The Automotive Industry to 2025 (and beyond)

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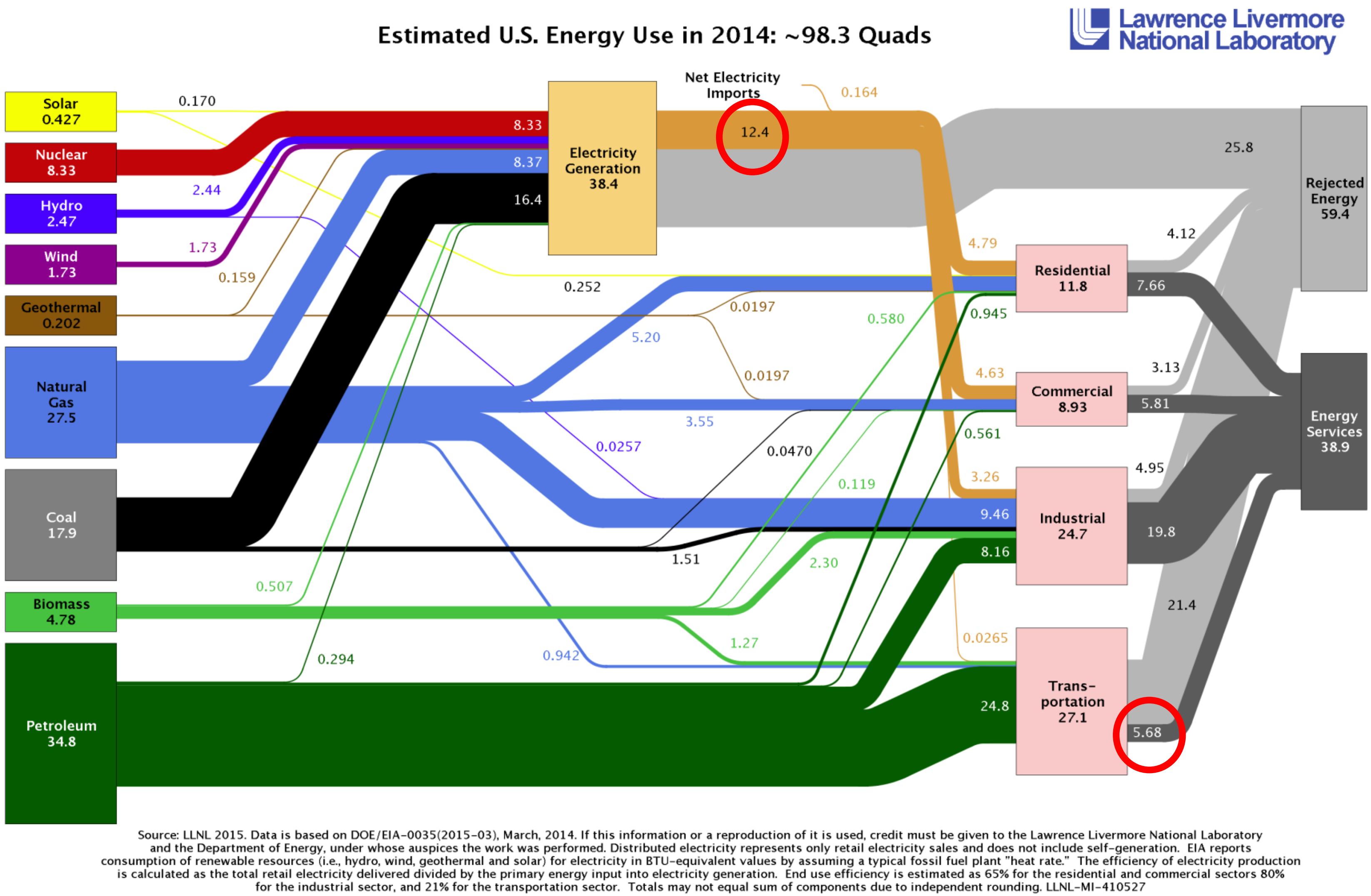
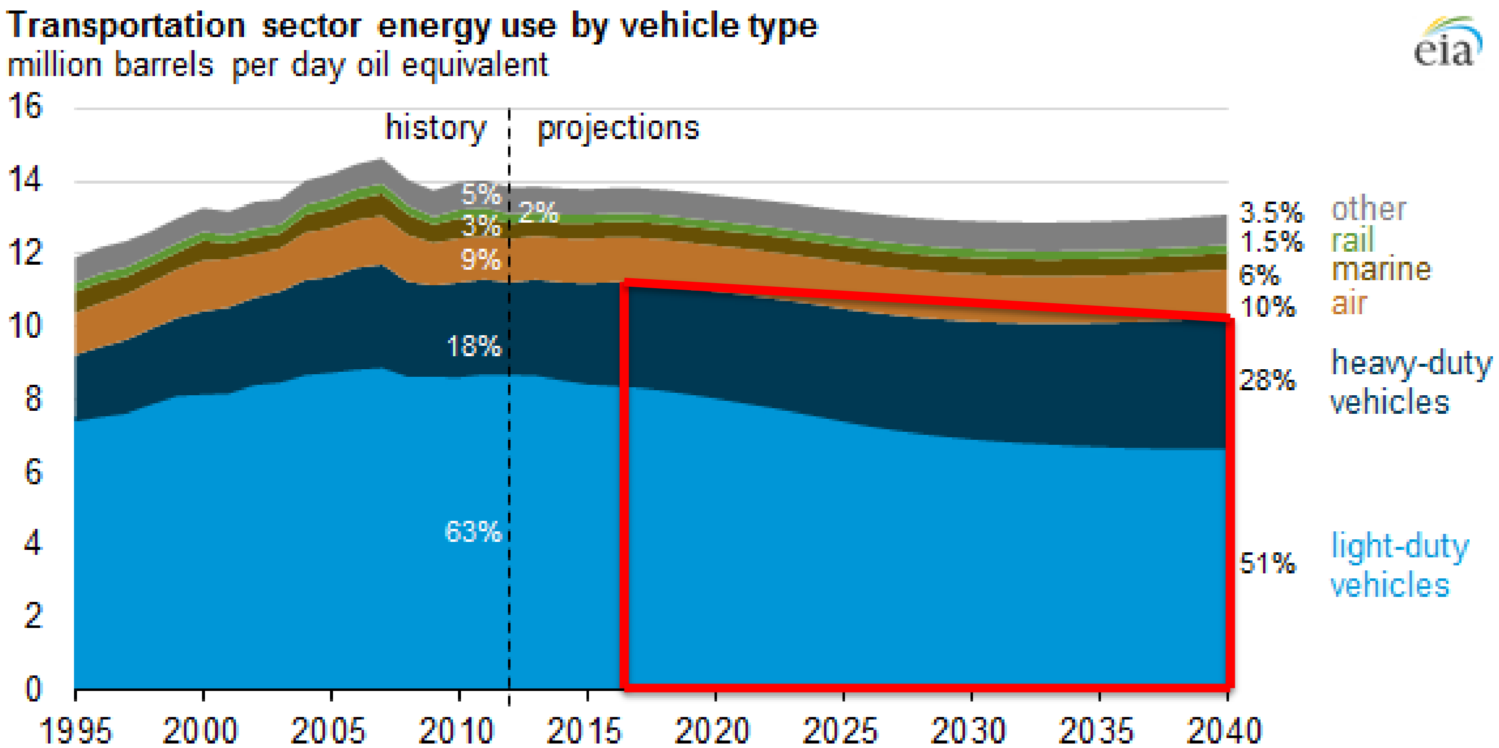
Advanced Research Projects Agency-Energy

RANGE Annual Meeting March 2016

The Obligatory Sankey Diagram



Energy Consumed by Transportation

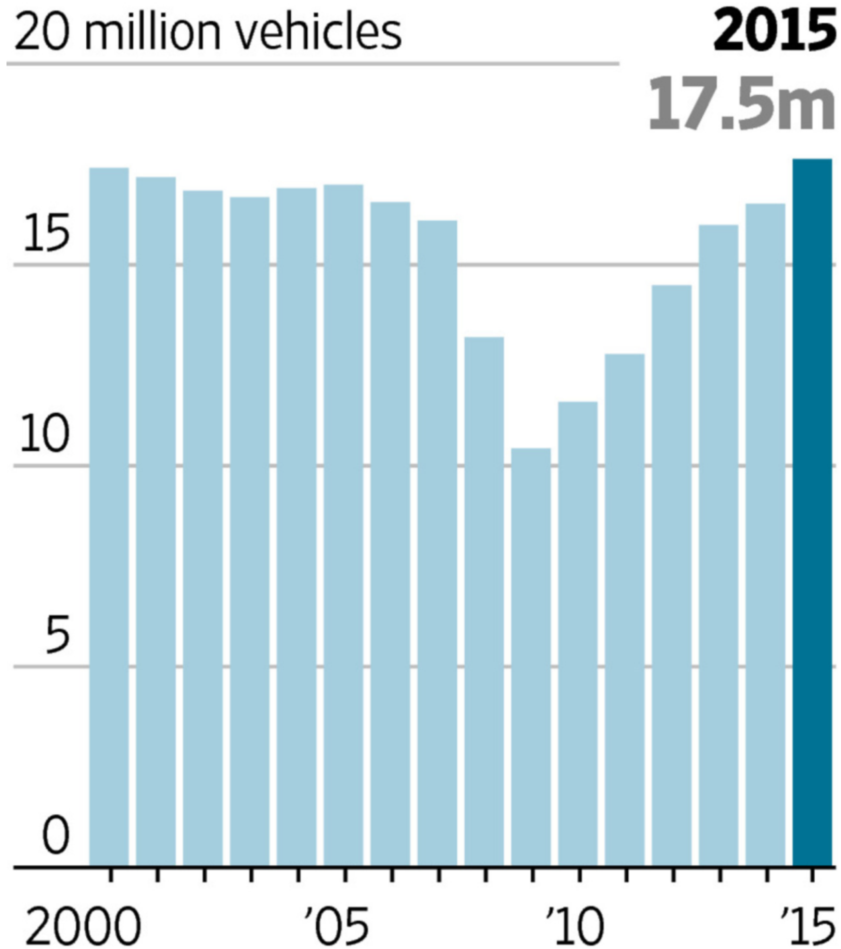


Heavy-duty and light-duty vehicles consume **~11 million barrels per day** oil equivalent, totaling **81%** of transportation sector energy consumption, or **~23%** of the US primary energy usage.

arpa·e
CHANGING WHAT'S POSSIBLE

Climb to the Top

Annual U.S. light-vehicle sales

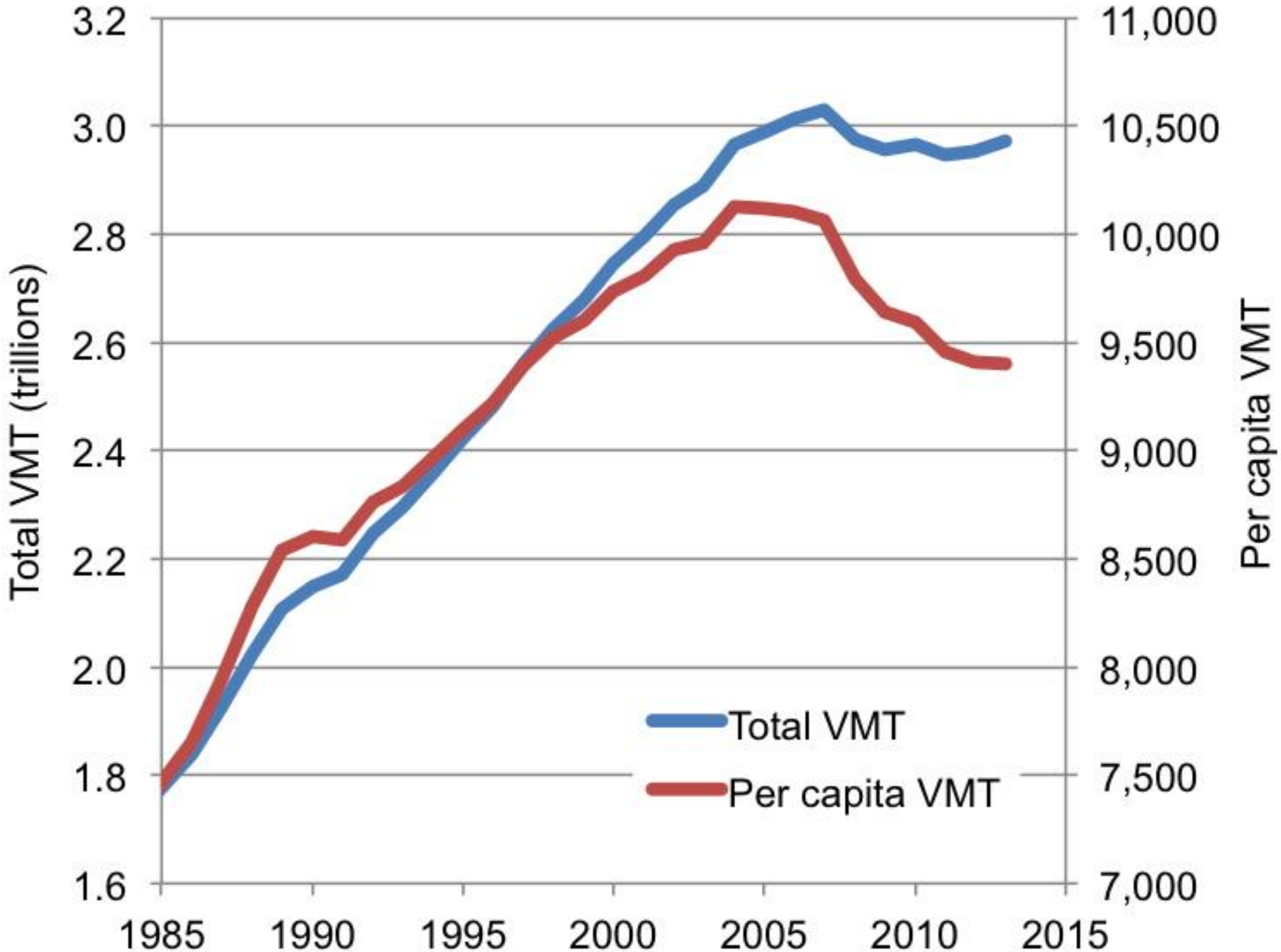


Source: Autodata

THE WALL STREET JOURNAL.

US Light-Duty Vehicle Sales – 2015

- US passenger car and light truck sales are considered a function of
  - **Household income** (steady – mean $72,641, median $51,939).
  - **Unemployment rates** (actually workforce participation) (down to 5.5%).
  - **Interest rates** (steady and low – prime rate 3.50%).
  - **Fuel prices** (down below $2.00/gal).
- 57% of sales are now pickup trucks, SUVs, crossovers and minivans.
- Record 2015 sales for Audi (202k), BMW (346k), Jeep (865k), Honda (1,409k), Hyundai (762k), Land Rover (71k), Kia (626k), Mercedes Benz (373k), Nissan (1,351k), Porsche (52k) and Subaru (583k).
- Average LD vehicle age is now 11.4 years (Polk).



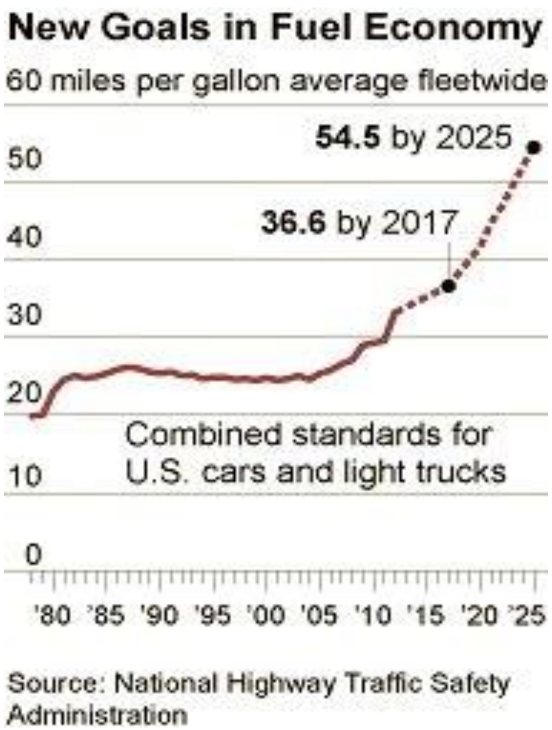
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
Total VMT (trillions)
11,000
10,500
10,000
9,500
9,000
8,500
8,000
7,500
7,000
Per capita VMT
1985
1990
1995
2000
2005
2010
2015
Total VMT
Per capita VMT

NHTSA, 2015

Vehicle Ownership and Economics

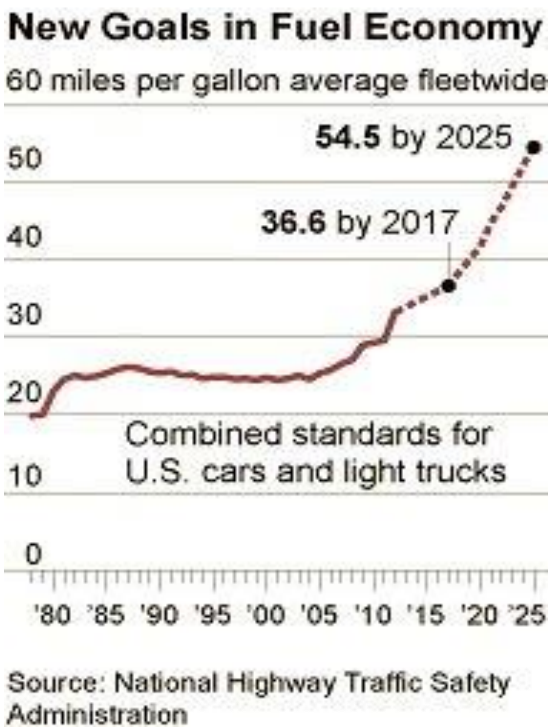
- Average vehicle purchase price $34,428 (Dec. 2015) (NADA).
- Average loan term 67 months (30% of all loans are 74-84 months) at $482/month with $28,936 financed (Experian).
- Average vehicle miles traveled (VMT) per year is now 12,700 (per vehicle) and 9,500 (per capita) (NHTSA).
- Car total cost of ownership is 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 business in the US alone!

Light-Duty Vehicles – Meeting CAFE in 2025



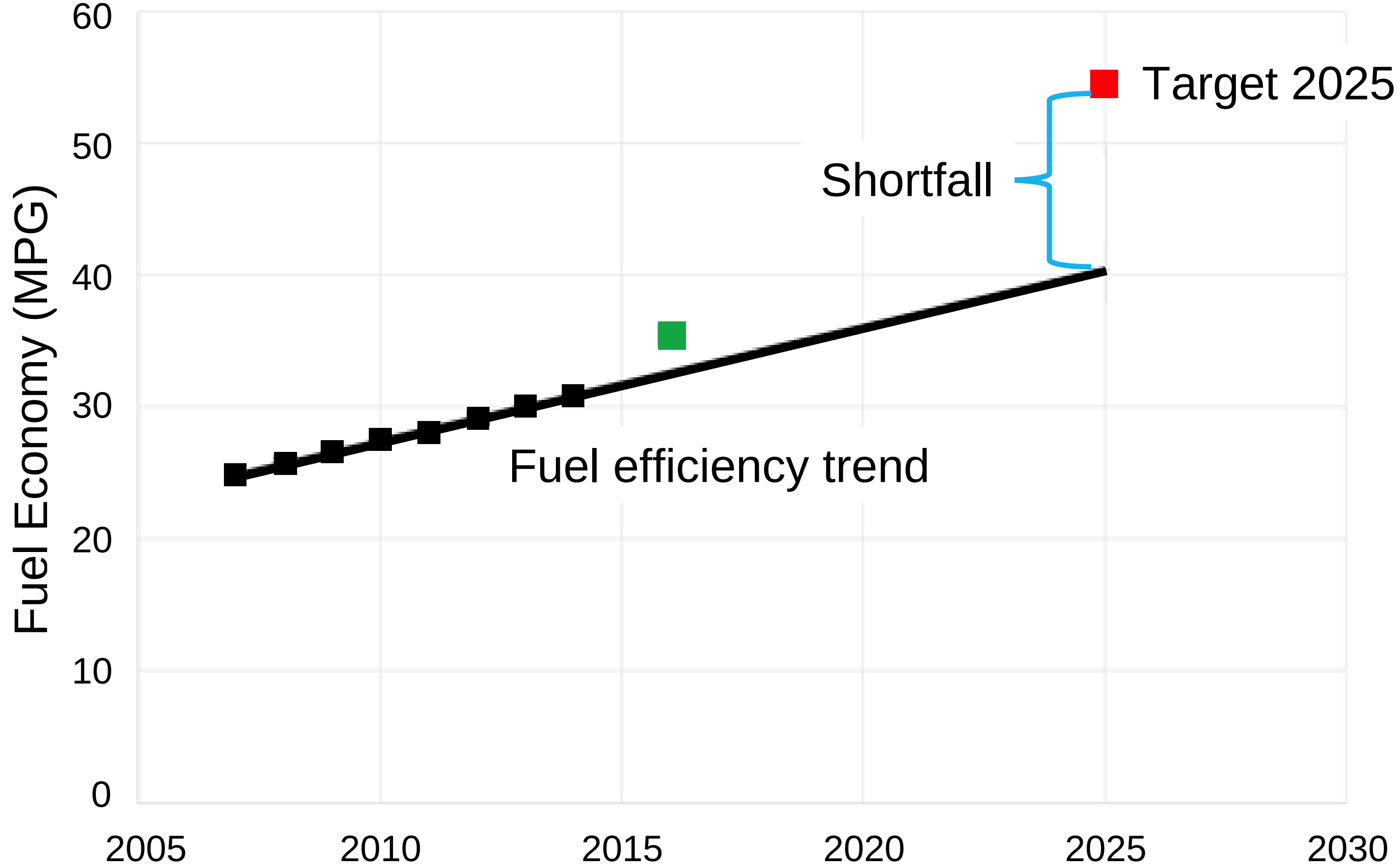
- OEMs will meet 2025 standards through a combination of technology and fleet mix, adjusting sales of BEVs, PHEVs, HEVs, (FCVs), diesel and conventional cars and light trucks.
- They will also pursue 'extra credits' and WTW.

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? Not reflected in regulations.

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



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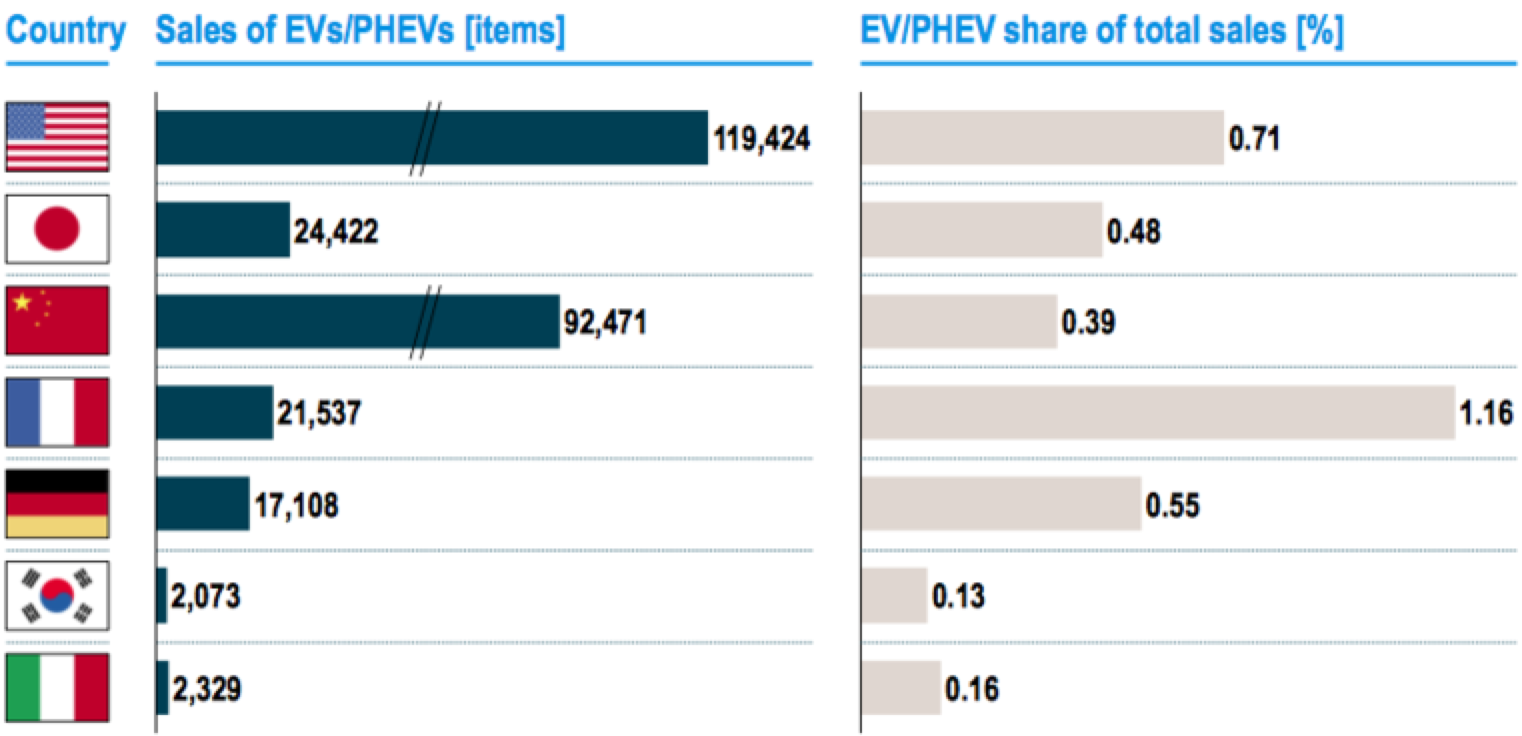
Sales figures and market share of EVs/PHEVs, Q3 2014 to Q2 2015

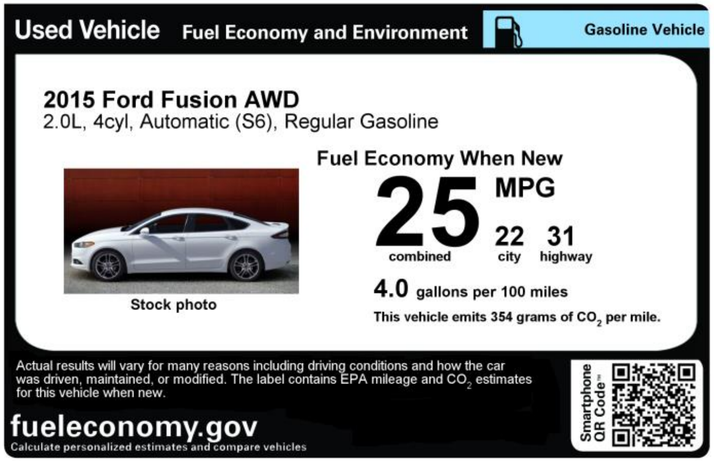


Source: fka; Roland Berger

3 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).

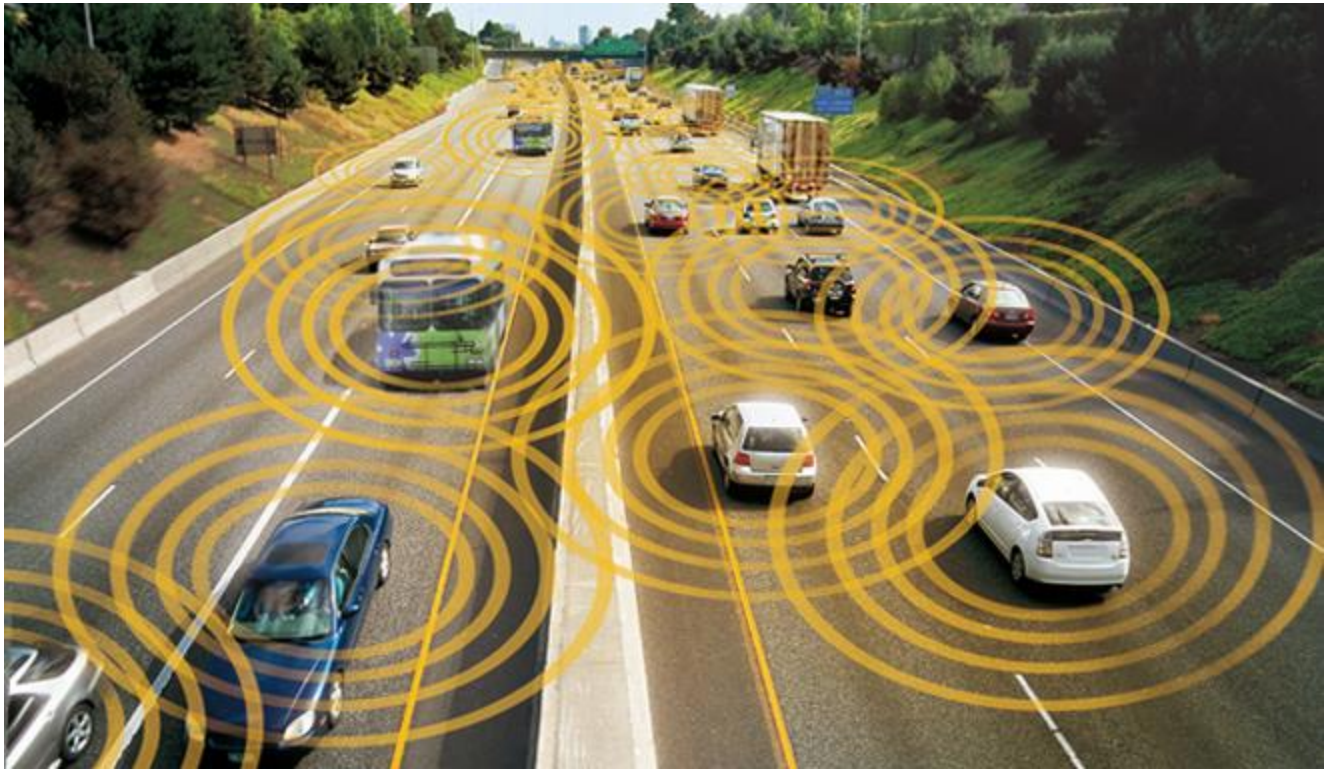


- Heavy-duty fuel economy regulated by EPA/NHTSA Phase 2 GHG rules.

Will be achieved by vehicle light-weighting, reducing aerodynamic and 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.

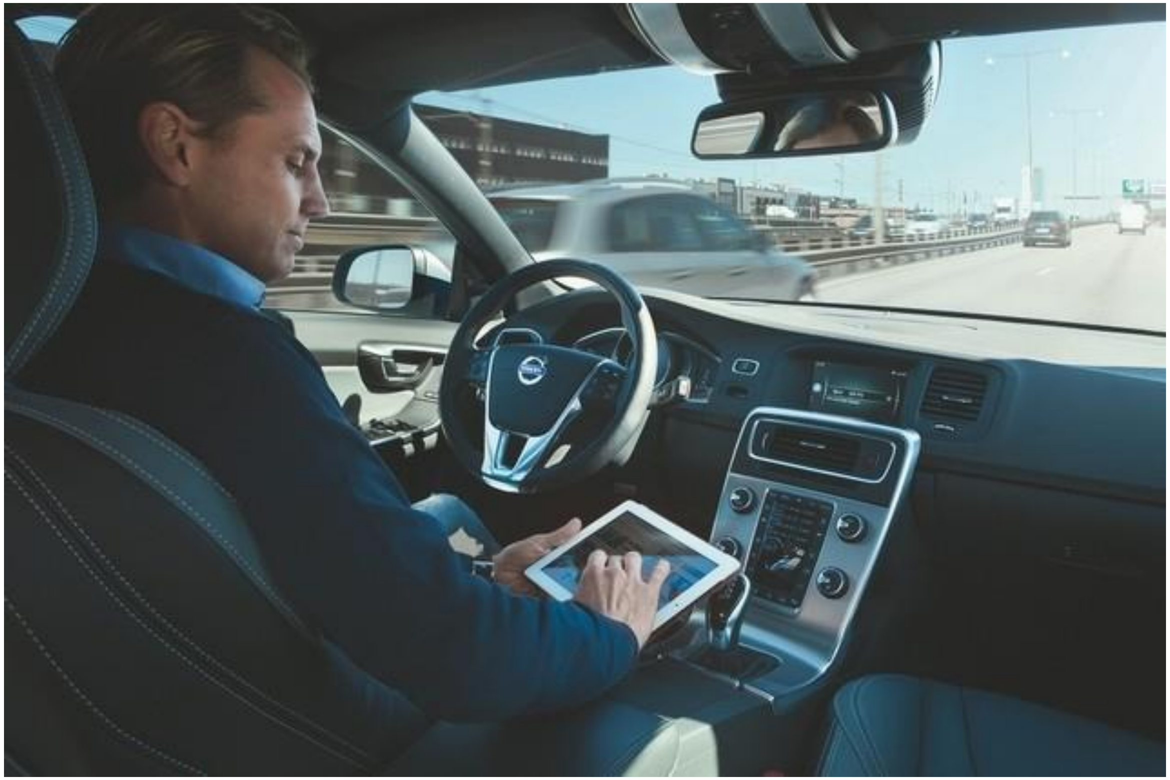


Connected Vehicles – V2V, V2I, V2X.

DENSO, 2015

Trend 3 – Vehicle Automation

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



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 (structures, air bags) – 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 your vehicle to all vehicles in a 150m radius.

Advanced Driver Assistance Systems (L3)

- ACC – adaptive cruise control (accelerator, brake).
- LKA – lane keeping assist (steering).
- AEB – advanced emergency braking (brake) (standard by 2022 by agreement).
- 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])

Fully Automated Operation (L3/L4)

- Machine vision (LIDAR, radar (short and long range), ultrasonic, stereoscopic cameras).
- Sensor fusion.
- High computational capability.
- Machine learning, and AI (‘deep learning’).
- Advanced decision making.
- Connectivity (V2V such as DSRC and V2X).
- Navigation – maps and real-time mapping.

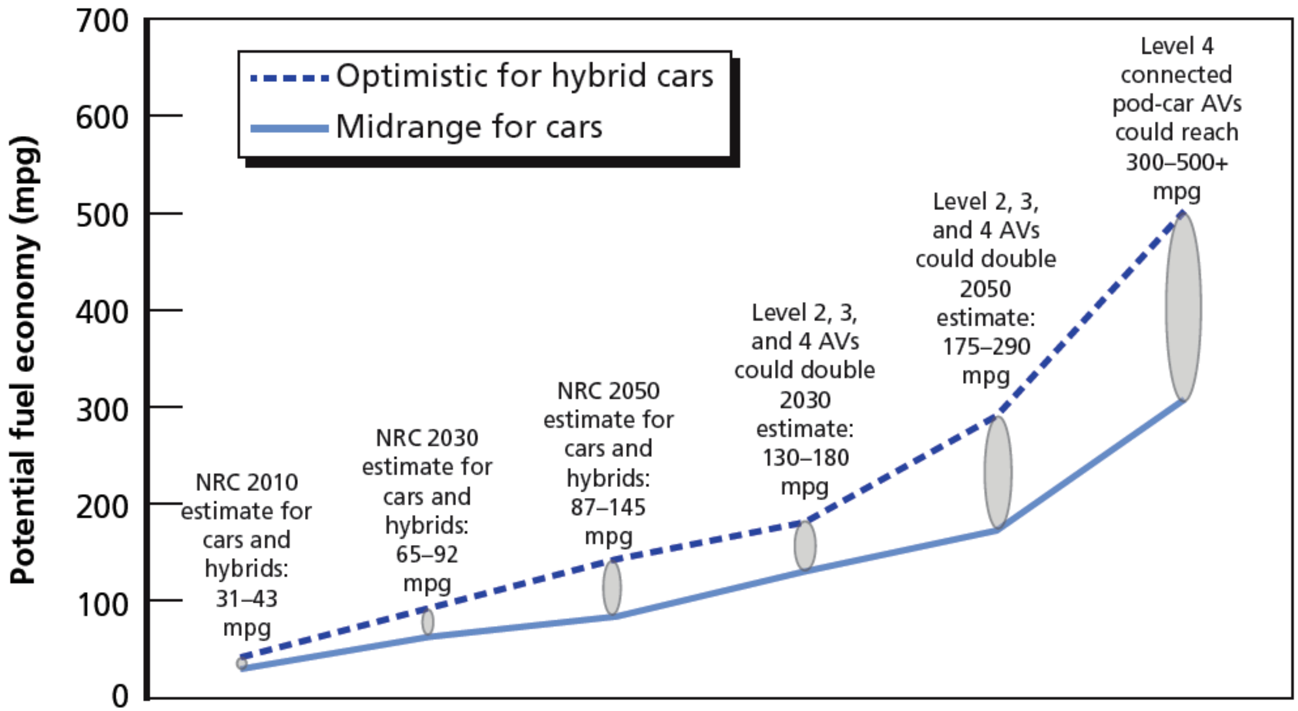
Requires the 99.999th percentile solution (currently at the 99th percentile?)

L4 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

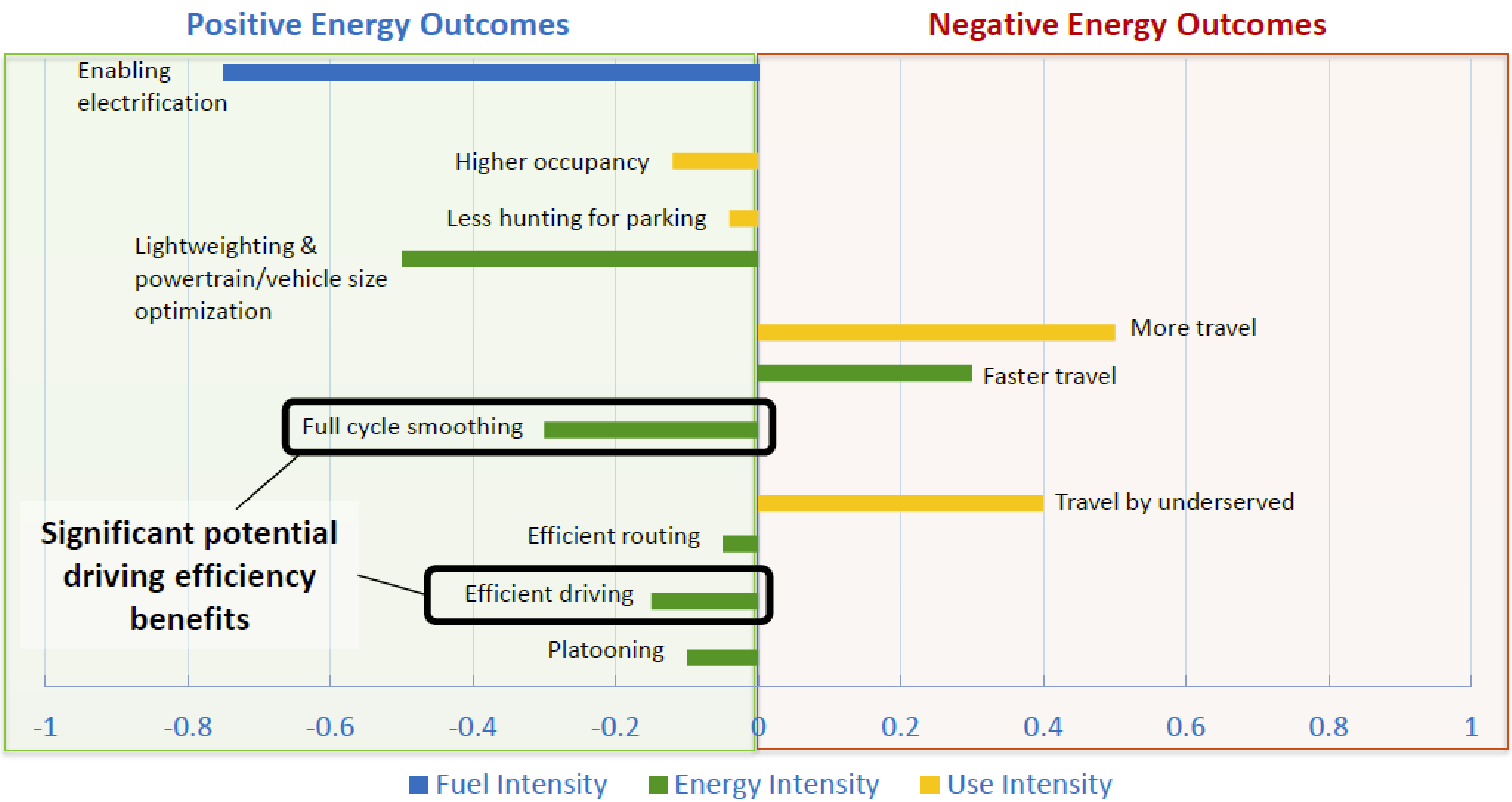


SOURCES: Analysis using data from NRC, 2013a; Folsom, 2012.

RAND *RR443-2.6*

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.*

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 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.

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.

Model	2015 Sales	2014 Sales	% Change
Audi A7	7721	8133	-5.07%
Audi A8	4990	5904	-15.48%
BMW 6-Series	8146	8647	-5.79%
BMW 7-Series	9292	9744	-4.64%
Jaguar XJ	3611	4329	-16.59%
Lexus LS	7165	8559	-16.29%
Mercedes-Benz CLS-Class	6152	6981	-11.88%
Mercedes-Benz S-Class	21934	25276	-13.22%
Porsche Panamera	4985	5740	-13.15%
Tesla Model S	26566	18480	43.76%
Total	100562	101793	-1.21%

TESLA SEC Filing, 2015

Consider the Tesla Model S compared to the Mercedes Benz S-Class:

Criterion	Compared to Mercedes S-Class
Safety	1x
Regulation	0.5x
Emissions	0x (really?)
Engineering Effort	0.5x
Reliability	0.5x
Utility	Performance 2x Range 0.5x Refueling Rate 0.01x
Economics	Price 1x, Sales 1x, Profitability 0x

The Tesla Model S should never have been a success. Evidence of a significant shift in consumer expectations – or just a function of the vehicle class (a rarefied atmosphere)? Model X and Model 3 sales will tell.

Huge Shifts in the 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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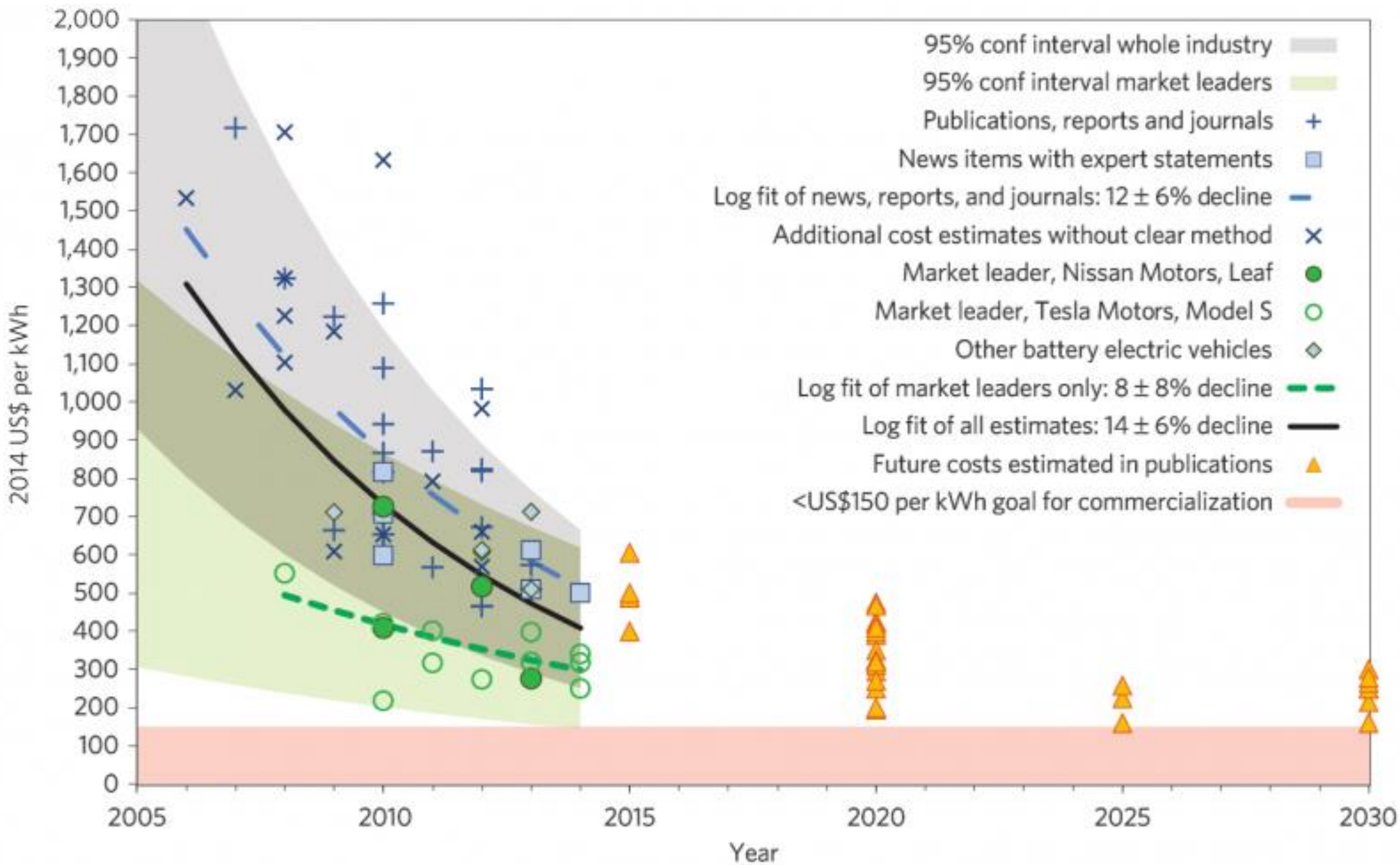
New Paradigm

- 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



2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
2014 US$ per kWh
2005
2010
2015
2020
2025
2030
Year
95% conf interval whole industry
95% conf interval market leaders
Publications, reports and journals
News items with expert statements
Log fit of news, reports, and journals: 12 ± 6% decline
Additional cost estimates without clear method
Market leader, Nissan Motors, Leaf
Market leader, Tesla Motors, Model S
Other battery electric vehicles
Log fit of market leaders only: 8 ± 8% decline
Log fit of all estimates: 14 ± 6% decline
Future costs estimated in publications
<US$150 per kWh goal for commercialization

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?
- 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.

The Future Vehicle Industry Landscape

- Vehicle OEMs – e.g. GM, Ford, BMW….
- Ride-sharing companies – e.g. Uber, Lyft….
- “Transportation 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."

- 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, more hybridization, downsizing, waste energy recovery, 48V systems?
- Vehicle structures – vehicle downsizing (more crossovers), 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?
- 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 automation requires or facilitates new vehicle architectures (electrification?) but will be slow in penetrating the full market.

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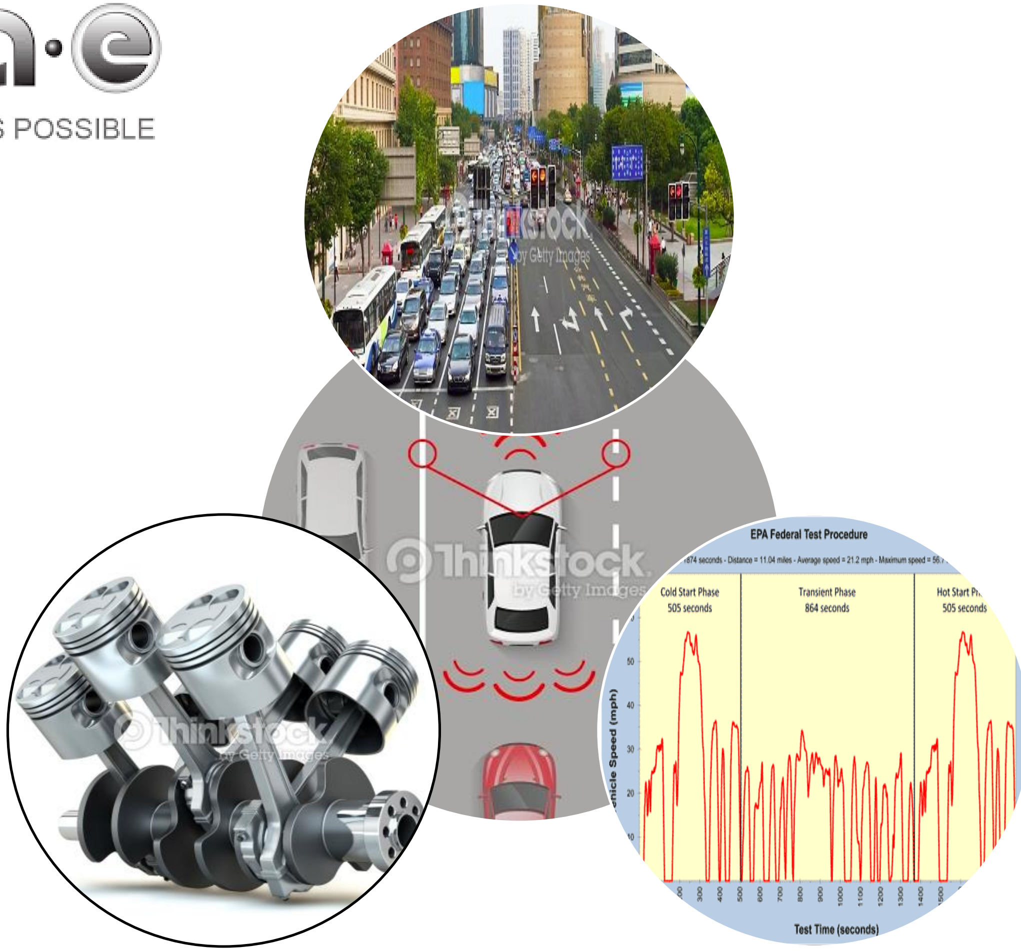
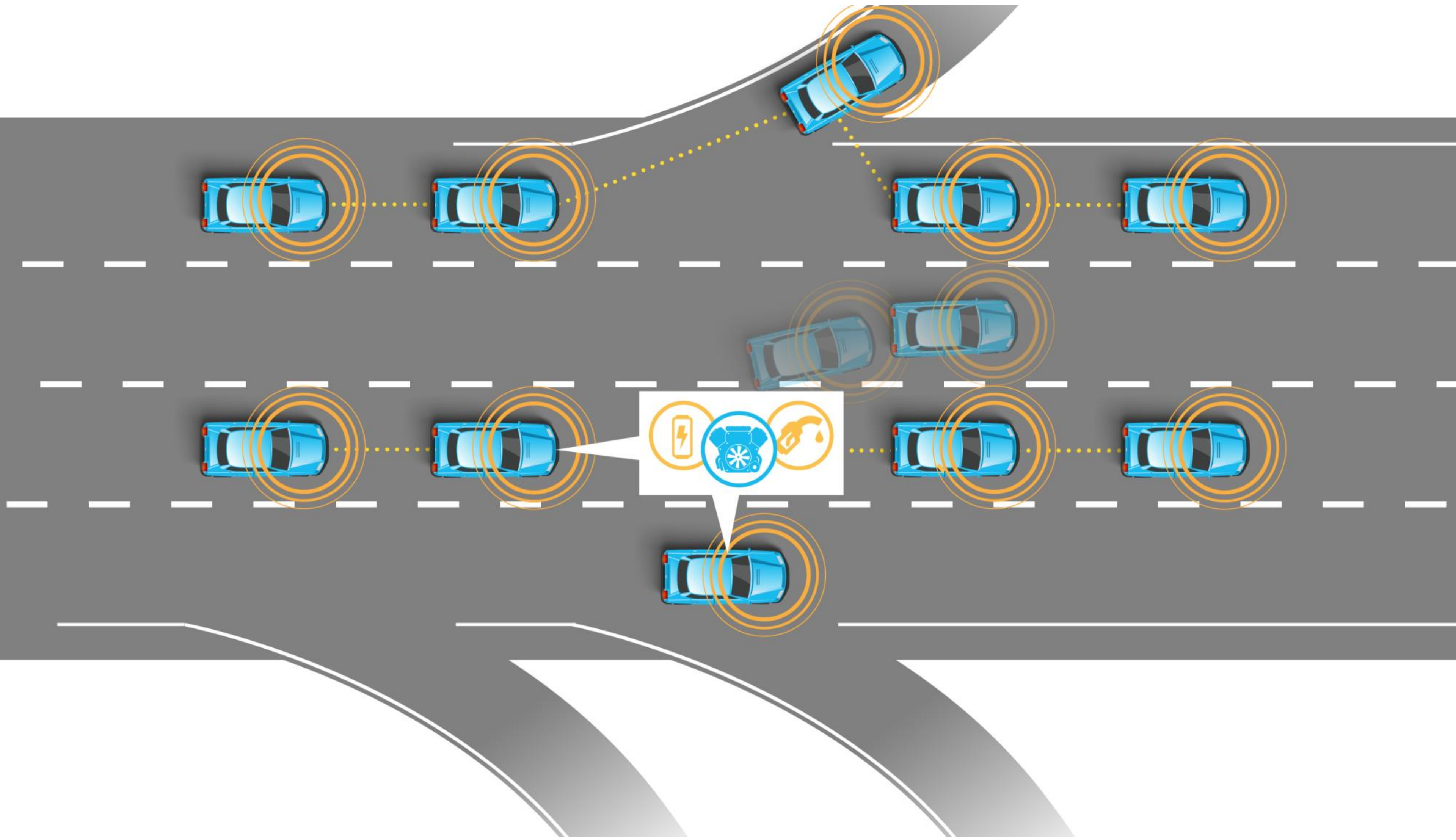
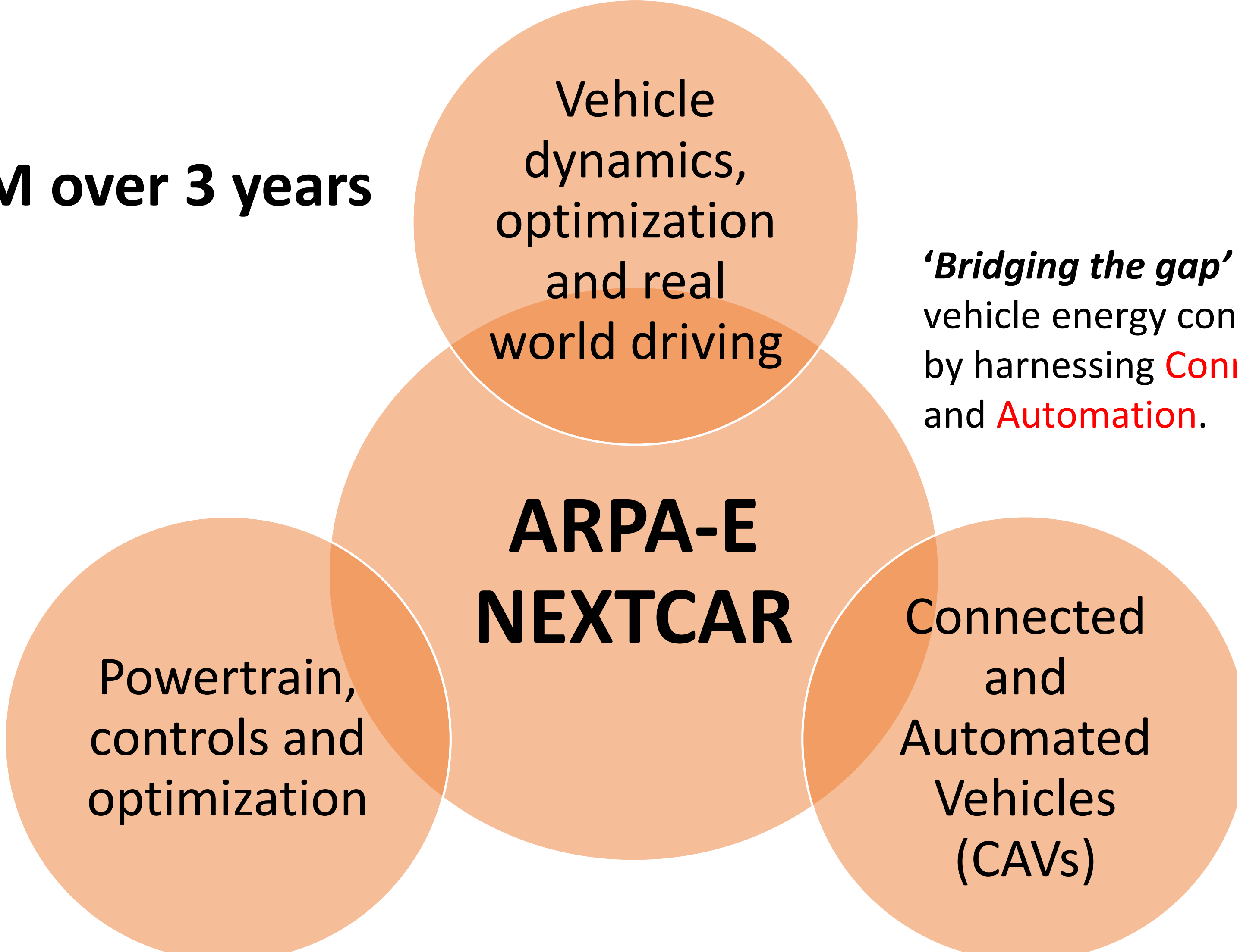




$30M over 3 years



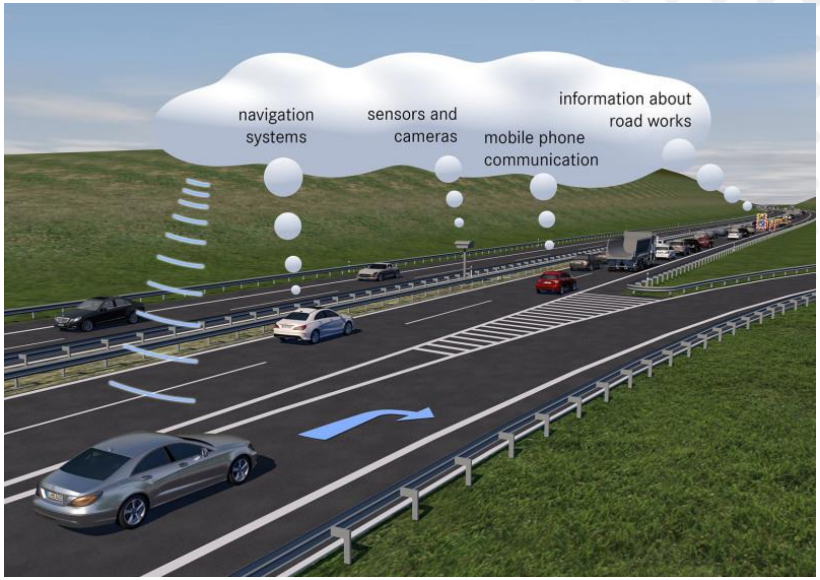
'Bridging the gap' to reduce vehicle energy consumption by harnessing Connectivity and Automation.

Engaging the Powertrain, Vehicle and Transportation Communities

U.S. DEPARTMENT OF ENERGY

ARPA-E's Vision

- What if a vehicle had perfect information about
  - Its route and topography
  - Environmental conditions
  - Traffic conditions ahead
  - Traffic behavior
  - Condition of its powertrain and aftertreatment systems (if any)
  - The quality of its fuel
  - ……and everything else?



Source: Daimler

ARPA-E's Vision

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  - Its route and topography
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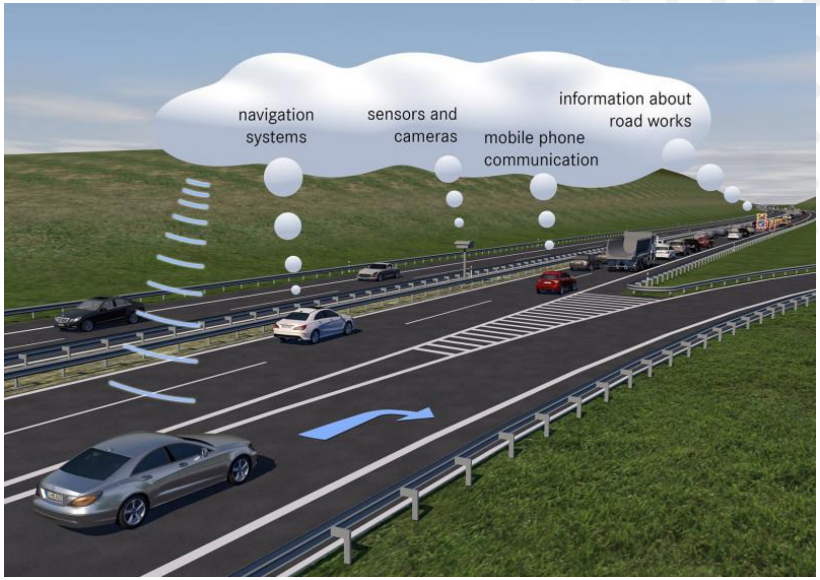
  - Traffic conditions
  - Traffic behavior
  - Condition of its powertrain and aftertreatment systems (if any)
  - The quality of its fuel
  - ……and everything else?
- And it cooperates with all the vehicles around it in order to reduce its energy consumption
- With perfect control and optimization



Source: Daimler

→ while platooning, employing speed harmonization for congestion mitigation, eco-approach and departure from traffic signals, as well as a single vehicle driving alone, and all other real-world driving scenarios….

Program Goal

Reduce the energy consumption of all future vehicles by an **additional 20%** through the use of connectivity and automation,

- in any vehicle application,
- in an energy and fuel agnostic fashion,
- while meeting future exhaust emissions regulations, as well as customer acceptability requirements (including acceleration, range, utility, driveability etc.),

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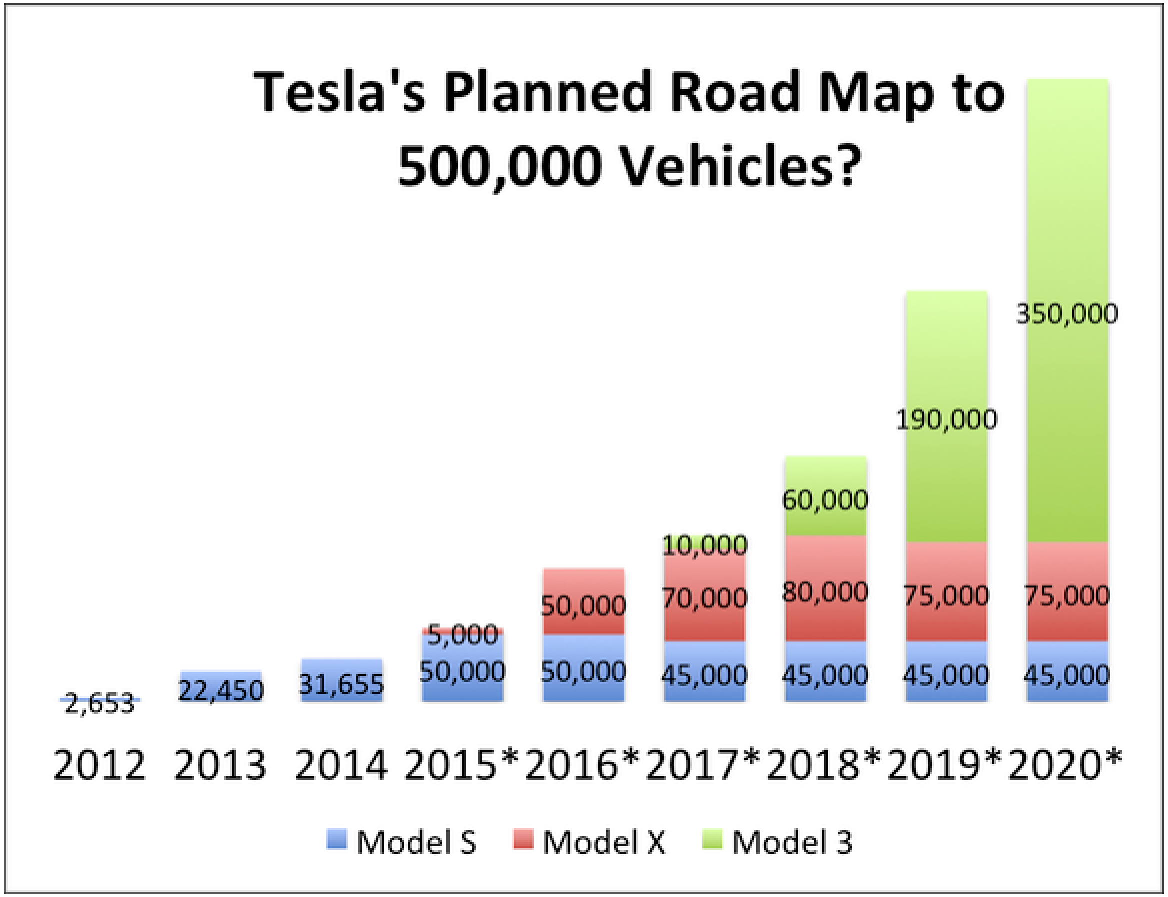
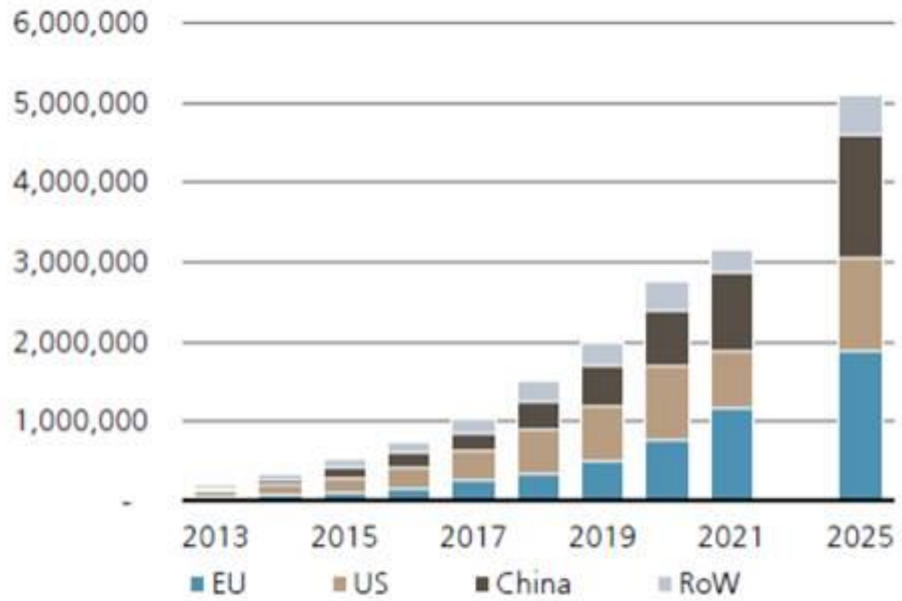
with a **$50/% energy consumption reduction** target.



Tesla's Planned Road Map to 500,000 Vehicles?
2,653
22,450
31,655
50,000
5,000
50,000
50,000
45,000
70,000
10,000
45,000
80,000
60,000
45,000
75,000
190,000
45,000
75,000
350,000
2012
2013
2014
2015*
2016*
2017*
2018*
2019*
2020*
Model S
Model X
Model 3

Figure 34: Global EV sales – 2014-21 and 2025 spot forecast



Source: Global EV Outlook, UBS estimates

2015 Global Vehicle Sales ~88.6M

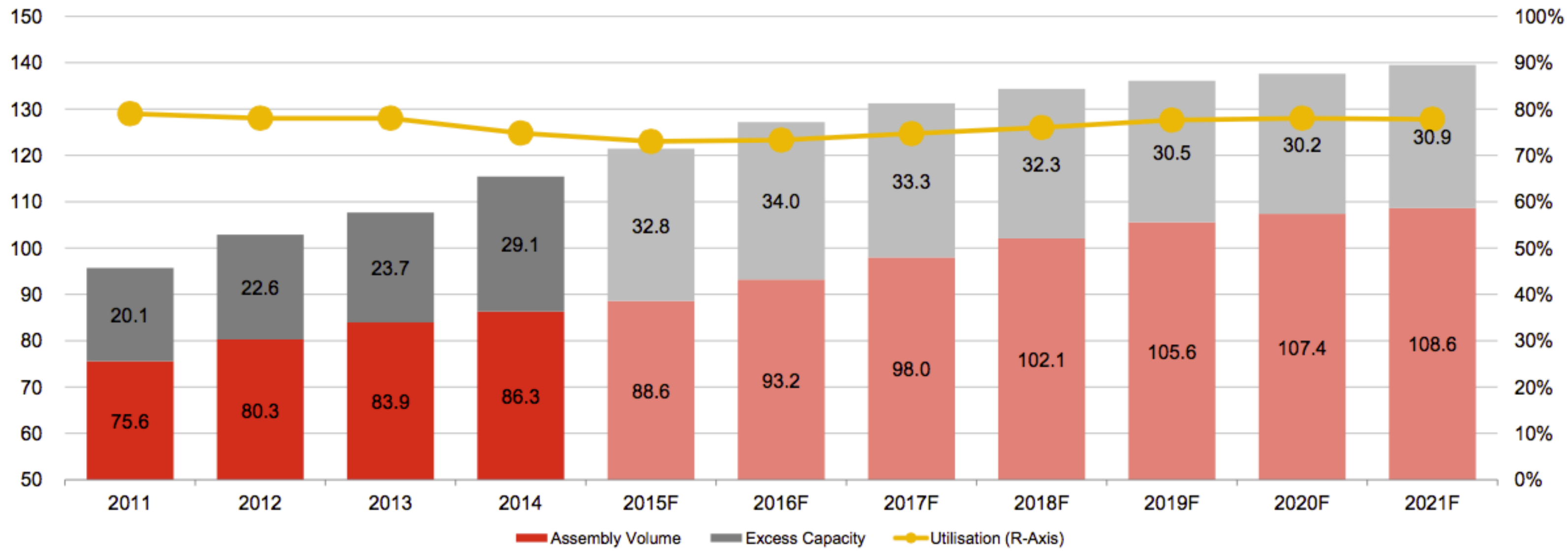
INTERNAL USE ONLY

Global Topline

Light vehicle assembly is expected to reach 88.6m units in 2015, representing a 2.7% YoY (year-over-year) increase. Autofacts is forecasting 2021 light vehicle assembly to reach 108.6m units, equating to a 3.5% CAGR* from 2015 – 2021.

Light Vehicle Assembly

2011 – 2021 (millions)



Source: Autofacts 2015 Q3 Forecast Release

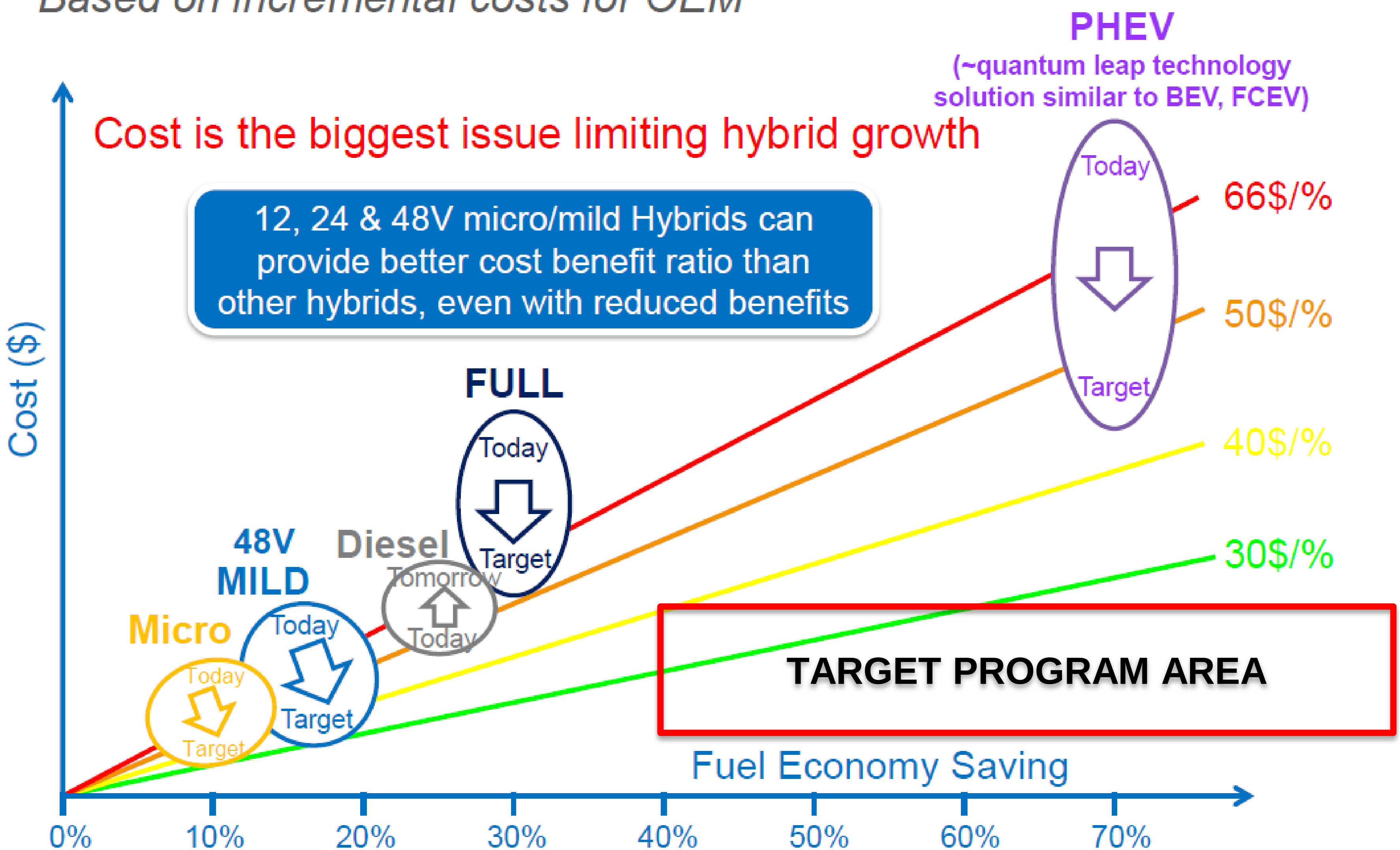
*CAGR = Compound Annual Growth Rate

Payback – 3 years

Parameter/ Metric	Conventional Gasoline Vehicle	Gasoline HEV	Gasoline PHEV	BEV
Vehicle miles traveled per year (VMT)	12,000	12,000	12,000	12,000
Gasoline fuel cost ($/gallon)	3.00	3.00	3.00	-
Fuel consumption/energy savings (%)	40	40	40	40
Total highway fraction driven (-)	0.45	0.45	0.45	0.45
Vehicle highway gas mileage (mpg/mpg_e)	28	34	38	137
Vehicle city gas mileage (mpg/mpg_e)	20	36	42	111
PHEV/BEV range (miles)	-	-	35	81
PHEV/BEV energy (Wh/mile)	-	-	360	270
Electricity retail cost ($/kWh)	-	-	0.11	0.11
Payback period (years)	3	3	3	3
Savings in 3 year payback period ($)	1,873	1,233	655	428
Normalized saving ($/%fuel consumption/energy reduction)	47	31	16	11

6 Cost Benefit Ratio Challenge for Hybrids

Based on incremental costs for OEM



Need to address both system cost and benefits for micro & mild hybrids to improve VALUE

Valeo