Looking From A Hilltop:

Automotive Propulsion System Technology

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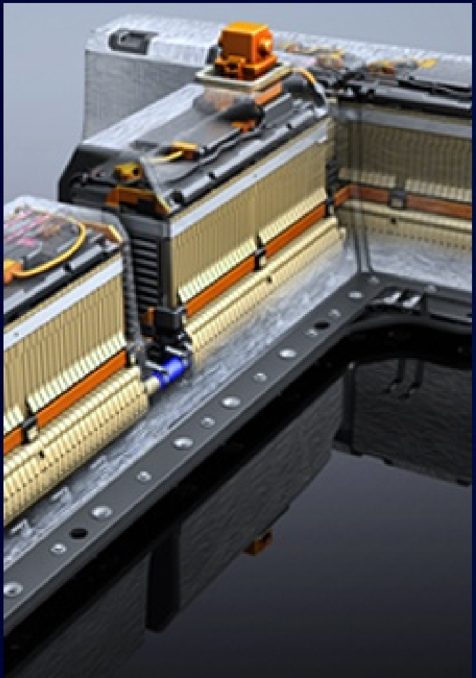
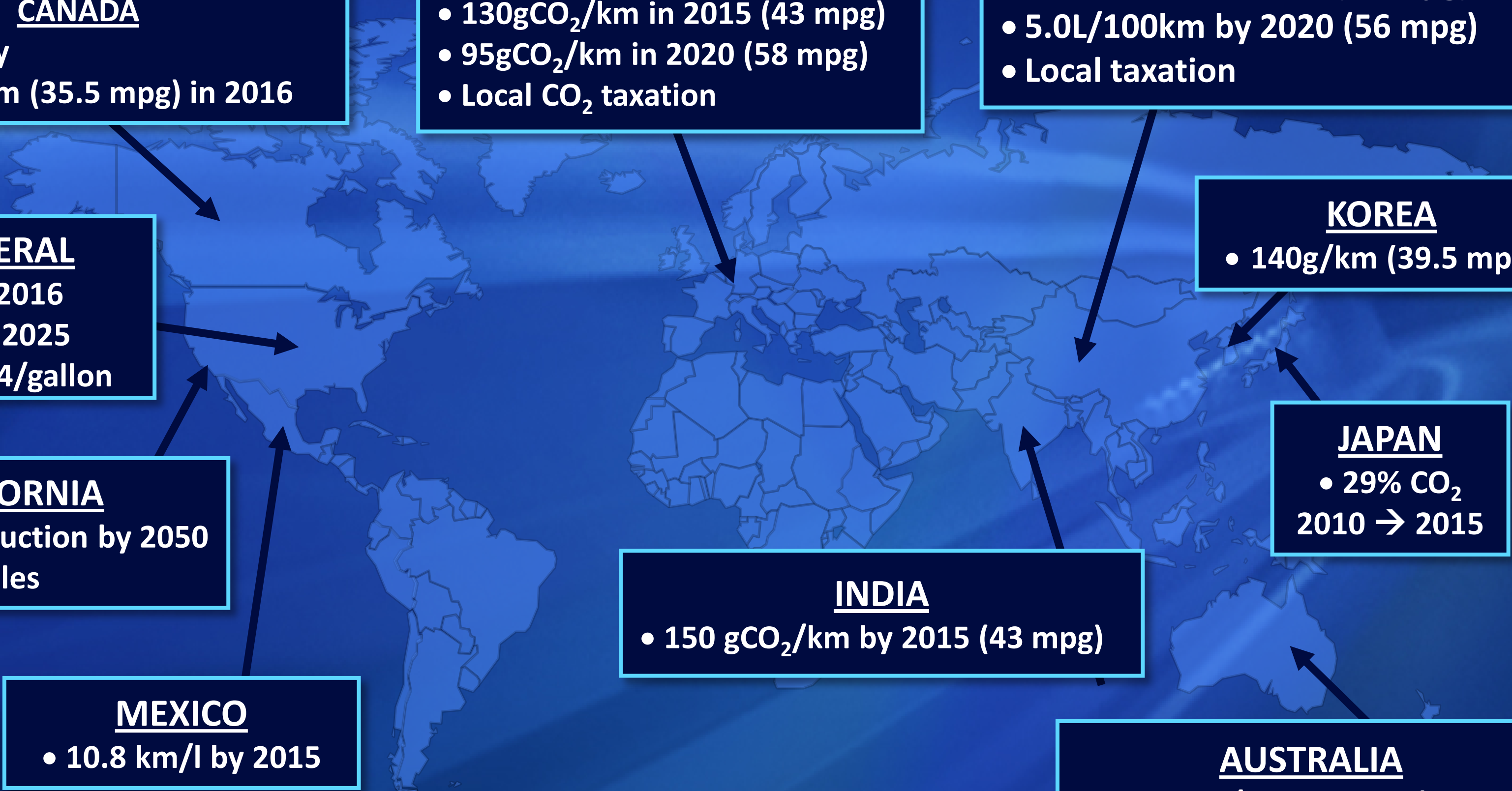



OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREENHOUSE GAS REQUIREMENTS



CANADA
- Green Levy
- 6.6L/100km (35.5 mpg) in 2016

EUROPEAN UNION
- 130gCO_2/km in 2015 (43 mpg)
- 95gCO_2/km in 2020 (58 mpg)
- Local CO_2 taxation

CHINA
- 6.9L/100km in 2015 (37 mpg)
- 5.0L/100km by 2020 (56 mpg)
- Local taxation

U.S. FEDERAL
- 35.5 mpg in 2016
- 54.5 mpg by 2025
- Gasoline $3-4/gallon

KOREA
- 140g/km (39.5 mpg)

CALIFORNIA
- 80% CO_2 reduction by 2050
- ZEV, PZEV rules

JAPAN
- 29% CO_2 2010 → 2015

INDIA
- 150 gCO_2/km by 2015 (43 mpg)

MEXICO
- 10.8 km/l by 2015

AUSTRALIA
- 190 gCO_2/km in 2015 (43 mpg)
- 155 gCO_2/km by 2024

OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREENHOUSE GAS REQUIREMENTS

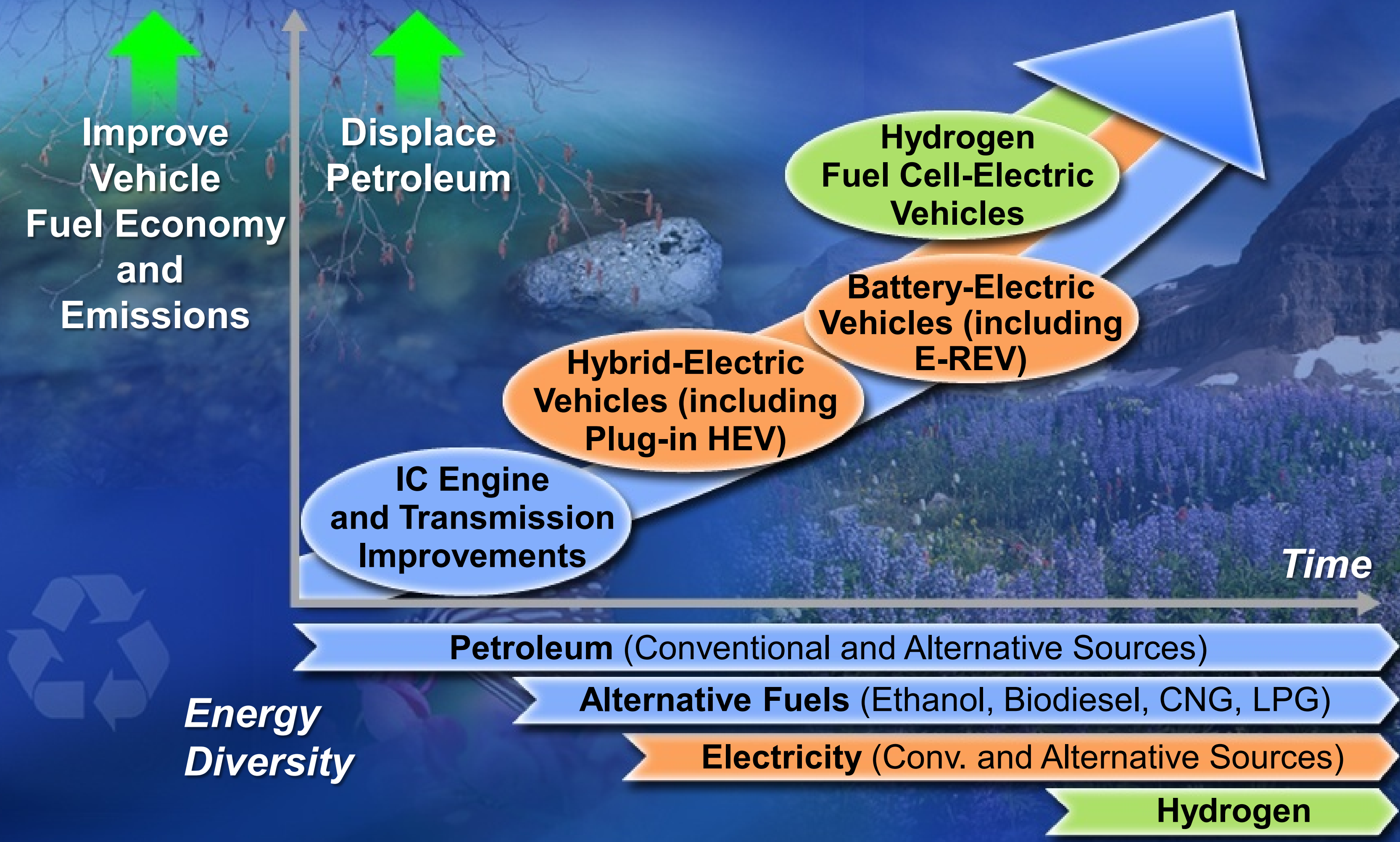
	MPG	YEAR
U. S.	54.5	2025
Europe	58	2020
China	56	2020

• 10.8 km/l by 2015

AUSTRALIA

• 190 gCO_2/km in 2015 (43 mpg)
• 155 gCO_2/km by 2024

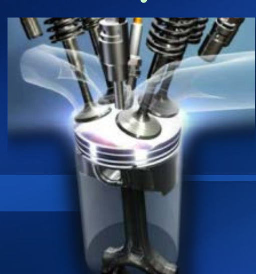
ADVANCED PROPULSION TECHNOLOGY STRATEGY



Chevrolet Cruze Fuel Energy Breakdown
(major fuel energy losses typical for combined EPA city and highway driving)

Mechanical Energy = Energy into Piston = 38% of Fuel Energy

Fuel Energy

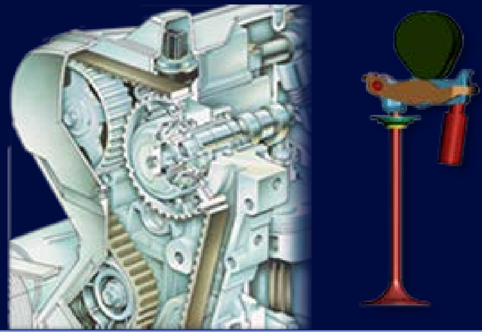


Exhaust and Coolant Heat Losses = 62% of Fuel Energy

SI ENGINES - Current state of the art

Spark Ignition Direct Injection

Cam Phasing, Variable Valve Lift, Active Fuel Management



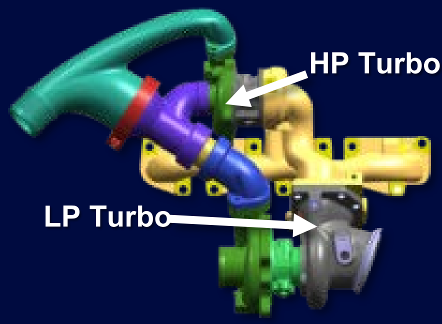
Downsized SIDI Turbo Boosting

Advanced Combustion

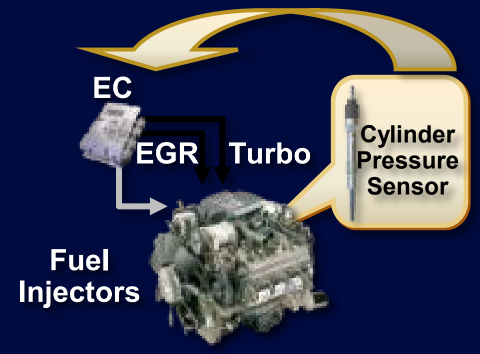
DOWNSIZED TURBO GASOLINE ENGINE

CI ENGINES – Current state of the art

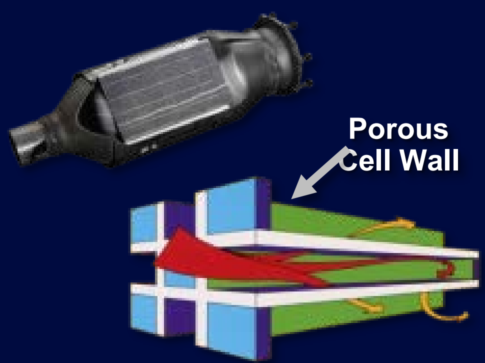
Advanced Boosting with Small Displacement



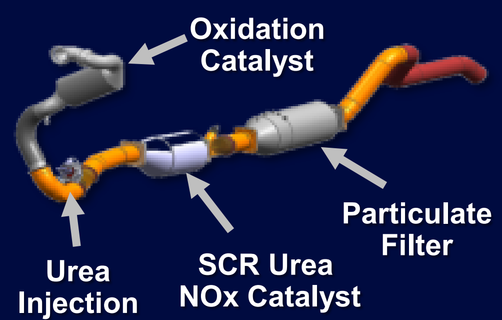
Cylinder Pressure Sensing



Diesel Particulate Filter



NO_X Aftertreatment



CHEVROLET CRUZE DIESEL

The Next Frontier In Engine Efficiency

Thermal management

Parasitic loss reduction

Friction reduction

Combustion system evolution

After treatment optimization

Electrification

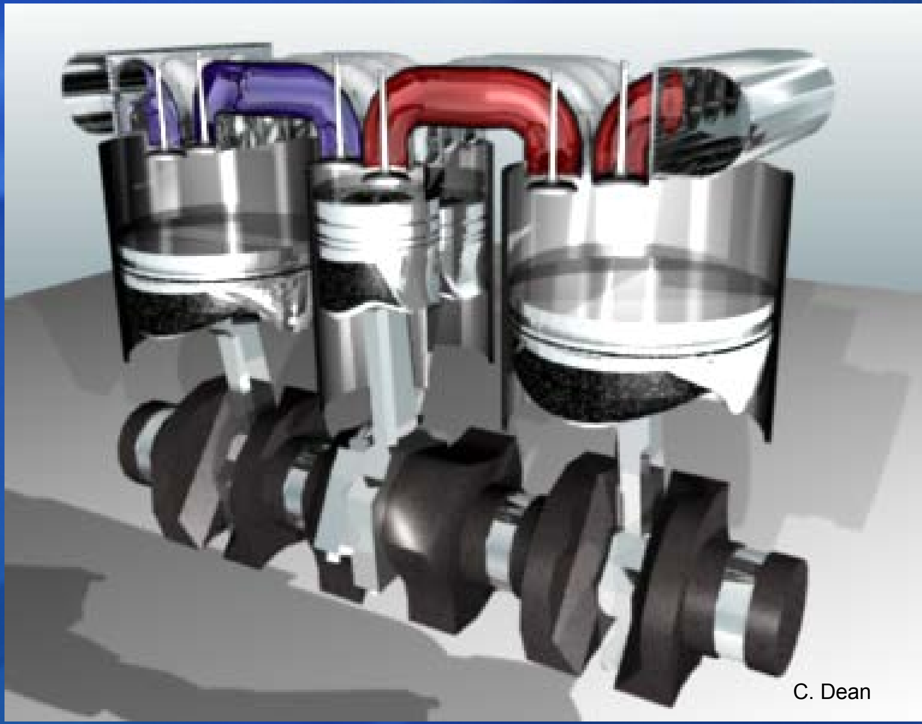
System Optimization

*** This is not really a new frontier ☺**
It is actually paying attention to fundamental engine design principles

ADVANCED IC ENGINES

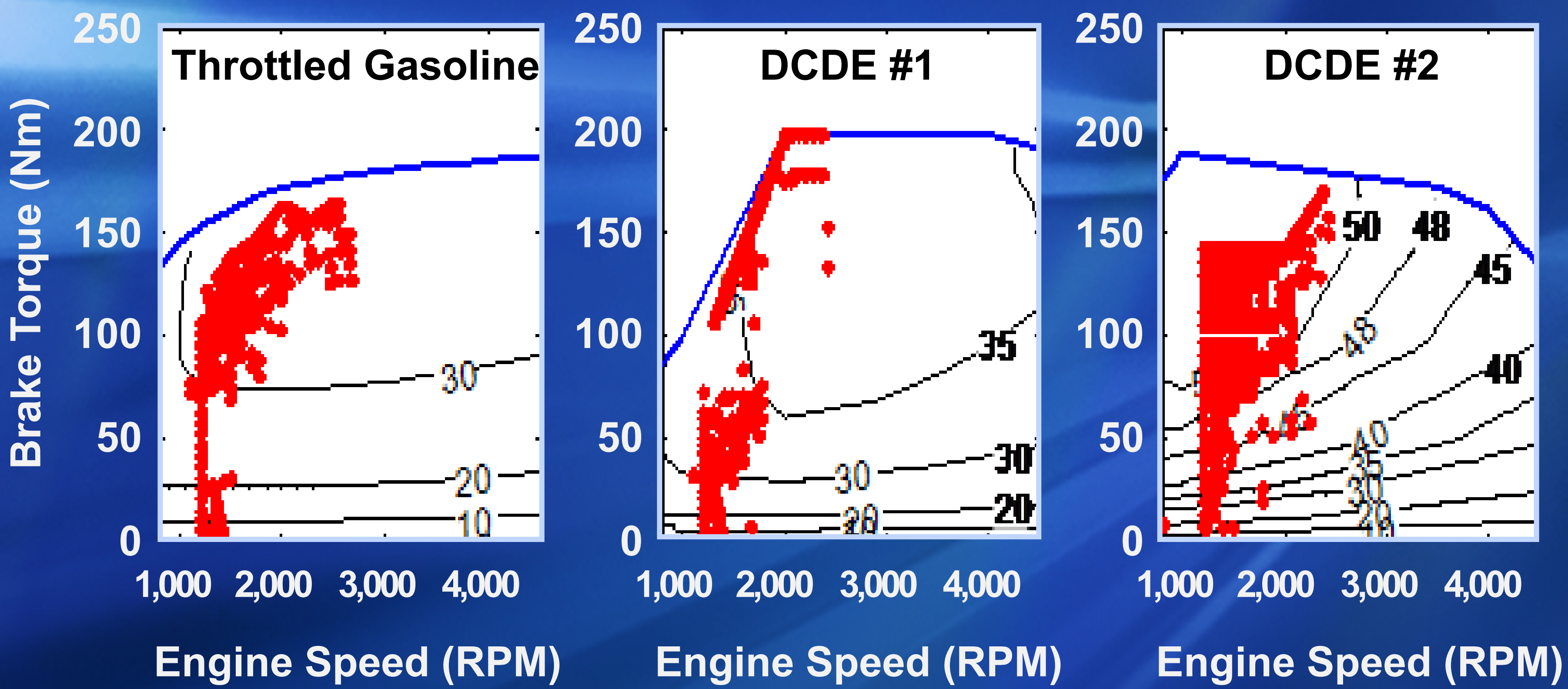
MAXIMIZING EFFICIENCY BY MINIMIZING LOSSES
THROUGH ARCHITECTURE OPTIMIZATION –
DUAL COMPRESSION, DUAL EXPANSION TECHNOLOGY

- Different stages of the cycle can be separated into different working volumes
- Possible to optimize each stage individually, including heat loss management and exhaust energy recuperation
- Initial modeling shows potential for very high thermal efficiency



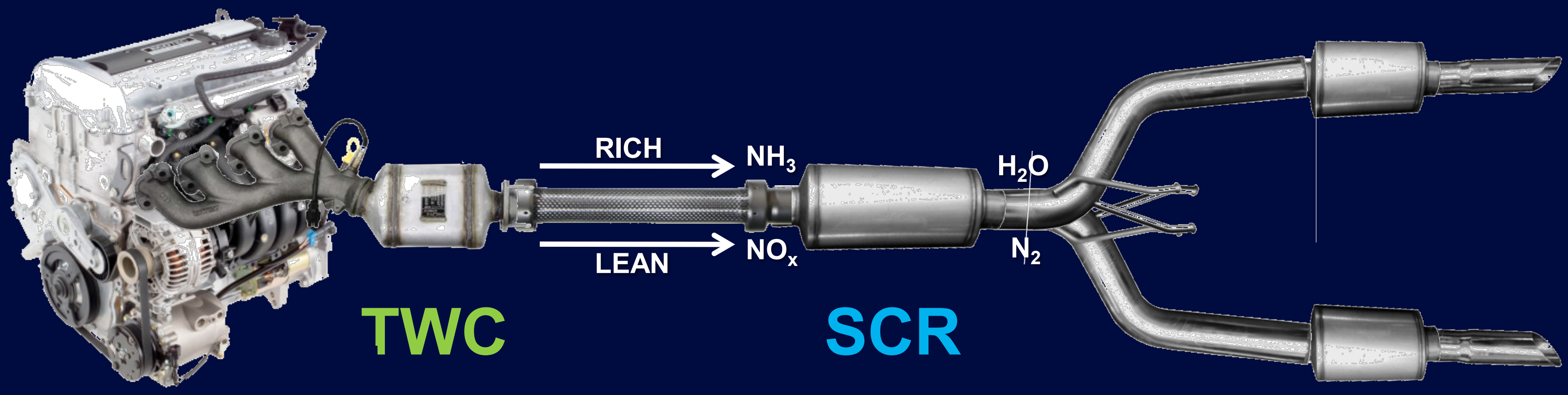
ADVANCED IC ENGINES

Operating points on brake thermal efficiency map (%)



PASS – HOW DOES IT WORK?

UREA-FREE SCR SYSTEM



DURING RICH:

$NO_X + H_2/CO \Leftrightarrow NH_3 + CO_2$

Use H_2 and CO to generate NH_3 over TWC and store NH_3 in multiple SCRs

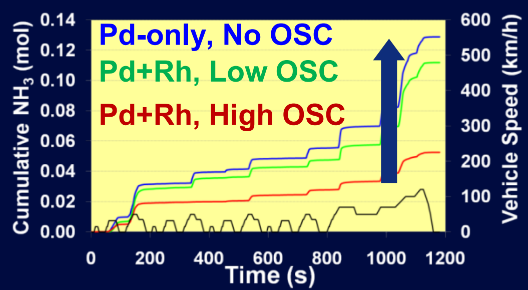
DURING LEAN:

$NO_X + NH_3 \Leftrightarrow N_2 + H_2O$

Use the stored NH_3 for lean NO_x conversion

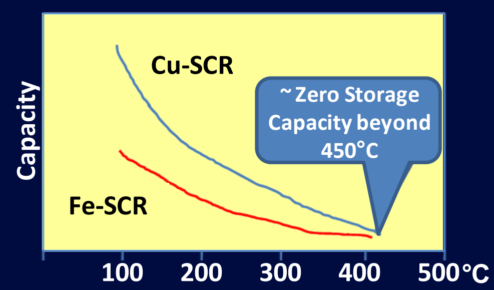
Aftertreatment Challenges

TWC Technology



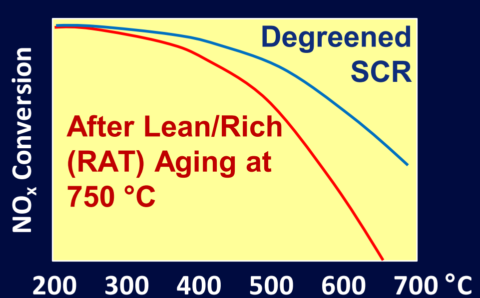
- High NH_3 Efficiency
- PGM & OSC Optimization

SCR Technology



- NH_3 storage beyond 450°C
- High-temperature No_x Efficiency

Thermal Durability

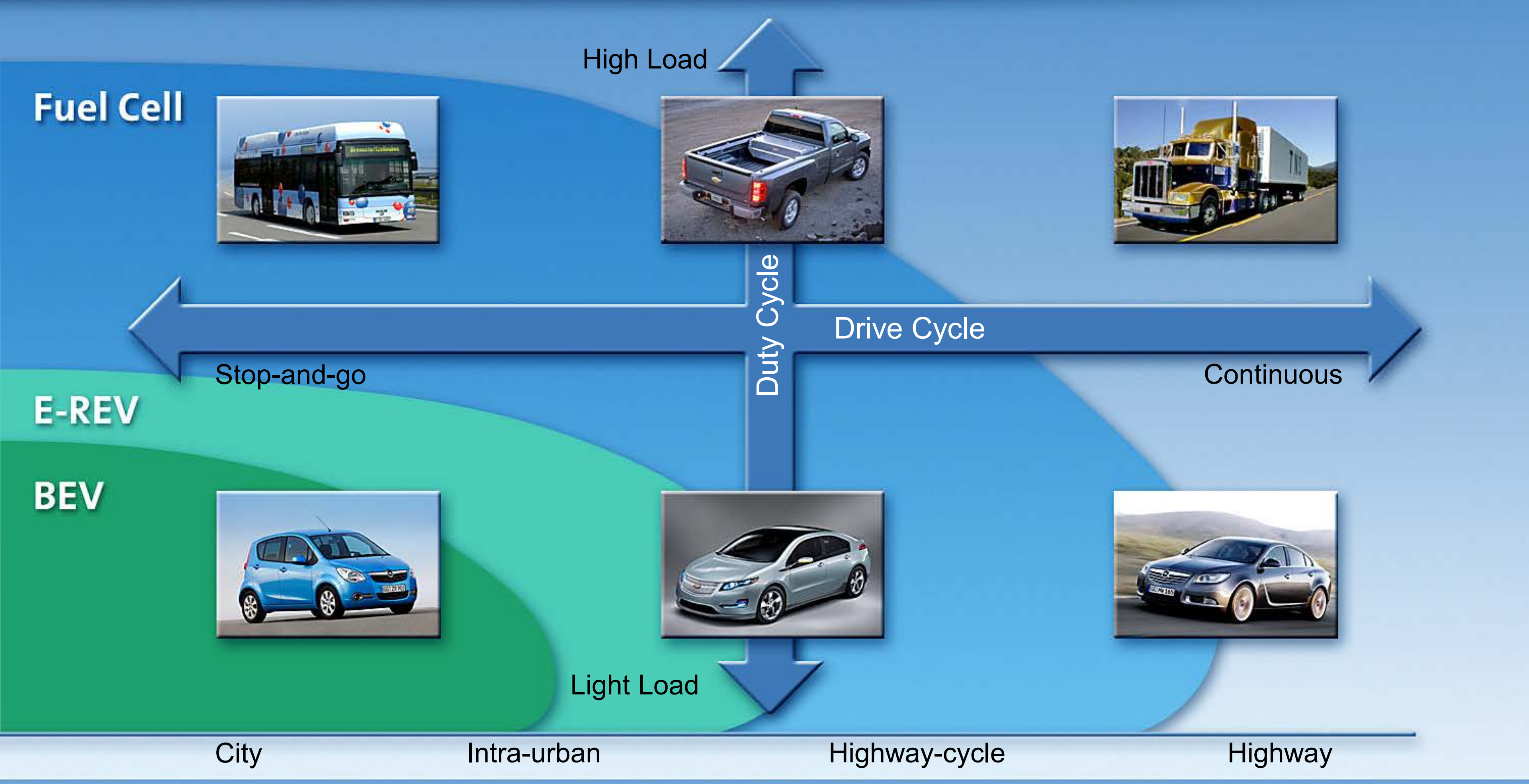


- Stable TWC under Lean Environment
- Stable SCR under Reducing Env.

PASS

Oxygen-tolerant Universal Aftertreatment

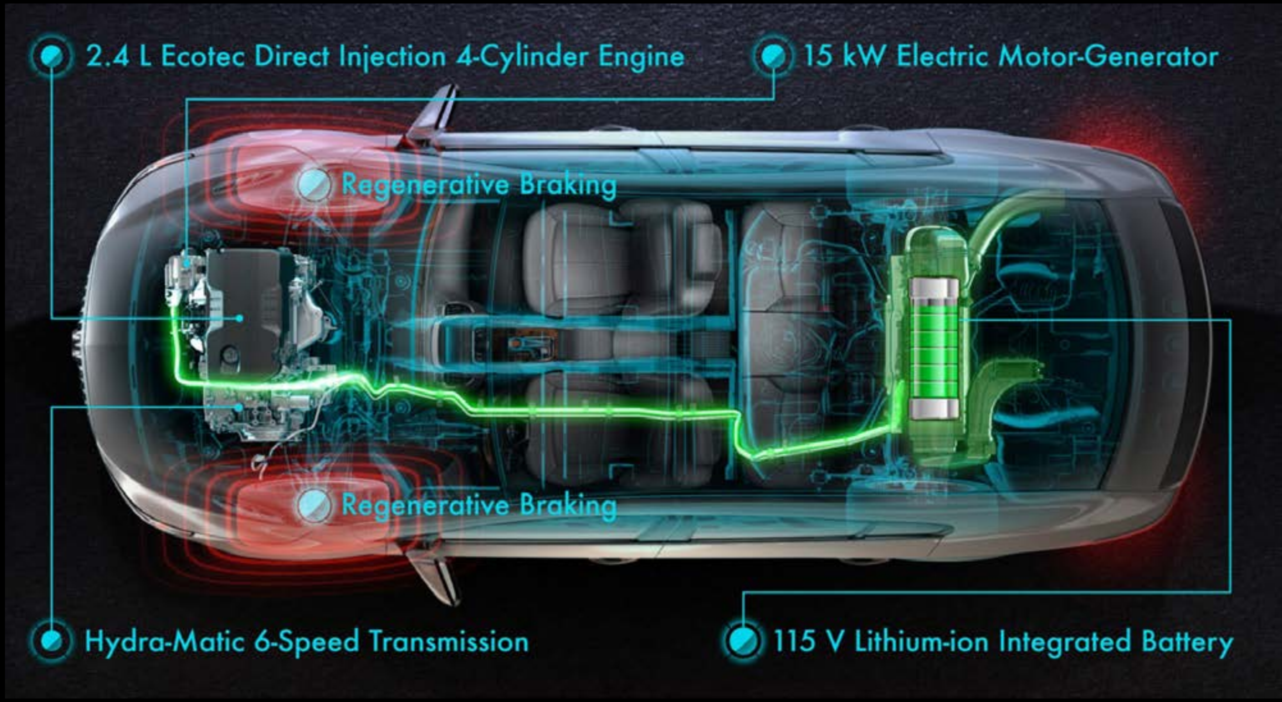
Propulsion System Technology Application Map



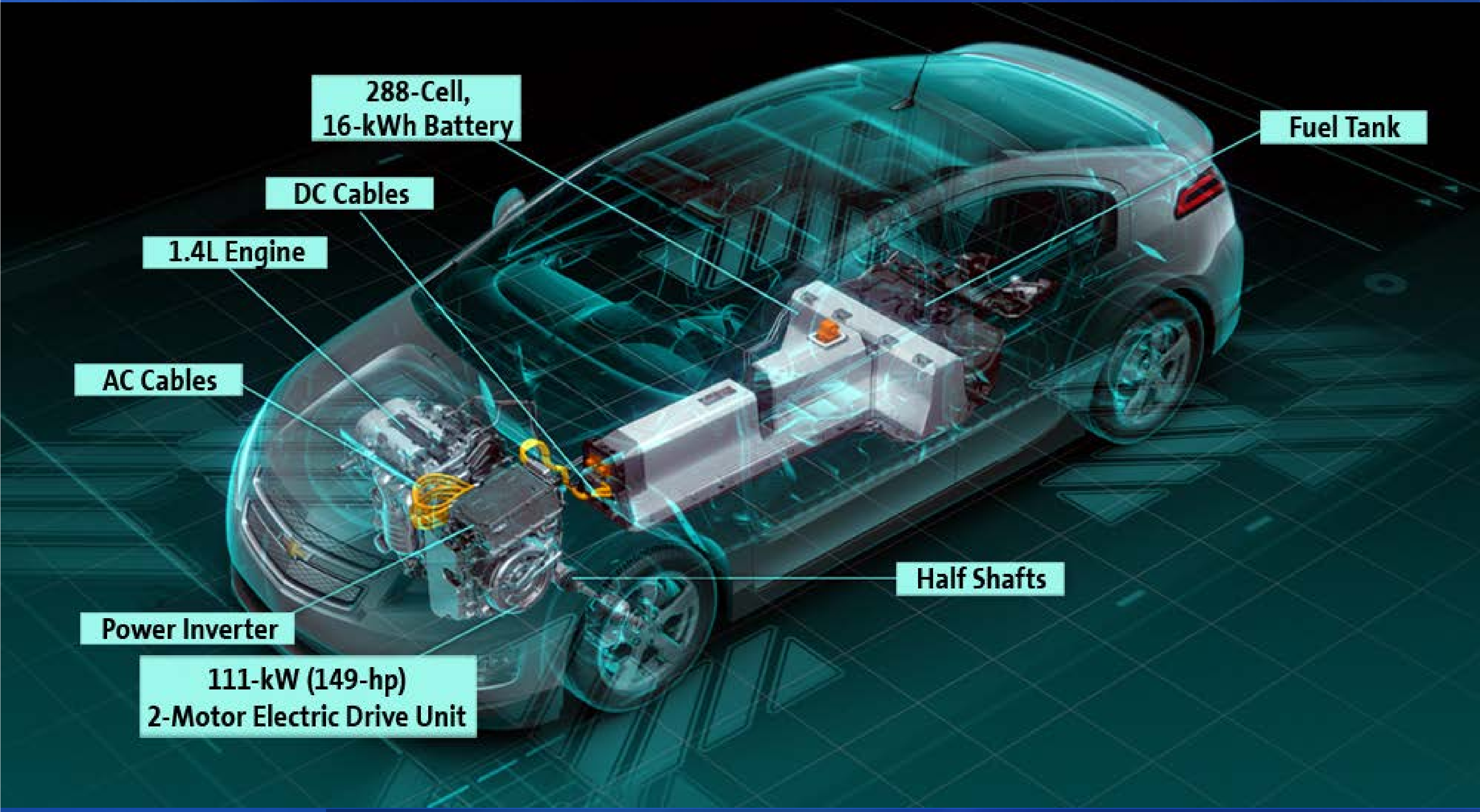
General Motors eASSIST™ Technology

LaCrosse
and Regal
36 Hwy MPG

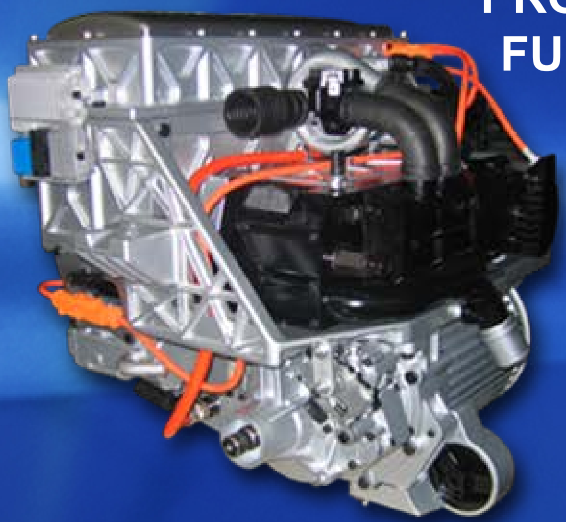
Malibu ECO
37 Hwy MPG



VOLTEC PROPULSION SYSTEM



WHAT If Battery Improvements Don’t Go Far Enough?

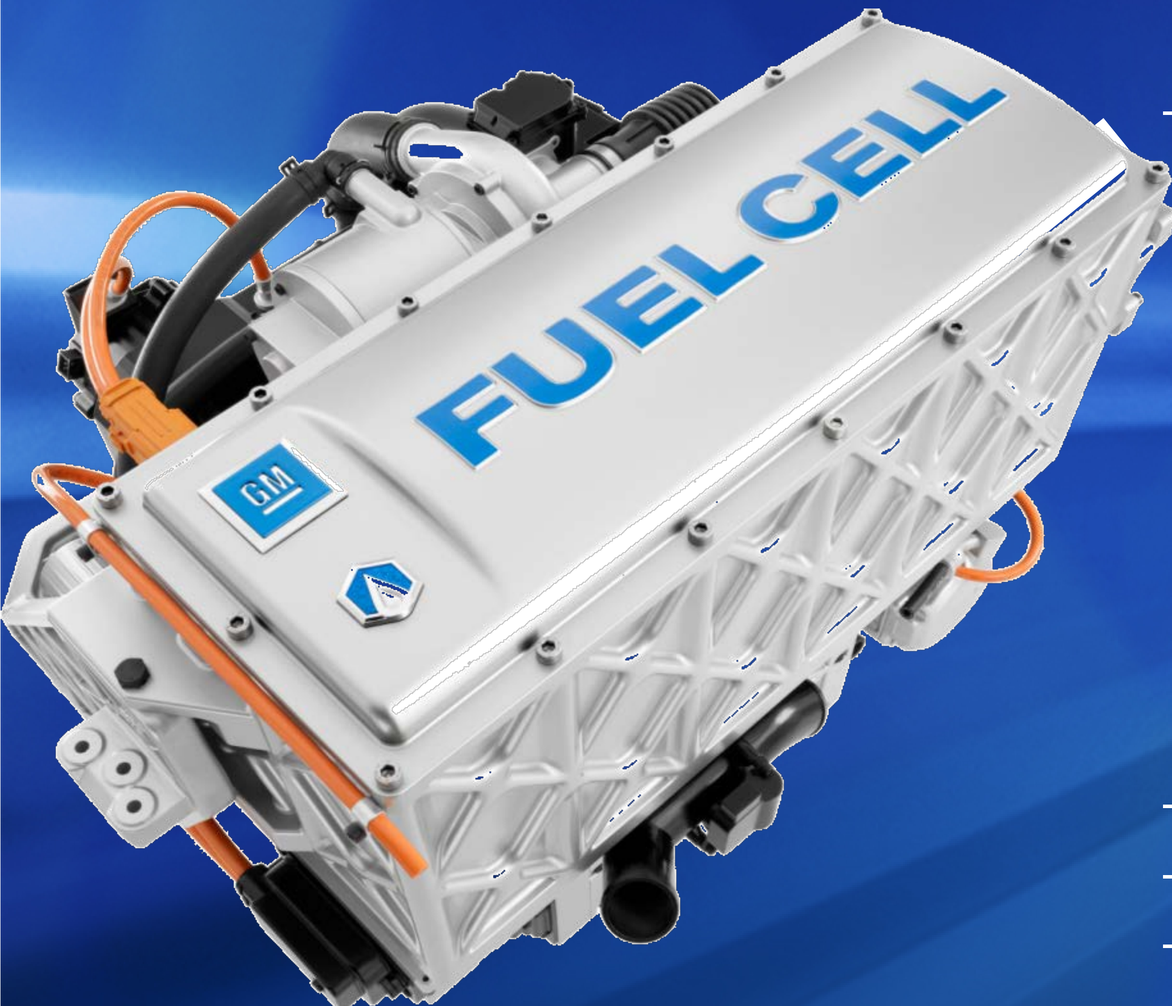


PRODUCTION-INTENT
FUEL CELL SYSTEM

6,000
ORDINARY DRIVERS

>2,500,000
MILES LOGGED

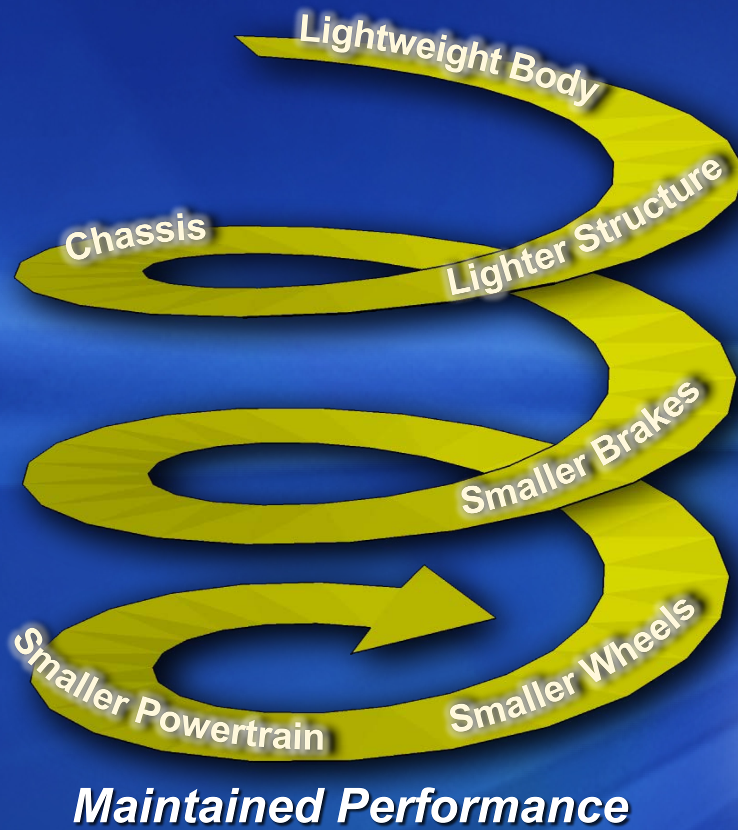
Hydrogen Fuel Cell Technology

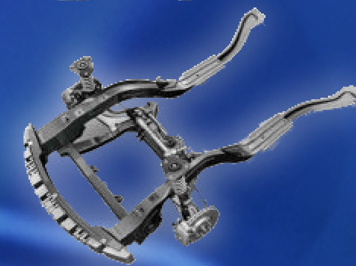


- Zero emissions and zero petroleum
- Compared to internal combustion engine:
  - More than twice as efficient
  - Comparable precious metal content
  - Comparable durability, range (300 miles) and performance
  - Fast refueling – within 3 minutes
  - 60% fewer part numbers
  - 90% fewer moving parts
- Cold and hot operation capability
- Family-sized vehicles
- Synergy with renewable energy sources

System Optimization in the Vehicle

- In a lighter vehicle, a smaller less powerful powertrain may be used
- These downsized powertrains can still benefit from the technology improvement





Energy Management of the Vehicle System:
- Thermal management
- Active management of the electrical system

Powertrain solutions only achieve their full potential, if combined with vehicle level optimizations such as mass reductions & aerodynamic improvements

Future Technology Outlook

SI and CI engine capability continues to converge

- Smaller displacements
- High pressure, direct fuel injection
- Broad application of turbocharging
- Advanced combustion processes
- Advanced aftertreatment
- Reduced friction
- Reduced mass
- Improved thermal management

Hybrid and Fuel Cell technology continues to mature

… but conventional engine technology continues to play a key role

GENERAL MOTORS COMPANY

Thank you for your attention