Bio Innovation Growth *mega* Cluster

BIG-C

Flanders, The Netherlands and North Rhine-Westphalia

Agenda 2014 / 2015

I. Introduction

BIG-C – the Bio Innovation Growth mega-Cluster aims on the transition of Europe's industrial (chemical and energy) mega-cluster in the Belgian region of Flanders, The Netherlands and the German state of North Rhine-Westphalia into a global leader of biobased innovation growth. In the light of governmental strategies, infrastructure, industries, academic institutions and societal expectations in the regions involved 4 feedstock to product value chains (F2P) have been defined to be pursued starting from domestic raw materials:

1. F2P Woody biomass (lignocellulose)
2. F2P Agro-based biomass
3. F2P Organic side streams
4. F2P CO/CO_2 –containing gas

These F2P value chains aim on producing bulk and fine chemicals of industrial significance and fuels. The resulting products feed the chemical value chains up to consumer market level, thus boosting the biobased and circular economy.

Several (key-)technologies developed in and outside the EU are ready to be scaled-up. Industrial feasibility of feedstock processing and transformation, equipment and the integration of carbon-providing and downstream consuming industries need to be demonstrated. Due to its comprehensive competitive position, the established industrial value chains and the willingness to move towards the circular economy, BIG-C is the most appropriate region for these demonstration plants.

I.1. Our vision: Transition into a circular economy

Mankind is challenged on the one hand by the growing demand in food & feed, fuel & energy, chemicals & materials and on the other hand faces raw material scarcity, growing emission of greenhouse gases and climate change. Therefore private and public stakeholders urgently seek to improve feedstock efficiency and to reduce side streams as well as climate-damaging emissions. In contrast to state-of-the-art industrial processing, residuals should not be considered as useless waste any more but as a material to be used in other processes. Today's linear economy needs to turn into a circular economy. Especially in Europe which is largely dependent on importing raw materials this transition will not only secure jobs and wealth but offers an opportunity to grow and maintain/gain leadership.

I.2. Our mission: Addressing the circular economy in chemistry

Concerning chemical industries the change from a fossil linear to a sustainable circular economy requires setting up chemical product trees starting from alternative and sustainable carbon sources. Using bio-resources such as biomass is an option especially if non-food biomass is valorised. Another important alternative resource especially for high volume chemicals is carbon containing industrial gas or municipal and industrial solid waste (MSW, ISW). These so far neglected resources offer a way forward to overcome feedstock challenges inherent to the use of biomass like limited cultivation areas and interference with food production and more markets of high demand either directly or indirectly.

I.3. This action meets EU policies

Both topics, the circular economy and the feedstock challenge, meet the European strategy „Towards a Circular Economy: A Zero Waste Programme for Europe" published in July 2014 by the European Commission ((COM(2014)398). This programme asks for making better use of resources for the economic and environmental benefit of Europe and refers to the Europe 2020 Strategy for smart, sustainable and inclusive growth (COM(2010)2020, COM (2011)21).

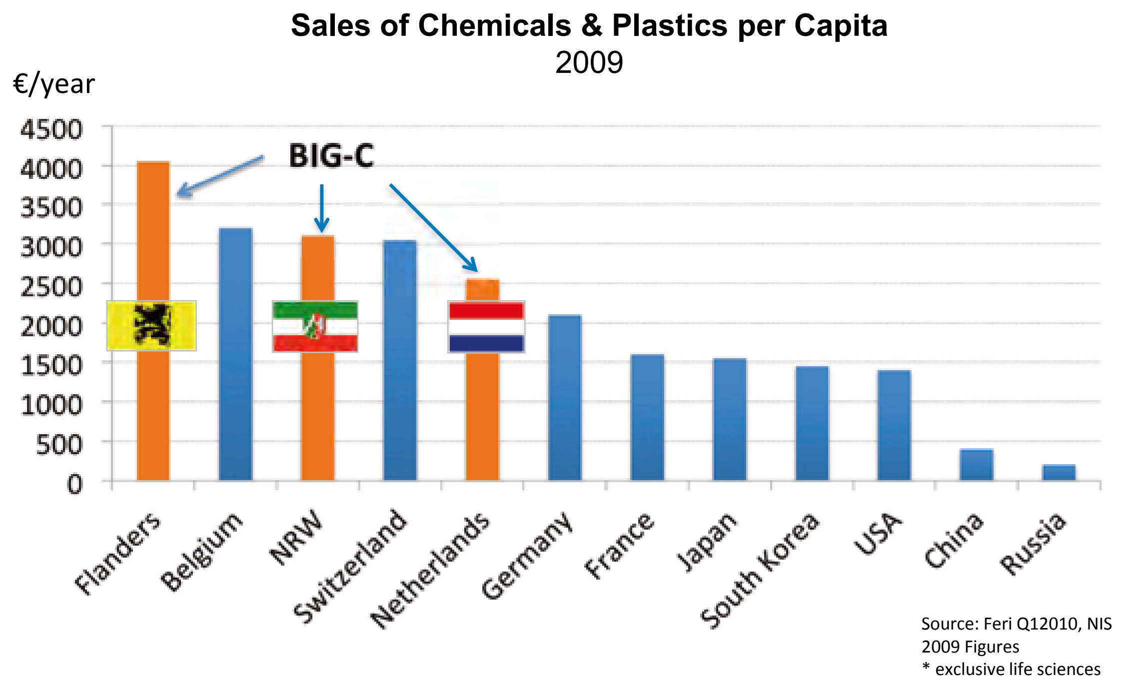
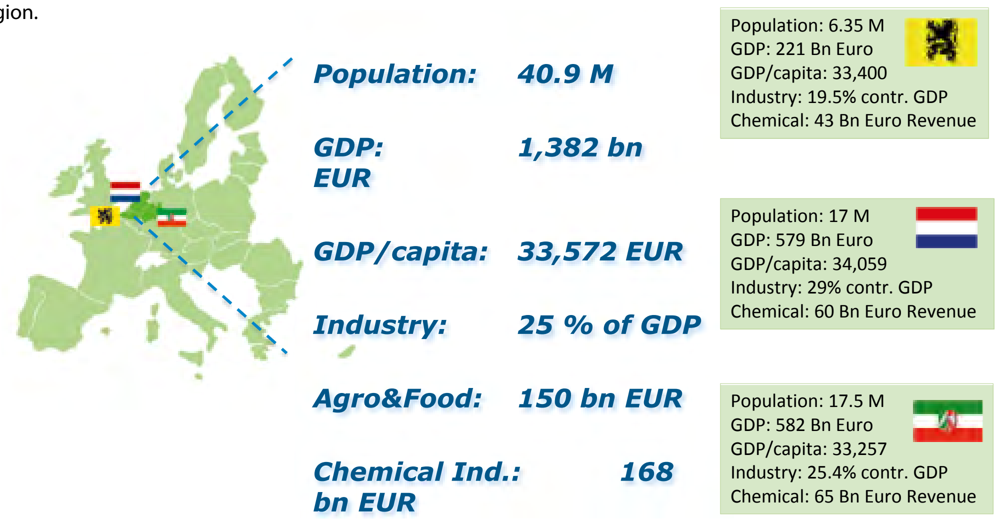


Figure 1: Sales of chemicals & plastics per capita .

Figure 2: Overview of the BIG-C region.



The concept of a circular economy envisions „designing out" waste throughout the value chain especially by valorising „industrial symbiosis", thus

- increasing feedstock efficiency,
- reducing side streams and
- climate damaging emission.

The value chains proposed here will be key to a circular economy.

Large scale circular use of CO/CO_2, MSW, ISW and biomass in chemical production needs a region providing:

a) excellent location factors concerning industrial value chains, infrastructure and logistics, research & development, human capacity building and public administration as well as

b) willingness of public and private stakeholders to change towards the circular economy. In other words it needs a region ready for "Smart Specialisation". This EU concept fosters a strategic approach to regional economic development by

- developing a vision for growth,
- identifying its competitive advantage,
- setting strategic priorities, and
- making use of smart policies and actions.

I.4. BIG-C region is most appropriate

To make the concept of the circular use of carbon real it needs a region to land. An excellent platform is offered by Europe's leading industrial mega-cluster comprising Flanders, The Netherlands and North-Rhine Westphalia. This border-crossing region is especially strong in refinery, chemical, power, steel and food industries and provides a long track record in at least 5 regional pillars of competitiveness:

- industrial value chains,
- infrastructure/logistics (highways, railways and aviation, high volume shipping and pipelines),
- human capacity building,
- research & development, and
- public administration.

This mega-cluster shortly published the joint initiative BIG-C (Bio-Innovation Growth mega-Cluster) to promote the transition into a circular economy. BIG-C follows the European Smart Specialisation strategy and addresses all pillars of competitiveness as mentioned above.

BIG-C's mega-cluster is not only an industrial hub but also the area of Europe's highest CO/CO_2 emission and municipal waste generation and belongs to the most productive agri- and silviculture regions. It is therefore the most appropriate region to demonstrate cross-sectorial circular use of such materials. Transferring "industrial symbiosis" into practice needs to integrate so far separated sectors such as:

- agro- and silvicultural industries producing biomass
- steel-, cement-, power industries generating large volumes of CO/CO_2,
- municipalities and processing industries providing critical volumes of MSW, ISW,
- chemical industries producing bulk chemicals,
- processing industries (incl. SME) serving end consumer markets,
- engineering competencies in the sectors involved,
- and logistic systems connecting production sites.

In addition are necessary:

- academic science and training providing the technology base and scientists,
- public governance and authorities promoting industrial progress and transition, as well as
- public acceptance based on a culture of industrial change.

Through its well-established cluster management organisations FISCH (Flanders), BE-Basic (Netherlands) and CLIB (NRW) – to name just a few - the BIG-C region looks back on a long track record in stakeholder management and design of a supportive environment of such complex industrial transition initiatives.

I.5 Flagships and projects
BIG-C identified several projects to prove technical, economic and ecological feasibility and which will accelerate the implementation of similar production facilities and mobilize the development of an extended product pipeline. The practical experience gained through operating these demonstration plants and managing its output in the BIG-C region will result in extensive know-how along bioprocessed value chains– the more as BIG-C is Europe's most developed mega-cluster concerning the chemical processing sector.

The 4 F2P value chains are pushed by growth markets (e.g. aviation fuel and aromatics), technologies (e.g. gas fermentation) or availability of abundant feedstock (e.g. lignocellulose, municipal waste). Feedstock streams might serve several product sectors while processing technologies find their use in more than one F2P value chain. Therefore 3 Flagship Topics have been defined:

- Chemicals from carbon monoxide (CO)
- Aromatics & fine chemicals from woody biomass
- Aviation biofuel from various feedstock

Flagship Topics might cover several projects and demonstration plants. Technology readiness level (TRL) 5-7 is expected. Demonstration plant projects should start in 2016.

The realisation of all these topics depends at first on motivated, well-educated and trained men and woman. Therefore BIG-C will address the vocational training of rising generations by another Flagship Topic:

- BIG-C Circular Economy Education

I.6 Feasibility to be proven by Key Performance Indicators (KPI)
Technical KPI of the demonstration plant are

- carbon emission into the atmosphere (emitting industry),
- primary fossil feedstock displacement (downstream consuming industry),
- chemicals originating from "secondary" (recycled) carbon,
- synergies by integrating production sites of emitting and downstream consuming industries.

From a more general view this activity addresses the priorities of

- enhancing resource efficiency (carbon),
- improving competitiveness of participating industries,
- reducing carbon emissions and other air pollutants,
- preserving agricultural resources,
- increasing domestic supply of sustainable fuels and chemicals,
- SME development and growth.

Furthermore the demonstration plant will trigger the regional "pillars of competitiveness" towards the circular use of CO/CO_2 concerning

- initiating industrial value chains including SME,
- adapting infrastructure including logistics,
- building specialized human capacity,
- initiating Research & Development, and
- developing appropriate public administration procedures.

I.7 Realisation through Public-Private-Partnership (PPP)
This initiative involves, beside technical, especially economical risk, concerning the achievement of competitive cost of production of the targeted chemicals, derived materials and consumer products. Therefore it needs risk-sharing in a PPP model.

BBI and SPIRE are PPPs set up within the European HORIZON 2020 Framework Programme and addressing biorefineries as well as sustainable processes through resource and energy efficiency. One of the approaches to be pushed is the circular use of woody biomass, MSW, ISW and industry sourced CO, making BBI and SPIRE appropriate programmes to

- build the PPP-consortium, and
- subsidize the demonstration plant according to a PPP model.

In realizing these new sector-crossing supply chain models agri- and silviculture industries, MSW , ISW managing municipalities, industries from the CO/CO_2 gas generating sector and industries from the downstream consuming chemical sector need to be involved. The latter will define the product portfolio of industrial interest. This circular supply chain model is in the public interest and will ultimately benefit industrial participants. To establish the economic, environmental and technical advantages a PPP offers an ideal mechanism to share risk and promote cooperation.

As the technology requires various disciplines (biotechnology, chemistry, engineering, equipment construction) companies offering special know-how, instruments and process(-steps) are required. Such business fields are often covered by small- and medium-sized enterprises (SME). Therefore SME engagement is a priority in this initiative and an opportunity for young companies to grow.

In addition, BBI and SPIRE supports horizontal actions including life cycle analysis (LCA), public acceptance and recognition of sustainable products, business models, proof of sustainability and skill sets - topics to be addressed in this initiative with the technical demonstration plant.

As BBI and SPIRE meet BIG-C's strategy it is considered to build the demonstration plants through these PPPs in cooperation with national and regional initiatives and supporting programmes. Integrating the region into the whole initiative is key in order to develop the regional "pillars of competitiveness" in parallel to the industrial transition.

The desired compounds for better performing materials with less environmental impact, safer production, safer consumer use (REACH) etc. are fully in line with the EU Lead Market Initiative and the KET programme (Key Enabling Technologies). These experiences will trigger entrepreneurship in BIG-C and lay the basis for export oriented industries – both concerning technologies and products. Established relationships to international partners in Brazil, Canada, Malaysia and more regions offer technology transfer and business opportunities into areas which are rich in sustainable renewable feedstock at very cost competitive conditions.

II. 1. BIG-C F2P flagship chemicals from carbon monooxide (CO)

Products for markets
Acetone–butanol–ethanol (ABE) fermentation is a process that uses bacterial fermentation to produce acetone, n-Butanol, and ethanol by e.g. bacteria of the Clostridia class. This is the type of simple but bulk volume platform chemicals to be targeted in this Flagship Topic. The finally targeted product(s) depend on the participating industries.

Feedstock for product
Currently industrial gas containing CO produced by e.g. steel mills is among the most relevant industrial "waste" streams. Synthesis gas from organic materials such as Municipal Solid Waste (MSW) or Industrial Solid Waste (ISW) provides another CO source. In the BIG-C region MSW up to 500 kg / resident are generated. Using CO offers a model of innovative circular integration and explores a new-to-the-market carbon source available in Europe in very big volumes from various processing and product streams.

As CO in synthesis gas might come with fossil as well as biologically bound carbon this technology provides a perfect model for the step wise transition from the current fossil-based into a bio-based respectively circular economy. Demonstrating the suitability of CO as an industrial feedstock is therefore a real innovative advance towards the circular economy using a carbon source

- abundant in Europe,
- outside of the food chain,
- available from fossil- and bio feedstock,
- currently considered a waste emission but in future a valuable feedstock.

Demonstration plant linking feedstock, product and market
The state-of-the-art technology to convert CO (synthesis gas) into hydrocarbons is chemical Fischer-Tropsch catalysis. Though invented already in 1925 and applied in high volume fuel production this chemical catalytic process still lacks selectivity and is not suitable for converting CO into narrowly defined chemicals.

The new technology targeted here is gas fermentation. Its innovative advance lies in the unique selectivity of the microbial conversion making the circular use of carbon feasible to specific production of defined chemicals. Thus, this technology responds generally to the raw material challenge as mentioned above (I) but also to a fermentation specific feedstock restriction, that is the dependence of state-of-the-art fermentation on agriculturally sourced feedstocks (e.g. sugar) and on the other hand the selectivity challenge, that is the low selectivity of state-of-the-art CO conversion.

From an economical point of view this technology is suitable in small and large scale whereas Fischer-Tropsch processes need to be very large. Concerning the capital cost and scale challenges gas fermentation is therefore more adaptable to regional and industrial specifics.

Start-ups like Lanzatech, Ineos Bio, Coskata and OPXBIO (USA) have shown the proof of concept of emission gas fermentation esp. for biofuel (ethanol) on lab- and pilot scale in New Zealand, China and the US.

Whereas emission gas provides CO in a gaseous form MSW and ISW need to be gasified in order to provide a CO gas stream. This flagship therefore includes gasification of soid waste (SW) to synthesis gas containing CO and H_2. MSW gasification has been demonstrated by e.g. Enerkem (Canada) and Concord Blue or Ecoloop (Germany) in Canada, India and Germany. Beside MSW this technology accepts Industrial Solid Waste (ISW; often characterized by a higher calorific value) and any organic materials such as biomass. Bulk chemicals are not addressed in pilot-scale MSW and ISW projects yet.

In the context of regenerative power generation there is another benefit of SW gasification to be mentioned. It delivers power in parallel to synthesis gas which can be stored easily. Producing gas and power therefore provides an option to balance non-uniform energy sources like sun and wind.
It may be emphasized that both gasification and gas fermentation are well adaptable to smaller as well as bigger capacities and therefore suitable to a wide range of municipality sizes.

European science delivered a significant share of basic knowhow especially in gas fermentation but lags behind in industrial development. There is a strong need to demonstrate the valorisation of CO-gas in practice at production site level integrating so far separated carbon-emitting and downstream consuming industries, and creating awareness on the relative maturity and adaptability of this technology set. This demonstration aims on accelerating market adoption and further on replication.

Demonstration plant projects are under preparation both for CO-emission and Solid Waste utilization. ArcelorMittal in Flanders and ThyssenKrupp in NRW consider to valorize CO-emission. Municipalities in Flanders, The Netherlands as well as NRW explore the use of solid waste in chemical production. Earlier mentioned technology providers like LanzaTech and Concord Blue as well as customer industries are willing to enter demonstration plant projects.

BIG-C added value
BIG-C is Europe's region of highest CO generation e.g. through steel mills in Flanders and NRW. Due to the high population density it is also a preferred area for future SW-based production facilities, as per citizen 500 kg of MSW are generated annually. The resulting platform chemicals find their customers in the mega-region in big chemical industries like BASF, Bayer Material Science, DSM, Evonik Industries or Lanxess plus hundreds of chemical SME. This flagship topic is therefore a perfect example of providing and utilizing a domestic carbon source by domestic stakeholders in a circular economy approach.

In case of MSW gasification another topic should be emphasized: Because utilization of MSW takes place before the eyes of private residents such a project will draw special attention. It provides therefore a concrete model to demonstrate the benefits of circular value chains to the wider public and gain acceptance.

II. 2. BIG-C F2P flagship aromatics & fine chemicals from woody biomass

Products for markets
This initiative aims on lignocellulosic biomass with focus on woody biomass to biobased aromatics. The aromatics will be produced from the lignin or the (hemi)cellulose sugars. Further targets are high added value applications such as carotenoids (e.g. astaxanthin) from those cellulosic and hemicellulosic sugars as well. A biorefinery based on this approach will lead to higher total value creation (lignin goes to prices much higher than its energy value and the sugars go to fine chemicals).

The world aromatic market is under pressure (benzene scarcity in the US due to shale gas, xylene scarcity in China due to xylene production facilities closure). It is expected that by 2020 the benzene demand will be 5 million tons/year higher compared to the production. Several efforts are under way to solve this problem. BIG-C will find in this approach a more environmentally friendly strategy than e.g. Coal To Aromatics projects in China. Chemical and materials companies will use the output of aromatics for further converting, formulation, testing and evaluation and development of the final industrial process. The following can be envisaged:

- PET, PEF, polycarbonates, PU, polyamides, nylon, polyesters producers
- Textile producers (biotumen, UV-stabilizers)
- Tyre producers (fillers and antioxidants)
- Inks and paint producers (resins, coatings)
- Resin producers and users (hardboard, car- and construction-industry, ...)
- Adhesive producers and users (automotive)
- Coatings
- UV-stabilizers and anti-oxidants
- Carotenoids, aroma's (food applications, ...)
- Styrene producers or uses
- BTX and phenol producers and users

It is expected, especially via the lignin-route, to come to many new innovative molecules with better performances and in some cases avoiding the use of dangerous production process or toxic molecules.

The aromatics approach is driven by the need to use highly functionalised biobased aromatic molecules that can be used in many applications (40 % of chemicals used are aromatics) among which many are of higher added value. However by doing so, hemicellulose and cellulose is released as a side product (opposite to existing chains) and can be used in the same value chains of polysaccharides or in new ones. This BIG-C F2P foresees as well at the sugar level new applications. A first example is the production of carotenoids.

Carotenoids are targeted to deliver bio-based alternatives to this steadily growing market (3 - 4 % AGR) which is estimated to reach 1 billion EUR in 2018. Today 90 % of carotenoids are produced synthetically from fossil carbon sources due to beneficial feedstock cost. However, the rising demand for natural carotenoids (and more bio-active compounds with nutritional value) drives the growing market of bio-based compounds.

A model carotenoid is astaxanthin which is a high-value carotenoid with intense red colour naturally occurring in marine organisms. Astaxanthin has excellent antioxidant properties, as well as anti-inflammatory and anti-cancer activities. The feed industry uses astaxanthin as an animal feed additive to impart coloration of food products. In fact, carotenoid pigments represent about 15 – 25 % of the cost of production of commercial salmon feed. While it constitutes only a very small portion of salmon feed (50 to 100 parts per million), astaxanthin accounts for up to 20 % of the cost as prices for (natural) astaxanthin are as high as 2,500 EUR / kg. The current world market for astaxanthin exceeds 200 million US dollars. Other carotenoids and related compounds will follow in the same strategic approach.

Feedstock for products
Projects within this Flagship Topic will make use of woody biomass by extracting ingredients such as tanning compounds and obtaining C5- and C6-sugars as well as lignin after different hydrolysis and separation approaches. Woody or lignocellulosic feedstock is seen as an abundant biomass resource (from tree short rotation coppice for industrial purposes, the pulp and paper industry, but also from second generation alcohol production, or other waste streams) available in the North of Europe via the strong forest-based economies, but also in Southern parts as Portugal.

It is available in the form of straw residues, wood fractions from flax, lignin fractions from wood waste, fibre fractions from anaerobic digestion (used for bioenergy production), and as side stream in second generation-biorefineries. In addition, new sources become available by the production or revival of old and new plants as flax and hemp for fibres, but also Miscanthus and elephant grass as new second generation feedstock. A special focus will be laid on poplar because of

- optimal energy- and eco-balance in short rotation coppice (SRC) compared to annual energy crops,
- optimal feedstock to cost ratio,
- available breeding technique (somatic hybridization) to optimise growth and biomass.

Currently poplar biomass is totally used in combustion, though bark and branches cannot be energy efficiently used due to a high ash fraction. In the proposed bio-refinery concept poplar biomass including these residues is utilized in producing chemicals, thus capturing more value. In addition poplar can be cultivated on poor and even contaminated soil, thus not only providing non-food biomass but also avoiding indirect land use change (ILUC). Combining poplar cultivation for industrial purposes and transformation of the resulting biomass will allow decentralized operation, thus increasing the efficiency of logistics as well as production and enable economically and ecologically sustainable production in rural regions.

Demonstration projects linking feedstock, products and markets

This flagship topic combines expertise in 4 modules:

1. Plant (tree) breeding (improving raw material) and cultivation

Plant breeding can optimize lignocellulosic biomass for industrial purposes concerning input (cultivation needs) and output traits (plant performance parameters). This module will focus on output traits like growth, biomass yield and processing characteristics. For example the lignin structure might be modified in order to make (hemi-)cellulose more available and lignin more accessible.

A special plant breeding method has already been applied successfully on poplar (Phytowelt Green Technologies GmbH) to optimize growth characteristics and biomass yield. The Flemish Institute for Biotechnology (VIB) is currently testing improved poplar varieties with altered lignin structure in field trials.

These poplar varieties are available for scale-up in culture and utilization. Currently up to 300 ha of land are estimated to be available in the targeted region to establish poplar plantations giving rise to 3,200 tpa of biomass with conventional poplar lines and up to 4000 tpa with proprietary lines (Phytowelt). Additional biomass could be obtained from a nearby dutch paper plant (4,000 tpa), as well as from available energy wood producing short rotation coppices (3,000 – 10,000 tpa of waste).

2. Lignocellulosic biomass digestion to sugars and lignin

Poplar but also specific residual streams can be taken as feedstock such as the woody part of flax, the fibrous part of waste digestate from anaerobic digestion, kraft lignin from pulp and paper industry, and hydrolysis lignin from second generation biofuel production. Woody biomass needs to be separated into (hemi)cellulose and lignin.

In this processing step biomass can be hydrolysed with further protection, addition and/or replacement of functional groups and afterwards separated in sugar- and lignin-derivatives. This will be done by chemical, bacterial, enzymatic, (bio-)electrochemical processes. Specific separation processes, either integrated, either as a post downstream process will be put in place focusing on high selectivity, high flow rates and low energy demands.

3. Conversion of sugars and lignin to aromatics, carotenoids and more chemicals

C5- as C6-sugars as well as lignin will be converted into aromatic molecules. The resulting molecules will be drop-ins and new molecules to be utilized in bio-based established and new/innovative materials. Up to now these processes are only partially developed at lab scale but with a high potential in innovation for materials. Ready for scale-up is a fermentation process to astaxanthin using lignocellulosic sugar (Phytowelt Green Technology GmbH), and for demonstration a number of fuels and chemical processes (DSM, Corbion, AKZO Nobel, SkyNRG and others).

4. Utilization in user industries and support platform

New compounds will require material development and testing in the customer industries. In order to do so, especially the companies involved in the chemical and material development need substantial sample amounts to proceed.

A support platform will be necessary to communicate about the new molecules and performances of the new materials. Market analysis will target on new business plans and Life Cycle Assessment will support sustainability communication and market introduction.

BIG-C added value

BIG-C's mega-cluster is not only an industrial hub but also in the heart of Europe's lingnocellulosic biomass production (delivering straw). The region is linked with north, south and east for wood delivery. Together with the activities of Greenport Venlo (NL) and the horticultural production sites on the German side of the border it forms the largest horticultural production area in Europe (www.venlogreenpark.nl/de/greenport-venlo) and is strongly linked with wood and lignocellulose production areas as Wallonia and North-France.

It is therefore the most appropriate region to develop fully bio-based aromatic and carotenoid molecules and especially to produce substantial amounts of these molecules to be tested by a whole series of big companies and SME in their clean processing and new materials programs (e.g. textile, hardboard, resins, coatings, paints and inks, automotive, polymers and plastics, food ingredients, etc.). This will lead not just to a combination of plant breeding and cultivation companies as well as biomass processing and chemical industries, but also to an integration with all kinds of materials developers, bringing the final recycling of materials also to a new era.

The poplar based demonstration plant is suggested by Phytowelt Greentechnolgies GmbH (Nettetal, Germany), Fraunhofer UMSICHT (Oberhausen, Germany), Competence Center Microbiology and Biotechnology of the Hochschule Niederrhein (University of Applied Sciences Niederrhein), Alterra/WUR (Wageningen, Netherlands) and VITO in Antwerp (Belgium) to be placed at a shortly developed industrial production site between Venlo (NL) and Nettetal (DE) at the border between the Netherlands and Germany (VENETE). The proposed duration is 5 years and total cost 36 million EUR.

The project aiming on aromatic chemicals includes VITO, TNO (Nl), KULeuven (Fl) Tecnaro (NRW) and more non-disclosed R&D institutions and companies. It foresees demo-sites for lignocellulose fractionation at Biobase Europe (Ghent), wood to aromatics in Antwerp, sugar to aromatics at the Green Chemistry Campus (Bergen-op-Zoom), further aromatics modifications at the Chemelot (Geleen) site.

II.3. BIG-C F2P flagship aviation biofuel from various feedstock

Products for markets

Among the products targeted by BIG-C Flagship Topics biobased aviation fuel is an exemption as it must meet ASTM specification as well as an official certification and in addition the future market can be predicted more reliably than for other chemicals addressed by BIG-C. Therefore this chapter focuses on presenting market scenarios and the business environment.

The aviation industry has committed to sustainable development in an international global context, as laid down in the global ATAG biofuels ambitions[1]. Essentially these are: promote improvements in fuel consumption efficiency by plane technology, aviation operations and infrastructure, introduction of sustainable aviation biofuels (as there is no technical alternative for combustion engines so far), carbon neutral growth from 2020 onwards, and reaching a 50 % emission reduction target by 2050 relative to the 2005 situation.

In addition, it should be realised that additional societal developments are also taking place, for instance cost reduction and improved work-life balance in business travel by enhanced use of remote communication technology and shift towards other forms of transportation (e.g. train) with inherently lower cost and emission schedules. Obviously, the latter development is only possible for land-connected destinations and practically impossible for intercontinental travel, which is the most significant contributor to aviation fuel consumption and GHG emission.

Adaptation to the BIG-C situation

Global jet fuel consumption increases by 4 - 5 % annually. A possible adaptation for the BIG-C situation is to stimulate modal shifts (e.g. improved connectivity of rail and road-based transport to and from major aviation hubs), and investing aggressively in more advanced facilities for remote communication. Such a set of measures may help to direct growth in the aviation sector to lower numbers than the average international growth, for instance to 2 - 3 % annually.

ATAG estimates developments in operations, infrastructure and technology to yield 1.5 % efficiency improvements – we propose to use this (global) number, since many of these developments are international (BIG-C does not have a substantial aeroplane industry, and airports follow international schemes already). For the balance in the overall reduction of fossil jet fuel consumption, the only available technological solution is the use of sustainable aviation biofuels. In the following estimates, three proposed scenarios have been implemented in the model with the following GHG-emission reduction (Today (*Vandaag*) – up to 35 % emission reduction,

[1] *Towards Sustainable Aviation*, joint declaration signed at the 6th Aviation & Environment Summit organized by ATAG in March 2012. See www.ATAG.org.

Tomorrow (*Morgen*) – up to 80 % emission reduction, and Future (*Overmorgen*) – 85 % emission reduction). Note that in all cases, there will always be a net CO_2 emission, yet much smaller than for the fossil case. The state of development for each category is: (1) Today – mature and investable yet resource constrained, (2) Tomorrow – emerging maturity, with promising but not unlimited resourcing and logistics challenges, (3) Future – embryonic in technology and market. Although we restrict prognoses to the first and second options, we do not lock them in on specific feedstock-technology-combinations.

Practical considerations

Realistic aviation fuels can only consider products that satisfy current engine conditions, since the lifetime of airplanes is long, replacement costs high and replacement rates low. Obviously, allowable fuels require ASTM certification, but we feel this is well possible for all scenario's.

Realistic commercial projects with plants built and operated require positive business cases and returns on investments, and have realistic life spans of 10 - 15 years. Dedicated feedstock infrastructure projects usually require long term investment tracks that are comparable to the rest of the energy and fuels industry. It should also be recognised that both domestic and foreign investments can provide good solutions to feedstock sourcing, production capacity and product distribution. Roll-out of the BioPort Holland concept to the BIG-C region connects regional supply worldwide, to hub-based production and bunkering for the internationally operating Netherlands-based aviation sector.

Feedstock sustainability is the most essential component of sustainable biofuels. Key players in the aviation industry such as KLM and SkyNRG have committed themselves already to work with robust standards that include ILUC and food security as well as biodiversity, GHG reduction, soil / water / air quality, pesticide use and human / labour / land rights including rural development. For instance, KLM and SkyNRG use the RSB-standard and associated low impact modules, which score high in recent assessment reports of sustainability standards by PwC, Ecofys and WWF[2].

At the moment, BIG-C governments have not specified specific standards or comparable policies, yet the development of and investment by a robust aviation biofuels industry and offtake of their products by airports and airlines requires a stable and affordable legal and certification framework. It should also be determined where the additional costs of certification (e.g. auditing schemes etc.) should be laid: fossil transportation fuels in all sectors are not certified on their sustainability impact, and introduction of novel and more sustainable biobased alternatives should not be extra hampered in this unlevelled playing field. This is urgent and should be done in a transparent European and global context.

Scenario prediction

The following numbers need to be scaled to the BIG-C's regional biojet demand, which is a multiple of the Dutch numbers below. To meet the international ATAG ambitions indicates the following projections for GHG (CO_2-equivalent) emission reduction in the 2015 - 2050 timeframe. In a business-as-usual scenario (dotted line), the emissions will explode from over 12 million tonnes per year today towards 37 million tonnes/year in 2050. In the proposed scenario, emissions roughly remain constant around 12 million tonnes / yr towards 2020, to reduce towards 6 million tonnes / yr in 2050.

The figure below shows the large impacts of TOI (Technology, Operations and Infrastructure) improvements as well as sustainable (2G) aviation biofuels to reach the proposed scenario (red line) relative to the reference (dotted line) scenario. This scenario will phase in primarily the tomorrow aviation biofuels, since these can scale GHG-emission reduction to the most significant levels. Note that conventional fossil kerosene reduces substantially but will not fade away entirely, allowing to buffer when biorenewable feedstocks are subject to seasonal effects, pest and other dynamics. In the 2050 situation,

Tomorrow's (2G) aviation biofuels will dominate the portfolio by over 90 % from their proposed first commercial introduction in 2020. Today's biokerosene will play a limited role, paving the way for the more sustainable Tomorrow's biofuels, ramping-up during 2014 - 2020 towards 150 kton / yr or more production scale (compare: 20 % of Neste Oil capacity in Rotterdam).

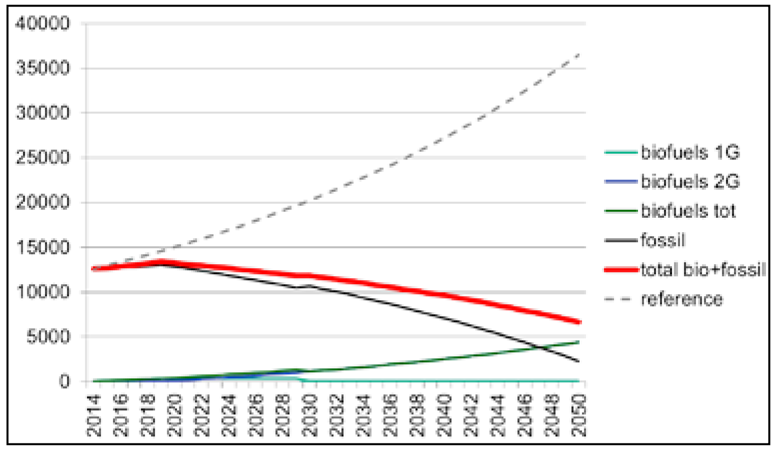


Figure 3: Projected CO_2 emissions for the timeframe 2015-2030 in ktons CO_2-equivalents per year.

[2] WWF International (and PwC) (2013), *Searching for Sustainability – comparative analysis of certification schemes for biomass used for the production of biofuels; Ecofys, WWF (2012) Low Indirect Impact Biofuel (LIIB) methodology.*

Investments

The development of the underlying biorenewable and fossil aviation fuels portfolio will look as is shown in figure 4 (in ktons per year). The bump around 2030 indicates (potentially) projected disinvestments in the relatively small 1G infrastructure that is required to prepare and orient aviation biofuels markets. The aviation fuels market will roughly double towards over 7.5 million tons/year in 2050, with over 90 % of (2G) aviation biofuels. This will require expanding production capacity with approximately 200 ktonnes per year. In terms of GDP contribution, this will yield added values to GDP in the multi billion euro's per annum range.

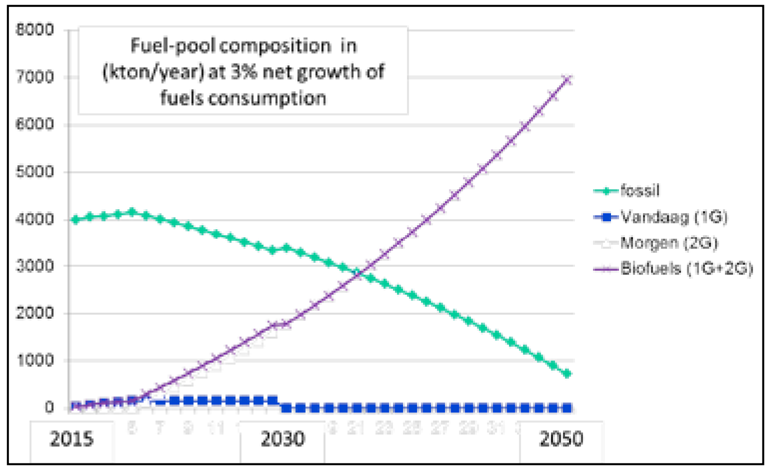


Figure 4: Projected biorenewable and fossil aviation fuels portfolio in ktons per year.

Innovation and international orientation

It is clear that Tomorrows (2G) aviation biofuels will have to take the majority of the GHG-emission reduction as opposed to the contribution of Todays (1G) jet biofuels. Given their current level of emerging maturity, significant development, piloting, scale-up of feedstock sourcing (domestic and international), production facilities and market/business models needs to happen.

Given the opportunity for BIG-C to capitalise on its leadership position through its proactive aviation industries and academics, it is proposed to launch an internationally oriented innovation program consolidating the BioPort Holland concept in the BIG-C region and beyond. When initiated at a significant level, such a public-private innovation program combines the harvesting economic opportunities as well as leading and professionalising the sustainability standards also in an international context. First estimates have been made for The Netherlands, but the case needs to be exploited further by taking the BIG-C regional case into account.

II.4 BIG-C flagship circular economy education

To promote and realize the concept of the circular economy communication with and participation of citizens are of key importance to raise awareness and create understanding and support for novel forms of industry and changed roles of citizens as well as to motivate young people to make circular economy activities the career choice of their life.

In BIG-C's regions Flanders, The Netherlands and NRW various and diverse technical, academic and post-academic training activities are already running on regional level. It will be the task of this Flagship Topic to build a BIG-C wide coordinated education and training curriculum and offer with selected partners. This Flagship Topic will not replace regional activities. It is intended to link and coordinate existing and new initiatives in order to improve efficiency and intensify the exchange of participants, training topics and education concepts.