Possible Energy Impacts of Vehicle Automation

Austin Brown, with slides also courtesy Chris Gearhart, Jeff Gonder and Alex Schroeder

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Discussion Topics

• Why connected and automated vehicles (CAVs) might matter for energy use
• What effects might manifest, and under what scenarios
• A few (early) thoughts on what we can potentially do to improve our prospects
26.8 Quadrillion Btu of transportation energy use
(note: does not include approximately 2.2 quadrillion Btu for offroad equipment)
Accelerating a 21st Century Transportation System

The emergence of intelligent and autonomous vehicles present significant energy and economic opportunities for the US

NHTSA Levels of Vehicle Automation

Level 0
No Automation

Level 1
Function-Specific Automation

Level 2
Combined Function Automation

Level 3
Limited Self-Driving Automation

Level 4
Full Self-Driving Automation

Energy Opportunities

INCREASE ENERGY EFFICIENCY

REDUCE PETROLEUM DEPENDENCY

EXPAND MANUFACTURING CAPABILITIES

CREATE HIGH TECH JOBS
Possible Energy Impacts of CAVs

- Platooning
- Efficient Driving
- Efficient Routing
- Travel By Underserved
- Full Cycle Smoothing
- Faster Travel
- More Travel
- Lightweighting / Optimization
- Less Hunting for Parking?
- Higher Occupancy
- Enabling Electrification

Probably require level 4

Probably require automation to be widespread / universal in some areas

Probably require new business models
Timing: Deployment of Connected and Autonomous Vehicles

Today

Safety Benefits
Appealing Consumer Amenities
Commercially Available Now

- Collision aversion
- Park assist
- Limited drive-cycle smoothing
- GPS route mapping

Near-Term

Fuel Economy Benefits
Additional Amenities + Savings
Low Barriers to Deployment

- Efficient driving route selection
- Improved drive-cycle smoothing
- Traffic signal timing coordination
- Vehicle “platooning”
- Parking space location
- Wireless charging alignment
- Charging station location

Long-Term

System-Wide Benefits
Dramatic Innovations
Deployment Challenges

- Fully autonomous hands-free driving
- Automated vehicle “valet” parking and retrieval

Image courtesy of Ford
Image by NREL/Media Fusion
Image Courtesy of GM
“Bookending” CAV Energy Impact Analysis

- **Identified dramatic potential energy impacts** (across automation levels)
  - Informed by related NREL work and literature review
  - Significant uncertainties remain; further research is warranted

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“Bookending” CAV Energy Impact Analysis

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Positive Energy Outcomes
- Enabling electrification
- Full cycle smoothing
- Lighter and more fuel efficient powertrains/vehicle size optimization
- Efficient driving
- Efficient routing
- Platooning

Negative Energy Outcomes
- More travel
- Faster travel
- Travel by underserved
- Travel demand impacts

Implications for advanced powertrains and vehicle design

Developing an Integrated R&D and Systems Analysis Framework

Integrated systems data analysis and vehicle research and development can enhance the impact of connected vehicles.
Discussion Point: Many CAV technologies may require such a real-world/off-cycle assessment approach

- E.g., efficient routing, cycle smoothing and adaptive control technologies
- Assess energy benefit from potential real-world change, and frequency of occurrence
- Could utilize existing pathway for demonstrating off-cycle credit beyond pre-defined table of technologies
Thanks! Questions?
Appendix
Evaluating Truck Platooning Efficiency Benefits

- Also potential safety and comfort benefits
- Many factors can influence
  - Vehicle spacing
  - Cruising speed
  - Speed variation
  - Baseline aerodynamics
  - Vehicle loading
  - Engine loading

Results from SAE Type II track testing of Peloton Technology system over a variety of conditions

Lammert and Gonder poster: www.nrel.gov/docs/fy14osti/62494.pdf
Real-World Data for Transportation Decision-Making

Secure Access Paired with Expert Analysis and Validation

Alternative Fuels Data Center (AFDC)
Public clearinghouse of information on the full range of advanced vehicles and fuels

National Fuel Cell Technology Evaluation Center (NFCTEC)
Industry data and reports on hydrogen fuel cell technology status, progress, and challenges

Transportation Secure Data Center (TSDC): Detailed fleet data, including GPS travel profiles

Fleet DNA Data Collection
Medium- and heavy-duty drive-cycle and powertrain data from advanced commercial fleets

FleetDASH: Business intelligence to manage Federal fleet petroleum/alternative fuel consumption

<table>
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<th>Features</th>
<th>AFDC</th>
<th>NFCTEC</th>
<th>TSDC</th>
<th>Fleet DNA</th>
<th>Fleet DASH</th>
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<td>Custom Reports</td>
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<td>Controlled Access via Application Process</td>
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<tr>
<td>Detailed GPS Drive-Cycle Analysis</td>
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</table>
Vehicle use conditions from disparate datasets can be merged in a common environment to investigate the interplay of conditions (thermal, drive cycle/routing, grade, etc.).

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Source</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Drive Cycles/Trip Distributions</td>
<td>NREL Transportation Secure Data Center</td>
<td>The TSDC houses hundreds of thousands of real-world drive cycles from vehicles across the country.</td>
</tr>
<tr>
<td>Climate Data</td>
<td>NREL National Solar Radiation Database</td>
<td>Home to TMYs from hundreds of U.S. locations, each containing hourly climate data.</td>
</tr>
<tr>
<td>Elevation/Road Grade</td>
<td>USGS National Elevation Dataset</td>
<td>Raw USGS elevations are filtered to remove anomalous data and produce smooth road grade curves.</td>
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</tbody>
</table>
Notes from Driver Feedback Fuel Savings Project

Motivation
- “Your mileage will vary”
  - Based on driving conditions & style
- Improve efficiency of existing vehicles

Approach
- Quantify savings from cycle changes
  - Vehicle simulations & cycle analysis
  - On-road experiments over repeated routes
- Identify/understand behavior influences
  - Literature review & expert consultation
  - On-road observations
- Assess feedback methods
  - Survey existing examples
  - Evaluate based on project’s other findings

2010 Prius Fuel Economy Histogram for 133 Drivers

Midsize Conventional Vehicle Assumptions
- Engine = 123 kW
- Curb mass = 1473 kg
- CD = 0.30
- Crr = 0.009
- FA = 2.27 m²
Driver Feedback Analysis Project: Key findings

- **Driving changes can save fuel**
  - 30%-40% outer bound for “ideal” cycles
  - 20% realistic for aggressive drivers
  - 5%-10% for majority of drivers

- **Existing methods may not change many people’s habits**
  - Other behavior influences dominate
  - Current approaches unlikely to have broad impact

Developed several recommendations to maximize savings…

Notes from Collaborative Project on Green Routing and Adaptive Control for the Chevy Volt

- **Candidate Routes**
- **NREL/GM Algorithms**
  - **Road Type**
  - **Real-time Traffic**
  - **Driver Aggression**
  - **Drive Cycle Model**
  - **Cycle Metrics**
  - **Road Grade**
  - **Vehicle State**
  - **Volt PT Model**

- **Estimated Energy Use**

- **Computationally heavy to develop**
  - Hundreds of thousands of drive cycles processed, analyzed, and simulated

- **Computationally light to implement in-vehicle**
  - Does not require determination of time/speed trace or real-time simulation of high-fidelity vehicle model

### Green Routing Example

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<tr>
<th>Route</th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tr>
<td>Distance, mi</td>
<td>81.6</td>
<td>76.2</td>
<td>67.6</td>
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<tr>
<td>Duration, min</td>
<td>107</td>
<td>107</td>
<td>113</td>
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<tr>
<td>Avg Elec Rate, Wh/mi*</td>
<td>0.83</td>
<td>0.89</td>
<td>1.0</td>
</tr>
<tr>
<td>Avg MPG*</td>
<td>0.45</td>
<td>0.50</td>
<td>1.0</td>
</tr>
<tr>
<td>Cost, $*</td>
<td>1.0</td>
<td>0.89</td>
<td>0.59</td>
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</table>

*Normalized Values*
Summary

- Demonstrated ability to model vehicle speed/accel profiles relative to road type
- Constructed high-level powertrain model employing cycle metrics and vehicle state as inputs
- Applied model using real-world distribution of O/D pairs, demonstrating:
  - Aggregate energy savings of up to 4.6% for green routing (relative to passenger value of time)
  - Average energy savings of 3.3% for mode scheduling

Modest aggregate savings, but may be cost-effective
Thoughts on Automation/Electrification Synergy

- Automation easier with electrified driveline
- Information connectivity helps with vehicle/grid integration
- Automated alignment for wireless power transfer (WPT)
- Automated plug-in electrified vehicle parking/charging
  - Value from valet anywhere, maximized electrified miles and infrastructure utilization, minimized anxiety about range and finding chargers
- Vehicle right-sizing for trip/range

Acknowledging some caveats

- Can also automate conventional vehicle powertrains to obtain on-demand valet and taxi benefits
- Shared-use automated taxis may have lengthy daily ranges
  - But improvements in battery cost, fast charging, WPT could still enable electrification
  - Also note operating cost/efficiency may become more important for such vehicles