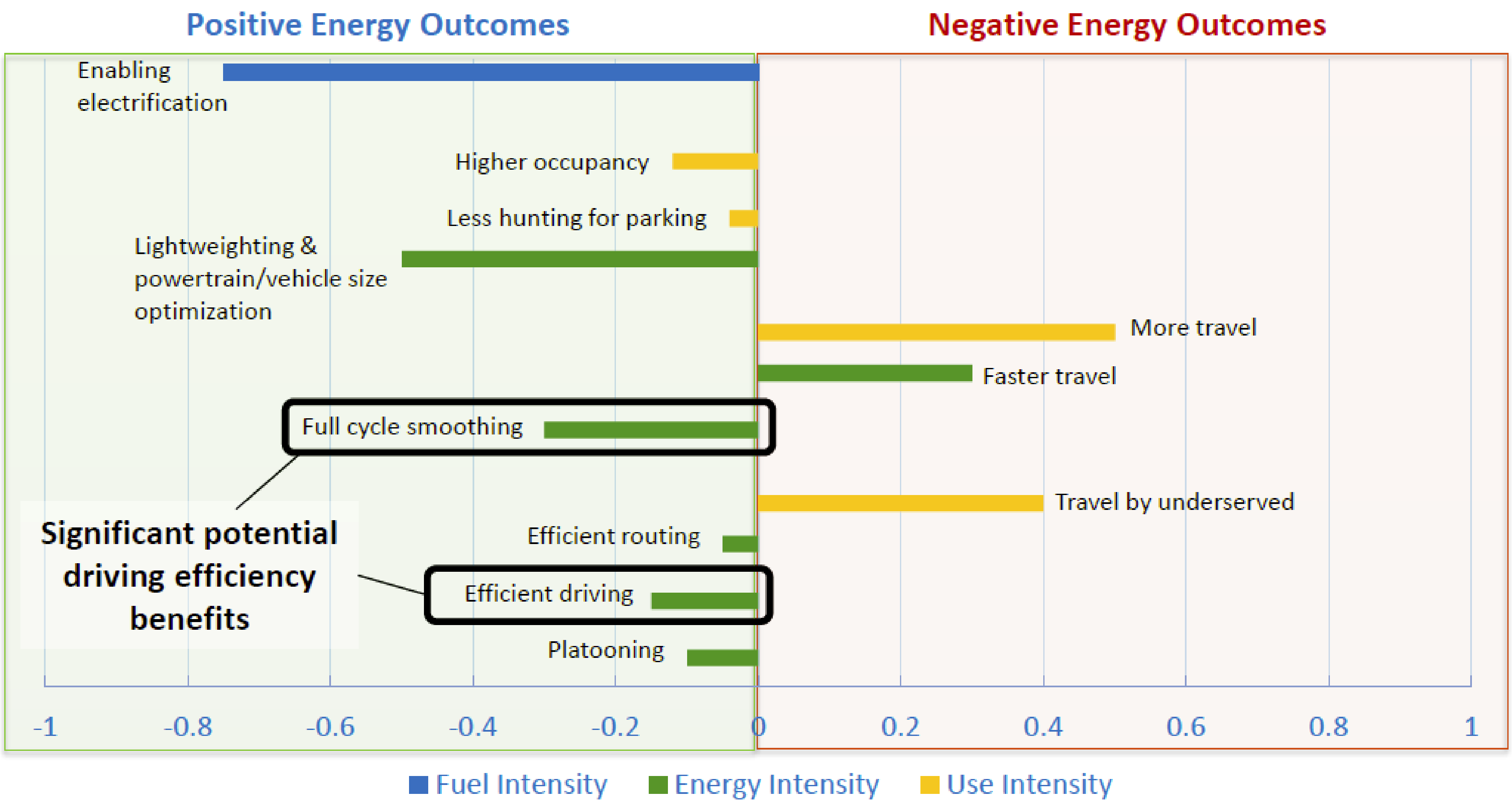
RAND *RR443-2.6*

Source: Autonomous Vehicle Technology – A Guide for Policymakers – Anderson et al., RAND Corporation, 2014

CHANGING WHAT'S POSSIBLE

Overall Energy Impacts Analysis

A few more comments on operations related impacts…



Brown, A.; Gonder, J.; Repac, B. (2014). "An Analysis of Possible Energy Impacts of Automated Vehicles." *Springer Book Chapter.*

Connectivity and Automation

- Facilitates collaborative vehicle behavior (requires V2V communication)
  - Platooning, congestion mitigation, CACC
- Facilitates interaction with infrastructure (requires V2I communication)
  - SPaT – signal phase and timing
  - Eco-approach and departure
- Facilitates congestion mitigation (requires V2X, cellular, satellite communication)
  - Eco-routing

The 10 Rules of Driving

1. **Keep right**, keep to the road, avoid on-coming traffic and stay centered within the driving lane.
2. Travel at the minimum of {the speed limit; the prevailing traffic speed; an appropriately **safe speed** dictated by road conditions, traffic and environmental conditions}.
3. **Stop** when required by traffic signals, traffic signs, traffic officers, stationary traffic ahead or obstacles or debris in the road.
4. Maintain a **safe following distance** (and do not follow too closely or run into vehicles ahead).
5. Come to a **stop, stand or park** only when safe and appropriate to do so and in a manner that will not impede traffic.
6. **Adjust speed and merge** in turn into traffic with suitable clearance at ramps, stops and merges.
7. **Take turns** at unregulated stops or merges.
8. **Avoid obstacles** (stationary and moving) with sufficient clearance to allow for directional changes (pedestrians, other road users, animals, debris, road repairs etc.)
9. **Pass only where safe** and do not obstruct or impede other (oncoming) traffic.
10. **Drive defensively** and predictively, and not selfishly (use common sense, be alert, be predictive and not merely reactive).

Fully Automated Driving – requires 100 million LOC?

Fully automated driving requires the following:

- Mapping **("refer")** – refer to pre-developed 3D maps of fixed features, together with overlays of temporary or moving obstacles for navigation.
- Machine vision **("see")** – inputs from multiple sensors including vision, radar, LIDAR, acoustics/ultrasonics to sense proximity, localization, displacement and velocity of vehicles, obstacles, roadway etc.
- Sensor and data fusion **("recognize")** – fuse inputs and data from machine vision and mapping (on and off-board) to create a comprehensive visual 'map'.
- Connectivity **("integrate")** – access additional information or data from off-board the vehicle and to coordinate with other vehicles (V2V, V2X).
- Decision making **("think")** – computational capability and advanced decision-making (not just rule-based).
- AI **("decide")** – artificial intelligence (of which 'deep learning' is a part) allows for learning and adaptation.
- Automation **("respond")** – control the vehicle in a safe and predictable fashion.

Requires the 99.9999^{th} percentile safety solution (currently at the 99^{th} percentile?

The Automotive Industry

- Is a very mature, conservative industry dominated by
  - Regulation (safety),
  - Regulation (emissions [optional] and now fuel efficiency),
  - Customer preferences,
  - While meeting strict cost and price constraints.
- To date regulation, incumbency and cost has protected the industry from extreme disruption.
- Industry has always been alert to ‘head-on’ threats
- But now there are a new generation of disrupters –
  cf. Tesla, Apple, Google, Uber, …

Will **electrification, connectivity and automated operation, and new models of ownership and usage** facilitate or accelerate the disruption of the industry?

The Disrupters

- Have incredibly deep pockets –
  - Apple has $220B in cash, which dwarfs the market capitalization of Ford ($54B), GM ($50B), VW ($63B), Tesla ($31B) and is greater than Toyota ($164B).
  - Uber (private) has a $50B value – greater than FedEx.
  - Bear in mind that the traditional automotive industry operates on very thin margins, and is the "world's greatest destroyer of capital".
- Traditional barriers to entry:
  - Regulation – Silicon Valley has never acknowledged regulation as a barrier to doing business.
  - Capital – Apple alone has 10x the capital required to succeed.
  - Engineering – not an issue with less complex powertrains (although the battery? Hence Tesla's Gigafactory).
- SV operates on its own time scales (~1-2 years vs. 6-10 years of the automotive industry).
- Tremendous market pull for high technology products.

Requirements for commercial success

Any new powertrain technology should be comparable to or better than the baseline in:

Criterion	Explanation
Power	Power density (or energy density including the fuel/energy storage capacity) ⇒ Customer acceptance
Efficiency	Fuel economy (over real-world dynamic driving) ⇒ Regulation Energy efficiency
Emissions	Regulated criteria pollutants (and now CO_2) ⇒ Regulation
Cost	Total cost of ownership (including capex and energy cost)
Reliability	Mean time between failures, maintainability
Utility	Acceleration, driveability, NVH, cold or off-cycle operation, ease of use, transparency to the user, and acceptable range
Fuel acceptability	Use a readily available fuel or energy source.

Huge Foundational Shifts in the Automotive Industry

Old Model

- Vehicle hardware as the differentiating factor
- Complex powertrain
- Long development cycles
- Human operator, stand-alone
- Single vehicle with a single user
- Owner is driver and user
- OEMs are foremost
- Tightly controlled supply chain
- “One sale, once”
- OEM profitability required or at least desired

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New Paradigm

- Software as the differentiating factor
- Simplified powertrain – electric?
- Short development cycles
- Automated operation, connected
- New models of usage – ridesharing
- New models of ownership
- Suppliers now hold the keys
- Electronics, electrics & batteries
- New models of monetization
- No requirement for immediate profitability

But be wary of non-linear thinking

- **Vehicle ownership** – there is no clear threat to the traditional model. Millennials have merely delayed purchases for several reasons (city dwellers, high debt loads, disinterest) but as soon as they move to the suburbs….
- **Vehicle purchase** – leasing and other new models will emerge.
- **Vehicle usage** – ride-sharing versus car sharing.
- **Disruption** – Uber has disrupted the taxi industry (at $1.50 to $2.00 per mile), but not the passenger car industry (with total cost of ownership at $0.60 per mile).
- **Economics** – vehicles are currently bought, sold, paid for and operated on a VMT basis. If total VMT does not decrease, it is not at all clear that sales will drop, or usage change significantly.
- **Fuel consumption** – future vehicles will be significantly more fuel efficient than today, with no other changes in regulation or economics.

The Future Vehicle Industry Landscape

- OEMs – e.g. GM, Ford, BMW….
- Ride-sharing companies – e.g. Uber, Lyft, GETT, Didi….
- “Mobility as a Service” providers.
- New ‘dark horses’.

- And so now we have
  - GM investing in Lyft (OEM+RS).
  - Uber looking to develop automated vehicles (RS=OEM).
  - Apple looking to develop an EV (‘Project Titan’) (new OEM).
  - Google developing automated vehicles (CAV OEM+mapping).
  - Ford Smart Mobility (OEM=RS).

  Just for a start…..

The Future of the OEMs

- BMW – Harald Krueger, CEO – March 16, 2016

"The iNext will cover all aspects relevant in the future: autonomous driving, digital connectivity, intelligent lightweight construction, a trendsetting interior and the next generation of electro-mobility.“

- VW will become a “new mobility company”
- Ford will become a “new mobility company”
- Toyota Research Institute - $1B for robotics research
- New alliances
  - DeepDrive – machine learning and AI – Ford, Toyota, VW, Nvidia, Qualcomm, Panasonic at UC Berkeley

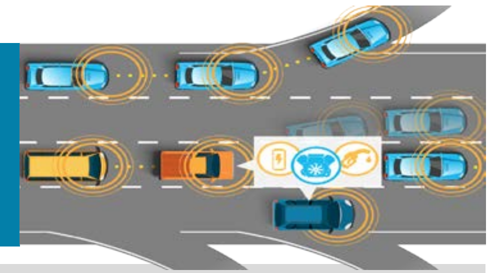
An enormous amount of activity……

The Probable Pathway to 2025 and Beyond

- **Vehicle powertrain technology** – more electrification, hybridization, downsizing, waste energy recovery, 48V systems?
- **Vehicle structures** – vehicle downsizing, weight reduction, more use of light-weight materials.
- **Vehicle ownership** – how will the 84 month ownership cycle be reconciled with 1-2 year product cycles?
- **Ride-sharing, car-sharing** – new ownership and usage models.
- **OEMs** – the center of gravity of the high-technology components of the vehicle has shifted to suppliers both old (Bosch, DENSO, Continental, Delphi) and new (Mobileye, Cruise Automation).
- **ADAS** systems will proliferate, leading to L3 automation (such as the Tesla Autopilot) being essentially standard (L3 is a suite of technologies).
- **L4-L5 automation** requires or facilitates new vehicle architectures (electrification?) but will probably be slow in penetrating the full market.
- **Regulations?**
- **The implication for energy usage** – energy usage in the LD fleet will almost certainly be reduced by 2025 and beyond (due to ongoing fleet turnover). After that timeframe, it is not clear.

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	$30 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.

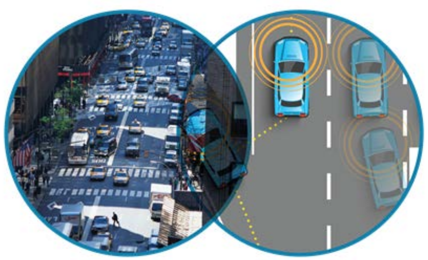
Potential Impact

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

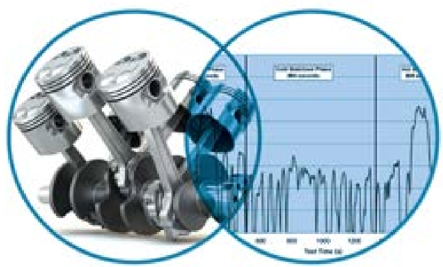
Collaborative Vehicle and Powertrain Solution

STATUS QUO

Two separate and independent efforts for improving vehicle energy efficiency



Independent Vehicle Dynamic Control

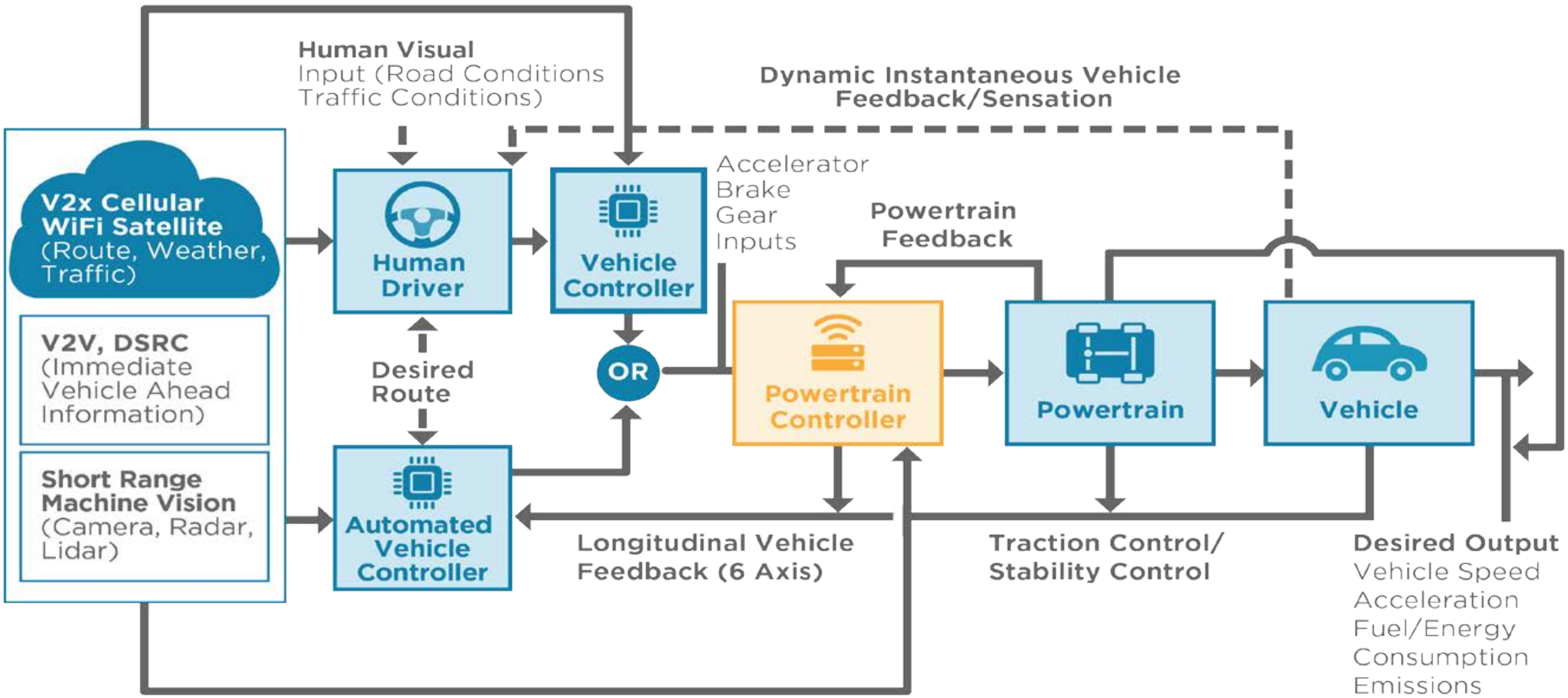


Powertrain Optimization

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

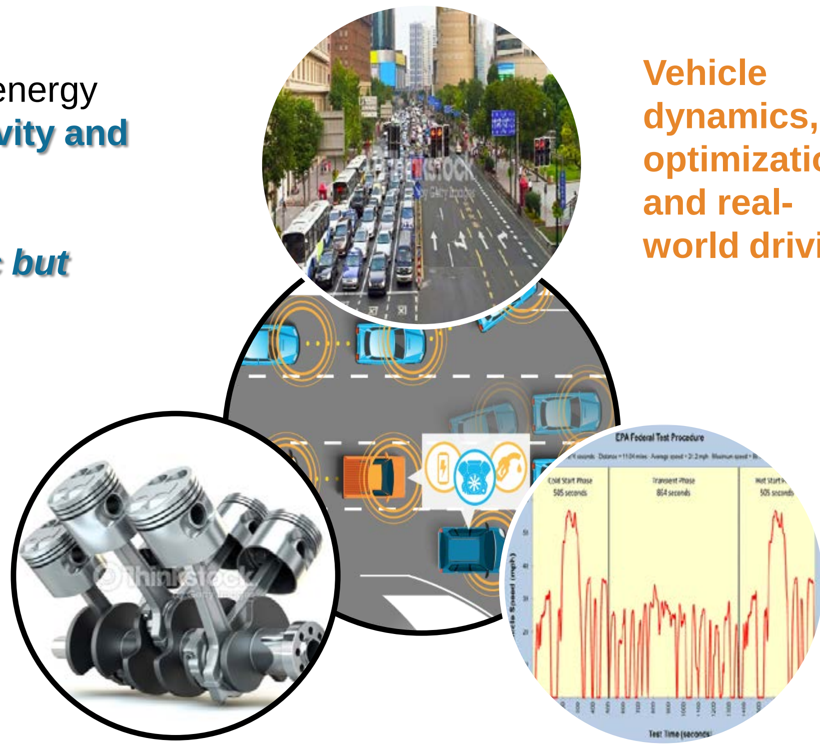


NEXTCAR: Engaging the Powertrain, Vehicle and Transportation Communities

'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.

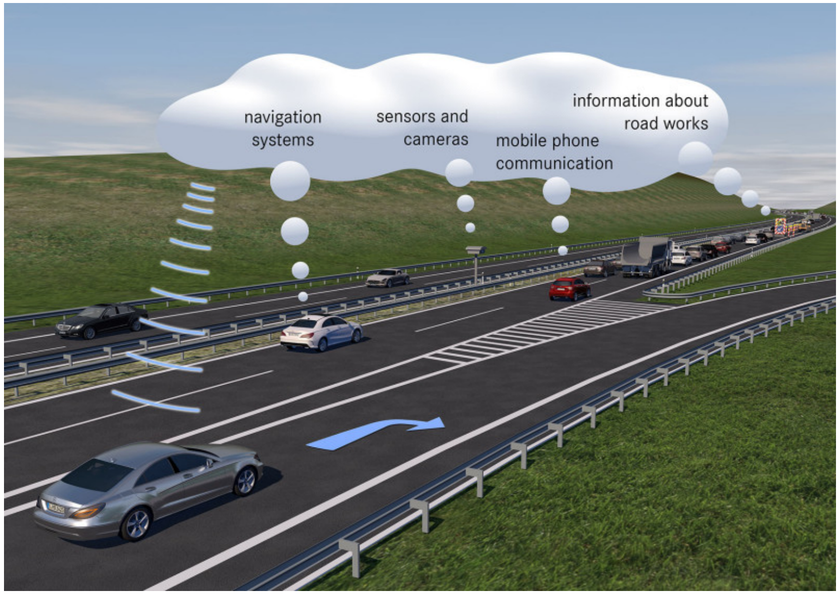


Powertrain control and optimization .

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.

Welcome to the Future.

Chris Atkinson, Sc.D.

Program Director, ARPA-E

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