The challenge of the modern bio-economy

It seems easy to imagine the transition to a bio-economy and to present this vision of clean industries to the public starting from biofeedstock. In fact, it is much more challenging than the preceding change from a pre-modern bio-economy to the current fossil-based industry more than 100 years ago. At that time oil added an apparently endless carbon source to traditional coal and agricultural feedstock. It bubbled out of the oil-well almost without cost. Logistics were easy due to its high energy and carbon density. It initiated disruptive innovations in cheap power-generation, mobility, and materials; resulted in new value chains; and gave birth to completely new industries in fuel and chemistry. Last but not least it disburdened agriculture significantly from providing feedstock especially for animal-based mobility. Consequently, agriculture could focus on providing food, feed, and fiber for a growing population of 2.5 billion in 1950.

The situation we face today is different from simply repeating a feedstock change again. The end of easy-to-produce fossil carbon sources is foreseeable. Of the known reserves of 5500 billion barrels of oil, only 1000 have been consumed, but the costs of production are steadily rising. Whereas the costs in Saudi Arabia are around 4–5 $/barrel, it can cost as much as 40 $/barrel when exploiting Canadian oil sand and may rise to 70 $/barrel when extracting oil shale. The rising expenses are paralleled by the falling EROI (energy return on investment). Today, producing oil needs 5% of its energy content with increasing tendency; at the beginning of the oil age it took only 1%. Consequently, agricultural carbon sources gain competitiveness and enter the chemical and fuel markets. However, simply returning to the pre-modern bio-economy is no longer possible because agriculture today has to feed and dress 7 billion people. We need to build the bio-economy urgently.

Need for national bio-economy strategies

The bio-economy’s most relevant drivers are (i) reducing the CO₂ footprint and (ii) the feedstock change from finite fossil to sustainable carbon sources. Both topics need disruptive technologies and have a dramatic impact on global feedstock production, infrastructure and logistics, trade, industrial processes, and production sites, with industrial as well as emerging economies involved. Already today
the growing industrial demand of biofeedstock drives land
acquisitions and value in biomass producing areas.\textsuperscript{8,9} In
2012, Germany may import cereals for the first time in 25
years because 6\% are used for generating power.\textsuperscript{10} On top of
this increasing industrial consumption, it is imperative to
secure food supplies and prepare for 2030 when the world’s
population may reach 8.3 billion.\textsuperscript{11} Achieving societal
acceptance and agreeing legal frameworks, research and
economic policies, governmental measures, and industrial
investments in this environment are extremely complex
issues.

For these reasons, the bio-economy’s global infrastruc-
ture, supply, and industries need to be built in a coordinated
way – at best, based on strategies which address the specif-
cics of the nation concerned. There are countries which are
(i) blessed with renewable biomass but missing integrated
processing industries (e.g. Brazil, Malaysia), (ii) strong in
feedstock and a highly developed fuel and chemical industry
(e.g. the USA, Canada, Russia), and (iii) developed nations
depending on feedstock imports like Germany. Many
nations already implement such national bio-economy
strategies.

\textbf{Brazil}

The No. 1 producer of sugar and the nation with large
reserves of arable land published a \textit{Biotechnology
Development Policy} in 2007.\textsuperscript{12} Its realization is coordinated
by the National Biotechnology Center\textsuperscript{13} and the Forum
on Competition in Biotechnology. Part of the strategy is
to build 1000 distilleries and become the world’s leading
ethanol exporter by 2025 (205 billion liters of ethanol to
be exported out of 250 billion liters total produce). One of
the key research organizations is the Brazilian Agricultural
Research Corporation (EMBRAPA).

\textbf{Malaysia}

The No. 1 exporter of palm oil published a \textit{National Biomass
Strategy} in 2011.\textsuperscript{14} It outlines how to mobilize palm oil bio-
mass by developing more efficient harvesting, collection,
pre-processing, and product transportation. External mar-
kets in Europe, Japan, and Korea as well as domestic down-
stream hubs are particularly addressed. BiotechCorp is the
organization implementing the strategy.

\textbf{Russia}

This nation owns significant reserves of agricultural and
silvicultural areas. The National Technology Platform \textit{Bio-
Industry and Bio-Resources} (Biotech 2030) was approved by
the president in 2011.\textsuperscript{15} It includes six sub-platforms: indus-
trial bioechnology, forestry, ecobiotechnology, agricultural
biotechnology and geomicrobiology, aquaculture biotechnol-
ogy and ‘food for life’, and embraces more than 160 partici-
pants – 50\% from industry and SMEs (small and medium-
sized enterprises).

\textbf{USA}

The USA exports wheat, corn, and soy. Concerning the
bio-economy, the focus is on fuel to end dependence on for-
eign oil and address the climate change. Three Bioenergy
Research Centers (BRC) have been established since 2007.
They address next-generation bioenergy crops, biomass
degradation, and microbe-mediated biofuel production.\textsuperscript{16}
A strong market pull comes from the US military.\textsuperscript{17} Fifty
percent biofuel should be used by the US Navy (300 million
gallons by 2020) and Air Force (400 million gallons by
2016).\textsuperscript{18} On September 16, 2011, President Obama announced
a comprehensive \textit{National Bio-economy Blueprint}.\textsuperscript{19}

\textbf{Canada}

This nation exports plant oil, cereals, and wood. In 2009,
Alberta implemented the Biorefining Conversions Network
(BCN) as part of the \textit{Alberta Innovates} system to advance
Alberta’s bio-industry sector.\textsuperscript{20} On the advice of the
Premier’s Council for Economic Strategy (May 2011) Alberta
Innovates works on a 10-year strategy (with a 20-year
horizon) for advancing Alberta’s bio-economy in improv-
ing feedstock logistics, greenhouse gas reduction, biomass
energy, biopolymers and green fluids, land remediation, and
abandonment services (Alberta Innovates, pers. comm.).

\textbf{Germany}

Strong in industry and science, Germany produces on 2.3
million ha (16.5\% of total acreage) a substantial amount of
biomass (86\% for energy, 14\% for industrial use)\textsuperscript{21} which
however, does not meet the demand of an export-oriented
industry. About 40\% of biomass processed in Germany is
imported;\textsuperscript{22} in the segment of chemical industries, this share
is even higher at 60%. The Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food, Agriculture, and Consumer Protection (BMELV) supported the Bio-economy Research and Technology Council who published its general strategy in 2010 and again – with the focus on sustainable energy – in 2012. In 2010, the BMBF published the National Research Strategy BioEconomy 2030. It targets economic growth as well as global responsibility and addresses global nutrition, sustainable agriculture, safe food, renewable resources for industry, biomass-based energy as well as cross-section activities. This program has a budget of €2.4 billion.

European Union

The European bio-economy already produces about €2000 billion (17% of EU GDP) and employs 21.5 million people. In 2011, to push biorefineries under the 7th Framework Program of the European Union, the project Star-COLIBRI developed a joint European Biorefinery Vision and Roadmap for 2030 which targets on bio-based products (30% biochemicals, 25% biofuel, 30% heat and power), versatile biomass supply chains, and growing integration of bio-based industrial sectors. Also, in 2011, nine European Technology Platforms published the White Paper The European Bioeconomy in 2030 addressing the need of investments, entrepreneurship, skilled workforce, an innovation-friendly regulatory framework, and societal appreciation for science and innovation. Based on these and other papers and a broad discussion with stakeholders, the European Commission proposed the program Horizon 2020 to be approved in 2012–2013 by the European Council and Parliament for the period 2014–2020. A proposed budget of €4.5 billion targets the bio-economy (after €2.3 billion in the period 2007–2013) out of a total budget of €80 billion.

Pushing the bio-economy

It seems that these and more nations – feedstock providers as well as industrial hubs – are more or less well prepared to develop and unfold the bio-economy. However, translating strategy into industrial reality is challenging and complex.

To achieve societal support, the strategy needs to be communicated to the public, politics, academia, and industry. For example, in Europe especially, biotechnology is welcome by only 50% of the population. A consensus-building process is necessary and should be initiated and moderated by independent and broadly accepted institutions. Academia and industry should develop strategic and tactic concepts and give input for governmental policies, measures, and research and development (R&D) funding programs. Governmental policies along the strategy need to be formulated for feedstock and industrial sectors as well as R&D. Adequate budgets to build the proper infrastructure and fund R&D need to be allocated by governments. Managing these budgets and selecting qualified R&D projects alongside the policies asks for efficient project execution organizations. Distant industries must be integrated and learn how to utilize new value chains of global dimensions. Chemical industries so far did not use bio-precursors delivered from bio-refineries in bulk volumes, those refineries must learn to use residual biomass; farms need economical logistics to exploit the value of residual biomass. It is the formation of new value chains connecting the production of biomass, energy, and chemicals that is challenging. In addition, this production-oriented value chain asks for completely new technologies and processes. Each of its steps therefore must meet the development-oriented value chain as well, which is about realizing a theoretical concept through R&D and scaling up to commercialization. In a climate of open innovation, such a demand of technologies offers the opportunity for founding and growing start-ups which identify essential technology steps, secure key intellectual property (IP), and build own-production facilities or licence the know-how.

Previous open innovation waves in, for example, transistors, computers, information technology, and biotechnology have shown that it needs a critical number of scientists, business, and finance people, a culture of mutual trust and entrepreneurial spirit, as well as organized communication platforms to breed open innovation. So-called innovation clusters are characterized by the regional concentration of interconnected companies, specialized suppliers, service providers, related industries, universities, and research institutions in a particular field that compete but also cooperate. Silicon Valley in California is a model where these success factors join and it is not by accident that the innovation waves mentioned above started and expanded from there (Fig. 1).
World-class clusters embrace the full production- and development-oriented value chains and promote

- Strong technology push connected with early technology intelligence
- Strong market pull connected with early market radar
- Open innovation by managing trans-sectorial communication
- Breeding start-ups and spin-offs
- Reducing risk and shortening time to market by collaboration
- Attractiveness for investors
- Global network into feedstock and industrial regions inducing unusual value chains
- Supportive infrastructure and government

As the bio-economy’s industries in feedstock, fuel, or chemicals are concentrated in different global regions, local clusters with focal points in different sectors will unfold. Malaysia’s cluster starts from the palm oil industry; Russia and Canada develop clusters covering the feedstock and industrial value chain more broadly; and Germany – which is leading in European bio-economy clusters – is the home of CLIB\textsuperscript{2021} – which is especially strong in chemical industries.\textsuperscript{35} To reach key performance indicators (Table 1) and fully exploit the bio-economy’s potential, value chains must be realized globally from the very beginning.

A biogas process based on vinasse in Brazil may find another application and market in sugarcane areas in South Africa and in Malaysia’s palm oil mills as well. CO/CO\textsubscript{2} transformation running in a steel mill in China should also work in Russia, Germany, or the USA. Canadian syngas fermentation based on lignocellulose should have a future with Russian wood or corn biomass in the USA. Platform chemicals useful in chemical industries might be produced in feedstock areas but further processed in the USA, Japan, China, or Germany. Because of this global dimension,

![Figure 1. The bio-economy’s value chain.\textsuperscript{33}](image)

### Table 1. Key performance indicators for bio-economy clusters.\textsuperscript{36}

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving fossil energy</td>
<td>PJ a; €/GJ</td>
</tr>
<tr>
<td>Saving CO\textsubscript{2} emission</td>
<td>€/t CO\textsubscript{2} eq.</td>
</tr>
<tr>
<td>Extra revenue of the agro-sector</td>
<td>€ million/a</td>
</tr>
<tr>
<td>Share of industrial biofeedstock produced</td>
<td>%</td>
</tr>
<tr>
<td>Value of industrial biofeedstock produced</td>
<td>€ million/a</td>
</tr>
<tr>
<td>Share of bio-based energy and chemicals</td>
<td>%</td>
</tr>
<tr>
<td>Extra revenue in energy and chemical sector</td>
<td>€ million/a</td>
</tr>
<tr>
<td>Import of biofeedstock</td>
<td>€ million/a</td>
</tr>
<tr>
<td>Impact on balance of trade</td>
<td>€ million/a</td>
</tr>
</tbody>
</table>
an isolated national cluster will be extremely limited. It needs to reach out to all bio-economy regions and connect.

Forming and linking national clusters is therefore key to speeding up the bio-economy and should be an essential element of national strategies. The path to the global bio-economy will be paved by a ‘cluster of clusters’.

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We thank the German Federal Ministry of Education and Research (BMBF), the Ministry of Innovation, Science and Research of the German State of NRW (MIWF) and the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) for funding the cluster management of CLIB2021, the CLIB-Technology Cluster, and CLIB-Graduate Cluster as well as industrial R&D projects.

Dedication
On behalf of the board of CLIB2021, this article is dedicated to Dr. Dr. h.c. Christian Patermann on occasion of granting the honorary doctorate by the Rheinische Friedrich-Wilhelms-Universität Bonn. We acknowledge his outstanding role in developing and pushing the European and German bio-economy strategy and policy.

Dr. Dr. h.c. Christian Patermann served in the European Commission as Director DG Research Biotechnology, Agriculture and Fishery and developed the concept of the Knowledge-Based Bio-Economy (KBBE) in the 7th EU framework research program. In addition, he acted as Vice-President of the Steering Committee IGFA (International Group of Funding Agencies in Global Change). He is member of the German Bio-economy Research and Technology Council (BioÖkonomieRat), advisor to the government of Northrhine-Westfalia, and member of the advisory board of CLIB2021.

We appreciate very much his visionary and strategic advice, his broad experience in industrial and political issues, as well as his generous willingness in sharing the excellent global network he has built throughout his great career.

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