Bioeconomy Value Chains

Commercial & Technical Options & Challenges

Dr. Manfred Kircher
Chairman Advisory Board CLIB\textsuperscript{2021}
June 5, 2013
University Guelph; Bioeconomy Seminar
CLIB 202: Cluster International Bioeconomy
90 Members; Focus on Chemicals & Energy

(Bio-)Chemical Industry

Feedstock-Industry

Agri- & Silviculture

Value

Energy

Value-Chain

Consumer Industries

Pharmaceuticals

Technologies Services

Henkel

Bottle

Pharma-
The Earth is Our only Resource
Europe pushes the Bioeconomy

GHG Reduction (%)

1990          2012       2020          2030                       2050

-8%

-20%

-40%

-80-95%

Kyoto GHG Emission Targets

Impact on Global Warming

100% 80% 60% 40% 20% 0%

Nitrous Oxide

Methane

Fluorinat. Gases

CO2

-100

-80

-60

-40

-20

0
Germany gives Bioeconomy Priority

2.10.2012; Leuna
Spitzencluster Bioeconomy
Lignocellulosic Biorefinery
CEFIC VIEWS ON THE EU BIOECONOMY
June 2012

Cefic has a high level of involvement in the bioeconomy, and considers the bioeconomy’s implications for the chemical industry as composed of three clear dimensions:

- access to renewable feedstock,
- innovation and
- market-driven demand generation.
Industrial Drivers towards the Bioeconomy

Drivers

- Economical & Ecological Sustainability

Options

Challenges

Product & Process Innovation

Renewable Feedstock
The Fossil Economy is based on Oil, Coal, Gas

11 bn t/a Carbon consumed

Coal: 7 bn t
Gas: 2.5 bn t
Oil: 3.9 bn t
Logistics of Fossil Feedstock is easy & cost-efficient
Fossil Feedstock serve Large-Scale Industrial Centers

Oil Refinery Wesseling, Germany

capacity: 16,3 mio t oil (equ. 13,9 mio t C)
The Fossil Value Chain starts from limited Regions.

Exports (mio barrel/day)
Fossil Feedstock deliver Energy Carriers & Chemical Precursors

- Organic Chemicals
- Pharmaceuticals
- Fine & Specialty Chemistry
- Detergent & Hygiene Chemicals
- Polymers
- Petrochemicals & Derivatives
- Agrochemicals

- Gasoline
- Diesel
- Kerosine
German Chemical Industries depend on Fossil Feedstock

Fossil Feedstock consumption

- Energy >93%
- Chemicals >7%

Chemical Feedstock

- Crude Oil Naphta 71%
- Natural Gas 14%
- Renewable Feedstock 13%
- Coal 2%

- 90% imported
- 65% imported
- 86% imported
Naphta makes 40 % of Chemical Cost

- Crude Oil
- Light distillate
- Heavy distillate
- Exit gas
- Residuals

Costs:
- Feedstock
- Auxiliary Materials
- Energy
- Cost of Labour
- Maintenance
- Depreciation
- Interest
Chemical Value Chains begin with Basic Chemicals

- Ethylene
- Propene
- 1,2-Dichlorethane
- Benzene
- Methanol
- Vinylchloride
- Formaldehyde
- 1,3-Butadiene
- Butene
- Cumole

Ethylene Production Cost depend on Feedstock & Region

- Oil (Asia)
- Natural gas (USA)
- Ethane, butane (Saudi Arabia)
- Shale gas (USA)

2012

US$/t

2013

MIT Technical Review; Kevin Bullis; Shale gas will fuel a US manufacturing boom; 9.1.2013
The German Chemical Industry produces Bioproducts

Germany 2008; Source: VCI

K. Hill, R Höfer; Biomass for Green Chemistry; in: R. Höfer (ed.) Sustainable Solutions for Modern Economies; RSCPublishing (2009)

Commercialization in the bioeconomy: Shift from R&D to production

- Ethylene
- Propylene
- Acrylic acid
- Lactic acid
- Succinic acid
- Sebacic acid
- 2,5-Furandicarboxylic acid
- Ethylene glycol
- Propylene glycol
- 1,3-Propanediol
- 1,4-Butanediol
- Isosorbide

Earlier 2005 2010 Today 2015

Bio-Feedstock enable Feedstock-Flexibility

1 Hectare of land produces 82.5 ton Sugar Cane
produces 5.6 t Ethanol
produces 3 ton Green Ethylene
produces 3 ton Green PE
Bioeconomy works with Mid-Size Plants

Braskem
Triunfo; Brazil
200,000 t Bio-Ethylene
requiring >280,000 t sugar
(equ. 118,000 t C)

280,000 t sugar from
65,000 ha sugar cane
(area with 100 km radius)
Success of Bio-Ethylene depends on Feedstock-Cost

MIT Technical Review; Kevin Bullis; Shale gas will fuel a US manufacturing boom; 9.1.2013
Bio-Feedstock gains Competitiveness

Oil (WTI) $/bbl

Sugar $/pound

www.finanzen.net
Cutting
Feedstock-Cost is Key

Drivers
Economical & Ecological Sustainability

Options
Bio-Feedstock

Challenges
Cost & Economy of Scale of renewable / fossil Feedstock

Product & Process Innovation

Renewable Feedstock
Process Innovation starts with Renewable Feedstock

Edmonton, Canada
- Natural gas; waste wood
- Biofuels; biomaterials

Goiânia, Brazil
- Vinasse
- Biogas; biomethane

Tambov, Russia
- Agro residues; Biofuel, biomaterials

Duisburg, Germany
- CO from steel mill
- Biofuels; biomaterials

Shanghai, China
- Biofuels; biomaterials

Borneo, Malaysia
- Waste wood; POME
- Biofuels; biomaterials

1 POME is palm oil mill effluent
Malaysia: Residual Biomass

Conversion of Palm-based Resources
(70 million tons lignocellulosic residues)

<table>
<thead>
<tr>
<th>Product</th>
<th>Revenue per MT (bln RM)</th>
<th>GDP-contribution %GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>bioelectricity</td>
<td>231</td>
<td>0.8</td>
</tr>
<tr>
<td>biofuels*</td>
<td>453</td>
<td>3</td>
</tr>
<tr>
<td>biochemicals**</td>
<td>2500</td>
<td>26</td>
</tr>
</tbody>
</table>

margin: 5% (electric), 10% (fuels), 15% (chem’s)

*ethanol, ** lactic acid for plastics

Source OPBC
Brasil: Processing Residuals

Producing Methane Fuel from Vinasse
(30 mio t/a equ. ~ GW range)

» Optimize biogas process  Brazil, Germany
» Adapt biogas plant  Brazil, Germany
» Purify bio-methane  Germany
» Build logistics  Brazil
Germany: Syngas & Industrial Flue Gas

Artificial photosynthesis
Renewable energy

H₂ + CO₂ → CO

Jet Fuels
Catalysis
2,3-BDO
Metabolic Engineering
Chemical Engineering
Downstream processing
Energy feedstock

Power
Steel

LCA

Source: Dr. Achim Marx (CLIB2021)
Industries take the Feedstock Advantage

Sugar-Carbon
- Reverdia
  - Sugar Beet > Succinat
- Braskem
  - Sugar Cane > Ethylene
- Dow
  - Sugar Cane > Propylene

Lignocellulosic-Carbon
- Direvo
  - Lignocellulose > PLA
- Novamonte
  - Lignocellulose > BDO
- Dong
  - Lignocellulose > Ethanol

Industrial Residues Out of use/recycling
- Abengoa
  - Municipal Waste > Ethanol
- Lanzatech
  - Steel Mill CO/CO2 > Ethanol
- Enerkem
  - Municipal Waste > Syngas
Product Innovation starts with Biosynthetic Pathways

Amino acids

Organic acids

Fuels & Solvents
Synthetic Biology enables man-made Bioproducts

**Escherichia coli**

1,3 PDO

**Klebsiella pneumoniae**

**Saccharomyces cerevisiae**
Biochemicals restart the Innovation Cycle

Number of New Polymers per Year

Source: DSM
Modern Biotechnology shortens Time-to-Market
Production & Innovation Value Chains to be addressed

(Bio-)Chemical Industry

Feedstock-Industry

R&D Support

Business Support

Consumer Industries

Pharmaceuticals

Adhesive

Cosmetics

Tire

Bottle

Value

Instruments, Engineering, Service, CRO, Academia

Investors, IP, Legal Advice, Infrastructure, Business Development
Innovation in Technologies & Value Chains

Options
- Economical & Ecological Sustainability

Solution
- Bio-Feedstock

Challenges
- Cost & Economy of Scale of renewable / fossil Feedstock

Product & Process Innovation
- Feedstock Processing & Transformation
- Unusual Value Chains Time-to-Market

Renewable Feedstock
Modern Bioeconomy competes with Established Sectors

Bio-Feedstock

- Vegetable Oils
- Animal Fat
- Starch
- Sugar
- Cellulose
- Fibres
- Proteins
- Rosin & Waxes
- Other

EU-Biochemicals
70 bn €

Food
47%

Chemicals & Biofuel
3%

Forestry & Wood Products
13%

Agriculture
19%

Pulp & Paper
18%

EU-Bioeconomy
2.200 bn €

EU-Economy
83%

EU-Bioeconomy
17%
Modern Bioeconomy steps into Feedstock Markets

**World:** 140 mio t ethylene - equ. 120 mio t C
165 mio t sugar - equ. 69 mio t C

**EU:** 20 mio t ethylene - equ. 17 mio t C
18 mio t sugar - equ. 8 mio t C

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**TOP 10 ETHYLENE PRODUCERS**

<table>
<thead>
<tr>
<th>Company</th>
<th>Sites</th>
<th>Of wholly owned complexes</th>
<th>Of partially owned complexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Saudi Basic Industries Corp.</td>
<td>15</td>
<td>13,392,245</td>
<td>10,273,759</td>
</tr>
<tr>
<td>2. Dow Chemical Co.</td>
<td>21</td>
<td>13,044,841</td>
<td>10,529,421</td>
</tr>
<tr>
<td>3. ExxonMobil Chemical Co.</td>
<td>20</td>
<td>12,515,000</td>
<td>8,550,550</td>
</tr>
<tr>
<td>4. Royal Dutch Shell PLC</td>
<td>13</td>
<td>9,358,385</td>
<td>5,946,693</td>
</tr>
<tr>
<td>5. Sinopec</td>
<td>13</td>
<td>7,895,000</td>
<td>7,725,000</td>
</tr>
<tr>
<td>6. Total AS</td>
<td>11</td>
<td>5,933,000</td>
<td>3,471,750</td>
</tr>
<tr>
<td>7. Chevron Phillips Chemical Co.</td>
<td>8</td>
<td>5,607,000</td>
<td>5,352,000</td>
</tr>
<tr>
<td>8. LyondellBasell</td>
<td>8</td>
<td>5,200,000</td>
<td>5,200,000</td>
</tr>
<tr>
<td>9. National Petrochemical Co.</td>
<td>7</td>
<td>4,734,000</td>
<td>4,734,000</td>
</tr>
<tr>
<td>10. Ineos</td>
<td>6</td>
<td>4,656,000</td>
<td>4,286,000</td>
</tr>
</tbody>
</table>

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http://www.ogj.com/content/dam/ogj/print-articles/Volume%20110/July%202/global-ethylene-t4.jpg
Biomass will be short
Biomass will gain Value

**Fossil Feedstock consumed**
- 11 bn t of Carbon used
  - oil, gas, coal

**Renewable Feedstock produced**
- 7 bn t Carbon fixed by agriculture
  - 14 bn t of biomass
Modern Bioeconomy moves into Global Biomass Regions

Expected Biomass Trade Routes by 2020 [TWh]

Source: The Future of Industrial Biorefineries; World Economic Forum, 2010
CLIB is a Global Radar
Russia: Technology Platform Biotech 2030

CLIB office
Moscow, Russia

Skolkovo Innovation Village
CLIB is a Global Radar
Malaysia: Biomass Strategy

CLIB office
Kuala Lumpur, Malaysia

11/2011; Kuala Lumpur; Malaysia
CLIB is Global Radar
Brazil: BioInnovation Hub

CLIB office
Sao Paulo, Brazil

08/2012 Petrobras; Rio de Janeiro, Brazil
CLIB is a Global Radar
Canada: Biorefining Conversions Network

CLIB office
Drayton Valley, Canada

BIO-MILE
Drayton Valley, Canada
Feedstock-Flexibility
Industrial Drivers

**Drivers**

- Economical & Ecological Sustainability
- Bio-Feedstock

**Options**

- Cost & Economy of Scale of renewable / fossil Feedstock

**Challenges**

- Product & Process Innovation
- Feedstock Processing & Transformation
- Unusual Value Chains
- Time-to-Market

**Renewable Feedstock**

- Bio-Feedstock Flexibility
- Access to Feedstock Global Infrastructure
Global, Continental & Regional Markets for Fossil- and Bio-Feedstock

Oil: Global Market

Bio-Feedstock: Regional Markets

Gas: Continental Markets

Amsted-Maxion Sugar Wagon; São José do Rio Preto SP, Brazil
Biomass Processing & Transformation advantageous in Biomass Regions


CLIB builds Bioeconomy Value Chains

Value-Chain

Feedstock-Industries

(Bio-)Chemical Industries & SME

Consumer Industries

CLIB 2021
CLUSTER INDUSTRIELLE BIOTECHNOLOGIE

Aviko
STORAENSO
Weyerhaeuser
BaoSteel
Stadtwerke Düsseldorf
LanzaTech
AGRITHERM
Enerkem

Evonik Industries
Direvo Engineering Biomass
Novamont

Henkel
L’ORÉAL
Goodyear
Coca-Cola

Ethanol
2,3 BDO
Corn
Seed
Lignocellulose
Sugar
Oil Palm
Plant-Biomass
Syngas
CO, CO2, H2
Fatty Acids
How to Build a Large-Scale Bioeconomy Megacluster Region

Monday, June 17, 2013 | 2:30 pm-4:00 pm

Manfred Kircher (Germany)  
Luuk van der Wiele (Netherlands)  
Dato' Issace Jebasingam John (USA)  
Debi Durham (USA)  
Ludo Diels (Belgium)

Techno-Economic Analysis of Renewable Chemicals and Fuels

Tuesday, June 18, 2013 | 2:30 am-4:00 pm

Manfred Kircher (Germany)  
Daniel Klein-Marcuschamer (Australia)  
Viondette Lopez (USA)  
Jamie Stephen (Great Britain)  
Richard Gustafon (USA)