A FUTURE FOR MOLECULES IN THE ENERGY SUPPLY?

Challenges and Opportunities for Sustainable Production of Chemicals and Fuels beyond the Shale Gale

UCSB

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Reserves: Our use of the term “reserves” in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Resources plays: our use of the term ‘resources plays’ refers to tight, shale and coal bed methane oil and gas acreage.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this presentation “Shell”, “Shell group” and “Royal Dutch Shell” are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words “we”, “us” and “our” are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. “Subsidiaries”, “Shell subsidiaries” and “Shell companies” as used in this presentation refer to companies in which Royal Dutch Shell either directly or indirectly has control, by having either a majority of the voting rights or the right to exercise a controlling influence. The companies in which Shell has significant influence but not control are referred to as “associated companies” or “associates” and companies in which Shell has joint control are referred to as “jointly controlled entities”. In this presentation, associates and jointly controlled entities are also referred to as “equity-accounted investments”. The term “Shell interest” is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

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THE WORLD IN 2050 – THE ENERGY CHALLENGE

9 billion people
4-5 times richer
Double the energy
Need to reduce CO₂ emissions
Increasing role for Renewables
Hydrocarbons remain indispensible
**Power remains concentrated in economic and political elites/governments**

- Top Down policy making in
  - Renewables
  - Hydrogen
  - Gas with CCS as a low carbon alternative to Coal

**Power devolves away from governments and elites**

- Spurs (local) innovation and economic growth

**Less consensus building:**

- Transition from Coal to Gas will be slower
- Slow adoption to Efficient energy usages measures and CCS
ANNUAL GLOBAL TEMPERATURE

Annual Global Average Temperature

Trend = 0.70 °C/Century
Base Line: 1981-2010 Average

Japan Meteorological Agency
GERMAN ENERGY MIX 2014

German energy mix
2014 (% of total)

Lignite 25.6
Coal 18
Nuclear energy 15.9
Natural gas 9.6
Renewables 25.8
Petroleum products 0.8
Other 4.3

Renewables (% of total energy mix)

Solar 5.8
Biomass* 8.0
Hydropower 3.4
Wind 8.6

* including biogenic waste

Source: Agora Energiewende
CO2 EMISSION PER HYDROCARBON FUEL SOURCE

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>CO2 Emission (lb/MM BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (anthracite)</td>
<td>228.6</td>
</tr>
<tr>
<td>Coal (bituminous)</td>
<td>205.7</td>
</tr>
<tr>
<td>Coal (lignite)</td>
<td>215.4</td>
</tr>
<tr>
<td>Coal (subbituminous)</td>
<td>214.3</td>
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<tr>
<td>Diesel fuel &amp; heating oil</td>
<td>161.3</td>
</tr>
<tr>
<td>Gasoline</td>
<td>157.2</td>
</tr>
<tr>
<td>Propane</td>
<td>139.0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>117.0</td>
</tr>
</tbody>
</table>

Rational for LNG substituting
- coal (power)
- gasoline/diesel (transportation)

http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11
Combined with the impact of higher economic development, Oceans sprawling suburbs lead to higher travel needs than Mountains compact cities.

Source: [www.shell.com](http://www.shell.com) – new lens scenarios
### SHELL – FUTURE TRANSPORTATION FUELS

**‘More Gas’**

<table>
<thead>
<tr>
<th>Premium Fuels</th>
<th>GTL Fuel</th>
<th>CNG/LNG</th>
<th>Biofuels</th>
<th>Hydrogen</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V-Power fuels:</strong></td>
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<tr>
<td>Best performance in Latest engine technology</td>
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<tr>
<td>• In 60 markets since 1998</td>
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<tr>
<td>• VP-Diesel with unique GTL component</td>
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<tr>
<td>• V-Power racing with 100 Octane and FMT-Technology</td>
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</tr>
<tr>
<td>• Shell Fuel Save for improved Fuel Economy</td>
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<tr>
<td><strong>Pioneer in the development of Gas to Liquid technology</strong></td>
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<tr>
<td>Premium diesel containing GTL Fuel launched in: Austria, Germany, Greece, Italy, Netherlands, Switzerland and Thailand</td>
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<tr>
<td><strong>Natural gas will account for over half of Shell’s total production in 2012</strong></td>
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<tr>
<td>• Established CNG offers in dedicated markets</td>
<td></td>
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<tr>
<td>• LNG for large engines (heavy duty on road / off-road, rail, marine)</td>
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<tr>
<td><strong>Leading in current and future biofuels</strong></td>
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<tr>
<td>First-generation</td>
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<tr>
<td>• 9.5 billion litres (2010)</td>
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<td>e.g. Brazilian Sugarcane Ethanol (COSAN JV)</td>
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<tr>
<td><strong>World’s largest public transport joint venture</strong></td>
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<tr>
<td>Concentration of Demonstration projects in EU/D and USA, China</td>
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</tr>
</tbody>
</table>

**Evaluation of Options**

**Performance fuels**

Energy Diversification

... based on CO₂ solutions
# Fuel Options for Modes of Transport

<table>
<thead>
<tr>
<th>Mode of Transport</th>
<th>Liquid Fuels</th>
<th>Gaseous Fuels</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LPG</td>
<td>CNG</td>
</tr>
<tr>
<td>Car</td>
<td>Short distance</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Long distance</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Truck</td>
<td>Light</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Rail</td>
<td></td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Ship</td>
<td></td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Aircraft</td>
<td></td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

++ (Fully) compatible  + With minor restrictions  ○ With major restrictions  - Not compatible
**UNIQUE QUALITIES OF GTL PRODUCTS**

**GTL Gasoil**

GTL Gasoil in new diesel fuel formulations to address market requirements for:
- improved engine durability
- reduced emissions
- less noise and smell

**GTL Base Oils**

GTL Base Oils in new engine oil formulations to address market requirements for:
- energy conserving/low viscosity lubricants
- improved engine durability
- reduced emissions
- improved after-treatment device durability

### Mack T 12

<table>
<thead>
<tr>
<th></th>
<th>HDDEO low SAPs SAE 5W-30 current</th>
<th>HDDEO low SAPs SAE 5W-30 Shell GTL</th>
<th>API CJ-4 limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. top ring weight loss (mg)</td>
<td>85</td>
<td>54</td>
<td>105 max.</td>
</tr>
<tr>
<td>Av. liner wear (micro meters)</td>
<td>21.3</td>
<td>14.5</td>
<td>24 max.</td>
</tr>
<tr>
<td>Oil consumption (grams/hour)</td>
<td>64.3</td>
<td>54</td>
<td>85 max.</td>
</tr>
</tbody>
</table>

### Shell G III and Mineral G III

<table>
<thead>
<tr>
<th>Property</th>
<th>Shell G III</th>
<th>Mineral G III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vk Kinematic cSt (100°C)</td>
<td>5.6 to 9.3</td>
<td>7.45</td>
</tr>
<tr>
<td>Vd Cold Crank m.Pa.s (-35°C) max.</td>
<td>5722</td>
<td>6119</td>
</tr>
<tr>
<td>Noack % weight</td>
<td>8.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Base Oil Viscosity (BoV) cSt (100°C)</td>
<td>4.59</td>
<td>4.45</td>
</tr>
</tbody>
</table>
UNIQUE QUALITIES OF GTL PRODUCTS

HIGHER VALUE NAPHTHA FEEDSTOCK

GTL Naphtha

GTL Naphtha is a highly paraffinic premium steam cracker feedstock:
- Enables feed slate optimization to fully utilize existing hardware

GTL N-Paraffin: A Cost Effective Feedstock

GTL N-Paraffin is a premium feedstock for the production of LAB / LAS, widely used in detergents:
- More cost effective than from kerosene extraction
- Allows freedom of location

GTL Kerosene

GTL Jet Fuel is approved for use in commercial aviation, delivering:
- Lower emissions (Sox, NOx, CO, soot particles)
- Less smell and smoke
- Better eco-toxicity
- Higher take-off load or better fuel economy
- Better thermal stability and less soot

Synthetic Fuels Consortium: Furthering R&D on GTL Jet Fuel

Pearl GTL Naphtha
Full Range Naphtha

LOW VALUE CHEMICALS
HIGH VALUE CHEMICALS
- Ethylene
- Propylene
- Butadiene
- Benzene

65% 59%

Our Customers

Linear Alkylbenzene
Household Formulations
- e.g. washing powder

GTL N Paraffin
N-Paraffin

Pearl Kerosene

Refinery

GTL Synthetic Fuels Consortium: Furthering R&D on GTL Jet Fuel

Typical Jet A-1
- Neat GTL
70:30 Blend

Energy content (MJ/Kg)
44.4
44.2
44
43.8
43.6
43.4
43.2
43
42.8
42.6
Global average annual chemical production has grown at 1.5 x global energy consumption.
Natural Gas:
- Affordable-Acceptable-Abundance
- Advantaged feedstock (ref hydrocarbon liquids) for base chemicals
- Olefins C2= and C3=
- Aromatics (BTX)

Alternative C-H activation limited by:
- Reactivity products - Oxidative Coupling
- Thermodynamics - Methane-to-Benzene
Methane to Benzene

Fixed Bed Experimental Results

<table>
<thead>
<tr>
<th>T, °C</th>
<th>CH₄ Conv*, % w</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>11.0</td>
</tr>
<tr>
<td>800</td>
<td>23.8</td>
</tr>
</tbody>
</table>

* Normalized for Coke. Test Conditions: 100 %v CH₄ Feed, Standard M2B Catalyst Pretreatment, GHSV = 1000 h⁻¹, 1 bar, 700-800 deg. C

- Increasing temperature to 800°C increases (doubles) CH₄ Conversion
- A Fluidized reactor enables higher operation temperature (short cat cycles)
- Very endothermic ΔH=530 kJ/mole benzene
Methane to Benzene Program Structure/Activities

Catalyst Development & Experimental Work

STCH M2B R&D
Hazen Research

Process Design & Development
Economics Evaluation

Process Development

Integration/Deployment

Activity Carried out at 4 Locations

IP
CRI Kataleuna
hte Company EE

Reactor Engineering
Separations
The Future for Molecules in the Energy Supply

Natural Gas

- Transportation Fuel
  - As is (LNG, CNG)
- CH4 activation: no alternative yet for synthesis gas
  - GTL liquids
- Chemicals: Making C-C bonds from CH4
  - No full conversion routes (except C-products)
  - Limited yield valuable products requires expensive separation & recycles

Shell Grand Challenges

Chemistry & Catalysis:
Shell needs to continue developing technology that can monetize Natural Gas as a fuel or chemical products and further exploit gas from stranded sources.