Future Fuel and Energy Utilization Systems

Kevin L. Bruch
Assistant Director - Engine Research
Caterpillar Inc.
- **Products:**
  Construction & Mining Equipment
  Diesel & Natural Gas Engines, Industrial Gas Turbines
  Electric Power, Remanufacturing, Logistics & Financial Services

- **Global Company – 2006**
  Corporate headquarters – Peoria, Illinois
  - >300 company facilities in 40 countries
  - 115 Manufacturing locations
    - 50 inside U.S.
    - 65 outside U.S. (23 countries)
  - 94,593 Employees (50% U.S.)
  - 2537 Patents in last 5 years

- **2006 Sales & R&D:**
  $41.5B Revenue (50% Outside the U.S.)
  $1.35B Corporate R&D

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**Caterpillar Revenue Growth**
This represents only a fraction of the engine offerings Caterpillar produces.
Caterpillar® Turbine Engines

Saturn (1 MW)
Centaur (3-4 MW)
Mercury (4-5 MW)
Taurus (5-8 MW)
Mars (9-11 MW)
Titan (14.5 MW)

Solar Turbines
A Caterpillar Company
Caterpillar Engine Applications

2006 Caterpillar Engine Revenue by Application

- On-Highway: 28%
- Electric Power: 18%
- Oil & Gas: 16%
- Marine: 8%
- Industrial/OEM: 7%
- Cat Machine: 23%

Caterpillar: Non-confidential
Technology & Solutions Division
Caterpillar Engine Research
Technology for …

Caterpillar’s Future

Emissions & Energy are only some of the issues!
What is the Technology Strategy?

• What are the critical technologies for our future?
• What is the technology roadmap?
• What is the future of Petroleum?
• What about Hydrogen?
• When will Caterpillar equipment use fuel cells?
• When will CO2 become a product requirement?
• What about renewable energy?
What about Game Changers?

• **Health effects**, including Sound & Ergonomic requirements
• **GHG regulations** and Kyoto implementation
• Petroleum, as the primary energy source, replaced by:
  – Coal, Tar Sands, Solar, Nuclear, Bio-Mass, Wind
• Breakthroughs in energy conversion and/or energy carrier:
  – Photovoltaic, Fuel Cell, Thermoelectric, Hydrogen, Battery
• **Recycling / Reuse** requirements
• **Dust Management** requirements
• **Internet / Wireless** -- everywhere, free, unlimited bandwidth
• **Policy shift** from energy invulnerability to energy survivability
Energy Drivers for Our Future

• Price of Oil

• Security of Fuel / Energy Supply

• CO₂

Reference: Energy Information Administration

Oil Price (inflated $) vs. Time

Reference: Energy Information Administration

Figure 2: The Path to U.S. Energy Security and Independence

Figure 3: Estimated Contributions of Each Resource to Eliminate U.S. Oil Imports in 2030
The Changing Perception of Greenhouse Gas

Growing public perception that climate change is a real issue.

Public perceptions drive political and legislative agendas.
Climate and Energy Initiatives

United States Climate Action Partnership (USCAP)

Business and NGO Partnership

• 13 initial members in the Partnership
• Recommending national legislation to “slow, stop and reverse the growth of greenhouse gas emissions”

“Legislation Design Principles”

• Account for global dimensions of climate change
• Recognize the importance of technology
• Be environmentally effective
• Create economic opportunity and advantage
• Be fair
• Encourage early action

GHG Emission Target Recommendation

% of Today’s GHG
Climate and Energy Initiatives

The Energy Technologies Institute

ETI

• Public/Private Partnership in UK

• 10 Year, $10M / Year / Company R&D Commitment

• Matching $$ from UK Dept. of Trade and Industry

• Targeting 10 companies in ETI
Climate and Energy Initiatives

United Kingdom Energy Technologies Institute (ETI)

ETI Themes

- **Large Scale Energy Supply Technology** - Improve efficiency of power generation and develop sustainable approaches to emission reduction technology from existing fossil fuel plants
- **Energy Security of Supply** - develop a mix of energy technologies to increase security and diversity of supply
- **End Use Efficiency / Demand Management** - increase the efficiency of energy on the demand side
- **Transport** - develop sustainable transport fuels and transport management technologies
- **Small Scale Energy Supply Technology** - develop new and emerging distributed energy supply options using small scale technology that utilize a local energy source
- **Support Infrastructures** - sustainable energy supply and infrastructure
- **Alleviating Energy Poverty** - develop proven and sustainable energy solutions that can be deployed locally
GHG and High Fuel Costs are Changing our Engine Research Drivers

The New Trend?:
Emissions => CO2 ("Well to Wheels" Fuel Efficiency)
O&O Cost => Cost driven more by Fuel Efficiency

Fuel Choices and Efficiency

Technology

CO2 ("Well to Wheels" Fuel Efficiency)
Emissions
O&O Costs
40% Liquid Fuel, 62% Imported, 68% transportation, 20% efficient, 80% lost energy
Energy/ CO₂ Scenarios

Caterpillar’s products must align with the future energy/CO₂ strategies and policies.

Energy’s future depends on outside pressures…

- NGO’s and Environmental Community
- Consumer CO₂ Views
- Technology
- Energy Prices
- National Security
- Shareholders’ Expectations
2020 Energy Scenario 1 - No Basic Change

Continued oil field development:
• A “dry well” only removes 35% of available petroleum
• Oil reserves have been 30 years for the past 50 years
• Long term oil prices at $50 to $60 per barrel
• Ultra clean fuel processing
• CO2 concerns stabilize

Petroleum supplemented with:
• Coal
• Tar Sands & Oil Shale
• Natural Gas

“US DOE says CO2 injection could quadruple oil reserves”
Reuters, Friday, March 3, 2006
Continued developments for
• Clean coal power
• Carbon sequestration
• Hydrogen from coal

“Virtually all projections show coal continuing to supply around half of the nation's electricity for the next 20 years”

DOE – Office of Fossil Energy

“Carbon sequestration is the ultimate solution to stabilizing global carbon emissions.”

DOE – Office of Fossil Energy

"... U. S. will sponsor a $1 Bil, 10-year demo project to create the world’s first coal-based, zero-emissions electricity and hydrogen power plant..."

President George W. Bush
February 27, 2003
2020 Energy Scenario 3 - Natural Gas

“More than 90 percent of the power plants to be built in the next 20 years will likely be fueled by natural gas.”
DOE - http://www.energy.gov/engine/content.do?BT_CODE=ELECTRICPOWER

“Annual U.S. natural gas consumption is projected to rise from 22.1 trillion cubic feet (Tcf) in 2004 to 30.7 Tcf in 2025.”

Methane Hydrate – “Worldwide estimates of the natural gas potential of methane hydrate approach 400,000,000 Tcf vs. 5,500 Tcf of proven gas reserves.”
2020 Energy Scenario 4 - Nuclear

2005 Energy Bill includes provisions for 6 new nuclear power plants.

“Only nuclear power plants can generate massive amounts of electricity without emitting an ounce of air pollution or greenhouse gases.”

President George W. Bush
August 8th, 2005

Currently 103 reactors in U.S.; 400 needed to meet U.S. energy needs.
Bio-diesel, Biomass to liquids:
1 billion dry tons of biomass could displace 30% of US oil use. Supply “potential exceeds 1.3 bil. dry tons per year.” U.S. Dept. of Ag. & U.S. Dept of Energy, Feb. 2005

“U.S. ethanol consumption has a CAGR of 28% over last four years” American Coalition for Ethanol, August 2005

Solar photovoltaic U.S. market has a CAGR of 30% over last 7 years and “may reach 10-15 GW ... by 2015” (a 40% CAGR through 2015). Energy Information Administration, Nov. 2005 and the “Solar America initiative” June, 2006

“Wind turbines now generate over 17 GW, currently the world’s fastest growing source of energy.”
Energy System View (the matrix multiplies!)

- Energy Systems – Source, Transport, Carriers, and Compact Power

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Energy Distribution</th>
<th>Energy Storage</th>
<th>Energy Conversion</th>
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<tbody>
<tr>
<td>Fossil</td>
<td>Power Lines</td>
<td>Batteries</td>
<td>Engines</td>
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<tr>
<td>Renewable</td>
<td>Pipeline</td>
<td>Hydrogen</td>
<td>Motors</td>
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<tr>
<td>Nuclear</td>
<td>Tankers</td>
<td>Refined fuels</td>
<td>Fuel cells</td>
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### Mobile/Transport Technology Matrix for Energy Drivers

<table>
<thead>
<tr>
<th>Time</th>
<th>Price of Oil</th>
<th>Supply Security</th>
<th>CO2</th>
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<tbody>
<tr>
<td></td>
<td>Energy Conversion Efficiency</td>
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<td></td>
<td>Energy Storage - Hybrids</td>
<td>Alternative Petroleum Production</td>
<td>Gen 1 BioFuels</td>
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<td>Energy Storage - Hybrids</td>
<td>Waste Heat Recovery</td>
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<tr>
<td></td>
<td>Smart sites/systems for minimizing energy usage</td>
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</tr>
<tr>
<td></td>
<td>Local xTL (Gas, Coal)</td>
<td>Gen 2 BioFuels - Designed for Desired Combustion</td>
<td>CCS @ Electricity Generation Plant feeding...</td>
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<td>Renewable H2</td>
</tr>
<tr>
<td></td>
<td>Electric Vehicles</td>
<td>Energy Storage - Electric Vehicles</td>
<td>Renewable H2</td>
</tr>
</tbody>
</table>
**Mobile Energy Outlook**

**Renewable Hydrogen Economy**
*(if Zero Carbon Liquid “Fuel” Required)*

- **xTLiquid – Gas → Coal → BioMass - Gen 2**
  (Alternative Fuels for Energy Survivability)

- **Hybrid and Electric Vehicles**
  (Effective Technology to Address Climate Change)

- **ULSDiesel, Gen 1 Biodiesel – soybean & rapeseed**
  (Improved Conventional Fuels to Lower Emissions/Carbon)

- **Optimized IC Diesel Engine – ACERT® Technology and Beyond**
  (Diesel Bridging Strategy – Emissions and Efficiency)
Stationary Energy Outlook

- **Optimized IC Diesel & Natural Gas Engine plus Flex Fuel**
  (Bridging Strategy – Emissions, Efficiency & Heat Recovery)

- **2005-10**
  - **Renewables (Wind, PV) plus GenSet support**
    (Effective Technology to Address Climate Change)

- **2010-20**
  - **xTG – Coal → BioMass - Gen 2 → SynGas**
    (Alternative Fuels for Energy Survivability)

- **>2020**
  - **Renewable Hydrogen Economy**
    (if Zero Carbon Liquid “Fuel” Required)
Summary

- Energy policies are only one of many challenges to the coming energy revolution.
- Caterpillar is positioning for many future energy developments / scenarios.
- High Energy Efficient System technology is of utmost near term importance.
- Energy Storage (Battery) Systems and Carbon Capture and Storage technology may hold the key to many solutions.
- The role of Renewables will grow in both transport and stationary power markets.
- New Fuels will be brought into play for Energy Security.
- Government/industry/university collaboration will become more critical to focus policy and technology.