GHG/CAFE Standard Impacts on Vehicles and Technologies

John German, ICCT

Univ. of Michigan Transportation Research Institute: *Automotive Product Portfolios in the Age of CAFÉ*

February 13, 2013
The standard provisions

Technology progress

Customers

Vehicle Impacts
The standard provisions

Technology progress

Customers

Vehicle Impacts
Comparison of passenger vehicle GHG standards

[1] China’s target reflects gasoline vehicles only. The target may be lower after new energy vehicles are considered.
Comparison of passenger vehicle GHG standards

[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
## Characteristics of Worldwide Standards

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Regulated metric</th>
<th>Attribute</th>
<th>Form</th>
<th>Categories, classes, other provisions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel Economy</td>
<td>Fuel Consumption</td>
<td>CO₂/GHG</td>
<td>Weight</td>
</tr>
<tr>
<td>European Union*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>United States</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Japan</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>China</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Canada</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>South Korea*</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mexico</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>India</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

#: CO₂ standards complemented by Air-conditioning, tyre pressure monitoring, gear-shift indicators etc.
* : FE/CO₂ standards include consideration for tyre pressure monitoring, gear-shift indicators
2017 and 2025 US Car and Light-Truck Standards

Greenhouse Gas Emissions (gCO2e/mile) vs. Footprint (Sq. Ft)

- **2017 L-T**
- **2017 Cars**
- **2025 L-T**
- **2025 Cars**

1 Sq. meter = 10.764 Sq. feet
A size-based standard fully captures benefits of lightweighting

- **Size-based design:**
  - Efficiency: 11-14 g CO₂/km benefit
  - Lightweighting: 7-8 g CO₂/km *actual* benefit

- **Mass-based design:**
  - Efficiency: 11-14 g CO₂/km benefit
  - Lightweighting: only 2-3 g CO₂/km *compliance* benefit

http://www.theicct.org/2010/08/size-or-mass/
Air Conditioning Credits

- CO$_2$ credits given based upon the GWP of the air conditioning refrigerant
  - Continuous incentive for better refrigerants without mandates or artificial deadlines
  - Allows manufacturers to consider both GWP and A/C system efficiency when choosing refrigerant

- CAFE and CO$_2$ credits for improved air conditioning efficiency
Off-Cycle Credits

Table II-22 Off-cycle Technologies and Credits and Equivalent Fuel Consumption Improvement Values for Cars and Light Trucks

<table>
<thead>
<tr>
<th>Technology</th>
<th>Adjustments for Cars</th>
<th>Adjustments for Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/mi</td>
<td>gallons/mi</td>
</tr>
<tr>
<td>High Efficiency Exterior Lights* (at 100 watt savings)</td>
<td>1.0</td>
<td>0.000113</td>
</tr>
<tr>
<td>Waste Heat Recovery (at 100W)</td>
<td>0.7</td>
<td>0.000079</td>
</tr>
<tr>
<td>Solar Panels (based on a 75 watt solar panel)**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Charging Only</td>
<td>3.3</td>
<td>0.000372</td>
</tr>
<tr>
<td>Active Cabin Ventilation and Battery Charging</td>
<td>2.5</td>
<td>0.000282</td>
</tr>
<tr>
<td>Active Aerodynamic Improvements (for a 3% aerodynamic drag or Cd reduction)</td>
<td>0.6</td>
<td>0.000068</td>
</tr>
<tr>
<td>Engine Idle Start-Stop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/ heater circulation system</td>
<td>2.5</td>
<td>0.000282</td>
</tr>
<tr>
<td>w/o heater circulation system</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Active Transmission Warm-Up</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Active Engine Warm-up</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Solar/Thermal Control</td>
<td>Up to 3.0</td>
<td>0.000338</td>
</tr>
</tbody>
</table>

- Starts 2014 for CO2, 2017 for FE
- OEMs can apply for higher credits than listed and can apply for other off-cycle credits
- Total off-cycle credits capped at 10 g/mi

Source: Greenpeace US rule summary, September 6, 2012
EV, FCV, CNG Credits (CO₂ only)

- 0 g/miCO₂ rating for EVs, PHEVs, FCVs
  - Per-company sales cap of 200,000 to 600,000 applies to MYs 2022-2025

- Multiple vehicle credits:

<table>
<thead>
<tr>
<th>Year</th>
<th>EV/FCV multiplier</th>
<th>PHEV/CNG multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2017</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>2018</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>2019</td>
<td>2</td>
<td>1.6</td>
</tr>
<tr>
<td>2020</td>
<td>1.75</td>
<td>1.45</td>
</tr>
<tr>
<td>2021</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>2022-25</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- Credits will be given for vehicles mandated by ZEV
- ICCT supports EV credits, but they should not be used to weaken the benefits of the standards
Pickup Truck Technology Credits

- Pickup trucks performing 15% better than their applicable CO2 target receive a 10 g/mi credit (0.0011 gal/mi)
  - Expires after 2021
- Those performing 20% better than their target receive a 20 g/mi credit (0.0023 gal/mi)
  - Credits continue for 5 years even if FE does not improve after year qualified
- These are artificial credits that reduce the benefits of the standards
  - Especially a concern due to the lower improvements required from light trucks
2025 Test Cycle Tailpipe Requirements

Does NOT include reclassifying cars as light trucks or making light trucks larger

Credits (maximum):
- A/C refrigerant: 13.8 gCO2/mi for cars; 16.4 for LDT (No use of AC credits = 54.5 mpg)
- A/C efficiency: 5 g/mi (.000563 gal/mi) for cars; 8 g/mi (.000810 gal/mi) for LDT
- Off-cycle: 10 g/mi (.001125) for cars and LDT
- Pickup: 20 g/mi (.002250) for pickup trucks only
- EV: Zero upstream + multiple credits (assumed 5% market share for cars and 1% for LDT)
The standard provisions

Technology progress

Customers

Vehicle Impacts
Where Does the Energy Go?

- **2008-10 vehicles are generally 15-20% efficient**

The Real Technology Breakthrough

Computers

- Computer design, computer simulations, and on-vehicle computer controls are revolutionizing vehicles and powertrains
- Especially important for lightweight materials
  - Optimize hundreds of parts – size and material
  - Capture secondary weight – and cost – reductions
- The high losses in the internal combustion engine are an opportunity for improvement
- Also reducing size and cost of hybrid system
Improved Cost Analyses - Teardown

Gears, Shafts

Housing, Clutches, Actuation System

FEV – Phase 2 Transmission Analysis
Technology Costs Dropping

Technology availability increases - and its costs decrease - over time

- Incremental vehicle costs and percent improvements versus MY2008 baseline
- Data from EPA/NHTSA 2012-2016 rulemaking and EPA/NHTSA/CARB TAR for 2020
## Pace of Technology Innovation is Accelerating

<table>
<thead>
<tr>
<th>Technology</th>
<th>Source</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo-charging and downsizing</td>
<td>2001 NRC Report</td>
<td>5-7%</td>
<td>$250-$400</td>
</tr>
<tr>
<td>(no cyl. reduction)</td>
<td>Draft RIA – 18 bar</td>
<td>12-15%</td>
<td>$342</td>
</tr>
<tr>
<td></td>
<td>Draft RIA – 24 bar</td>
<td>16-20%</td>
<td>$550</td>
</tr>
<tr>
<td></td>
<td>Draft RIA – w/ boosted EGR</td>
<td>20-25%</td>
<td>$967</td>
</tr>
<tr>
<td>4- to 6-speed automatic</td>
<td>2001 NRC Report</td>
<td>3-4%</td>
<td>$150-$300</td>
</tr>
<tr>
<td></td>
<td>Draft RIA</td>
<td>3-4%</td>
<td>($15)</td>
</tr>
<tr>
<td>Automatic to DCT</td>
<td>Draft RIA</td>
<td>4-6%</td>
<td>($154-$223)</td>
</tr>
</tbody>
</table>

- Cost is direct manufacturing cost
- NRC Report is Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, 2002
- Draft RIA is for NHTSA/EPA proposed standards for 2017-25 light-duty vehicles
**Pace of Technology Introduction is Accelerating**

<table>
<thead>
<tr>
<th>Year</th>
<th>GDI</th>
<th>Turbo</th>
<th>6-speed Auto</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>4.2%</td>
<td>3.6%</td>
<td>25%</td>
</tr>
<tr>
<td>2010</td>
<td>8.3%</td>
<td>3.5%</td>
<td>38%</td>
</tr>
<tr>
<td>2011</td>
<td>13.7%</td>
<td>7.4%</td>
<td>52%</td>
</tr>
<tr>
<td>2012</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>19%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


### 2010 vs 2012

<table>
<thead>
<tr>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ford Focus</strong></td>
<td><strong>Ford Focus</strong></td>
</tr>
<tr>
<td>EcoBoost</td>
<td>EcoBoost</td>
</tr>
<tr>
<td>1.6L, 4 cyl., 74 kW</td>
<td>1.0L, 3 cyl., 74 kW</td>
</tr>
<tr>
<td>---</td>
<td>SS+DI+turbo</td>
</tr>
<tr>
<td>1,175 kg</td>
<td>1,195 kg</td>
</tr>
<tr>
<td>M5, 11.9 s</td>
<td>M5, 12.5 s</td>
</tr>
<tr>
<td>14.6 km/l</td>
<td>21.4 km/l</td>
</tr>
</tbody>
</table>

- **+47%**

<table>
<thead>
<tr>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Audi A3</strong></td>
<td><strong>Audi A3</strong></td>
</tr>
<tr>
<td>1.6L, 4 cyl., 75 kW</td>
<td>1.2L, 4 cyl., 77 kW</td>
</tr>
<tr>
<td>---</td>
<td>SS+DI+turbo+7DCT</td>
</tr>
<tr>
<td>1,185 kg</td>
<td>1,150 kg</td>
</tr>
<tr>
<td>M5, 11.8 s</td>
<td>7DCT, 10.4 s</td>
</tr>
<tr>
<td><strong>14.4 km/l</strong></td>
<td><strong>20.1 km/l</strong></td>
</tr>
</tbody>
</table>

- **+40%**

New powertrains introduced in Europe
Next-generation Gasoline Engines

**Fiat MultiAir**
Digital Valve Actuation

**Honda Prototype Engine Base**
( Electro-magnetic valve )

**HCCI Engine**

Improvement in fuel economy: 30%

Dual-loop high/low pressure cooled exhaust gas recirculation

Heat release rate

Requires increasing the self-ignition region
Turbo-Boosted EGR Engines

- Highly dilute combustion – considerable efficiency improvement
- Advanced ignition systems required

Terry Alger, Southwest Research Institute, “Clean and Cool”, Technology Today, Summer 2010
Turbo Dedicated EGR Engines

- Highly dilute, low temperature combustion
- Advanced ignition systems required
- PSA 2017 introduction
Input Powersplit: Planetary Gearing

- Toyota and Ford: Optimizes city efficiency, inexpensive CVT
- Achilles' Heel: Fixed torque split between engine and generator

- Two large motors
  - generator must handle part of engine output
  - Motor must handle generator plus battery output

- Cruising efficiency loss
  - Part of engine output always incurs losses in generator and motor

- Power recirculation possible

Source: Hybrid Synergy Drive, Toyota Hybrid System II, Toyota Motor Corp., May 2003
Future Low-Cost Hybrid

- Advanced P2 hybrid system – not yet in production
  - Small, single motor integrated into automated manual transmission
    - Major reductions in cost of hybrid system
    - Must be high volume to cover high capital costs of transmission redesign
  - Reduction in transmission clutch cost, possible use of single-clutch manual transmission

- New, higher-power Li-ion batteries – smaller, lighter, and lower cost

Nissan Fuga/M35 parallel hybrid layout
Lightweight materials offer great potential

Material composition of lightweight vehicle body designs:

- **Reference**
  - Body weight reduction: 16%
  - Approximate fuel economy improvement: 10%

- **Lotus (Low Development)**
  - Body weight reduction: 39%
  - Approximate fuel economy improvement: 25%

- **Volkswagen / SuperlightCar**
  - Body weight reduction: 42%
  - Approximate fuel economy improvement: 27%

- **Lotus (High Development)**
  - Body weight reduction: 57%
  - Approximate fuel economy improvement: 37%

- **RMI Revolution**

Also incremental improvements in aerodynamics and tire rolling resistance.
Vehicle Mass-Reduction Cost ($/lb)

- US agencies collaborated to assess available studies and model costs associated with vehicle mass-reduction
  - Agencies assessed and weighted the available mass-reduction studies for redesign of vehicle models in the 2017-2025 timeframe
  - Regulation analyses apply *cost-per-pound-reduced* vs percent vehicle mass reduction
  - Ultimately, agencies projected average vehicle mass would decrease by 8-11% by 2025
Major New Mass-Reduction Work

- **Lotus Engineering (CARB)**
  - Continuation of 2010 study (-20%, -33% mass Toyota Venza)
  - Includes crashworthiness safety (NHTSA FMVSS) validation
  - Demonstrates cost-effective 30% mass reduction at < $0/vehicle

- **EDAG / Electricore (NHTSA)**
  - Technical assessment of -22% mass Honda Accord at $319/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation

- **EDAG WorldAutoSteel “Future Steel Vehicle”**
  - 12-18% mass reduction, no additional cost, with only using steels

- **FEV (US EPA)**
  - Technical assessment of -18% mass Toyota Venza at no cost
  - Includes crashworthiness safety (NHTSA FMVSS) validation
Vehicle Mass-Reduction Cost

CONFIDENTIAL, PRELIMINARY

- FSV and FEV studies indicate 12-18% weight reductions at zero cost
- EDAG and Lotus studies indicate larger mass reductions at costs on the CARB cost trend line

![Graph showing incremental mass reduction cost versus percent vehicle curb weight reduction. The graph includes data from various studies such as FSV 2012, FEV 2012, Lotus 2012, EDAG 2012, and others. The x-axis represents percent vehicle curb weight reduction ranging from 0% to 35%, and the y-axis represents incremental mass reduction cost in dollars per pound reduced. The graph also shows a trend line for the CARB evaluation cost ( Crawley 2012, Plotkin 2009, Das 2008, Plotkin 2009, Das 2008, Das 2008).]
The standard provisions
Technology progress
Customers
Vehicle Impacts
In-depth interviews of 60 California households’ vehicle acquisition histories found *no evidence* of economically rational decision-making about fuel economy.

- Out of 60 households (125 vehicle transactions) 9 stated that they compared the fuel economy of vehicles in making their choice.

- 4 households knew their annual fuel costs.

- None had made any kind of quantitative assessment of the value of fuel savings.
Consumers are, in general, LOSS AVERSE

2002 Nobel Prize for Economics
(Tversky & Kahnemann, J. Risk & Uncertainty 1992

- Uncertainty about future fuel savings makes paying for more technology a risky bet
  - What MPG will I get (your mileage may vary)?
  - How long will my car last?
  - How much driving will I do?
  - What will gasoline cost?
  - What will I give up or pay to get better MPG?

“"A bird in the hand is worth two in the bush."

Causes the market to produce less fuel economy than is economically efficient
New Customer Profile

- Innovator
- Early Adopter
- Early Majority
- Majority
- Hanger-On

Increasingly risk averse
The standard provisions
Technology progress
Customers
Vehicle Impacts
2017 and 2025 US Car and Light-Truck Standards

Greenhouse Gas Emissions (gCO2e/mile)

Footprint (Sq. Ft)

2017 L-T

2017 Cars

2025 L-T

2025 Cars

1 Sq. meter = 10.764 Sq. feet
Footprint Standards do not Impact Size

Table I-6 Model Year 2025 CO₂ and Fuel Economy Targets for Various MY 2012 Vehicle Types

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Example Models</th>
<th>Example Model Footprint (sq. ft.)</th>
<th>CO₂ Emissions Target (g/mi)</th>
<th>Fuel Economy Target (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Example Passenger Cars</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compact car</td>
<td>Honda Fit</td>
<td>40</td>
<td>131</td>
<td>61.1</td>
</tr>
<tr>
<td>Midsize car</td>
<td>Ford Fusion</td>
<td>46</td>
<td>147</td>
<td>54.9</td>
</tr>
<tr>
<td>Full size</td>
<td>Chrysler 300</td>
<td>53</td>
<td>170</td>
<td>48.0</td>
</tr>
<tr>
<td><strong>Example Light-duty Trucks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small SUV</td>
<td>4WD Ford Escape</td>
<td>43</td>
<td>170</td>
<td>47.5</td>
</tr>
<tr>
<td>Midsize crossover</td>
<td>Nissan Murano</td>
<td>49</td>
<td>188</td>
<td>43.4</td>
</tr>
<tr>
<td>Minivan</td>
<td>Toyota Sienna</td>
<td>56</td>
<td>209</td>
<td>39.2</td>
</tr>
<tr>
<td>Large pickup truck</td>
<td>Chevy Silverado</td>
<td>67</td>
<td>252</td>
<td>33.0</td>
</tr>
</tbody>
</table>

*Note: The table provides an example of the CO₂ and fuel economy targets for various vehicle types. The targets are based on the footprint of each vehicle, which is calculated at the end of each model year, when production volumes are determined.*
2016 US Car and Light-Truck Standard Increase

Annual % increase

Footprint (sq. ft.)

36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74

LDT - 2012 to 2016
Car - 2012 to 2016

1 Sq. meter = 10.764 Sq. feet
2016 and 2021 US Car and Light-Truck Standards

Annual % increase

Footprint (sq. ft.)

1 Sq. meter = 10.764 Sq. feet
Real Gasoline Price

Real Gasoline Prices
(2011 $ per gallon)

Motor Gasoline Retail Prices, U.S. City Average, adjusted using CPI-U

AEO2013 early release
New Vehicle Fuel Economy

New Vehicle MPG (CAFE values)
Combined car and light truck

Car + Light Truck mpg
From 2011 EPA FE Trends Report

2012 – 2025 NHTSA CAFE standards
2026 – 2035 +4% per year
New Vehicle Gasoline Cost per Mile

Real Gasoline Cost for New Vehicles - Cents per Mile (2011 $ per gallon)

$3.94
Real Fuel Cost - % of Disposable Income

Real Fuel Cost of Driving a New Vehicle 10,000 Miles
% of Per Capita Disposable Income

BEA, Table 2.1, Personal Income and It's Disposition
Forecasted Per Capita Disposable Income from AEO2013 Early Release
Summary

• Standards needed due to consumer “loss aversion”
• Improvements in conventional powertrains and load reduction will be far greater than expected
  • Only modest number of hybrids – and no xEVs – needed
  • P2 hybrid cost will be accepted by the mass market ~2022
• Standards will have no impact on vehicle sales
  • Fuel savings will be larger than increased car payment
• Future vehicles may increase in size
  • Footprint system provides no incentive to downsize
  • Differential changes to the light truck footprint curve increase the incentive to reclassify cars as trucks and to make light trucks larger
  • Fuel share of disposable income will decrease
Thank You