The Automotive Industry to 2025 (and beyond)

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RANGE Annual Meeting March 2016
The Obligatory Sankey Diagram

Estimated U.S. Energy Use in 2014: ~98.3 Quads

Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
Heavy-duty and light-duty vehicles consume \(~11\text{ million barrels per day}\) oil equivalent, totaling \(81\%\) of transportation sector energy consumption, or \(~23\%\) of the US primary energy usage.
Climb to the Top
Annual U.S. light-vehicle sales

20 million vehicles 2015

17.5m

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Sales of EVs/PHEVs [items]</th>
<th>EV/PHEV share of total sales [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>119,424</td>
<td>0.71</td>
</tr>
<tr>
<td>Japan</td>
<td>24,422</td>
<td>0.48</td>
</tr>
<tr>
<td>China</td>
<td>92,471</td>
<td>0.39</td>
</tr>
<tr>
<td>France</td>
<td>21,537</td>
<td>1.16</td>
</tr>
<tr>
<td>Germany</td>
<td>17,108</td>
<td>0.55</td>
</tr>
<tr>
<td>South Korea</td>
<td>2,073</td>
<td>0.13</td>
</tr>
<tr>
<td>Italy</td>
<td>2,329</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Source: Ika; 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 99.999\textsuperscript{th} percentile solution (currently at the 99\textsuperscript{th} 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?
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...

Positive Energy Outcomes
- Enabling electrification
- Lightweighting & powertrain/vehicle size optimization
- Full cycle smoothing
- Efficient driving
- Platooning

Negative Energy Outcomes
- Higher occupancy
- Less hunting for parking
- More travel
- Faster travel
- Travel by underserved

Significant potential driving efficiency benefits

Fuel Intensity, Energy Intensity, Use Intensity

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:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Power density (or energy density including the fuel/energy storage capacity) ⇒ Customer acceptance</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Fuel economy (over real-world dynamic driving) ⇒ Regulation</td>
</tr>
<tr>
<td></td>
<td>Energy efficiency</td>
</tr>
<tr>
<td>Emissions</td>
<td>Regulated criteria pollutants (and now CO₂) ⇒ Regulation</td>
</tr>
<tr>
<td>Cost</td>
<td>Total cost of ownership (including capex and energy cost)</td>
</tr>
<tr>
<td>Reliability</td>
<td>Mean time between failures, maintainability</td>
</tr>
<tr>
<td>Utility</td>
<td>Acceleration, driveability, NVH, cold or off-cycle operation, ease of use, transparency to the user, and acceptable range</td>
</tr>
<tr>
<td>Fuel acceptability</td>
<td>Use a readily available fuel or energy source.</td>
</tr>
<tr>
<td>Model</td>
<td>2015 Sales</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Audi A7</td>
<td>7721</td>
</tr>
<tr>
<td>Audi A8</td>
<td>4990</td>
</tr>
<tr>
<td>BMW 6-Series</td>
<td>8146</td>
</tr>
<tr>
<td>BMW 7-Series</td>
<td>9292</td>
</tr>
<tr>
<td>Jaguar XJ</td>
<td>3611</td>
</tr>
<tr>
<td>Lexus LS</td>
<td>7165</td>
</tr>
<tr>
<td>Mercedes-Benz CLS-Class</td>
<td>6152</td>
</tr>
<tr>
<td>Mercedes-Benz S-Class</td>
<td>21934</td>
</tr>
<tr>
<td>Porsche Panamera</td>
<td>4985</td>
</tr>
<tr>
<td>Tesla Model S</td>
<td>26566</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100562</strong></td>
</tr>
</tbody>
</table>
Consider the Tesla Model S compared to the Mercedes Benz S-Class:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Compared to Mercedes S-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1x</td>
</tr>
<tr>
<td>Regulation</td>
<td>0.5x</td>
</tr>
<tr>
<td>Emissions</td>
<td>0x (really?)</td>
</tr>
<tr>
<td>Engineering Effort</td>
<td>0.5x</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.5x</td>
</tr>
<tr>
<td>Utility</td>
<td>Performance 2x</td>
</tr>
<tr>
<td></td>
<td>Range 0.5x</td>
</tr>
<tr>
<td></td>
<td>Refueling Rate 0.01x</td>
</tr>
<tr>
<td>Economics</td>
<td>Price 1x, Sales 1x, Profitability 0x</td>
</tr>
</tbody>
</table>

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
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.
ARPA-E

NEXTCAR

Vehicle dynamics, optimization and real world driving

$30M over 3 years

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

Engaging the Powertrain, Vehicle and Transportation Communities

Powertrain, controls and optimization

Connected and Automated Vehicles (CAVs)
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

- What if a vehicle had **perfect information** about
  - Its route and topography
  - Environmental conditions
  - 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

→ 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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- while meeting future exhaust emissions regulations, as well as customer acceptability requirements (including acceleration, range, utility, driveability etc.),

with a $50/% energy consumption reduction target.
Tesla's Planned Road Map to 500,000 Vehicles?


- Model S: 2,653 22,450 31,655 50,000 50,000 45,000 45,000 45,000 45,000
- Model X: 5,000 70,000 10,000 80,000 75,000 75,000
- Model 3: 190,000 350,000

Legend:
- Blue: Model S
- Red: Model X
- Green: Model 3
2015 Global Vehicle Sales ~88.6M
**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

PwC Autofacts ©
## Payback – 3 years

<table>
<thead>
<tr>
<th>Parameter/ Metric</th>
<th>Conventional Gasoline Vehicle</th>
<th>Gasoline HEV</th>
<th>Gasoline PHEV</th>
<th>BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle miles traveled per year (VMT)</td>
<td>12,000</td>
<td>12,000</td>
<td>12,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Gasoline fuel cost ($/gallon)</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>-</td>
</tr>
<tr>
<td>Fuel consumption/energy savings (%)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Total highway fraction driven (-)</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Vehicle highway gas mileage (mpg/mpg&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>28</td>
<td>34</td>
<td>38</td>
<td>137</td>
</tr>
<tr>
<td>Vehicle city gas mileage (mpg/mpg&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>20</td>
<td>36</td>
<td>42</td>
<td>111</td>
</tr>
<tr>
<td>PHEV/BEV range (miles)</td>
<td>-</td>
<td>-</td>
<td>35</td>
<td>81</td>
</tr>
<tr>
<td>PHEV/BEV energy (Wh/mile)</td>
<td>-</td>
<td>-</td>
<td>360</td>
<td>270</td>
</tr>
<tr>
<td>Electricity retail cost ($/kWh)</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Payback period (years)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Savings in 3 year payback period ($)</td>
<td>1,873</td>
<td>1,233</td>
<td>655</td>
<td>428</td>
</tr>
<tr>
<td>Normalized saving ($/%fuel consumption/energy reduction)</td>
<td>47</td>
<td>31</td>
<td>16</td>
<td>11</td>
</tr>
</tbody>
</table>
Cost Benefit Ratio Challenge for Hybrids
Based on incremental costs for OEM

Cost is the biggest issue limiting hybrid growth

12, 24 & 48V micro/mild Hybrids can provide better cost benefit ratio than other hybrids, even with reduced benefits

PHEV
(~quantum leap technology solution similar to BEV, FCEV)

Today
66$/%  50$/%  40$/%  30$/%

TARGET PROGRAM AREA

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