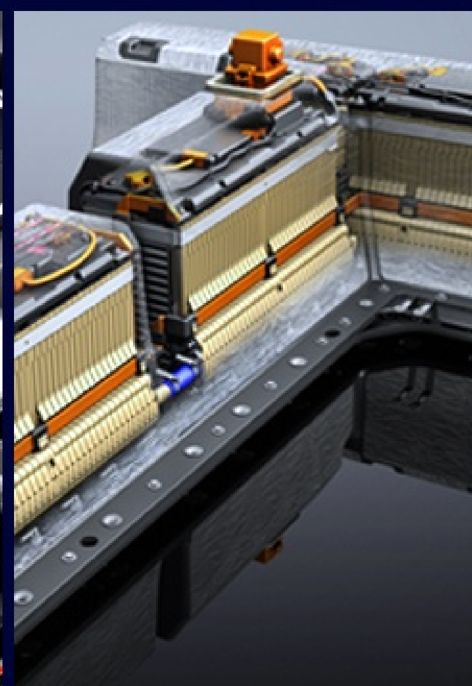
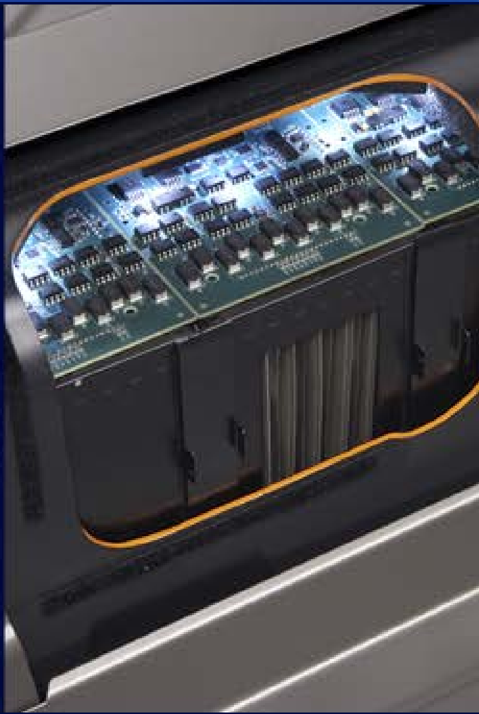
ADVANCED ENGINE TRENDS, CHALLENGES & OPPORTUNITIES

Alan Taub
Vice President, Global Research & Development, General Motors

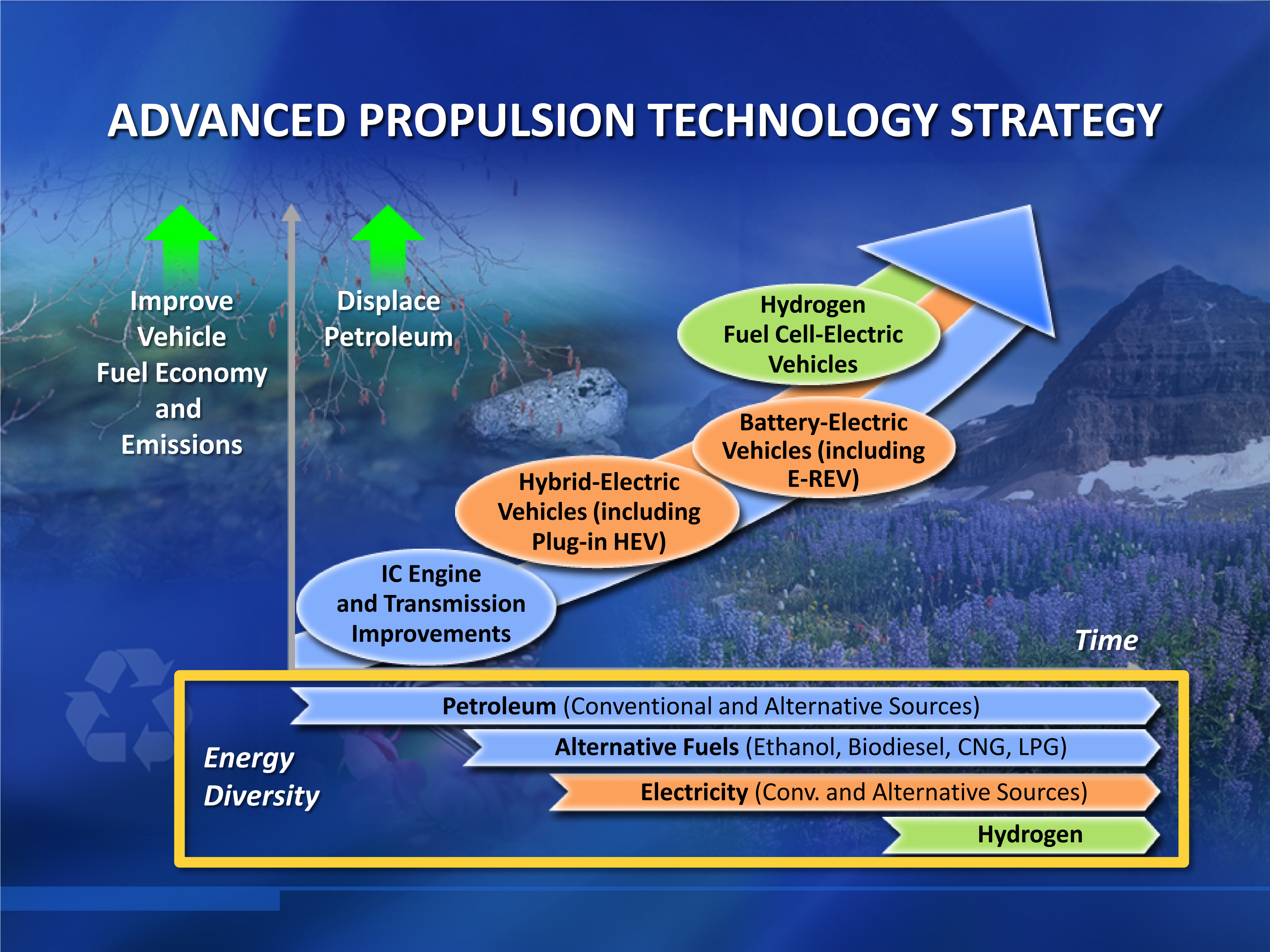


MEGA TRENDS FOR FUTURE POWERTRAINS



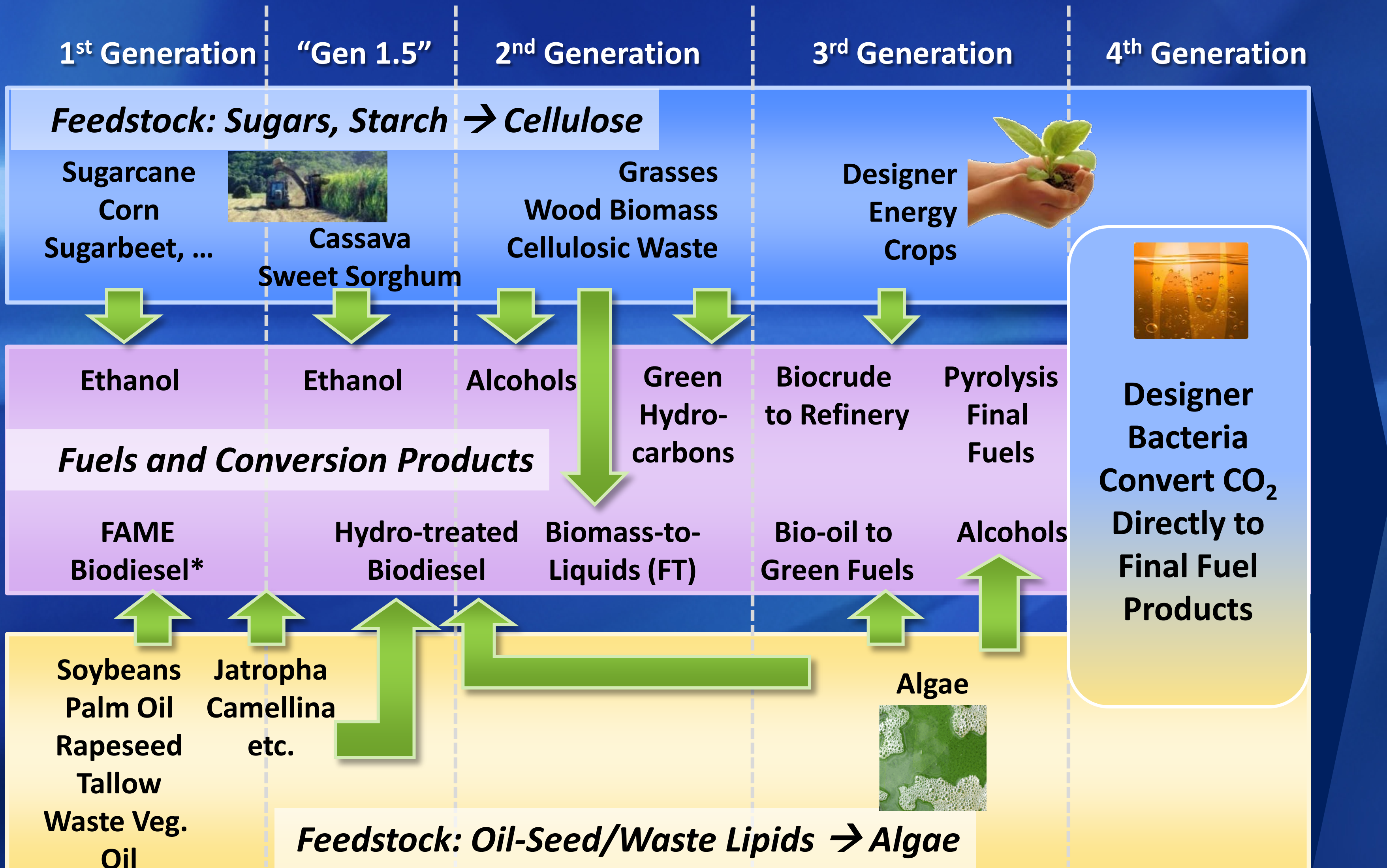
ENERGY DIVERSITY

POWERTRAIN EFFICIENCY

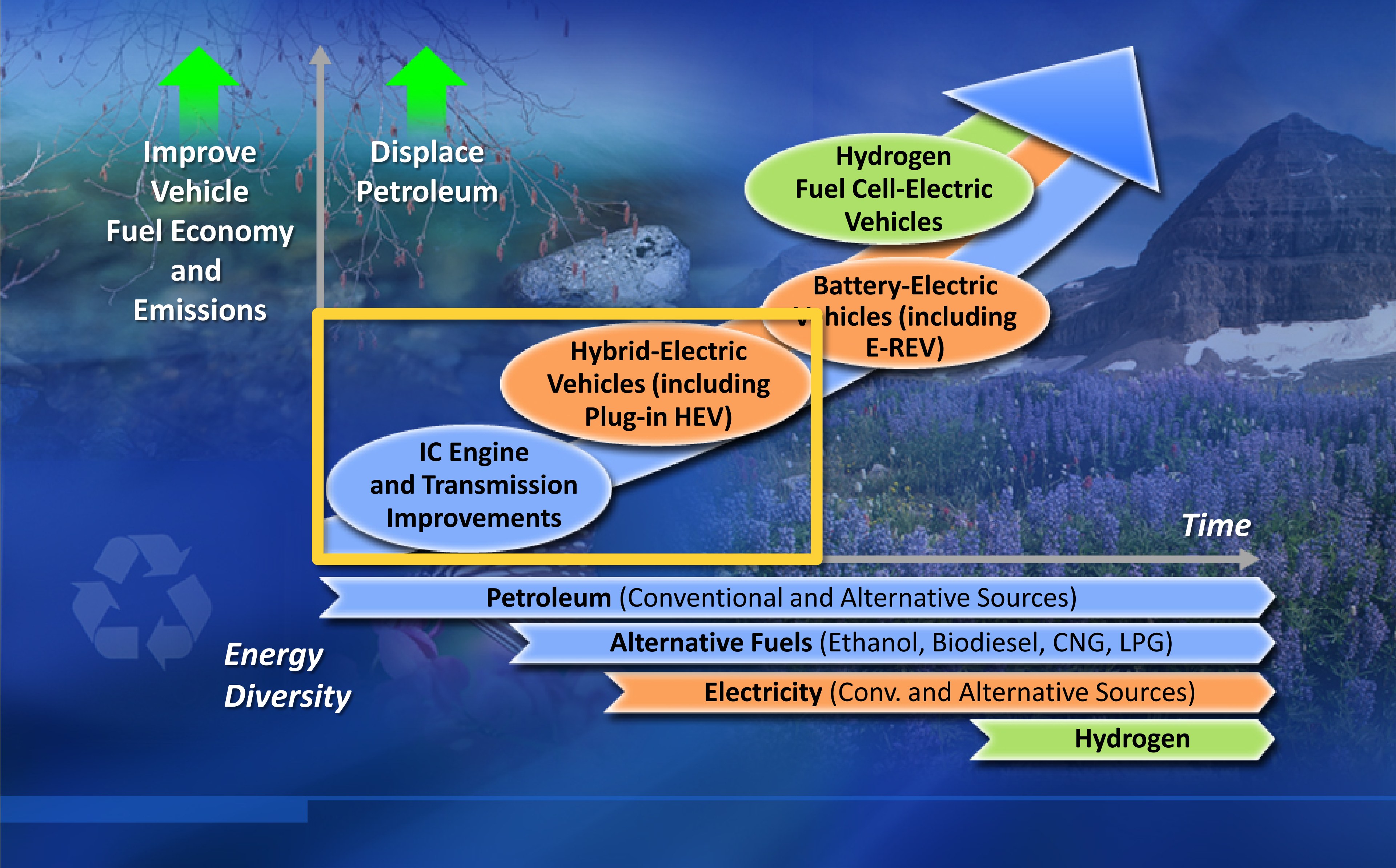

ADVANCED PROPULSION TECHNOLOGY STRATEGY
Improve Vehicle Fuel Economy and Emissions
Displace Petroleum
IC Engine and Transmission Improvements
Hybrid-Electric Vehicles (including Plug-in HEV)
Battery-Electric Vehicles (including E-REV)
Hydrogen Fuel Cell-Electric Vehicles
Time
Energy Diversity
Petroleum (Conventional and Alternative Sources)
Alternative Fuels (Ethanol, Biodiesel, CNG, LPG)
Electricity (Conv. and Alternative Sources)
Hydrogen

ENERGY DIVERSITY – CNG AND LPG

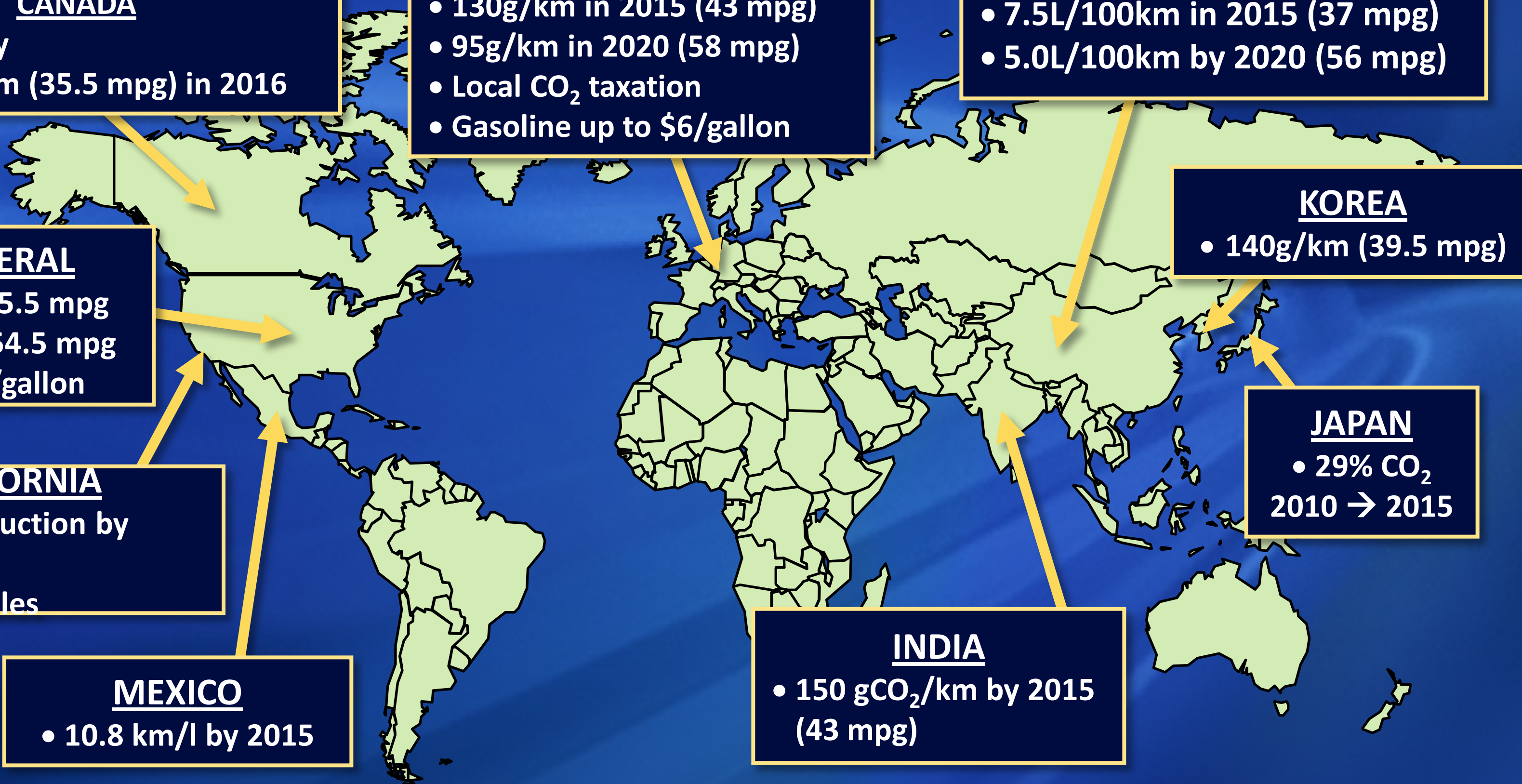
BIOFUELS TECHNOLOGY ROADMAP



ADVANCED PROPULSION TECHNOLOGY STRATEGY



OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREEN HOUSE GAS REQUIREMENTS



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

EUROPEAN UNION
- 130g/km in 2015 (43 mpg)
- 95g/km in 2020 (58 mpg)
- Local CO_2 taxation
- Gasoline up to $6/gallon

CHINA
- 7.5L/100km in 2015 (37 mpg)
- 5.0L/100km by 2020 (56 mpg)

KOREA
- 140g/km (39.5 mpg)

U.S. FEDERAL
- In 2016, at 35.5 mpg
- By 2025, at 54.5 mpg
- Gasoline $3/gallon

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

JAPAN
- 29% CO_2 2010 → 2015

MEXICO
- 10.8 km/l by 2015

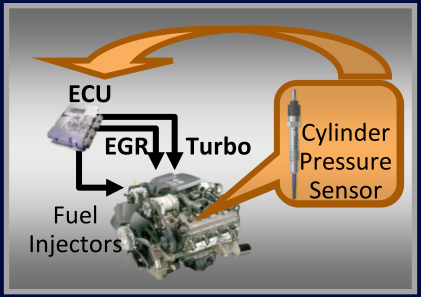
INDIA
- 150 gCO_2/km by 2015 (43 mpg)

ADVANCED IC ENGINES

Achieve maximum fuel economy and minimum emissions potential for diverse range of application through synergistic integration of building block technologies

Downsized Boosting

Cylinder Pressure Sensing



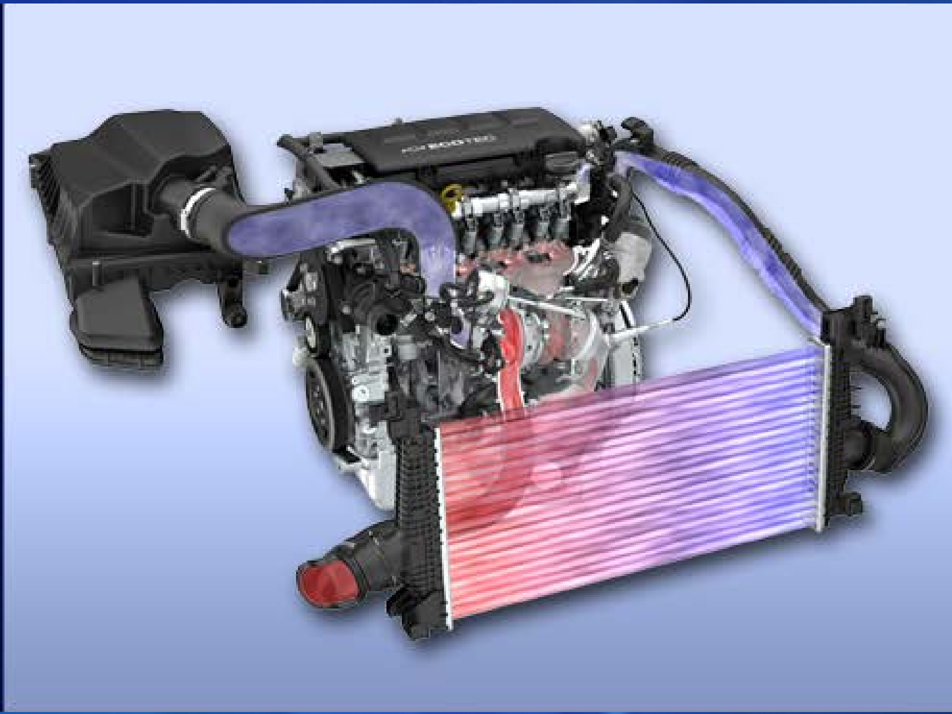
Dilute Combustion

Electrification

Charge Boosting, Charge Dilution, Active Sensing, and Electrification will be the focus in the future

DOWNSIZED TURBO GAS ENGINE

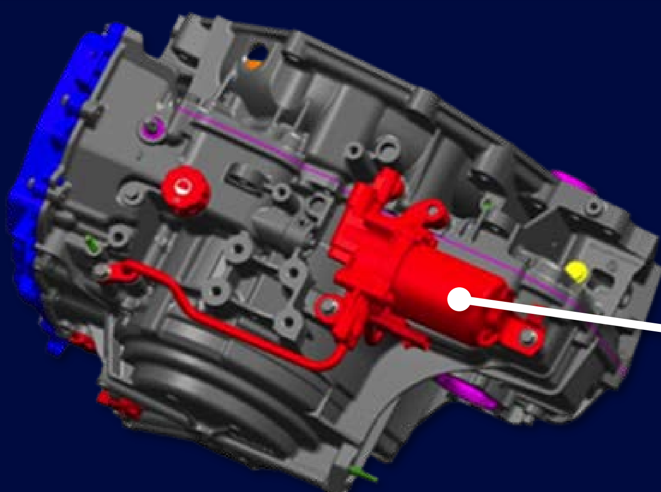
CHEVROLET CRUZE



1.4L TURBO ECOTEC

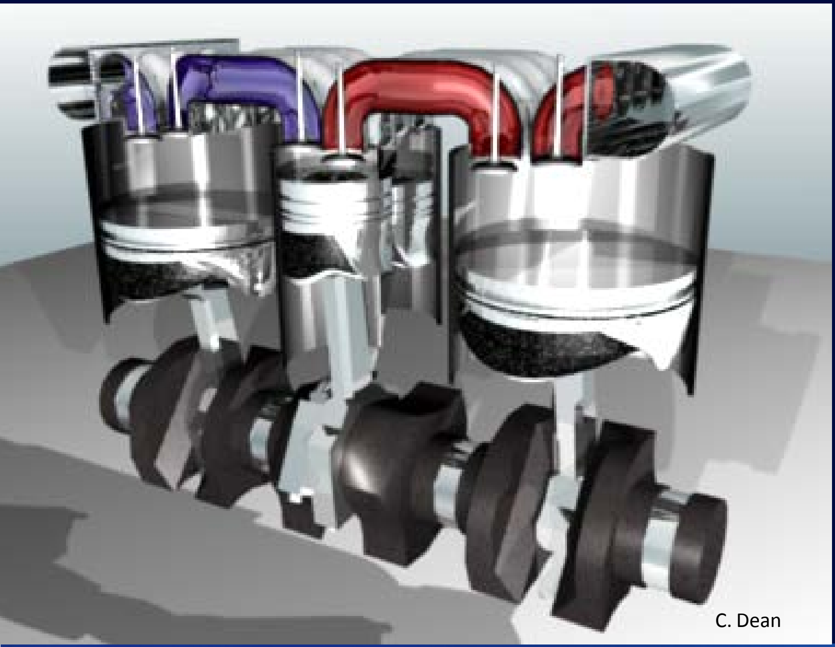
HOMOGENEOUS-CHARGE COMPRESSION-IGNITION (HCCI)

STOP-START SYSTEMS



ADVANCED IC ENGINES

ONE POTENTIAL HIGH-EFFICIENCY DCDE MANIFESTATION

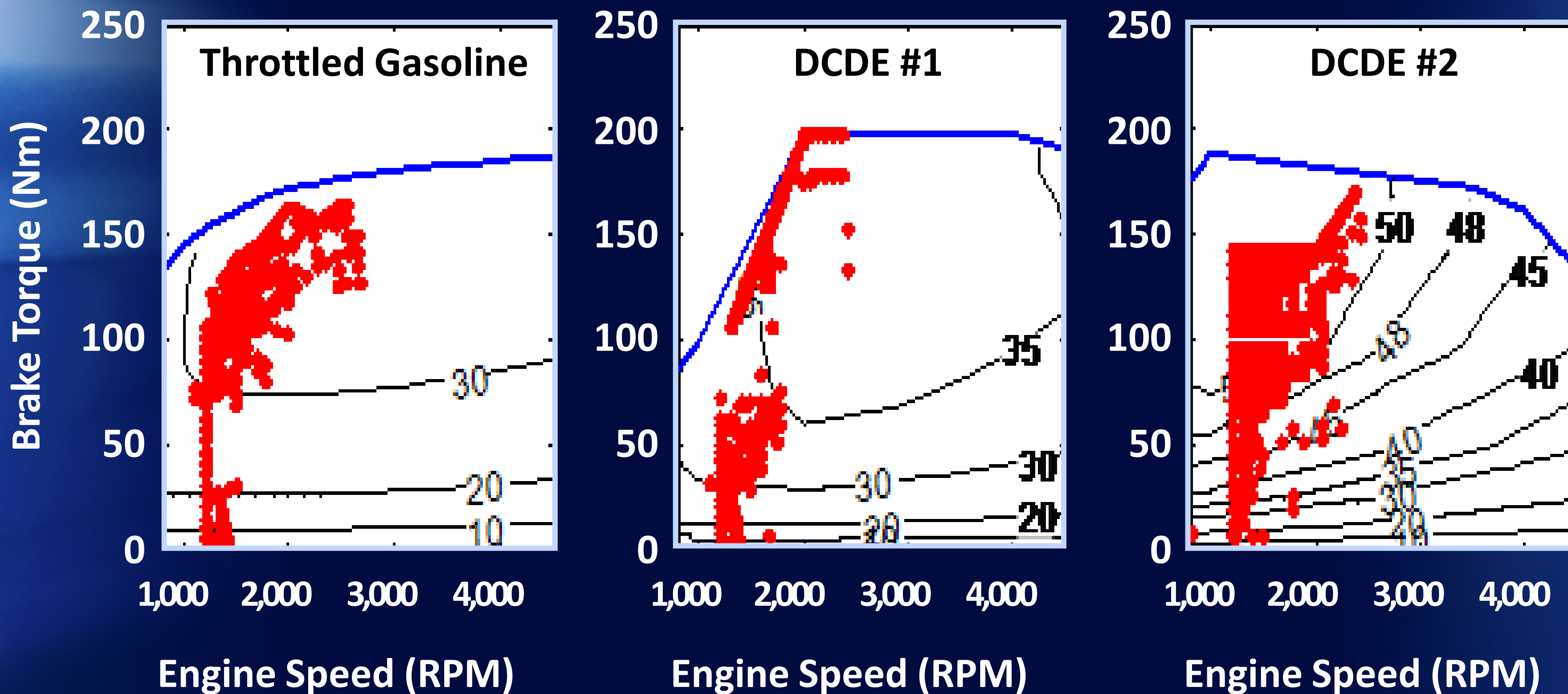


C. Dean

- Different stages of the cycle can be separated into different working volumes
- Possible to optimize each stage individually, potential for 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 (%)

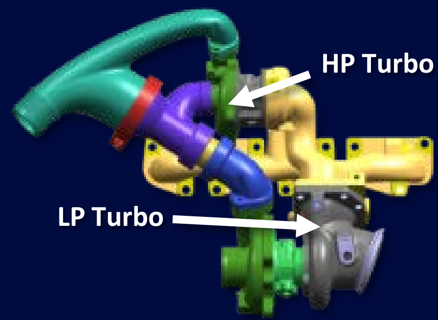


DIESEL ENGINES – ACHIEVING THE LOWEST EMISSIONS

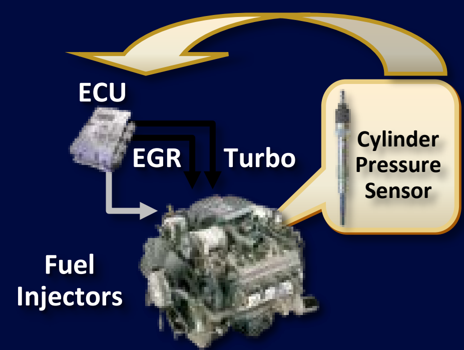
Base Engine Technologies

- High Pressure Injection
- Lower Compression Ratios
- Higher Peak Cylinder Pressure

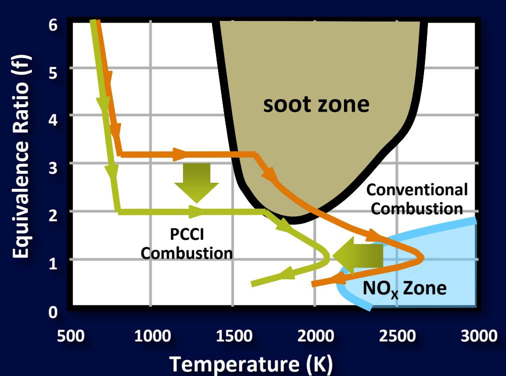
Advanced Boosting with Small Displacement



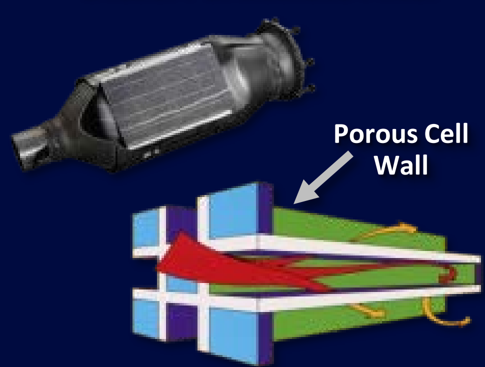
Cylinder Pressure Sensing



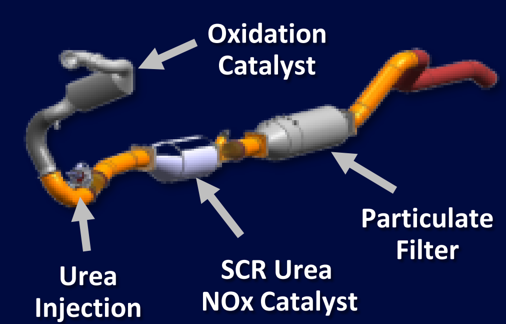
PCCI Combustion



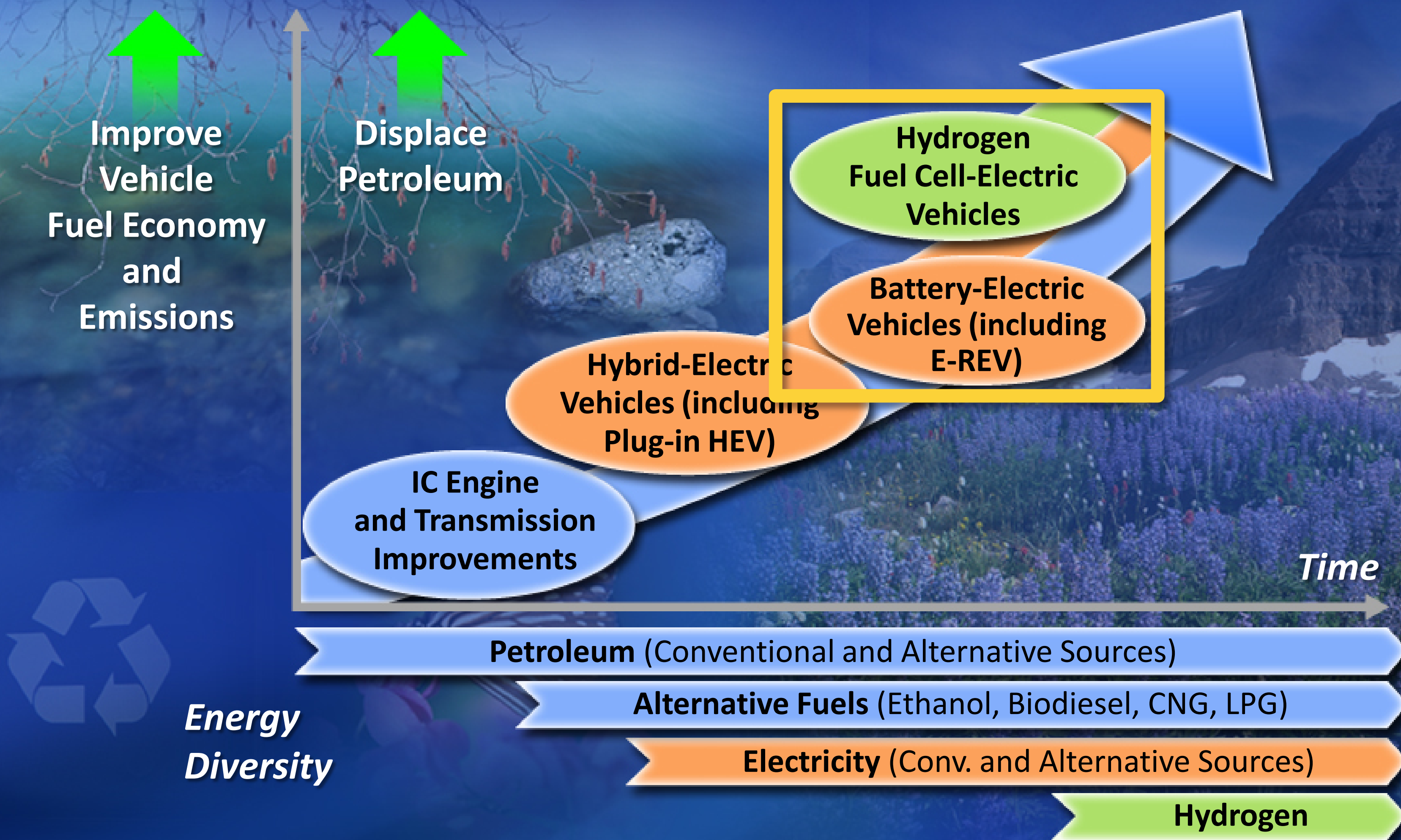
Diesel Particulate Filter



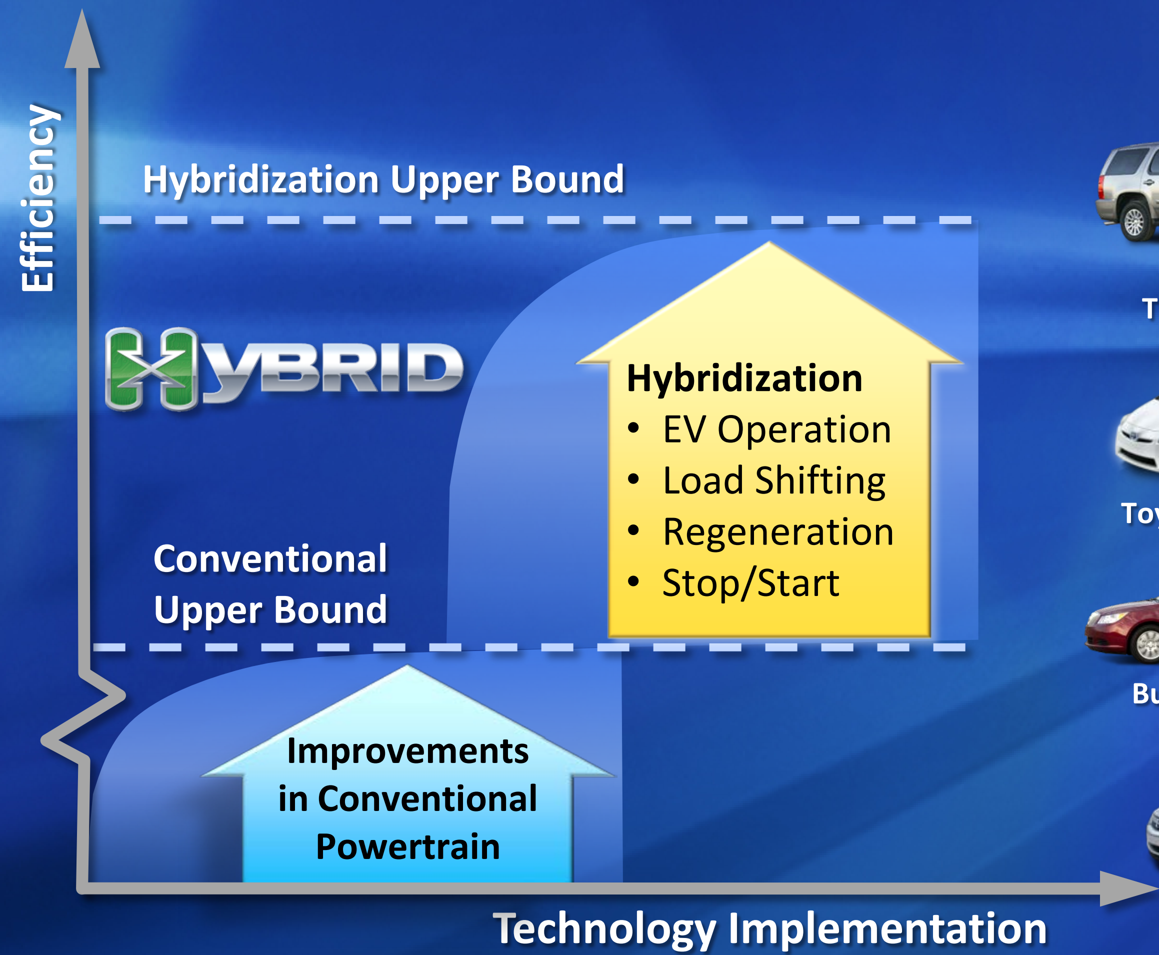
NO_X Aftertreatment



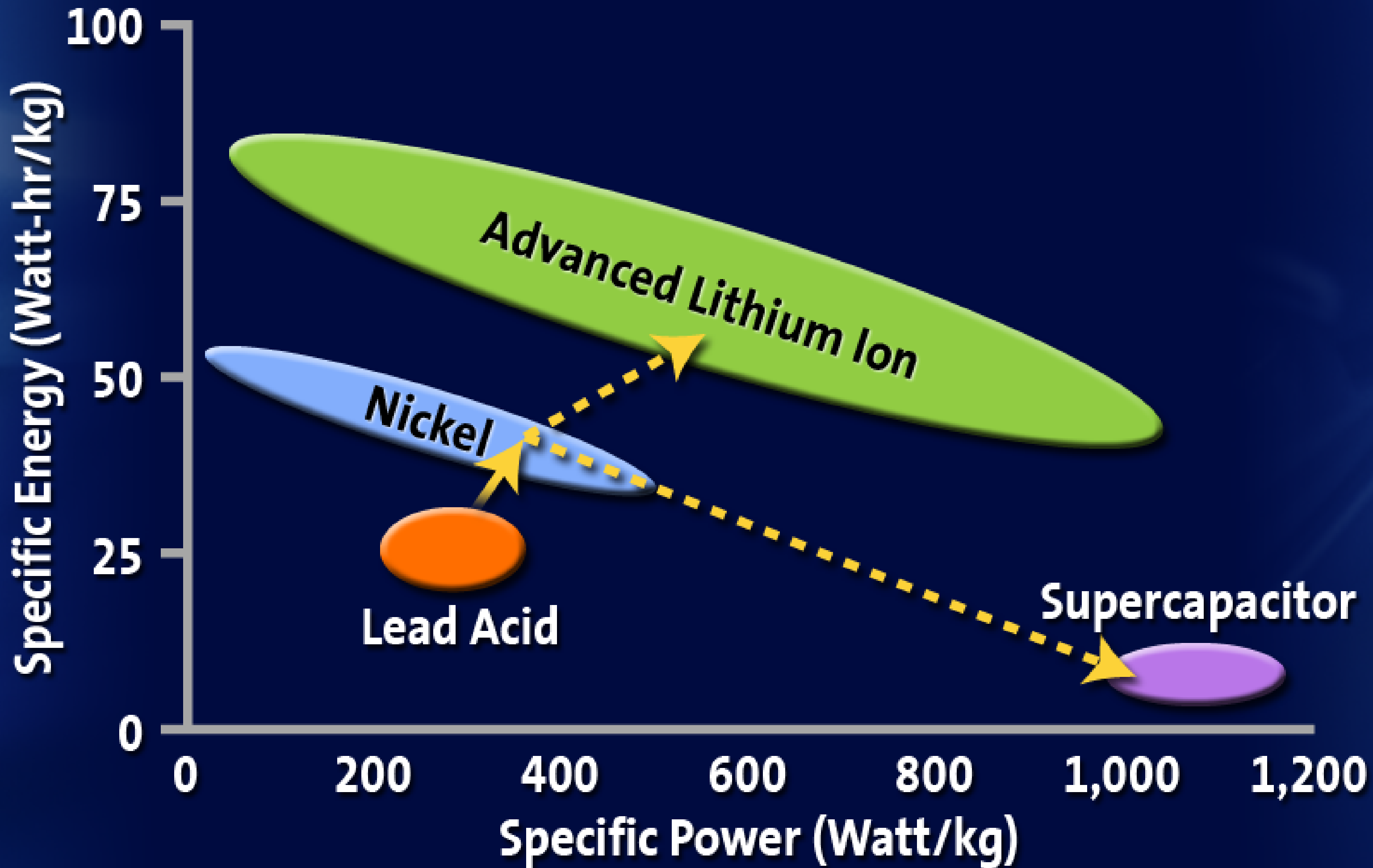
ADVANCED PROPULSION TECHNOLOGY STRATEGY



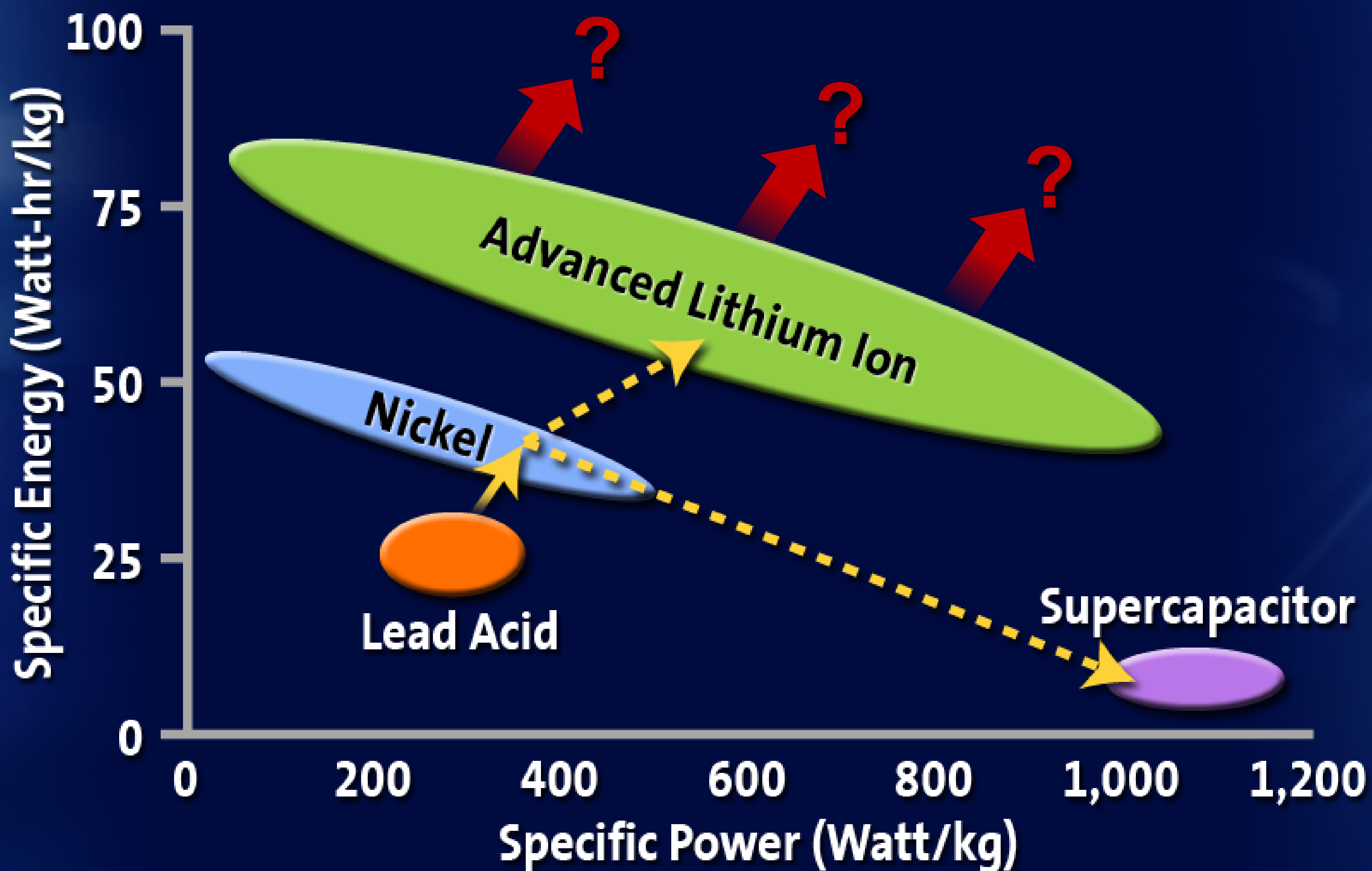
HYBRIDIZATION



BATTERY TECHNOLOGY IMPROVEMENTS



BATTERY TECHNOLOGY IMPROVEMENTS



VOLT

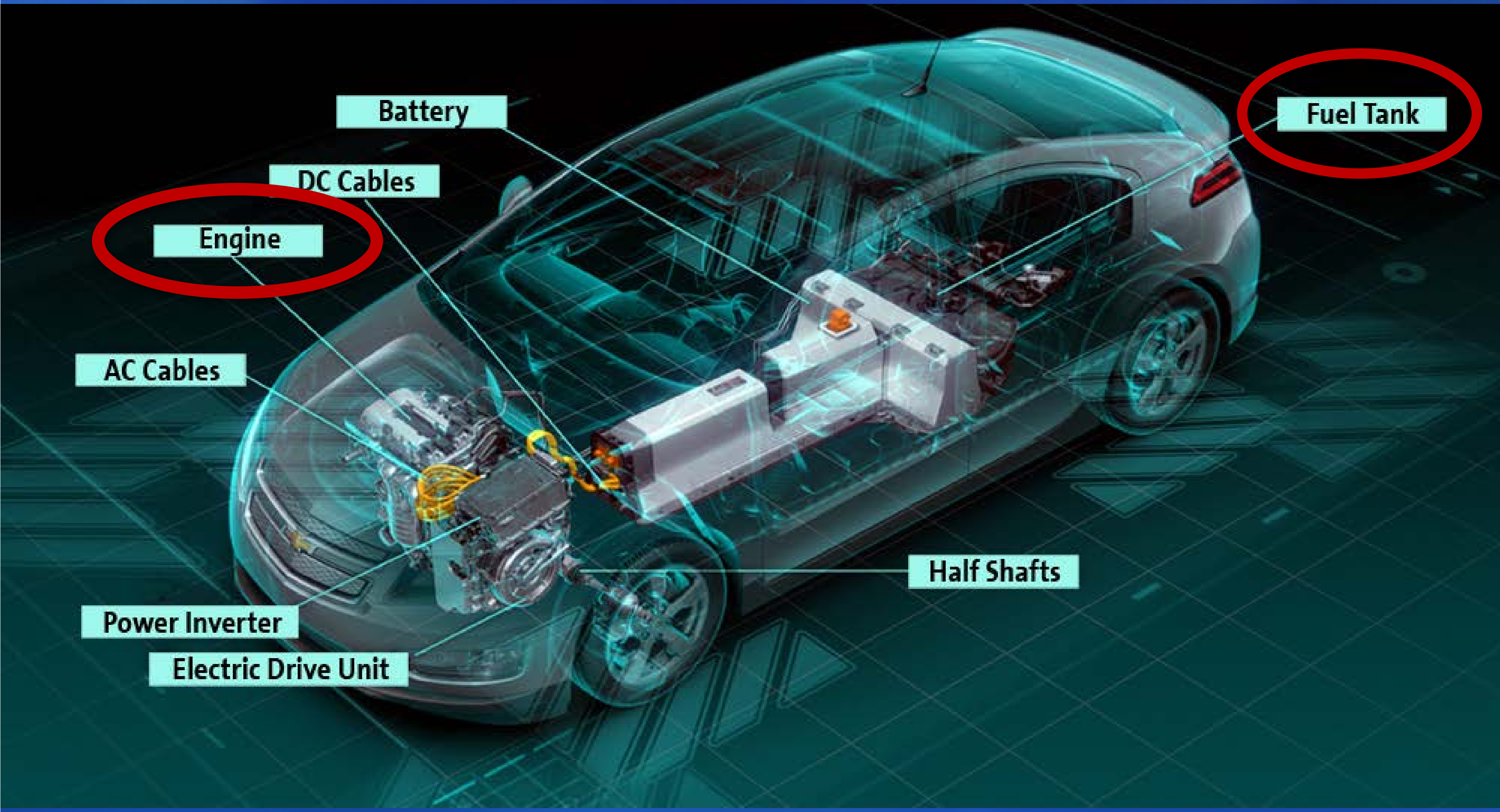
Overcoming RANGE Anxiety

25-50 miles
BATTERY
Electric Driving

+

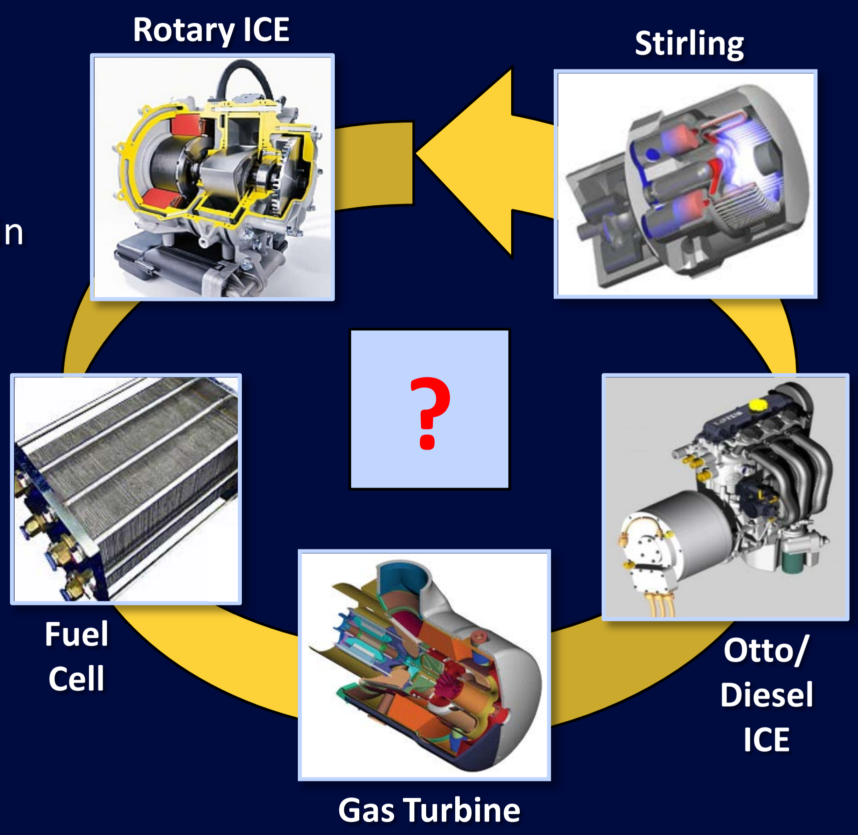
HUNDREDS of miles
EXTENDED RANGE
Driving

VOLTEC PROPULSION SYSTEM

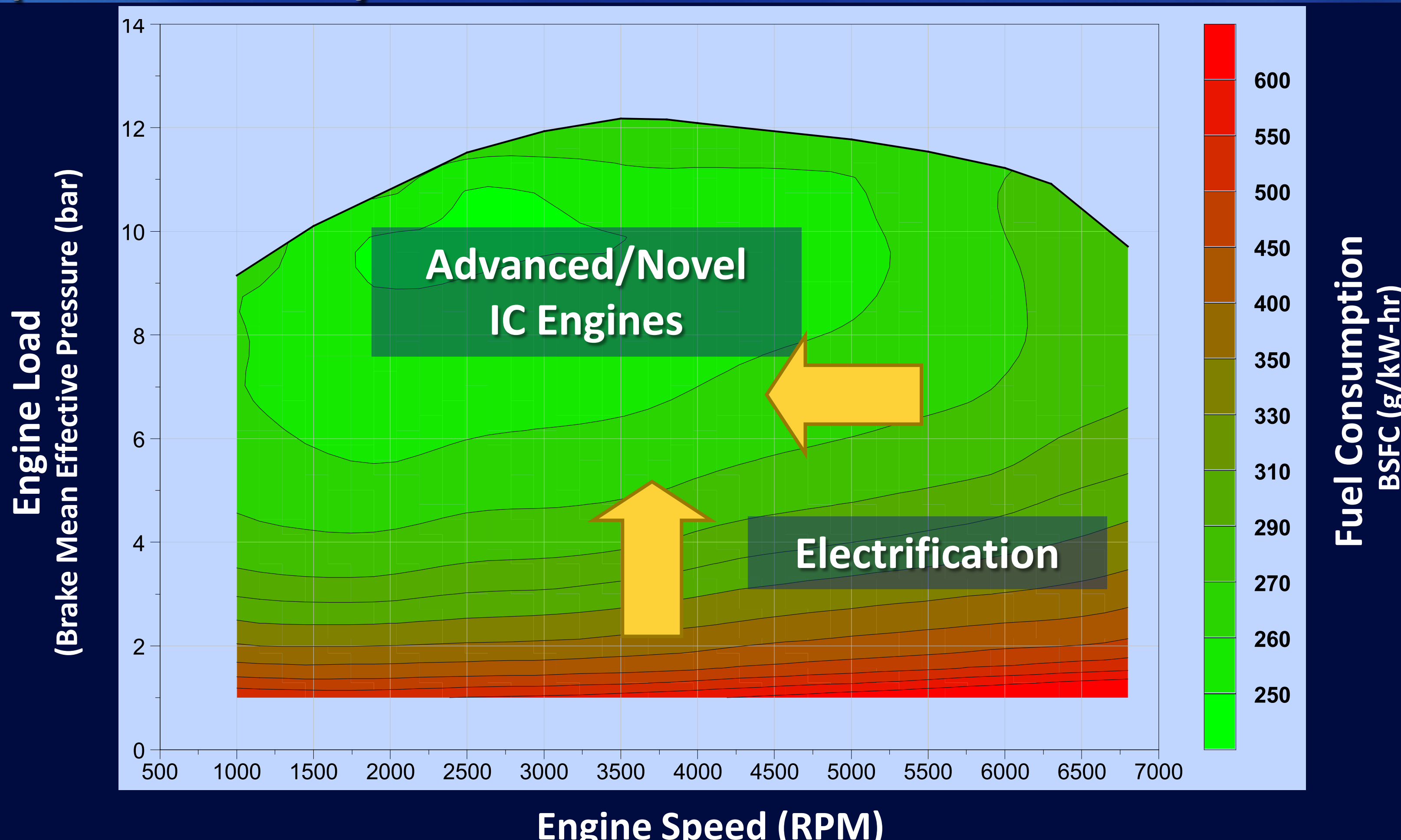


APU MOTIVATION

- Why use an APU?
  - Customer-utility
    - Reduce range-anxiety
    - Provide "limp-home" capability
    - Improve cold weather functions (cabin heating, windshield defrost)
  - Reduce battery weight and cost
- Tradeoffs
  - ZEV capability (except fuel cell)
  - NVH
- Function
  - Dedicated onboard battery charger
  - No prime mover capability
  - Fixed power operation



UPPER-BOUND EFFICIENCY IMPROVEMENT (ESTIMATED)



Electrification of the vehicle adds opportunities for further combustion and engine optimization, energy diversity, different fuels, and novel IC engines

RESEARCH CHALLENGES

- Characterizing, predicting and controlling *stochastic cycle-to-cycle variation* in in-cylinder processes (flow, spray, combustion, emissions)
- Surface chemistry and physics to enable *high-efficiency, low-temperature catalysis and filtration*
- Experiments and modeling of dense *near-nozzle sprays and nozzle internal flow regions*
- *High-pressure, dilute combustion*
- Efficient, accurate *reduced chemical kinetic schemes*
- *System integration tools* using validated, reduced-order, reduced-complexity models for engine and aftertreament systems
  - Including real-time calibration, control and diagnostics


GM