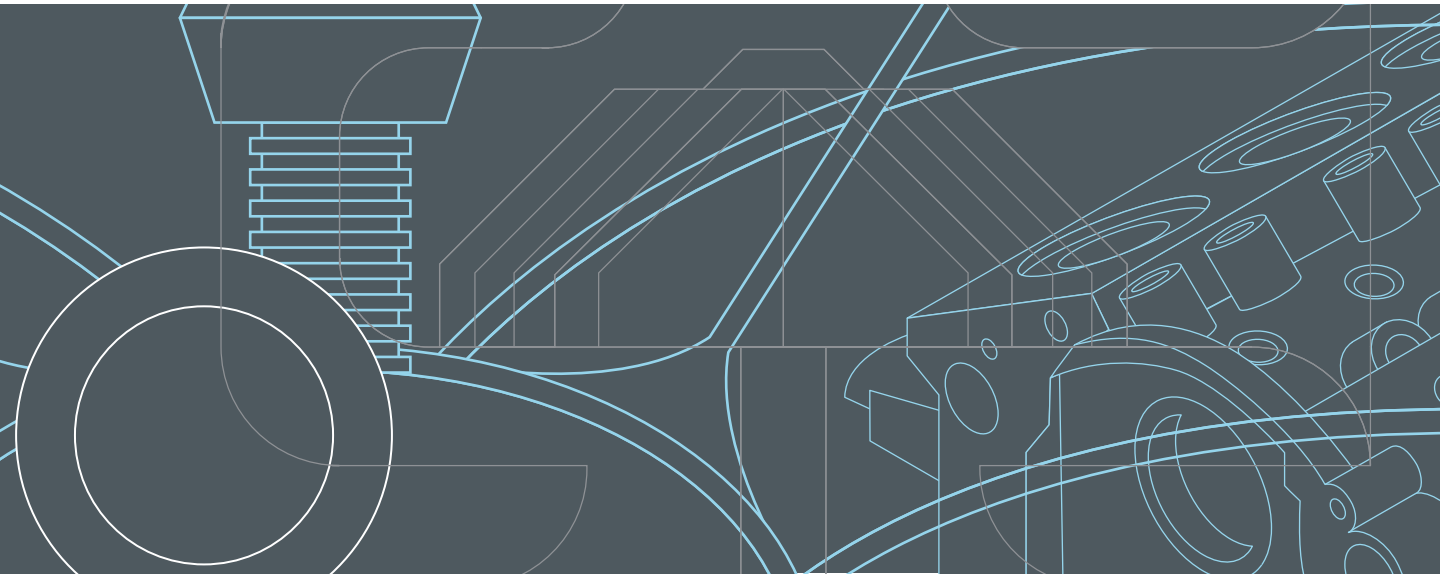


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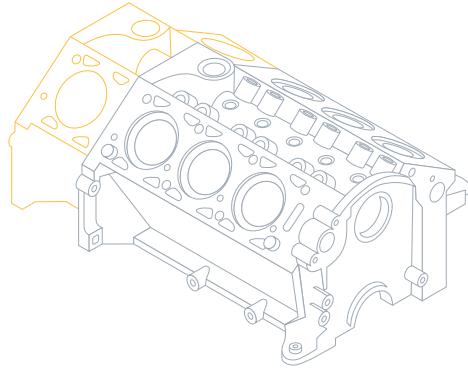
The International Council on Clean Transportation is an independent nonprofit organization that works directly with regulatory agencies and policymakers to control greenhouse gas emissions and conventional pollution in the transportation sector. Part of the ClimateWorks Network, the ICCT provides scientifically sound, technically rigorous analysis to inform the design, implementation, and enforcement of vehicle efficiency and fuel standards in countries accounting for 80 percent of the global automotive market, including China, the European Union, the United States, India, Brazil, South Korea, and Mexico.

1225 I Street NW
Washington, DC 20005
+1.202.534.1600

One Post Street, Suite 2700
San Francisco, CA 94104
+1.415.399.9019

48 Rue de Stassart, bte 6
1050 Brussels
+32.486.182.847

www.theicct.org



THE REGULATORY ENGINE: HOW SMART POLICY DRIVES VEHICLE INNOVATION

By Drew Kodjak, Executive Director; Anup Bandivadekar, Senior Researcher;
John German, Senior Fellow/Program Director; and Nicholas Lutsey, Senior Researcher
International Council on Clean Transportation

Automakers and parts manufacturers worldwide are revving their R&D engines to turn out low-carbon technologies. Toyota's Prius hybrid remains the fuel economy leader for mass-market autos, while Nissan and others have grabbed the spotlight with all-electric vehicles, and General Motors now offers a plug-in hybrid electric car. But many other companies are making moves that are less attention-grabbing yet just as important—tweaking the internal combustion engine in a multitude of ways that can slash oil consumption and greenhouse gas emissions across a far larger segment of the vehicle fleet.

Hidden behind this burst of vehicle technology innovation is a powerful force. New regulations to reduce greenhouse gas emissions—also known in some markets as fuel economy standards—are driving a flood of investments in new technologies that do much more than reduce carbon dioxide emissions or improve vehicle efficiency. These regulations are creating jobs; fostering automotive businesses such as battery, electronics, and lightweight materials manufacturing; and helping to solve a problem shared by all nations: the inefficient consumption of expensive, polluting oil.

NEW TECH UNDER THE HOOD

In the United States, automakers are incorporating a potent combination of valve train, engine, and transmission technologies in their new vehicle designs. Ford, for example, recently introduced four- and six-cylinder EcoBoost engines that raise fuel efficiency 20 percent and reduce CO₂ emissions 15 percent.

EcoBoost incorporates an amalgamation of technologies—125 patents and patent applications—but its real breakthrough is that it increases efficiency by modifying existing technologies and combining them in new ways, all at a relatively low cost. EcoBoost uses **direct injection** to deliver highly pressurized gasoline directly into the cylinder, creating a charge cooling effect and allowing a higher compression ratio without the risk of detonation. Plus, by decoupling fuel injection from air intake, variable cam phasers can increase valve overlap and air intake at low engine speeds. Fuel injection can be delayed until after the exhaust valve is closed, so no unburned fuel is emitted. This increases engine torque at low engine speeds, enhancing efficiency. In addition, **turbochargers** use waste energy from the exhaust to drive a turbine that compresses incoming air before it enters the cylinders, boosting the engine's output. This allows the engine to be downsized for improved efficiency. Because the EcoBoost engine runs unusually hot, Ford is adapting a common emissions-control technology, **exhaust gas recirculation**, to reduce the combustion temperature. This "cooled EGR" system takes a portion of the exhaust, cools it in a heat exchanger, and draws it back into the engine's cylinders. The lower combustion temperature boosts the turbocharger, adding power and torque even at low rpm, yet reducing fuel use.

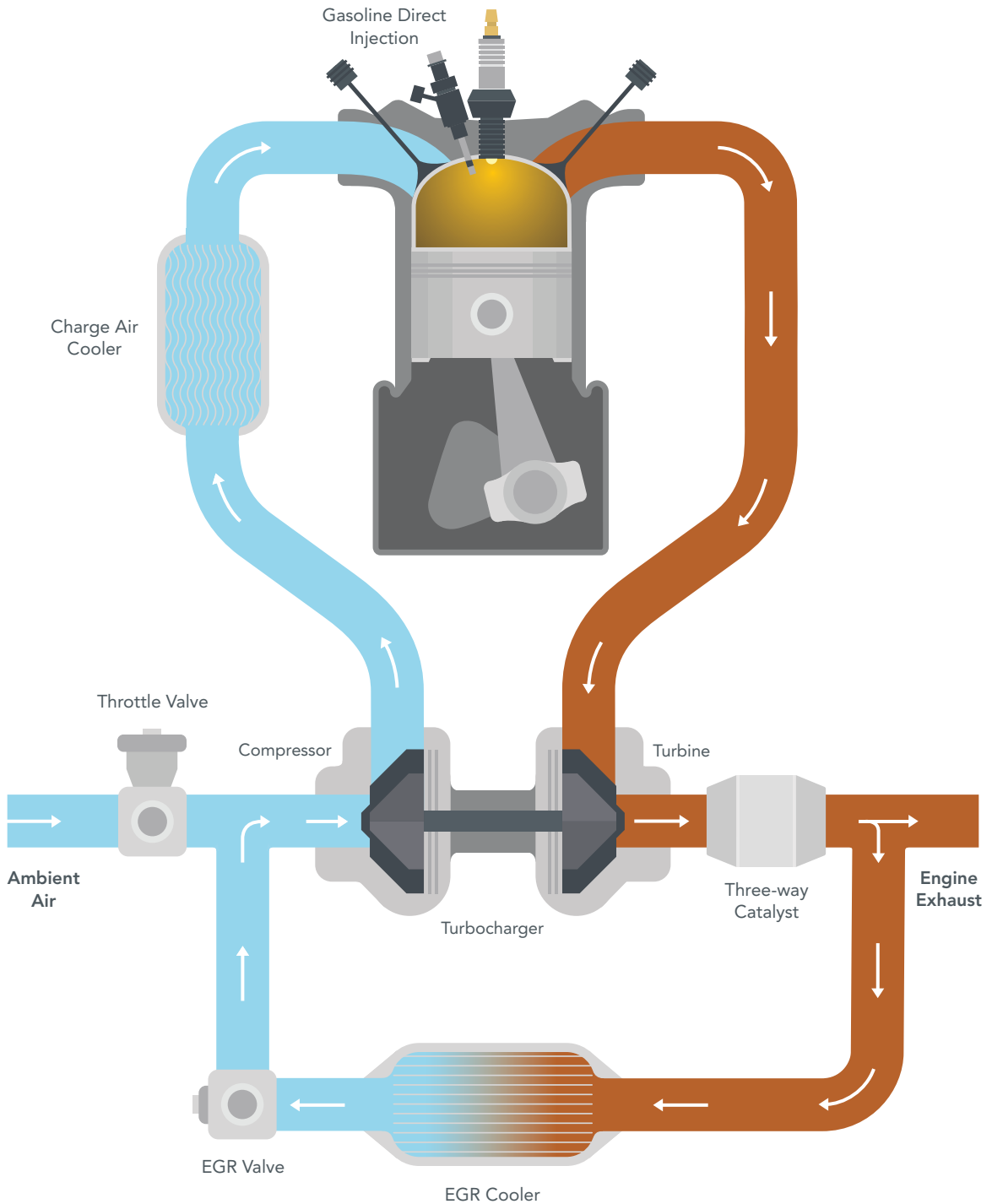
It's not the sort of sexy technology that would make Hollywood stars pony up more than \$100,000 for a sports car, but that's exactly the point. With a price premium of only about \$700, EcoBoost gives car buyers a more affordable option than electric or even

"Ford is pursuing multiple technology paths to provide solutions for climate change."

— Derrick Kuzak

Vice President for Global Product Development, Ford Motor Co.

NEXT-GENERATION HIGH-EFFICIENCY ENGINE



New engines under development combine gasoline direct injection, turbocharging, and cooled exhaust gas recirculation in various ways to boost efficiency.

hybrid cars, allowing them to recoup the added cost through fuel savings in a fraction of the time. EcoBoost is now standard in the Ford Taurus SHO, and Ford plans to offer it in about 90 percent of its other models worldwide by 2013.

“Ford is pursuing multiple technology paths to provide solutions for climate change,” says Derrick Kuzak, Ford’s vice president for global product development. “One of our principles is ... providing near-term solutions that are affordable for our customers and available in high volumes.”

In addition to EcoBoost, Ford is deploying a host of innovations that improve efficiency, including advanced vehicle designs and materials that whittle vehicle weight 250 to 750 pounds, six-speed PowerShift dual-clutch automated manual transmissions, improved aerodynamics, and electrified accessories such as power steering.

Manufacturers and suppliers are also shifting development of automatic transmissions into high gear. A six-speed transmission can improve fuel economy between 4 and 6 percent, and an eight-speed can boost efficiency another 2 to 3 percent. Continuously variable transmissions, which provide an infinite number of gear ratios, or dual-clutch automated manual transmissions typically get up to 10 percent better fuel economy than a conventional four-speed automatic.

These emerging, largely unnoticed technologies are boosting the fuel economy of mainstream cars. New models of the Chevrolet Cruze, Ford Fiesta, Ford Focus, and Hyundai Elantra will combine mass reduction, aerodynamic improvements, engine efficiency, and transmission technologies and achieve an official EPA highway fuel economy rating of at least 40 miles per gallon.

Several automotive developers, including suppliers Bosch and Valeo, are taking a different tack, borrowing a much-noted feature of hybrid engines: start-stop technology, which turns off the engine when the vehicle comes to a stop and restarts it when the driver’s foot leaves the brake pedal. Bosch pioneered a start-stop system for internal combustion engines that can reduce fuel consumption by about 5 percent, depending on conditions. BMW, Toyota, Mazda, Renault, Mahindra, and Tata have already introduced it in some models, and Ford is planning to add it to its future EcoBoost models.

The cost of hybrids has dropped significantly. Nissan, Hyundai, Volkswagen, Audi, and Porsche will introduce models that have a basic parallel hybrid system with two clutches, one before and one after the electric motor. This allows the electric motor to be decoupled from the engine, increasing the amount of energy that can be recaptured through regenerative braking and greatly extending the electric motor’s ability to power the vehicle with the engine off. This parallel hybrid system is almost as efficient as Toyota’s power-split hybrid system, but it’s far less complex and expensive. The lower cost will attract more customers and accelerate hybrids’ market penetration.

Vehicle efficiency improvements span the globe

- ⚙️ Cummins Inc., which manufactures diesel engines for trucks, 18-wheelers, and other heavy equipment, is working with the U.S. Department of Energy to improve vehicle freight efficiency by a whopping 50 percent. Cummins combines an efficient and clean diesel engine, an advanced waste-heat recovery system, an aerodynamic tractor-trailer combination, and a fuel-cell auxiliary power unit that reduces engine idling.
- ⚙️ Hyundai's Hybrid Blue Drive technology, which debuted in 2010, uses an all-aluminum engine and a lithium-polymer battery to shave weight. Hyundai says cars with the new technology can be driven much faster in electric-only mode than competing models. Other innovations include friction-reducing engine components and continuously variable valve timing on both camshafts.
- ⚙️ PSA Peugeot Citroën has developed a new stop-start system for diesel engines. Dubbed e-HDi, it delivers improvements of up to 15 percent in fuel efficiency and CO₂ emissions¹ and will be deployed on Peugeot and Citroën models in early 2011.
- ⚙️ Mitsubishi Fuso Truck and Bus Corporation created a new diesel power train for its commercial light- and medium-duty trucks and large buses that lowers fuel consumption by about 10 percent. The engines' dual-clutch transmission merges the efficiency of a manual transmission with the ease of an automatic for city driving.
- ⚙️ Bajaj, India's second-largest two-wheeler manufacturer, is championing a low-cost, low-emissions car for the nation's millions of motorcyclists who want to trade up to a car. The Bajaj-Renault ULC car is expected to be on the road by 2012, with a target of 30 kilometers per liter (71 miles per gallon) and 80 to 90 grams of CO₂ emissions per kilometer. In comparison, its chief low-cost competitor, the Tata Nano, has fuel economy of 23.6 kilometers per liter and emits 101 grams of CO₂ per kilometer. On average, small cars in India get 15 to 18 kilometers per liter and emit 140 to 150 grams of CO₂ per kilometer.




¹ On the E.U. test cycle. The benefits on the U.S. test cycle are approximately half those on the E.U. cycle.

Meanwhile, a revolution is brewing in the development of lightweight materials: high-strength steel, aluminum, plastics, and magnesium. Over the next decade, vehicle weights are expected to drop by at least 20 percent; 30 to 35 percent reductions should be feasible by 2030. A 10 percent weight reduction yields about a 6 to 7 percent improvement in fuel economy. As vehicle designs jettison excess weight, advanced technologies like hybrids become increasingly cost-effective.

A promising internal combustion technology is boosted exhaust gas recirculation (EGR), which uses the turbocharger to increase air intake and allow EGR to operate at higher loads. At maximum load, the higher rate of exhaust recirculation decreases heat loss, improving efficiency and greatly decreasing detonation, which in turn allows much higher compression ratios for further gains in efficiency and power. These engines are still in development, but they offer the potential for large gains in efficiency.²

² The High-Efficiency, Dilute Gasoline Engine (HEDGE) Consortium is working on three types of boosted-EGR engines. www.swri.org/9what/releases/2010/hedge.htm

“In the coming years, much of the increased fuel efficiency will come from a lot of small technological improvements that are already under way,” says Anup Bandivadekar, a senior researcher at the International Council on Clean Transportation. “They include six- and seven-speed automatic transmissions, dual-clutch transmission, improved engine lubrication, reduced aerodynamic drag, lightweight materials, and a lot more.”

EFFICIENCY GAINS AND COSTS			
	Technology	Reduction in CO ₂ emissions	Incremental price per vehicle
 Engine	Low-friction lubricants	0.5%	\$3
	Engine friction reduction	1–3%	\$50–100
	Variable valve timing and lift	3–4%	\$125–259
	Cylinder deactivation	6%	\$150–169
	Turbocharged downsized engine	5–7%	\$149–1,099
	Camless valve actuation	5–15%	\$501
	Gasoline direct injection (stoichiometric)	1–2%	\$209–346
 Transmission	Continuously variable transmission	6%	\$192–224
	Six-speed automatic	4.5–6.5%	\$99
	Six-speed dual clutch	5.5–13%	\$47–92
 Vehicle	Aerodynamic drag reduction (20% cars, 10% trucks)	2–3%	\$42
	10% reduction in tire-rolling resistance	1–2%	\$6
	10% reduction in weight	6.5%	\$518–666
	High-efficiency alternator and electrified accessories	1–2%	\$76
	Electric power steering	1.5–2%	\$94
	Integrated stop-start system	7.5%	\$351–437
	Hybrid motor assist	20–30%	\$2,854–4,431

Source: “Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Joint Technical Support Document,” U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, April 2010. www.epa.gov/otaq/climate/regulations/420r10901.pdf

INNOVATION DRIVES JOBS

These innovations not only reduce fuel use and emissions; they can also boost profits and create jobs, from the U.S. Rust Belt to Europe to southern China.

A key example came in May 2010, when Toyota announced a joint venture with Tesla Motors to reopen the shuttered NUMMI plant in Fremont, California, and employ 1,000 workers. They will produce the Tesla Model S sedan and an all-electric version of Toyota's RAV4 SUV at the plant, building on Toyota's success with the hybrid Prius and other fuel-efficient cars.

In Cleveland, Ohio, Ford reopened a mothballed plant in 2009 to build EcoBoost engines, investing \$55 million and hiring 250 workers. Expanding production will employ thousands more across the country.

In China, BYD Auto has received a \$230 million investment from Warren Buffett and an \$88 million co-investment from Daimler. Development and production of BYD's new F3DM plug-in hybrid and planned E6 electric car employ hundreds of engineers and other workers at the company's sprawling headquarters in Shenzhen, near Hong Kong.

General Motors announced plans to hire 1,000 engineers to work on its electric vehicles. BMW AG says it is recruiting 2,600 new employees to develop models with lower CO₂ emissions to meet regulators' demands for cleaner-running cars. And Bosch, which invests roughly 400 million euros each year in engineering electric drives, has increased the number of workers developing technology for hybrid and electric vehicles from about 100 people in 2004 to some 800 today; another 650 people work on lithium-ion battery technology for vehicles through its joint venture with Samsung SDI.

VEHICLE EFFICIENCY STANDARDS: ENGINE OF GROWTH

What is driving these investments? Across the globe, innovation and economic growth are being stimulated by tightened fuel economy regulations.

Recent research shows that the shift to greater fuel economy can drive demand for additional manufactured components, which promotes greater investment and greater labor content per vehicle. Specifically, the research found that "supplying the U.S. automobile market with more efficient cars could provide a net gain of over 190,000 new jobs." However, the location of those jobs largely depends on policy decisions, including fuel economy standards and domestic production incentives.³

³ Alan Baum and Daniel Luria, "Driving Growth: How Clean Cars and Climate Policy Can Create Jobs," March 2010. www.uaw.org/sites/default/files/Driving_Growth_Paper_CAP_NRDC_UAW_Mar2010_FINAL.pdf

“Tighter regulations are a fact of life. Back in the ‘90s we saw this as burdensome, but we now see this as an advantage. If we have the advantage, either in fuel economy or emissions or both, we’re going to gain market share, we’re going to be able to enter new markets. As a result, we secure employment and grow the business.”

— Tim Solso

Chairman and CEO of Cummins Inc.

An increasing number of automakers and parts manufacturers are realizing that getting ahead of emissions and fuel economy standards is good for public relations and the bottom line. Examples abound of companies that spearheaded investments in low-carbon technology and innovation and gained a market advantage, adding profits and jobs.

“Tighter regulations are a fact of life. Back in the ‘90s we saw this as burdensome, but we now see this as an advantage,” says Tim Solso, chairman and CEO of Cummins, the diesel engine manufacturer. “If we have the advantage, either in fuel economy or emissions or both, we’re going to gain market share, we’re going to be able to enter new markets. As a result, we secure employment and grow the business.”

New regulations—and recognition of powerful, long-term public policy drivers such as climate change and oil security—have created an opening for high-tech and other innovative companies to expand into the automotive market. In China, for example, BYD’s plug-in hybrid model emerged soon after China adopted its first fuel economy standard for autos and light-duty trucks in 2005. In the United States, the Tesla-Toyota joint venture was launched a year after the Obama administration announced new national fuel economy standards of 35.5 miles per gallon by 2016. Since 2008, when Hyundai earned the best average fuel economy of automakers in the U.S. market, its market share has soared 44 percent. And Hyundai pledged in 2010 that its entire U.S. product lineup will average at least 50 miles per gallon by 2025—a 60 percent improvement over its current models.

“We want to lead the industry in fuel efficiency,” John Krafcik, the CEO of Hyundai Motor America, announced in August 2010. “We’re doing it now. We want to help set the trajectory for the industry.”

A laggard hopes to lap an upstart

In auto manufacturing, the race to be green sometimes means playing catch-up. In China, SAIC Motor Corp. is catching up as fast as it can.

SAIC, one of China's largest automakers, had long thought it had no reason to fear BYD. Founded by Wang Chuanfu in the mid-1990s to manufacture low-cost rechargeable batteries, BYD had become the world's top producer of cell phone batteries by the early 2000s. After purchasing a near-bankrupt automaker in Shaanxi Province in 2003, BYD shocked the auto industry in 2008 by producing the world's first plug-in hybrid, the F3DM, and announcing plans for its fully electric E6.

SAIC reacted by investing \$300 million to develop a different hybrid technology and throwing its engineering team into high gear. SAIC is also investing an additional \$880 million in clean energy vehicles, including a project with U.S. lithium-ion battery maker A123 Systems to develop a plug-in hybrid and an electric car. The plug-in is scheduled to be launched by 2012, while the rest remains under a cloak of secrecy. The technology may be green, but the competition is red hot.

Like Ford and other companies, Hyundai expects its engineers to focus primarily on currently available technologies. Only 15 to 20 percent of future models are projected to be hybrids or hybrid plug-ins, and 5 percent powered by fuel cells or batteries.

Krafcik admitted that Hyundai's goal is ambitious but said he is "very confident" the company can reach it. "We don't know specifically how to get there," he added. "But we do have a road map."

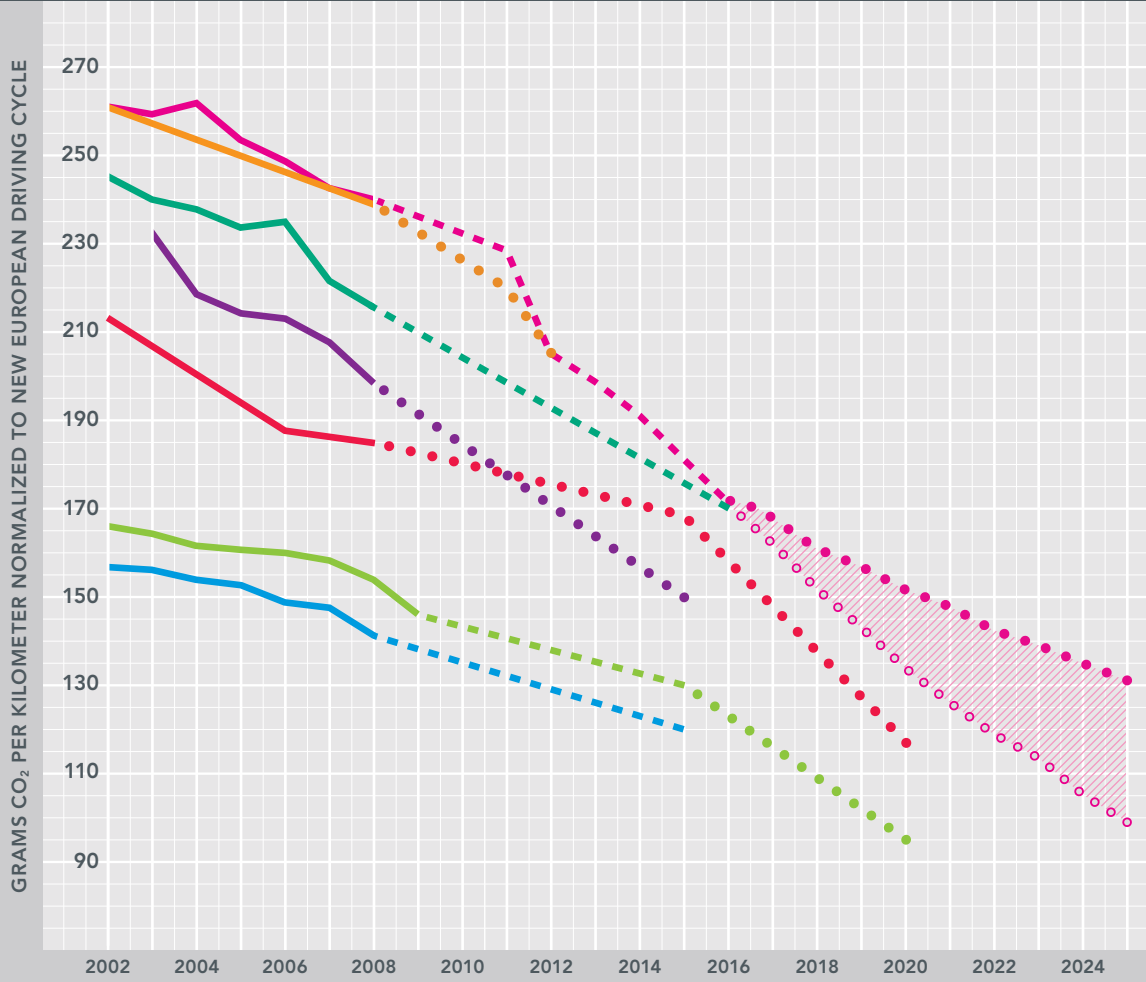
SMART FUEL STANDARDS PROVIDE A CLEAR ROAD MAP

Auto manufacturers operate on long time horizons; they need clear signals of upcoming standards and benefit from stable rules of the road. The most effective fuel efficiency regulations are predictable, stretching more than a decade into the future. Policymakers, executives, and investors alike are realizing the importance of steady, continuous strengthening of low-carbon regulations.

In fits and starts over the past three decades, about 70 percent of the world's transportation greenhouse gas emissions have come under regulation by national governments. The United States, European Union, Japan, China, Australia, Canada, and South Korea have adopted a variety of efficiency standards. In some cases these standards began as voluntary guidelines; all but Australia's are now mandatory. Mexico plans to announce fuel efficiency standards soon, and India, Indonesia, and Thailand are drawing up regulations.

VEHICLE GREENHOUSE GAS EMISSIONS BY REGION

ACTUAL FLEET AVERAGES PLUS ENACTED AND PROPOSED TARGETS



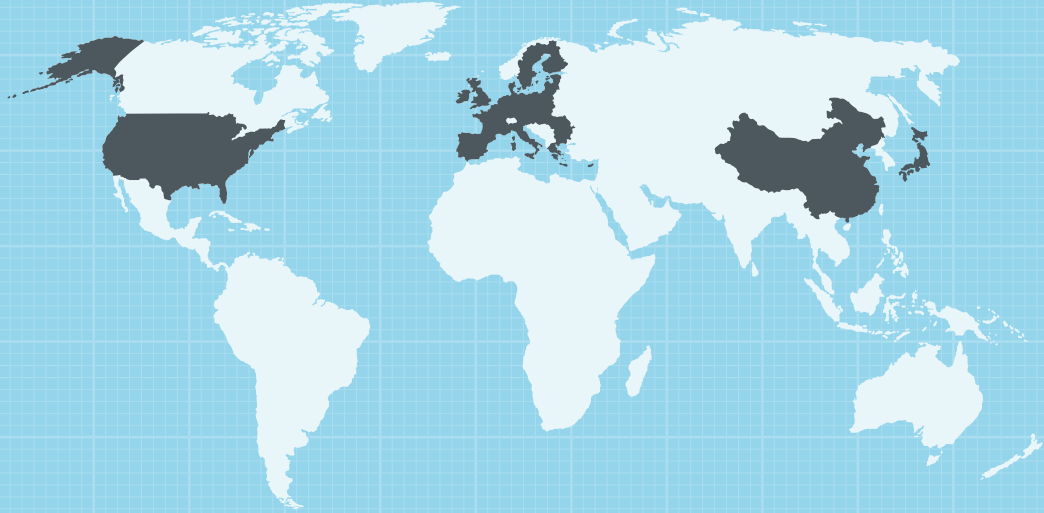
LEGEND

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|--------------------|------------|---------------------------------------|--------------------------------------|
| Japan | Canada | Solid line:
Historical performance | Proposed U.S. 3% target ¹ |
| E.U. | California | Dashed line:
Enacted targets | Proposed U.S. 6% target ¹ |
| China ² | U.S. | Dotted line:
Proposed targets | Uncertain targets |
| S. Korea | | | |

¹ Uncertain U.S. fleet targets of 3%–6% annual GHG emissions reductions between 2017 and 2025, as proposed in the Notice of Intent filed September 30, 2010, by the Environmental Protection Agency and the National Highway Traffic Safety Administration.

² China's target reflects a gasoline fleet scenario. If other fuel types are included, the target will be lower.

Regional standards



UNITED STATES

Although first to establish mandatory fuel economy standards, the U.S. has let its standards for autos stagnate at 27.5 mpg since 1985. (Its light-truck standards were raised approximately 2 percent per year from 2005 to 2010.) In 2010, the federal government finalized a 35.5-mpg fuel economy standard that will be fully phased in by 2016, and announced the world's longest timeline for greenhouse gas emissions standards, through 2025.

EUROPEAN UNION

After years of relying on voluntary targets, in 2009 the E.U. adopted CO₂ emissions standards for passenger cars: an average of 130 grams of CO₂ per kilometer by 2015, and a proposed target of 95 grams of CO₂ per kilometer (equivalent to 62 mpg) by 2020. The latter goal, if adopted, would reduce CO₂ emissions by 27 percent in 2030.

CHINA

Since China adopted fuel economy standards for autos and light-duty trucks in 2005, nationwide new-vehicle fuel economy has improved by 10 percent. Progress has slowed recently, but the government has made fuel economy a high priority and recently announced subsidies for buyers in several cities of up to 50,000 yuan (about \$7,500) for plug-in hybrids and up to 60,000 yuan (\$9,000) for full-electric cars.

JAPAN

The Top Runner system, introduced in 1998, divides the Japanese auto fleet into classes by weight. The most fuel-efficient vehicle in each weight class is designated the "top runner." At set intervals, all cars sold in that weight class must achieve this top-runner standard, and a new top runner is designated. In 2006, Japan introduced the world's first heavy-duty vehicle standards.

Smart standards playbook

Worldwide, the track record of vehicle efficiency standards shows that the effective standards are based on:

⚙️ **Consistent, predictable improvement.**

Efficiency standards send the most effective signal to the market when they're raised by a constant, predictable amount—ideally 3 percent to 6 percent annually over several decades—with sufficient lead time for manufacturers to synchronize investments with product retooling cycles.

⚙️ **Footprint, not weight.** Weight-based standards foster a shift to heavier vehicles because they are more lenient for heavier vehicles, so manufacturers have little incentive to use lightweight materials. Size- or footprint-based standards encourage development of high-strength aluminum, plastics, magnesium, and other materials that reduce weight and boost fuel economy.

⚙️ **Greenhouse gas-based emissions.** GHG-based standards are more effective than fuel economy standards because they cover methane, nitrous oxide, and emissions from

vehicle air-conditioning (about 5 percent of total vehicle emissions), in addition to carbon dioxide.

⚙️ **Covering the entire market.** Heavy-duty trucks and buses accounted for 22 percent of transportation emissions in the U.S. in 2009, up from 15 percent in 1990. In China, they accounted for 52 percent of transportation emissions in 2005. However, only Japan has approved fuel economy standards for heavy-duty trucks, although the U.S. has proposed standards for 2014–17. The U.S. National Academy of Sciences recently found that existing and emerging technologies could reduce heavy-duty vehicle fuel consumption 40 to 50 percent from 2015 to 2020. Many heavy-duty truck manufacturers and component suppliers pride themselves on energy efficiency. For instance, Mitsubishi is preparing for Japan's standards to take effect in 2015, and Cummins is trying to get ahead of its competitors by anticipating similar government policies. (See "Vehicle Efficiency Improvements Span the Globe," page 5.) Ideally, standards should cover the entire spectrum of vehicles.

The most effective standards follow a few simple guidelines: They are based on vehicle size rather than weight; they cover the whole vehicle fleet, including trucks; and they become more stringent over time.

Employing a scaling factor to vary the stringency of the emissions standards by weight or, preferably, vehicle size addresses manufacturers' primary argument that standards limit their ability to provide the vehicles people want. In the U.S., for example, adoption of footprint-based standards opened the door to aggressive increases in fuel economy.

These standards can trigger a virtuous cycle, in which smart policy fosters investment in new technology, which creates more economical choices and reduces climate and energy problems. As the market responds and shows that the standards are feasible, this, in turn, paves the way for more ambitious standards.

The ClimateWorks Foundation supports public policies that prevent dangerous climate change and promote global prosperity.

ClimateWorks' goal is to limit annual global greenhouse gas emissions to 44 billion metric tons by the year 2020 (25 percent below business-as-usual projections) and 35 billion metric tons by the year 2030 (50 percent below projections).

These ambitious targets require the immediate and widespread adoption of smart energy and land use policies. ClimateWorks and its network of affiliated organizations promote these policies in the regions and sectors responsible for most greenhouse gas emissions.



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