A market overview on bio-based fuels and chemicals

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Processing Lignocellulosic Biomass Conference
CPI, Wilton Centre
8 November 2012

With thanks to Laurie Guillodo
This presentation provides a market overview for bio-based fuels and chemicals

1. What are bio-based fuels and chemicals?
2. Why produce them from lignocellulose?
3. How are markets growing?
4. What are the challenges, and how can they be overcome?
Three main types of feedstock are used to produce biofuels

<table>
<thead>
<tr>
<th>Biofuels – Feedstocks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>“First Generation” feedstocks</strong></td>
</tr>
<tr>
<td><strong>Food components:</strong> Vegetable oil, sugar and grain and animal fats</td>
</tr>
<tr>
<td><strong>“Second Generation” feedstocks</strong></td>
</tr>
<tr>
<td><strong>Non-food biomass:</strong> Energy crops, waste biomass and agricultural arisings</td>
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<tr>
<td><strong>“Third Generation” feedstocks</strong></td>
</tr>
<tr>
<td><strong>Algal biomass:</strong> Algae grown for fuel use</td>
</tr>
</tbody>
</table>

*This is what we mean by lignocellulosic biomass*

Source: Arthur D. Little; Images © Centre for Sustainable Energy and The New York Times
A range of types of biofuel can be produced from these feedstocks – though not all have yet been commercialised.

### Types of biofuel

<table>
<thead>
<tr>
<th>Types of biofuel</th>
<th>Feedstock</th>
<th>Fossil comparator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioethanol</td>
<td>Distillation and fermentation of grain and sugar</td>
<td>Petrol</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Transesterification of vegetable oil</td>
<td>Diesel</td>
</tr>
<tr>
<td>Biogas</td>
<td>Anaerobic digestion of food and agricultural waste to produce CH$_4$</td>
<td>Natural gas</td>
</tr>
<tr>
<td>Others</td>
<td>Dimethyl ether, biobutanol, furanics, hydrotreated vegetable oil, pure vegetable oil…</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- Commercialised
- Not fully commercialised

*These are often called “advanced biofuels”*
The market for liquid transport biofuels is driven by regulatory incentives

Biofuels – drivers

- Improving fuel security
- Reducing carbon emissions
- Using existing fuel infrastructure\(^1\)
- Lobbying from farming groups
- Support for rural communities

Regulatory incentives

- **Mandates:** The EC requires 10% of transport fuels to come from renewable sources by 2020\(^2\)
- **Incentives:** In the UK, fuel blenders buy Renewable Transport Fuel Certificates at point of duty, or pay a buy-out price\(^3\)

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1) Full compatibility in blends up to 5% of biofuel without vehicle engine modifications; in some cases up to 10%  
Some “first generation” biofuels produced from crop waste materials have been successful.

**Waste vegetable oil**
- **Argent Energy** in Scotland produces biodiesel from:
  - Old chip fat
  - Rendered abbatoir waste
  - Out of date packs of meat
- Some of this material would otherwise cost producers to dispose of

**Biogas from sugar beet pulp**
- Sugar producers such as **AB Sugar** in the UK and **Suiker Unie** in the Netherlands use excess beet pulp in anaerobic digestion.
- Methane can be supplied to the gas grid or used to generate heat and power.

However, other types of biofuel – particularly those produced from oil crops and grain – are dependent on regulatory incentives.

Sources: Arthur D. Little analysis; company websites.
However, biofuels produced from virgin food crops have faced significant challenges and some negative PR in recent years.

<table>
<thead>
<tr>
<th>“First generation” biofuels from virgin food crops – challenges</th>
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</thead>
<tbody>
<tr>
<td><strong>1. Competition with food</strong></td>
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<tr>
<td>- Demand for food is increasing</td>
</tr>
<tr>
<td>- Agricultural productivity has not greatly improved in some oil crops used for biofuels</td>
</tr>
<tr>
<td>- Together, these factors have resulted in direct and indirect land use change, for meat production and growing palm oil</td>
</tr>
<tr>
<td>- Land clearance can mobilise soil carbon sinks in sensitive areas</td>
</tr>
<tr>
<td><strong>2. Fluctuating crop prices</strong></td>
</tr>
<tr>
<td>- Crop prices have fluctuated considerably in recent years relative to the price of oil, with changes mainly due to poor harvests in some regions</td>
</tr>
<tr>
<td>- As a result, some first generation plants are operating below capacity</td>
</tr>
<tr>
<td><strong>3. Dependency on regulation</strong></td>
</tr>
<tr>
<td>- Some biofuels are reliant on regulatory incentives to be economically viable</td>
</tr>
<tr>
<td>- These incentives are often changing!</td>
</tr>
<tr>
<td><strong>4. GHG reduction benefits</strong></td>
</tr>
<tr>
<td>- Greenhouse gases emitted during manufacturing, transportation and use of biofuels</td>
</tr>
</tbody>
</table>

Sources: Arthur D. Little, USDA
Indirect land use change is being addressed – in part – through sustainability criteria for biofuels, though these do not currently address all the implications of biofuel production.

### Competition with food and indirect land use change

Measures are under development to improve the sustainability of biofuel production.

#### Sustainability implications of biofuels

<table>
<thead>
<tr>
<th>Environmental issues</th>
<th>Social and community issues</th>
<th>Greenhouse gas emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct land use change</td>
<td>Fair land ownership</td>
<td>Minimising transportation of bulk biomass and finished fuels</td>
</tr>
<tr>
<td>Maximising water use efficiency</td>
<td>Labour rights</td>
<td>Mobilisation of carbon sinks</td>
</tr>
<tr>
<td>Maintaining biodiversity</td>
<td>Effective agricultural extension</td>
<td></td>
</tr>
</tbody>
</table>

#### Measures to improve sustainability

- Users of biomass and food crops for fuels now need to demonstrate:
  - A minimum GHG saving
  - That crop feedstocks are not being sourced from land of high biodiversity value or carbon stock

- However, these basic criteria do not take into account wider sustainability issues at point of production.

- Programmes such as Biopact and initiatives such as the NTA 8080 standard are under development, but are frameworks, rather than requirements.

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Crop prices for some of the main agricultural commodities – especially wheat – have fluctuated considerably in the last four years.

Fluctuating crop prices

Global crop prices (US$ per metric tonne) 2007 – 2012

The EC recently announced that it is considering capping the amount of biofuels produced from virgin food crops that can contribute towards renewable energy targets.

"We must invest in biofuels that achieve real emission cuts and do not compete with food”

“We are of course not closing down first generation biofuels, but we are sending a clear signal that future increases in biofuels must come from advanced biofuels”

European Commission announcement, 17th October 2012

This suggests that lignocellulosic biomass is a key component of Europe’s future transport fuels agenda

Biofuels produced from lignocellulose bring four main advantages

- Make use of waste biomass and crop side-streams
- Avoids competition with food crops
- Higher yields obtainable within a given land area
  - In terms of energy, where biomass crops are grown
- Processing technologies are already available
  - Though not all of these are fully proven at scale using biomass as a feedstock
- Better GHG mitigation benefits
  - Compared to most\(^1\) first generation biofuels

OECD / IEA, 2008. From first to second generation biofuel technologies: an overview of current industry and RD&D activities; Arthur D. Little analysis 1) Generally on a par with ethanol produced from sugar cane in Brazil.
The market for advanced biofuels – which includes those produced from lignocellulose – is projected to expand rapidly, though there have been delays in commercialising them.

### Biofuels from lignocellulose: Always the technology of the future...

**Forecast global biofuel demand (2010-2050)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Biojet</th>
<th>Biomethane</th>
<th>Advanced biofuels</th>
<th>Conventional biofuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
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<tr>
<td>2020</td>
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<tr>
<td>2025</td>
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<td>2030</td>
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<td>2035</td>
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<td>2040</td>
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<tr>
<td>2045</td>
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</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
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</tbody>
</table>

**Interpretation**

- Lignocellulosic biofuels are expected to become full scale commercial reality in the next 1 – 3 years.

**However…**

- Forecasts are extremely variable.
- Previous forecasts have suggested that this should have happened by now.

**What’s causing the delay?**

By 2050, biofuels are projected to account for c. 27% of total demand for transport fuels, up from c. 3% today.

Source: Technology Roadmap - Biofuels for Transport © OECD/IEA, 2011. 1) Advanced biofuels includes those produced from lignocellulosic biomass, hydrotreated vegetable oil, and biofuels produced from algae.
Both biological and thermochemical routes can be used to produce biofuels from lignocellulose…
... both of which are under late stage commercial development.

Biofuels from lignocellulose: Manufacturing processes

Legend:
- Feedstock
- Biological process
- Thermochemical process
- Product

Examples:
- Bioethanol
- Biobutanol
- Biodiesel & bionaptha
- Bioethanol

Source: Arthur D. Little, adapted from Van Thurjil, 2003; World Economic Forum, 2010. The future of industrial biorefineries
According to company announcements, at least 500 million litres of production capacity are reportedly due to come online using biological routes within the next 2 years.

### Biofuels from lignocellulose: Planned biological facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Capacity (litres)</th>
<th>Raw Material(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbicon (Dong)</td>
<td>5 million</td>
<td>Wheat straw, Molasses</td>
</tr>
<tr>
<td>Abengoa</td>
<td>114 million</td>
<td>Corn stover</td>
</tr>
<tr>
<td>DCE</td>
<td>114 million</td>
<td>Corn stover</td>
</tr>
<tr>
<td>Beta Renewables / Novozymes</td>
<td>59 million</td>
<td>Wheat straw</td>
</tr>
<tr>
<td>Cofco / Sinopec / Novozymes</td>
<td>68 million</td>
<td>Corn stover</td>
</tr>
<tr>
<td>GraalBio</td>
<td>82 million</td>
<td>Sugarcane bagasse, straw</td>
</tr>
<tr>
<td>Blue Sugars</td>
<td>18 million</td>
<td>Sugarcane bagasse</td>
</tr>
</tbody>
</table>

**Source:** Arthur D. Little analysis of company announcements
Some thermochemical plants are also about to begin operation – though some close-to-market opportunities have been stopped.

**Biofuels from lignocellulose: Planned biological facilities**

- **Emery**
  - Pilot plant
  - Corn stover

- **Linde**
  - Pilot plant
  - Cereal straw

- **Choren**
  - 18 million litres
  - Wood residues
  - Stopped

- **Enerkem**
  - 38 million litres
  - MSW and wood residues

- **KiOR**
  - 50 million litres
  - Farmed and residue wood
  - About to become operational

- **Air Liquide**
  - Pilot plant (Bioliq process)
  - Cereal straw

- **Range Fuels**
  - 375 million litres
  - Wood residues
  - Stopped

Source: Arthur D. Little analysis of company announcements
Some producers closest to commercialisation using thermochemical routes have suffered recent setbacks, run out of capital and filed for bankruptcy.

### Biofuels from lignocellulose: Recent setbacks

<table>
<thead>
<tr>
<th>Company and technology</th>
<th>Range Fuels</th>
<th>Choren</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Syngas to ethanol and methanol</td>
<td>Gasification followed by Fischer Tropsch biomass-to-liquids</td>
</tr>
<tr>
<td></td>
<td>Wood chips</td>
<td>Wood chips and agricultural waste</td>
</tr>
</tbody>
</table>

| Problems                | Process found not to be economically viable | Delays in scale-up and commissioning of the gasifier |
|                        | Encountered cash flow problems             |

The US Government has reduced its mandate for second generation biofuels from 500 million gallons to 8.65 million gallons¹

This suggests that the basic economics of biofuels from lignocellulose are a major issue – and one which could be improved by producing biofuels in an integrated biorefinery setting.

**Biofuels from lignocellulose: Biorefineries and bio-based chemicals**

- **Sources**
  - Dedicated biomass energy crops
  - Forest waste and agricultural arisings
  - Established wood fibre supply chain

- **Available biomass pool**
  - Existing technologies
  - Advanced technologies

- **Uses**
  - Biomass heat and power
  - Fischer tropsch diesel
  - Furfural

- **Biorefineries**
  - Biorefineries could help improve process economics by:
    - Sharing synergies in feedstock supply
    - Generating heat and power
    - Looking for added value products, such as bio-based chemicals
  - Overall production costs could be reduced by 30%¹ in a biorefinery

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*Biorefineries can also be used to produce bio-based chemicals from lignocellulosic biomass – though they have not yet been commercialised*

¹ Non-exhaustive. 1) IEA Bioenergy, 2012. Bio-based chemicals – value added products from biorefineries, citing an economic study of 12 biorefineries at Wageningen University
Bio-based chemicals produced from lignocellulose can be classified into three main types:

1. **Extraction of novel molecules from lignocellulose**
   - Extraction of novel aromatics
   - e.g. furans and phenols

2. **Direct use of lignocellulose**
   - Use of the lignin macromolecule as a structural fibre
   - e.g. cellulose whiskers

3. **Platform chemicals**
   - Production of chemical intermediates
   - e.g. succinic acid, lactic acid

The main type today, and comprises:
- Chemicals which are **direct substitutes** to existing petrochemicals
- Chemicals with **added functionality** such as biodegradability
The market for these bio-based chemicals is driven by pressure from customers and consumers, rather than by regulation.

**Bio-based chemicals from lignocellulose: Drivers**

- Pressure from consumers for “green” products
- Pressure from suppliers of consumers
- Carbon footprint of products
- Drop-in replacement for hydrocarbons

Regulation is not a major driver for bio-based chemicals – but in some circumstances it can act as a restraint.
There is a vast range of bio-based platform chemicals and an even bigger range of production routes.

The market for bio-based chemicals is complex, and highly fragmented.

Of this wide range of alternatives, production capacity is projected to expand for certain platform chemicals such as ethylene and methanol.

If both first and second generation feedstocks are used, bio-based chemicals could account for up to 17% of the UK chemical market.

Source: Adapted from ICIS / Nexant, 2012. Bio-based chemicals on the fast track to commercialisation. 1) Source: BERR / Arthur D. Little, 2009. Quantitative Modelling of Industrial Biotechnology and Renewable Chemicals. Figures from the “Knock on wood” scenario, which assumes that second generation biofuels will be successfully commercialised.
Bioethylene is one example of where synergies between second generation bioethanol production and the production of bio-based chemicals may lie in the future.

### Bio-based chemicals from lignocellulose: Bioethylene as a platform chemical

#### Bio-ethylene: Current derivatives

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Derivative</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>Ethylene glycol</td>
</tr>
<tr>
<td>14%</td>
<td>1,2 dichloroethane</td>
</tr>
<tr>
<td>12%</td>
<td>Polyethylenes</td>
</tr>
<tr>
<td>7%</td>
<td>Styrene monomers</td>
</tr>
<tr>
<td>7%</td>
<td>Other</td>
</tr>
</tbody>
</table>

#### Production

- **Bio-ethylene processing is well understood:**
  - Dehydration of bioethanol using an alumina catalyst
  - Cracking of bionaptha from Fischer Tropsch processing of biomass
- **Used as a building block for producing bio-based polymers,** especially:
  - Polyvinyl chloride from 1,2 dichloroethane
  - Poly-ethylenes
  - Polyethylene terephthalate
- **Some interest in bioethanol to bio-ethylene plants:**
  - Dow plans a 300,000t plant in Brazil

However, the economics don’t quite stack up yet!

*Sources: Arthur D. Little analysis; IEA Bioenergy, 2012. Bio-based chemicals – value added products from biorefineries*
Across both bio-based fuels and chemicals there are considerable challenges – but none which we believe cannot be overcome

### Summary: Challenges and solutions

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Transportation and logistics</th>
<th>Equipment and process technology</th>
<th>Producers of bio-based fuels and chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural production</td>
<td>Improving yields of biofuel crops</td>
<td>Obtaining large quantities of sustainably sourced biomass</td>
<td>Handling heterogeneous feedstocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Technology barriers at scale-up</td>
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<td></td>
<td>Rise of competing fuel technologies</td>
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<td></td>
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<td></td>
<td>Fragmented processing routes and end markets for bio-based chemicals</td>
</tr>
</tbody>
</table>

**Solutions**

- **Agricultural production**
  - Target yield improvements for non-food purposes
  - Connect with producers
  - Optimise side-streams

- **Transportation and logistics**
  - Use accreditation bodies where possible
  - Help develop sustainability standards
  - Look for supply chain synergies

- **Equipment and process technology**
  - Find designs which can handle lower quality, variable feedstocks

- **Producers of bio-based fuels and chemicals**
  - Partner with tech suppliers
  - Pursue biorefineries
  - Aim for higher value chemicals (e.g. polymers)
  - Pursue specialty fuels markets (e.g. aviation)

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Above all, it is vital to build the business case for any investment in this area to ensure you can make any money out of it
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