Sustainable Powertrain Technologies

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Presentation Outline

- **Sustainability Challenge**
  - Sustainable Mobility Issues
    - Toxic emissions
    - CO₂
    - Energy
  - Fuel Consumption and CO₂ Challenges

- **Technological Response**
  - Engines
  - Fuel Cells
  - Hybrids

- **Summary/Conclusions**
  - Sustainable Technologies
  - A Diverse Powertrain Portfolio
Sustainable mobility provides for the safe freedom of movement for people and goods in ways that use renewable sources of energy while creating no adverse impacts on the earth and its environment.
The Challenges of, and Need For, Sustainability Are Self-Sustaining!

Economic Growth
Increase in industrial activities
Increase in personal income
Increase in consumption

Transport Services
Facilitate movement of goods and services
Improve access to work, education, etc.

Transport Impacts
Growth in trip rates
Motorization
Changes in mode share
Urban expansion

Economic and Environmental Impacts
Emissions (Conventional + GHG)
Congestion
Collisions
Noise, etc.

Enables
Creates
Inhibits
Produces

Source: Adapted from Molina and Molina 2002, p. 214.
The Sustainability Challenge: Economic and Population Growth Will Increase Transportation Energy Demand > 80% by 2030

Nominal Per Capita GDP At PPP (5000s)

Population

Transportation Energy Demand

Source: Global Insight and US DOE
Fuel Consumption and \( \text{CO}_2 \)

The Leading Contributors to Global
Warming, Economic Uncertainty and War
Oil Reserves Remain Highly Geo-Politically Concentrated

Total: 1319.1 billion barrels

Source: Global Insight Energy Group
Median Country Risk* Indices of Oil Reserves and Demand Indicate a High Degree of Uncertainty Over the Oil Supply

Source: Global Insight Energy Group and Country Risk Service

* Country Risk = uncertainty of stable business conditions
High-Risk Sources of Oil Lead to Oil Price Uncertainty and Volatility

• High levels of business risk lead to price volatility and uncertainty

• Increasingly uncertain oil price potentially leads to economic and/or political instability

• These self-supporting factors make management of the oil market increasingly difficult
Vehicle-related Environmental Risks Are Focused on Climate Change Related to Fossil Fuel

- Criteria emissions have been addressed
  - Low-emissions performance must be assured for the useful life of each vehicle

- But greenhouse gas / global warming, primarily due to carbon emissions, is the key issue

Source: Sustainable Mobility Project

Source: Environmental Protection Agency
There Is Enough Oil, But We MUST Better Manage All the Risks

• While there are ample reserves of fossil energy, access is becoming increasingly costly and risky:
  – Oil price
    • Driven by shortfalls in available capacity
    • Gradual rise as the more easily extracted, politically stable, available resources are depleted
    • Swings in oil price can result in economic uncertainty
  – Environmental challenges
    • Exploration
    • Production
    • Greenhouse Gas (GHG) Emissions
  – Geopolitically risky
• The world is looking for a sustainable solution
  – Renewable fuels
  – Efficiency
As It Is Very Risky to Continue on Our Current Path, Enlightened Energy Policies Are Needed

Energy Policy

Environmental Risks

Access to Supplies in Unstable Regions

Economics & Balance of Trade
Enlightened Energy Policies Will Focus on Conservation Supplemented By Alternative Fuels Cutting Fossil Demand and Hence Carbon Emissions Up to ~40%

- Conservation efforts will be driven by regulations
  - Responsible for up to 30% reduction in global demand
  - Fuel economy/consumption requirements
  - CO\(_2\) performance limitations
  - Carbon-based taxation

- Alternative fuels will play an important but minor role
  - CNG in specialized urban fleet applications (~10%)
  - Biofuels meeting from 5 to ~15% of demand
    - Biodiesel
    - Ethanol
Business-As-Usual Automotive Technology Is Not Expected to Meet Future Conservation Requirements – Even in the Near Term

- In North America, the normal trajectory of year-to-year improvements will not keep pace with expected CAFE increases*

- In Europe, the rate of improvement is insufficient to meet the voluntary targets*

* Global Insight/TIAX Future Powertrain Technologies study, circa 2001
Technological Response

It is clear that more stringent standards on toxic emissions will be set forth while the pressure to reduce fossil fuel consumption will remain. How will these challenges be met?
Advanced Conventional Powertrains Face Major Challenges Over Their Entire Service Life

• **Diesel**
  - Fuel Injection
    - >>2200 bar
    - 6 pulses/cycle
    - Fully flexible rate shaping
    - < 0.2% variation in rated fuel quantity
    - < 0.5% crank angle variation in timing
  - Control of EGR rates under all conditions
  - Model-based predictive control
  - Fully flexible variable valve events
  - Low sulfur/phosphorus lubricants
  - Biodiesel compatibility?

• **Spark Ignition**
  - Move from premixed to direct injection
  - Challenges for both premixed and direct injection are similar to Diesel, plus:
    - Downsizing / boosting
    - Fully flexible control of compression ratio
    - Unthrottled operation
    - Low sulfur/phosphorus lubricants

• **All: Exhaust treatment systems**
  - For <2.5 micron particulates
  - NOx reduction
  - Low temperature chemistry
Boosted DGI Offers Significant Potential to Reduce Fuel Consumption and CO₂

Recently announced performance of BMW spray-guided DGI engine

- New family of BMW DGI engines offer a 10-15% improvement over class-leading premixed engines
  - Spray guided
  - Variable cam phasing
  - Turbocharging
  - Thermal management (electric water pump)
  - 200 bar fuel pressure
  - NOx storage converter

- Operates in lower left quadrant of engine speed-load regime

A New Combustion System Will Evolve
Conventional Combustion Systems Are Limited By Atomization/Vaporization, Mixing and Heat Transfer

The Premixed SI engine has a diffusion flame that relies on in-cylinder mixing and heat transfer to spread the flame front across the cylinder.

In its simplest form, combustion in a DI Diesel consists of a series of droplets that burn stochiometrically at their surface and rely on mixing and heat transfer from one burning fuel droplet to the next to spread combustion.

(Illustrations and simplifications with apologies to combustion specialists)
Homogenous Charge Compression Ignition* (HCCI) Escapes the Pollutant Forming Limitations of Mixing and Heat Transfer, Yielding Diesel Fuel Economy With Virtually No NOx and Particulate

In an HCCI engine, the air and fuel are well-mixed, resulting in an overall lean air/fuel ratio

Combustion is initiated by the heat of compression, as in a Diesel, but all the fuel molecules ignite spontaneously, rather than rely on heat transfer and mixing from one molecule to the next

* Also known as Controlled Auto Ignition (CAI)

(Illustrations and simplifications with apologies to combustion specialists)
HCCI Is Coming, But Further Development Is Needed

- The combination of pre-mixed, unthrottled, homogeneous charge and ultra-lean combustion explain the unparalleled performance benefits of HCCI.
- A critical limitation of HCCI is that the engines are prone to misfire and knock unless maintained within a certain operating window which makes control over a sufficient range of operating conditions challenging.
- A mixed-mode HCCI-diesel engine could overcome these challenges by using pilot injection to control HCCI ignition timing during low and part load, while switching to conventional diesel operation when more power is needed.
- If the control issues are successfully addressed, the mixed-mode HCCI-diesel could combine fuel economies comparable to the best diesel engines, with exhaust emissions comparable to the best spark-ignition engines.
But, What About the Other Alternatives?

Fuel Cells
Alternative Fuels
Hybrids
Fuel Cells Remain a Distant Dream

• Despite hundreds of millions spent on development, fuel cells are still challenged by a number of factors such as:
  
  – **Cost**: Johnson Mathey forecast the value of platinum per fuel cell by 2010 with 1 million 30 to 50 kW units per year being produced to be US$ 600 per vehicle*
  
  – **Hardening** at an affordable cost for everyday use
  
  – **A low-impact source of Hydrogen**

Without a Highly Efficient Means of Producing and Using Hydrogen, Diesel and Gasoline Will Remain the Primary Fuels of Choice For the Foreseeable Future

- Reductions in GHG must come from conservation efforts or the use of Diesel- and gasoline-like fuels made from carbon already in the biosphere
- Reduced dependency on fossil fuels can also move us toward the goal of reduced dependency on the current unstable sources of oil
- Development of bio-based liquid fuels compatible with the existing fuel infrastructure, perhaps blended with fossil-based fuels, appears to be the proper direction
  - Renewables have the added advantage that they can be employed by the existing, in-use fleet. Need no new vehicle technology to take advantage of these fuels. The benefit is immediate but limited to about 10%
  - Supplies limited by arable land, fuel-food balance and acceptance of genetically modified fuel crops
Hybrids Appear to Be THE Solution
or Are They?

Duty Cycle-sensitive Costly
Meet Regulatory Requirements in the Lab
Limited Benefit in the Real World
Hybridization Can Be Applied At Many Levels

- **Parasitic load management**
  - Use of electric motors to drive accessories independent of the engine
  - Gain efficiency through optimized duty cycle of each accessory
  - Likely to require 42-volts for full implementation
  - Can be implemented with any driveline hybrid or stand-alone

- **Micro-hybrid**
  - Stop-start operation, no torque boost
  - 14 - 42-volts

- **Mild-hybrid:**
  - Integrated starter-alternator with motor assist, voltage > 100 v (Honda Insight and Civic)

- **Full-hybrid:**
  - Prius-type with equal load sharing capability between engine and electric drive, voltage >>200 v

- **Dual-mode hybrid:**
  - Dual-mode capability, either drive can propel the vehicle for a significant portion of the duty cycle
Hybrids Can be Made From Various Combinations of Engines: Gasoline Full Hybrid ~= Diesel Mild Hybrid

Performance Normalized Relative Fuel Consumption and CO₂ Over the European Test Cycle

Source: Global Insight and TIAX, *Future Powertrain Technology*, Final Report based on modeling over the European test cycles using GT Drive for a typical light vehicle
The Benefits of Driveline Hybrids Are Highly Duty-Cycle Dependent: Market Acceptance May Be Limited

- Hybrids can show significant fuel savings and emissions reductions in regulatory testing
- But in the real-world, not all consumers will find them cost-effective
- Market will be limited to vehicles used in urban areas
- Likely to be used by OEMs to bridge the gap between ICE performance and regulatory needs

Relationship between Engine-Idle Time and Potential Fuel Savings Due to Stop-Start Operation in Various European Driving cycles

Source: Schmidt et al; Potential of Regenerative Braking Using an Integrated Starter/Alternator, SAE Technical paper 2000-01-1020
The Acceptance of Hybrids Will Be Governed By 4 “Rules”

- Hybrids will be successful in applications where:
  1. Highly transient duty cycle—repetitive, predetermined duty cycle even better—enables optimized system design
  2. Fuel economy is important
  3. Brake maintenance costs are high
  4. Per unit distance paid driver or mission (stops/hour)

- But, system optimization is critical

- Therefore, hybrids have the best long-term prospects of satisfying the sophisticated customer who makes a purchase decision based on expected mission profiles and a hybrid system optimized for that duty cycle
The DI Engine, Diesel or Gasoline, On the Other Hand, Delivers Good Fuel Economy Relative to Traditional Gasoline Engines, Regardless of Duty Cycle

- The ideal DI engine is unthrottled and operates closer to maximum efficiency levels at all speeds and loads compared to a gasoline engine.

- Therefore, an investment in DI technology, Diesel or Gasoline, can reliably meet expectations for fuel consumption, regardless of duty cycle, for all vehicle buyers.
Compared to Hybrids: DI Gasoline & Diesels Have the Consumer Advantage, But an Uncertain Regulatory Future

**DIESELS & BOOSTED DI GASOLINE**
- Have an uncertain future relative to toxic emissions
- Deliver high levels of tangible customer satisfaction
  - Fuel economy
  - Towing torque
  - Performance
- And Perceptions of
  - Durability
  - “Green”
- High volumes require higher levels of OEM investment
  - Technology can be purchased or development shared

**GASOLINE HYBRIDS**
- Provide future certainty relative to toxic emission
- Deliver variable levels consumer satisfaction
  - “Feel Good” environmental purchase
  - Added performance?
  - Disappointing fuel consumption
  - Uncertain battery-related issues of maintenance cost
- Require minimal OEM investment
  - Technology can be purchased or development shared
**HCCI Removes the Uncertainties**

**HCCI**
- Able to meet future NOx and Particulate standards
- Deliver high levels of tangible customer satisfaction
  - Fuel economy
  - Towing torque
  - Performance
- While providing long term
  - Durability
  - “Green”
- High volumes require higher levels of OEM investment
  - Technology can be purchased or development shared
- Potentially helped by hybrid driveline

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Commercial, As Opposed to Personal-use Applications of Driveline Hybrids Show the Best Promise of Long-term Market Acceptance

- **Medium duty**
  - Urban delivery
- **Heavy duty**
  - Refuse truck (door-to-door)
  - Urban delivery
  - Urban bus
- **As well as selected light vehicles**
  - Urban taxi
  - Delivery/courier services
  - High mileage urban fleets
- **Those who market hybrids will need the capability to accurately forecast the expected benefits for each end-user**

**Expected Global Market Share: 2020**

- ~25% of Global HD Truck Market by 2020
- <10% of Global Car and Small Truck Market
In Summary....
Sustainability Embraces a Diverse Technology Portfolio

- **Piston Engines**
  - Downsized and boosted, direct injection gasoline
  - Advanced Diesels
  - HCCI

- **Fuels**
  - Gasoline-ethanol blends
  - Biodiesel
  - Pure ethanol?

- **Hybrids**
  - All-vehicles: Parasitic load management – electrically-driven accessories
  - Urban vehicles: Hybrids based on internal combustion engines and batteries
    - Gasoline – for light duty
    - Diesel for heavy duty
    - Spark-ignition of heavy- and light-duty CNG
The Assumption of One or Two Base Technologies For the Industry or Even a Region Is No Longer Valid, But a Diverse Portfolio May Not Be Affordable.

Diesel

Urban Stop & Go

Hybrid

Heavy-duty Pickup - towing

Conventional

Line-Haul

Gasoline

City Car

Commuter Car

Non-towing highway cruising

Source: GM, Global Insight and TIAX, Future Powertrain Technology Studies, (light- and heavy-duty)
Thank You

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