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

Energy Diversity

Petroleum (Conventional and Alternative Sources)

Alternative Fuels (Ethanol, Biodiesel, CNG, LPG)

Electricity (Conv. and Alternative Sources)

Hydrogen

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 – CNG AND LPG
## Biofuels Technology Roadmap

### 1st Generation
- **Feedstock:** Sugars, Starch → Cellulose
  - Sugarcane
  - Corn
  - Sugarbeet, ...
  - Cassava
  - Sweet Sorghum
  - Grasses
  - Wood Biomass
  - Cellulosic Waste

### 2nd Generation
- **Fuels and Conversion Products**
  - Ethanol
  - Ethanol
  - Alcohols
  - Green Hydrocarbons
  - Pyrolysis
  - Final Fuels

### 3rd Generation
- **Designer Energy Crops**
  - Biocrude to Refinery
  - Bio-oil to Green Fuels
  - Alcohols

### 4th Generation
- **Feedstock:** Oil-Seed/Waste Lipids → Algae
  - Soybeans
  - Palm Oil
  - Rapeseed
  - Tallow
  - Waste Veg. Oil
  - Jatropha
  - Camellina etc.

### Designer Bacteria
- Convert CO₂ Directly to Final Fuel Products
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OUTLOOK FOR GLOBAL FUEL ECONOMY AND GREEN HOUSE GAS REQUIREMENTS

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

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

**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 CO₂ taxation
- Gasoline up to $6/gallon

**KOREA**
- 140g/km (39.5 mpg)

**JAPAN**
- 29% CO₂ 2010 → 2015

**MEXICO**
- 10.8 km/l by 2015

**INDIA**
- 150 gCO₂/km by 2015 (43 mpg)

**CALIFORNIA**
- 80% CO₂ reduction by 2050
- ZEV, PZEV rules

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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

- Starter Motor
- Electric Auxiliary Pump
- Starter Motor
- Electric Auxiliary Pump
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 (%)

Throttled Gasoline

DCDE #1

DCDE #2

Brake Torque (Nm)

Engine Speed (RPM)
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

NOx Aftertreatment

- Oxidation Catalyst
- SCR Urea NOx Catalyst
- Particulate Filter

Equivalence Ratio (f) vs. Temperature (K)

- PCCI Combustion
- Conventional Combustion
- NOx Zone
- Soot Zone
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HYBRIDIZATION

- Hybridization Upper Bound
- Conventional Upper Bound

Hybridization
- EV Operation
- Load Shifting
- Regeneration
- Stop/Start

Improvements in Conventional Powertrain

Chevrolet Tahoe Hybrid
Chevrolet Silverado Hybrid
Toyota Prius IV
Ford Fusion
Buick LaCrosse eAssist™
Honda Insight
Opel Astra
Volkswagen Passat Bluemotion
BATTERY TECHNOLOGY IMPROVEMENTS

- **Advanced Lithium Ion**
- **Nickel**
- **Lead Acid**
- **Supercapacitor**

**Graph:**
- **Y-axis:** Specific Energy (Watt-hr/kg)
- **X-axis:** Specific Power (Watt/kg)
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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
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 aftertreatment systems
  - Including real-time calibration, control and diagnostics