Technology Leapfrog: Or, all recent auto technology forecasts underestimate how fast innovation is happening

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The key to vehicle efficiency standards is technology forecasting, which is the centerpiece of a painstaking process the regulatory agencies go through to determine challenging but realistic mpg targets. The 2017–2025 light duty fuel economy (NHTSA) and CO_2 (EPA) standards are based upon technology assessments done in 2012. Because of the long leadtime, the EPA regulation provided for a mid-term evaluation for the 2022–2025 model years. (NHTSA's rule only runs through 2021, so a mid-term evaluation there isn't needed; instead, a new rule will be forthcoming.) The regulatory agencies have been doing a lot of work to update their technology benefit and cost estimates for this evaluation. The first step was a Technology Assessment Report (TAR) issued in September 2016. The next step will be a complete report, due by April 2018.

We at the ICCT cooperated over the past year-plus with vehicle suppliers on an independent series of reports on technology advancements since 2012. These reports found substantial reductions in the cost of many technologies. More importantly, many technology improvements have occurred in the last 5 years that had not been factored into the 2012 assessment by the agencies—the efficiency gains from those innovations are a sort of bonus that helps automakers meet the targets more easily than the agencies had forecast. Examples of those "bonus" technologies: high-compression-ratio naturally aspirated engines (e.g. Mazda SkyActiv); Miller cycle (basically Atkinson cycle for turbocharged engines); dynamic cylinder deactivation (can shut off individual cylinders every other revolution); variable compression ratio; lower cost 48v hybrid systems; E-boost (small, 48v electric compressor motor within a turbocharger); improved continuously variable transmissions; lightweighting advances; and numerous thermal management strategies.

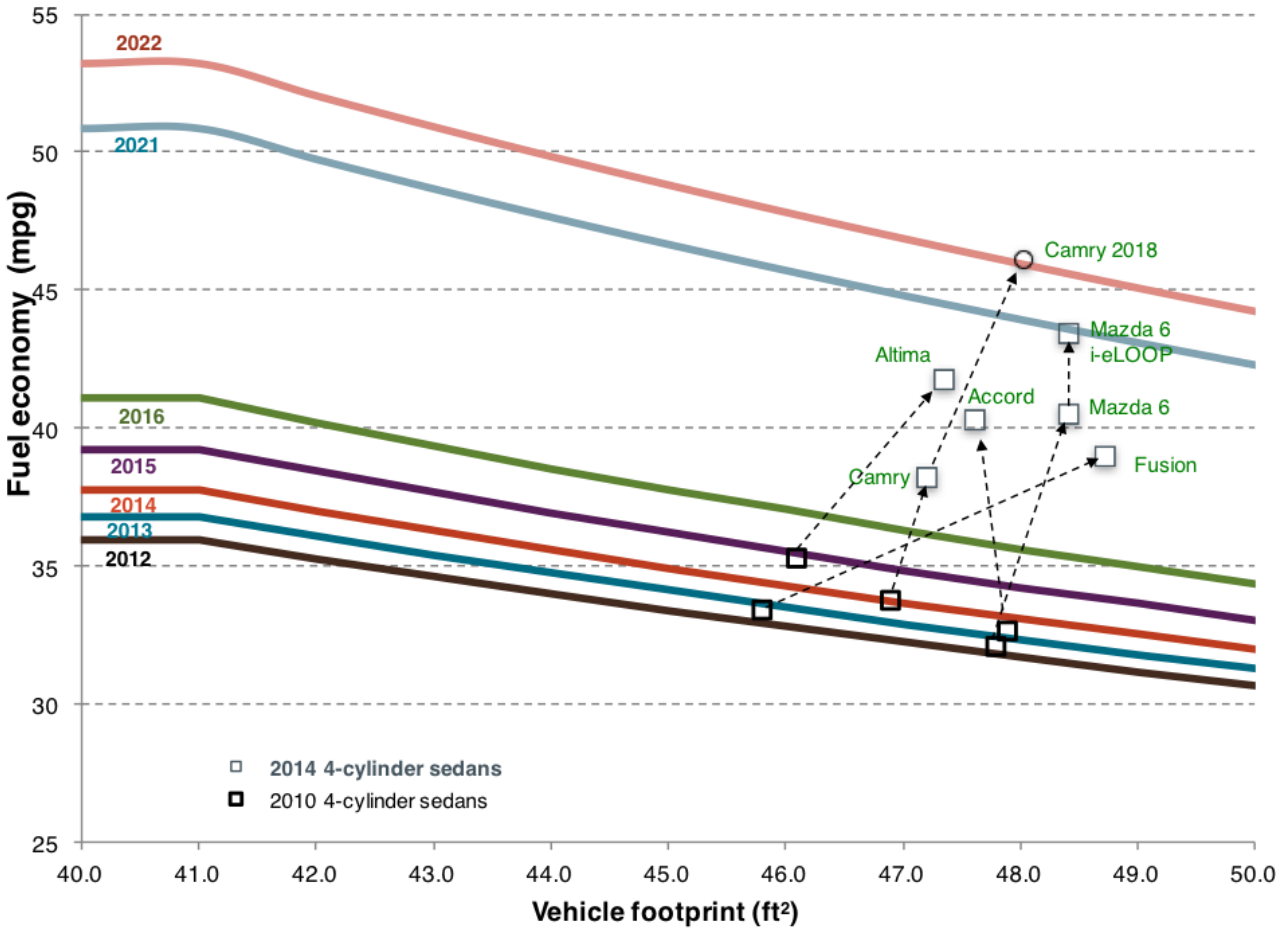
In fact, even the reassessment that the agencies did just last year as the first step in the mid-term evaluation failed to consider a number of technology advances that are already in production or close to production—such as E-boost, dynamic cylinder deactivation, variable compression ratio, and numerous thermal management strategies—and continued to overestimate the cost of some technologies.

Well, despite the best efforts of the agencies, suppliers, and the ICCT, recent announcements from Toyota, Mazda, and Volvo have already made the updated technology assessments of the past year obsolete, as the industry continues to play technology leapfrog at an astounding rate.

Start with the 2018 Camry. The Camry redesign included only modest weight reduction and the base engine did not include any kind of hybridization, not even a stop/start system. Yet the fuel economy for the standard engine improved by more than 20%. Toyota accomplished this primarily by developing an engine with very high efficiency (Dynamic Force Engine). The basic structure of very high compression ratio (13.0:1) and Atkinson cycle functions is similar to the Mazda SkyActiv engine, but Toyota leapfrogged it by adding a lot of small improvements, including:

- Longer stroke
- Widening the angle of the valves
- VVT-iE (Variable Valve Timing intelligent system by Electric motor) on the intake side – the electric motor provides better control than oil pressure
- Combination of both higher-pressure direct fuel injection (DI) and lower-pressure port fuel injection (PFI)
- Multi-hole (six per injector) nozzle direct injectors
- Variable cooling system
- Full variable oil pump
- Cooled Exhaust Gas Recirculation (EGR) system
- High efficiency intake port with laser-clad valve seats

Individually these improvements are small, but they add up. To illustrate the improvements made by Toyota, the chart below plots mid-size car fuel economy against the footprint-based fuel economy targets. The bold squares are 2010 fuel economy values (unadjusted test results), the lighter squares are improvements implemented in 2014, including the Mazda 6 with SkyActiv, and the round circle is the 2018 Camry. When compared against the Mazda 6 SkyActiv engine without the optional e-loop advanced stop/start system, Toyota has leapfrogged the efficiency of the Mazda SkyActiv system by about 14%. (A small part of the improvement is due to the 8-speed automatic transmission on the 2018 Camry.) In fact, the base 2018 Camry meets its 2022 fuel economy target without even considering off-cycle and air-conditioning efficiency credits, without a stop/start system, and with very modest weight reduction. Just maximizing the off-cycle (10 gram/mile CO_2) and air conditioning efficiency (5 gram/mile CO_2) "menu" credits would increase the 2018 Camry mpg by 3.9 mpg up to 50.0 mpg, just 0.4 mpg below its 2024 target of 50.4 mpg. The Camry can easily reach its 2025 target of 52.7 mpg with modest weight, aerodynamic drag, or tire rolling resistance reduction, adding a stop/start system, or even petitioning EPA for additional off-cycle credits beyond the ones listed in the off-cycle "menu."



But Mazda is not standing still. Oh, no. They just announced they are taking another massive leapfrog into homogenous charge compression ignition (HCCI) for 2019. HCCI has been the holy grail of gasoline engine efficiency for decades, but controlling the timing of ignition of the fuel is extremely difficult. Diesel fuel ignites immediately upon injection, so the timing is controlled by the fuel injection, but HCCI is pre-mixed and the gasoline ignites as the cylinder temperature rises due to compression. Mazda solved the ignition timing problem by injecting a tiny amount of fuel directly at a spark plug and coordinating this additional fuel injection with a spark to precisely control the combustion timing and ignite the lean, pre-mixed fuel around it. Mazda calls this process
Spark **C**ontrolled **C**ompression **I**gnition, or SPCCI. Here are key excerpts from Mazda's statement:

- "A proprietary combustion method called Spark Controlled Compression Ignition overcomes two issues that had impeded commercialization of compression ignition gasoline engines: maximizing the zone in which compression ignition is possible and achieving a seamless transition between compression ignition and spark ignition."

- "Compression ignition and a supercharger fitted to improve fuel economy together deliver unprecedented engine response and increase torque 10-30 percent over the current SKYACTIV-G gasoline engine."

- "Compression ignition makes possible a super lean burn that improves engine efficiency up to 20-30 percent over the current SKYACTIV-G, and from 35-45 percent over Mazda's 2008 gasoline engine of the same displacement. SKYACTIV-X even equals or exceeds the latest SKYACTIV-D diesel engine in fuel efficiency."

Meanwhile, Volvo has announced something just as radical. Instead of maximizing the efficiency of the engine, Volvo has decided that 48v hybrid systems are the path to the future and will make them standard on every vehicle they redesign starting in 2019. As we explained in detail here, 48v hybrids deliver more than 60% of the benefits of full hybrids at only 30%–40% of the cost. Making the 48v hybrid system standard allows Volvo to integrate the electric motor into the powertrain, for further cost reduction and packaging improvements.

Here's the thing: The technologies announced by Toyota, Mazda, and Volvo are equally applicable to all vehicles, including sport utility vehicles, crossovers, and pickup trucks. Toyota notes that the Dynamic Force engine is "currently being adapted to V-6 and V-8 engines, and it will also spread to trucks and utility vehicles", and Volvo is adding its 48v hybrid system to every vehicle in its model lineup.

Proponents of rolling back the standards continue to rely on a Novation Analytics study commissioned by the U.S. Alliance of Automobile Manufacturers to make their case. That study is an excellent analysis of 2014 vehicles and technology in the U.S., and a great reference for baseline vehicles. However, it is not an engineering assessment of future technology. Instead, it simply assumes that the average engine in 2025 will have the same efficiency as the better (defined as 90th percentile) engines in 2014. To make it worse, even though the best 2014 engine was the Mazda SkyActiv engine, the Novation Study discarded it because Mazda only had 2% of the market and Novation therefore assumed that average 2025 engines wouldn't even match the efficiency of the 2014 SkyActiv engine – that one that Toyota has already leadfrogged by 14% in the Camry—the top-selling passenger car in the United States—and that Mazda will leapfrog again in 2019. Not only is 2019 less than half way to 2025, but none of these engines include the 48v hybrid system that Volvo will start making standard on all of its redesigned vehicles in 2019. The failure to incorporate these – and many other – rapid technology advancements caused Novation to improperly conclude that about a third of the 2025 fleet would have to be full hybrids. The Novation style approach might be appropriate in a world where the pace of technology innovation was limited and slow. But as we have demonstrated in this short paper, and in far more depth in the ICCT/supplier technology working paper series, innovation is happening at a rapid clip. Credible analysts must adapt to this reality in order to stay accurate and relevant.

And here's something else to ponder: Mazda only has 2% of the U.S. market, and Volvo is even smaller, yet both of them have already figured out pathways to meet the current 2025 standards. Completely different pathways, to boot, illustrating the wide variety of solutions available to different manufacturers. If the little guys with limited resources can do it, why can't the big guys with their far larger budgets?

The bottom line is that technology is coming at astounding rates. The current 2025 standards will not be difficult to meet and will cost a lot less than anybody has forecast. When NHTSA and EPA reevaluate the "appropriateness" of the 2025 standards, we would hope they take this information, and the underlying trend of accelerating technology innovation, into account.

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