Biofuels and Bio-based Chemicals: Opportunities & Barriers

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The way we produce and use energy today is not sustainable. A new direction is needed.
For us, as a company, the debate about whether man-made climate change is happening is over.

The debate now is about what we can do about it. Businesses, like ours, need to turn CO₂ management into a business opportunity by leading the search for responsible ways to manage CO₂, and use energy more efficiently. But that also requires concerted action by governments to create the long-term, market-based policies needed to make it worthwhile for companies to invest.

With fossil fuel use and CO₂ levels continuing to grow fast, there is no time to lose."
Shell’s position on Climate Change

- Among first energy companies to acknowledge the threat of climate change
  - Take action ourselves!
  - Call for coordinated action by governments, industry and energy users

- Technology is a key enabler:
  - reduce CO2 emissions
  - Capture and sequester CO\(_2\) from current energy systems & technology

http://www.shell.com/home/content/responsible_energy/environment/climate_change/
Global demand for energy is growing.

Supplies of “easy oil cannot keep up with demand growth.

More energy means more CO₂ emitted at a time when climate change looms as a critical global issue.

**World population**

- 1950: 1 billion people
- 1975: 1 billion people
- 2000: 1 billion people
- 2025: 1 billion people
- 2050: 1 billion people

**Climbing the energy ladder**

- GJ per capita (primary energy)
- GDP per capita (PPP, ‘000 200 USD)

Data shown 1970-2005

Source: UN Population Division

Source: Energy Balances of OECD and Non-OECD Countries © OECD / IEA 2006
2- Scenarios

- Policymakers pay little attention.
- Greenhouse gas emissions not seriously addressed — until major climate shocks.

- Local actions begin to address the challenges
- Price is applied to emissions:
  - stimulates development of clean energy technologies
  - CO2 capture and storage
  - energy efficiency
  - Biofuels and alternative energy

“Blueprints” results in far lower CO2 emissions.
Blueprints: What This Means for Energy

- Broader anticipation of challenges
- Critical mass of parallel responses to hard truths
- Effective carbon pricing established early
- Aggressive efficiency standards
- Growth shifts to electrification
- New infrastructure develops
- CCS emerges after 2020

Source: Shell International BV and Energy Balances of OECD and Non-OECD Countries©OECD/IEA 2006
The Energy Challenge Trilemma

The “three C’s” or “three E’s”

Efficiency/Economy (Cheap)

Carbon Capture & Storage

Energy security (Convenient)

Environment (Clean)

Balancing demands of society and markets
Energy technology change takes time

Global production of primary energy sources.

Terajoules/year


*Coal and natural gas used in power generation with carbon capture and storage

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Shell: 30+ years GTL development

1973
- Laboratory Amsterdam grams/d

1983
- Pilot plant Amsterdam 3 bbl/d

1993
- Bintulu Malaysia current capacity 14,700 bbl/d

TODAY
- Pearl GTL Qatar 140,000 bbl/d

CONTINUED TECHNOLOGY DEVELOPMENT
Energy-related CO₂ emissions account for 62% of the global total.

Transport accounts for about 23% of energy-related CO₂ emissions. Road transport accounts for 17%.

Global population is growing and demand for mobility is increasing.

The number of vehicles on the road is expected to double to more than two billion by 2050.

Energy Related CO₂ Emissions*

- Industry & Manufacturing: 76.5% Power Generation, Buildings & Commerce
- Road Transport: 17% Commercial Heavy Duty and Passenger Light Duty Vehicles
- Other Transport: 6.5% Rail, Aviation, Marine

Source: International Energy Agency

* 62% of global CO₂ emissions

Estimate of worldwide vehicle demand

NO SINGLE ALTERNATIVE TO OIL BASED ROAD TRANSPORT FUELS

- All fuel options will be needed
- Countries and regions will choose portfolios of fuel solutions based on cost, security of supply, existing infrastructure and CO₂ emissions
- Not just fuels: Improvements in CO₂ emissions through vehicle efficiency, fuel technology and driving habits
- The internal combustion engine and liquid fuels will continue to play an important role
- Electric and hydrogen will play an important role if technical and infrastructure challenges can be overcome
- Natural gas will continue to find a niche in local markets
Today’s biofuels are the most realistic commercial solution to take CO₂ out of the transport fuels sector over the next twenty years.

Global CO₂ abatement cost curve for the Road Transport sector - Mix Technology World scenario
Societal perspective; 2030

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €100 per t CO₂ e in a penetration scenario if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0
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**CO$_2$ Abatement Curve**


<table>
<thead>
<tr>
<th>Abatement costs</th>
<th>$/tonne of CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>building insulation</td>
<td>-$183</td>
</tr>
<tr>
<td>commercial vehicles fuel efficiency</td>
<td>-$134</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>-$113</td>
</tr>
<tr>
<td>air conditioning</td>
<td>-$110</td>
</tr>
<tr>
<td>water heating</td>
<td>-$70</td>
</tr>
<tr>
<td>fuel efficiency in vehicles</td>
<td>-$68</td>
</tr>
<tr>
<td>sugarcane biofuel</td>
<td>-$17</td>
</tr>
<tr>
<td>industrial efficiency</td>
<td>-$14</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$1</td>
</tr>
<tr>
<td>Livestock</td>
<td>$10</td>
</tr>
<tr>
<td>Forestation</td>
<td>$14</td>
</tr>
<tr>
<td>EOR with CCS</td>
<td>$21</td>
</tr>
<tr>
<td>Wind</td>
<td>$25</td>
</tr>
<tr>
<td>Cofiring biomass</td>
<td>$27</td>
</tr>
<tr>
<td>CCS with new coal</td>
<td>$28</td>
</tr>
<tr>
<td>CCS retrofit</td>
<td>$42</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>$46</td>
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</tbody>
</table>
More than 65 countries have or are developing renewable fuels mandates.

Legislative priorities differ – energy security, support for domestic agriculture, environment.

Policies have created an international market for biofuels. Shell is working to meet obligations & benefit from opportunities.

The International Energy Agency has estimated that biofuels could represent 30% of the world’s road transport fuel mix by 2050.
The most widely used transport biofuels are ethanol and biodiesel.

Ethanol is usually made by fermenting crops high in sugar.

Biodiesel (FAME) is made from vegetable oil crops through transesterification.

Hydro-treating (HVO) uses a different process to biodiesel and can be blended at higher concentrations.

### TODAY’S ROAD TRANSPORT BIOFUELS

<table>
<thead>
<tr>
<th>Organic raw material</th>
<th>Process</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane</td>
<td>Fermentation</td>
<td>Ethanol (blend with gasoline)</td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rape seed</td>
<td>Transesterification</td>
<td>FAME (blend with diesel)</td>
</tr>
<tr>
<td>Palm oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soya bean</td>
<td>Hydro-treating</td>
<td>HVO (blend with diesel)</td>
</tr>
</tbody>
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BIOFUELS REDUCE CO₂ TODAY AND DIVERSIFY FUEL SUPPLY

- Biofuels are a low ‘well-to-wheel’* CO₂ sustainable alternative to gasoline and diesel available today.
- But CO₂ emission reductions depend on whole journey to combustion – feedstock production, process used, distribution and use in vehicles.
- Biofuels diversify transport fuel pool and offer prospect of improved energy security.
- Biofuels can be used in existing liquid transport fuel infrastructure.
- For some countries biofuels can offer economic and rural development opportunities.

*Well-to-Wheel CO₂ analysis calculates the CO₂ emissions relating to a particular fuel pathway. The calculation divides the pathway into two parts: (i) ‘Well-to-Tank’ (WtT) CO₂ emissions – from the production and distribution of the fuel feedstocks and the actual fuel (ii) ‘Tank-to-Wheel’ CO₂ emissions – from the use of the fuel in the vehicle.


Typical greenhouse gas emission saving compared to fossil fuel comparator % (EU)**
SHELL: A LEADER IN TODAY’S BIOFUELS

- 30-year history of biofuels development and investment
- Growing investment in infrastructure to store, blend and distribute biofuels
- World’s largest distributor of biofuels – 9 billion litres in 2010
- Building capacity in biofuels that provide best combinations of performance and low ‘well-to-wheel’ CO₂ performance from more sustainable feedstocks

Current Shell activity

Possible Shell involvement

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PROPOSED SHELL COSAN JOINT VENTURE

- Brazilian sugar cane – lowest CO₂, most sustainable and cost competitive of today’s biofuels
- Non-binding Memorandum of Understanding with Cosan proposes $12 billion joint venture
- 2 billion litres of ethanol production capacity per year – with room to grow
- Robust sustainability principles, standards and operating procedures

Ethanol fuel in Shell’s retail network
Automated sugarcane harvesting
A number of CO₂ and sustainability issues have been linked to the production of ethanol and FAME.

The ‘well-to-wheel’ CO₂ performance of biofuels can vary widely depending on the feedstocks and production and processing techniques used.

Direct and indirect social and environmental impacts of biofuels production must be addressed.

There are a number of social issues linked to biofuels production, including workers’ rights and local community land rights.

There are also environmental issues such as rare habitats and species, indirect land use change, soil and water, CO₂ emissions.
PROMOTING CO₂ AND SUSTAINABILITY STANDARDS

- Advocating for the adoption of ‘well-to-wheel’ CO₂ standards to reward low CO₂ biofuels
- Need for a single robust approach for calculating ‘well-to-wheel’ carbon intensity of fuels
- Engaging industry, governments, intergovernmental agencies and policy makers to encourage sustainability standards in the biofuels supply chain
- Participating in industry initiatives working on voluntary guidelines for particular feedstocks
- Pledged support for international multi-stakeholder coalition seeking to enforce a moratorium on rainforest and peatland clearance for palm oil in Southeast Asia
- Working with the European Committee for Standardisation (CEN) to develop sustainability requirements in support of the European Energy Directive and Fuel Quality Directive
SUSTAINABILITY OF SHELL’S BIOFUELS SUPPLY CHAIN

- Championing sustainability standards in our own biofuels supply chain
- Rules and practices to help assess risks, implement controls, monitor compliance and report our progress
- Sustainability clauses in new and renewed term contracts:
  - feedstocks not knowingly linked to violation of human rights or produced in areas of high biodiversity value
  - suppliers develop and implement supply chain traceability systems
  - suppliers join relevant international bodies developing sustainability criteria particular feedstocks

Shell’s Biocomponent Purchases Covered by Sustainability Clauses

- Fully signed up: 81.6%
- Partially signed up: 18.3%
- Yet to sign up: 0.1%

Shell Global Biocomponent Feedstock Purchase Q4 2009

- Corn: 45.6%
- Sugar Cane: 33.6%
- Rape Seed: 11.1%
- Wheat: 7.7%
- Other: 2%
WORKING WITH OTHERS TO PROGRESS KNOWLEDGE

- Working with environmental and social experts to develop projects to help address the potential direct and indirect impacts of biofuels
- Sharing experience and expertise
- Long-term collaboration with the International Union for Conservation of Nature (IUCN):
  - Addressing conservation and livelihood risks and opportunities in the biofuels supply chain
  - Providing opportunities for IUCN to influence global markets towards more sustainable biofuels production processes
- Working with other oil companies and NGOs including WWF and IUCN to investigate ways to promote sustainable production of biofuels feedstocks on underutilised or marginal lands
LEADING DEVELOPMENT OF ADVANCED BIOFUELS

- Advanced biofuels, using feedstocks such as crop wastes or inedible crops and new conversion processes
- Offer the potential for improved CO₂ reductions and improved fuel characteristics.
- Accelerating research, development and demonstration of advanced biofuels
- Dedicated Shell biofuels teams across 4 research centres in the US, UK, Netherlands and India
- Research agreements with experts in leading academic institutions across the world

- Technical partnership with leading biotechnology companies
- Our aim: to narrow down technology options to a feasible set of commercial solutions
Shell is successfully progressing new technologies from lab-based process to demonstration phase and towards commercial scale-up.

Shell aims to narrow down advanced biofuels technology options to a feasible set of commercial solutions.

In the long term all biofuels will need to be cost competitive with all road transport fuels.

In the short term, government policies, incentives and financial support accelerate development from lab to commercial deployment.
Shell and Iogen Corporation 50:50 equity partners in Joint Venture company Iogen Energy since 2002

Joint technology programme developing the processing technology to make ‘cellulosic’ ethanol from lignocellulose (straw) using enzymes

World’s first commercial demonstration cellulosic ethanol plant opened in 2004 (Ottawa, Canada):
  — Produced more than 500,000 litres in 2009
  — Month long retail demonstration in Ottawa, June 2009

CO₂ emissions of enzymatic cellulosic ethanol from straw could be up to 90% less than gasoline

Full-scale commercial plant under assessment with focus on a site in Saskatchewan, Canada
Shell has held a 14.7% equity stake in Codexis, California since 2007.

Joint technology development programme to ‘evolve’ natural enzymes into improved variant enzymes capable of performing to specification.

Codexis is working closely with Shell and Iogen Energy to enhance the efficiency of enzymes used in the Iogen cellulosic ethanol production process.

Researching new enzymes to convert biomass directly into components similar to gasoline and diesel.
Joint technology development programme to convert plant sugars directly into a range of high performance liquid transport fuels rather than ethanol, since 2008.

Uses catalysts to convert plant sugars into hydrocarbons.

Sugars can be sourced from crops and non-food sources.

Fuels have higher energy content than ethanol (or butanol) and deliver better fuel efficiency.

Could result in biofuels that can be used at high blend rates in standard gasoline engines.

Potentially eliminates requirement for specialized infrastructure, new engine designs and blending equipment.

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Majority shareholder in Cellana since end 2007

Joint technology development programme to operate a pilot facility in Hawaii to grow marine algae as a feedstock to produce vegetable oil for conversion into biofuel

Algae hold great promise:
- grow very rapidly
- rich in vegetable oil
- cultivated in ponds of seawater (minimising use of fertile land and fresh water)

Academic research programme screening natural microalgae species to determine highest yields and most vegetable oil

Long term potential to absorb or ‘capture’ waste CO$_2$ directly from industrial facilities such as power plants
Chemicals from Bio-Based feedstocks

- Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas

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Growing tomatoes with refinery CO2

- CO₂ capture from refinery H₂ plant (Pernis Refinery, the Netherlands)
- Route to greenhouse: 2X increase in CO₂
  - 25% increase in tomato production rate
  - Implemented 2005
- “Organic CO₂” consortium
  - Cheaper than gas heaters to provide CO₂
  - Synergistic use of refinery offgas: 325,000 tonnes of CO₂ emission reduction.

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C-Fix: a CO$_2$ value-added solution

- Carbon-rich refinery residue
- Used as binder for “Carbon Concrete”
- 1 tonne cement binder prevents 2.5 tonnes of CO$_2$ emissions
- SO$_2$, NO$_x$, and CO emissions also reduced

C-Fix breakwater armour units in IJmuiden, the Netherlands
There is no single alternative to oil based road transport fuels – all sustainable fuel options will be needed.

Today’s biofuels are the most realistic commercial solution to take CO₂ out of the transport fuels sector and diversify supply over the next twenty years.

Shell is building capacity in biofuels that provide best combinations of performance and low ‘well-to-wheel’ CO₂ performance from more sustainable feedstocks.

Shell and Cosan have recently announced a proposed JV for the production of Brazilian sugar cane ethanol.

Shell advocates for the adoption of ‘well-to-wheel’ CO₂ and sustainability standards to reward biofuels that perform well.

Shell continues to invest significantly in advanced biofuels research and development and to work aggressively on commercialization.

Basis for future chemical feedstocks will follow fuels into bio domain.
Challenges: Back to the Future for Energy

http://www.eia.doe.gov/emeu/aer/eh/frame.html

- Coal replaces woody biomass to start industrial revolution
- Steam replaces wind / clipper ships (1850’s)
- Petroleum replaces coal as preferred transportation fuel (1900’s)
- Electric / natural gas driers replace the solar clothes drier 1960

Petroleum & natural gas previously replaced the “alternative energies” we are now moving back to! Replacement was due to economics and convenience!
Sugar cane: Energy Density

- Collection radius and transport efficiency
Energy Density: volumetric and mass
Oxygen content of Biomass

NTNU Combustion Handbook:
http://www.handbook.ifrf.net/handbook/cf.html?id=23
# H/C ratio of fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>C-source</th>
<th>H/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (nat. gas)</td>
<td>fossil</td>
<td>4.0</td>
</tr>
<tr>
<td>Oil (gasoline US)</td>
<td>fossil</td>
<td>2.3</td>
</tr>
<tr>
<td>Oil Shale</td>
<td>fossil</td>
<td>1.4</td>
</tr>
<tr>
<td>Coal</td>
<td>fossil</td>
<td>0.8</td>
</tr>
<tr>
<td>Wood*</td>
<td>renewable</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*80% cellulose 20% lignin - H2O

J. Ausubel and C. Marchetti, 1998
Biofuels & bio-based chemicals: Challenges and barriers

- Feedstock density
- Oxygen
- Water
- Timeframe for new energy infrastructure
- Sustainability