Diversification of the world's energy sources and its challenges for the technical professions.

CPAC-SI

July 2009

Honeywell
UOP Road Map

Crude Oil & Natural Gas

Exploration

UOP
- Process Technology
- Catalysts
- Adsorbents
- Equipment
- Services

Refining
- Gasoline
- Diesel
- Jet Fuel
- Lubrication
- Liquefied Gas

Petrochemicals
- Olefins (ethylene, propylene, butadiene)
- Aromatics (benzene, toluene, xylenes)
- Methanol

Plastic
Rubber
Adhesives

Fiber
Paint
Pharmaceutical

Industries We Serve:
- Transportation
- Household Products
- Chemical
- Healthcare
- Utilities
- Technology
- Construction

Bridging Exploration and Consumer Products

Removes Odors within Food and Beverage Packaging. Air Brakes, Refrigeration, Med Oxygen, Insulated Glass, Personal Care & Cosmetic, Environmental Protection, etc.
Outline

• Introduction: Mega Trends that impact Energy Diversification
• Crude Oil
• Coal
• Natural Gas
• CO2 Capture and Sequestration
• Summary of Opportunities
Mega Trends: Population Growth

Mega Trends: Population Growth

Source: Population Reference Bureau
Mega Trends: Water

- Sparsely Populated
- Water Abundant
- Water Concerns
- Water Stressed
- Water Scarce

< 0.5% of the World’s Water is Easily Accessible and has an Acceptable Salinity Level

Source: NAS Review of the Desalination and Water Purification Technology Roadmap, 2005
Mega Trends: Political Unrest

- Iranian Revolution
- Hostage Crisis in Teheran
- Iran-Iraq War
- Desert Storm
- Cruise missiles S. Iraq
- Unrest in Venezuela
- Militant attacks in Nigeria

Nominal $/bbl
Mega Trends: Energy use per capita

Source: World Resources Institute
Mega Trends: Increase in atmospheric CO2
Global Warming Roulette Wheel

Result: Rapid Growth and Diversification of Global Primary Energy Demand
Crude Oil Consumption and Quality

Source: eia.doe.gov
Refining flow diagram
Energy & CO₂ in a Refinery

- 700,000 million cubic feet of natural gas/year
- 8% of crude is consumed as energy
- Energy costs 50% to 60% of total variable operating costs (excluding feedstocks)
- $80 to $100 million/year on energy & 1.2 to 1.5 million metric tons/year of CO₂
- CO₂ emissions increase with heavier feedstock, cleaner fuels, conversion and complexity

<table>
<thead>
<tr>
<th>Refining Unit</th>
<th>% of Energy Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDU/VDU</td>
<td>17</td>
</tr>
<tr>
<td>Fluid Catalytic Cracking (FCC) Unit</td>
<td>20</td>
</tr>
<tr>
<td>Refiner</td>
<td>14</td>
</tr>
<tr>
<td>Hydrocracking</td>
<td>10</td>
</tr>
<tr>
<td>Alkylation and Hydrotreating</td>
<td>15</td>
</tr>
<tr>
<td>Coker</td>
<td>4</td>
</tr>
<tr>
<td>Utilities</td>
<td>15</td>
</tr>
<tr>
<td>Offsite</td>
<td>5</td>
</tr>
</tbody>
</table>
## Energy Related Opportunities in Refining

<table>
<thead>
<tr>
<th>Area of Savings</th>
<th>Actions</th>
<th>Energy Improvement</th>
<th>Profit Increase</th>
<th>CO₂ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved operation and control</td>
<td>• Improve online monitoring, control and optimization through multivariable, predictive control and optimization applications</td>
<td>2 to 4%</td>
<td>$3 to 5M/year</td>
<td>24,000 to 48,000 metric tons/year</td>
</tr>
<tr>
<td>Improved heat recovery</td>
<td>• Increase heat recovery within and across process units.</td>
<td>4 to 9%</td>
<td>$4M to 8M/year</td>
<td>48,000 to 108,000 metric tons/year</td>
</tr>
<tr>
<td>Advanced Process Technology</td>
<td>• Employ new process technology, design, equipment and catalyst technology</td>
<td>3 to 7%</td>
<td>$5M to 10M/year</td>
<td>36,000 to 84,000 metric tons/year</td>
</tr>
<tr>
<td>Utilities Optimization</td>
<td>• Optimization and controls for onsite steam and power production/supply and demand optimization</td>
<td>2 to 3%</td>
<td>$3M to 6M/year</td>
<td>24,000 to 36,000 metric tons/year</td>
</tr>
</tbody>
</table>
| H2 and Fuel Gas Management   | • Optimize H2 recovery  
• Maximize LPG recovery          | 1 to 2%            | $8 to 10M/year   | 32,000 to 44,000 metric tons/year |

**Total**  
12 to 25%  
$23M to 39M/year  
164,000 to 320,000 tons/yr

Basis: for a 100,000 BPSD refinery; natural gas cost @ $6/MMbtu
Strong Incentive for Residual Oil Conversion

**World Supply Demand Balance**

- Market for VR conversion projects expected to stay strong for next 10+ years

**Incentive for Conversion**

- Higher transportation Fuel Prices support high conversion technologies
Coal Reserves and Distribution

- Coal is more wide-spread as compared to Oil & Gas.
- USA, China, India and others are viewing their coal reserves as energy security options for the future.
- Current production / consumption rates forecasts coals availability for next 160 years. [BP2005]
- Safe to transport and store.
- Coal can be stockpiled at mines, power stations or at intermediate points.
- Coal based electricity is well established and reliable.

<table>
<thead>
<tr>
<th>Location of World's Fossil Fuel Reserves (Gigatonnes of Oil Equivalent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>North America</td>
</tr>
<tr>
<td>Europe</td>
</tr>
<tr>
<td>Middle East</td>
</tr>
<tr>
<td>Former USSR</td>
</tr>
<tr>
<td>China</td>
</tr>
<tr>
<td>South America</td>
</tr>
<tr>
<td>Africa</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
</tr>
</tbody>
</table>
Coal Uses – Now and by 2030

- Global Energy demand is projected to grow almost 60% by 2030 to 16.5 Billion Tonnes of Oil equivalent.
- 2/3 of this increase will come from Asian developing economies.
- The challenge of coal use is environment.
- CLEAN COAL technologies are under development – IGCC, CO2 storage and sequestration etc.
DOE Roadmap – Key Advances

- Technical Difficulty
  - Reliability, Life
  - Fuel Flexible, Dry Slurry Feed
  - Adv. Air Sep
  - IGCC, Hot Des, Adv Turbines, CO2 demos
  - Novel CO2 capt
  - Capacity, Efficiency

- Key Advances
  - H2 Sep
  - Cost, Efficiency
  - H2, FC CO2 seq.
  - Oxycombustion, materials
  - USC – 1400 F
  - USC – 1250 F
  - Direct Coal to Chem
  - Polygen
  - H2 Turbines, Large SOFC
  - Ultra Supercr.
  - Novel CO2 capt
  - Polygen

- Timeline
  - 2015
  - 2025

- Table
<table>
<thead>
<tr>
<th>Demonstration</th>
<th>Deployment</th>
<th>CO2 Capture</th>
<th>Near Zero Emissions</th>
</tr>
</thead>
</table>

- Diagram elements:
  - IGCC
  - Supercritical
  - Polygen

- DOE Roadmap – Key Advances

- UOP (A Honeywell Company)
Natural Gas Supply and Demand
The big picture

Green: stock: EIA Current Reserves (rough)

Source: Victor and Hayes, UC Berkeley Energy Resource Group
Strong Growth in Gas Consumption Forecast

- 2025 double 2001
- Increased share of world energy market
- Growth rate twice that of oil
- 3.9% growth in developing nations
- 2.2% growth in industrialised nations
- Significant new production in the US shifts LNG import balance.

Source: EIA

DOUGLAS-WESTWOOD
Opportunities - Offshore Technologies

Drivers:
- Remote resources
- Security issues
- Offshore liquids production
- Government policies
- Possible cost savings on infrastructure
- Flaring reduction

Offshore gas production to increase strongly, mainly in FSU, Asia, Africa & Mid East
Gas Fields vs Size of Resource

Scale-limits and efficiency at large scale

Economics and feasibility at small scale

Source: IHS Energy 2007
LNG Plant Categories

- Rapidly accelerating market
- Remote Control
- Process Analytics for optimality and reliability

Courtesy: Statoil
Natural Gas: Conversion Options

NG Monetization by Route

- Via Halogens
- Hydrates
- Direct Aromatics
- Cracking to C and H2
  - Oxidative Coupling to Olefins
- Direct Formaldehyde
- Direct Methanol

Via SynGas

Syngas Production
  - Syngas to FT liquids
  - Syngas to Alcohols
  - Syngas to DME
  - Syngas to MeOH
  - Syngas to Formaldehyde

Syngas Conversion
  - Hydrogen

LNG

Power Production
Current Oxidative Coupling Catalyst Performance Limits

IIA Metal Oxides
- BeO
- MgO
- SrO
- BaO/CaO
- Na/CoO
- Li/MGO
- Co/CoO
- Bi/Mgo
- LiCO3/MgO
- Na3CO3/CaO

IIIA, IVA, VA Oxides
- TiO2
- PbO
- Sb2O3
- In2O3
- Li-Sn-O
- Cs-Sn-O
- GeO2
- BaPbO3

Complex Metal Oxides
- LaAlO3
- PbMoO4
- PbWO4
- PbCrO4
- LiCa3Bi2O5Cl3
- LiYO4Na2CeO3
- CeO3.95Yb2O3.95
- SrCeO3.95Yb2O3.95
- Pb2Mn3Si2O9

Transition Metal Oxides
- MnO2
- Mn3O4
- NaMnO4/MgO
- Mn2SiO3
- NaMnO4/MgO
- Y2O3
- TiO2
- Na2CO3/TiO2
- NaCl/NiO

Lanthanide Metal Oxides
- La2O3
- Pr2O3
- Sm2O3
- Gd2O3
- Tb2O3
- Na2La2O7
- SrLa2O3Li2O
- Na2CeO3
- Li2SmO3
- K2SmO3
- Cs2SmO3

TARGET PERFORMANCE

30 % Yield

J.C. Bricker, personal communication, 2007
The CCS see-saw … and a deadline

Reaching an agreement in Copenhagen this December to sharply cut greenhouse gas emissions is "the world’s last chance to stop climate change before it passes the point of no return."
—EU Environment Commissioner Stavros Dimas, February 2009
Objective –

Stabilize climate by stabilizing atmospheric GHG (CO₂)
Ample and affordable energy, no impact on growth

*Reduce annual emissions by 7 GtC by 2054*

Wedge model for CO$_2$ concentration stabilization

Total = 25 Gigatons carbon
50 years

$1 \text{ GtC/yr}$
@$100/\text{tC}$
~ $2.5 \text{ trillion}$

Potential Wedges:

- CO$_2$ capture and storage
- Renewable electricity and fuels
- Energy Efficiency and Conservation
- Fuel Switching
- Nuclear Fission
- Forests and Soils

Magnitude of The Challenge

What is needed to achieve 1 GtC/yr reduction?

**Example 1: Electric Power**

Carbon capture (and storage) for 800 GW coal power generation (+1400 plants)

**Example 2: CO₂ Storage**

- 3500 Sleipners @ 1 Mt CO₂/yr
- 100x U.S. CO₂ injection rate for EOR
- A flow of CO₂ into the earth equal to the flow of oil out of the earth today
Carbon Capture and Storage Approaches

**Post Combustion**

- CO₂ Capture
- Power & Heat
- Air Separation Unit
- N₂ / O₂ / H₂O

**Precombustion Decarbonisation**

- POX + CO₂ Sep
- H₂
- Power & Heat
- N₂ & H₂O

**Oxyfuel**

- Air Separation Unit
- Power & Heat
- O₂
- N₂ / H₂O

Source: CO₂ Capture Consortium

CO₂ Storage

- CO₂ / H₂ / CO
- CO₂ / H₂O
- N₂ / O₂
## Carbon Capture Technology Scenarios

<table>
<thead>
<tr>
<th>Technology</th>
<th>Natural Gas</th>
<th>Post-Combustion</th>
<th>Pre-Combustion</th>
<th>Oxyfuels</th>
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</thead>
<tbody>
<tr>
<td>Solvent Absorption¹</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>Membranes²</td>
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<tr>
<td>Adsorption³</td>
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<td>✔</td>
<td>✔*</td>
<td>✔*</td>
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<tr>
<td>Cryogenics⁴</td>
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<td>✔</td>
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<tr>
<td>Hydrates⁴</td>
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<tr>
<td>Chemical Looping⁵</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Source: adapted from CO2CRC 2004.
• Verification of CO₂ sequestration an essential aspect of CO₂ mitigation systems
• Extensive systems for monitoring, auditing, remediation, reporting will be required
• End-to-end chain must be considered: from sensors and instrumentation to industry/national audit trails
• Risk management perspective: potential failure modes and models must be identified, mitigation strategies established
Remote control of CO₂ Transportation and Injection

- Geographically dispersed plant and equipment such as pipelines, valves, compressors, gas treatment, wellheads and underground systems with minimal staffing. Requires remote control and remote monitoring technology.

- Dynamic process fluctuations and the large scale of assets require self-regulating automation for plant to operate to design and to modulate to ambient conditions

- Sensing of safety-critical parameters and plant and equipment shutdown on detection of onset of breaches

- Sense and measure parameters for various stakeholders including operations, maintenance and compliance
Summary of Opportunities

- **Crude Oil**
  - Improved characterization of hydrocarbons
  - Improved monitoring of process equipment (temperature)

- **Coal**
  - On line sensing of concentrations (oxygen, contaminants) for better on line control
  - Improved monitoring of process conditions for polygen etc.

- **Gas**
  - Process analytics for reliability and optimality (hydrocarbons, N2)
  - Developing understanding of the fundamentals of conversion

- **CO2**
  - Fundamentals of capture technology
  - CO2 monitoring and control in storage and transportation.
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    ◦ Tariq Samad
    ◦ Brendan Sheehan
  - Other
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