National Research Council Report
Cost, Effectiveness and Deployment of Fuel Economy Technologies for Light-Duty Vehicles

UMTRI Conference on Powertrain Strategies for the 21st Century
July 22nd, 2015

Therese Langer, Transportation Program Director
The American Council for an Energy-Efficient Economy (ACEEE)

- ACEEE is a 501(c)(3) nonprofit that acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, & behaviors
- 50 staff; headquarters in Washington, D.C.
- Focus on end-use efficiency in industry, buildings, & transportation
- Other research in economic analysis; financing; behavior; energy efficiency programs; & national, utilities, state, & local policy
- Funding:
  - Foundation Grants (52%)
  - Contract Work & Gov’t. Grants (20%)
  - Conferences & Publications (20%)
  - Contributions & Other (8%)
Primary Energy Savings – Recent and Prospective Agency Actions

Source: Ungar et al. 2014, ACEEE
Midterm Evaluation of Fuel Economy and GHG Standards

• 2017-2025 rule requires that agencies conduct a midterm evaluation of the standards by 2018
• NHTSA standards for 2022-2025 are provisional
• NRC study an input to the midterm evaluation
Legislative Mandate for Two Vehicle Studies (EISA 2007)

SEC. 107. NATIONAL ACADEMY OF SCIENCES STUDIES.

(a) In General
As soon as practicable..., the Secretary of Transportation shall execute an agreement with the National Academy of Sciences to develop a report evaluating vehicle fuel economy standards....

(b) Report
The Academy shall submit the report to the Secretary, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Energy and Commerce of the House of Representatives, with its findings and recommendations not later than 5 years after the date on which the Secretary executes the agreement with the Academy. (Phase 1 report *Assessment of Fuel Economy Technologies for Light-Duty Vehicles, 2011*)

(c) Quinquennial Updates
After submitting the initial report, the Academy shall update the report at 5-year intervals thereafter through 2025. (Mandate for current study)
Summary of Task Statement

• Present estimates of cost, efficiency improvements, and barriers to deployment of gasoline, diesel, hybrid, and other engine and non-engine technologies for 2020 to 2030 time frame

• Broadly assess the methodologies and programs used to develop CAFE standards, including test procedures and attributes, as well as consumer behaviors related to vehicle technologies

• Assess the assumptions, concepts, and methods used in estimating the costs of fuel economy improvements and examine how fuel economy technologies may be integrated into manufacturing processes
Midsize cars won't need electrification to hit 54 mpg, researchers say
U.S. report finds fuel-economy targets can be met -- at a cost
– Automotive News

For Automakers, Fuel Economy Targets May Be Less of a Stretch – New York Times

Report: Automakers will speed vehicle weight reductions – Detroit News

U.S. researchers see auto fuel standards driving technology - Reuters

Car Buyers May Face Sticker Shock From Fuel Efficiency Rules - Bloomberg
Major Findings and Recommendations (excerpt)

• The committee notes that the use of full system simulation modeling in combination with lumped parameter modeling and teardown studies contributed substantially to the value of the Agencies’ estimates of fuel consumption and costs.

• The committee conducted a study using full system simulation modeling for various gasoline engine (including valve train improvements and turbocharging/downsizing with cooled exhaust gas recirculation) and transmission (including 6 and 8-speed automatic) with researchers at the University of Michigan and found general agreement with the Agencies’ estimates.
Other NRC Comments on Agency Analysis

• Committee found agencies’ analysis “thorough and of high caliber on the whole”

• Agency effectiveness estimates on target to date (2014)
Agencies’ Technology Effectiveness Projections on Target to Date

2008 vs 2014 Fuel Economy

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2014 w/tech projections</th>
<th>2014 actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion</td>
<td>30</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Malibu</td>
<td>30</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Camry</td>
<td>30</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Accord</td>
<td>30</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
NRC Technology Effectiveness and Cost Estimates for 2025

- Committee members differed on what were most plausible estimates.
- Hence report provides two estimates of effectiveness and/or cost for most technologies (but members agreed that both estimates were possible values).
Example of Effectiveness and Cost Results:

Turbocharging and Downsizing Level 1 (18 bar BMEP, 33% Downsizing) – Midsize Car with I4 Engine

<table>
<thead>
<tr>
<th></th>
<th>NHTSA</th>
<th>NRC More Optimistic</th>
<th>NRC Less Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Consumption Reduction</td>
<td>8.3%</td>
<td>8.3%</td>
<td>7.7%</td>
</tr>
<tr>
<td>Cost in 2025</td>
<td>$245</td>
<td>$245</td>
<td>$282</td>
</tr>
<tr>
<td>Cost per % FC Reduction</td>
<td>$30</td>
<td>$30</td>
<td>$37</td>
</tr>
</tbody>
</table>

Source: NRC Report, Tables S.1 and S.2

Cost per % Fuel Consumption: Ratio of NRC to NHTSA Values

- NRC Lower Cost/Higher Effectiveness
- NRC Higher Cost/Lower Effectiveness
Technology Cost per % Fuel Consumption Reduction: Agency vs. NRC Estimates for Selected Technologies in 2025 (Midsize Car w I4 Engine)

Length of bar represents ratio of NRC cost per % fuel consumption to agency cost per % fuel consumption.
Technology Cost and Effectiveness
– Major Points

• Reasonable agreement between NRC and NHTSA on most technology cost and effectiveness; selected technologies need particular attention in the midterm evaluation

• Biggest differences on transmissions and mass reduction

• Smaller but significant differences on powertrain types with limited representation in agencies’ compliance scenario
Transmissions (excerpt)

• As engines incorporate new technologies, such as TRBDS, the benefits of increasing transmission gears or switching to continuously variable transmissions (CVT) or dual-clutch transmissions (DCT) diminish.

• Benefits from parasitic loss reduction can exceed the benefits from increasing the number of gears and full benefits are still available when used with advanced engine technologies.

• The committee recommends that the Agencies expand their analysis to include CVT in the list of applicable technologies for the midterm review.

• The committee recommends that the Agencies update the analyses of technology penetration rates for the midterm review to reflect the anticipated low DCT penetration rate in the U.S. market.
Mass Reduction

- More lightweighting will occur than agencies assumed
- Long-term safety impact likely positive, but care needed through transition period
- Agencies need new methodology for analyzing costs of mass reduction
- High levels of mass reduction (20% for trucks) will be costly, but manufacturers will pursue due to other benefits
“Results of the committee’s technology pathway examples cannot be interpreted as assessments of the compliance costs for the 2017-2025 standards.”
Technology Assessment - Observations

- For midsize car, advanced power train not needed to meet 2025 target
- Technologies not in agencies’ compliance scenario will be available (high compression ratio engines, electrically assisted superchargers, ethanol boosting), which may allow manufacturers to:
  - Meet standards at lower cost or
  - Achieve still higher fuel economy
Other Issues

- Committee considered many other issues, including structure of program, manufacturing impacts, consumer impacts
- Provided current review of thinking on these issues; but perennial questions remain, e.g.:
  - Performance assumptions going forward – Acceleration time will/should continue to decrease? Performance benefits of FE technologies? Value of performance to consumer?
  - Consumer valuation of fuel savings (energy efficiency gap)
  - Indirect cost estimates
How Big Are Indirect Costs?

The industry average ratio of indirect costs to direct manufacturing costs appears to fluctuate within a range of ± 0.1 over time. An investigation of the ratio of total costs to direct manufacturing costs by the National Highway Traffic Safety Administration (NHTSA) for 1972-1997 found that the ratios fluctuated between 1.4 and 1.6 but without any apparent trend (Figure 7.2). In this regard, the ratio of total to direct costs represents the average markup above direct costs for all technologies produced in a given year.

Figure 7.2 indicates that to cover costs, provide a return to investors, and remain competitive in the marketplace, OEMs have typically set prices that average 1.5 times direct costs (Blincoe 2013). The consistency of the 1.5, or 50 percent, markup from manufacturing costs to retail price is noteworthy and suggests that it is reasonable to assume that the relative share of indirect costs may not change much in the future. For this reason, the Final Rule increased the estimated 46 percent markup to 50 percent for use in estimating the indirect cost multipliers used in calculating the total costs of technologies used to meet the standards (EPA/NHTSA 2012).

The similarity of the indirect cost shares across manufacturers and over time is also consistent with the view that competition among manufacturers is robust in that a manufacturer with substantially above-average indirect costs would be unsuccessful in the market.

Source: Rogozhin, Gallaher, Helfand, and McManus 2010
Manufacturing Considerations

The product development process of auto manufacturers is accelerating for several reasons, including need to:

- Implement new technologies to meet steadily increasing CAFE/GHG standards;
- Respond to consumer demands and industry trends.

More rapid deployment, although better for meeting regulations and responding to other demands, will increase stranded capital and incur higher product deployment costs.

Further complicating the deployment of new technologies is the growth of global platforms.

Global platforms can be considered a constraint, especially in the short term where supply chains are not fully developed, as well as an opportunity, especially in the long term where scale economies can provide cost reductions.
Assessment of CAFE Program Methodology and Design

The 2017-2025 CAFE/GHG standards are different from the earlier CAFE standards in a number of important ways:

- Combined fuel economy and greenhouse gas emission standards;
- Use of a footprint-based standard;
- Added flexibility for manufacturer compliance through credit markets.

In the setting of the standards’ structure, the committee found:

- The agencies are commended for producing a combined program for both CAFE and GHG standards for vehicles.
- The CAFE/GHG program incentivizes manufacturers to produce alternative-fueled vehicles.
- The standards are based on the existing two-cycle certification tests which are not accurate representations of real-world driving behavior.

Recommendation: The Agencies, perhaps in collaboration with other federal agencies, should conduct an on-going, scientifically-designed survey of the real-world fuel economy of light-duty vehicles. Making use of information gained from the survey of real-world fuel economy, the Agencies should plan a transition to replace the current two-cycle procedure with a procedure which appropriately uses the 5-cycle tests.
Therese Langer
tlanger@aceee.org
202-507-4013
Diesel Compression-Ignition Engines

Compression-ignition (CI) engines fueled by diesel have the highest thermodynamic efficiency of all internal combustion engine types.

CI engines provide large reductions in fuel consumption relative to baseline SI engines with a higher cost and price, but with a lower total cost of ownership.

Challenges for diesel vehicles to meet new emission standards for particulate matter, nitrogen oxides, and volatile organic compounds have prompted the development of improved aftertreatment systems that may reduce both the costs and size of the systems.

The committee recommends that the Agencies expand their full system simulations supported by mapping the latest diesel engines that incorporates as many of the latest technologies as possible. The Agencies also should conduct a teardown cost study of a modern diesel engine with the latest technologies to provide an up-to-date estimate of diesel engine costs.
Electrified Powertrains
(HEVs, PHEVs, BEVs and FCEVs)

Electrification of the powertrain is a powerful method to reduce fuel consumption and GHG emissions.

- Technologies include stop-start, mild hybrid, strong hybrid HEV (e.g. Prius), plug-in hybrid PHEV (e.g. Volt, Plug-in Prius), battery electric BEV (e.g. Leaf, Tesla) and fuel cell hybrid FCEV;
- GHG emissions benefits of electrification are critically related to the fuel mix for electricity generation.

Electrification is increasing, but penetration remains low. The committee found:

- Agencies’ estimates of battery cost for the HEV, PHEV and BEV are broadly accurate;
- Agencies’ assumptions about the P2-type hybrid need to be examined, including size and cost of the motor and technologies needed for performance and comfort;
- Agencies’ estimates of non-battery costs for PHEV and BEV may be too low.

The Agencies should examine auto manufacturers’ experiences of battery life to determine the appropriate state of charge swing for PHEVs and BEVs so that they can assign costs appropriately. The Agencies also should perform teardown cost studies of the most successful examples of hybrids, PHEVs, and BEVs.
Mass Reduction and Safety

Reducing vehicle mass across the entire fleet while holding vehicle footprint constant will have a beneficial effect on societal safety risk.

- The committee concludes that mass will be reduced across all vehicle sizes with proportionately more mass removed from heavier vehicles.
- Most current studies that analyze the relationships among vehicle footprint, mass, and safety support the argument that removing mass across the fleet in this manner while keeping vehicle footprints constant will have a beneficial effect on safety for society as a whole.
- While reducing mass across the entire fleet will ultimately be beneficial, there will be a transition period as the variance in distribution of mass across the fleet increases and could lead to an increase in risk with older heavier vehicles remaining on the road and a lighter fleet being introduced.

The committee recommends that NHTSA should carefully consider and, if necessary, take steps it believes could mitigate the possible increases in risk during the transition period as the fleet moves from current vehicle designs to a more lightweighted fleet.
Cost Considerations

The Committee found that the Agencies’ use of the learning-by-doing concept for estimating cost reductions over time and volume is unconventional:

- it is strictly a function of time rather than cumulative production;
- allows a technology to accomplish significant cost reductions even if its production volumes remain very low.

However, the committee appreciates the difficulties of implementing volume-based learning in the compliance models used by the Agencies.

The committee recommends that Agencies make clear the terminology associated with learning and assess whether and how volume-based learning might be better incorporated into their cost estimates, especially for low-volume technologies. The Agencies should also continue to conduct and review empirical evidence for the cost reductions that occur in the automobile industry with volume, especially for large-volume technologies that will be relied on to meet the CAFE/GHG standards.
Consumer Impacts and Acceptance

How consumers respond to the more fuel efficient vehicles of the future is critical for the success of the standards.

- Automakers perceive typical consumers require 1-4 year payback periods for fuel economy technologies.
- The extent and explanation for consumer undervaluation of fuel economy remains a subject of debate.

Consumers are buying fuel-efficient versions of vehicles that suit their wants and needs.

- Markets are segmenting in ways that may allow for better fuel economy without a loss in other valued characteristics, such as the shift from SUVs to CUVs.
- There is evidence that most consumers will not widely adopt technologies that interfere with driver experience, comfort or perceived utility even for large improvements in fuel economy.

Recommendation: The Agencies should study the value of vehicle attributes to consumers, and the existence and extent of consumer undervaluation of fuel economy (the energy paradox).