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Is this the model passenger car for 2025 CAFE compliance? Hybrids and plug-ins such as Toyota's Prius family and Ford's 2013 C-Max Hybrid and PHEV (shown) are among only a few cars that currently fit into the 54.5-mpg window.

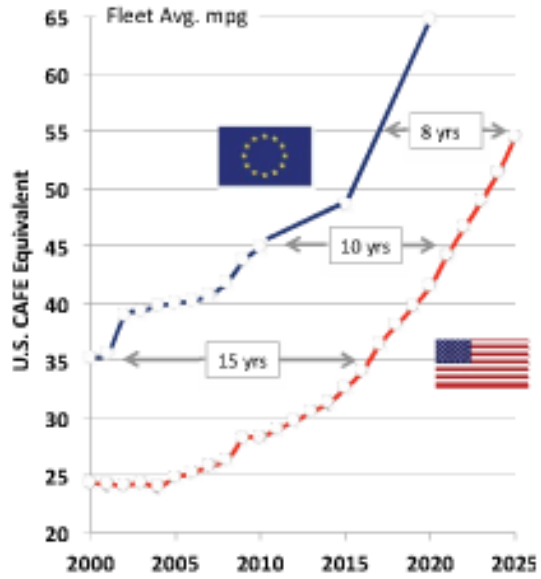
Mapping the road to 54.5 mpg

Part 1 of *AEI*'s three-part series looks at the CAFE challenge and the product-development options being weighed to meet it—while engineers look forward to the critical 2018 midterm review.

by Lindsay Brooke

AEI's three-part series on the industry's pathways for meeting the aggressive new U.S. fuel efficiency regulations.

The CAFE rules force the U.S. fleet to close the fuel efficiency gap with Europe



Source: Martec Group; ICCT conversion between NEDC and USEPA lab certification test procedures

Learnings from developing Europe's low-CO_2-emitting car fleet will play a major role in the industry's march toward meeting U.S. 2025 fuel efficiency regulations.

In automotive product development, achieving a 5% increase in efficiency across a subsystem, or overall in the vehicle, is a very big deal. This is, after all, an industry in which engineers will practically kill to get an extra 1% out of anything. A 10% efficiency gain is cause for jubilation.

That's why the new U.S. Corporate Average Fuel Economy (CAFE) regulations that raised the auto industry's overall fleet fuel economy requirement from 25.3 mpg in 2010, to 34.1 mpg by 2016—the biggest CAFE increase since the 1978-84 period—were regarded as a very tough bogey. But it's nothing compared with what comes next.

The 54.5-mpg fleet-average fuel economy ultimately set for MY2025 was announced last August by the Obama administration in a nearly 2000-page document. This second phase of the new CAFE, ramping up from 2017, represents a mighty 59% increase over the 2016 target. Remarkably, it is 99% higher than the 27.3-mpg standard of 2011.

The standards are the most aggressive in auto-industry history, according to a 2012 report by the strategic-analysis consultancy **Scenaria**. They are projected to save approximately 4 billion barrels of oil and 2 billion metric tons of greenhouse gas emissions (GHG) over the lifetime of the 2017-25 standards, according to the U.S. **EPA**.

While they establish certainty about fuel economy requirements, the new standards also create new headaches for the industry. Which technologies should automakers use to meet the new standards? How much cost will they add—and will the incremental cost drive up vehicle retail prices?

"This is a pretty tall hurdle, without doubt," said Dr. Gary Smyth, Executive Director of **General Motors**' North American Science Labs and a veteran powertrain engineer. "Getting even close to the new numbers, particularly for a full-line manufacturer like us, will require a combination of many solutions. And none of them will be inexpensive."

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MY2016-MY2025 Combined Passenger Car and Light Truck Greenhouse Gas and CAFE Standards										
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
GHG standard (g/mi) a	250	243	232	222	213	199	190	180	171	163
GHG-equivalent fuel econ. (mpg equiv.) a	35.5	36.6	38.3	40	41.7	44.7	46.8	49.4	52	54.5
Fuel economy (CAFE) std. (mpg) a	34.1	35.4	36.5	37.7	38.9	41	43.0 b	45.1 b	47.4 b	49.7 b

Source: EPA and NHTSA, 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards, Prepublication Version, August 28, 2012.

a. Due to the complexity of the CAFE/GHG system, these numbers are based on projected sales of vehicles in different size classes. The standards are size-based, and the vehicle fleet encompasses large, medium, and small cars and light trucks. Thus if the sales mix is different from projections, the achieved CAFE and GHG levels would be different. For example, the CAFE numbers are based on NHTSA's projection using the MY2008 fleet as the baseline. A newer projection, based on the MY2010 fleet, leads to somewhat lower numbers (roughly 0.3—0.6 mpg lower for MY2017-2020 and roughly 0.7-1.0 mpg lower for MY2021 onward).

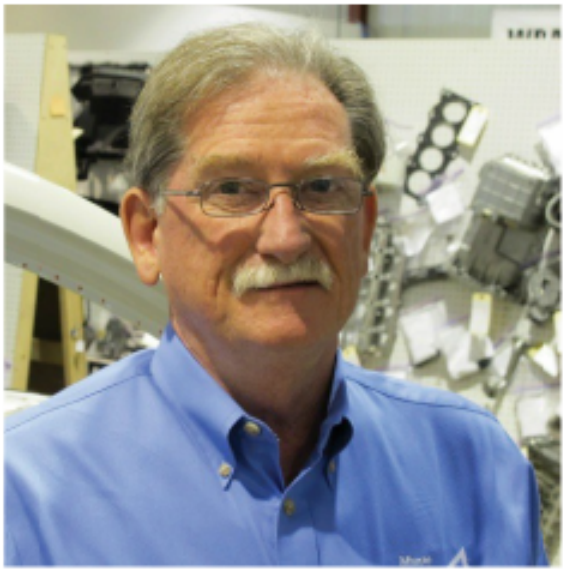
b. Projected. NHTSA only has authority to set CAFE standards in five-year increments. Thus, only rules through MY2021 have been finalized. For MY2022 onward NHTSA must issue a new rule, which has not been proposed as of September 2012.

Observed Casey Selecman, an engineer and industry analyst with the **Martec Group**: "Having to increase fleet fuel economy by 4% per year, as called for by the new CAFE, is a massive task—particularly to do it on a six-year vehicle product cycle. Even Europe in its diesel heyday of the early 2000s wasn't doing that," he said.

The challenge of meeting 2017-25 CAFE, which industry leaders agree will require significant investment in technology resources, innovation—and potentially some breakthroughs—inspired *AEI* to create this three-part series of articles. Part 2, which looks at options for creating the 54.5-mpg passenger car, runs in the Nov. 6 print edition. Part 3 covers the even greater challenge of light-truck compliance—and the future of the American pickup; it will appear in the Dec. 4 digital edition.

The majority of the nearly two dozen experts interviewed for this series predict the industry will be able to develop and bring to market technologies required to meet the aggressive 2017-25 CAFE standards. But all of them also questioned whether it can be done without unacceptably raising future vehicle prices.

Even the government seems unsure of whether the CAFE program will deliver sufficient consumer-payback value. As noted in the section of the regulations titled MY2017 and Later Final Rule, page 1110: "…we do not at this point have sufficient confidence in the estimates of



Powertrain "is going to be your biggest friend or your worst enemy in how you're going to get to 54.5 mpg—powertrain and lightweighting initiatives," said Sandy Munro, of Munro & Assoc. (Lindsay Brooke)

the role of fuel economy in consumers' vehicle purchases to come to definitive conclusions about the impacts of the rule on vehicle sales."

Separate-but-equal cars and trucks

As with the current phase of CAFE covering 2012-16, the rules now set for 2017-2025 are complex and loaded with technology credits aimed at promoting certain solutions over others (see sidebar). And as with the 2012-16 rules, the second-phase regs are based on vehicle size. This formula was established by the Bush administration under an MY2011 light-truck rule. It assigns each car and light truck a fuel-economy "target" based on its footprint, which is the vehicle's track-width measurement multiplied by its wheelbase.

The sales-weighted average of the targets for an automaker's fleet is the CAFE average that the company must achieve in a given model year. In other words, no vehicle is required to meet a specific fuel economy number, and the average fuel economy required will vary among manufacturers.

Truck fleet fuel economy is calculated in a similar manner to that used for cars, but with a different formula. As currently proposed for 2025, the truck targets range from 30.2 to 50.4 mpg, compared with 21.1 to 27.1 mpg in 2011. The truck formula is designed so that the low end of the range rises less than the high end to help accommodate larger trucks.

Experts say the size-based criteria create a more complicated regulatory system than the previous one. But it arguably discourages OEMs from simply making vehicles smaller to comply. Many in the industry initially feared an extreme jump in CAFE regulations was designed to drive Americans into small cars while killing larger cars and full-size trucks. (See Part 2, "Creating the 54.5-mpg car.")

Real-world mpg explained

Because the new CAFE is based on size, every automaker gets a different CAFE requirement based on product mix and the size of the car and truck models that are actually sold. For every model year, each OEM must calculate the CAFE requirement for its entire product portfolio, and then calculate the sales-weighted average for its actual mix. In that way **Ford**, for example, with its hefty

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chunk of full-size pickups and SUVs, has a lower CAFE requirement than **Hyundai**, which (so far) relies mainly on small and midsize cars.

While the 54.5 mpg number gets the headlines, the combined "real world" mpg customers will see on a vehicle's window sticker will be about 20% lower—45.4 mpg for cars and 32.1 mpg for light trucks under 8500 GVW, for a projected car/light truck fleet average of 40 mpg. That's because the CAFE figures are based on the EPA's city and highway fuel economy tests used since the 1970s, along with the results of three other emissions tests.

The calculations behind the 2017-25 regulations use CO_2 emissions (g/mi traveled), which convert to fuel economy in mpg. The numbers are derived from EPA's determination that each gallon of gasoline burned produces 8887 g of CO_2. Thus the 35.5 mpg target for 2012-16 is based on reaching a cars/trucks fleet average of 250 g/mi (8887 divided by 250). The CO_2 emission target will drop in stages to 163 g/mi (54.5 mpg) for 2025, as the accompanying chart shows.

The new regs incorporate credits for various technologies not measured to a real-world extent with the EPA's existing five-cycle testing. (See "The CAFE credit maze explained" sidebar.) The credit for such off-cycle items could amount to about 3 mpg if several are used—and even more if a manufacturer provides data to justify it.

There also are credits for the plug-in hybrid electric, battery electric, and fuel cell vehicles (FCVs). To incentivize their sales, the government incorporated a

The CAFE credit maze explained

The technology credits baked into the new CAFE regulations include fuel saved by idle-stop-start systems, friction losses reduced by faster warm-up times for engine and transmission oils, and many more. The credits aren't just "giveaways," as the old flex-fuel credits were often regarded. Most of them actually improve vehicle efficiency in real-world driving. Indeed, under the new regs flex-fuel vehicles will receive credits only if automakers can prove how much fuel their E85-capable vehicles actually burn in real-world use.

Major technology areas receiving credits include:

Air conditioning: A/C technology plays a significant role in the new CAFE formula, with two types of credits in the new rules. One is for efficiency, aimed at fuel economy. The other is for low-global-warming impact of the refrigerant. This is an **EPA** effort to encourage use of R-1234yf, with its global warming number of 1410, in lieu of the present choice, R-134a, which is rated at 1430. The 1410 number means the release of 1 g of R-134a would have the same global warming effect as releasing 1410 g of CO_2. The lower the number, the less effect the refrigerant has on global warming.

The global-warming credits are tied to use of tight seals, so refrigerant leaks less into the atmosphere. Because R-134a is more reactive, even a tight-sealing system receives a credit of just 6.3 g/mi for cars, 7.8 g/mi for trucks. R-1234yf has such a small effect because if it leaks out, it dissipates quickly (in just a few days vs. many years for R-134a). So it gets larger credits—13.8 g/mi for cars, 17.2 g/mi for trucks.

Both refrigerants are used with technologies that improve operating efficiency—better heat exchangers, more efficient compressors, and occasionally for R-134a (but certainly for R-1234yf) the addition of an internal heat exchanger (IHX). More precise compressor controls will be needed to better match compressor output to cooling load, reducing energy wasted by cooling air to 32° F (0° C) and then reheating it to a cabin-comfort level. Because of this, both refrigerant systems can receive the same efficiency credits: 5 g/mi for cars and 7.2 g/mi for trucks (fleet average of 5.7 g/mi).

IHXs potentially produce a larger benefit for R-1234yf,

Behind this inconspicuous Malibu Eco grille is a technology—active-aero grille shutters—that counts for CAFE credits.

but pose a tough balancing act for A/C calibration engineers. **Cadillac**, the first domestic brand to install R-1234yf in the U.S. (used in the 2013 XTS), put a temporary hold on using R-1234yf in the 2013 ATS. GM engineers said they need to recalibrate the system for better performance with the IHX.

Idle-stop-start: These systems are grouped with a broad array of technologies expected to play an important role in raising vehicle fuel economy. They include high-efficiency exterior lighting; waste heat (exhaust) recovery; active engine and transmission oil warm-up systems; and active aerodynamic systems—grille shutters, deployable spoilers, air suspension, etc.—contributing to a minimum 3% drag, or Cd, reduction.

Car makers have asked for window-sticker credits for idle-stop-start systems, but U.S. EPA argues that would be "double dipping" since under CAFE stop-start already gets carbon credits—worth 2.0 g/mi on cars and 2.9 g/mi on trucks not equipped with an electric pump to circulate coolant, and 2.5 g/mi on cars (4.4 g/mi on trucks) with the coolant pump. The electric pump is no longer available as a separate (1.0 g/mi) credit. (EPA also still lacks a sufficient test cycle in which a window-sticker fuel economy rating for stop-start could be achieved.)

These technologies offer a theoretical credit total of 10.8 g/mi for cars (14.1 g/mi for hybrids, PHEVs, and EVs), 17.8 g/mi for trucks (21.1 g/mi for hybrids, including PHEVs and EVs). But as noted below, these credits are capped, to a limit of 10 g/mi for a vehicle fleet.

Electrification: To incentivize sales of electrified vehicles, CAFE assigns a temporary "technology multiplier" to the sale of each battery-, fuel-cell- (FCV), and CNG-powered vehicle, with the value of the multiplier descending each model year from 2017-21. For example, for EVs a factor of 2 is applied, meaning if an automaker sells 5000 EVs it will be credited with 10,000 sold in that company's fleet fuel economy calculations. In 2020, each EV and FCV counts as 1.75 vehicles, and 1.5 in 2021. Plug-in hybrids (and CNG models that also run on gasoline) have a factor of 1.6 in 2017, dropping to 1.45 in 2020 and 1.3 in 2021.

Hybrid full-size pickup trucks get per-vehicle credits if sold in substantial numbers. The credit is 10 g/mi for mild hybrids and 20 g/mi for strong hybrids, respectively. There's also a performance-based incentive credit that achieves significant emissions reductions below the target level corresponding to the trucks' footprint. The credit is 10 g/mi for pickups achieving 15% lower CO_2 than their target, and 20 g/mi for pickups achieving 20% lower. Access to the hybrid- and performance-based credits in any model year is predicated on achieving a minimum penetration of the technology in a manufacturer's full-size pickup truck sales.

Solar/thermal control: A schedule of new credits for these technologies also was released, as a subset to the overall list of credits. The credits cover features such as solar-control glass, body reflective paint, active seat ventilation, and passive or active cabin ventilation. Active ventilation can be a fan system triggered by the in-car temperature sensor to moderate the vehicle's interior temperature.

A related example is a vehicle with solar panels that recharge the battery pack and/or keep the interior of the car cooler by running a fan to reduce cabin temperatures during a parked-in-the-sun heat soak. This will reduce the amount of cooling the A/C has to do when the car is operating, lowering the fuel consumption from that system. A 75-W solar panel array alone earns 2.5 g/mi if used for cabin ventilation and battery charging (3.3 g/mi if for battery charging only).

While some of the credits seem generous, they also may face caps. The total number of solar/thermal control credits could total 8.3 g/mi for cars, 10.3 g/mi for trucks. But a car can't get more than 3.0 g/mi, and a truck more than 4.3 g/mi. This is designed to prevent a manufacturer from "overloading" a vehicle with credits. And those solar/thermal credits are part of the 10 g/mi total fleet average that a manufacturer may claim.

Paul Weissler

EPA Projections for Fleetwide Tailpipe Emissions Compliance with CO_2 Standards – Combined Passenger Cars and Light Trucks, grams per mile

		Incentives			Projected	Credits			
Model Year	Projected CO_2 Compliance Target	Advanced Technology Multiplier	Pickup Mild HEV + Strong HEV	Intermediate Volume Provision	Achieved CO_2	Off Cycle Credit	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2016 (base)	250	0	0	-	250	0.5	5.8	4.8	261
2017	243	0.4	0.0	0.1	243	0.6	7.5	5.0	256
2018	232	0.7	0.1	0.3	234	0.8	9.9	5.0	249
2019	222	1.0	0.1	0.1	223	0.9	11.7	5.8	242
2020	213	1.0	0.1	0.1	214	1.0	13.4	5.8	234
2021	199	0.8	0.2	-	200	1.1	15.0	5.8	222
2022	190	0.0	0.2	-	190	1.4	15.0	5.8	212
2023	180	0.0	0.2	-	181	1.7	15.0	5.8	203
2024	171	0.0	0.2	-	172	1.9	14.9	5.7	194
2025	163	0.0	0.3	-	163	2.3	14.9	5.7	186

multiple of 2 on each EV or FCV sold in MY2017. So 5000 units sold will be counted as 10,000 for an automaker's fleet fuel economy calculation. The multiplier reduces to 1.5 by 2021. For PHEVs, the multiplier begins at 1.6 in 2017 and phases down to 1.3 in 2021.

By incorporating language for plug-in electrics and FCVs, the federal government struck a balance in satisfying California's zero-emissions vehicle (ZEV) mandate—getting the state's air-quality regulators to buy into the national rules—while maintaining a standard set of rules across all 50 states, noted Suzanne Cole, CEO of the regulatory-affairs firm **Miller Cole LLC**.

"This was really a win for the industry, as it desperately sought to avoid gravitating back to a California-vs.-the-other-states situation—two sets of regulations that would be hugely expensive," she said.

Cole noted that automakers can choose to comply with the rules by buying ZEV credits from each other. The rules also provide specific incentives for mild- and strong-hybrid light-duty trucks if sales are sustained above a certain level.

Martec Group's Selecman asserts that the ZEV credits aren't an effective way of complying with CAFE. "The difference in consumption between a conventional car's 55 mpg and a plug-in's 100 e-mpg equivalent, in terms of the CAFE calculation, is fractional," he said. "So adding those e-mpg's instead of having a lot of 55-mpg cars will really have a minimal impact on the overall compliance. It doesn't move the needle enough."

Overall, the powertrain component "is going to be your biggest friend or your worst enemy in how you're going to get to 54.5 mpg—powertrain and lightweighting initiatives," said Sandy Munro, CEO and founder of **Munro & Associates**, a product development and technology consultancy.

The critical 2018 midterm review

Product planners, engineers, and company leaders generally agree that the

2017-25 CAFE standards are a tough set of challenges. And they're almost unanimous about the importance of the midterm review of the program that's set for the 2018 time frame. The review—another win for the industry—will determine whether the 2021-25 phase remains technically feasible, cost-effective, and ultimately saleable to the end customer.

"Frankly, we think the 2018 review is one of the most important, if not the most important, aspects of the program," Tom Baloga, Vice President of Engineering for **BMW North America**, told *AEI* in spring 2012. 'Right now, no one really knows whether we'll need some technologies that haven't yet been invented or proven. The industry and government may need to make adjustments by then." AEI

Part 2 of the Meeting CAFE 2017-25 series appears in the Nov. 6 print edition of AEI.

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