DENSO

SAE INTERNATIONAL®

The ICE - Is it dead again?!

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The Economist

Electric cars

The death of the internal combustion engine

It had a good run. But the end is in sight for the machine that changed the world

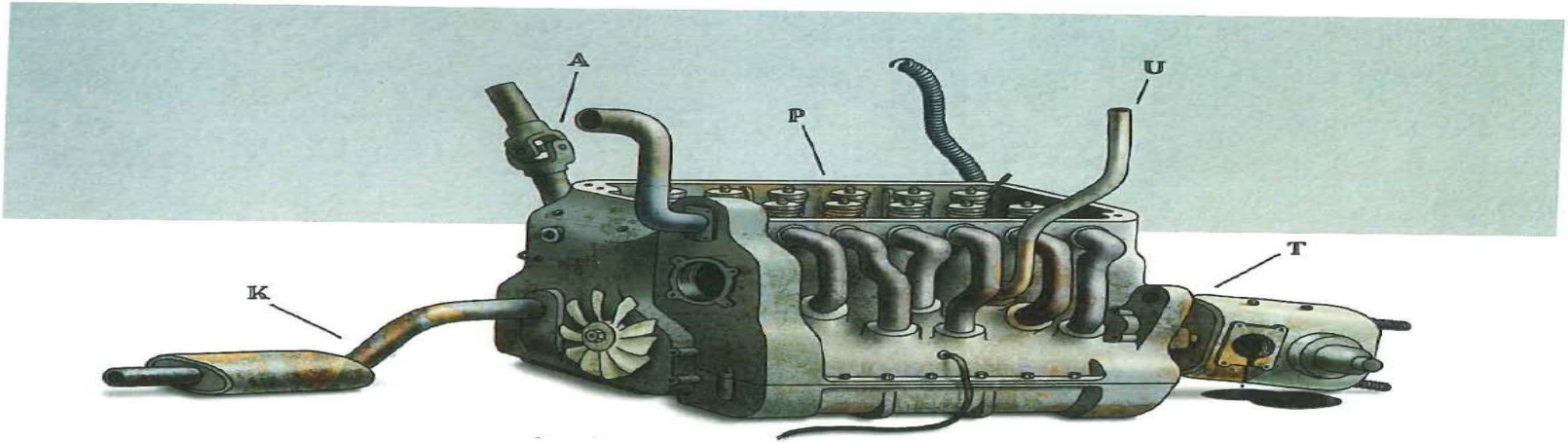

Fig. 1 The Internal Combustion Engine

Jon Berkeley

China, in EV push, plans ban on fossil-fuel vehicles

September 9, 2017 **Bloomberg**

Global Supplier of Advanced Automotive Technology, Systems and Components with $40.2 Billion in Sales

(As of March 31, 2017)

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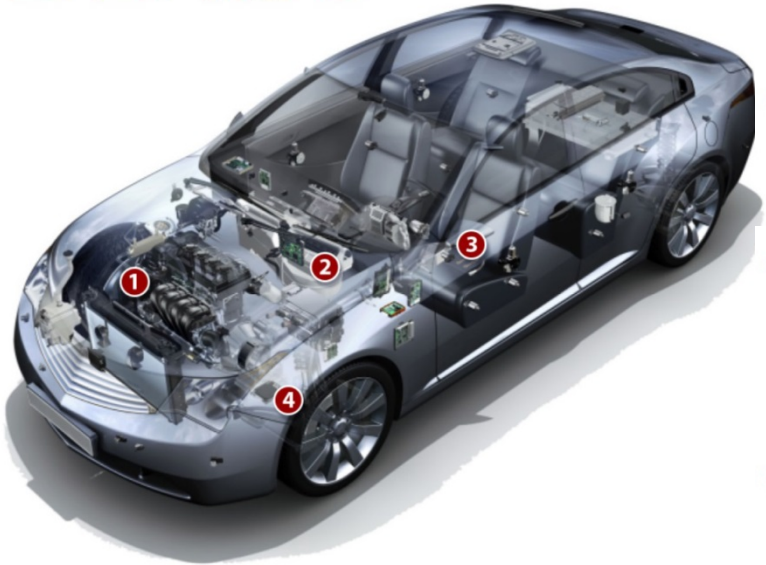


1. **Powertrain Control System**
   Engine management system, Gasoline direct injection, Hybrid components, Starter, Alternator, etc.
2. **Thermal Systems**
   Heating Ventilation Air Conditioning (HVAC), Compressor, Heat exchangers, Battery thermal management, etc.
3. **Information & Communications Systems**
   Instrument cluster, Head-up display, Human machine interface technologies, Horn, Keyless entry, Wireless phone charger, etc.
4. **Driving Control & Safety Systems**
   Passive safety technologies, Airbag sensing system, Active safety technologies, Traction control system, Antilock braking system, etc.

1680 - Dutch physicist, Christian Huygens designed (but never built) an internal combustion engine that was to be fueled with gunpowder.

1807 - Francois Isaac de Rivaz of Switzerland invented an internal combustion engine that used a mixture of hydrogen and oxygen for fuel. Rivaz designed a car for his engine - the first internal combustion powered automobile. However, his was a very unsuccessful design.

1824 - English engineer, Samuel Brown adapted an old Newcomen steam engine to burn gas, and he used it to briefly power a vehicle up Shooter's Hill in London.

1858 - Belgian-born engineer, Jean JosephÉtienne Lenoir invented and patented (1860) a double-acting, electric spark-ignition internal combustion engine fueled by coal gas. In 1863, Lenoir attached an improved engine (using petroleum and a primitive carburetor) to a three-wheeled wagon that managed to complete an historic fifty-mile road trip. (See image at top)

1862 - Alphonse Beau de Rochas, a French civil engineer, patented but did not build a four-stroke engine (French patent #52,593, January 16, 1862).

1864 - Austrian engineer, Siegfried Marcus*, built a one-cylinder engine with a crude carburetor, and attached his engine to a cart for a rocky 500-foot drive. Several years later, Marcus designed a vehicle that briefly ran at 10 mph that a few historians have considered as the forerunner of the modern automobile by being the world's first gasoline-powered vehicle (however, read conflicting notes below).

1866 - German engineers, Eugen Langen and Nikolaus August Otto improved on Lenoir's and de Rochas' designs and invented a more efficient gas engine.

1873 - George Brayton, an American engineer, developed an unsuccessful two-stroke kerosene engine (it used two external pumping cylinders). However, it was considered the first safe and practical oil engine.

1876 - Nikolaus August Otto invented and later patented a successful four-stroke engine, known as the "Otto cycle".

1876 - The first successful two-stroke engine was invented by Sir Dougald Clerk.

1883 - French engineer, Edouard Delamare-Debouteville, built a single-cylinder four-stroke engine that ran on stove gas. It is not certain if he did indeed build a car, however, Delamare-Debouteville's designs were very advanced for the time - ahead of both Daimler and Benz in some ways at least on paper.

1885 - Gottlieb Daimler invented what is often recognized as the prototype of the modern gas engine - with a vertical cylinder, and with gasoline injected through a carburetor (patented in 1887). Daimler first built a two-wheeled vehicle the "Reitwagen" (Riding Carriage) with this engine and a year later built the world's first four-wheeled motor vehicle.

1886 - On January 29, Karl Benz received the first patent (DRP No. 37435) for a gas-fueled car.

1889 - Daimler built an improved four-stroke engine with mushroom-shaped valves and two V-slant cylinders.

1890 - Wilhelm Maybach built the first four-cylinder, four-stroke engine.

ICE Challengers

- Early 1900's Steam
- Next came electric
- Next the Gas turbine
- 2017 still 90 million plus ICE engines built each year for transportation applications
- Electric is challenging again

Chevy Bolt – Longest range Electric tested by Consumer Reports

Ford CMax

BMW – i8

Electric Cars are Hear to Stay

Every major OEM has a full electric vehicle and extending to entire vehicle lines

EV have range of over 200 miles moving to 300 miles

Charge times are being reduced

UK, France and Germany banded ICE vehicles

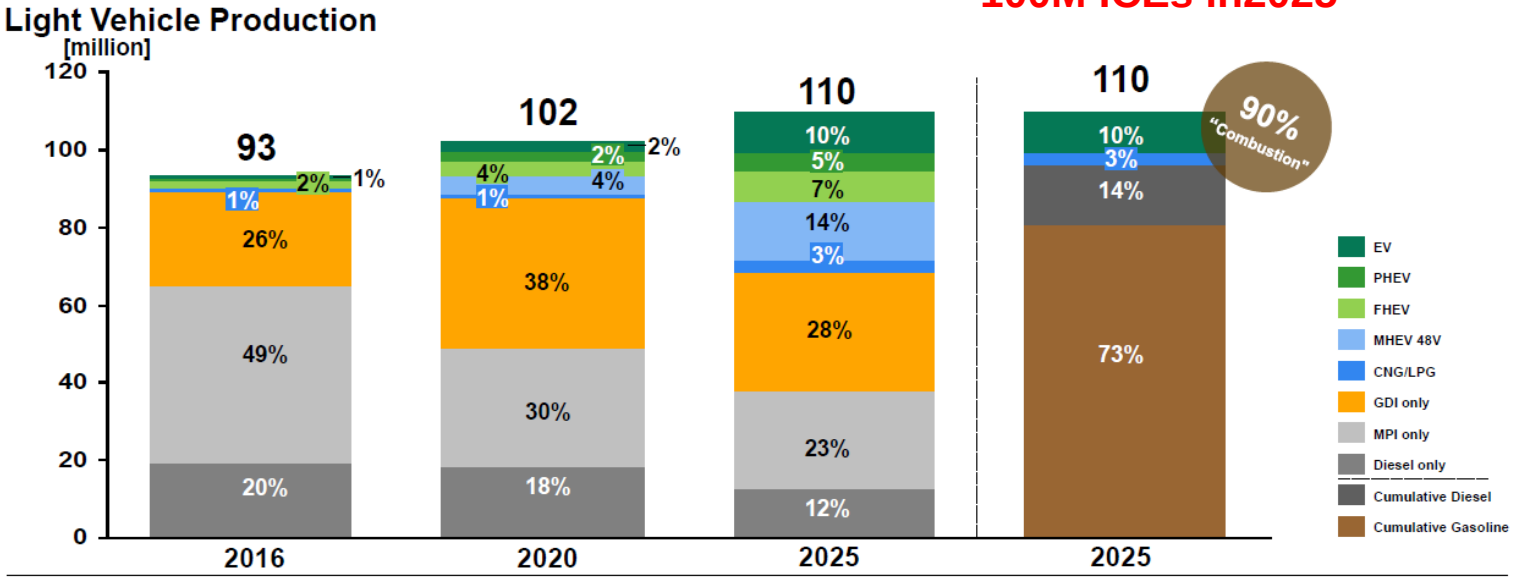
Conclusion ICE is dead again!!

Maybe Not – Hybrid?

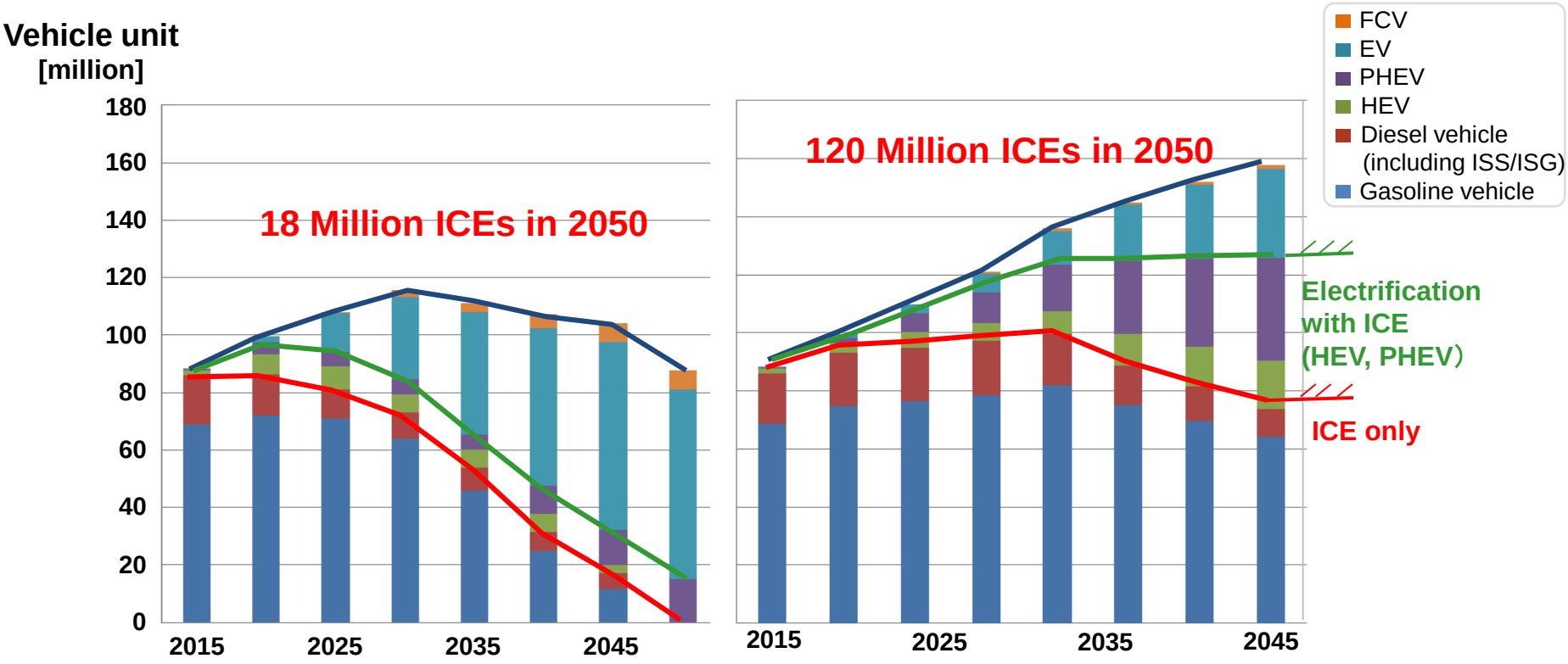
Short Term Forecast

What Is the Road Ahead?

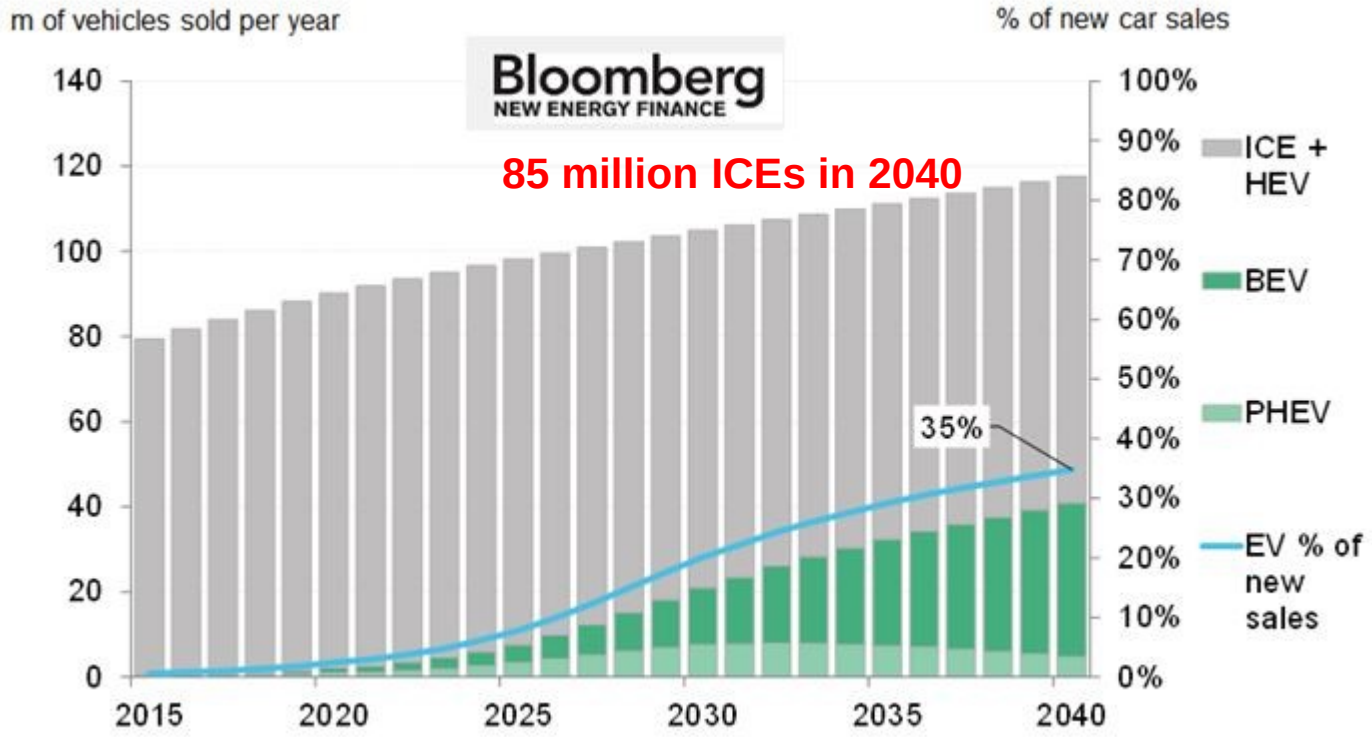
100M ICEs in2025



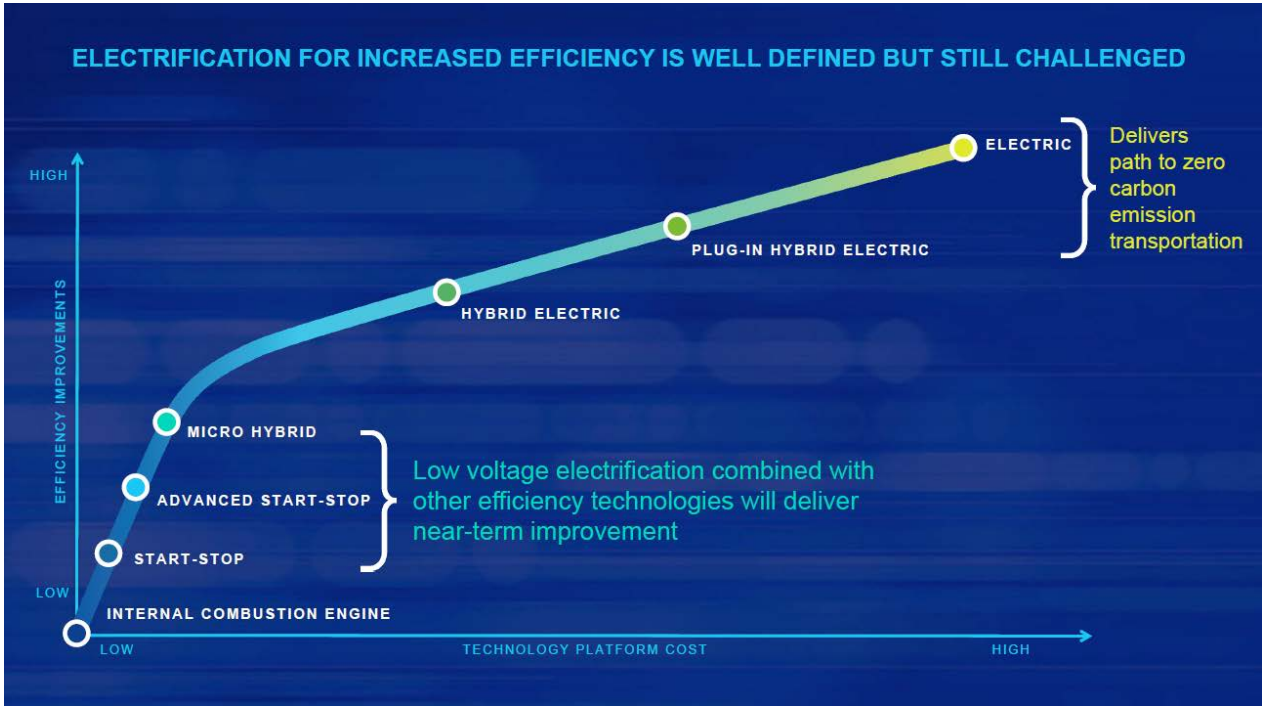
Two Potential Future ICE Scenarios



Bloomberg ICE Forecast



Electrification



But not all Electric

Toyota: 'Electrification Doesn't Mean Death of IC Engine'

Sexy battery-electric vehicles from Tesla and others are in the news, but Toyota, which arguably has more experience selling electrified vehicles than anyone, outlines a very different electrification strategy at the Center for Automotive Research's Management Briefing Seminars here.

Ben Schlimme, powertrain executive program manager-Advanced Planning and Research, Toyota Motor North America, presents a vision of the future that includes a broad portfolio of hybrid-electric vehicles, plug-ins and fuel-cell cars and trucks going out to 2050.

Citing Toyota's history of success selling electrified vehicles, including 10 million hybrid-electric vehicle sales globally since 1997 and 3.2 million in the U.S., he says success is born out of delivering a compelling value proposition to consumers in an ever-evolving market, not selling a specific type of propulsion system.

Toyota is developing many powertrains for the future, including a fuel-cell system for heavy-duty commercial trucks, but Schlimme still is bullish on Toyota's latest internal-combustion engines which now are exceeding 40% thermal efficiency, an almost unheard-of number in the engine world until recently.

In fact, he spends a good part of

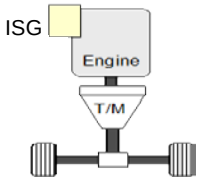
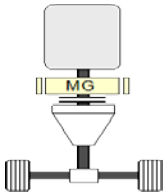
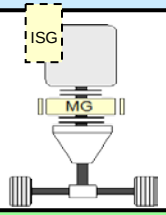
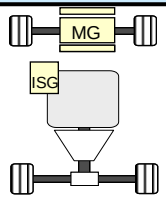
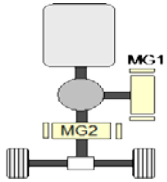
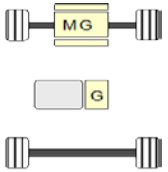
... *continued on page 14*

Toyota's Schlimme: No single EV solution.

System Trend in Different Market

Main Stream Major Minor

MG : Motor generator
CL : Clutch

System / Market	Belt-ISG	1MG Mild	1MG 2CL	Axle Split	Power Split	Range Extender
						
Japan Korea						
EU	(under 60V)					
US	(over 60V)				(inc. 2mode)	
China					(inc.Serial-Parallel)	

Solutions may vary but all require ICE

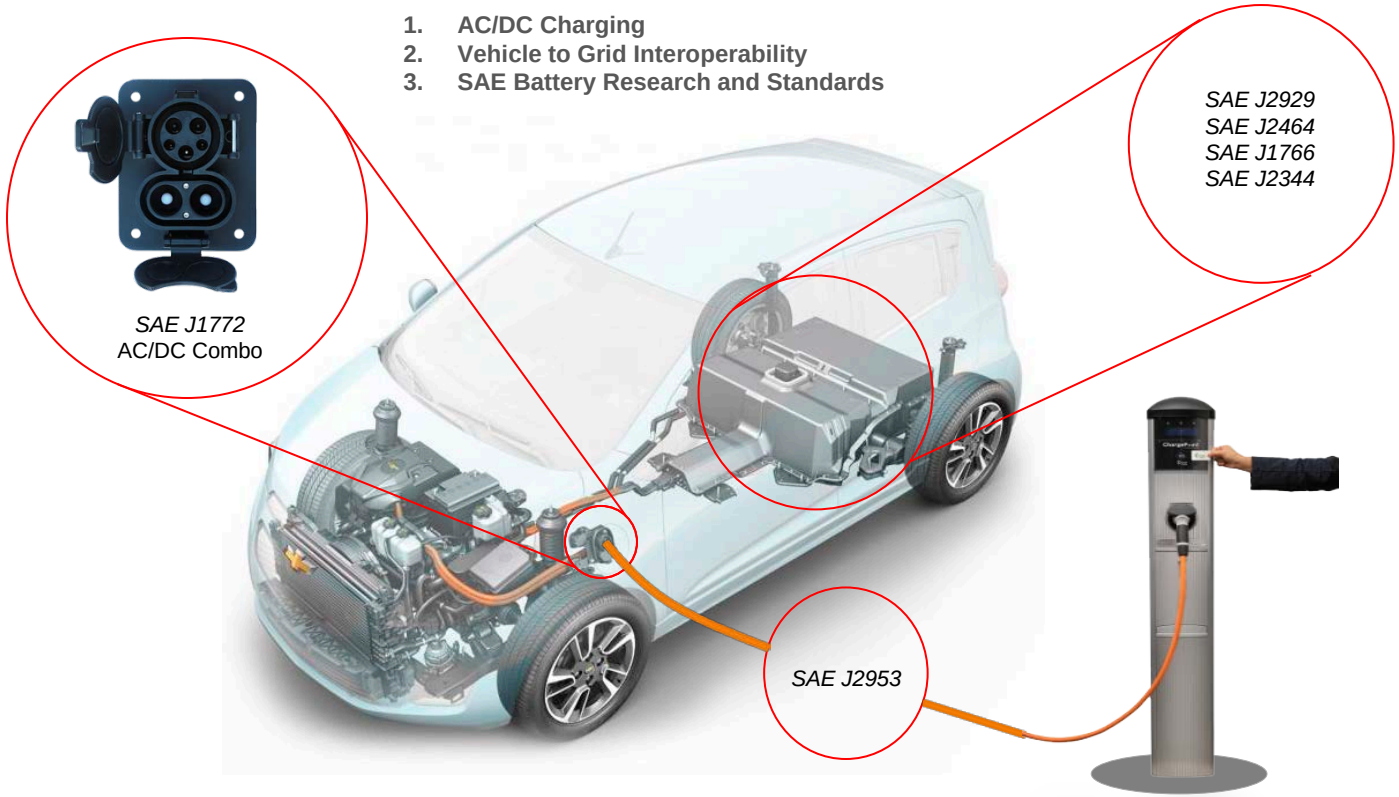
System Comparison

		Advanced Lead-acid	12V Li-ion Starter Battery	**48V Li-ion System**	Full HEV
Fuel Saving Functions	Start-Stop	✓	✓	✓	✓
	Start-Stop Advanced	✓	✓	✓	✓
	Recuperation	✓	✓	✓	✓
	Extended Recuperation	✗	✗	✗	✓
	Passive Boost	✓	✓	✓	✓
	Coasting	✗	✓	✓	✓
	High-speed Coasting	✗	✗	✓	✓
	e-Driving	✗	✗	✓	✓
Efficiency	Service Life	3yrs	8yrs	10~15yrs	10~15yrs
	CO_2 Savings[1)]	2 ~ 5%	5~10%	12~20%	15~30%
	Weight	20 ~ 29kg	11kg	Battery 7~8kg System 25~30kg	Battery 20~30kg System 60~75kg
	System Cost (USD)				
	Level of R&D Effort	Low	Low	Moderate	High

Battery technology and voltage may vary but most alternatives include ICE

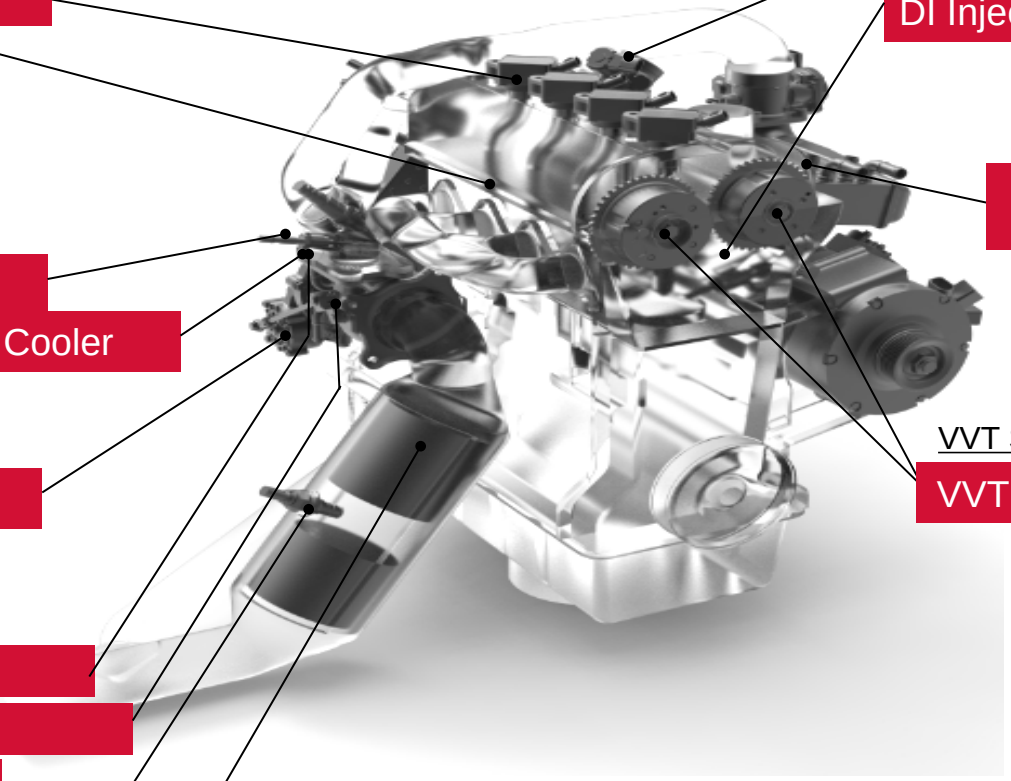
How is SAE Involved?

1. AC/DC Charging
2. Vehicle to Grid Interoperability
3. SAE Battery Research and Standards



Today’s ICE is Complex

Today's ICE



Ignition System

- High Output Ignition Coil
- Long Life Spark Plug

EGR System

- EGR Temperature Sensor
- LPL Butterfly EGR Valve / Cooler

Boost System

- Electronic WGV Actuator

After-Treatment System

- Quick Response EGT Sensor
- Quick Response AFR Sensor
- Rear Oxygen Sensor
- Quick Light-Off Catalytic Substrate

Direct Injection System

- DI Pump
- DI Injector

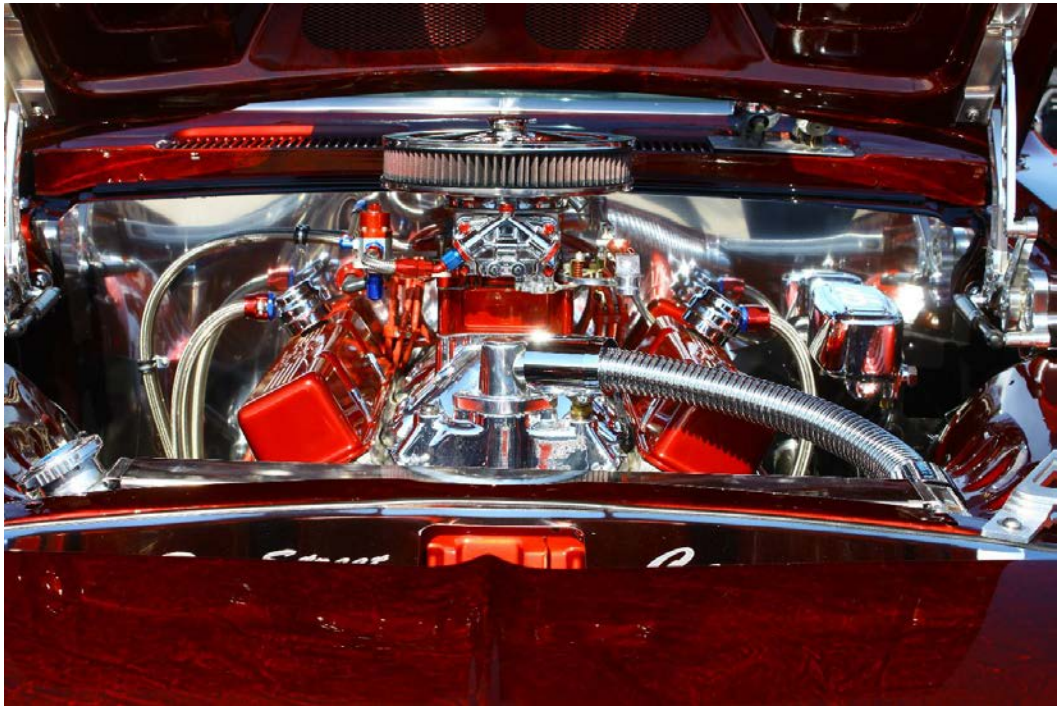
Intake Air System

- Water-cooled Charge Air Cooler

VVT System

- VVT (Intake and Exhaust)

What is next? More complex or simplified?



The Next ICE more Complex Operation and Control

SKYACTIVE-X Mazda Engine

Technological innovations

- Spark Controlled Compression Ignition
  - maximizing the zone in which compression ignition is possible
  - seamless transition between compression ignition and spark ignition

Features

- 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[3]
- Compression ignition makes possible a super lean burn[4] that improves engine efficiency up to 20 - 30 percent over the current SKYACTIV-G, SKYACTIV-X even equals or exceeds the latest SKYACTIV-D diesel engine in fuel efficiency
- With high efficiency across a wide range of rpms and engine loads, the engine allows much more latitude in the selection of gear ratios, providing both superior fuel economy and driving performance

Today's ICE

Ignition System

Lower energy ignition system

PFI

Intake Air System

No WCAC

EGR System

No Cooler EGR

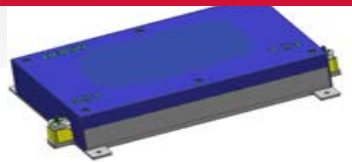
No Boosting

Simplified VVT

48V ISG System

ISG

Lithium-Ion Battery Pack

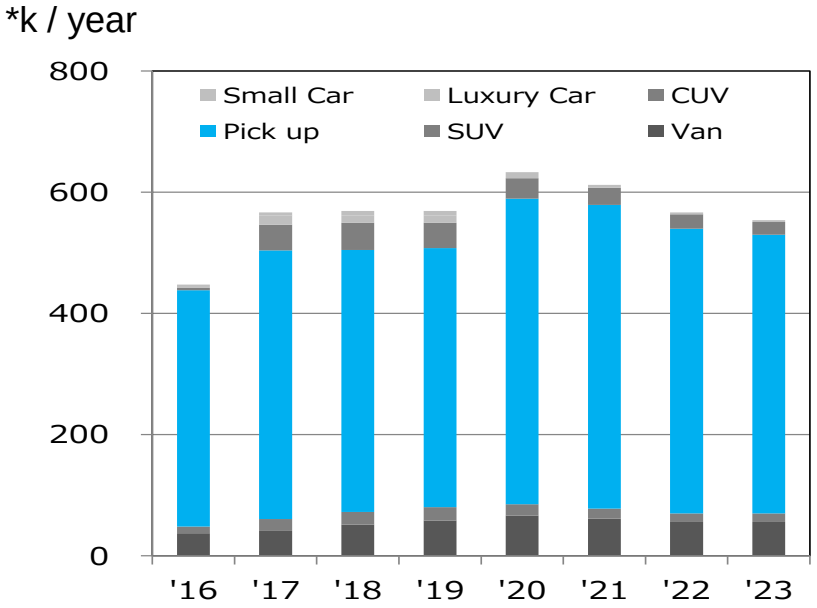


After-Treatment System

Simplified Aftreatment

Diesels

Diesel Sales Forecast in NA*1



*1 WardsAuto/AFS

Diesel pick-up truck will remain they provide fuel economy and power

Engines – On-Road and Non-Road

CAGR: **5.8%**

Source:
KGP and Umicore assumptions

CAPITAL MARKETS DAY

Diesel Market Remains Strong

ICE Conclusions

- Pass car applications for **electrified** vehicles remain strong
- On highway truck light, medium and heavy duty applications remain primarily Diesel
- Agricultural and construction equipment remain Diesel

ICE will be continue to survive !!!

Counter Articles

The Internal Combustion Engine Is Not Dead Yet

New York Times - By NORMAN MAYERSOHN AUG. 17, 2017

https://www.forbes.com/sites/.../the-internal-combustion-engine-will-survive-us-all

The Internal Combustion Engine Will Survive Us All

Bertel Schmitt , Contributor Forbes. Jul 20, 2017

https://www.forbes.com/sites/bertelschmitt/2017/07/20/the-internal-combustion-engine-will-survive-us-all/#34f73583a3dd

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