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Working Party on Biotechnology, Nanotechnology and Converging Technologies

BIOREFINERIES MODELS AND POLICY

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EXECUTIVE SUMMARY

Managing the transition towards a bio economy largely hinges on the development of so-called advanced (cellulosic, integrated) bio refineries (e.g. Iles and Martin, 2013; Kleinschmit et al., 2014). However, their development has been slower than anticipated for a number of technical and policy reasons (Hellsmark et al., 2016). These types of bio refineries have burgeoned in the last few years, and it is worthwhile reviewing their current status. This requires not only a review of the types of bio refineries but the public policies supporting them as well. Different modalities would require different policies and policy mixes. This will be self-evident if only marine and domestic waste bio refineries are considered. The marine bio refineries are perhaps the least developed model, and a number of biological and chemical stages, as well as different pre-treatments can be envisaged. Domestic waste bio refining must interact with municipal waste management policy, for example, while marine bio refining would have no such requirement.

Greatest interest is in the integrated bio refinery concept, but the numbers of these available world-wide are very low. The economic rationale for the concept is very clear. Indeed, there are strong imperatives for integration in petrochemical and oil refining. There are many times when making liquid transportation fuels is not very profitable or not profitable at all. The idea of making chemicals and electricity at the same site as fuels makes economic sense. However, in the case of bio refining the economics are unproven, value chains are uncertain, the supply chains are fragmented, the many stakeholders need to be engaged and a market has to be developed for the products. While all this has to happen, many of the products that would be either drop-in chemicals, or that would fulfil equivalent roles of petrochemicals and fuels, are still in the R&D phase, and many are struggling to break out from R&D into commercialisation as the result of technical and feedstock challenges around scaling up to production scales that can influence a market.

Waste bio refining has become a defining issue for the future of the bio-based industries. Shortly after the most recent boom in bio refining began in the early years of this century, the controversy over competition for land for food production, the so-called ‘food versus fuel’ debate, got underway. This threatened the credibility of bio-based production, and led to a search for technologies that would enable lignocellulosic (or cellulosic) bio refining. This resulted in the second generation1 biofuels era, in which agricultural and forestry ‘waste’ materials are the feedstocks. They are first pre-treated to produce fermentable carbon sources, which are then used to produce biofuels and bio-based materials.

An extension of the search for waste materials that can be used in bio refining is municipal solid waste (MSW), which contains a significant organic fraction. When looking at wastes collectively, a vast amount of solid, liquid and gaseous wastes is available, but this is limited in practice for various reasons. Collecting straw or forestry residues, for example, may not be worthwhile for farmers or forest owners, and therefore might need to be incentivised. MSW contains a lot of fermentable materials, but they are mixed up with non-fermentable materials. Industrial waste gases exist in profusion and are often in a relatively pure form, but microbial processes for their fermentation are immature, and there may be little incentive for companies to capture waste gases.

An attractive business model for the future is integrated bio refining, in which large facilities produce bio-based fuels, chemicals and electricity at the same site or complex. One of the pervading issues around

[1] First generation biofuels were made from sugar or vegetable oil. Second generation has come to mean production from biomass, in various forms e.g. lignocellulosic, or cellulosic. Second generation has come to be synonymous with cellulosic and advanced biofuels.

this model is how to maintain year-round operation: agriculture is seasonal, and forestry is made much more difficult in some countries in winter. A great draw of both waste industrial gases and MSW as feedstocks is that they are available year-round.

However, a crisis of sorts has arrived in cellulosic bio refining i.e. that use plant or tree-based materials as feedstock. In the US Renewable Fuels Standard (RFS), the EPA is enforcing 230 million gallons of cellulosic biofuel blending for 2016, whereas the RFS statute nominally requires 4.25 billion gallons. This represents a 95% reduction. The reason is simply that the technical problems surrounding conversion have proven so intractable that only a handful of the bio refineries involved have reached commercialisation.

Policy highlights

A large range of public policy issues is raised by the general concept of bio refining and its place in a future bio economy. Waste bio refining has many of the same issues, but also some specific ones are raised, not least of them being the question of where to site such facilities for both rural and urban benefits. There are many pieces of information that national and regional governments need to know if public-private partnerships (PPPs) of this kind are envisaged. There are fundamental questions that need answers, and the most important of these are laid out in this report. Some of the most important policy considerations are:

- Waste bio refining should be driven at ministerial level. This lends political credibility, but should also make for more efficient communication and coordination between different ministries, especially agriculture, environment and energy;

- It is important that greater emphasis is given to higher value products rather than just concentrating on energy projects, especially electricity and liquid and gaseous fuels. Great economic benefit and job creation potential lies here. Nevertheless, governments will still be focussed on bio refining for fuels and electricity to meet climate goals, especially in light of the Paris Agreement, now ratified;

- A government department or ministry could be charged with taking the measures to ensure that information on waste streams is collected in such a way that these wastes can become biorefining resources. In the case of MSW this will entail for many countries a further separation strategy at the home to ensure that there is an on-specification feedstock;

- In many countries, waste regulations have become increasingly strict and punitive. A flexible approach to waste regulation is required to make sure that potentially useful waste feedstocks are not shut out from bio refining as a result of regulatory barriers;

- To avoid past issues around sustainability, environmental impacts of processes and products should be compared effectively. This will involve a harmonisation of approaches, hopefully leading ultimately to biomass sustainability assessment;

- As well as looking to experiences in other countries, public policy should ensure that sufficient funding is given to academic/industrial knowledge transfer and near-market research. This is especially true of some of the synthetic biology approaches to biocatalyst development that could lead to breakthroughs in bio refining efficiency;

- The importance of demonstrator facilities is emphasised, but these are not popular with the private sector as their production output is generally too small to influence a market. And the first flagship facilities are very difficult to get built as they are untried and debt management can become a crippling issue. Government and the private sector need to work together in some form of PPP to ensure an adequate demonstration capability;

- Policy stability is needed to encourage the private sector to make sufficient investments. Taxation and incentive structures should focus on providing this policy stability, whilst minimising long-term market distortions;

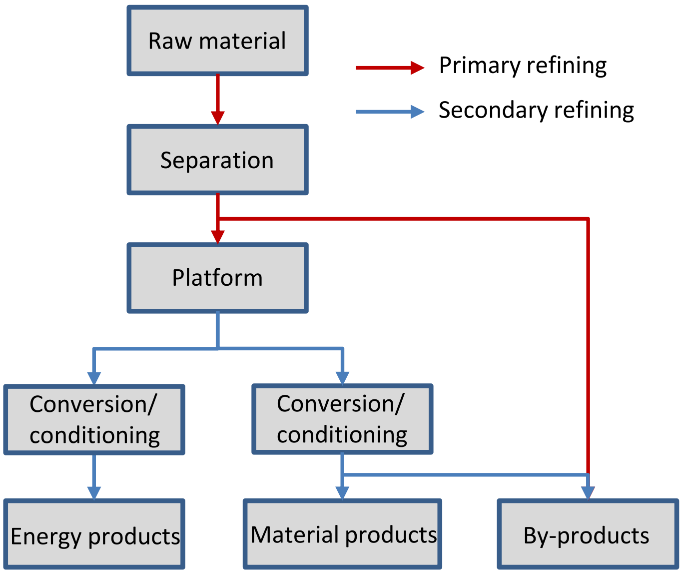
- Fragmented value chains might best be addressed at regional level: the most prominent of the regional clusters in industrial biotechnology are involved in creating the supply and value chains;

- Public reaction is likely to be a critical issue, and in the case of MSW the location of the bio refinery could be a deciding issue when obtaining public support. Cooperation between national and region government is needed. Key benefits of bio refining need to be emphasised, especially the case of indirect job creation in the industrial ecosystem.

WHAT IS A BIOREFINERY: DEFINITIONS, CLASSIFICATION AND GENERAL MODELS

Definitions of a bio refinery are important for gathering data and observing trends. They are important to governments when it comes to public funding initiatives. It is necessary then, to identify what actually happens in a generalised model of a bio refinery and then explore the different models and definitions. Figure 1 is a schematic of the general processes that occur and the order that they occur in.

Figure 1. General schematic of a bio refinery



Source: Peters et al. (2011)

The International Energy Agency (IEA Bioenergy Task 42 Biorefinery, 2009) described a bio refinery as "*the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)*" (see Box 1). This definition suggests that bio refineries should produce both non-energetic and energetic outlets and applies to product-driven bio refinery processes. Both primary products and energy-driven processes are considered as true bio refinery approaches provided that the final goal is the sustainable processing of biomass (de Jong and Jungmeier, 2015). Some of the existing definitions of 'bio refinery' are shown in Box 1.

Box 1. Examples of definitions of bio refinery

The term ‘green biorefinery’ have been defined as “*complex systems based on ecological technology for comprehensive (holistic), material and energy utilization of renewable resources and natural materials using green and waste biomass and focalising on sustainable regional land utilization*”. The term ‘complex systems’ can now be regarded as ‘totally integrated systems’ (Kamm, 1998).

According to Kamm et al. (2006; 2007), The US Department of Energy (DOE) uses the following definition: “*A biorefinery is an overall concept of a processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products. Its operation is similar to that of petrochemical refineries*”.

The US National Renewable Energy Laboratory (NREL) uses the following definition: “*A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today’s petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic biobased industry*”.

The International Energy Agency (IEA) describes the biorefinery as “*the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)*”. This means that biorefinery can be a concept, a facility, a process, a plant, or even a cluster of facilities.

A future definition of biorefinery could include processes that utilise living organisms to convert waste products from non-biogenic sources, including CO_2 from fossil fuel combustion.

Source : mostly from Schieb et al. (2015)

The IEA bio refinery classification system is useful in clarifying different models in operation and under development. The widespread adoption of the IEA system would help clarify several issues. The classification approach of the IEA consists of four main features which are able to identify, classify, and describe the different bio refinery systems: platforms, products (energy and bio-based materials and chemicals), feedstocks, and conversion processes.

The raw material or feedstock constitutes a highly varied range of organic materials (containing carbon).[2] Feedstocks can be grouped. Energy crops from agriculture (e.g. starch crops, short rotation forestry) constitute the major feedstocks at present. Biomass residues from agriculture, forestry, trade and industry (e.g. straw, bark, used cooking oils, waste streams from biomass processing) form another major category of feedstock, and it is to these bio refineries that future progress is hoped for. Even less conventional feedstocks include municipal solid waste (MSW) and waste industrial gases such as CO and H_2 from the steel-making process.

Concerning conversion processes, the IEA classification system identifies four main groups:

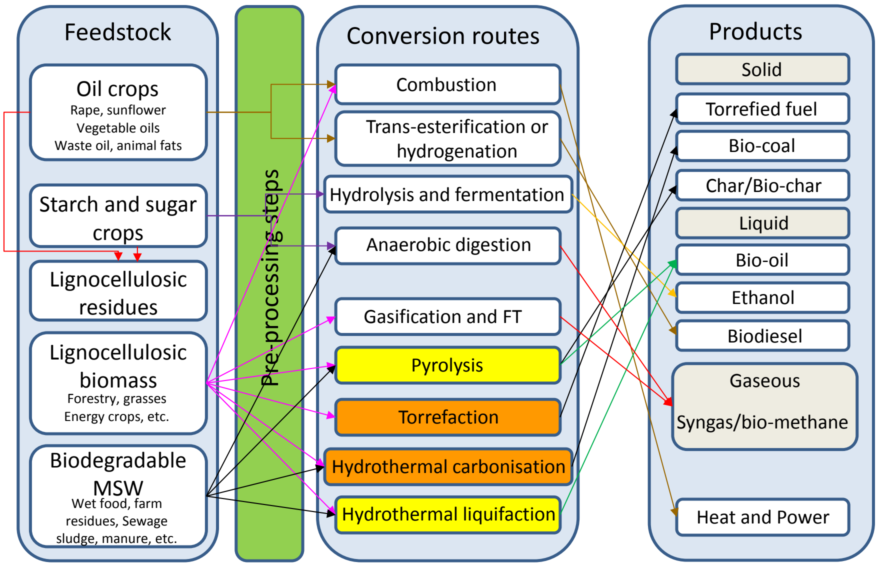
- Biochemical (e.g. fermentation, enzymatic conversion);
- Thermochemical (e.g. gasification, pyrolysis);
- Chemical (e.g. acid hydrolysis, steam explosion, esterification);
- Mechanical processes (e.g. fractionation, pressing, size reduction).

2 Organic chemistry can be defined as a chemistry sub-discipline involving the scientific study of the structure, properties, and reactions of organic compounds and organic materials, i.e., matter in its various forms that contain carbon atoms. However, bio refining most normally refers to ‘renewable’ carbon.

Energy products can be considered usually as liquid fuels (e.g. ethanol, biodiesel, bio-based jet fuel), but also biogas is possible. Wood chips, pellets, and lignin are possible solid fuel outputs. Material products could be any of a large number of bio-based chemicals, plastics and textiles. Energy products might also be residues at the end of the process that can be burned to generate electricity and/or heat. By-products could include animal feed and soil conditioners.

The diversity of bio refineries is already large, and Figure 2, showing different feedstocks and conversion processes, testifies to this diversity.

Figure 2. Conversion processes in a fuel bio refinery



Discrepancies regarding bio refinery numbers

The literature already contains major discrepancies regarding the numbers of bio refineries that have been established. This may result from a difference in definitions. Consider that in 2014-2015 approximately 180 bio refineries were identified in the US and 37 in Europe. A press release of September 2012 about a report produced by Pike Research mentioned a global number of 1 400 existing ‘conventional’ bio refineries as opposed to 1 800 new bio refineries which would be commissioned globally between 2012 and 2022 for a total of USD 170 billion. Of those 1 800, 925 or more would be advanced (second generation) bio refineries which are defined as being based on non-food feedstocks.

Therefore there is potential for misunderstanding, even though the IEA classification system should remove such. This could impact the funding of bio refinery projects by governments and also confuse data gathering exercises in these crucial early years of bio-based production from bio refineries. Why this matters can be illustrated by the future potential of bio refining: Schieb et al. (2015) forecast that, in order to make the industrial bio economy a success the number of bio refineries, both in the US and Europe, should be increased to 300-400. That represents a large investment, most of which will need to come from the private sector. And the private sector will therefore need assurances regarding future policy stability.

The IEA bio refinery complexity index (BCI)

All current models of bio refineries are high-risk investments. Even Brazilian ethanol mills have gone through difficult times, and at present there is a spate of bankruptcies in the industry,[3] a problem caused by the global financial crisis, adverse weather and low sugar prices. Bio refineries range from single feedstock-single product operations to multiple feedstock-multiple products. In other words the complexity of bio refineries varies greatly. Arguable, the greater the complexity the greater prospects for economic viability as one feedstock can be replaced by another, and the product stream can be changed, when conditions dictate so.

However, different degrees of complexity makes it difficult for industry, decision-makers, and investors to decide which of these concepts are the most promising options on the short, medium, and long term, and to judge on the technological and economic risks involved. In response, IEA Bioenergy Task 42 has published a *Biorefinery Complexity Index* (BCI) which can be used to calculate the complexity of some selected bio refinery concepts (Jungmeier, 2014). It bears strong resemblance to the Nelson Index used in petro-refineries. The Nelson Index[4] is an indicator for the investment intensity, the cost index of the refinery, the value addition potential of a refinery and the refinery's ability to process feedstocks into value-added products. The higher the complexity of the refinery the more flexible it is considered to be.

The essence of the BCI calculation is in the number of features in the bio refinery (used to calculate the '*feature complexity index'*, FCI) and the *technology readiness level* (TRL). The complexity increases by the number of features in a bio refinery. A high TRL of a feature has lower technical and economic risks, and so a lower complexity. Thus the complexity of a commercial application, in which all features are commercially available, is then only determined by the number of features; whereas in non-commercial application the TRLs increase additionally the complexity of the bio refinery system.

For each of the four features (platforms, feedstocks, products, and processes) of a bio refinery the TRL can be assessed using standard descriptions from 1 (lowest) to 9 (highest, with the system proven and ready for full commercial deployment).[5] Based on the TRL the *feature complexity* (FC) for each single feature of a bio refinery is calculated. With the number of features and the FC of each single feature the *Feature Complexity Index* (FCI) for each of the four features can be calculated. The BCI is the sum of the four FCIs. To simplify the presentation the *Biorefinery Complexity Profile* (BCP) is introduced. Details of how to make the appropriate calculations are given by Jungmeier (2014).

$$BCP = BCI \times (FCI_{Platforms}/FCI_{Feedstocks}/FCI_{Products}/FCI_{Processes})$$

The BCP and the BCI are considered to be capable of comparing different biorefinery concepts and their development potential. The higher the BCI the more beyond 'state of the art' is the biorefinery. Furthermore this system is flexible as it can take into consideration changes in TRL of features through research and development. It therefore can be used in addressing the economic and technical risks for any given biorefinery project or concept to aid decision making by public and private sector investors.

3 http://www.soybeansandcorn.com/news/Mar19_15-Number-of-Sugar-Ethanol-Mills-in-Brazil-Continues-to-Decline

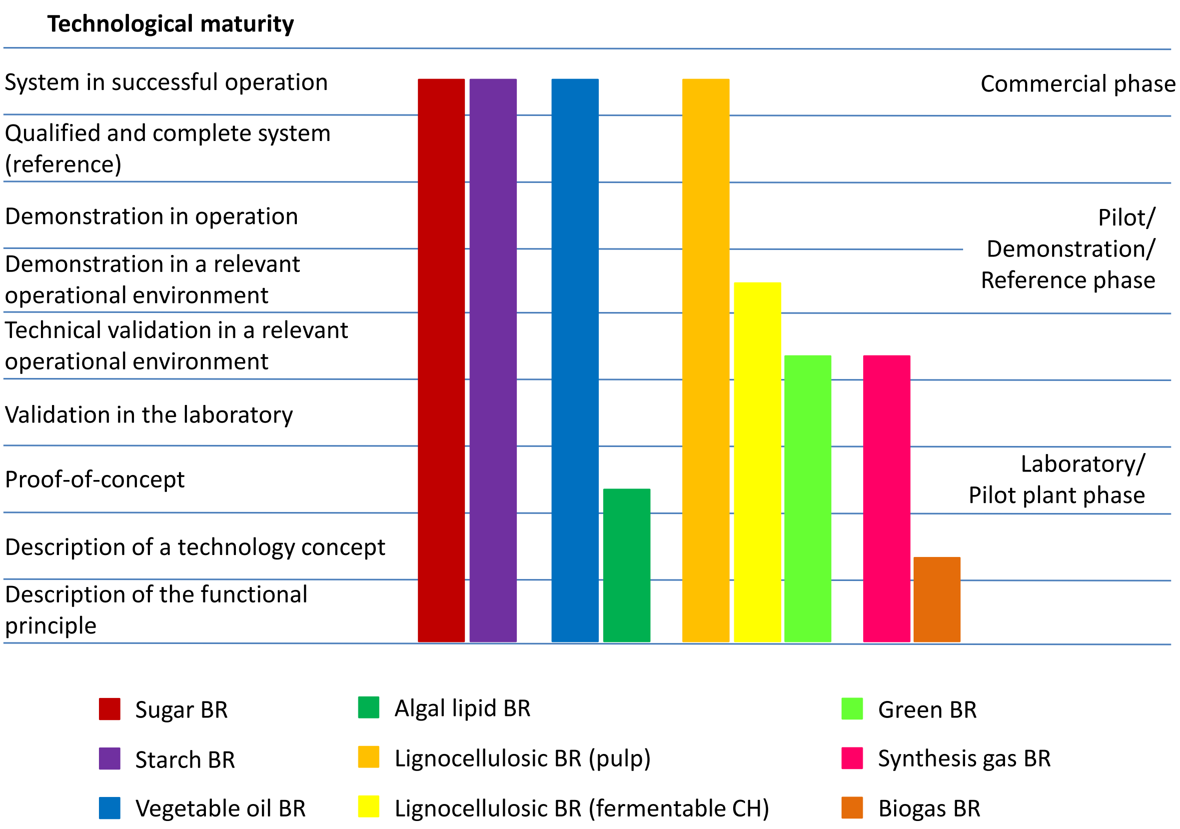
4 https://en.wikipedia.org/wiki/Nelson_complexity_index

5 Further information on TRLs is given in the section on Replacing the Oil Barrel.

Biorefinery types – a brief description

There are myriad different concepts arising for different bio refineries. However, these are concentrated into a small number of what can be seen as bio refinery 'types'. Many are described in the literature now. A good starting point is *The Biorefinery Roadmap* (2012) (Federal Government of Germany, 2012). Excellent unit process descriptions are found in the Star-COLIBRI (2011) *European Biorefinery Joint Strategic Research Roadmap*. The former is especially helpful (Figure 3) as it also estimated the current status of technological development at the time of publication. Things have moved on since 2012, but this status has not really changed significantly. What changes have occurred can also be described.

Figure 3. Development status of various bio refinery models

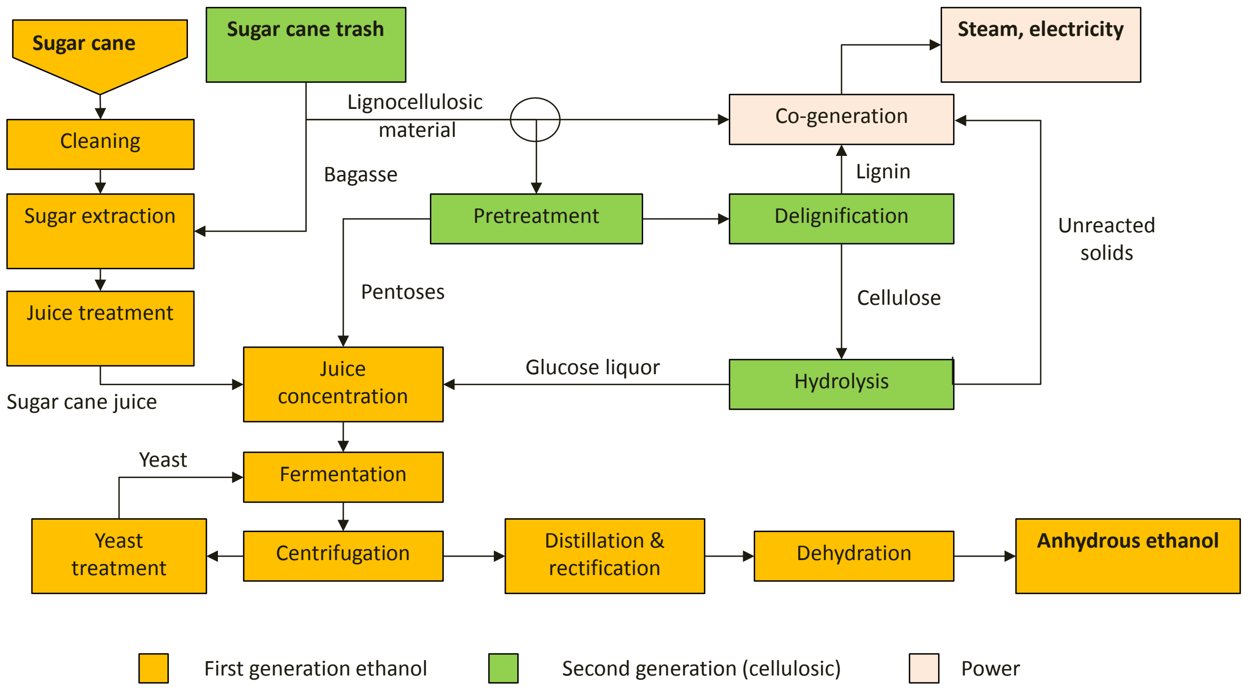


Source: Federal Government of Germany (2012)

The typical sugar cane bio refinery

In terms of economical sustainability, Brazilian sugar cane is the most favoured feedstock for bio refineries at present (e.g. UK Bioenergy Strategy, 2012). As of 2011, there were 490 sugar cane ethanol plants and biodiesel plants in Brazil (Brazil Biotech Map, 2011). This number has declined for various reasons, to somewhere around 300 operational sugar cane/ethanol plants as of mid-2016, with some of the closures permanent. The first generation bioethanol production process from sugar cane is shown on Figure 4. The typical Brazilian ethanol mill has a processing capacity of 500 tons of sugar cane per hour (wet basis), equivalent to 2 million tons per year. Most of the industrial processing of sugar cane in Brazil is done through a very integrated production chain, allowing sugar production, industrial ethanol processing, and electricity generation from by-products. The typical steps for large scale, highly optimised production of sugar and ethanol include milling, electricity generation, fermentation, distillation of ethanol, and dehydration.

Figure 4. Integrated first and second generation ethanol production from sugar cane



Source: Dias et al. (2013)

In the Brazilian sugar cane industry, large amounts of lignocellulosic materials, especially bagasse, are readily available, typically produced as by-products of sugar and ethanol production. Most of the bagasse produced in the mills, where sugar cane juice is separated from the fibre, is used as fuel in cogeneration systems to supply the energy demand of the bioethanol production process. The use of sugar cane lignocellulosic fractions as fuels in electricity production for sale to the grid is commercially and technically feasible in Brazil (Cardona et al., 2010). If electricity prices are favourable, more lignocellulosic material may be diverted for production of steam and electricity (see the circle on Figure 4), and vice versa when ethanol prices are more attractive (Dias et al., 2013).

Lignocellulosic or cellulosic bio refinery

Lignocellulose is composed of carbohydrate polymers (cellulose, hemicellulose), and an aromatic polymer (lignin). It is the most abundant raw material for bio refining as it contains large amounts of fermentable sugars. However, a barrier to the use of lignocellulose from biomass in bio refining is that the sugars necessary for fermentation are tightly bonded within the lignocellulose. In fact, lignocellulose has evolved to resist degradation and to confer structural stability and robustness to the cell walls of plants. Much of the technical effort to unleash this vast bounty for bio refining is related to overcoming this recalcitrance of the feedstock i.e. it is the ‘conversion’ that has been the bottle-neck.

Lignocellulosic biomass can be grouped into four main categories (Tan et al., 2011):

1. agricultural residues (e.g. corn stover and sugar cane bagasse);

2. dedicated energy crops;

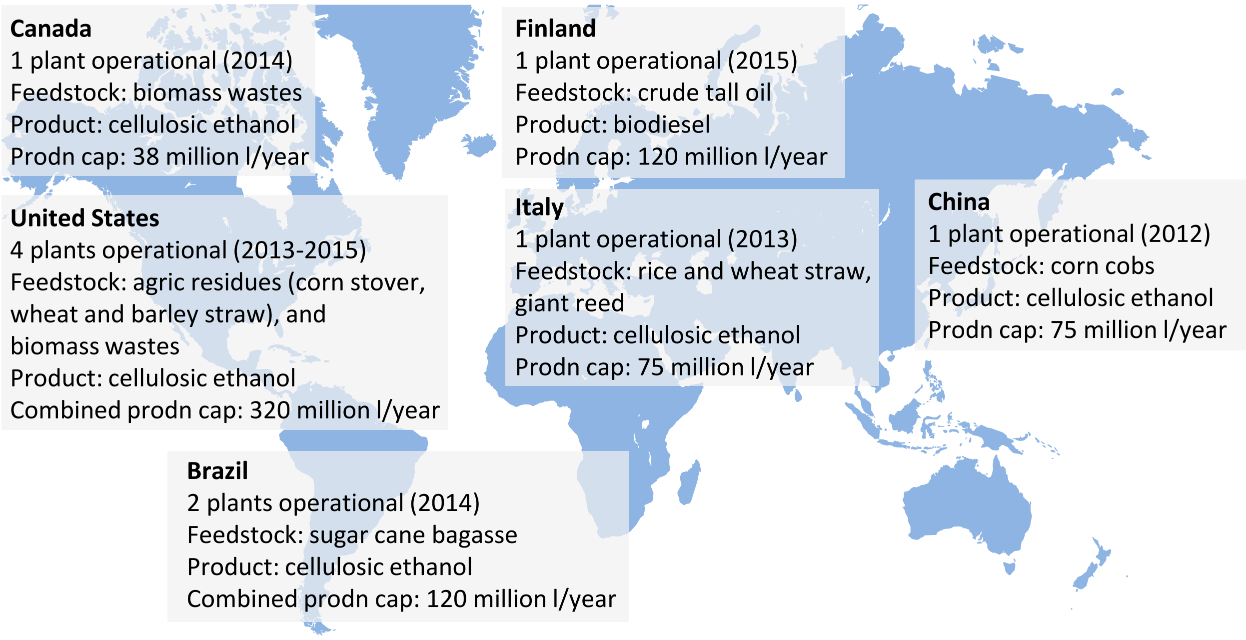
3. wood residues (including sawmill and paper mill discards), and;

4. municipal paper waste.

Second generation biofuels plants may have capital costs of the order of five times greater than starch ethanol plants (Wright and Brown, 2007). For first generation bioethanol, the most significant cost was feedstock (Carryquiry et al., 2011). About 40–60% of the total operating cost of a typical bio refinery is related to the feedstocks chosen (Parajuli et al., 2015). However, the most significant cost element for second generation cellulosic biofuels may be conversion cost i.e. the cost of conversion of woody biomass into fermentable sugars.

A crisis of sorts has arrived in cellulosic bio refining. In the US Renewable Fuels Standard, the EPA is enforcing 230 million gallons of cellulosic biofuel blending for 2016, whereas the RFS statute nominally requires 4.25 billion gallons. This represents a 95% reduction. The reason is simply that the technical problems surrounding conversion have proven so intractable that only a handful of these bio refineries have reached commercialisation (Figure 5).

Figure 5. Figure 6. Global capacity in cellulosic bio refining



As a result of these technical barriers and policy uncertainty, investments in these bio refineries have been drastically reduced. In fact, a new one has been approved for construction in July 2016 in Renfrew, Ontario, Canada. As such, this may be the only commercial-scale cellulosic biofuel project that has gained approval anywhere in the world over the past two years. The financing is overwhelmingly coming from the public sector. It will convert forestry waste into Ensyn biocrude for further processing in oil refineries.[6]

6 Ensyn was granted key regulatory approvals by the California Air Resources Board pursuant to the low carbon fuel standard (LCFS) on the company's application for its biocrude renewable fuel oil (RFO) to be used in co-processing by California oil refineries (*Biodiesel Magazine*, February 09, 2016).

Waste bio refineries: rubbish to bio-based products and electricity

Although these can be categorised as lignocellulosic bio refineries, domestic waste bio refineries are treated separately here to highlight their future potential. The use of domestic waste materials as a feedstock for bio refineries holds out the promise of being the most sustainable type. The reality will be determined by the efficiency of collection of waste materials. There is no doubt that there is a large amount of waste that can be used as feedstock, but there has to be the political will to incentivise its collection.

Utilising municipal waste not only reduces the amount of waste going to landfills, it also breaks the link between food crops and bioethanol production. An example of a waste bio refinery is the Vero Beach, Florida facility.[7] At full production, this waste bio refinery is expected to produce 8 million gallons of advanced cellulosic bioethanol and six megawatts (gross) of renewable power using renewable biomass including yard, vegetative, and agricultural wastes. The waste material goes through a gasification process to create synthesis gas, or syngas. (Syngas can then be used to manufacture a range of chemicals, either through synthetic chemistry or fermentation (Latif et al., 2014)). The heat recovered from the hot syngas is fed into a steam turbine and is used to generate renewable electricity. The renewable electricity powers the facility and the excess electricity is expected to power as many as 1 400 homes in the Vero Beach community. A relatively small facility, it has 60 full-time employees and provides USD 4 million annually in payroll to the local community.

This is also a good example of a public-private partnership (PPP). These are deemed to be a way to get high-risk bio refineries built in the absence of substantial interest from venture capital investors. Ineos Bio and New Planet Energy, Florida, in a PPP with the US DoE (USD 50 million cost-matched grant) and USDA (USD 75 million loan guarantee), have constructed this waste bio refinery. Perhaps the best example at present is the Enerkem plant in Edmonton, Canada.

Algal bio refineries

Both micro- and macro-algae are extremely promising feedstocks for future bio refineries for a variety of reasons (IEA Bioenergy Task 39, 2011):

- The land requirement for algae is much less than for terrestrial crops, thus alleviating pressure on food crops;
- They grow rapidly and have a higher solar conversion efficiency than most terrestrial plants;
- They can be harvested batch-wise or continuously almost all year round;
- They can use waste CO_2 sources, thereby potentially mitigating the release of GHG into the atmosphere, and;
- There is potentially a vast amount of oil available compared to terrestrial crops (Table 1); the differences are of magnitude orders.

[7] http://www.ineos.com/businesses/INEOS-Bio/News/~/INEOS-Bio-Facility-in-Florida-Begins-Producing-Renewable-Power/

Table 1. Oil yields from various terrestrial plants compared to algae

Crop	Oil yield (gallons /acre)
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed	127
Jatropha	202
Oil palm	635
Algae	10 000

Source: Pienkos (2009)

However, of all the road transport biofuels technologies reviewed by Accenture (2009), algal technology was deemed to be the most difficult and will take the longest to achieve commercial scale. Nonetheless some companies claim that the first commercial plants will be available soon. Efforts are taking place in various parts of the world, including Australia, Europe, the Middle East, and New Zealand and the US (Pienkos and Darzins, 2009). That prediction of 2009 remains accurate, as marine bio refining still presents large technical challenges. The design and engineering principles for marine bio refining are in their infancy compared to bio refineries for terrestrial crops. The development of stable cultivation technologies - harvesting, product extraction, and bio refinery processes - represent the main challenges of algal biotechnology for production of high-value or bulk products. Genetic engineering for strain improvement and higher product yields, and the need to gain market and regulatory acceptance of such organisms are other major challenges (Sayre et al., 2013).

The seaweed (macroalgae) industry is small but mature, and has plenty of scope for expansion. Nearly 7.5-8 million tonnes of wet seaweeds are harvested worldwide per year (Subba Rao and Mantri, 2006), but the treatment of spent seaweed is a challenging task. Apart from the oil, macroalgae contain various higher value chemicals, such as plant proteins, alginates, and phenolics. Moreover, fermentation of seaweed hydrolysates can produce many by-products, such as glycerol, organic acids (e.g., acetate, succinate), biomass protein, and other minor products (Wei et al., 2013). And because seaweed biomass does not contain lignin, residuals after fermentation can be used as animal feel or a feed supplement. Therefore there is great scope for cascading use of biomass with algae and cyanobacteria (Ducat et al., 2011). For example, a study has examined the production of ethanol from spent biomass generated from the seaweed processing industry using baker's yeast, and the potential for converting galactose and alginate monomers to bioethanol through fermentation (Sudhakar et al., 2016).

Certain caveats must in be invoked when discussing the potential of algal technologies, especially microalgal technologies. There are several comprehensive analyses that study the design and economics of microalgal processes, but they leave the actual species unspecified. By doing so, the assumptions used in those analyses may be inaccurate. With this in mind, the need for rapid, accurate and defendable taxonomic identification of microalgae and cyanobacteria strains is paramount for culture collections, industry and academia, particularly when addressing issues of intellectual property and biosecurity (Emami et al., 2015).

Similarly, there are locations with sufficient year-round levels of sunlight, that are close to plenty of water, in the vicinity of carbon-intensive industries that can supply inexpensive CO_2, and with developed road and rail networks that can support distribution of the raw materials and end products. But these locations are by no means commonplace (Klein-Marcuschamer et al., 2013).

Biofuels can be produced from algae via a variety of routes, and there is considerable industrial interest:[8]

- Conversion to bioethanol (e.g. Alegenol);
- Extraction of oils (e.g. SGI, Solix Biofuels, Sapphire Energy, Algasol);
- Production of oils from feedstock via dark fermentation (e.g. Solazyme);
- Oil plus ethanol (e.g.Green Star);
- Conversion of whole algae to biocrude via pyrolysis (e.g. BioFuel Systems SL);
- "Green crude" (e.g. Sapphire Energy, Muradel);
- Algal bio refinery - biofuels and other products (Petro Algae, HR Bio petroleum).

At the National Marine Bioenergy Research Centre[9] in collaboration with the department of Biological Engineering of the Inha University at Incheon, Korea, an experimental algae production system is being tested. Algae are produced in semipermeable membranes in the sea. In this system no energy for the culturing needs to be added as the sea movement is keeping the culture moving. As seawater contains more nutrients than fresh water, also no extra nutrients need to be added, they are taken up through the semi-permeable membrane.

In the experimental set up the amount of bioethanol produced from red or brown algae was up to three times higher than from sugar beet or sugar cane, the best performing land energy crops. For the production of biodiesel from microalgae the yield was even up to ten times higher than from oil palm, which is the best performing biodiesel production crop on land. This production system has in fact passed all government criteria and the oil produced has a better quality than palm biodiesel.

Waste gas and syngas bio refineries

Gas fermentation offers an opportunity to utilise resources as diverse as industrial waste gases, coal, and municipal solid waste (after gasification) for the production of fuels and chemicals. A 1995 demonstration at the laboratory scale showed the feasibility of converting gases to bioplastics (Tanaka et al., 1995). Hydrogen, oxygen, and CO_2 were converted to a bio-based, biodegradable plastic in the absence of another source of carbon. Other bio-based products have been shown to be feasible at laboratory scale. For example, the steel mill off-gas CO and syngas can be fermented to a variety of useful products, such as ethanol and 2,3-butanediol (Köpke et al., 2011).

However, taking gas fermentation technology to commercialisation has taken a long time. LanzaTech, a waste gas-to-fuel and -chemicals start-up founded in New Zealand, converted steel mill waste gases to ethanol at demonstrator level in 2013, producing roughly 380 m^3 of ethanol per year at a steel mill near Shanghai, China (Pavanan et al., 2013). In 2014, the company closed a USD 60 million investment from the New Zealand Superannuation Fund, a sovereign wealth fund, to develop the technology further.

A system to be built at an ArcelorMittal steel mill in Ghent, Belgium would be about 30 times larger than the Shanghai plant, producing some 47 000 tons of ethanol a year (*Financial Times*, 2015b). It will

8 http://www.biofuelstp.eu/algae-aquatic-biomass.html

9 http://www.mbe.re.kr/

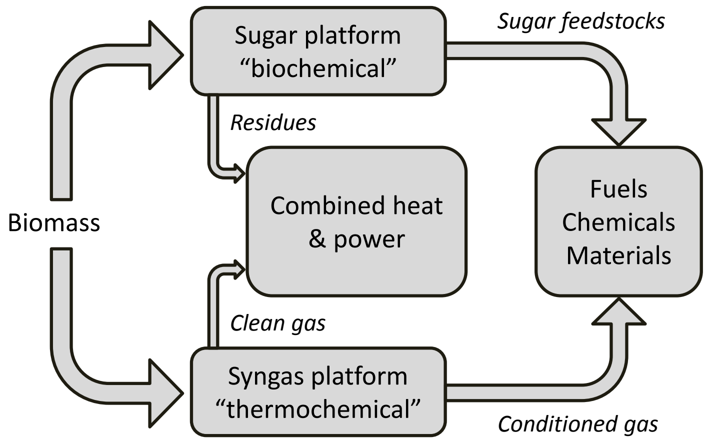
cost EUR 87 million to install, and the project has received EUR 10 million in EU research funding. If the system at Ghent proves to be commercially viable, ArcelorMittal, the world's largest steel maker, hopes to install it across its operations, a move that could eventually lead to the production of up to 10% of Europe's bioethanol a year.

The steel industry has long struggled to deal with its emissions (OECD, 2015b). The top three industrial GHG emitters are steel, cement and chemicals. This bio refining technology would not only help reduce emissions from steel making, but would also add value to the core business of steel making. It also does not compete for land or interfere with food as no crops are required.

The integrated chemical and biological bio refinery concept

Put succinctly, the integrated bio refinery (Figure 6) would make full use of all the components of multiple feedstocks (particularly cellulosic) to produce value-added multiple co-products including energy (electricity and steam) and various bio-based chemicals and plastics, along with fuel-grade ethanol or other fuels, and perhaps even other products such as paper.

Figure 7. Schematic of a generalised integrated bio refinery

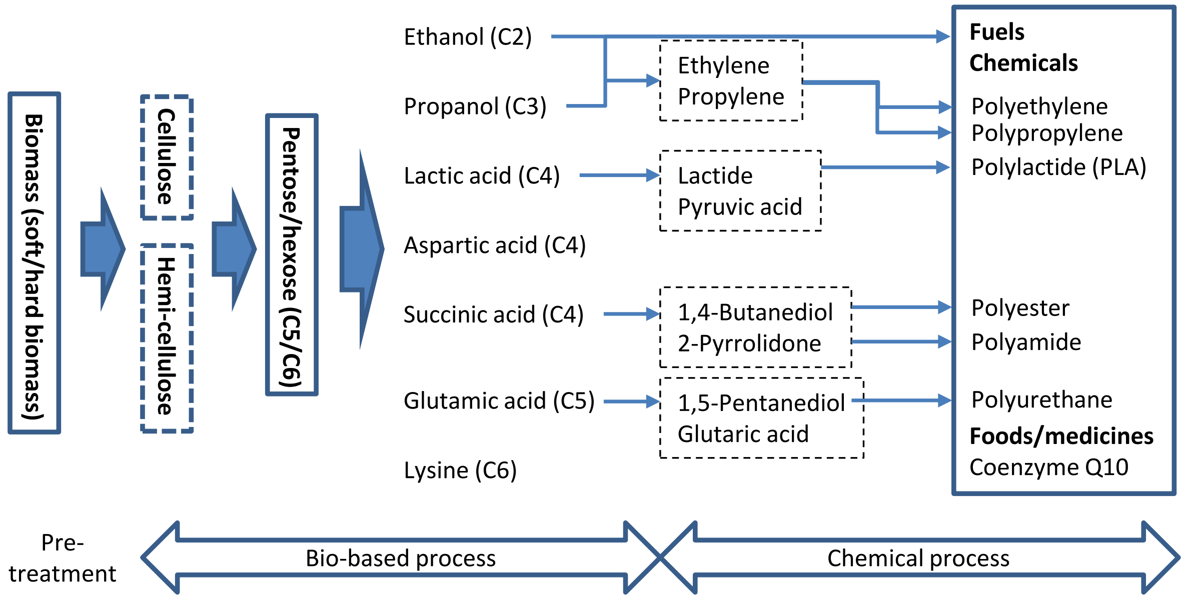


Source: www.nrel.gov/biomass/biorefinery.html

In this concept chemicals and fuel production are integrated within a single operation. In such an operation, high value products become an economic driver providing higher margins to support low value fuel, leading to a profitable bio refinery operation that also exhibits an energy impact. This is how many petrochemical oil refineries are operated - the 7 to 8% of crude oil dedicated to chemical production results in 25 to 35% of the annual profits of integrated petrochemical refineries (Bozell, 2008).

Many configurations are possible depending on the choice of chemicals to be manufactured on-site. Figure 7 shows just one possible configuration for an integrated bio refinery manufacturing multiple chemicals. It illustrates that a combination of biotechnology and chemistry is an essential feature.

Figure 8. An integrated bio refinery for fuel and chemicals production



Such a bio refinery is obviously technically very complex, even more so than a petrochemical facility. But there are some advantages that should be considered compared to single feedstock, single product bio refineries that make this model particularly attractive:

- The ability to switch between feedstocks and products when, for example, one particular feedstock is too expensive;
- Switching between feedstocks helps cope with seasonal availability (Giuliano et al., 2016);
- Integration avoids the low-margins trap of producing high volume fuels (OECD, 2014a), and there is less fractional market displacement required for cost-effective production of high-value co-products as a result of the economies of scale provided by the primary product (Lynd et al., 2005);
- The economies of scale provided by a full-size bio refinery lower the processing costs of low-volume, high-value co-products;
- Bio refineries maximise value generated from heterogeneous feedstock, making use of component fractions;
- Common process elements are involved, lowering the need for equipment duplication, with subsequent decreases in capital cost;
- Co-production can provide process integration benefits (e.g. meeting process energy requirements with electricity and steam co-generated from process residues)
- The ability to operation like a ‘waste exchange’.

A lesson can be observed from US biodiesel production from soybean oil. Between 2005 and 2008 the price of soybeans doubled. Many biodiesel production plants halted production,[10] and construction of new plants was delayed. Such eventualities may be avoidable if low production volume, higher value-added products can also be made at the same site. The integrated bio refinery also gives the flexibility to use different feedstocks if one feedstock is unavailable.

The benefits notwithstanding, there are several defining challenges that are proving difficult to overcome (Cheali et al., 2015):

- Challenges to achieve the maximum efficiency with improved designs as well as expansion by integration of conversion platforms or upstream and downstream processes;
- Challenges to account for a wide range of feedstock, processing paths and product portfolios (Tsakalova et al., 2015) and formulate local/regional solutions instead of solutions on a global basis as is the case for fossil-fuel based processes (i.e. local supply and value chains);
- Challenges relating to design (i.e. feedstock characteristics, feedstock quality and availability; trade-offs between energy consumption for feedstock and product distribution, production and product market prices).

Real examples of truly integrated bio refineries are not yet available, not as a result of low oil and gas prices, but rather for the technical challenges in perfecting processes with waste materials as feedstocks. A candidate that has many characteristics is the ARB-BRI complex in Northern France, although the feedstocks are food crops (Box 2).

[10] http://www.public.iastate.edu/~nscentral/mr/08/0516/highsoy.html

Box 2. The Agro-Industrie Recherches et Développements (ARD) Biorefinery hub and Bioraffinerie Recherches et Innovation (BRI) at Bazancourt-Pomacle, Northern France

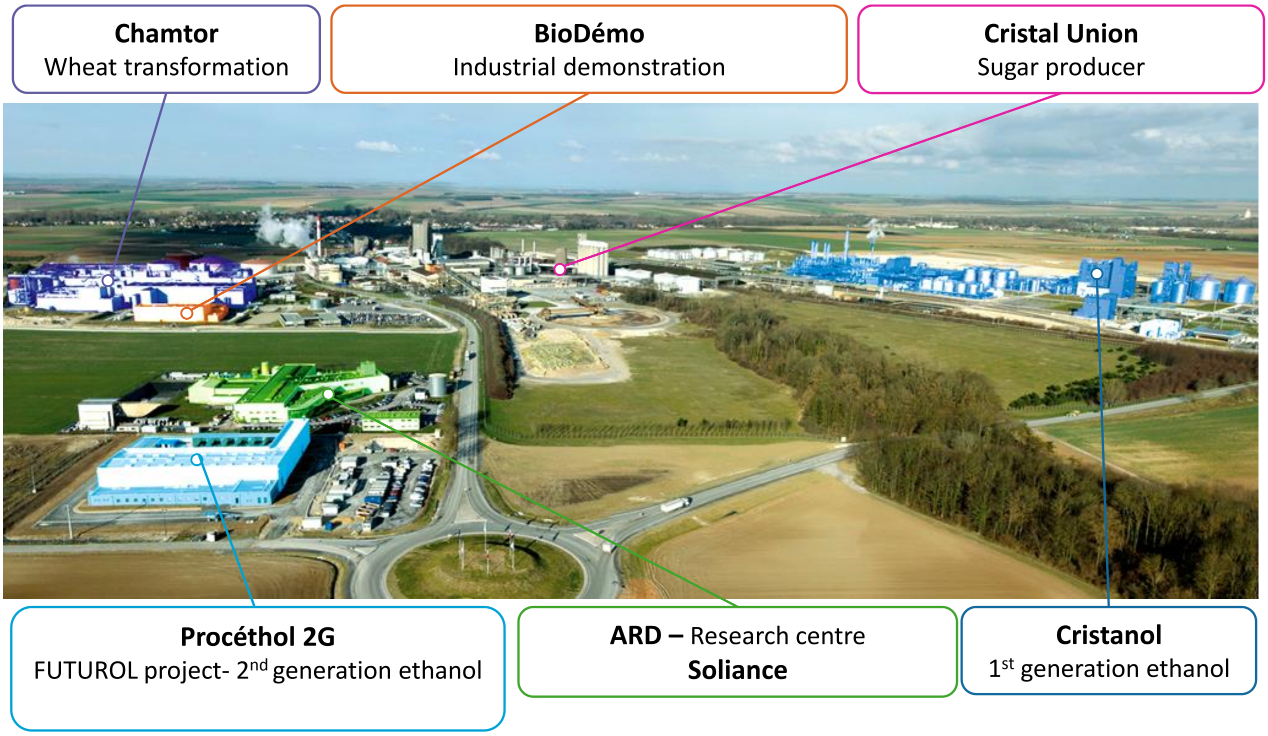
ARD is a mutualised private research structure, owned by major players in the French agri- business as well as regional farming cooperatives, the latter being a particular strength of this facility. It was created in 1989 by exploiting the notion of value creation through non-food applications to find new opportunities from the produce of its shareholders (e.g. cereals, sugar beet, alfalfa, oilseeds). Subsequently ARD started two subsidiaries – Soliance (molecules for cosmetic products), and the largest capacity demonstration platform in France, BIODEMO, which has hosted Amyris, BioAmber and Global Bioenergies.[11]

The innovation hub Bioraffinerie Recherches et Innovation (BRI) is an open hub in the field of bio refining. BRI brings together various bio refineries at Bazancourt-Pomacle, the R&D centre ARD, as well as the French engineering schools Ecole Centrale Paris, Agro Paris Tech and NEOMA Business School. Therefore it covers the value chain from fundamental research to the pre-industrial prototype.

It has had public financial support from the Ministry of Industry of France, the General Council of the Marne Département, the Region Champagne-Ardenne and the city of Reims. The combination of farming cooperatives, private industry and backing through regional and national public policy and funding is perhaps the optimal model that can be reproduced in many locations.

Further added value has been created through an industrial ecology network. It has become clear that the end-of-pipe philosophy is insufficient in pollution prevention. Equally, cleaner production has its limits. The industrial ecology approach considers, in the absence of a viable cleaner production alternative, using waste as a marketable by-product. Using waste from one process as an input to another process at the same site removes transportation and waste disposal or treatment costs.

Figure 9. Business units at Bazancourt-Pomacle



Source: Schieb and Philp (2014)

11 http://www.global-bioenergies.com/succes-du-premier-test-disobutene-dans-son-pilote-industriel-de-pomacle-bazancourt/

Wood bio refineries

Again, there is much cross-over between cellulosic and integrated bio refineries. Some of the issues are identical, especially the conversion technologies. Wood bio refining makes sense in many countries that have a long history of pulp and paper-making. The relatively high energy density of wood is attractive for transportation purposes. An advantage enjoyed by pulp and paper mills in bio refining stems from the perfected kraft processing of wood. The kraft process converts wood into wood pulp, which consists of almost pure cellulose fibres, the main component of paper. The kraft process entails treatment of wood chips with a hot mixture of water, sodium hydroxide, and sodium sulphide, known as white liquor, that breaks the bonds that link lignin, hemicellulose, and cellulose.

One difference from the cellulosic bio refineries is that wood contains much more lignin than, say, agricultural residues. Lignin is also recalcitrant to bio refining but is a major potential source of all manner of aromatic compounds. Aromatics are extremely important industrial chemicals and bio-based drop-ins or alternatives are not easy to produce. The interest in lignin as a source of chemicals or materials is increasing and processes for lignin isolation from kraft processes are being installed.

The potential of lignin is not just in drop-in alternative chemicals. Lignin is a polymer that can be derivatised for various applications, for example, lignin epoxide for printed circuit board, segmented polyurethane plastics and others. The new wood bio refinery processes will produce sulphur-free lignin, which offers several advantages in chemical and material production. Although these sulphur-free lignin from new wood bio refinery processes have advantages, lignin sulphonates and lignin sulphates from “old” pulping processes exhibit performance properties because of the sulphonate and sulphate groups.

Lignin applications are becoming increasingly visible: the amounts of lignin produced annually are huge, and the variety of valuable compounds that could be produced from the aromatic lignin could answer the doubts over the ability of bio-production to produce aromatics.

Several other future options include: extraction of cellulose fibre and valuable products from bark (e.g. fine chemicals and pharmaceuticals), wood extractives (fatty acids used in products like water-based resins), pulping liquor (carbohydrates used as hydrocolloids, emulsifiers and food ingredients). There are several comprehensive sources of information on the chemistry of wood (e.g. Sjostrom, 1993).

Two major lines of development for innovative wood bio refinery processes have been suggested that concur with the above analysis (Bioökonomierat, 2016):

- The digestion of wood with subsequent enzymatic hydrolysis to obtain fermentation feedstocks and lignin;
- Thermochemical processes which provide fuel or basic chemicals as a result of pyrolysis or gasification.

The most advanced wood bio refineries are to be found in Scandinavian countries. Borregaard (Norway) boasts the most advanced bio refinery in the world. One of the most valuable products currently made from wood is vanillin, and a Borregaard bio refinery has been making it for over 50 years,[12] with an annual production of 1 500 tonnes from spruce wood.

In 2009, Chempolis, a Finland-based bio refining technology corporation, commissioned a bio refinery in Finland, which also functions as a technology centre for testing customer raw materials for

12 http://www.borregaard.com/News/The-flavor-that-carries-Vanillin-for-50-years

bioethanol, biochemicals, and papermaking fibres. It was billed as the world's first demonstrator 'third generation' wood-to-ethanol bio refinery.

The Komi Republic in Northern Russia could host a plant that would produce 100 000 tonnes of bioethanol per year from wood waste (*Il Bioeconomista*, 2016). The total investment required is estimated at EUR 136 million. A process to create a pool of investors is underway, with different options for the realisation of the project being considered, including a public private partnership. Under the plans, the facility would process up to 400 000 tonnes per year of feedstock such as unusable timber and sawmill residues. The Komi Republic has rich forest resources. The local authorities have proposed a site of 15.6 acres for the construction of the plant.

Wastewater bio refineries

Probably the most widespread application of biotechnology worldwide is biological wastewater treatment technology. The core technologies have an unparalleled role in pollution prevention. Yet, in developing countries 90% of sewage and 70% of industrial wastes are discharged without treatment into surface water. It has been acknowledged that wastewater management would play a central role in achieving future water security in a world where water stress will increase (UN-Water, 2015).

There is over a century of experience in biological wastewater treatment, and advances beyond basic biochemical oxygen demand (BOD) and chemical oxygen demand (COD) removal are available. It is also scalable in terms of size and intensity. Small, modular systems requiring minimal civil engineering and maintenance are available for small, remote communities, and highly intensive plants can cater for city-sized populations. Therefore it would appear that large problems could be solved simply with greater implementation of current biological wastewater treatment technologies (El-Chichakli et al., 2016).

However, two points are worth bearing in mind.

1. Converting biodegradable materials in wastewater into non-toxic biomass, water and CO_2 has no added value.

2. Current treatment of municipal wastewater accounts for approximately 3% of global electricity consumption and 5% of non-CO_2 greenhouse gas emissions, principally methane from anaerobic digestion (Li et al., 2015). In many cases, large wastewater treatment plants are the largest energy-consuming facilities in a city.

Future wastewater bio refinery models could well be derived from current R&D showing promise. Considering the energy content embedded in wastewater is 2–4 times the energy used for treatment, future utilities could become energy-positive if energy recovery technologies were developed (McCarty et al., 2011). Moreover, these facilities could also recover other value-added resources such as nutrients, metals, chemicals, and clean water and therefore could become closed loop waste bio refineries of very high productivity and efficiency (Lu and Ren, 2016), and potentially carbon-negative. While global stocks of phosphate for fertilizers are being depleted, nutrients such as the phosphates and nitrogenous pollutants in wastewater contribute to disastrous instances of eutrophication.

Plastics from wastewater

Research is demonstrating how the organic carbon present in domestic wastewater can be converted by mixed microbial cultures into poly-hydroxyalkanoate (PHA) bio-based plastics, which are biodegradable and have a range of functions that can replace traditional fossil-based plastics. A pilot-scale bio refinery process was operated over 22 months at the Brussels North Wastewater Treatment Plant (WWTP) in order to evaluate PHA production integration with services of municipal wastewater and sludge management (Morgan-Sagastume et al., 2015). Full-scale demonstration of the complete value chain alongside continuous polymer production remains to be validated (Paillard, 2016). Currently this technology is at TRL 6.

Microbial electrolysis cells: electricity from wastewater

Microbial electrolysis cells (MECs) can theoretically convert any biodegradable waste into H_2, biofuels, and other value-added products. Since their invention in 2005 (Kadier et al., 2016), research has increased the H_2 production rate and yield by orders of magnitudes. However, there are still many challenges remaining, and they need to be overcome in order for MECs to be applied in large scale systems (Randolph and Studer, 2013).

It is theoretically possible to integrate MEC technology into lignocellulosic bio refining. These bio refineries produce large amounts of wastewater that contains biodegradable organics, which can be used in MECs for additional energy production (Zeng et al., 2015).

Hungarian researchers (Szollosi et al., 2016) have developed a microbial fuel cell (MFC) technology to produce a low-alcohol beer at the same time as generating small amounts of electricity. Perhaps one day it will be possible to brew beer from wastewater in an energy-positive and carbon-negative process?

In Canada, Metro Vancouver (23 local authorities in British Columbia) is working with Genifuel to build a demonstration plant that will use a technology that can convert raw sewage into bio crude oil. The technology is being licensed from the Department of Energy's Pacific Northwest National Laboratory[13].

Biogas bio refining

Anaerobic digestion of sewage sludge to produce biogas, a mixture of hydrogen, methane and carbon dioxide, has been used for over a century in the biological treatment of wastewater. Typically, it stabilises sewage sludge by removing pathogens. However, methane is typically used to generate electricity and this can often be enough to power an entire wastewater treatment plant, adding to the environmental and economic sustainability of such such plants.

Anaerobic digestion is highly scaleable and has been perfected down to individual farm level, where a variety of waste materials can be converted to biogas e.g. sludge, grass, solid manure, chicken manure and straw. Moreover, the effluents after anaerobic digestion are better balanced to meet crop needs than raw manure slurries, thereby reducing the need for supplementary chemical N and P fertilizers (Massé et al., 2011) while reducing GHG emissions (Siegmeier et al., 2015).

Now, biogas production is being seen as part of the bio refinery concept (Kaparaju et al., 2009). Multiple biofuels production from, say, wheat straw (bioethanol, bio hydrogen and biogas) can increase the efficiency of biomass utilisation enshrined within the cascading use of biomass concept. The volatile fatty acids (VFAs) produced from anaerobic microbial activity, often considered a nuisance or environmentally damaging, have the potential as the precursors for the biotechnological production of polyhydroxyalkanoates (PHAs) as bio-based plastics (Martinez et al., 2016).

The BioGas to Bio Refinery[14] research project is funded by the Centre for Advanced Sustainable Energy (CASE) in Northern Ireland and it aims to produce an evidence-based roadmap for the

13 https://singularityhub.com/2016/12/18/canadas-building-a-plant-that-will-make-fuel-out-of-poop/?utm_source=Singularity+Hub+Newsletter&utm_campaign=9d1ed5d7be-Hub_Daily_Newsletter&utm_medium=email&utm_term=0_f0cf60cdae-9d1ed5d7be-58153281

development of a bio economy there. The research involves a review of the potential of feedstocks for biogas production in Northern Ireland and the demonstration of the environmental and economic benefits of advanced utilisation options for biogas from wastes. The project began in 2016 and is scheduled for completion in June 2017.

Food waste bio refining

It is well known that huge volumes of food are wasted, either pre- or post-production. Roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (UN FAO, 2011).What is usually not appreciated is that the energy used in producing the food is also then wasted, and the GHG emissions associated with the production are in vain. Food that is produced but not eaten is responsible for adding 3.3 billion tons of greenhouse gases to the planet's atmosphere making up food wastage as the third top emitter after the total emissions of the United States and China (UN FAO, 2013).

TerraServ, a South African start-up formed in 2014, is developing a process to biologically convert food wastes into products such as hand sanitizers, whiteboard cleaners and glass cleaners under the brand name *EcoEth.*[15] The feedstocks are generally off-specification foods from manufacturers, goods damaged in transit or past their sell-by date. In the current phase of development (mid-2016) the company processes around 200 kg of food waste per month. Within the next year it intends to increase this to 1-12 tonnes per month. The process is based on fermentation to ethanol. Ultimately the aim is to recycle wastewater and employ biological wastewater treatment, and to use as much solar heating as possible to minimise the carbon footprint (Coetzee, 2016).

Enterra[16] of British Columbia, Canada, takes food waste from farmers, grocery stores and food producers in Metro Vancouver and the Fraser Valley, and feeds it to voracious black soldier fly larvae. In turn, the larvae can be processed into fertilizer and animal feed ingredients. For example, this has recently been approved in Canada to be used in chicken feed.

14 https://qubbiorefinery.wordpress.com/

15 http://www.ecoeth.co.za/Our-Products/EcoEth/

16 http://www.enterrafeed.com/

FINANCING BIOREFINERIES

"*Without a doubt, the biggest challenge for public authorities is to move beyond the presumption that providing grants and subsidies is the most effective financial instrument in any circumstance for supporting enterprise and other economic activity in the local area*".
Evers et al. (2001)

Introduction

This paper is concentrating on the 'commercialisation' and 'scalable production', phases i.e. demonstration and full-scale production. Not only are first-of-kind projects high risk, the closer a project is to 'scalable production', the fewer the financing options.

In 2016 certain categories of bio refineries are still high-risk investments. There are at least hundreds, perhaps upwards of 1 000 first generation bioethanol mills worldwide. In Brazil these function according to the market, but in competition with gasoline: hence the light vehicle fleet is overwhelmingly flex fuel, so that the consumer can choose between ethanol and gasoline according to the local spot price.

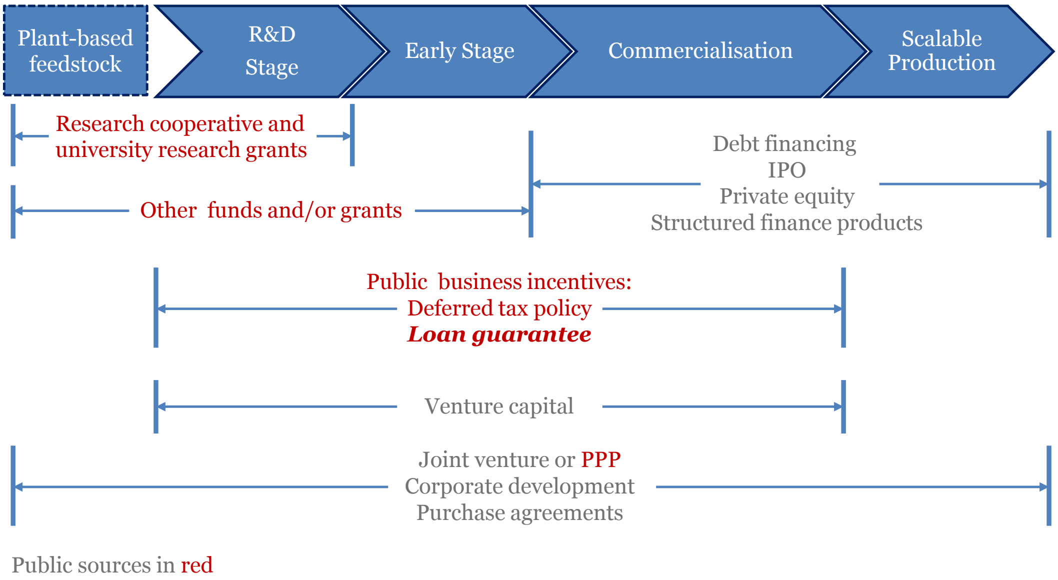
The greatest financial risk, however, is with the bio refineries that most policy makers favour – the second generation, cellulosic bio refineries (primarily, at this stage in history, mostly for the production of second generation ethanol) (Peplow, 2014). Policy makers favour these bio refineries because they are seen to be facilities that can tackle some of the toughest of the so-called grand challenges: climate change, energy security and resource depletion. However, an additional policy goal is tackled by cellulosic bio refineries in that the feedstocks are intended to be residues and waste materials rather food or feed crops, thus avoiding creating a competition for land between food and industrial needs. Late in April 2015, the European Parliament passed a draft law to cap crop-derived biofuel production and accelerate the shift to alternative sources (*Il Bioeconomista*, 2015).

In the US, the public agencies most directly involved in bio refining are the US Department of Agriculture (USDA) and the US Department of Energy (USDOE). Both agencies help finance bio refineries by the same instrument – the loan guarantee. In Europe, the situation is radically different, and a little more background is required to explain this situation.

It has long been observed in Europe that a gap in the innovation cycle has existed. Europe is seen to have top class research establishments, infrastructure and capability. It has also been seen to be much less able at commercialising the results of promising research. The Bayh-Dole Act of 1980 set public research establishments in the US on a clear path to commercialisation of R&D (McManis and Noh, 2006) by permitting a university, small business, or non-profit institution to elect to pursue ownership of an invention in preference to the government.

Funding mechanisms for industrial biotechnology and bio refinery projects are summarised in Figure 8.

Figure 10. Funding mechanisms in industrial biotechnology



Source: Adapted from Milken Institute (2013)

Demonstrator plants

Demonstrator plants are larger than pilot plant but smaller than full-scale production plants (Figure 9). Many of the technical, supply chain and economic issues become apparent, and can therefore be addressed, at the demonstrator phase. It is therefore a vital stage to prevent very expensive mistakes at the full-scale production phase. This option is also suitable for gaining experience from small scale experiments aimed at attracting potential participants' interests (e.g. investors, credit institutes, local public policy makers, suppliers of raw materials, final users) who are not yet aware of the opportunities deriving from the new business. Yet demonstrator plants are notoriously difficult to finance, a barrier that could be addressed through public-private partnerships (PPPs) or other public support mechanism.

Figure 11. Three scales of bio-based production

(a)

(b)

(c)

Note: (a) pilot; (b) demonstration, and (c) full scale.

Source: (a) Courtesy of Pierre Guerin Technologies, France; (b) 10 000 litre demonstrator plant at the Centre for Process Innovation, UK; (c) Commercial cellulosic ethanol plant, Kansas, US.

The funding gap most relevant is at the demonstrator phase. It is a critical phase in process development where technical and economic barriers are likely to be highlighted. It has said that investment in this phase is a weakness of Europe (OECD 2015a).

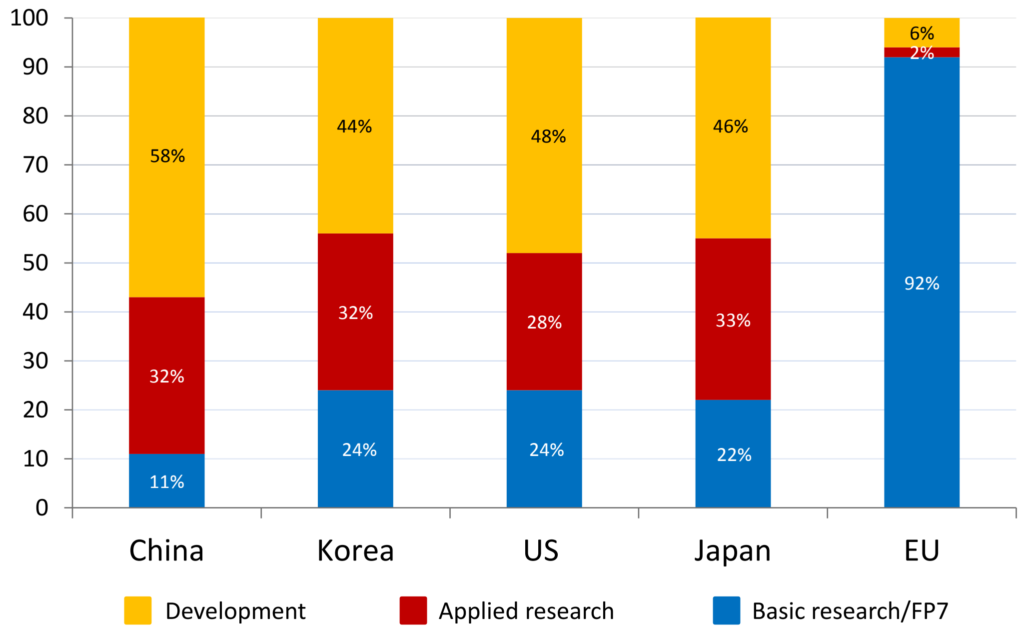
Whether demonstrator or full commercial scale, the costs involved are much larger than allocated to research programmes. Hence the need for private sector involvement. The current answer in Europe is the European bio-based industries PPP, which has been years in planning and development, and which was finally launched in 2014. The PPP was brought into force on 27 June 2014, with a total budget of EUR 3.7 billion for bio-based innovation from 2014-2020 (Horizon 2020). EUR 975 million of this is EU funds, with the other EUR 2.7 billion from private investments.

Coetzee (2016) listed the advantages TerraServ considers from piloting their process. These advantages equally apply to demonstrators:

- It has helped identify pitfalls in the process, and where control and instrumentation is critical (as these can make up a significant amount of the total capital required);
- It has helped optimise the process from technical and business perspectives;
- It has been useful to develop novel technology needed in a full-scale process;
- It is a tangible asset that can be shown to stakeholders and potential investors;
- It produces an actual product that can be used to establish market interest before committing capital to a full-scale process.

Figure 10 shows the funding of development scale projects in four countries and the EU, revealing a significant difference across the globe.

Figure 12. International comparison of the share of basic, applied and development activities.



Sources: http://ec.europa.eu/dgs/jrc/downloads/events/20130425-ket-sme/20130425-ket-sme-crean.pdf; Falholt, P. http://www.academia.edu/8097142/03_Per_Falholt

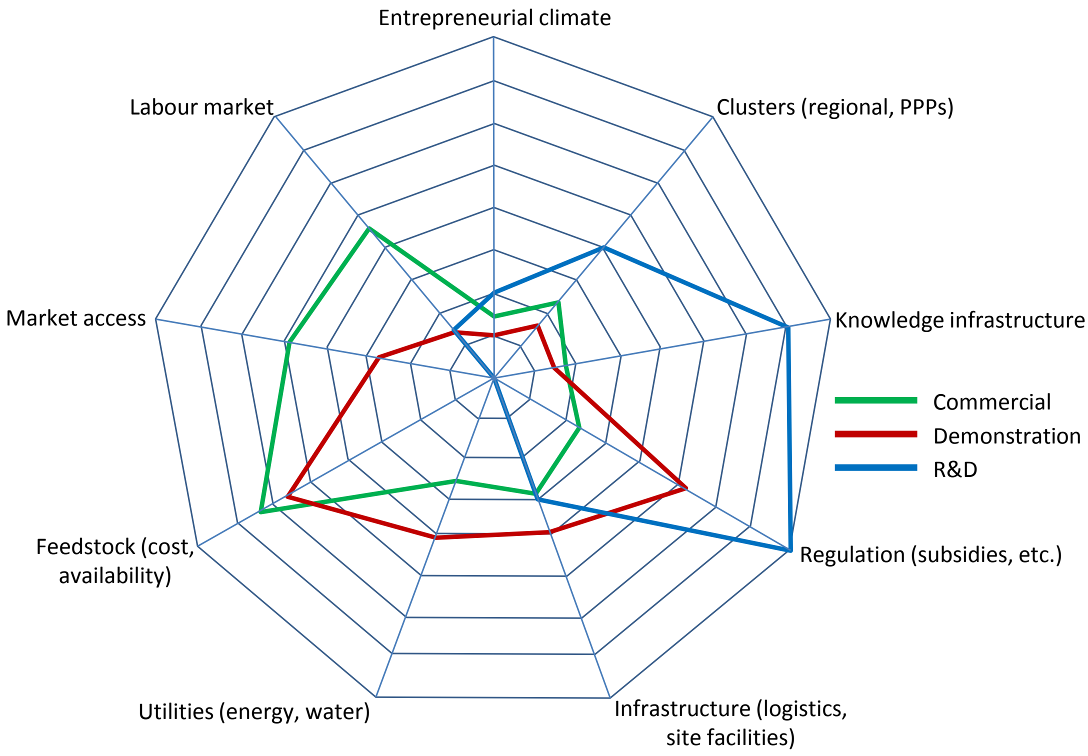
Two ends of the spectrum

The way such a complex construction project as bio refinery is financed has a dramatic effect on how the project can be executed. For example, the Crescentino cellulosic bio refinery had difficulties with debt management. Equity funding is the preferred project funding approach from the engineering perspective and it is the quickest way to deliver the project. The key decisions, like purchasing major equipment, are with the company so no outside approval is needed. For, say, a new petrochemicals plant this would be a preferred route – investors know that the risks are low and the dividends are generally steady, if not spectacular, over long periods. For a first-of-kind bio refinery, especially for large expensive facilities, it is not common; the risks are too high and it creates dilution for existing shareholders if significant capital is raised as equity.

At the other end of traditional project financing is a straight bank loan for a large proportion of the required funding. This normally carries significant restrictions and approvals. In the case of a bio refinery, there is significant risk in the feedstock supply chains, and all contracts for this would require careful and time-consuming review. Also, all major equipment purchases would require sign-off. At least for first-of-kind bio refineries, not all of these details can be known at the time of fund-raising. Even if this funding route were possible, it would require extended timelines for the many approvals, which of course increases the costs. Hence it has not proven popular, but given time, as more cellulosic bio refineries are built and, if they prove financial viability, this route may become more realistic.

It will be clear then that different financing situations pertain to different stages of development of bio refineries. This is an important point for policy makers who must decide on the optimal public investment strategies for the different stages of the process (from basic R&D through to commercialisation). The critical differences are highlighted in Figure 11.

Figure 13. Criteria determining bio-based investment decisions



Source: Suurs and Roelofs (2014)

Whilst much of this self-evident it is instructive to have this information reproduced in a single diagramme. In R&D, public research subsidy is of course top priority while issues of feedstock may be irrelevant. However, feedstock costs are of critical importance at demonstration phase, and even more so at commercialisation. The other two criteria critical to determining commercial success are the labour market

– making sure that there is an adequate supply of skilled labour, and market access – which can be influenced by public procurement.

Loan guarantees and debt finance

> “*And loan guarantees should be examined before loans. The creativity, resources and know-how of markets can provide powerful support to policy. However, local and regional policymakers often overlook the role of markets*”.
> OECD, 2003

The most common form of financing for such technologies in the US is a hybrid of equity, teamed with either federal grants or a federally backed loan guarantees. In the case of a grant, it is a source of funding that does not need to be paid back, but it is subject to meeting a series of technical hurdles. To build bio refineries, both the USDA and USDOE have favoured 20-year loan guarantees.

A government loan guarantee is a promise by the government (the guarantor) to assume the debt obligation of a private borrower if that borrower defaults. Loan guarantees are similar to traditional project finance, but the government accepts the technology risk and backs the loan. This streamlines the approval steps and the control. In the case of Crescentino, this may have removed many of the problems of debt management.

USDA 9003 ‘Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program’ highlights

Under the new provisions of the programme (Box 3) to bring bio-based chemicals within its remit, bio refineries must produce an advanced biofuel, but they are not required to sell it as a biofuel. It removes a previous requirement that 51% of the product be sold as advanced biofuels. The options are:

- It (the bio refinery) may sell the advanced biofuel that it produces as a biofuel, a renewable chemical, or for other non-fuel usage;
- It may process the advanced biofuel into renewable chemicals or other bio-based products, or;
- It may use the biofuel as a fuel for heat or power in its processes or to generate electricity.

In broad terms, two types of projects are eligible within the programme: bio refineries and bio-based product manufacturing facilities (as these may be treated differently in the US). This is a welcome development as it expands opportunities for new technologies, new processes, and products and provides loan guarantees to bio-based product manufacturing facilities, whereas previously the programme was open only to biofuel bio refineries.

The application process has also been changed. It is now a two-phase process: by limiting the information required during phase one, the burden associated with putting together an application is lessened on applicants that are not selected to move on to phase two. For scoring purposes, bio refineries and bio-based product manufacturing are ranked separately and compete against similar projects. Applications with the highest priority score rankings, in each category, are invited to submit phase 2 applications.

Box 3. Changes to the USDA Farm Bill, Program 9003

For the Farm Bill of 2014, Program 9003, the USDA 'Biorefinery Assistance Program' was renamed the 'Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program'. The USDA was directed to ensure diversity in the types of projects approved and to cap the funds used for loan guarantees to promote bio-based product manufacturing at 15% of the total available mandatory funds. The important point to note, however, is that the same policy mechanism is now being used to support both biofuels and bio-based products and materials. It provides loan guarantees up to USD 250 million.

Funds may be used to fund the development, construction and retrofitting of:

- Commercial-scale bio refineries using eligible technology
- Bio-based product manufacturing facilities that use technologically new commercial-scale processing and manufacturing equipment to convert renewable chemicals and other bio-based outputs of bio refineries into end-user products on a commercial scale
- Refinancing, in certain circumstances, may be eligible.

Importantly the program makes a distinction between bio refineries, and bio-based manufacturing facilities. The terms and conditions, and eligibility are clearly set out (http://www.rd.usda.gov/programs-services/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance). Federal participation (loan guarantee, plus other Federal funding) cannot exceed 80% of total eligible project costs, The borrower and other principals involved in the project must make a significant cash equity contribution.

InnovFin product overview

The InnovFin-EU Finance for Innovators[17] was launched by the EC and the European Investment Bank (EIB) Group in the framework of Horizon 2020 to provide guarantees or direct loans (EUR 24 billion available) to research and innovation projects. InnovFin aims to improve access to risk finance for research and innovation projects, research infrastructures; public-private partnerships and special-purpose projects promoting first-of-a-kind, industrial demonstration projects (Scarlat et al., 2015).

This is a major step in Europe as loan guarantees had previously been missing from the portfolio of funding mechanisms for bio economy projects. Loan guarantees have been commonly used for these purposes by the US Department of Agriculture and Department of Energy for bio refinery project financing. A summary of InnovFin products is shown on Table 2.

Table 2. Overview of InnovFin products

SMEs	Mid-caps	Large caps	Advisory
SME Guarantee*	MidCap Guarantee*	Large projects	
SME Venture capital	MidCap Growth finance		

Source: Fernández Gutiérrez (2016).

Notes: * denotes indirect products

- Direct products: the EIB group directly issues a loan to a borrowing project (loan covers up to 50% of total project costs).
- Indirect products: the EIB group offers (counter-)guarantees to an intermediary partner bank which then issues loans to borrowing projects ((counter-)guarantees cover up to 50% project costs.)
- There is no common EU definition of mid-cap companies. While SMEs are defined as having fewer than 250 employees, mid-caps are broadly said to have between 250 and 3000 employees.

17 http://www.eib.org/products/blending/innovfin/

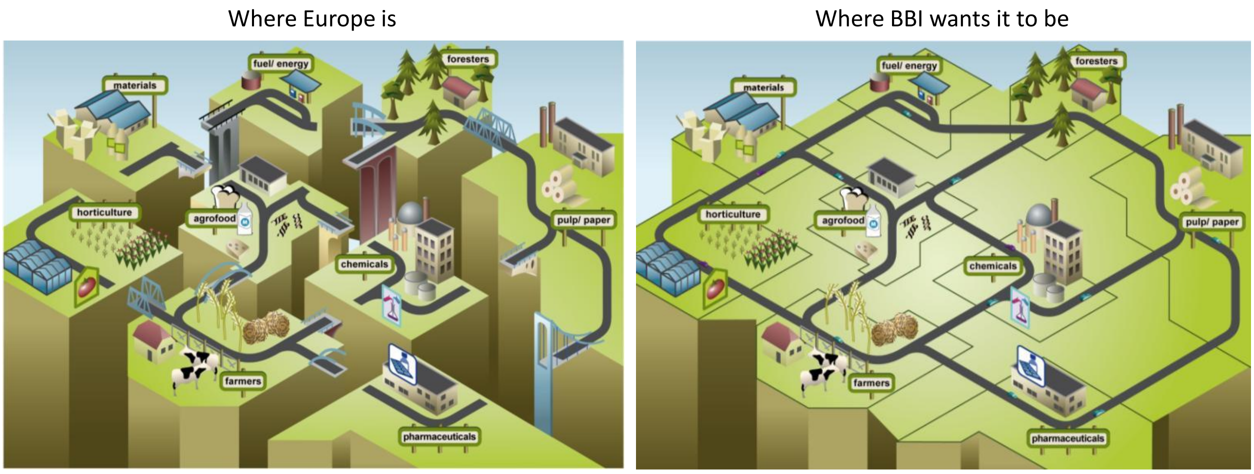
A bio-based industries instrument for Europe: the BIC/BBI

The European bio-based industries PPP was launched in 2014. There has been a perception that Europe lags behind in bio economy matters, especially when it comes to full-scale commercialisation. Good ground work done in basic research is then often capitalised upon abroad.

One of the reasons for this, but not the only one, is that the phases of the innovation chain beyond R&D are usually much more expensive. In the case of bio-based production, they are also very high risk. From the viewpoint of industry, a lack of policy stability, but also a governmental drive towards establishing a bio economy, means that it is unwilling to shoulder the entire financial burden in building the first key facilities without public support.

Another challenge for Europe has been that the different industry sectors that should act together in bio economy development have been operating in isolation. These span agriculture, agri-food, forestry/pulp and paper, technology providers, chemicals and energy (Figure 12).

Figure 14. The vision of the BBI and its consortium to bring the appropriate European industry sectors together in the evolution of a European bio economy that is joined up



Source: Carrez (2014).

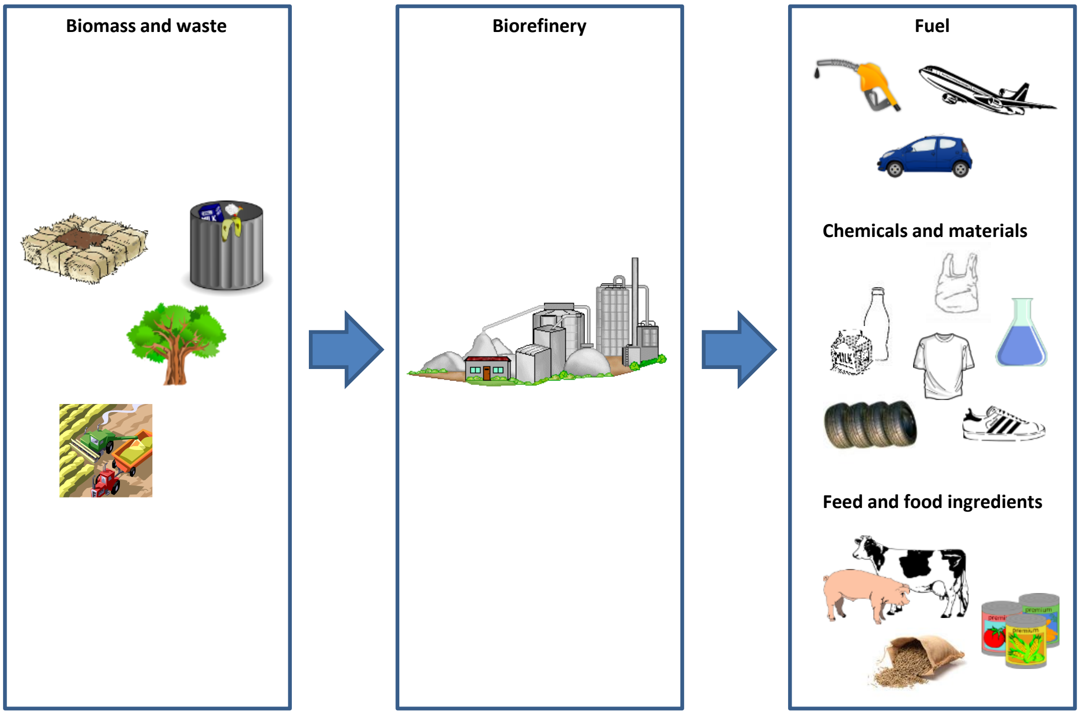
The establishment of this PPP in Europe, the Bio-based Industries Initiative (BBI),[18] is meant to address these issues. The PPP was brought into force on 27 June 2014, with a total budget of EUR 3.705 billion for bio-based innovation from 2014-2020, around 75% of which comes from the Bio-based Industries Consortium (BIC), the private partner of BBI. EUR 975 million of this is EU funds, with the other EUR 2.7 billion from private investments.

As of May 2016, membership consisted of 70 full members (large companies, SMEs and regional clusters) and 155 associate members (universities, RTOs, European trade organisations, European Technology Platforms (ETPs) and private banks). The membership spans the critical sectors of a bio economy: agriculture, agri-food, forestry, pulp and paper, technology providers, chemicals, energy and others.

18 http://www.bbi-europe.eu/

Having these diverse sectors represented is essential as a focus of the PPP is the complete value chain. Where there are gaps in a new value chain, it is impossible to operate properly. In bio-production the value chain concept is depicted in Figure 13.

Figure 15. Bio-based industrial value chains



Source: Redrawn from Carrez (2016)

A major task for BBI and its consortium is to level the fragmentation and build bridges between the sectors (Figure 12). This is expected to be achieved through a Strategic Innovation and Research Agenda (SIRA) that concentrates on value chains. The specific value chains (VCs) suggested by SIRA are (Bio-based Industries Consortium, 2013):

- VC 1: From lignocellulosic feedstock to advanced biofuels, bio-based chemicals and biomaterials, realising the feedstock and technology base for the next generation of fuels, chemicals and materials;
- VC 2: Next generation forest-based value chains utilising the full potential of forestry biomass by improved mobilisation and realisation of new added value products and markets;
- VC 3: Next generation agro-based value chains, realising the highest sustainability and added value by improved agricultural production, and new added value products and markets;
- VC 4: New value chains from (organic) waste, from waste problems to economic opportunities by realising sustainable technologies to convert waste into valuable products;
- VC 5: Integrated energy, pulp and chemicals bio refineries realising sustainable bioenergy production, by backwards integration with bio refinery operations isolating higher added value components.

Focusing on higher added value

The consistent theme is the emphasis on higher added value. This is how Europe will attempt to break away from concentrating on first generation biofuels and bioenergy, which have consistently been shown to offer lower added value, and probably lower job creation potential, with higher GHG emissions reductions to meet several of its biggest challenges – climate change obligations, energy security, rural regeneration, chemicals industry competitiveness and overcoming unemployment and low growth.

Absolutely crucial to SIRA is its range of projects, which spans R&D, demonstration, flagship and supporting projects. To break out from the trap of capacity building outside of Europe, flagship projects are meant to optimise technology for biomass conversion and ensure price competitiveness, both by building new operations, and upgrading existing and abandoned industrial sites by their conversion to bio refinery operations. Each value chain area will lead to at least one flagship project.

As of 2014 there were ten funded projects: seven funded *research* projects tackling specific value chain challenges such as sustainability, technology and competitiveness; two *demonstration* projects that will demonstrate the technological and economic viability of bio refinery systems and processes for making chemicals from wood, and for making high value products for detergents, personal care, paints and coatings and composites from sugar beet pulp; one *industrial scale flagship* project that will make use of cardoon grown on arid and marginal lands.

The first call for proposals of 2015 was dedicated to flagships. Three projects were chosen: second generation bioethanol production built on lignocellulosic non-food feedstock (straw); microfibrillar cellulose (MFC): large-scale supply and market creation of MFC to demonstrate an industrial symbiosis between the biomass and the forest industry; cellulosic ethanol from unused crop residues and crops grown on marginal lands.

For the second call of 2015 a budget of EUR 108 million was allocated for 3 support actions, 11 research projects and 9 demonstration projects. The investments made by BIC members to date (January 2016) are shown in Table 3.

Table 3. BIC members estimated investments (preliminary results)

Value chain	Estimated total investment of the BIC members in EUR million (January 2015)	Estimated total investment of the BIC members in EUR million (January 2016)
VC1	305	1387
VC2	1810	2537
VC3	30	107
VC4	15	31
VC5	0	2
Total	2160	4064

Source: Carrez (2016).

The BIC/BBI is a PPP established to finance major bio-based production projects in Europe. The Bio-based Industries Consortium (BIC) is the private partner in the EUR 3.7 billion PPP on Bio-based Industries (BBI) with the EU.

The BBI is an instrument to support industrial research and innovation, to overcome the innovation "valley of death", the path from research to the marketplace that has long been identified as a weakness in Europe. It encourages partnership with the private sector to fund and bring together the resources needed to address the challenges involved in commercialising major technologies and facilities.

Central elements of the strategy for BBI are aimed at de-risking for industry

The core elements of the BBI strategy are:

- A robust framework that brings clarity for activities and investments;
- Long term stability and predictability;
- A joint approach, across sectors, across nations;
- Joint financial commitment and a jointly defined programme, that will unite parties that would otherwise find these activities to be too risky for an individual sector/company to carry out on its own;
- Leveraging of further investments;
- It is industry driven and is therefore result- and market-oriented.

Investment in R&I and skills

In The European Horizon 2020 programme, funding for bio economy research is available through Societal Challenge (SC) 2: Food Security, Sustainable Agriculture and Forestry, Marine and Maritime and Inland Water Research and the Bio economy. This is funded to the level of EUR 3.8 billion. Within its objectives is policy integration through: increased multi-disciplinary and cross-sectoral R&I, smart specialisation (European Structural and Investment Funds, ESIF), and; the European Fund for Strategic Investments (EFSI). A good example of how EFSI mobilises funds in the bio economy arena is the EUR 75 million loan agreement between the European Investment Bank (EIB) and Metsäliitto Cooperative for the construction of a new large-scale bio-product mill in Finland.

Alternative instruments

Some more innovative instruments are emerging for what are seen to be ‘green’ projects i.e. major environmental projects such as wind farm and solar energy projects. Their deployment in bio refinery projects to date is unknown, but is certainly not widespread yet. The Finland international bio refinery competition is directly aimed at bio-based production.

COP21 and Energy Union Integrated Research, Innovation and Competitiveness Strategy (EURICS)[19]

It is recognised by the EC that deep decarbonisation of the economy is not possible without the bio economy. The EC will launch of a new Research, Innovation and Competitiveness Strategy of the Energy Union (EURICS). It will be part of the 2016 State of the Energy Union, planned for November 2016. The strategy will provide the Commission's follow-up to the outcome of COP21 as regards R&I.

Major innovations explicitly stated as needed are:

- Replacement of fossil resources for energy, fuels, chemicals, materials (plastics) by sustainably produced biomass – without compromising food security;

19 http://ec.europa.eu/smart-regulation/roadmaps/docs/2016_rtd_001_energy_union_research_strategy_en.pdf

- Biomass production (agriculture) is a major source of GHG emissions (e.g. livestock, fertilizer production) but also a possible sink of CO_2 (e.g. forestry and soils).

Green Bond Principles

A recent development, this has the potential to become the major financing route for 'green' projects. Green Bonds enable capital-raising and investment for new and existing projects with environmental benefits.[20] The Green Bond Principles instrument is a mechanism to raise large capital sums, with the financing and management of project risks undertaken by the project sponsors, not the investors that might or might not have the capacity to manage said risks.

Recently, a consortium of investment banks announced their support of the Green Bond Principles – Bank of America, Merrill Lynch, Citi, Crédit Agricole Corporate and Investment Banking, JPMorgan Chase, BNP Paribas, Daiwa, Deutsche Bank, Goldman Sachs, HSBC, Mizuho Securities, Morgan Stanley, Rabobank and SEB. The initiative is very new and still evolving. The Bank of America Corporation has announced that it has issued a "green bond" consisting of a three-year, fixed-rate bond that is USD 500 million in aggregate principal amount. This issuance of bonds is part of the company's ongoing commitment to advance renewable energy initiatives and promote energy efficiency.

The OECD now annually convenes the Green Investment Financing Forum[21]. The 3rd GIFF event was held in Tokyo in 2016, in association with the Asian Development Bank Institute (ADBI). This event, as in previous years, gathered senior policy makers and key actors in financing green investment from around the world for a targeted discussion, this time themed on Asia. The issues discussed were: mobilising private investment in low-carbon and climate-resilient infrastructure; managing financial risks arising from climate change; challenges and opportunities for institutional investors; development of green bond markets; early stage equity finance; greening the traditional banking sector; role of public financial institutions including public green banks; the potential for local and retail green finance; new and emerging actors in green finance; and policies and regulation to get on a low-emissions pathway.

UK Green Investment Bank

Over a dozen national (Australia, Japan, Malaysia, Switzerland, United Kingdom) and sub-national governments have created public green investment banks (OECD, 2016). The primary reason is that there are major barriers to scaling up low-carbon and climate-resilient infrastructure investment. The United Kingdom Green Investment Bank plc. (UKGIB) is a funding institution created in 2012 by the government of the United Kingdom to foster private sector investment in projects related to environmental preservation and improvement. A non-partisan, House of Commons committee on climate change stated that, since traditional sources of capital for investment in green infrastructure (utility companies, project finance and infrastructure funds) could not provide even half the amount needed by 2025, there would be a funding gap of hundreds of billions of pounds (Sterling) that needed to be covered by the state budget (House of Commons, 2011).

The bank differs from a typical 'fund' in that it must not just disburse government money, but as a 'bank' it should be able to raise its own finance and fill a gap in the market for government-backed bonds, bring in banking expertise and offer a range of commercially-driven interventions - loans, equity and risk reduction finance. To make such a mechanism viable, it must attract private sector investment and operate commercially without being influenced directly by the government. The UKGIB is mandated to operate as

[20] http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/green-bonds/green-bond-principles/

[21] http://www.oecd.org/environment/cc/2016-green-investment-financing-forum.htm

a ‘for profit’ bank and became operational in October 2012, with GBP 3 billion of UK taxpayer capital. An investment alliance with Abu Dhabi-backed clean energy firm Masdar has been signed to bring in additional funding to support UK projects over the next seven years.

Projects that the UKGIB can invest, into many of which bio-based production falls, include: large energy de-carbonisation projects; SMEs; innovation; new technologies and R&D; community scale action; investment priorities; and nuclear power.

New York Green Bank Initiative

The USD 1 billion New York Green Bank Initiative opened in February, 2014. The New York Green Bank, initially capitalised with USD 210 million in funding, will partner with private-sector institutions to provide financing for qualifying clean energy projects and to accelerate clean energy deployment in the state of New York.

In its first request for proposal, the New York Green Bank invited clean energy industry participants to proposed projects, including those related to energy generation and energy savings, which may include a wide range of commercially proven technologies, including biomass projects.

Bpifrance

La Banque publique d'investissement (Bpifrance) finances businesses of all sizes from the seed phase to transfer to stock exchange listing, through loans, guarantees and equity. Bpifrance accompanies firms developing export activities, in partnership with UBIFRANCE and Coface, and provides support to their innovation projects.

Two equal shareholders of Bpifrance are the French State and the Deposits and Consignment Fund (*Caisse des Dépôts*). Therefore it acts in support of public policy established by the State and the Regions. In common with many French initiatives in industrial biotechnology, Bpifrance is highly supportive of regional innovation: 90% of all of its decisions are made regionally, where entrepreneurs are located.

SPIRE and Horizon 2020

The Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) PPP is not dedicated to bio-based production, but its objectives fit with its policy goals and those of the bio economy more generally. SPIRE, in turn, is part of Horizon 2020, the EU framework program for research and innovation, which runs from 2014 to 2020 and comprises a EUR 80 billion budget.

It is a contractual PPP dedicated to innovation in resource and energy efficiency in the process industries (hence the fit to bio-based production). Its objective is to develop the enabling technologies and solutions along the value chain to reach long term goals for Europe in terms of global competitiveness and environmental and social sustainability. Eight industry sectors, including chemicals, have contributed to the development of SPIRE, via European Technology Platforms and Industry Associations.

The PRODIAS (PROcessing Diluted Aqueous Systems) (Box 4) project addresses downstream processing in bio-based production. In many bioprocesses, downstream processing can be extremely expensive, especially as large volumes of wastewater are often produced.

Box 4.The PRODIAS project

EU funding of the PRODIAS (PROcessing Diluted Aqueous Systems) project is enabled via the PPP with SPIRE (Sustainable Process Industry through Resource and Energy Efficiency).

A consortium of companies in the European process industry from the areas of biotechnology, renewable resources, chemistry, process engineering, equipment supply as well as research organizations recently launched project PRODIAS. The project focuses on unlocking the potential of renewable-based products made via industrial biotechnology, by significantly decreasing production costs, increasing productivity and efficiency, lowering energy consumption, and accelerating process developments.

Under the leadership of BASF, the partners include: Cargill Haubourdin, France; University of Kaiserslautern, Germany; Imperial College London, UK; Alfa Laval, Sweden; GEA Messo PT, the Netherlands; Xendo, the Netherlands; UPM, Finland and Enviplan, Germany. The goal is to develop cost- and energy-efficient technologies for water purification, removal and product-recovery needed to support downstream processing in industrial biotechnology.

The total project budget is about EUR 14 million with the European Union contributing EUR 10 million.

Bio refinery competitions

Competitions have the ability to simplify rules and regulations, and to drive innovation. As part of the Finnish Bio economy Strategy, launched in 2014, there was an international bio refinery competition (Box 5) with the objective to accelerate commercialisation of novel processes, product and business innovations related to the bio economy and boost new bio refinery investments in Finland. Although modest in the cash investment involved, such an initiative may be important in leveraging other funding as this is, effectively, a public sector contribution and that should therefore signal serious intent, and hopefully policy stability, to the private sector.

The entrants to such a competition should also send signals to government about the types and diversity of activities involved. This information, for example, could be used in developing a national or regional bio refinery roadmap.

Box 5. Winners of the International Biorefinery Competition

In June 2014 an international competition was launched as part of the bio economy strategy to expedite the commercialisation of bio economy innovations and the emergence of new bio refineries in Finland. It is part of the drive by the Ministry of Employment and the Economy to implement the Finnish government's bio economy, cleantech, and digitalisation strategy for accelerating new areas for growth. Three entrants to the International Bio refinery Competition won awards in 2015.

- Spinnova Ltd., for its new textile fibre production technology which makes it possible to spin yarn directly from wood fibre.
- Biovakka Suomi, for its concept for combining the production of biogas, nutrients, and transport fuel.
- The Kemijärvi Consortium, that incorporates novel Finnish technology for the production of new biomaterials and biochemicals.

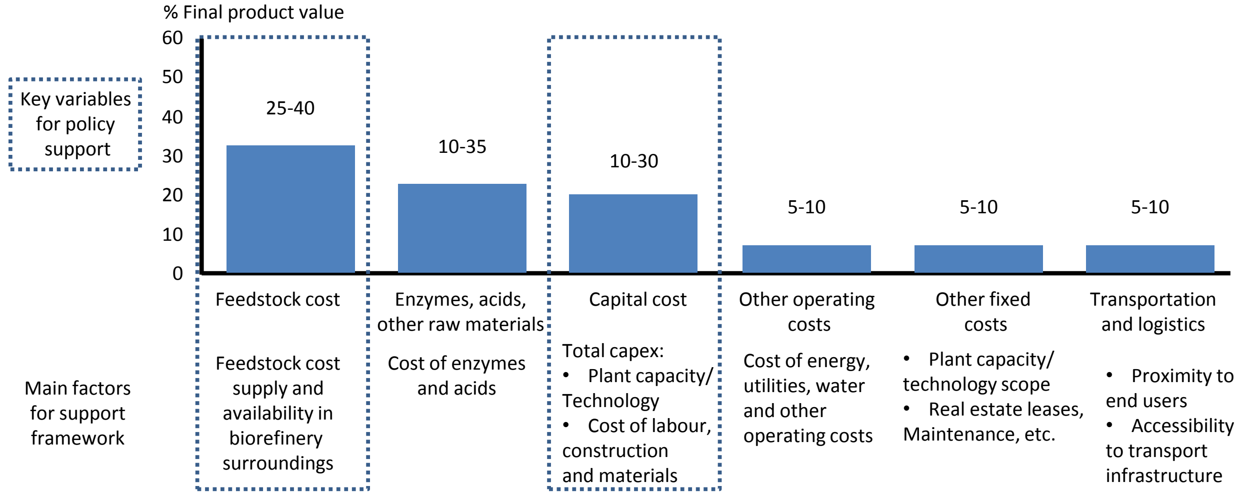
The prize money is relatively modest at EUR 100 000. However, a diverse array of proposals from different bio-economy areas took part in the competition. They varied in size from demonstration plants worth less than a million euros to bio-refineries requiring hundreds of millions of euros in investment. The intent is that relatively small public investments leverage much larger private investments.

Source: Adapted from (1). VTT Ventures Ltd., http://www.vttventures.fi/spinnova-ltd-wood-fibre-yarn-project-wins-biorefinery-competition and (2). Finland Times, Feb 26, 2015, http://www.finlandtimes.fi/business/2015/02/26/14606/Spinnova%E2%80%99s-project-wins-bio-refinery-competition

Where next for bio refinery finance?

The simple answer is '*more of the same'*, but regarding public investments it has been suggested that there are specific areas that would be worth tackling as priorities (Figure 14).

Figure 16. Key variables for policy support in bio refinery finance



Source: Redrawn from Panoutsou (2015)

This analysis is consistent with the view that feedstock costs have to be stabilised to encourage the private sector to build the necessary supply and value chains. As most of the jobs associated with bio refining are outside the bio refineries (Table 4), then it also makes sense for policy makers to focus on this issue.

Table 4. Estimated direct, indirect and induced jobs associated with annual operation of bio refineries for three analysed cases.

	Jobs (FTE per year)			
	Direct	Indirect	Induced	Total
Case 1: Cellulosic ethanol, Iowa	56	240	110	410
Case 2: Renewable diesel, Georgia	56	350	130	540
Case 3: Fast pyrolysis, Mississippi	73	370	120	570

Source: adapted from Zhang et al. (2016). The induced effect refers to impacts resulting from changes in household spending of workers directly or indirectly employed in the construction and operation of the bio refinery and of those who produce and supply the feedstock.

Capital cost is also a critical issue as the first of the flagship facilities are being built but more need to follow, especially those using novel, non-food feedstocks. Long delays associated with cellulosic bio refineries attest to this need. However, R&D subsidy is clearly still required in several key areas, especially conversion technologies.

The answer is also country-dependent. A tool that would aid policy makers is a national bio refinery roadmap, backed up by a leadership council to make sure that milestones are met. The construction of a national roadmap requires countries to know what feedstocks are available locally and what needs to be imported (if anything).

Policy implications

The over-riding concern, independent of geography, for the private sector concerning bio-based production is about policy stability and uncertainty: governments need to make the explicit connection between uncertainty and investment risk. There are many worries; those generating the greatest uncertainty are outlined.

- Public perception has been influenced by years-long debates about indirect land-use change (ILUC) and ‘food versus fuel’. The fears about ILUC in Europe, for example, appear to be receding, but this may be temporary.
- Eligible feedstocks: there is apparent political support for cascading use of biomass as it aligns with the Circular Economy and zero waste. Therefore the use of wastes and residues is supported, but the uncertainties exist about available capacities for second generation biofuels.
- The availability and acceptability of energy crops for second generation biofuels. The public policy concerns are typically about displacing food crops with non-food crops for industrial use, and the effects on food prices. This also then results in worries about available capacities for second generation biofuels.
- Looming over these issues is what happens with the Renewable Energy Directive (RED) beyond 2020.
- Finally, and directly related to this paper, is the lack of finance schemes for such large projects. Officials from Biochemtex, owners of the Crescentino plant in Italy, in public presentations state that what is needed is credit/loan guarantees (in addition to, or as an alternative to, grants).

The overall result could be diversion of investments and capacity building in other continents. Brazil currently has also had some issues around policy uncertainty,[22] but this may be transient, and Brazil's first cellulosic biorefinery is open (*Biofuels Digest*, 2014b). Given Brazil's ambitious plans for sugar cane expansion, and the amount of high-energy waste available from sugar cane processing, Brazil will continue to be a favoured location for cellulosic bio refining investments. Asian ambitions are also strong. For example, Malaysia is committing large resources to a bio economy with a focus on value-added (OECD, 2015a).

The US has also seen some investment moving abroad, estimated in 2015 to be around USD 13.7 billion, with the loss of up to direct 80 000 jobs (*Biofuels Digest*, 2015a) directly related to policy uncertainty about second generation biofuels in the Renewable Fuel Standard.

Research centres and clusters should become more investment savvy

By knowing: what types of financial instruments are available, nationally and regionally (even at the city level); who the venture capital firms of interest are; the strengths of the research areas and individual researchers; local and wider small, medium and large companies with interests in industrial biotechnology (not necessarily dedicated biotechnology firms); and, crucially, how to partner different organisations and individuals; then research centres and clusters can improve the chances of getting projects funded by taking away background work that others may be unwilling to do.

An excellent example is Toulouse White Biotechnology (TWB) (Box 6) where a cornerstone of the investment strategy is a consortium agreement that streamlines contracting and project management.

Box 6. Financial instruments used at Toulouse White Biotechnology (TWB)

TWB is a pre-industrial demonstrator for sustainable production based on industrial biotechnology. It is considered a "*future centre of excellence in the field of industrial, or white, biotechnology*", aimed at being a Joint Service Unit under the auspices of INRA (the National Institute for Agricultural Research), INSA (the National Institute for Applied Sciences) and CNRS (the National Centre for Scientific Research). There are currently 23 industrial partners and nine public institutions involved, and they all adhere to a collaboration agreement that simplifies contract negotiations.

Collaborative academic-industry research programmes (pre-competitive) are co-financed by private companies (annual fees act as a main source of funds for this) and academic research organisations participate for free on projects.

Competitive projects are financed exclusively by private companies. Regional sources of funding are also important, but European funding can be involved as the region has Industrial biotechnology as a smart specialisation.

Intermediate projects are financed by private partners (between 15 to 50% of total costs of the project). The public funding can come from national public funding or European funding under Horizon 2020.

Source: courtesy of Michel Manach, TWB

Supply and value chains in bio refining – the industrial ecosystem

A particular concern for policy makers is how to scale up and roll out initiatives beyond demonstrator and flagship projects. Government programmes are promoting research and development across supply and

[22] In 2014, with not enough refineries to meet Brazil's growing demand for fuels, Petrobras started to import gasoline and diesel and sell it at a loss in the domestic market, pricing the fuel artificially low to help the government control inflation (*Financial Times*, 2014). This cast doubt on the competitiveness of bioethanol.

value chains, but supply markets receive little attention (Knight et al., 2015). This creates one of the conditions that deter investors. This pertains across different technologies but is of exceptional importance in bio refining for several factors, some of which are:

Suppliers and bio refiners can often be expected to be in remote, rural locations;

Suppliers of biomass such as agricultural and forestry residues in many countries are small-scale operations, and therefore there are many of them, thus complicating supply chains;

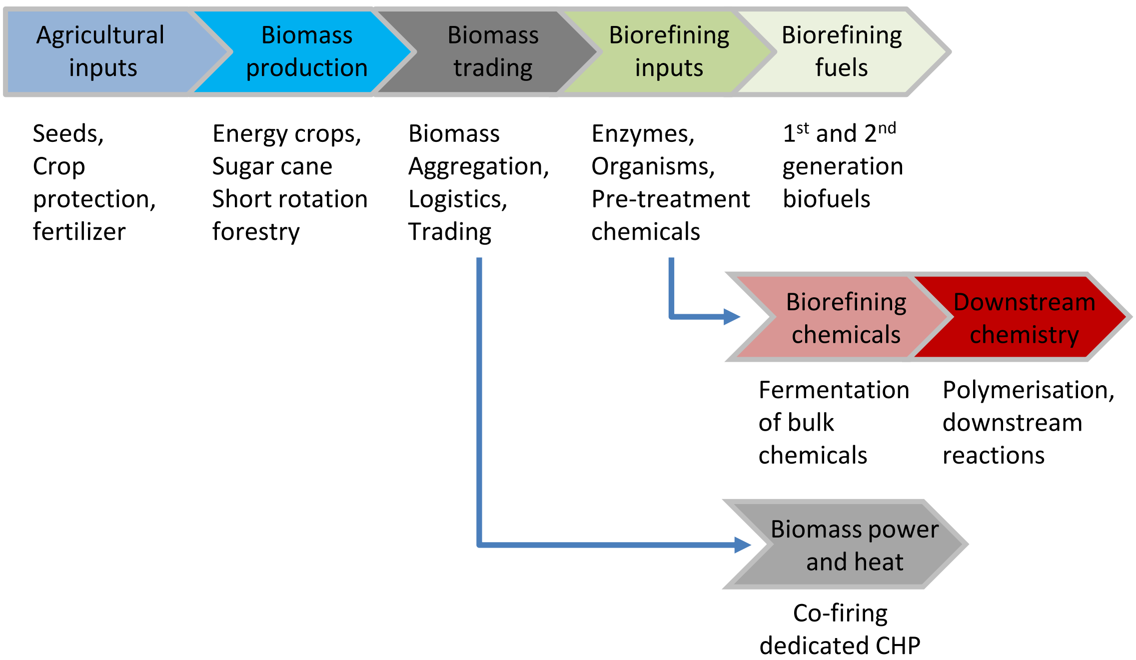
The skills sets are very diverse, requiring large variety in the types of companies in the supply and value chains. The skills may be available in urban settings, but not in rural locations;

There are a large number of sectors involved and they often do not communicate with each other.

This lack of attention to supply markets possibly reflects reluctance by governments to be seen to be intervening in markets and potentially contravening anti-competitive practices (Institute of Risk Management and Competition and Markets Authority, 2014). There may be a perception of a grey border between effective collaboration to promote whole system innovation and change and the motivation of self-interest, thereby creating (perceived) conflict of interest in public service.

The area is under-researched and deserves the attention of research funding bodies: as has already been seen in the young bio refining industry, the large investments in the actual buildings themselves can become stranded through a lack of supply of feedstocks. For this reason it is necessary to understand the generalities and the specifics of the supply and value chains of bio refining (Figure 15).

Figure 17. The general value chain of industrial biotechnology and bio refining

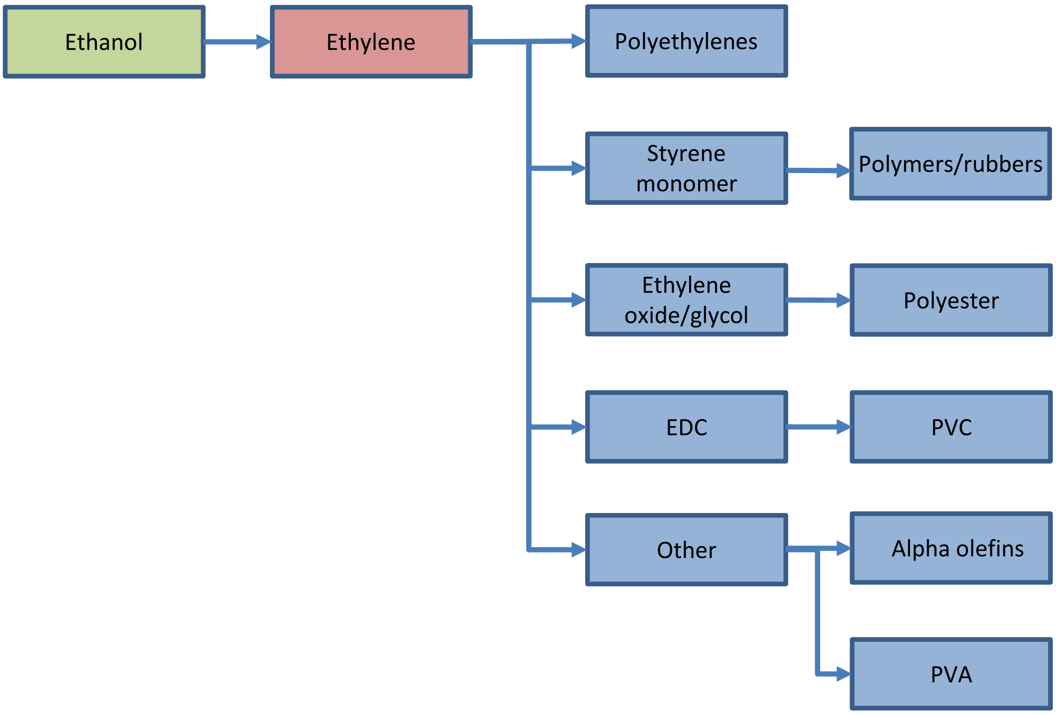


Source: Adapted and redrawn from World Economic Forum (2010)

What will be clear from this figure is that the stakeholders concerned are so different that they would never come into regular contact with each other in the fossil economy. However, to make bio refining sustainable, they need to. There are roles to be played by policy makers to prevent this communication process from being random, ad-hoc and inefficient.

The concepts of circular economy and cascading use of biomass depend completely on being able create added value. This is why the value chains are so important. They are far easier understood by the private actors in bio-based manufacturing because pricing data on many chemicals are not easy to obtain, and the options for chemistry-based value addition are intuitive only to those in the profession. This can be illustrated by the example of adding value to ethanol through diverting it to the ethylene chain (Figure 16).

Figure 18. Adding value to ethanol through the ethylene value chain



The dehydration of ethanol to ethylene, albeit an old and under-researched reaction (Morschbacker, 2009), creates other possibilities for adding value to bioethanol. Ethylene is an extreme example as it is currently the most consumed intermediate product in the world. There are many other value chains that could be devised that are based on drop-in or novel-use bio-based chemicals and applications. For example, lactic and succinic acids are being used for bioplastics production as durable alternatives to high-volume thermoplastics, rather than drop-ins. Succinic acid, on the other hand, can be chemically converted for a range of other uses (e.g. lubricants, coolants, solvents, fine and specialty chemicals). It has a current production capacity of around 30 000 tonnes per year and a corresponding market value of USD 225 million (Taylor, 2010). Therefore it is, in comparison to petrochemicals, tiny in the market, but with a lot of potential for growth.

Pricing is dynamic and only really known to industry insiders. Price sensitivity means refiners need to have access to different feedstocks at different prices. But then feedstock price is also dynamic. For example, the markets for forestry residues for wood-based power plants are limited by the transportation distance (Kizha et al., 2015). Adding value to forest residues may extend the distances that it is worth hauling forestry residues and enhance the sustainability of the operation.

Options for policy makers

In these early days of the bio refining economy, public policy can help to join up all the stakeholders as it is clear that the economic sustainability of such operations are case-by-case and highly nuanced. There is an incontrovertible need for cooperation between the public and private sectors. The public actors should ideally be at the interface between the many feedstock suppliers and the private sector manufacturers (chemistry and energy companies). Farmers and foresters cannot be expected to know about bio-based chemical value chains, and the manufacturers would find it very difficult and time-consuming to communicate with the many suppliers.

Analysis points to the potential importance of buyer cooperatives and other forms of supply market intermediaries (Knight et al., 2015). This is consistent with the activities of publically funded regional clusters in industrial biotechnology becoming involved with supply and value chains. Farming and forestry cooperatives would appear to be central to the issue as talking to large numbers of individual farmers and foresters would be fraught with inefficiencies and inconsistencies.

Another interface of value, often overlooked, is local agricultural and forestry machine rings. For farm and forest owners, harvesting equipment costs are a significant burden, especially as it becomes more specialised and expensive. In addition, new energy crops may need completely new harvesting equipment, or at least modifications to existing equipment. Therefore machine rings allow farmers and foresters to hire equipment as seasonally required rather than paying to own equipment that may lie dormant for large periods in a year. This is especially true in nations where farms and forest are small. The professional custom hire business may also benefit the uptake of the bio economy in developing countries. For example, they are regarded as useful for achieving sustainable agriculture in Thailand (Koike, 2009).

In a study of forestry machine rings in Slovenia, the owners of machine rings perceived that knowing the level of mechanisation of its members is one of their particular strengths (Malovrh et al., 2012). Slovenian forests are typically small in size, and the lack of subsidies for investments in equipment was identified as a critical threat. Therefore in a growing bio refinery economy, machine rings could become centrally important to feedstock production but also as a conduit of communication between the biomass suppliers and the bio refiners. They could conceivably be a conduit for innovation through feedback from the end-users regarding strengths and weaknesses of equipment.

Loan guarantees with large companies could be used for this type of activity. DuPont is working with US farmers by providing innovative services to meet growing demand from the biofuels industry. DuPont Crop Protection further helps growers produce and maximise the yield and quality of feedstocks including sugar cane and corn with solutions that help reduce weeds and control insect and disease. This type of activity could clearly help build relationships with biomass suppliers.

Encouraging software design to improve decision making would be a relatively low-cost public sector intervention. If software tools are accepted as *de facto* standards, then they can help to standardise business approaches. An example is the high-throughput model-based screening and integration of biomass processing paths published by Tsakalova et al. (2015). A database developed by Black et al. (2016) for the assessment of biomass supply chains for bio refinery development covers origin, logistics, technical and policy aspects. Parajuli et al. (2015) reviewed sustainable pathways for bio refinery value chains and sustainability assessment methodologies.

There are lessons for nations and regions from the BBI JU, which is funding specific research projects relating to value chains. At a higher level, it may even be true that developing an understanding of how to engender sustainable markets despite high supply uncertainties is vital to the entire sustainability agenda.

BIOWASTE BIOREFINING

Introduction

The term "waste" (Box 7) as related to use as feedstock in bio refineries refers to a wide range of materials. They include: agricultural residues, such as straw and animal manure and sludges; by-products of animal rendering, especially animal fat; forestry residues; waste industrial gases, especially carbon monoxide (CO) and carbon dioxide (CO_2), and; the organic fraction of MSW (e.g. food wastes, plastic waste if not sorted for recycling). Nevertheless waste bio refining will need, on a case-by-case basis, to be investigated regarding its true sustainability. For example, the collection of waste materials and their delivery to a bio refinery site involves both economic and environmental costs involving the use of fossil fuels, and concomitant GHG emissions for their transportation. Careful supply chain design and security will be essential.

Materials like straw may not be waste materials at all as they may have other uses, e.g. wheat and barley straw for animal bedding. It is an important distinction that must be used in designing supply chains for bio refineries. Indeed, calculating the volumes of such materials could be part of a bio refinery roadmap (national or regional). Ideally a waste bio refinery should be capable of processing multiple waste streams as agricultural wastes are seasonal, forestry residues may not be readily available in winter months, and municipal waste should be available year-round.

Box 7. Waste or resource?

It is fashionable to use the word 'resource' to describe waste, the theory being that all waste should be a resource if the circular economy is to be realised. 'Resource' might be used in the context of a feedstock such as sugar, or sugar cane. On the other hand, bagasse is a fibrous 'waste' material of sugar cane processing that can be used in bio refining also. So it could also be argued that it is a resource. Similarly, materials that end up in landfill sites, or are burned or similarly disposed of, will be termed 'waste'. Wood chips are manufactured products used for bioenergy purposes. However, forestry residues, for example, are 'waste' materials of forestry that can eventually become a resource. Wastes could alternatively be considered 'renewable resources' that can be used and reused to generate valuable and marketable products (Velis, 2015).

The EU Waste Framework Directive defines waste as any substance or object that the holder discards or intends to discard or is required to discard.[23] It also sets out the requirement to manage waste in accordance with a 'waste hierarchy'. The hierarchy affords top priority to waste prevention, followed by preparing for re-use, then recycling, other types of recovery (including energy recovery), and last of all disposal (e.g. landfill).

The earliest of the bio refineries during the modern era of industrial biotechnology (effectively from the beginning of the 21st century) were very often ethanol bio refineries using food crops as the source of biomass to produce fermentable sugars. These were already very common in Brazil. For the vast majority of countries, the luxury of home-grown, highly efficient, highly sustainable sugar cane as the source of carbon is not possible. The 21st century boom arrived with corn starch bio refining to ethanol for two purposes:

1. As a replacement for methyl tertiary butyl ether (MTBE) as a fuel oxygenate;

2. As a gasoline supplement (typically a 10% blend of ethanol with 90% gasoline), with a view to further high percentage ethanol fuels (typically E85, with 85% ethanol).

23 https://www.gov.uk/waste-legislation-and-regulations#eu-waste-framework-directive

It was not long however, until controversy over the use of a food crop for energy purposes arose. From the early years of this century considerable emphasis has been placed on food crops as a biomass source for liquid biofuels production. The rapid expansion of the bio-ethanol industry based on corn (maize) as a feedstock (first generation biofuels) was accompanied by a debate concerning the role of biofuels in food prices increases around 2008, the so-called food *versus* fuel debate (e.g. Mueller et al., 2011). Evidence links first-generation biofuels to the price spike, some of it showing a marginal effect among a host of factors, but the actual extent of the linkage will probably never be known. Many studies (e.g. Abbott et al., 2008: Timmer, 2008, IFPRI, 2010; De Gorter et al., 2013) have arrived at the view that there were several causes, interacting in a complex way, and that biofuels were only a part of the cause. However, the quest was already underway to use organic waste sources as carbon sources in future bio refineries. Using wastes materials in bio refining has several advantages:

- It relieves pressure on land, thereby enhancing sustainability;
- It avoids the issues around indirect land use change (ILUC) (Van Stappen et al., 2011);
- It avoids issues such as the food *versus* fuel debate;
- It improves public opinion through the first three;
- In the case of waste industrial gases, especially CO and CO_2, as well as the above four advantages, uses greenhouse gases (GHGs) that would otherwise become emissions i.e. it contributes to science and policy goals around reducing emissions in climate policy;
- In the case of MSW all of the above apply (as MSW is converted to methane in landfill sites, and methane is a much more potent GHG than CO_2), and an additional policy challenge is also addressed – the diminishing supply of suitable sites for new landfills, a problem for many countries.

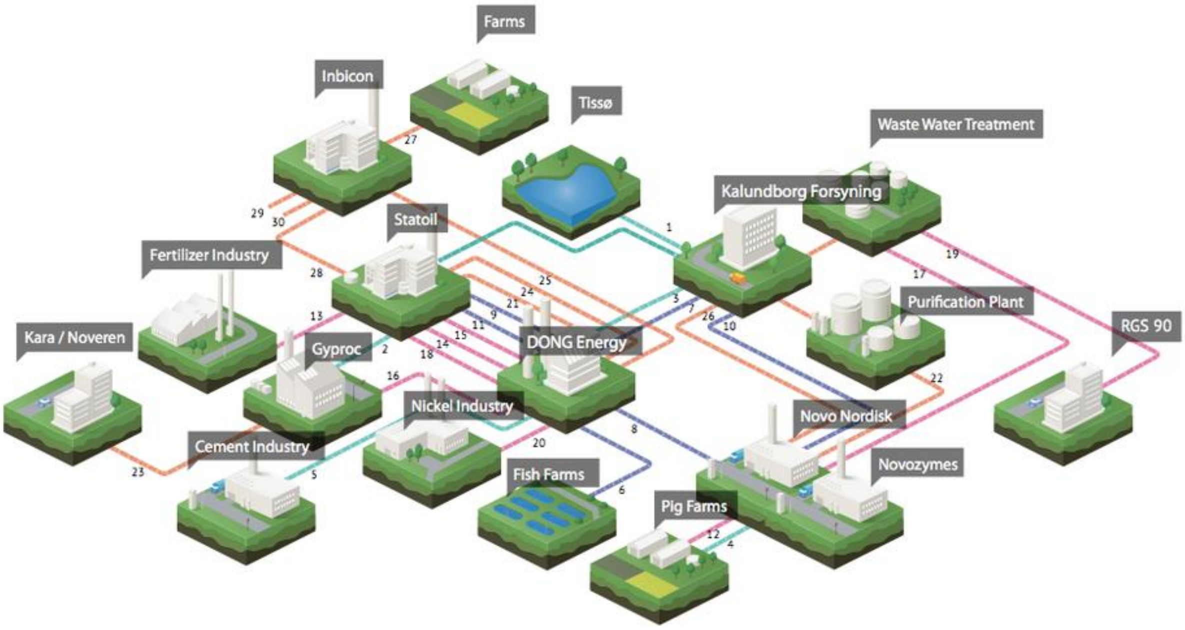
Lessons from waste exchanges: the case of Kalundborg

Waste exchange can also be called industrial symbiosis. Industrial symbiosis is defined as “the sharing of utilities and by-product resources among industries” (Chen and Ma, 2015). The industrial symbiosis at Kalundborg, Denmark, is a role model of industrial symbiosis at the town level, where energy, water, and by-product exchanges have contributed to the efficient use of inputs. There are obvious ways for waste bio refining to learn from waste exchanges. In fact, a waste bio refinery would be a complementary facility at a waste exchange site.

Kalundborg was the setting for the practical realisation of the idea of waste exchange, or industrial symbiosis as early as 1972. A waste product from one business becomes a feed in another (Erkman, 1997) e.g. fly ash from Asnæs is sent to a cement company, and gypsum from its desulphurisation process is sent to Gyproc for use in gypsum board (Ehrenfeld and Gertler, 1997). Companies have continuously implemented symbiotic practices at the site. Today there are more than 30 exchanges of water, energy and other by-products between Kalundborg Municipality and eight other companies (Figure 17). There are currently over thirty exchanges of materials at Kalundborg,[24] with the Asnæs Power Station (Dong Energy) at the heart of the network. There are also agricultural companies that have an interest in this type of industrial symbiosis as purchasers of fertilizer products and waste heat.

[24] https://www.kalundborg.dk/Erhverv/Erhvervsudvikling/Kalundborg_Symbiosis.aspx

Figure 19. Kalundborg waste exchange



Source: http://www.cyclifier.org/project/kalundborg-symbiosis/

Effectively the concept can be translated into a bio economy by the incorporation of bioenergy, biofuels and bio-based materials production via a bio refinery that can utilise waste materials, wastewater, gases and heat. This is part of the evolution of Kalundborg. In a bio refinery demonstration plant, bioethanol is being manufactured from straw and other residue materials. This, the Kalundborg Cellulosic Ethanol Plant research project (Kacelle)[25] was funded as part of the EU Seventh Research Framework Programme. The construction of a commercial plant based on the research findings has now begun in Denmark.

Around EUR 54 million was invested for the construction and development of the new plant at Kalundborg, which is owned by Inbicon / Dong Energy. Inbicon received grants of KR 76.7 million (EUR 10.3 million) for design and construction from the Danish Energy Authority under the Danish EUDP programme. The EU Seventh Framework Programme financially supported the demonstration of the plant with grants of EUR 9.1 million. Earlier, the European Fifth Framework supported the development of the technology.

In another step in the sustainable, bio-based direction, the Danish utility company Kalundborg Forsyning, Novo Nordisk, Novozymes and DONG Energy will ensure that, from the end of 2018, Asnæs Power Station will be able to deliver steam, heating and electricity generated using woodchips instead of coal.[26]

It is necessary to mention here that Kalundborg and some other subsequent waste exchanges were not publically planned projects; rather they arose spontaneously as a result of private industry initiatives with a

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25 http://www.inbicon.com/en/global-solutions/danish-projects/kacelle/kacelle-project

26 http://www.dongenergy.com/en/media/newsroom/news/articles/one-step-closer-to-a-green-future-for-asn%C3%A6s-power-station

view to capturing greater value from waste materials. However, Ehrenfeld (2003) argued that industrial ecosystems provide a greater level of public benefit than standard industrial networks because they offer increased environmental benefits.

Policy makers could bear in mind some experiences from this when designing bio refinery schemes. Planning team members must view private firms as producers of particular wastes or users of established by-products. Private company employees, on the other hand, are paid to create the most value from given inputs, not to produce a regular supply of particular by-products. Therefore, waste streams will constantly change with time as companies are encouraged to reduce waste streams.

The comparison to bio refining is not perfect. There will always be putrescible domestic waste, forestry and agricultural residues and other potential feedstocks. However, in the example where waste industrial gases such as H_2, CO and CO_2 (typical steel mill waste gases) may be harnessed for industrial fermentation processes, the availability for bio refining should not become a reason for companies not to make processes more efficient and reduce emissions. They can be expected to continuously reduce waste production, which will diminish feedstock supplies for bio refining.

As many such bio refineries in these early years of the bio economy are likely to result from PPPs, then it is essential that the engagement of the private sector heeds such issues. As close a synergy as possible between public planning and private industry is to be encouraged.

Other policy ideas

Chertow (2007) identified three policy ideas that are useful for government and business to move industrial symbiosis forward during different stages of discovery. These are more-or-less applicable to waste bio refining.

1. *Bring to light kernels of cooperative activity that are still hidden*. There are obvious roles for academic institutions here. Governments could provide R&D subsidy support that favours multidisciplinary applied research to bring innovative bio-based solutions to specific waste problems. This is likely to be very fertile territory for the academic research sector. A condition of funding could be a preliminary assessment of the scalability of the technology.

2. *Assist the kernels that are taking shape*. This could be the support of demonstrator facilities. Demonstration phase i.e. beyond large pilot, is a critical phase in process development where technical and economic barriers are likely to be highlighted.

3. *Provide incentives to catalyse new kernels by identifying "precursors to symbiosis"*. Examples of these precursors to symbiosis are resource sharing projects involving cogeneration, landfill gas, and wastewater reuse, and the development of bio-waste value chains. A stellar example of the resource sharing aspect is illustrated in the *Alchemis*[27] project at the Hooge Maey landfull site, Antwerp, Belgium. In this project, algae are mass-produced in photo-bioreactors on a landfill site. Algal growth requires sunlight, water, nutrients and CO_2. Nutrients and CO_2 are provided by the emissions from the anaerobic decomposition of MSW in the landfill. Energy for the automated production process and downstream processing and concentration of the algae is provided by the biogas from the landfill site as well. In addition, the algae result in lower energy consumption in the on-site water treatment unit, as they directly absorb the ammonium contained in the wastewater. Bio-based raw materials are extracted from the algae which can be used in the chemical industry. They replace raw materials that are now extracted from fossil fuels. The algae project was developed together with seven partners and received partial financial support from

[27] http://www.alchemis.ugent.be/

Environmental and Energy Technology Innovation Platform (MIP)[28] for three years. Partners are from both the public and private sector.

Flexible waste management regulation

If waste management regulations become over-stringent, this can disable the exchange of waste materials in industrial symbiosis. For example, the piping of flue gas from Statoil to Gyproc at Kalundborg and the sale of liquid sulphur by Statoil to Kemira would not have been approved in some countries because both substances would be classified as hazardous waste. Waste regulation has become increasingly stringent in most OECD countries. The flexibility of the Danish waste regulation system, coupled with the fact that the Danish Ministry of the Environment[29] encourages attempts to find uses for all waste streams on a case-by-case basis, allows companies to focus their energies on finding creative ways to become more environmentally benign instead of "fighting the regulator" (Desrochers, 2002). In Europe, the legal qualification of some residues or co-products as waste hinders a broad range of potential bio refinery initiatives. Furthermore, local environmental and spatial permits for managing bio-wastes are limiting possibilities (Fava et al., 2015).

In this context policy that encourages the development of an institutional framework that forces companies to internalise their externalities while leaving them the necessary freedom to develop new and profitable uses for by-products, should be given high priority.

Geography and its importance for public policy

A lot has been said of rural bio refining in recent years. There are pros and cons to this approach, but it is well understood that one of the policy goals of a bio economy is rural regeneration, needed in many OECD countries as agricultural efficiencies have drastically reduced the proportion of people working in agriculture. As the landfill dilemma is principally an issue of large conurbations, then the rural model for MSW bio refining is less likely to be attractive: there is often public resistance to building landfills in rural locations to take urban waste. It is equally likely that this will apply to rural MSW bio refining unless there are significant incentives, such as local jobs.

The landfill dilemma and lessons for waste bio refining

It is becoming more difficult to find suitable sites for properly engineered landfilling in most countries. Even in a country like Australia, with a large land mass and low population, there are good reasons to consider the available supply of landfill to be a scarce resource that should be used conservatively (Pickin, 2009). A country with quite the opposite conditions is Japan, where there is limited space and high population density. In Japan, it is becoming increasingly difficult to obtain public acceptance to install waste disposal facilities, such as landfill sites, due to a rising pressure on land use and growing public concern over environmental and health protection (Ishizaka and Tanaka, 2003). Unless many new suitable landfill sites can be found, the UK is due to run out of space for its rubbish by 2018 (Local Government Association, 2014), and serious consideration is being given to mining old landfill sites for resource recovery .

Since the 1980s more than three-quarters of all landfills in the US have closed (*Biomass Magazine*, 2011), while waste quantities have ballooned. The waste output of Chicago is now more than 300% what it was in the early 1980s, with remaining landfills getting further from the city. Across the US it has gone up about 65%, with over half of it still being landfilled (USEPA, 2014). Figures for 2013 show an Illinois-

28 http://www.mipvlaanderen.be/en/webpage/123/homepage.aspx

29 http://eng.mim.dk/contact/

wide landfill life expectancy of 21 years (Illinois Environmental Protection Agency, 2014). For Chicago itself, it could be less than ten years. Since 1997, four of the boroughs of New York City have sent MSW by road or rail to landfills as far away as Ohio, Pennsylvania, South Carolina, and Virginia. Meanwhile, New York State has imported MSW from New England and Canada to its up-state landfill sites.

In the EU the waste management and recycling sector has a high growth rate, is labour-intensive and provides between 1.2 and 1.5 million jobs (Fava et al., 2015). Waste volumes, however, continue to grow. Variation is maximal: some countries landfill 100%, others nil[30]. On the whole, European data show that preferences for treating waste have shifted in the past decade, with more waste being pushed up the waste hierarchy to be recovered for energy or recycled.

Meanwhile, new landfill construction might be the single-least popular kind of construction a municipality might have to undertake. Among the complex regulatory issues inherent to the process of landfilling are: siting restrictions in floodplains, wetlands and faults; endangered species protection; surface water protection; groundwater protection; disease and vector (rodents, birds, insects) control; open burning prohibitions; explosive methane gas control; fire prevention through the use of cover materials; prevention of bird hazards to aircraft; and closure and post-closure requirements. So from several directions, there is continuous pressure to reduce the amount of material being landfilled. Some of MSW, if it can be sorted, can be directed towards bio refining.

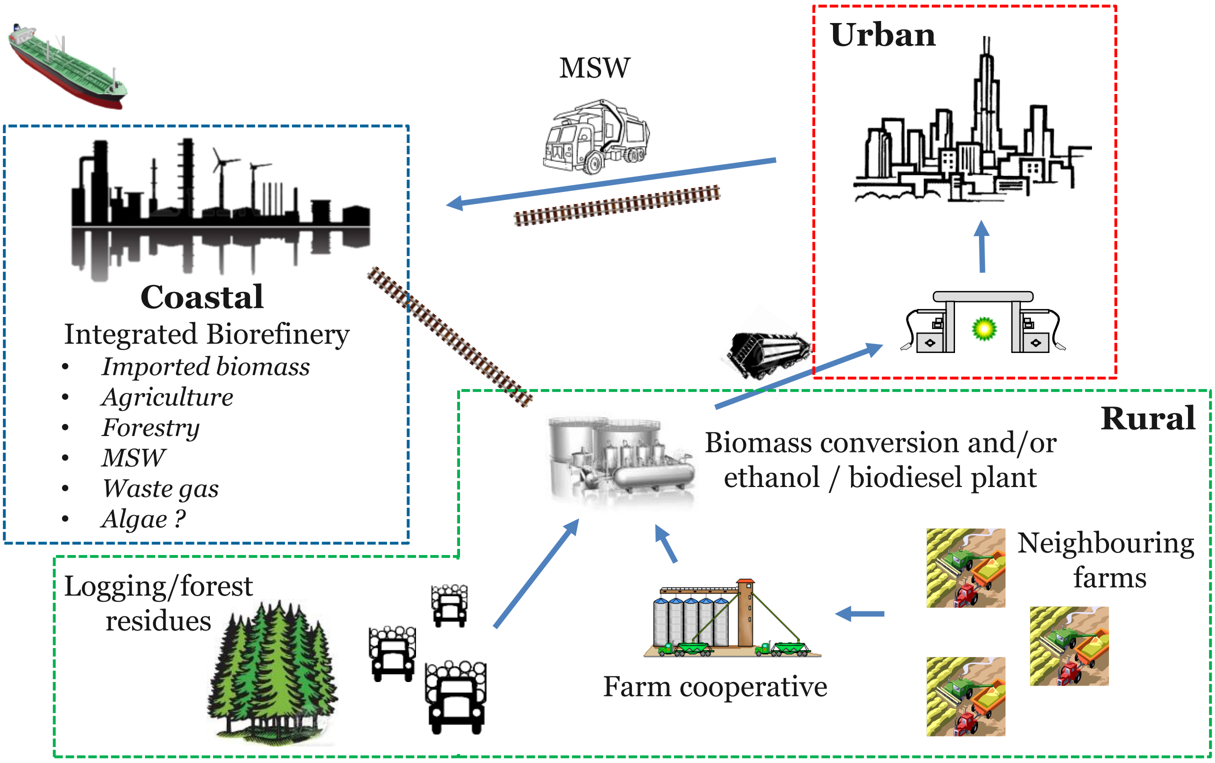
Furthermore, there are powerful policy motivators. For example, in the EU the so-called ‘landfill directive’, Directive 99/31/EC, limits the quantities of biodegradable wastes (kitchen and similar wastes, including paper) that can be landfilled. Sending organic material to landfill can then be discouraged via taxes on landfill tipping (Scharff, 2014). Several US states, including Connecticut, Vermont, California and Massachusetts are passing legislation to drive organic waste diversion, thus (slowly) creating regulatory pressure to adopt other conversion technologies. Over the last decade, Japan has shifted from a waste management policy to an integrated waste and material management approach that promotes dematerialisation and resource efficiency. Landfill shortage and dependency on natural resources imports have been key drivers of these changes (OECD, 2010).

Alternative models to consider

Taking local geographical, infrastructure and social conditions into account, alternatives to the rural location may need to be considered. Figure 18 examines some of these.

30 https://stats.oecd.org/Index.aspx?DataSetCode=MUNW

Figure 20. Alternatives to the entirely rural model for bio refinery locations



Why the coastal/rural or coastal/suburban bio refinery makes sense

Importing biomass, specifically wood chips, for electricity generation may be necessary or desirable. A coastal location with port facilities makes sense. Subsequent transport of wood chips into the rural setting to generate electricity to send back to a city may not. Many cities struggle to regenerate former industrial site on coasts e.g. docklands.

To compensate for the loss of a large bio refinery in the countryside, it may make economic sense to build small industrial facilities in rural locations for several reasons:

- This would bring some jobs to the countryside (rural regeneration);
- Transporting agricultural and forestry residue biomass, low in energy density, does not make economic sense. Converting this biomass into ethanol and/or concentrated sugar solutions or biocoal at rural cellulosic plants may make better sense. (Storing a concentrated sugar solution also provides a bio refinery feedstock outside of the crop growing seasons). Ethanol can then be sent either to the large integrated bio refinery or a petrol blending plant, or both. This creates at least two markets for ethanol – for fuel and for chemicals;
- Many cities struggle to regenerate former coastal industrial sites e.g. docklands;
- Transport distances would be smaller;

- Environmental footprint of the small plant would be less than a full integrated bio refinery, and there would be lesser conflict with brownfield policies;[31]
- It is still possible in a small facility to generate electricity;
- There could be significant numbers of indirect rural jobs e.g. warehousing, farmers' cooperatives to collect agricultural residues, haulage jobs;
- Small facilities require lower quantities of water – for example, at the Crescentino bio refinery the total water requirement comes from the biomass and no river water is needed.

Transporting MSW by road, rail or barge over relatively short distances to a coastal location is likely to be shorter than to a rural facility. Hauling MSW into a rural location is a practice that could be unpopular with country people (smells, wear-and-tear on roads, safety issues around schools).

Another factor for consideration is the future commercial deployment of marine bio refineries, to date still struggling behind other bio refinery types. Abundant seawater and access to waste CO_2 from, say coastal petro- refineries and petrochemicals plants may be major determinants of the location of marine bio refineries. It might be prudent to build integrated bio refineries at coastal locations so that in future it would be possible to co-locate marine bio refineries when they are ready for deployment.

Waste materials available for bio-based production

Theoretically, a vast treasure trove of solid, liquid and gaseous wastes is available, but limited in practice for various reasons. Collecting straw or forestry residues, for example, may not be worthwhile for farmers or forest owners, and therefore might need to be incentivised. Municipal solid waste contains a lot of fermentable materials, but they are mixed up with non-fermentable materials. Industrial waste gases exist in profusion and are often in a relatively pure form, but microbial processes for their fermentation are immature, and there may be little incentive for companies to capture waste gases.

There is no doubt that there is a large amount of waste that can be used as feedstock, but there has to be the political will to incentivise its collection. In the case of rice straw, for example (OECD, 2015a), well over half a billion tonnes is available in Asia, and this material is routinely burned. The situation is well illustrated by the EU example.

Bio-production bottlenecks in the US have occurred as a result of multiple factors such as high costs of biomass resources, the recalcitrant nature of lignocellulosic feedstocks, the high cost of enzymes or chemical to de-construct biomass, and the need for optimised bioprocesses for a wider array of varying feedstocks. The USDA has been addressing the needs for new feedstocks (Box 8) while at the same time helping to maintain and develop the first generation ethanol and biodiesel industry.

[31] In town planning, brownfield land is an area of land previously used or built upon, as opposed to greenfield land which has never been built upon. Brownfield status is a legal designation which places restrictions, conditions or incentives on redevelopment.

Box 8. The need for new feedstocks in the US: initiatives of the USDA

To address bio-production bottleneck factors, the US Department of Agriculture (USDA) introduced five Regional Biomass Research Centres. One advantage of this USDA programme was that it provided incentives for field researchers, those optimising crops as feedstocks for biofuels, to work closely with researchers developing bio refinery technologies. As the industry evolved, focus has gone from creating corn and grain-derived ethanol to creating cellulosic ethanol, and now toward development of integrated processes that produce drop-in replacement to petroleum products. Technologies to produce advanced biofuels such as *n*-butanol, pyrolysis bio-oil, hydroxymethylfurfural, liquefied biogas, and even (bio) hydrogen have been developed and are arguably commercially viable.

It should be noted, though, that the corn ethanol industry is a multimillion dollar enterprise that merits research towards making it as efficient as possible. One strategy to ultimately reach the Renewable Fuels Standard (RFS) targets is to make stepwise improvements in the existing bio refinery concepts. These stepwise improvements must include a regional strategy that builds in enough flexibility to use the "*cheapest sources of renewable carbon*" within a given region. Such flexibility implies, for example, using grain sorghum, switchgrass, or miscanthus in the US Midwest, sweet sorghum or cane sugar in the US South, guayule bagasse in the US Southwest, almond hull sugars in California and even citrus peel waste in Florida. Another key element is the ability to integrate existing ethanol plants with other operations, specifically utilising thermochemical conversion of all biomass sources or utilising integrated digester to produce biogas and biogas-derived products. Bio refinery strategies are best optimised when field feedstock research on yield, crop quality and biomass cost is coordinated with bio refinery strategies (Orts and McMahan, 2016).

Source : Courtesy of Harry Baumes, USDA

Waste gases

Looking at various sources of information, Adani (2015) has attempted to quantify how much of different categories of waste are available and to put those numbers into the context of industrial production. Fermentable gases are produced in large quantities from different sectors. However, their collection from some of these sectors is not feasible. Two of those which are feasible for collection are also major contributors to emissions: energy supply and industry.

Clearly in the sectors where collection is feasible, CO_2 is by far the most important gas, although it should also be borne in mind that methane (CH_4) is far more potent as a greenhouse gas. Four critical figures given by Adani (2015) regarding the potential of gas utilisation in waste bio refining are:

- Consumption of renewable raw material for chemical industry and others: 857 million tonnes per year;
- Total mass used producing chemicals: 271 million tonnes per year;
- Total mass from CO_2 industry and energy production: 7 596 million tonnes per year;
- Total mass from bio-waste and food loss: ~ 354 million tonnes per year.

The figures would indicate, at least at a superficial level, that the amount of CO_2 available is far in excess of what is required. Totals, however, can mask many feasibility issues e.g. the efficiency of the use of gases in bio refinery operations, other technical aspects relating to e.g. purity of gases, ease and cost of collection. Some preliminary estimates from LanzaTech, a leading company in gas fermentations, suggest that more than 30 billion gallons per year of high value products can be produced from steel mill waste gases alone; this is a considerable contribution to the worldwide energy and chemical pool.[32]

Residual biomass

Bentsen et al. (2014) suggested that there are over 3.5 billion tonnes of residual biomass generated every year in the world, representing about 66% of world energy consumption in transport. In Europe, another study identified 900 million tonnes per year of waste and residues (Wasted, 2014). Considering existing competing use and soil quality conservation, 223-225 million tonnes per year of residual biomass is available for advanced biofuel production, equivalent to 12% of current road fuel consumption or 16% of projected consumption in 2030.

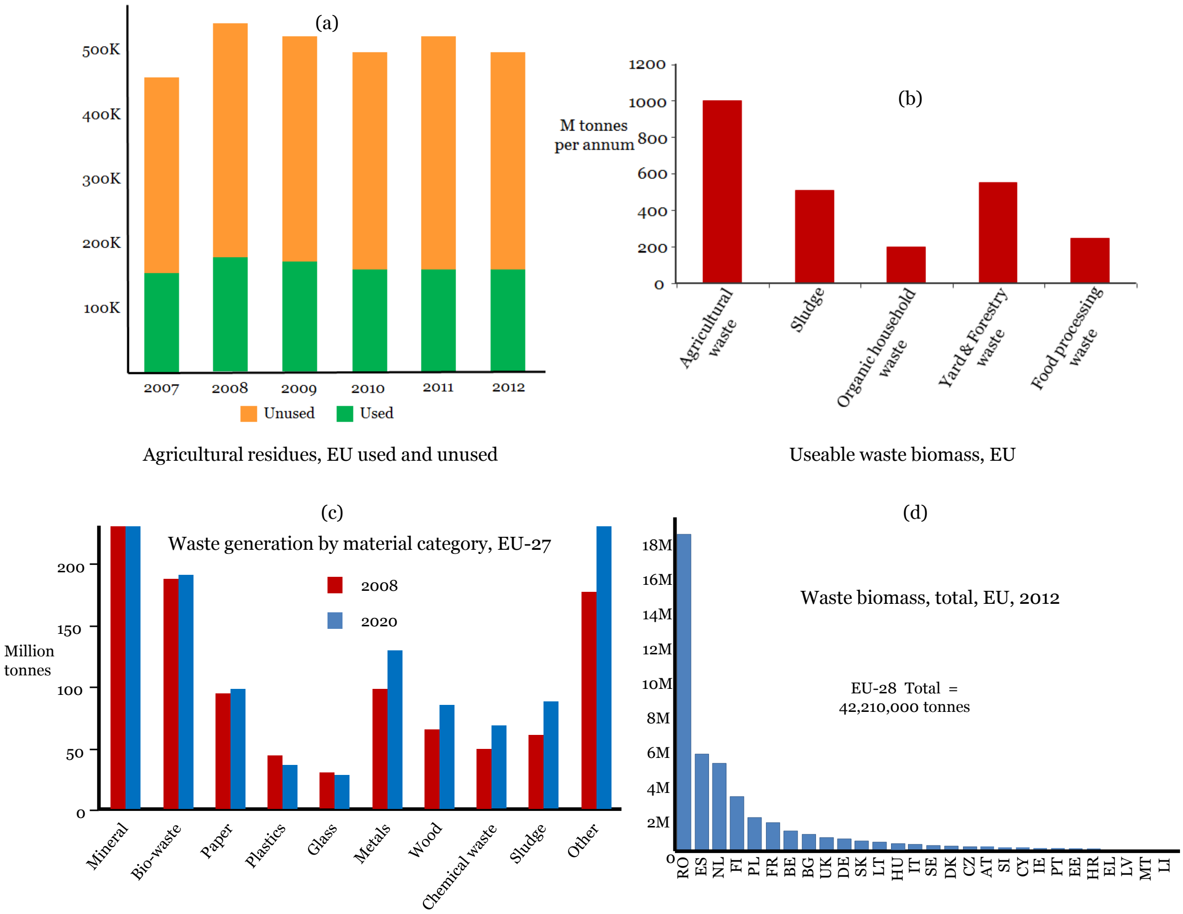
The Department for Environment, Food and Rural Affairs (Defra) of the UK estimates that 100 million tonnes of bio-waste is available for biogas production in the UK. This includes agricultural residues, food and drink waste and sewage sludge (House of Lords, 2014). The serious caveat is about purity. Every stage at which purification of material is required for a bio-based process represents an additional cost.

The problem of terminology and definitions, and how these influence potential estimates

Figure 19 shows several estimates of the quantities of waste materials generated annually in the EU. There is a problem of definition, which leads to huge variation in figures across different sources.

[32] http://www.aiche.org/academy/videos/conference-presentations/gas-fermentation-industrial-waste-gases-fuel-and-chemicals

Figure 21. Data from different sources highlight the discrepancies in waste potential.



Note: (a) https://biobs.jrc.ec.europa.eu/market/agricultural-biomass/(b) Fava et al. (2015)/ (c) OECD (2014b)/ (d) https://biobs.jrc.ec.europa.eu/market/waste-biomass-total

Comparing (a) with (b), for example, the figures are very different, and this may relate to the difference between “agricultural residues” and “agricultural waste”. Comparing (c) with (b), the numbers for “sludge” are very different, and the use of the term “bio-waste” in (c) could incorporate all of the categories in (b). The numbers in (d) refer to “waste biomass” in the EU, 2012.

Therefore the mixture of terms and a lack of standardised definitions make it very difficult to truly assess the volumes of different (waste) materials that can be used in bio refining. This compares poorly with the easily identifiable volumes that would be available from crop feedstocks, such as volumes of sugar cane or sugar beet: these figures are collected internationally and are readily comparable. Therefore an important message for both the public and private sectors is that standardisation is needed of terms and definitions:

- For the public sector, when attempting to make strategic documents like bio refinery roadmaps. For example, how would it be possible to create a timeline for a national or regional bio refining industry in the absence of certainty around feedstock volumes?;

- For the private sector, building a bio refinery to a certain tonnage capacity needs certainty on available feedstocks also.

The issues around definitions can be summarised.

The development of common definitions will enable better data collection by both private and public entities. This would help resolve the issue of comparison between different data sources mentioned above.

- Bio economy: lack of an agreed definition is a hindrance (denies the science input, no international databases, possible trade barriers).

- Bio-waste: most of the statistics do not distinguish between wet and dry weight, so no comparisons can be performed.

- It is extremely important to clarify the definition of bio-waste. According to the European Commission: “*Bio-waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste*.” By leaving out forestry and agricultural residues, the tonnages generated will be very different.

- Definition of ‘waste disposal’ could be changed to allow collection, transportation, sorting in view of its conversion in bio refineries. Effectively, if a material is to be converted in a bio refinery then it should no longer be regarded as a waste but as a resource. If this is done officially, many of the problems around collection and transport would be nullified;

- A definition of ‘bio-based product’ and a harmonised framework for bio-based products is needed as a standard for public procurement and business development. Progress has been made by the European Committee for Standardisation (CEN) in the development of a coherent and harmonised standardisation framework for bio-based products, but there is still a need to spread the use of the developed standards with a view to capitalise on their market pull potential. This international cooperation can be done by, for example, exchange of Best Practices and experiences in order to reach a more coherent approach to bio-based products globally. Without it, trade barriers are certain to develop;

- An assessment of *competitive potential*, which generally requires an economic model of competing technologies, is required. For example, the future of zero-carbon transportation depends whether cellulosic ethanol becomes economical at large scale and whether that can compete with electric vehicles.

Ultimately, integration of actors across sectors and hence the creation of new value chains is limited by disparity and lack of control of terminology and standards. In short what is called for is commonly agreed vocabulary throughout value chains, from feedstock suppliers to bio refining to downstream actors in the application sectors.

Municipal solid waste volumes

> "*CEO* [of Enerkem] *Vincent Chornet looked at the big picture of potential, and it is big. Although there are 1.3 billion metric tons of MSW, about 420 million of them are suitable for Enerkem. That's as much as 160 billion liters (42 billion gallons) of renewable fuels (or chemicals) from one sector alone — more than doubling the addressable market for biofuels with just the one feedstock — and vastly outstripping the current $$ being brought in via waste to energy (incineration) technologies, which is around $7.6B, or a fraction of the $70B+ market available with the new technology*".
>
> *Biofuels Digest* (2015b)

The figures for tonnages of MSW (Box 9) mentioned above are global tonnages. The figures merit further investigation from the public policy perspective. Although this appears to be an unprecedented opportunity to really make a difference to the landfill dilemma, it is necessary to examine how the private sector may interact with public policy. For example, would this activity interfere with other markets, especially recycling, energy recovery and electricity generation, and industrial composting?

Addressing the latter part of the quotation, combusting mixed waste also comes with issues, such as cost, sorting, scrubbing the gas stream to remove toxins, GHG emissions, and, in some locations, negative public reaction. Moreover, as the quotation hints, the product, electric power, is low value and effectively zero value-added.

Different figures give a perspective on what MSW tonnages translate to in bio-based production (Table 5).

Table 5. Conversion of tonnages of MSW into crude oil and bio-based equivalents

Quantity of MSW = 260 Million Tons/year	
Biomass Feedstock (10% Water)	140,400,000 Tonnes per year
Crude Oil Equivalent	322,436,000 barrels per year
Equivalent Diesel Fuel	14,490 Billion gallons per year
Ethanol Equivalent	24,500 Billion gallons per year
Electricity Equivalent	164,300,000 MW per year

Source: Hennessey (2011)

Box 9 What is MSW?

Generally, in European countries and OECD nations, MSW covers waste from households (82% of total MSW) including bulky waste, waste from commerce and trade, office buildings, institutions and small businesses, yard and garden waste, street sweepings, the contents of litter containers, and market cleansing waste (Eurostat, 2003). The definition of MSW excludes waste from municipal sewage networks and treatment, as well as municipal construction and demolition waste. However, national definitions of MSW may differ (OECD, 2007). In a developing economy, MSW is generally defined as the waste produced in a municipality. Most of the MSWs generated in developing countries are non-segregated and, therefore, it may be either hazardous or non-hazardous (Karak et al., 2012). It is likely in many countries to contain a significant amount of food waste, which is extremely useful for gasification or fermentation.

Regarding municipal waste, about 65% of the waste generated is biodegradable. In order to reduce the environmental pressures from landfill, particularly methane emissions and leachates, the EU Directive on the landfill of waste 1999/31/EC[33] requires Member States to reduce landfill of biodegradable municipal waste to 75% of the amounts generated in 1995 by 2006, to 50% by 2009, and to 35% by 2016.

In the US, the number of landfill sites has dropped by 75% in the past 25 years. However, this number is deceptive. Much of the decrease is due to consolidation of multiple landfills into a single, more efficient facility. Also technology has allowed for each acre of landfill to take 30% more waste. So during this time, the available landfill per person has actually increased by almost 30%. As of 2010, total US MSW generation was 250 million tons. Organic materials continue to be the largest component of MSW. Paper and paperboard account for 29% and yard trimmings and food scraps account for another 27%; plastics 12%; metals 9%, rubber, leather and textiles 8%; wood is approximately 6.4% and glass 5% (Hennessey, 2011).

The earliest MSW bio refineries are open for business

There are at least two high-profile bio refineries that have been established through public-private partnerships to convert MSW into bio-ethanol and methanol. The Ineos Vero Beach, Florida, facility is relatively small: in 2013 it began producing 8 million gallons of cellulosic ethanol per year from vegetative, yard, and municipal solid waste. It received a USD 75 million loan in 2011 (USDA News Release, 2014). The other is the Enerkem plant in Edmonton, Canada (Box 13). Both are gasification and fermentation plants i.e. the pre-treatment of MSW involves gasification to get it into an on-specification state for use as a feedstock.

Other MSW bio refineries are approved, planned or under construction. The USDA has awarded Fulcrum a USD 105 million Bio refinery Assistance Program loan guarantee through Bank of America to construct a facility in Storey County, Nevada, to convert MSW into biodiesel and jet fuel. The plant is expected to produce 11 million gallons of fuel annually (USDA News Release, 2014). It is set to begin operations late in 2017.[34]

No country faces the landfill dilemma in starker terms than China. The breakneck pace of development combined with rapid urbanisation means that waste production is equally rapid and the disposal problems very challenging. In 2015, Enerkem expanded its business relationships signing three separate agreements with Chinese companies in Shanghai and Qingdao.

Where are some of the other projects that might be advanced in the future?

In Maine, the University of Maine has been hired by a consortium of 187 towns and their MSW streams to evaluate whether Fiberight's technology could be a good option for the state's waste. The

33 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31999L0031&from=EN

34 http://fulcrum-bioenergy.com/facilities/

company is producing its Trashanol at a facility in Lawrenceville, Virginia. Currently the consortium's waste is processed by a waste-to-energy plant in Orrington it partially owns but will not likely be profitable after 2018 when its current power offtake agreement expires.

In Thailand, Phuket's Provincial Administration Organization is seeking USD 22.6 million to build a waste-to-biofuel facility that would use the entire island's MSW as feedstock. Funding for the project will be sought from the national Ministry of Natural Resources and Environment.

In Canada, Iris Solutions, Plenary Harvest Surrey and Urbaser S.A. have been shortlisted from an original group of 11 companies to invest in, build and operate the city of Surrey's USD 60 million residential kitchen and yard waste into renewable fuel project. The fuel is destined to power the city's garbage collection vehicles.

Is MSW bio refining a truly sustainable and economic business model?

In the face of growing waste management and disposal costs, the demand for petro-based products, be they fuel, plastics or chemicals, also continues to rise. Although policy in sustainability has been notoriously slow, sustainability goals and mission statements are increasingly common as part of business for many large corporations. The danger is that, in the absence of public policy, industry may go it alone, which may not result in the most sustainable solutions or the most desired public policy goals.

The policy pros and cons

This section is largely a summary and extrapolation of some considerations in Renewable Waste Intelligence, 2014.

Revenues are uncertain. There are two potential revenue streams for a bio refinery facility: firstly the gate or tipping fees[35] from taking the waste; and secondly the revenues from selling biofuels. Gate fees vary enormously by country and region, and landfill tax tends to make gate fees higher. Where gate fees are low, the production of biofuels from waste is not cost-competitive with landfill. Therefore public stimulus is indicated in order for countries, regions or cities to break out of the landfill dilemma.

For waste treatment facilities such as incinerators or composting plants the fee offsets the operation, maintenance, labour costs and capital costs of the facility along with any profits and final disposal costs of any unusable residues.

It has been argued for some years that a policy shift to more support for bio-based chemicals is needed. In this particular case, chemicals usually have higher margins than liquid fuels, have more value added and create more jobs than biofuels. Therefore diversification of MSW bio refineries to also make bio-based chemicals would seem to improve the economics irrespective of gate fees.

This is a competitive market. Anaerobic digestion (AD) is a very old, tried-and-tested technology that has been brought up-to-date in the last decade. It is the anaerobic fermentation of waste to biogas, which is over 50% methane. AD facilities are generally cheaper to design and build than waste-to-biofuels bio refineries, plus they are significantly better proven. The flexibility of AD as a process allows for biogas to

35 Gate fee and tipping fee are interchangeable terms meaning the same thing. It is the charge levied upon a given quantity of waste received at a waste processing facility. In the case of a landfill it is generally levied to offset the cost of opening, maintaining and eventually closing the site. It may also include any landfill tax which is applicable locally. http://en.wikipedia.org/wiki/Gate_fee

be used to generate electricity, it can piped as gas, it can create fertilizer and power can also be adapted to provide combined heat and power.

Incineration is also both proven and effective at disposal and energy generation. Early incinerators had a bad reputation, but the challenges have been overcome. In Japan, incineration with energy capture has been increasingly popular as it can be used to tackle the vast waste plastics problem (Yamashita and Matsumoto, 2014).[36] Burning the other organic fraction of MSW with plastics reduces the sorting difficulties. So MSW bio refineries are in competition with other buyers such as incineration utilities (Knight et al., 2015).

There are counter-arguments that favour waste-to-biofuels (and/or chemicals). Firstly, the technology creates fuel from non-recyclable and non-compostable MSW i.e. it can work in partnership with other sustainable waste technologies, not against them. Secondly, more experience is being gained with gasification technology, and this will help with the economics and the confidence in using a process such as the Enerkem process. There is also an embryonic technology to turn waste gases (and natural gas) into animal feed and value-added chemicals through fermentation. Calysta[37] of Norway uses natural gas-fed fermentation to produce feed-quality protein with high nutritional value for use in aquaculture.

Eventually, the diversity of chemicals that can be produced after gasification will be higher. With environmental regulations constantly becoming more stringent, any technology that can improve both economic and environmental outcomes whilst creating jobs has to be taken seriously, even if currently the alternatives such as landfill are more competitive. Landfill is no solution for the 21st century.

Biofuels are dependent on government intervention. There is no shortage of proof for this. Public procurement, production mandates, tax incentives are all there as evidence. However, it is not so well known that fossil fuels are also highly subsidised through production and consumption subsidies: globally fossil fuel consumption subsidies amount to over half a trillion dollars (USD) per annum (IEA, 2012; IEA, 2013). Moreover, waste to biofuels and bio-products projects are attracting interest and investment without the need for a market based heavily on subsidy (Renewable Waste Intelligence, 2014). And, as already emphasised, policy makers could look to the future of this technology beyond fuels. The first glimmerings of public policy to support bio-based chemicals have appeared. The 2014 amendments to the Bio refineries Assistance Program 9003 of the USDA is a landmark shift in this direction (Box 3).

Scale-up is now the critical issue

MSW bio refineries are thus far unproven at commercial scale. Second generation biofuels are so recent that there is no long term success story standing as evidence of a scalable, repeatable business model. The successes of first generation ethanol in Brazil are not transferrable to other countries. Thus there is even less experience with waste-to-biofuels projects and facilities. Without high quality, robust data from functioning operations, the justification for large capital injections will remain a barrier. However, as described, the number of such projects is gradually growing. They can be regarded as flagship projects, and if successful they should help de-risk future projects. Nevertheless, policy makers will be obliged to study the business case carefully on a case-by-case basis. This will require close communication between municipalities and their waste management operators, the private sector and the potential investors along with public agencies offering investment.

36 The ultimate destination for about 3% of plastic waste is the oceans. It has been estimated that the plastic waste entering the world's oceans could double in the next ten years (Jambeck et al., 2015).

37 http://calystanutrition.com/nutrition/

BIOREFINERY CASE STUDIES: DIFFERENT PERSPECTIVES FROM DIFFERENT COUNTRIES

Enabling bio-based growth in Scotland

There is a clear connection between the growth of industrial biotechnology/green chemistry in large OECD economies that have a major chemicals sector. The loss of competitiveness in chemicals in OECD countries is a serious economic threat. Thus capacity building in industrial biotechnology is particularly evident in the OECD countries whose economy is heavily dependent on industrial chemistry e.g. Belgium, France, Germany, Italy, the Netherlands. However, a loss of competitiveness in a small country with a large stake in the chemicals sector could have even worse ramifications economically. Scotland is a country in that category.

Scotland currently has 43 companies working in industrial biotechnology employing over 1 100 FTEs, with industrial biotechnology already contributing GBP 189 million (turnover) and GBP 61 million in gross value added (GVA) to the Scottish economy. With a long history in engineering, chemistry and the life sciences, it has been identified that there is good potential in Scotland for the development and successful application of industrial biotechnology.

To realise this potential, Chemical Sciences Scotland[38] is making industrial biotechnology a priority over the next five years. It aims to increase awareness of industrial biotechnology as a transformational tool. It will encourage company adoption of industrial biotechnology via company growth and improved turnover. It is address skills requirements through a programme of targeted training and development. As a small country, Chemical Sciences Scotland sees the value of collaboration with overseas partners.

It is the mission in Scotland to "*grow industrial biotechnology related turnover in Scotland to GBP 900 million by 2025*". These goals are elaborated in the Scottish government's *National Plan for Industrial Biotechnology* (Scottish Enterprise, 2014). Along with *The Bio refinery Roadmap for Scotland* (Scottish Enterprise, 2015), there is clear evidence that Scotland is building capacity from R&D to full-scale implementation of industrial biotechnology.

Delivered over the next ten years, the *Biorefinery Roadmap for Scotland* will focus on four key themes: developing unique resources and capabilities to build bio refineries within Scotland; identifying and working with the companies delivering the bio refineries; strengthening research and innovation in bio refining, and; creating the market environment for investment.

The first major public investment in Scotland, however, is in the industrial biotechnology innovation centre, IBioIC.[39] Launched in 2014, it was set up to bridge the gap between education and industry in industrial biotechnology. In line with Scottish government policy, the deliverables for IBioIC are:

- To mitigate and de-risk projects of high potential;
- To provide a skilled workforce with industrial biotechnology qualifications at all academic levels;
- To furnish guidance for policy makers based on expert knowledge of the bio economy, and;

[38] http://www.scottish-enterprise.com/industry-support/chemical-sciences

[39] http://www.ibioic.com/

- To create strategic, innovative and sustainable industrially relevant solutions.

The near-term expectations for industrial biotechnology by 2020 for industrial biotechnology are: 500 new direct jobs; GBP 30 million invested; more than GBP 100 million in inward investment; GBP 400 million in bio-based revenue; 200+ active industry members; 200+ people trained, and; demonstrator scale facilities. The 2030 target is to generate GBP 1 to 1.5 billion of GVA contribution annually to the Scottish economy, representing a growth of revenue from today's estimated value of GBP 190 million, to between GBP 2-3 billion.

Like most European countries, there is likely to be a lower impetus on food crops as feedstocks for bio refining. Therefore waste bio refining is a priority for Scotland also. Several of these have already been identified (Table 6), deriving from Scottish strengths in primary and secondary production.

Table 6. Feedstocks in Scotland

Feedstock	Relative Supply	Cost to the Gate	Typical Value of Biorefinery Products	Competion for Feedstock	Technical Readiness	Score
Secondary Production						
Whisky Residues	3	3	1	3	2	54/81
Wood Residues	2	2	2	3	2	48/72
Organic Arisings*	2	3	1	3	2	36/54
Primary Production						
Wood	2	2	2	3	2	48/72
Macroalgae	3	1	3	3	1	27/81
Coal Based Methane	2	2	2	1	2	16/24
Grains	2	1	2	1	3	12/12
Vegetables	2	1	3	1	2	12/18
Oil Crops	1	1	2	1	2	4/6

* = consisting of industrial and municipal waste

Source: Kilburn (2015)

Like in any country there are challenges associated with feedstocks (logistical, technical and economic) (Table 7).

Table 7. Challenges associated with feedstocks in Scotland

Waste stream	Potential Platform Products	Logistical Challenges	Technical Challenges	Commercial Challenges and opportunities
Whisky residues (spent grains and pot ale)	Biogas Fermentable sugars Protein	Bulky Digestate	Economic conversion processes	Optimising the value
Wood and woody residues	Synthesis gas Fermentable sugars Lignin Cellulose	Bulky Annual variability	Lignin conversion	Economics of scale Developing higher value products
Municipal waste	Synthesis gas Biogas Fermentable sugars	Variability Contamination Bulky	Consistent products from a variable feed	Optimising the value
Industrial waste/ residues	As wide and varied as the sources	Volume Collection	As wide and varied as the sources	Finding the sweet spot of volume, process and demand
Macro-algae (seaweed)	Specialty chemicals Alginates Fermentable sugars	Seasonality Harvesting Storage	Hierarchy of product value Year-round storage	No commercial successes

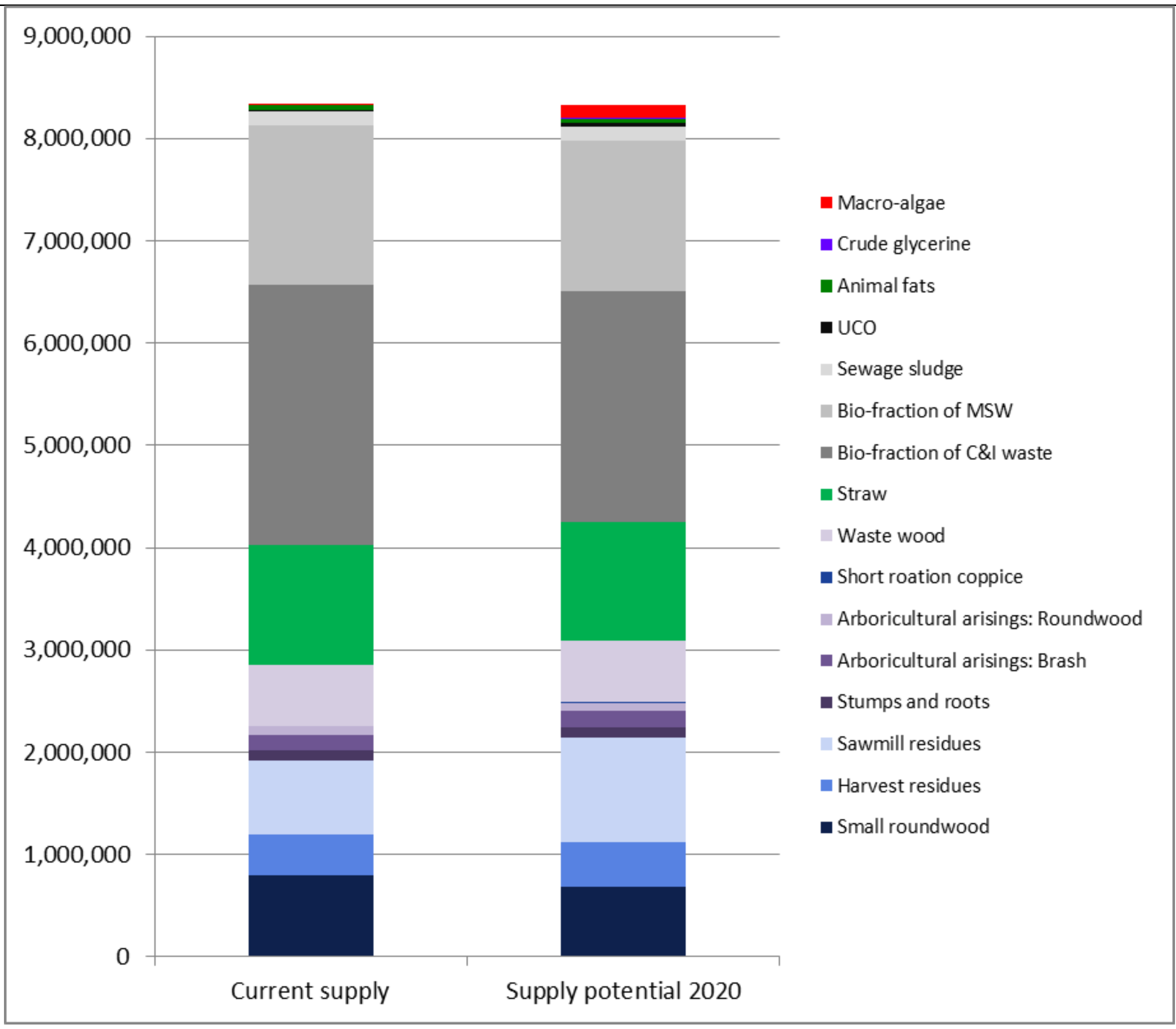
Source: Kilburn (2015)

A comprehensive study of feedstocks and their availability in Scotland has been conducted (Box 10).

Box 10. Bio refinery feedstock potential in Scotland

The assessment of feedstock potential indicates that the most abundant biomass feedstocks currently produced in Scotland are residues and co-products from the timber value chain - specifically small roundwood and sawmill residues; household, commercial and industrial bio-based wastes, and straw. Considering the current markets for these resources, the most accessible resources are residues from the timber value chain and the bio-based fraction of household, commercial and industrial waste. Whisky waste has always been a problem in Scotland: it is very high strength, highly biodegradable, and is produced in large volumes. There is considerable potential for its bio refining to useful products, and currently bio-butanol is a favoured focus.

Bio refining feedstock production in Scotland, current and 2020 supply excluding competing uses (oven dry tonnes per year).



Over the medium to long term there is significant potential for the production of macro-algae in Scotland, although there is high uncertainty regarding the total volumes of material that may be sustainably harvested, production costs, and the market price that would have to be realised to stimulate the supply chain. However, there is more general uncertainty beyond 2020 around feedstock availability, in part due to a lack of policy on renewable energy targets post 2020.

Source : E4tech (UK) (2014)

Bio refineries for producing chemical compounds: an Italian success story and lessons learned

Italy has been particularly successful in industrial biotechnology in Europe, although there is no specific national bio economy strategy in Italy as yet. However, there is a generally favourable legislative framework for eco-innovation (Box 11). Much of the success is down to the activities and vision of Novamont, a bio-based chemistry company of Italy, headquartered in Novara, with production, field and experimental facilities distributed widely through the country and beyond. Novamont was able to develop expertise in biodegradable plastics production as a result of a single-use plastic bag ban in Italy (OECD, 2013).

Box 11. Some favourable policies in Italy

In January 2011, Italy promoted a first of its kind regulation aimed at replacing traditional plastic carrier bags with biodegradable and compostable bags (compliant with the harmonised CEN Standard 13432) and reusable long-life bags. This initiative represented an example of how innovation and growth in the field of bio-based industries can be achieved by legislative *ad hoc* measures that encompass environmental benefits and stimuli for investments and job creation:

- Financial law 2007: Shopping bags since January 2011 have to be either biodegradable and compostable or reusable;
- DL152/2006: 65% separate collection in 2012. Organic waste to be collected either in biodegradable and compostable bags (EN13432) and paper bags or in bins;
- New law 28, 24/3/2012: non-reusable shopping bags have to be certified by accredited bodies as biodegradable and compostable according to the norm EN13432. There is an additional threshold thickness for reusable bags.

The Italian National Technological Cluster of Green Chemistry[40] (SPRING) is on its way to producing a roadmap. The roadmap will be used for two purposes. On the one hand, at a political/institutional level, it proposes regional, national and European institutions policy actions to overcome possible barriers and highlights the potential impact of the proposed actions in terms of competitiveness, development, employment and sustainability. On the other hand, at a technical level, it proposes themes of R&D of primary importance and facilitates the matching in terms of supply/demand among the Cluster members, thus encouraging the creation of partnerships and facilitating access to funding opportunities.

Novamont has been at the heart of this success as a result of critical factors relating to bio-based biodegradable plastics:

The adoption of clear and simple norms in the area of separate collection of organic waste;

The evolution of research and innovation in the field of biodegradable and compostable plastics from renewable origins.

The separate collection of organic waste in Italy has increased from 2.6 million tons (organic and green waste) in 2006 to 5.2 million tons in 2013, with less than 4.8% impurities. There are currently 240 composting plants and 43 anaerobic digestion plants in Italy. But it was the stimulation of a bio-based plastics industry that can be seen as the real value-added breakthrough in Italy. There were several very important lessons learned from the bioplastics value chain case in Italy.

- A solution to a critical environmental issue (organic waste generation), was achieved by adopting feasible and ambitious standards and creating development through integrated local supply chains starting from products and not from fuels.
- Traditional downstream technologies/productions were revitalised by new products and through continuous development.
- Multi-disciplinarity and collaboration among different sectors broadened the horizons (organic waste, industry in the local areas, agriculture, schools, universities, research centres, local, national and European institutions and large-scale distribution).

40 http://www.clusterspring.it/home-en/

- The validity of the initial hypothesis on products and third-generation integrated bio refineries was confirmed. It became clear that starting from local areas and the environmental and life quality problems was the successful approach.

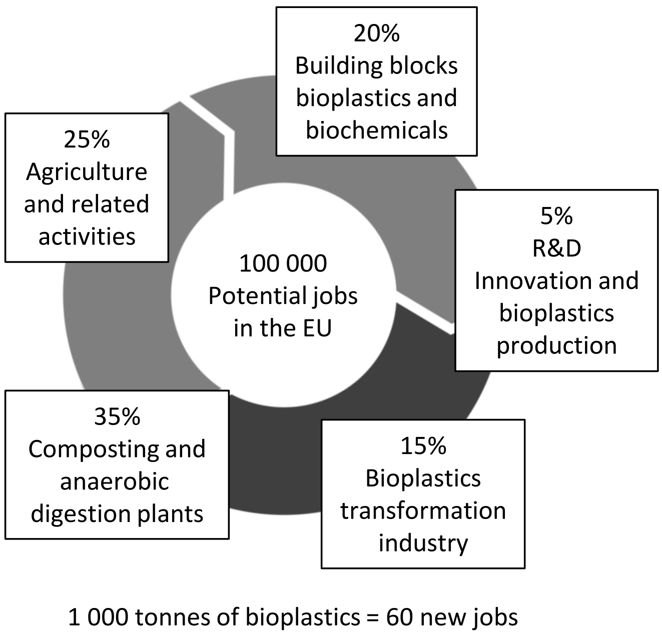
- Legality was a necessary condition for innovation and development.

- A fundamental concept: creating a high-quality replacement market that could merge the solution of an environmental problem with the restart of local production chains.

Although sharing some things in common, chemicals bio refineries are quite different in character from bio refineries solely from the production of biofuels. The Novamont vision for these future bio refineries is the *bio refinery integrated in the local area*. These are primarily dedicated to the production of chemicals and high added-value products. Different local raw materials are sourced (e.g. low-input crops, scraps) that respect local biodiversity. The use of marginal lands and re-industrialisation of de-industrialised/no longer competitive sites is a sustainable approach that saves threatened, high skill jobs. The vision also calls for the integration of a wide and increasing range of low-impact technologies and plants. Finally an interdisciplinary approach and interconnection with the world of farming, research, environment, consumers and with local institutions is also a necessary element of the vision.

This vision is possible because, unlike the petrochemical supply chains for bioplastics, the bio-based supply chains can be firmly rooted in local areas and communities with economic, social and environmental advantages not seen in petrochemical supply chains (Figure 20). Many of the jobs created in the petrochemical supply chain are in the countries that export oil. In bio-based supply chains more jobs can be created domestically, they can stimulate other business, such as composting and anaerobic digestion, and boost local agriculture.

Figure 22. The value of a supply chain rooted in local areas for the production of bio-based plastics



Source: Redrawn from Gregori (2015). Percentages are of total jobs.

Cardoon: making products from low-value biomass on marginal land

Cardoon is a thistle-like plant in the sunflower family. The wild cardoon is adapted to dry climates and can grow on marginal lands, and grows up to about 1.5 metres tall or more. In some countries it is considered an invasive weed. However, it has other characteristics that make it an attractive feedstock for bio refining. It has attracted attention as a possible source of biodiesel fuel.

The oil extracted from the seeds of the cardoon is similar to safflower and sunflower oil in composition. Cardoon is the feedstock for the first bio refinery in the world converting the installations of a petrochemical plant in Porto Novo, Sardinia, providing biomass and oils for the building blocks of bioplastics. However, the long stalks and the roots can be used as a source of cellulosic biomass for bio-production. For example, the roots are a source of inulin and fructose.

After three consecutive years of experimentation, Novamont had involved more than 50 farmers on 500 hectares. Biomass production is over 15 tons per hectare, and seed production over 1.5 tons per hectare. Part of the development done in the project was to engineer harvesting equipment suitable for the stony ground of Sardinia (Figure 21). The biomass can be harvested in the form of cylindrical bales.

Figure 23. Cardoon harvesting at Matrìca experimental fields, August 2014

Source: Gregori (2015).

Several areas in Sardinia have been identified as suitable for growing cardoon. This is also good news for farmers. As a result of the culmination of various factors, land degradation has been a serious concern on Sardinia (Aru et al., 2006). In the Sassari province alone, around 70 000 hectares of arable land have been lost between 1982 and 2010. Thus growing cardoon for industrial purposes on degraded, marginal land provides an alternative income.

Cardoon in bio-based production: the first flagship of the BBI JU

This project (First2Run[41]) is the first flagship project of the European PPP in bio-based production. The BBI has allocated a grant of EUR 17 million to the project, coordinated by Novamont, in partnership with four companies and one university. The total eligible cost of the project is about EUR 25 million, with around EUR 30 million of estimated additional activities. As a flagship, the project is focused not only on research, but also on the capacity to increase the competitiveness of European industry in green chemistry. The project is funded in the topic '*Added value products from under-utilised agricultural resources'* (Box 12).

41 http://www.first2run.eu/

Box 12. The programme BBI.VC3.F1 - Added value products from under-utilised agricultural resources

Specific challenge: The agro-industry has significant opportunities for developing high added value products by valorising currently underexploited resources in new applications and markets. Two main feedstocks have been identified in this context:

1. Growing dedicated non-food feedstock in regions that are unsuitable for the production of food crops (e.g. oil crops in dry or marginal land); and

2. Residues and side-streams from the agro-food value chain that are currently un- or under-utilised (e.g. vegetable pulp, bran, leaves).

While demonstration activities are already being pursued to this end, the challenge lies in demonstrating at industrial scale a first of a kind, cost-effective new bio-based value chain for the conversion of the targeted streams into biochemical intermediates and subsequent production of added value products, e.g. biolubricants, bioplastics or biofillers.

Scope: Demonstration of the techno-economic viability of the sustainable conversion, by an integration of chemical and biotechnologies, of currently under-utilised agricultural streams (which can be either oil crops grown in dry environments, crops from marginal lands, or residues from the agro-food value chain) from a local integrated supply chain into bio-chemical intermediates, and their subsequent processing into end-products (e.g. biolubricants, bioplastics and biofillers) at industrial scale (e.g. more than 30 ktons per year). Proposals should employ all possible means of industrial symbiosis and energy integration with the industrial environment and, wherever possible, make use of existing facilities. Safety, quality and purity of the end products should meet commercial requirements. Proposals should prove the economical access to sufficient raw material to set up the new supply chain and provide evidence that the used feedstock streams are either grown on land that is unsuitable for food production or represent a under-utilised residue from the agro-food industry. A life-cycle assessment should be carried out in order to evaluate the environmental and socio-economic performance of the demonstrated value chain. Involvement of end-users is required with a view to ensuring the viability of the developed concepts in the value chain.

It is considered that proposals with a total eligible budget of at least EUR 25 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals with another budget.

Expected impact

- Demonstrating a new local bio-based value chain maximising the use of currently underutilized agricultural resources for the production of chemical building blocks and consumer products e.g. biolubricants, bioplastics and biofillers.

- Developing new products with more than 70% bio-based content and less than 2.3 kg CO_2 eq. per kg emissions.

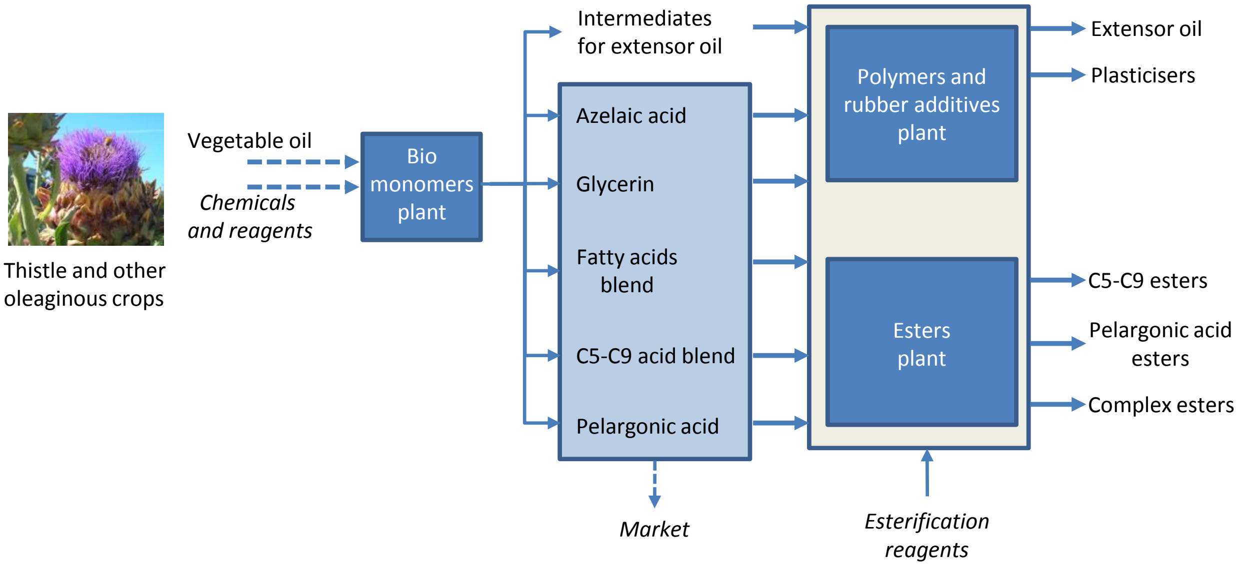
- Demonstrating products with a 3 times higher value than the current application of feedstock side streams, leading to a significantly higher total valorisation of the agricultural crops.

- Creating green jobs facilitating the development of entrepreneurial activities throughout the entire region, with advantages for the primary sector (i.e. agriculture and livestock farming), the secondary sector (e.g. logistics, bioproduct transformation industry) and the tertiary sector.

Source : Adapted from http://cordis.europa.eu/programme/rcn/666531_en.html

By- and co-products from the process will also be valorised for energy, feed for animals and added-value chemical production (Figure 22).

Figure 24. Cardoon as a feedstock for bio-based production



Source: Redrawn from Gregori (2016).

Policy implications

Some of the fundamental policy goals of a bio economy are demonstrated in this project. Apart from the often-quoted policy goals of greenhouse gas (GHG) emissions reduction, food and energy security, other sustainability policy goals are evident.

- Chemicals are a cornerstone of the economy of some OECD countries, but having been losing competitiveness. Bio-based and green chemistry are viewed as ways to improve the competitiveness of the chemicals sector.
- The development of a bio economy could contribute to national policy goals for reindustrialisation[42] to bring manufacturing jobs back. In Italy, Novamont has a policy of conversion of closed or moribund industrial plants into bio-based production plants to save local, high-skilled jobs and create new jobs.
- The experience of Sardinia points to another goal. It has much degraded land (Aru et al., 2006), so cardoon cultivation and harvesting on degraded land helps with another policy goal common to many OECD countries, that of rural regeneration.

However, much remains to be done in policy. As a bio-based industry leader in a country struggling to keep its industry competitive whilst fulfilling green aspirations, Novamont identified several policy areas for action.

- Recognise the value of diversity (tradition/innovation) and of the origin of products (quality *versus* quantity).

42 http://www.eurekanetwork.org/content/reindustrialisation-europe-innovation-jobs-growth

- Fieldwork training programmes using integrated projects as inter-disciplinary training centres could be made involving public and private cooperation.

- Promote a zero organic waste in landfill campaign.

- The BBI PPP should be recognised as a key acceleration tool for the bio economy.

- Set up standards for innovation, and maintain proper control and compliance. For example, the widely used, ISO harmonised CEN Standard 13432 for compostability (EN 13432:2000) is performed by companies and is not third-party verified and certified, leaving it open to 'greenwashing'.

- Create instruments for better regulation, and build an overall policy approach to develop bio economy. Examples of opportunities for this are: integration with the circular economy package (European Parliament Briefing, 2016), and; the roadmap for revision of the Fertilisers Regulation (European Commission, 2015b).

- Make measures to support the use of bio-based products in sectors where environmental pollution is clearly a risk (e.g. bio-lubricants and bio-herbicides).

An advanced lignocellulosic bio refinery in Italy for the production of biofuels and biochemicals

The production of biofuels and bio-based chemicals at the same industrial facility is an ultimate goal of bio-production i.e. the integrated bio refinery. Despite many barriers, the advanced biofuels industry has made impressive progress in a relatively short period. In some OECD countries this has been supported in policy, especially in the US and in Europe. However, recent policy inconsistencies have caused investments in advanced biofuels to stall. The Italian government is the first in Europe to set up such a policy to boost demand for next generation fuels. (Box 13).

Box 13. Advanced biofuels policy in Europe and Italy

Europe

The Renewable Energy Directive (2020 targets):

- 10% renewable energy (sustainable biofuels);
- Food-based biofuels capped at 7% and no support post-2020;
- Non-binding 0.5% minimum national targets for advanced (highly sustainable) biofuels.

The Energy Union Package includes:

- EU target -40% GHG emissions by 2030;
- 27% renewable energy.

Italy

- Complementary to the EU directive, Italy has set binding mandates for advanced biofuels starting in 2018 (initial target 0.6% advanced biofuel in petrol and diesel, increasing up to 1% in 2022);
- Severe penalties in case of non-compliance (up to EUR 940 per tonne).

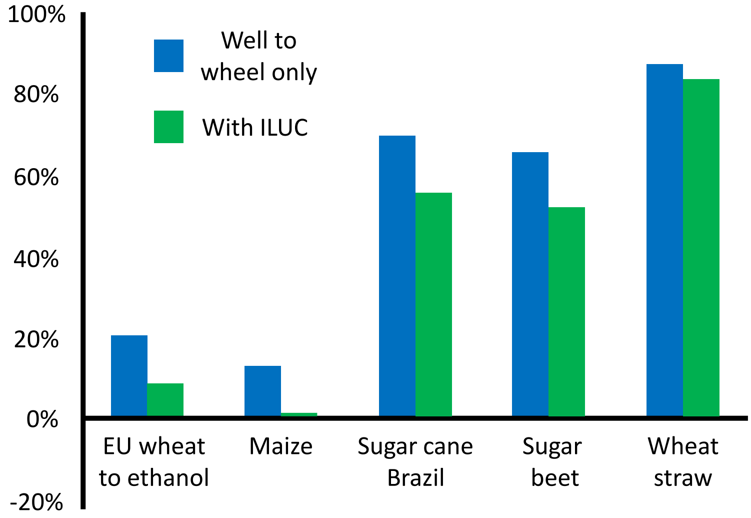
Biomass policy

To date, the EU has defined a set of biomass sustainability criteria that guarantees real carbon savings and protects biodiversity. These are as yet non-binding. The main criteria are:

- Biofuels should deliver significant emission saving versus fossil (>35% GHG savings);
- Biomass cannot be grown in areas converted from land with previously high carbon stock such as wetlands or forests;
- Biomass cannot be obtained from land with high biodiversity such as primary forests or highly biodiverse grasslands.

Emissions savings up to 85% are now possible using wheat straw as a feedstock for ethanol (Figure 23). It should be borne in mind, however, that each has to be established on a case-by-case basis depending on a range of factors e.g. primary fossil energy used, transportation, specific pre-treatment and fermentation process, water and wastewater treatment and recycling. The biofuels business is highly dependent on access to reliable and cheap supplies of sustainable feedstock.

Figure 25. Emissions savings from different biofuels



Source: Cobror (2015).

In one scenario, 4% volume of petrol is displaced by ethanol from agri-residues in Europe. The effects would be:

- EUR 4 billion per year of oil import avoided;
- EUR 4.5 billion of additional income for farmers;
- EUR 28.5 billion of investments would be mobilised;
- Over 100 000 new jobs would be created;
- Over 30 million tonnes per year of CO_2 would be saved.

The marginal land issue

Energy crops such as *Arundo donax*, *Mischanthus* and switchgrass are interesting because of the high biomass yield per hectare (up to 40 tonnes) and minimum requirements for cultivation, and the possibility to grow them on marginal land. A long-debated issue with marginal land is that its definition and potential is unclear. Studies have identified up to 1 billion hectare worldwide of marginal land potential for bioenergy production. Gelfand et al. (2013) identified 35 locations across the North Central United States where bio refineries with production potential above 133 million litres could be built. These bio refineries could produce ~ 21 billion litres of cellulosic ethanol per year (equal to about 25% of EISA[43] mandate for 2022).

Land type with potential for energy crop cultivation include fallow land, abandoned arable land, degraded soil, contaminated land. So at face value marginal land can contribute additional sustainable biomass capacity to meet the bioenergy targets without conflicting with food. There are two main challenges to achieving this:

43 EISA: The US Energy Independence and Security Act of 2007

Choosing the right crops to ensure sufficient productivity with environmental benefits: To achieve sufficient yields on inherently unproductive lands requires the right choice of plants with characteristics that facilitate growth on marginal soils;

Understanding the landscape dynamics that influence the supply and distribution of feedstocks: Growing biofuel feedstocks on marginal lands may further amplify the complexity of feedstock supplies. Parcels of marginal lands might be spread across landscapes. They may or may not be connected by a suitable road network, or be of suitable size for successful harvesting and handling of biomass. Transport, management and biodiversity implications need to be understood.

The world's first cellulosic bio refinery at Crescentino, Italy

The Crescentino bio refinery, co-financed (around EUR 150 million) by Framework Programme 7 and by Piedmont region, is the first commercial scale plant built to produce bioethanol (capacity 40 000 tonnes per year) from agricultural residues and energy crops using enzymatic conversion. Using wheat straw, rice straw and *Arundo donax* on marginal land, it creates economic, environmental and social opportunities. It will generate ~100 direct jobs at capacity, and up to 400 indirect (e.g. local logistics of biomass collection and transport). It can generate 13 MW of electricity entirely from lignin, enough to power the plant with extra to sell back to the grid. Additionally, the plant does not abstract river water; the water requirement is satisfied by the biomass, and wastewater is treated and recycled on-site.

Like other flagship projects, this required high initial capital expenditure and present very high risks to potential investors. Key constraints still need to be overcome: a supply of biomass that is sustainable and perceived to be so by key stakeholders; access to credit/loan guarantees, in addition to or even as an alternative to grants; and above all a clear, stable and positive policy framework. At the moment such conditions are better met in the US, Brazil and China than in the EU, although the provision of loan guarantees is now possible in Europe.

The same technology is utilised at the GranBio bio refinery, Alagoas, Brazil. With a production capacity of 65 000 tonnes per year, the plant uses the same technology as at Crescentino to deliver ethanol while using locally sourced sugar cane straw and bagasse as feedstock. This plant also generates its own power by using the lignin produced as a by-product of the process. GranBio invested USD 190 million to build the plant and USD 75 million on the steam and electricity co-generation system.

Promoting bio economy in Finland – policy landscape, business ecosystems and programme activities

Unlike many European countries, Finland has a major biomass advantage in the size of its timber industry. Finland has 73% forest cover.[44] The bio economy is already important for Finland, accounting for more than 10% of the entire economy and a quarter of its exports. The goal is to increase the turnover from EUR 60 billion to EUR 100 billion by 2025, thereby creating 100 000 new jobs in the process. This translates to an annual growth rate of 4%, which is ambitious but it is considered achievable as the bio economy is a global growth sector.

The Finnish bio economy combines wood processing, chemistry, energy, construction, technology, food and health. However, in Finland the bio economy is dominated by the forest bio economy (over 60% of turnover), which sets it apart from many of the other Member States where the bio economy is largely based on agriculture.

[44] http://data.worldbank.org/indicator/AG.LND.FRST.ZS

Finland is creating cooperative, innovative solutions for versatile use of its natural assets, particularly its forests. Traditional forest, energy and chemical industries are being integrated into a new ‘industrial ecosystem’. In this ecosystem wood is refined into traditional and novel forest products, energy, biofuels and bio-based chemicals. In the future, this integration in the bio economy ecosystem will continue by including the construction, food and textile industries.

The Finnish government has defined ‘bio economy and clean solutions’ as one of the five priorities. It will invest EUR 300 million in the coming three years into: cost-efficient carbon-free, clean and renewable energy; wood on the move from forests and new bio-based products; circular economy and implementation of clean technologies; profitable food production and blue bio economy, and; fair nature policy.

Selected actions from the government Action Plan are:

- Updating the Energy and Climate Strategy for 2030[45] to meet the revised targets for renewables (over 50% by 2030), energy self-sufficiency (over 55% by 2030) and the share of renewables in traffic (40% by 2030);

- Increasing the supply of wood by 20% and promoting investments in the forest sector, bio economy and clean solutions;

- Accelerating new innovations in bio economy and circular economy by piloting and demonstration using national and European financing, especially the BBI JU and the EFSI. These provide good opportunities to supplement the national funding for investments in piloting, demonstration and commercial plants;

- Improving the financial position of growth SMEs through financing instruments;

- Reducing administrative burden.

Smart&Green Growth Towards 2025

According to Tekes,[46] the Finnish funding agency for innovation, the clean technology market will double in size to over USD 1 trillion by 2020. Demand will grow for solutions based on renewable and recyclable technologies, and clean technology services will become more common. The Smart&Green Growth Towards 2025[47] initiative addresses these new market opportunities and realities.

The initiative’s mission is to shift from raw materials-focused activities to market orientation i.e. on creating new customer value. The goal is for the bio economy to become a customer-oriented, dynamic growth sector, which will be reinvented based on high added-value products, digitalisation and new business models. The time to market from product development will be shortened and new business activities can therefore be scaled up more quickly. Bio economy-relevant products are forecast to be new, high value-added bio-products, materials and chemicals, medicines and wellbeing, and nutrition and food (Figure 24).

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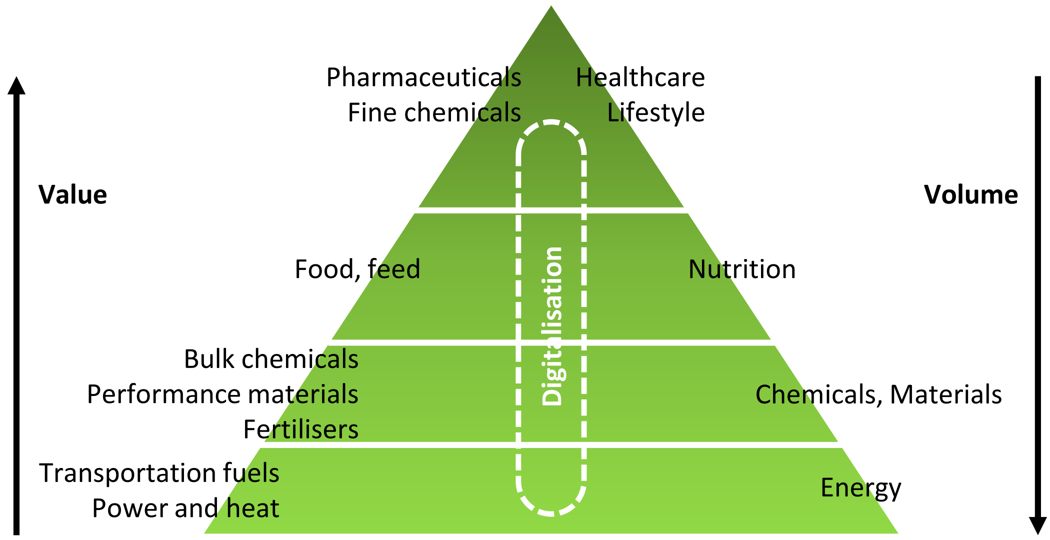
45 https://www.tem.fi/files/36292/Energia-_ja_ilmastostrategia_nettijulkaisu_ENGLANNINKIELINEN.pdf

46 https://www.tekes.fi/en/

47 https://www.tekes.fi/en/programmes-and-services/tekes-programmes/smartgreen-growth--clean-transition-to-the-bioeconomy/

Figure 26. New markets and networks based on higher value-added bio-products.



Source: Redrawn from Manninen (2016).

The BioNets programme[48] aims to generate for Finland's bio- and circular economy: innovative and international business ecosystems; new business development platforms; new bio economy actors via digitalisation and the circular economy, and; pilot and demonstration projects.

Projects in the preparation phase for the BioNets programme reflect the range of bio economy developments envisaged in Finland:

- *Circulation of nutrients*, with the Baltic Sea Action Group;
- New business from wood fibres, with CLIC Innovation Oy;
- Raw materials and energy from waste, with EERA Waste Refining Oy;
- *Smart packaging*, with Pöyry Management Consulting Oy;
- *Smart water*, with Gaia Consulting Oy;
- *Ento business/insect economy*, with Invenire Market Intelligence Oy;
- *Lignin ecosystem*, with Pöyry Management Consulting Oy.

Policy implications

- Finland’s well-being is based on its ability to use renewable resources efficiently and sustainably. That message is not only international, but has become global.

48 https://www.tekes.fi/en/programmes-and-services/tekes-programmes/smartgreen-growth--clean-transition-to-the-bioeconomy/bionets--network-and-profit/

- The national bio economy strategy and the government emphasis on the bio economy have created a positive outlook for the future which can be seen in increase of investments.

- Energy and material use of biomass are strongly linked. Without an increase in bio-products there will be no increase in residue-based bioenergy and biofuels. Government policy support ought to reflect the importance of bio-based products and not be solely focussed on biofuels and bioenergy.

- Future focus is in promoting emerging business ecosystems and value-added bio-based products. Beyond Finland, countries and regions depend on these new value and supply chains to make a successful international bio economy.

Bio refining in Canada

In some aspects, Canada is a very good fit for a bio-based industry, having access to very large amounts of biomass, a large, skilled workforce, a well-developed biotechnology sector. Nevertheless Canada also faces challenges in developing bio-production.

Characteristics of a bio economy in Canada would be access to huge quantities of relatively inexpensive (sometimes even free) biomass, but much of which is inaccessible due to the geography of the country. Some estimates of available waste biomass in Canada have been made:

- Agricultural residues: approximately 48 million tonnes per year;

- Forest residues: approximately 20 million tonnes per year;

- MSW: typically 1 kg per inhabitant per day.

The price of these materials ranges from: USD -30 per tonne for municipal solid waste (MSW) and sludges, to USD 60-80 per tonne for residual forest biomass and residual agricultural biomass, to USD 120 per tonne for wood chips and prime straws.

However, it should also be borne in mind that Canada has a wealth of other feedstocks available, including a variety of non-waste feedstocks such as existing crops, purpose-grown annual and perennial crops. Other waste-related feedstocks of importance are livestock manure and food waste.

MSW

This is very inexpensive; citizens will pay to have it taken away. Typically a city of 1 million inhabitants will produce 365 000 tonnes of urban waste per year. As 1 tonne of this waste produces approximately 360 litres of ethanol, this equates to total of 130 million litres of ethanol per year from a city of 1 million. However, its status as non-homogenous biomass does not really describe how highly variable its chemical composition is. Its conversion remains a considerable challenge: bio-based processes work best with as homogenous a feedstock as possible. Therefore its conversion to a homogenous intermediary is a high priority. The most suitable process so far is thermochemical. Nevertheless, these technical challenges have been conquered by Enerkem of Quebec.

The Enerkem MSW bio refinery in Edmonton tells a story worthy of the attention of large cities. Successful cities often acquire an increasingly complex landfill problem as they produce increasingly more waste. In Edmonton, Canada, a solution through MSW bio refining has been offered by Enerkem in collaboration with the public sector (Box 14).

Box 14. Enerkem MSW bio refining and Edmonton's solution to landfilling

The City of Edmonton is moving from 60% waste recovery for recycling into other materials, already a high proportion, to 90%, arguably the best in the world. This is to be achieved via a MSW bio refinery that converts residuals from the City of Edmonton's composting, recycling and processing facilities, waste that would otherwise be landfilled, into biofuels. The annual amount of this refuse derived fuel (RDF) is 100 000 tonnes.

From the Edmonton municipality point of view, it costs roughly CAD 70 per tonne, in fully loaded costs, to open up a new landfill. When a combustion technology to generate some power and slow the rate at which the site is filled to capacity is added in, that rises to around CAD 90 per tonne of waste. The Enerkem deal with Edmonton calls for a 25-year, CAD 45 per tonne deal that ultimately converts 30% of the city's waste stream to liquid fuels and chemicals. The first products are ethanol and methanol.

The company believes that the optimal configuration for a municipality could include up to four modules for a capacity of 38 million gallons, with a cost as low as CAD 1.05 per gallon before amortisation and depreciation.

Beyond Edmonton, cities that have expressed strong interest in finding solutions sooner rather than later to landfilling problems include Philadelphia, Toronto and Los Angeles. Developing waste projects in California can be complex, but there is the added attraction of creating molecules that fit well with the California Low Carbon Fuel Standard. In 2015 there is a commitment to complete a commercial-scale facility in Varennes, Quebec, an option to double the capacity in Edmonton which the city and company are now mutually exploring. Enerkem is partnering with AkzoNobel, Van Gansewinkel, Air Liquide, AVR to build another waste-to-chemicals plant in the Netherlands that will produce methanol from synthesis gas generated from residual waste[49] .

Source : Various and Biofuels Digest, 2014a

Residual agricultural and forestry residues

These are less affordable than urban wastes, but the carbon structure is more homogeneous and 'constant' (cellulose, hemicellulose, lignin and extractives). At USD 60-80 per tonne, they are considerably more expensive and the transportation can be problematic given the distances involved. Between them there are about 68 million tonnes per year available.

Competition for biofuels in Canada

With a reference oil barrel price of USD 46.07 per barrel (October 2015), petrol costs approximately USD 10.50 per GJ; diesel costs approximately USD 10.63 per GJ. Ultimately second generation bio refineries have to be competitive with fossil and first generation ethanol (without subsidies). Biomass is a key factor in the process. To make this possible requires that:

- Biomass is combined with the appropriate type of conversions;
- Highly heterogeneous material such as MSW should be converted to a homogeneous intermediary;
- Lesser heterogeneous material such as lignocellulosic residues should be fractionated and each fraction should be upgraded.

The transportation factor cannot be under-estimated in such a large country with widely dispersed biomass and a widely dispersed population. Smaller bio refineries may be considered in order to limit transportation fees (which depend on the price of oil). This is consistent with the European and the US

49 https://www.portofrotterdam.com/en/news-and-press-releases/rotterdam-is-proposed-location-for-waste-to-chemicals-plant

viewpoint of rural regeneration through localised bio refining and knock-on benefits in indirect jobs in communities that may have become employment black-spots through job losses due to agricultural efficiencies.

BioFuelNet Canada (BFN): a Canadian government initiative

BioFuelNet Canada (BFN) is an integrated community of academic researchers, industry partners and government representatives who engage in collaborative initiatives to accelerate the development of sustainable advanced biofuels. BFN's research is funded through a mix of government and private contributions, and is structured around the themes of feedstock, conversion, utilisation, and social, economic and environmental sustainability.

The activities extend beyond academic research, such as: online courses and webinars; large-scale networking events; business-to-business matchmaking; investment tracking and intelligence; and policy consulting (Lavoie, 2015). Hosted by McGill University, it has (November, 2015): 27 Canadian universities; 140 partner organisations; 175 researchers, 73 of whom are funded by BFN; 61 international links, and; 240 current students, with another 102 already graduated.

The network benefits from a CAD 25 million grant over 5 years (2012 to 2017) through the federal Network of Centres of Excellence programme. BioFuelNet activities are focused on unlocking the potential of lignocellulosic feedstocks and other advanced biofuel feedstocks for the production of advanced biofuels. With lignocellulosics making up over 90% of available biomass in Canada, the challenge of effectively converting this biomass into fuels is central to the growth of the Canadian biofuels industry.

A PPP gets the world's largest bio-based succinic acid plant built in Sarnia, Canada

"The opening of the Bio Amber Sarnia facility is key to the development of Sarnia's very unique bio-industrial complex, delivering good jobs, significant exports, and diverse markets for Ontario farmers with the full support of the Government of Ontario. The production and development of sustainable chemicals by Bio Amber, working from within the existing chemistry cluster in Sarnia, is an economic and environmental win for the community and the province."

Brad Duguid, Member of Provincial Parliament Scarborough-Centre, Minister of Economic Development, Employment and Infrastructure, Canada.

The Sarnia plant making bio-based succinic acid opened in August 2015. It is the world's largest succinic acid plant, with a capacity of 30 000 tons per year, built at a cost of USD 141.5 million. It is billed as using a disruptive technology that actually allows the product to be lower cost than oil-based production, with a 100% reduction of GHG emissions compared to the equivalent production process that uses petroleum.

There is increasing demand for renewable building block chemicals in large global markets, and succinic acid is a versatile building block as it can be used in plastics, paints, textiles and coatings, artificial leather, food and flavours and personal care products. Approximately 300 construction jobs and 60 full-time jobs were created by the project. The project was supported financially by a repayable contribution of up to USD 12 million through FedDev Ontario's Prosperity Initiative for the construction and operation of the plant.

Ensyn and cellulosic bio refining, July 2016

Ensyn currently operates a small cellulosic bio refinery in Renfrew, Ontario. It has the distinction of operating on a steady-state basis, and selling actual product (bio crude) to customers in Canada and the US. In July 2016 (*Biofuels Digest*, 2016) it was announced that Ensyn and its partners (Arbec Forest Products and Groupe Rémabec) have made a final investment decision to approve construction of a 10.5 million gallon plant in Port-Cartier, Quebec. It will convert approximately 65 000 dry tonnes per year of forest slash and other forest residues from local sources to bio crude. The bio crude will be sold to customers in the Northeastern US and in Eastern Canada for heating purposes and as a renewable feedstock for petroleum refineries for the production of low carbon transportation fuels. As such, this may be the only commercial-scale cellulosic biofuel project that has gained approval anywhere in the world over the past two years.

The nature of the partners is important to this project, and may act as a model for others. Arbec is a privately-held forest products company operating in Eastern Canada. Arbec owns twelve wood processing plants in Quebec and New Brunswick, ten of which are in partnership with Groupe Rémabec. Groupe Rémabec is a major forest products company operating in Quebec, with a focus on timber harvesting and wood processing. Groupe Rémabec harvests more than three million cubic metres of lumber yearly.

There are also lessons from the financing model. The governments of Canada and Quebec played a major role in the financing of the project. The project cost, at today's exchange rates, is USD 79.7 million, broken down as follows:

- USD 20.88 million from Sustainable Development Technology Canada;[50]
- USD 13.54 million from Natural Resources Canada's Investments in Forest Industry Transformation[51] programme;
- USD 7.74 million from Investissement Québec[52];
- USD 17.02 million from the Government of Québec.

In addition, the Québec Ministry of Forests, Wildlife and Parks has reserved 170 000 green tonnes of residues from government forests for the plant. The project partners are supplying the remaining USD 2.172 million, and Ensyn owns 50% of the equity.

Apart from being so unusual in terms of the timing of the investment, this example may represent an unprecedented case of public financing, where the vast majority comes from public funding.

CCEMC and CO_2 Solutions, Canada

In April 2007, Alberta became the first jurisdiction in North America to pass climate change legislation requiring large emitters to reduce greenhouse gas (GHG) emissions. Two years later the Climate Change and Emissions Management Corporation (CCEMC) was created as a key part of Alberta's Climate Change Strategy and movement toward a stronger and more diverse lower-carbon economy.

50 https://www.sdtc.ca/en - funded by the Government of Canada

51 http://www.nrcan.gc.ca/forests/federal-programs/13139

52 http://www.investquebec.com/quebec/en/

The Government of Alberta administers the collection of all compliance funding each year and pools those funds in the Climate Change and Emissions Management Fund. The funds are sourced from industry and made available to the CCEMC through a grant from the Government of Alberta.

Alberta's Specified Gas Emitters Regulation identifies that facilities that emit more than 100 000 tonnes of CO_2 equivalent per year must reduce emissions intensity by 12% below a baseline. Organisations that are unable to meet their targets have three compliance options: make facility improvements to reduce emissions below the required threshold; purchase Alberta-based carbon offset or Performance credits; or pay CAD 15 into the Climate Change and Emissions Management Fund for every tonne they exceed the allocated limit.

The CCEMC manages its resources as a portfolio of projects with a wide spectrum of investments. The organisation funds projects at all levels of the innovation chain, with the bulk of its investment in projects at the demonstration and implementation phases.

For example, in 2012 and 2013, CO_2 Solutions secured CAD 5.2 million in grant funding from the Government of Canada's ecoENERGY Innovation Initiative and CCEMC towards a CAD 7.5 million project to optimise and pilot the technology for biological CO_2 capture from oil sands production.

The government of Alberta outlined a plan in November 2015 for cutting the province's GHG emissions (*Financial Times*, 2015a). The proposals include an end to coal-fired power generation and a carbon price of CAD 30 per tonne to 2018 and rising in real terms after that. The plan has been backed both by environmental groups and by oil companies that are large producers in the oil sands.

POLICY QUESTIONS REGARDING: R&D, FINANCING AND REGULATORY NEEDS AND OPPORTUNITIES FOR BOOSTING BIO-WASTE BIOREFINERY PRACTICES

A series of questions were posed to speakers and the general audience by the Secretariat at an OECD workshop in Rimini Fiera, November 2015, entitled *Biowaste Biorefining: Biowaste Exploitation in Multi-Purpose Biorefinery Schemes*. Additional material was collected subsequently. The speakers were given a further opportunity to elaborate on answers post-workshop. What follows is a summing up of the answers gathered to the questions posed. It is worth adding that none of the speakers disagreed with the relevance or importance of the questions. The following account can be taken as representative of the major policy issues relating to bio-waste bio refining.

Clearly industrial biotechnology has moved way downstream from its earlier days in R&D. The construction of bio-waste bio refineries could now either founder in the wake of policy uncertainty or become the model of industrial production sustainability in the post-fossil fuel world. Much is at stake, both for OECD nations and the world. There are many policy issues arising, and there will be many more to come. At this point, the most pressing issues arising, mostly in Europe, are discussed and potential solutions offered. The issues are shared by other OECD countries and relevant beyond the shores of Europe.

Bio refinery financing

Question: Would loan guarantees remove the debt management problem in Europe?

Workshop answer: This is part of the solution. Loan Guarantees of up to 80% are being offered (or have been offered in past) for bio refinery projects up to USD 250 million. This is either impossible in Europe, or nearly so, due to State Aid rules which invoke a 'matched funding' rule (implying a 50% maximum). It was agreed that Loan Guarantees would help with debt finance management, but it is not the only solution required. Loan Guarantees are really essential for companies that invest in flagships in the bio economy sector.

Another investment factor for a company that is more important than public contributions is the cost of the feedstock, the lower the cost the more attractive it is for a company to invest in that country or region. Both the United States and Europe have seen investments go to other countries, such as Brazil, where the feedstock is cheaper. However, the policy framework in some of these countries is also more certain, and longer term. In the US and in Europe just now there is uncertainty around the future of cellulosic ethanol: in the US is it immediate as the Renewable Fuels Standard (RFS) is embattled, and in Europe there is no certainty beyond 2020, so investment in biofuels just now in Europe is stymied.

Question: Why the big difference in approach between the US and Europe?

Workshop answer: The answer to this may be incomplete. There may be a need for information on different approaches by the banks. As yet, the European Investment Bank (EIB) has not been involved in financing bio refineries, but conditions are now in place to allow this through the InnovFin programme.

Another difference between the US and Europe lies in the very different approach to cellulosic ethanol: in the US, due to the market being dominated by petrol, cellulosic ethanol is perceived as the only biofuel able to significantly reduce the emission of the transport sector. As such, RFS sets specific volume target for cellulosic ethanol, therefore minimising the off-take risk and providing market certainty to investors.

Moreover the US has implemented measures dedicated to the market uptake of innovative products via the BioPreferred Programme. Managed by the USDA, the goal of the BioPreferred programme is to increase the purchase and use of bio-based products, in order to reduce reliance on petroleum, increase the use of renewable agricultural resources and contribute to reducing adverse environmental and health impacts. The two major parts of the programme are:

- Mandatory purchasing requirements for federal agencies and their contractors, and;
- A voluntary labelling initiative for bio-based products.

While the BioPreferred programme does not provide financial support for its participants, the USDA's Rural Development Agency offers loan and grant programmes that may be applicable.

Waste supply chains

Question: Is it possible to set targets for the biomass price in Europe?

Workshop answer: In a limited manner, but feedstocks are so diverse that an overall target price is rendered meaningless. More important is target prices for products rather than for biomass. From a feedstock perspective, a further consideration is the implementation of a bio economy model where resources are channelled towards technologies which require less quantity of renewable raw materials available locally. In this way Europe can specialise on niche added value products without emulating models of countries which have larger surface of arable land and the availability of (cheaper) feedstocks.

Question: Is there a need for public policy to enable any waste material collection and sorting?

*Workshop answer***:** Yes. There is a precedent for this. A public-private collaboration between the USDA's Natural Resource Conservation Service (NRCS) and DuPont[53] aims to set voluntary standards for the sustainable harvesting of agricultural residues for renewable fuel. The first plant involved in this national agreement is near the town of Nevada, Iowa, where DuPont has built a 30 million gallons per year cellulosic facility. This plant will use harvested residues from a 30 mile radius around the facility.

There are a number of studies attempting to estimate how much residual biomass should be left on the ground to maintain soil fertility. Variation among studies is significant. Wasted (2014) estimated the proportion to be 30%. The same report also estimated the amount of residual biomass, either agricultural or forest, available for making advanced biofuels.

Another matter is the very large numbers of owners involved. Across the EU there are some 16 million forest owners and less than 14 million farm owners. This suggests that there will be a need for well-resourced infrastructure to monitor and control the collection of waste materials.

Question: There are still large uncertainties about the volumes of available waste materials for bio refining. What can be done about this?

Workshop answer (provided by the Secretariat, with no disagreements): Public policy could incentivise (subsidise) specific R&D into determining volumes of waste materials with greater certainty. This would require coordination of various national and regional agencies. There may be a conflict between bio refining (and bio economy more broadly) and circular economy in that efforts to reduce the

53 http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2013/03/0058.xml&printable=true&contentidonly=true

quantities of waste may result in reducing the volumes of waste bio refinery feedstocks. On the other hand, circular economy policies might also incentivise further separation (and collection) of organic wastes, thereby creating an advantage for bio refining.

Bio-based chemicals policy

Question: There is still a level playing field issue in Europe.[54] Are there ideas about kinds of public incentives for bio-based chemicals?

Workshop answer: Both taxing current industries and incentivising innovative ones are politically difficult.

Today there is not a truly level playing field between bio-based products (both biofuels and bio-based materials) and fossil products: in fact, fossil based products are heavily subsidised and their negative contribution to the global warming (i.e. climate change impact) is not accounted.

The International Monetary Fund (IMF) published a report in 2013[55] showing that almost 9% of all annual country budgets are spent supporting oil, natural gas and coal industries through direct subsidies, consumer rebates and avoided taxes on pollution. The report estimated that worldwide subsidies to fossil fuels total a staggering USD 1.9 trillion – equivalent to 2.7% of global GDP, or 8% of government revenues. It would be advisable to devote part of the subsidies to fossil fuels and products to compensate for the higher cost of bio-based products.

Moreover, the opinion is often expressed that subsidies to biofuels should be ended due to their distortion of the market. But Table 7 shows how petrol prices vary in different countries (compiled before the recent oil price crash). At the time of compiling, petrol was over 177 times more expensive in Norway than in Venezuela. The fossil fuels market is already highly distorted.

Table 8. Table 9.Variations in petrol prices among different countries

Country	USD per litre (95 RON)
Australia	1.36
Bahrain	0.27
Denmark	2.35
EU average	2.05
France	2.28
Norway	2.66
Qatar	0.28
Russia (Moscow)	0.94
Saudi Arabia	0.16
United States	1.02
Venezuela	0.015

Carbon taxation has sometimes proven politically unpopular, but the revenues from a carbon tax could be used to promote the use of truly sustainable biofuels and bio-based products. Pricing carbon emissions through a carbon tax is another powerful incentive to invest in cleaner technologies and adopt greener industrial processes. Moreover, revenues from taxation can be used to promote the use of bio-based products.

54 Much more public policy support for bioenergy and biofuels than for bio-based materials, while the latter offers greater value-added and job creation potential.

55 www.imf.org/external/np/sec/pr/2013/pr1393.htm

Stronger and solid market pull measures for added-value products is an essential element: the much needed change of paradigm leading to a post petroleum and resource efficient society cannot be just science or technology pushed and needs to be complemented by market driven mechanisms. Without a market, no new product or process can survive.

Question: What about a Bio-based Materials Directive for the EU? A good idea or bad idea?

Workshop answer: There was little or no enthusiasm expressed for such an initiative. It is not so much that it is a bad idea; it is simply extremely difficult to make it happen as the prevailing thinking is to have flexibility and a technology-neutral approach in the post-2020 EU policy framework.

Situation in Italy

Question: There is relatively little government intervention in bio-production in Italy. Is that how the industry would prefer it?

Workshop answer: Definitely not. The Italian private sector would like to see some government strategy. Italy has the first advanced biofuels mandate (see Box 14). However, it may be difficult to meet the demand solely with domestic production in Italy to achieve the target, given current circumstances, and Italy may be required to import second generation ethanol biofuels.

Italy has many existing conditions that can favour the transition to the bio economy: geographical conditions, the structure of the agricultural sector, the industries, infrastructure, research skills and others. In particular, Italy has a distinctive and virtuous model of collaboration between the agricultural and corporate spheres. This is often overlooked in these early stages of bio economy development, and yet farmers and foresters are the key stakeholders. In particular, farmers are already 'bioeconomists' and custodians of sustainability. The distinctive successes already achieved in France and Italy have been achieved in close collaboration with farmers and local communities. This is one of the most important messages, and governments of other countries could do more to promote this collaboration. There is no need for reinvention – France and Italy have shown the way.

Investments of over a billion EUR have already been made in Italy in the area of chemicals from renewable sources for the re-industrialisation of sites of national importance and for the construction and launch of four flagship plants, the first of their kind in the world. A further two hundred million EUR in private-sector investments has been made in the research and development of multidisciplinary projects involving universities and leading research centres.

But there is still a lack of an overall, comprehensive and coherent sustainable strategy linking different sectors (industry, energy, agriculture, waste management, etc.) and of demand-side measures to boost market uptake for added value products.

Public procurement

Question: Is the time right for public procurement of bio-based materials ?

Workshop answer: Yes, but public procurement is very difficult for bio-based production.

It is easier to see how public procurement works for biofuels. For example, incentivising flex-fuel vehicles (FFV) in public fleets can quite clearly be done. However, in Europe most of these are diesel vehicles, and therefore it would be more about incentivising the fuels. Besides, owning a FFV does not guarantee uptake of bioethanol – if there are few E85 pumps at fuel stations, then petrol or low-ethanol blends of petrol will be used, thus defeating the purpose of the FFV. Such a policy to incentivise ethanol pumps and storage at fuel stations has been initiated in Sweden.

Sweden is reported to have the largest bioethanol bus fleet in the world, with over 600 ethanol-operated buses in service. In 1994, the first three flex-fuel cars (powered by both ethanol and petrol) were imported. At the same time, the BioAlcohol Fuel Foundation (BAFF), founded in 1983 under the name of The Swedish Ethanol Development Foundation (SSEU), began lobbying other municipalities to invest in ethanol. At present, there are over 1700 E85 pumps found throughout Sweden. Sweden has produced a range of other consumer-oriented, demand-side policies supportive of biofuels to complement the supply side.

On the supply side, Ford Sweden and Saab have become leaders in flex-fuel ethanol cars, and Volvo currently markets several ethanol-fuelled models, an example of supply- and demand-side policies operating simultaneously and producing spill-overs (OECD, 2014a).

It would be useful to promote the adoption of a new EU fuel standard, like E20 (20% ethanol in blend) rather than current E10. With recent engine developments and EU standards (e.g. Euro-6),[56] E20 can be easily integrated in the fuel pool with pumps almost anywhere in Europe.

The European Commission could encourage contracting authorities in all EU Member States to give preference to bio-based products in tender specifications (Green Public Procurement); this could be accompanied by the development and the implementation of clear and unambiguous European and international standards (with reference to minimum environmental criteria) for such product categories.

Ethanol and 2020

Question: What is the best that Europe could do about the uncertainty beyond 2020?

There are rather negative consequences of the lack of certainty for investors, who prefer to invest somewhere else where policies are stronger, clearer and more stable. And yet cellulosic ethanol has proven to be the most sustainable biofuel on the market.

The only way to promote the production and use of cellulosic ethanol in Europe is a combination of measures:

- New standards in place in Europe (E20 at least);
- Financial support (grants for flagship plants and loan guarantees for 2nd-,3rd-, 4th-of-kind);
- Clear, stable (until 2030) policy framework;
- Most important of all are compulsory blend targets for cellulosic ethanol or at least for advanced biofuels (as in Italy).

Without an obligation, there is no reason for refiners to use advanced biofuels as long as they are more expensive than petrol or diesel and in particular there is no way to have refiners blend ethanol as long as the vast majority of the fuel market in Europe is diesel.

56 http://www.smmt.co.uk/industry-topics/environment/intro/european-engine-emission-standards/

Standards setting for bio-based chemicals

Question: Would setting standards e.g. for GHG emissions reductions make an impact on the bio-production industry? (i.e. similar to targets for ethanol).

Workshop answer: Yes. But there are other standards that need to be considered, and also existing standards need to be 'legalised'. The standard mentioned was the Standards for Compostability (EN 13432). The issue is that the standard should be performed by an independent third-party authority to prevent green-washing.

High-level and rigorous standards for bio-based products are essential since their lack results in a decrease in quality and sustainability and in the loss of competitive advantage for innovative sectors.

Regulatory regime for biotechnology products

Question: The US is in the process of looking into updating the regulatory regime (it hasn't been changed since 1992). Is this also needed in Europe?

Workshop answer: Yes. Specifically mentioned were waste regulations. If these are too stringent and inflexible, then it becomes very difficult to transfer wastes that might act as bio refinery feedstocks in significant tonnages without breaching regulations. The definition of 'waste disposal' must be changed to allow transportation in view of fact that waste is to be converted to products.

According to the current interpretation of the Waste Framework Directive,[57] and to the cascading approach, energy is deemed to be the least valuable use of waste. However, it is unclear whether bioethanol should be regarded as energy (fuel) or as bio-based chemical. In reality, ethanol is both an energy carrier and a chemical and, as such, it may not be wise to 'legalise' it only in its traditional energy use (e.g. burning).

A strategy for Italy

Question: What public policy measures would the Italian private sector like to be taken in a 'strategy'? According to the German Bioeconomy Council, an Italian bio economy strategy is under development. What else is needed?

Workshop answer:

- Enhancing synergies between sectors and territorial levels, in terms of policy and funding instruments;
- Policy framework which favours the allocation of renewable resources to the highest value use (e.g. bioplastics and biochemical);
- Funding of demonstrator plants and flagships (based on innovative technologies) and their scaling up for industrial production;
- Market-pull measures for innovative bio-based products;
- High-level and rigorous standards;

[57] http://ec.europa.eu/environment/waste/framework/

- Promotion of harmonised certification and labelling schemes;

- Enhancing the role of the National Technology Cluster of Green Chemistry as a cross-sectoral platform in the field of bio economy.

It is likely that an Italian bio economy strategy is underway, but its completion date is not known, and whether this is conceived and structured as a roadmap with a relevant action plan, or just as a white paper on bio economy. For investors, due to the described uncertainties post-2020, this marks the difference between firm national commitment and mere wishful thinking. Clear timing and targets are needed.

Finally

Question: What has been missed?

Workshop answer: The Common Agricultural Policy (CAP) has obvious relevance to bio refineries deployment. In particular, national and/or regional rural development programmes have strong impact on the use of land and natural resources to produce bio-based products. It could be helpful to devote some of the CAP resources to evaluate the potential use of marginal land in Europe for the production of non-food crops to be destined to the production of bio-based products (both biofuels and bio-based materials).

POLICY CONSIDERATIONS

Policy certainty, stability and consistency

Above all, the private sector is looking for policy certainty, stability and consistency. Companies can invest in many countries, and a lack of policy certainty in any one country will drive investments outside that country. A timeframe of 15-25 years to give the bio-based industry a competitive advantage over fossil-based production is needed. Fossil-based production already enjoys massive subsidies, decades of experience to perfect their processes, supply and value chains, and the operating plants are by and large fully amortised by now.

If society needs a change in production, and bio-production is seen to have sufficient ‘public good’, then major changes in society need to take place. It is far from within the private sector interests to ‘go it alone’, and for decades to come, public investments will be needed to bring about this production revolution. It is necessary, however, to create the policy that delivers greatest cost-effectiveness for the tax-payer, for the policy to be tapered, flexible and with clearly defined end-points so that the industry can make the timely investments that will be needed post-public policy (in a free, competitive market).

Farmers and foresters cannot be ignored

The distinctive successes already achieved in France and Italy have been achieved in close collaboration with farmers and local communities. This is one of the most important messages, and governments of other countries could do more to promote this collaboration. Forest bio refining is gradually increasing in popularity. Scandinavian countries are taking a lead.

Many forests are small, and in many OECD countries farms are not large. When trying to build the industrial ecosystem for bio refining, there are a lot of stakeholders to consider. Foresters and farmers are at the start of the chain, and here reside potentially the most complex logistics for achieving sustainable value chains.

Forest management

Forestry, both for logging and residues, will become increasingly important in the bio economy and in bio refining. It is vital that governments protect forestry from over-exploitation. There will be a need for increased tree planting but in most countries this cannot be on a large scale, and it cannot be done at speed. Relevant national legal regulations, forestry programmes and funding guidelines will have to be adapted accordingly.

Experiences in Canada with the mountain pine beetle (Bosch et al., 2015) point to a need to be proactive in the fight against known, future and invasive pests. Countries can cooperate in research and implementation to make monitoring programmes to prevent calamities. Genomics research has much to offer in this regard. Increased regulatory vigilance will be called for.

Timber extraction has varied local (e.g. recreation and tourism) and global (e.g. effects on biodiversity and carbon and water quality) impacts.[58] Naturally, expansion of forestry for a bio economy could increase these negative environmental impacts. The chosen methods for harvesting have large impacts on the ability of a forest to regenerate (Long, 2006). Best management practices in all aspects will need to be drawn up e.g. type of harvesting (e.g. distance of clear cutting from waterways), types of equipment used, limiting new access roads, avoiding sensitive areas like wetlands.

A sustainable bio economy needs sustainable forestry. Sustainability certificates could be because they can provide all stakeholders with clarity about the origin of wood and local production conditions. Controlling illegal logging requires both a technology (e.g. satellite monitoring, DNA barcoding) and a regulatory approach (e.g. certification) to be effective. Some countries are participating in the rehabilitation of damaged forests beyond their national borders. This is to be encouraged for the sustainable expansion of forestry for bio economy purposes.

Many countries have bioenergy targets that rely on wood chips for heat and/or electricity generation. However, using wood in this way prevents adding value. Therefore governments could look at all options for renewable energy, and balance the advantages of job creation and value-added from using timber for material purposes compared to energy purposes. Like other forms of biomass, there needs to be a level playing field for energy, fuel and materials use. And like other forms of biomass, wood should be viewed as a resource for cascading use.

Research and skills in forestry could become a limiting factor in some countries. Governments could look to funding research and training programmes to create a new generation of foresters with wider multi-disciplinary skills coherent with the needs of a bio economy. Provisioning training centres rurally might have the added benefit of bringing more rural jobs. It is entirely feasible that this could be a publically funded function of regional hubs.

Research subsidies

Perhaps the greatest challenge in bio-based production, and also specifically in waste bio refining, is the multi-disciplinary nature of the subject. Research subsidies will have to create not only the new knowledge required, but also the cadre of specialist people.

Research programmes in bio refining need to be designed with care. There is a need for a balance between upstream R&D that would be more laboratory based, and downstream research activities that are closer to market e.g. satisfying needs to create an industrial ecosystem. There is an obvious need for co-sponsoring of research programmes between various research councils e.g. biotechnology, natural science, engineering to prevent overlaps and duplication.

Bio refinery financing

Innovative instruments are being developed to finance bio refinery construction, such as green banks established with tax-payer money but operated on the lines of a commercial bank. In Europe the main mechanisms is the public-private partnerships involving matched funding. It has been mentioned that the loan guarantee mechanism, which has been largely absent in Europe for bio refinery construction, but used frequently in the US, would help debt finance management. With the arrival of InnovFin in Europe, it may become easier to finance bio refineries through loan guarantees. Other models ought to be considered, and hybrid models may be more effective than any single existing model.

58 http://www.fao.org/forestry/environment/11787/en/

Market creation and public procurement (PP)

Public procurement in bio-production is difficult, especially concerning materials as many materials are sold through business to business. An incentive structure could include: procurement guidelines; production subsidies; pricing incentives, and; competition policies. PP affects a substantial share of world trade flows. While there seem possibilities in PP for facilitating market entry for bio economy innovative products there are intrinsic obstacles on both sides of the market, both on the supply and the demand side.

Moreover public procurers naturally tend to be very price-sensitive, which is a barrier for any innovative product. Various governmental schemes currently address this issue: The USDA BioPreferred-Program specifically aims to increase the purchase and use of bio-based products. In the EU the 2014 legislation for innovative public procurement concentrates on innovative solutions and even facilitates the development of innovative products but does not mention specific innovative products or product groups. There are projects established in Europe to address this weakness.

A level playing field

Public policy support has been very much skewed towards bioenergy and biofuels, with little consideration for bio-based materials. This goes against the concepts of 'integrated bio refinery', 'cascading use' and 'circular economy'. New smart policy for bio-based materials is needed.

With much policy focus on waste materials, it should also be considered that many ethanol mills and some bio refineries use food crops as feedstocks without negative effects. All forms of biomass ought to be considered for bio refining, not just wastes and by-products.

Regulations/standards

The regulations and standards approach can also be a tool for market creation through, for example, product registration and life cycle assessment. A way for waste bio refining to win here is the application of rational, harmonised sustainability certification, where just now this area is a patchwork of voluntary schemes that is confusing and lacks the credibility of enforcement.

Regulations governing the use of biomass, especially cascading use, in the various application sectors differ among the sectors and at national and international levels. This can hinder investments in new facilities and also R&D into new products and applications. The specific challenge is two-fold.

1. Firstly, there is a need to boost the use of instruments, in particular common standards, reducing barriers to trade in bio-based products among value chains and hence to expand their market potential.

2. Secondly, regulatory hurdles hindering investments into existing and new value chains, products and applications across sectors, have to be removed and establishing a level playing field for bio-based products is a priority.

Flexible waste management regulation

Waste regulation has become increasingly stringent in most OECD countries. In Europe, the legal qualification of some residues or by-products as 'waste' hinders a broad range of potential bio refinery initiatives. Local environmental and spatial permits for managing bio-wastes are limiting possibilities. An example is crude glycerol, a 'by-product' of biodiesel production. Crude glycerol is a production residue that the chemical industry uses in the manufacture of several products, such as in cosmetics and pharmaceuticals. However, some national authorities classify crude glycerol as 'waste' because it needs to be refined before being used for consumer applications. This classification imposes administrative and financial burdens that discourage investments in existing business practices aimed at keeping the value of materials in the economy for as long as possible.

Infrastructure investment

Developing new infrastructure is always expensive. However, many bio-based products can exploit to some extent the existing infrastructure. For example, petrol stations can offer biofuel pumps as well as fossil fuel pumps, or ethanol in low proportions can be blended with petrol with relative ease and sold through the existing infrastructure. Similarly, bio-based polyethylene is identical to the oil-based product, and can enter the existing recycling infrastructure.

There is a dual infrastructure requirement that can be readily seen for waste bio refining: first of all, there is the infrastructure required to collect and transport the waste to the bio refinery; and there is also the infrastructure required along the value chain of the products. Both, however, are partially in place, so this is not a case of starting from scratch. One aspect of this will be greater encouragement for the public to separate biodegradable waste from other municipal solid waste at home, which is already enshrined in the future of reduction in landfill of waste.

Foresight research

This maps the links between evolving research programmes, regulatory frameworks, policy initiatives and the development of new technologies. Here the early development of a technology roadmap would be particularly useful. The German government produced a bio refineries roadmap in 2012 (Federal Government of Germany, 2012). In 2015, Scotland did the same.[59] Bio refiners ought to be able to see what is coming from R&D and the timescales involved.

Public forums

To avoid the deadlock found in many countries relating to GM technology, industrial biotechnology, and especially synthetic biology, requires early and continued public engagement and dialogue. The public may be encouraged by the environmental benefits of using synthetic biology in a waste bio refinery to decrease the burden of increasingly problematic waste generation and disposal. On the other hand, many communities with an existing negative perception of waste treatment and disposal facilities may also be opposed to waste bio refining on principle.

In many countries there will also be a need for greater dialogue between urban and rural communities to build greater trust between the two. Rural locations that have been the recipients of past unwanted landfill sites will understandable be wary. Other issues to consider are: the effects on local house prices; availability of shops and other facilities; conflict with brownfield policies, opinions of the farming communities and farmers cooperatives; effects of heavy vehicles on rural roads and safety concerns in villages; effects on tourism and wilderness intrusion. Policy makers could look to experiences with wind farms, new sewage plants and open cast (strip mining) projects to gauge what public opinion is likely to be like.

Development commitments

These apply financial and other support e.g. technology transfer, to developing countries. There is a tremendous opportunity to learn from the experiences of some of these countries. For example, the next

59 http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

generation of Brazilian bioethanol mills will use the waste material from sugar cane, bagasse, either to make ethanol, chemicals or to generate electricity, depending on market conditions. This is particularly pertinent at present with testing times for Brazilian ethanol due to low sugar prices and persistent drought conditions.

Other demand-side policy options

What other policies would create a demand for the products of bio refineries? An obvious example is a carbon price that would accompany a low-carbon or zero-carbon economy (summarised in DSTI/STP/BNCT(2016)14). Further potential for biofuels is dependent on advances in other technologies, especially carbon dioxide capture and storage. Bioenergy combined with carbon dioxide capture and storage (BECCS) has potential as a negative emissions technology. With many uncertainties around the feasibility of its large-scale deployment (and when), BECCS requires serious policy attention regarding feasibility.

Generic issues around waste utilisation and bio refining

It is argued here that the decision on where to locate is not a simple one, despite much discussion about rural locations. There are multiple factors that can be taken into account. A decisive factor may be a decision to include municipal solid waste (MSW) as a feedstock. For a national or regional government to consider waste bio refining, there must be sufficient knowledge of:

- What wastes, and what quantities, are available within a radius of the proposed plant that guarantees sustainability. The main limitation of the use of raw materials from agriculture is related to their typical low economic value and energy density. Long distance transportation is a limiting factor (Mayfield et al., 2007);

- What wastes may need to be imported (for example, to maintain year-round operation). The location of the nearest port may be a decisive factor;

- What type of bio refinery is to be constructed (the more feedstocks that can be used, the greater the likelihood of success);

- What forms of pre-processing are to be used (gasification extends the range of potential feedstocks considerably);

- Where the physical location might be (access to different types of biomass, including potentially MSW, public acceptance, NIMBYism (“not in my back yard”);

- What agencies can be called upon to gather data;

- What new infrastructure will need to be provided (e.g. road, rail, electricity);

- The initial roles of the public sector (e.g. loan guarantees to de-risk private investment);

- Local waste licensing regulations (e.g. there may be specific prohibitions regarding transport of waste materials);

- Risks (e.g. odour, economic, health, environmental);

- Implications for existing markets, especially recycling, incineration and industrial composting;

- Public perceptions (about waste, industrial plant, brownfield/greenfield policies, GM biocatalysts, effects on local amenities, effects on house prices);
- How to make the regulatory framework sufficiently flexible;
- Availability of a qualified workforce with the requisite technical skills (Lopolito et al., 2011);
- Large plants may need seawater for cooling purposes, small plants may get as much water as needed from the biomass. Recycling water and wastewater treatment may be a necessity, and existing policy could be helpful or prohibitive;
- Cities understandably may wish to invest in a bio refinery if it brings benefits and jobs to the city itself (Bazancourt-Pomacle, however, is rural/semi-rural and Reims Metropole is one of the consortium of investors). Bazancourt-Pomacle also has Champagne Ardennes and La Marne Conseil Général as investors, and Crescentino has Regione Piemonte. The ground-breaking MSW bio refinery of Enerkem in Edmonton, Canada has the City of Edmonton as an investor. Different investors will have different political agendas, which have to be carefully managed;
- Many gaps between R&D, demonstration and prototype production plants (common in many countries);
- Bio-based products are often not competitive with petrochemical products (this is not surprising as the latter industry has had decades to perfect its processes and products, and the young bio-based industry needs policy support to make it more competitive);
- Lack of consistent political leadership.

Policy alignment

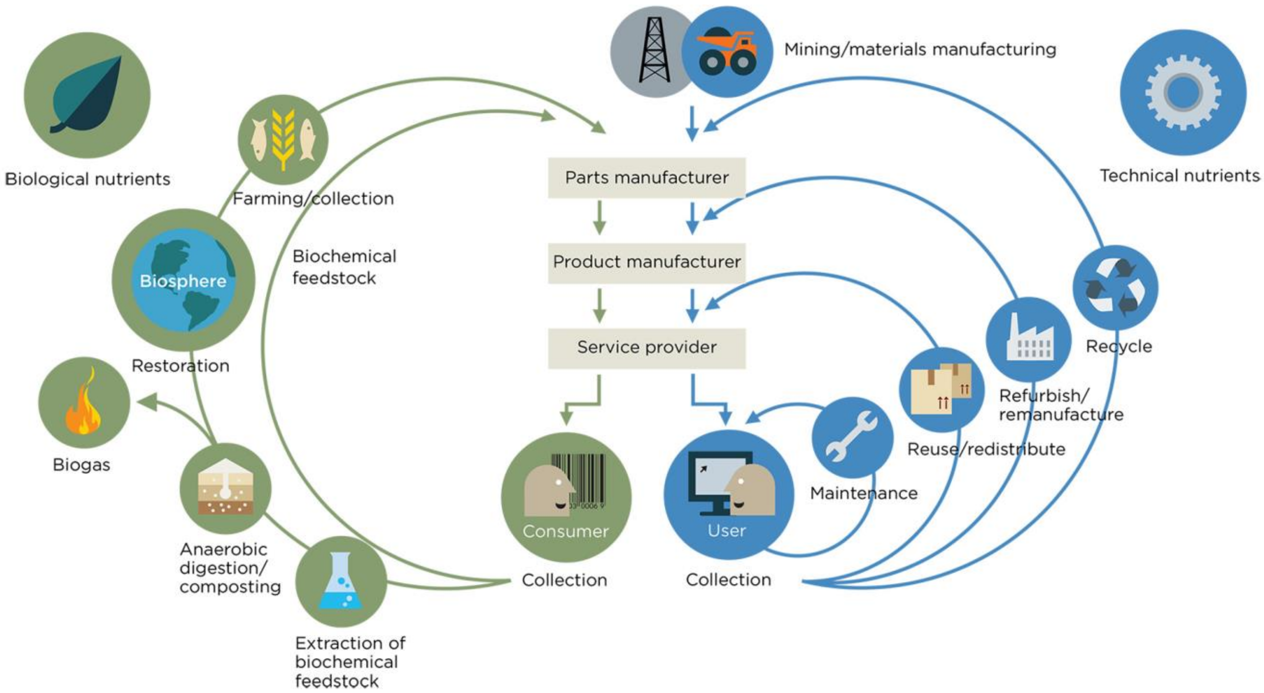
Bio economy strategies call for substantial substitution of fossil-based resources (oil, gas and coal) with renewable resources. Many governments have set targets for emissions reductions to meet international obligations, and as a result there has been a drive towards using biomass in electricity generation, for liquid and gaseous fuels and for bio-based materials production (e.g. chemicals, plastics and textiles). According to the International Renewable Energy Agency, at least 154 countries have set renewable energy targets as of mid-2015 (IRENA, 2015a; 2015b).

Thus, the transformation from a fossil-dependent society to one based on renewables is no longer the subject of academic debate. In June 2015 the G7 outlined the plan to phase out fossil fuels by the end of this century. The G7 text (G7 Germany, 2015) called for as-close-as-possible to a 70% reduction on 2010 emissions by 2050, in line with the overall goals of the Paris Agreement from COP21. Such a major upheaval calls for policy action on many fronts e.g. tax, energy, agriculture, governance, investment. Science and technology quite clearly hold the answers to many of the questions regarding this low-carbon, non-fossil future, as evidenced by the growth of solar and wind technologies.

Bio-production is directly linked to several of the societal grand challenges and policy goals. These are principally, climate change mitigation, energy security and resource depletion. Indirectly, bio-production can also be linked to food security (as the industrial use of biomass has the potential to impact on food security), soil destruction and water security. Therefore bio-production touches on the most important human challenges of now and the future, which collectively could be called ‘sustainable development’, and is therefore directly linked to the United Nations 2030 Agenda for Sustainable Development (General Assembly of the United Nations, 2015).

In 2015, the European Commission launched an action plan for a circular economy (European Commission, 2015a), in which the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised. This is another large policy action consistent with a vision of a sustainable future. A key policy goal of bio-production and bio refining, especially for second generation biofuels and bio-based materials, is the valorisation of waste. These aspirations for bio-based production are clearly aligned with the circular economy concept (Figure 25).

Figure 27. A circular economy concept that accounts for bio-based production



Source: http://www.ellenmacarthurfoundation.org

The integrated bio refineries, exploiting the overall lignocellulosic waste components to generate fuels, chemicals and energy, have recently been described as "*the pillar of the circular economy*" (Liguori and Faraco, 2016).

The climate deal achieved in Paris in 2015 has been hailed as the biggest policy breakthrough in climate politics yet. In common with bio economy goals, the agreement reached in Paris aims at reducing the carbon pollution that threatens the planet, and creating more jobs and economic growth driven by low-carbon investments. It is hoped that the Paris Agreement (UN FCCC, 2015) is sufficiently robust that the transition to a low carbon economy is now unstoppable.

The policy goals of waste bio refining are also consistent with the Green Growth concept.[60] Green growth has been defined as follows (OECD, 2011):

> *"Green growth is about fostering economic growth and development while ensuring that the natural assets continue to provide the resources and environmental services on which our well-*

60 The concept officially emerged in June 2009, when all 30 OECD member countries at the time (plus Chile, Estonia, Israel and Slovenia) signed a Green Growth declaration. See: http://www.oecd.org/env/44077822.pdf

being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities".

The first country that incorporated Green Growth into major policy was the Republic of Korea, with a National Green Growth Strategy, which included three major objectives and ten policy directions (Zelenovskaya, 2012) consistent with climate change mitigation.

Korea has taken waste disposal very seriously. Between 1995 and 2007, the percentage of MSW landfilled went from 72.3% to 23.6%. This reduction in landfilling has opened new business opportunities. Korea's Landfill Gas Recovery Project is a major Clean Development Mechanism project that exemplifies Green Growth ambitions. The landfill gas recovery plant generates electricity and is saving on CO_2 emissions to the level of millions of tonnes, is saving the country money (up till 2017 this is expected to be around USD 126 million), and reducing Korean oil imports.[61]

[61] http://www.unep.org/greeneconomy/AboutGEI/SuccessStories/WasteManagementinRepublicofKorea/tabid/29892/Default.aspx

REFERENCES

Abbott, P., C. Hurt and W.E. Tyner (2008), "What's driving food prices?", Farm Foundation Issue Report. *Farm Foundation,* Oak Brook, IL.

Accenture (2009), "Betting on Science. Disruptive technologies in transport fuels", http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture_Betting_on_Science_Study_Overview.pdf

Adani, F. (2015), "Availability of bio-waste types (including gases)", Presentation at the joint workshop of the Italian National Technological Cluster of Green Chemistry and the OECD: *Bio-waste Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes*, Economdo 2015, Rimini Fiera, Italy.

Aru, A., D. Tomasi and A. Vacca (2006), "Aspects of environmental degradation in Sardinia", Chapter 17 in: *Water Resources for the Future*. Proceedings of the International Conference organised in collaboration with the Italian Ministry for the Environment and Territory, Porto Cervo, Sassari, Sardinia, Italy 22-24 October 2003. Eds. L. Tennyson and P.C. Zingari. Pub. Food and Agriculture Organisation of the United Nations Rome, 2006.

Bentsen, N.S., C. Felby and B.J. Thorsen (2014), "Agricultural residue production and potentials for energy and materials services", *Progress in Energy and Combustion Science* 40, 59-73.

Bio-based Industries Consortium (2013), "Strategic innovation and research agenda (SIRA). Bio-based and renewable industries for development and growth in Europe".

Biofuels Digest, 2014. "Enerkem: Alberta's municipal waste to fuels juggernaut, in pictures", October 2014.

Biofuels Digest (2014), "GranBio starts cellulosic ethanol production at 21 million gallon plant in Alagoas, Brazil", September 2014

Biofuels Digest (2015a), "US policy instability cost $13.7 billion in renewables investment: report", May 2015

Biofuels Digest (2015b), "Who said what: The hottest slides from ABLC 2015", March 2015.

Biofuels Digest (2016), "Ensyn breaks ground on new 10 million gallon advanced biofuels project in Quebec", July, 2016.

Biomass Magazine (2011), "The role of MSW for future biorefineries", http://biomassmagazine.com/articles/6746/the-role-of-msw-for-future-biorefineries/?ref=brm

Bioökonomierat (2016), "Wood in the bioeconomy - opportunities and limits", *BÖRMEMO* 05, 19/04/2016, preliminary version.

Black, M.J., J. Sadhukhan, K. Day, G. Drage and R.J. Murphy (2016), "Developing database criteria for the assessment of biomass supply chains for biorefinery development", *Chemical Engineering Research and Design* 107, 253–262.

Bosch, R., M. van de Pol and J. Philp (2015), "Define biomass sustainability", *Nature* 523, 526-527.

Bozell, J.J. (2008), "Feedstocks for the future – biorefinery production of chemicals from renewable carbon", *CLEAN- Soil, Air, Water* 36, 641-647.

Brazil Biotech Map (2011), Brazilian Association of Biotechnology (BRBIOTEC). http://www.cebrap.org.br/v1/upload/pdf/Brazil_Biotec_Map_2011.pdf

Cardona CA, Quintero JA and Paz IC (2010), "Production of bioethanol from sugar cane bagasse: status and perspectives", *Bioresource Technology* 101 4754-4766.

Carrez, D. (2014), "The bio-based industries initiative PPP and a focus on higher added-value", Presentation at the OECD Workshop held in Turin, Italy, October 2014, "*Present and Future Policy for Bio-Based Production*". OECD Publishing, Paris.

Carrez, D. (2016), "The current status of the BBI Joint Undertaking", Presentation at the OECD workshop *Innovation for a Sustainable Bioeconomy*, Paris, May 25, 2016.

Carriquiry MA, Du X and Timilsina GR (2011), "Second generation biofuels: Economics and policies", *Energy Policy* 39, 4222-4234.

Cheali, P., J.A. Posada, K.V. Gernaey and G. Sin (2015), "Upgrading of lignocellulosic biorefinery to value added chemicals: Sustainability and economics of bioethanol-derivatives", *Biomass and Bioenergy* 75, 282-300.

Chen, P.-C. and H.-W. Ma (2015), "Using an industrial waste account to facilitate national level industrial symbioses by uncovering the waste exchange potential", *Journal of Industrial Ecology* 19, 950–962.

Chertow, M.R. (2007), "Uncovering industrial symbiosis", *Journal of Industrial Ecology* 11, 11-30.

Cobror, S. (2015), "Advanced lignocellulosic biorefinery for the production of biofuels and biochemicals", Presentation at the joint workshop of the Italian National Technological Cluster of Green Chemistry and the OECD: *Bio-waste Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes*, Ecomondo 2015, Rimini Fiera, Italy.

Coetzee, W. (2016), "Sweet dreams", *The Chemical Engineer* 899, 30-33.

De Gorter H., D. Drabik and D.R. Just (2013), "How biofuels policies affect the level of grains and oilseed prices: Theory, models and evidence", *Global Food Security* 2, 82–88.

De Jong and Jungmeier (2015), "Biorefinery concepts in comparison to petrochemical refineries", Chapter 1 in: Industrial Biorefineries and White Biotechnology. Elsevier B.V. http://dx.doi.org/10.1016/B978-0-444-63453-5.00001-X.

Desrochers, P. (2002), "Cities and industrial symbiosis. Some historical perspectives and policy implications", *Journal of Industrial Ecology* 4, 29-44.

Dias, M.O.S., T.L. Junqueira, O. Cavalett, L.G. Pavanello, M.P. Cunha, C.D.F. Jesus, R.M. Filho and A. Bonomi (2013), "Biorefineries for the production of first and second generation ethanol and electricity from sugar cane", *Applied Energy* 109, 72–78.

Ducat, D.C., J.C. Way and P.A. Silver (2011), "Engineering cyanobacteria to generate high-value products", *Trends in Biotechnology* 29, 95-103.

E4tech (UK) (2014), "Biorefining in Scotland research project", Final Report, Version 2.0. E4tech (UK) Ltd, London.

Ehrenfeld, J. (2003), "Nudging the market: Kinder, gentler public policies", Paper presented at USC Symposium on Sustainable Industrial Development, 7 November 2003, Los Angeles, CA.

Ehrenfeld, J. and N. Gertler (1997), "Industrial ecology in practice. The evolution of interdependence at Kalundborg", *Journal of Industrial Ecology* 1, 67-79.

El-Chichakli, B., J. Von Braun, C. Lang, D. Barben and J. Philp (2016), "Five cornerstones of a global bioeconomy", *Nature* 535, 221-223.

Emami, K., E. Hack, A. Nelson, C.M. Brain, F.M. Lyne, E. Mesbahi, J.G. Day and G.S. Caldwell (2015), "Proteomic-based biotyping reveals hidden diversity within a microalgae culture collection: An example using *Dunaliella*", *Scientific Reports* 5, Article number: 10036, doi:10.1038/srep10036

EN 13432:2000. "Packaging - Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for the final acceptance of packaging".

Erkman, S. (1997), "Industrial ecology: an historical view", *Journal of Cleaner Production* 5, 1–10.

European Commission (2015a), "Closing the loop - An EU action plan for the Circular Economy", COM(2015) 614/2, Brussels.

European Commission (2015b), "Revision of the fertilisers regulation (EC) No 2003/2003", http://ec.europa.eu/smart-regulation/roadmaps/docs/2012_grow_001_fertilisers_en.pdf

European Parliament Briefing (2016), "Closing the loop. New circular economy package", European Parliamentary Research Service PE 573.899, January 2016.

Eurostat, (2003), "Waste generated and treated in Europe", Office for Official Publications of the European Communities, Luxembourg.

Evers, J., T. Fisher, L. Foschi, C. Guene, M. Jung, M. Rodriguez and V. Vandemeulebroucke (2001), "Finance for local development: New solutions for public-private action", New Economics Foundation, Evers and Jung, Fondazione Choros, INAISE

Fava, F., G. Totaro, L. Diels, M. Reis, J. Duarte, O.B. Carioca, H.M. Poggi-Varaldo and B.S. Ferreira, (2015), "Biowaste biorefinery in Europe: opportunities and research & development needs", *New Biotechnology* 32, 100-108.

Federal Government of Germany (2012), "Biorefineries roadmap", Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), Berlin. May 2012.

Fernández Gutiérrez, M. (2016), "Bio-based industries in the European Bioeconomy", Presentation at the OECD workshop *Innovation for a Sustainable Bioeconomy*, Paris, May 25, 2016.

Financial Times (2014), "Petrol price increase raises Brazil inflation fears", November 07, 2014. http://www.ft.com/cms/s/0/ea974c28-669e-11e4-91ab-00144feabdc0.html#axzz3gGIMAT91

Financial Times (2015a), “Alberta outlines plan for carbon tax”, November 23, 2015. http://www.ft.com/intl/cms/s/0/06443bc2-919e-11e5-bd82-c1fb87bef7af.html#axzz3sIJDG1xl

Financial Times (2015b), “Microbes from rabbit gut help turn waste to fuel”, *Financial Times*, July 12.

G7 Germany (2015), “Think ahead. Act together”, Leaders’ Declaration G7 Summit 7-8 June 2015. https://sustainabledevelopment.un.org/content/documents/7320LEADERS%20STATEMENT_FINAL_CLEAN.pdf

Gelfand, I., R. Sahajpal, X. Zhang, R.C. Izaurralde, K.L. Gross and G.P. Robertson (2013), “Sustainable bioenergy production from marginal lands in the US Midwest”, *Nature* 493, 514-520.

General Assembly of the United Nations (2015), “Transforming our world: the 2030 agenda for sustainable development”, A/RES/70/1. United Nations. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

Giuliano, A., M. Poletto and D. Barletta (2016), “Process optimization of a multi-product biorefinery: The effect of biomass seasonality”, *Chemical Engineering Research and Design* 107, 236–252.

Gregori, G. (2015), “Biorefineries for producing chemical compounds”, Presentation at the joint workshop of the Italian National Technological Cluster of Green Chemistry and the OECD: *Bio-waste Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes*, Ecomondo 2015, Rimini Fiera, Italy.

Gregori, G. (2016), “Cardoon in bio-based production: a flagship for Europe”, Presentation at the OECD workshop *Innovation for a Sustainable Bioeconomy*, Paris, May 25, 2016.

Hellsmark, H., J. Mossberg, P. Söderholm and J. Frishammar (2016), “Innovation system strengths and weaknesses in progressing sustainable technology: the case of Swedish biorefinery development”, *Journal of Cleaner Production* 131, 702-715.

Hennessey (2011), “Municipal solid waste to biofuels 2011 summit”, Biomass feedstock from MSW. Backbone for the biorefining industry.

House of Commons (2011), “The Green Investment Bank. Second Report of Session 2010–11”, Report HC505, March 11, 2011.The Stationery Office, London

House of Lords (2014), “Waste or resource? Stimulating a bioeconomy”, Report of the Science and Technology Select Committee, HL Paper 141. The Stationery Office Limited.

IEA (2012), “World Energy Outlook 2012”, Paris: IEA Publishing.

IEA (2013), “Market Trends and Projections to 2018”, Paris: IEA Publishing.

IEA Bioenergy Task 42 Biorefinery (2009), “Bio-based chemicals. Value added products from biorefineries”, eds. de Jong, E., H. Langeveld and R. van Ree.

IEA Bioenergy Task 39 (2011), “Algae as a feedstock for biofuels. An assessment of the current status and potential for algal biofuels production”.

IFPRI (2010), "Reflections on the global food crisis. How did it happen? How has it hurt? And how can we prevent the next one?", International Food Policy Research Institute Washington DC. ISBN 978-0-89629-178-2.

Il Bioeconomista (2015), "EU Parliament supports shift towards advanced biofuels", April 28, 2015.

Il Bioeconomista (2016), "In Northern Russia a plant to produce 100,000 tonnes of bioethanol per year from wood waste", February 06, 2016.

Iles, A., and A.N. Martin (2013), "Expanding bioplastics production: sustainable business innovation in the chemical industry", *Journal of Cleaner Production* 45, 38-49.

Illinois Environmental Protection Agency (2014), "Illinois landfill projections of disposal capacity as of January 1, 2014", Illinois Environmental Protection Agency, Springfield, IL. http://www.epa.state.il.us/land/landfill-capacity/2013/landfill-capacity-report-2014.pdf

Institute of Risk Management and Competition and Markets Authority (2014), "Competition law risk, a short guide", Crown copyright, London.

IRENA (2015a). "IRENA Renewable Energy Capacity Statistics, 2015", http://www.irena.org/DocumentDownloads/Publications/IRENA RE Capacity Statistics 2015.pdf.

IRENA (2015b). "IRENA Renewable Energy Target Setting 2015", http://www.irena.org/DocumentDownloads/Publications/IRENA RE Target Setting 2015.pdf.

Ishizaka, K. and M. Tanaka (2003), "Resolving public conflict in site selection process - a risk communication approach", *Waste Management* 23, 385-396.

Jambeck, J.R., R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman, A. Andrady, R. Narayan and K.L. Law, (2015), "Plastic waste inputs from land into the ocean", *Science* 347, 768-771.

Jungmeier, G. (2014), "The biorefinery complexity index", http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/6/2/f/ac61fa53-a1c0-4cbc-96f6-c9d19d668a14_BCI%20working%20document%2020140709.pdf.

Kadier, A, Y. Simayi, P. Abdeshahian, N.F. Azman, K. Chandrasekhar and M.S. Kalil (2016), "A comprehensive review of microbial electrolysis cells (MEC) reactor designs and configurations for sustainable hydrogen gas production", *Alexandria Engineering Journal* 55, 427–443.

Kamm, B., M. Kamm and K. Soyez (eds) (1998). "Die grune bioraffinerie/the green biorefinery". In: Technologiekonzept, Proceedings of 1st international symposium green biorefinery/Grune Bioraffinerie, Oct 1997, Berlin, Neuruppin. ISBN 3-929672-06-5.

Kamm, B., M. Kamm and P. Gruber (2006), "Biorefinery systems – an overview", In: Kamm B., M. Kamm and P. Gruber (eds.), Biorefineries – industrial processes and products. Status Quo and future directions, vol 1. Wiley-VCH, Weinheim, pp 3–40.

Kamm, B., P. Gruber and M. Kamm (2007), "Biorefineries – industrial processes and products", Ullmann's Encyclopedia of Industrial Chemistry, 7th ed. Wiley-VCH, Weinheim.

Kaparaju, P., M. Serrano, A.B. Thomsen, P. Kongjana and I. Angelidaki (2009), "Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept", *Bioresource Technology* 100, 2562–2568.

Karak, T, R.M. Bhagat and P. Bhattacharyya (2012), "Municipal solid waste generation, composition, and management: the world scenario", *Critical Reviews in Environmental Science and Technology* 42, 1509-1630.

Kilburn, R. (2015), "IBioIC: From concept to commercialisation, enabling bio-based growth", Presentation at the joint workshop of the Italian National Technological Cluster of Green Chemistry and the OECD: *Bio-waste Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes*, Ecomondo 2015, Rimini Fiera, Italy.

Kizha, A.R., H.-S. Han, T. Montgomery and A. Hohl (2015), "Biomass power plant feedstock procurement: modeling transportation cost zones and the potential for competition", *California Agriculture* 69, 184–190.

Klein-Marcuschamer, D., Y. Chisti, J.R. Benemann and D. Lewis (2013), "A matter of detail: Assessing the true potential of microalgal biofuels", *Biotechnology and Bioengineering* 110, 2317–2322.

Kleinschmit, D., B.H. Lindstad, B.J. Thorsen, A. Toppinen, A. Roos and S. Bardsen (2014), "Shades of green: a social scientific view on bioeconomy in the forest sector", *Scandinavian Journal of Forestry Research* 29, 402-410.

Knight, L., A. Pfeiffer and J. Scott (2015), "Supply market uncertainty: Exploring consequences and responses within sustainability transitions", *Journal of Purchasing & Supply Management* 21, 167–177.

Koike, M. (2009), "Custom hire systems for agricultural machines in Southeast Asia: in a rural community in Thailand", *Engineering in Agriculture, Environment and Food* 2, 144-149.

Köpke, M., C. Mihalcea, F. Liew, J.H. Tizard, M.S. Ali, J.J. Conolly, B. Al-Sinawi and S.D. Simpson (2011), "2,3-Butanediol production by acetogenic bacteria, an alternative route to chemical synthesis, using industrial waste gas", *Applied and Environmental Microbiology* 77, 5467–5475.

Latif, H., A.A. Zeidan, A.T. Nielsen and K. Zengler (2014), "Trash to treasure: production of biofuels and commodity chemicals via syngas fermenting microorganisms", *Current Opinion in Biotechnology* 27, 79–87.

Lavoie, J.-M. (2015), "Biofuels and biorefineries in Canada – adapting the process to the complexity of biomass", Presentation at the joint workshop of the Italian National Technological Cluster of Green Chemistry and the OECD: *Bio-waste Biorefining: bio-waste and organic by-products exploitation in multi-purpose biorefinery schemes*, Ecomondo 2015, Rimini Fiera, Italy.

Li, W.-W., H.-Q. Yu, and B.E. Rittmann (2015), "Chemistry: reuse water pollutants", *Nature* 528, 29–31.

Liguori, R. and V. Faraco (2016), "Biological processes for advancing lignocellulosic waste biorefinery by advocating circular economy", *Bioresource Technology* 215, 13-20.

Local Government Association (2014), "Daily headlines, January 15, 2014", http://www.local.gov.uk/daily-news-headlines/-/journal_content/56/10180/5837892/NEWS#

Long, A.J. (2006), “Environmentally sound forest harvesting”. Report SS-FOR-6, one of a series of the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Lopolito, A., G. Nardone, M. Prosperi, R. Sisto and A. Stasi (2011), “Modeling the bio-refinery industry in rural areas: A participatory approach for policy options comparison”, *Ecological Economics* 72, 18-27.

Lu, L. and Z.J. Ren (2016), “Microbial electrolysis cells for waste biorefinery: A state of the art review”, *Bioresource Technology* 215, 254–264.

Lynd, L.E., C. Wyman, M. Laser, D. Johnson and R. Landucci (2005), “Strategic biorefinery analysis: analysis of biorefineries”, NREL National Renewable Energy Laboratory. Subcontract Report NREL/SR-510-35578.

Malovrh, Š.P., P. Grošelj, L.Z. Stirn and J. Krč (2012), “The present state and prospects of Slovenian private forest owners' cooperation with machinery rings”, *Croatian Journal of Forestry Engineering* 33, 105-114.

Manninen, J. (2016), “Promoting bioeconomy in Finland - policy landscape, business ecosystems and program activities”, Presentation at the OECD workshop *Innovation for a Sustainable Bioeconomy*, Paris, May 25, 2016.

Martinez, G.A., S. Rebecchi, D. Decorti, J.M.B. Domingos, A. Natolino, D. Del Rio, L. Bertin, C. Da Porto and F. Fava (2016), “Towards multi-purpose biorefinery platforms for the valorisation of red grape pomace: production of polyphenols, volatile fatty acids, polyhydroxyalkanoates and biogas”, *Green Chemistry* 18, 261-270.

Massé, D.I., G. Talbot and Y. Gilbert (2011), “On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations”, *Animal Feed Science and Technology* 166–167, 436–445.

Mayfield, C.A., C. Darwin Foster, C.T. Smith, J. Gan and S. Fox (2007), “Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States”, *Biomass and Bioenergy* 31, 631–637.

McCarty, P.L., J. Bae and J. Kim (2011), “Domestic wastewater treatment as a net energy producer–can this be achieved?”, *Environmental Science and Technology* 45, 7100–7106.

McManis, C.R. and S. Noh (2006), “The Impact of the Bayh-Dole Act on genetic research and development: evaluating the arguments and empirical evidence to date”, Retrieved from https://www.law.berkeley.edu/files/mcmanis(1).doc

Milken Institute (2013), “Unleashing the power of the bio-economy”, Milken Institute, Washington DC.

Morgan-Sagastume, F., M. Hjort, D. Cirne, F. Gérardin, S. Lacroix, G. Gaval, L. Karabegovic, T. Alexandersson, P. Johansson, A. Karlsson, S. Bengtsson, M.V. Arcos-Hernández, P. Magnusson and A. Werker (2015), “Integrated production of polyhydroxyalkanoates (PHAs) with municipal wastewater and sludge treatment at pilot scale”, *Bioresource Technology* 181, 78–89.

Morschbacker, A. (2009), “Bio-ethanol based ethylene”, *Journal of Macromolecular Science Part C: Polymer Reviews* 49, 79–84.

Mueller, S.A., J.E. Anderson. and T.J. Wallington (2011), "Impact of biofuel production and other supply and demand factors on food price increases in 2008", *Biomass and Bioenergy* 35, 1623–1632.

Näyhä, A. and H.-L. Pesonen, (2012), "Diffusion of forest biorefineries in Scandinavia and North America", *Technological Forecasting & Social Change* 79, 1111–1120.

OECD (2016), "Green investment banks: scaling up private investment in low-carbon, climate-resilient infrastructure", Green Finance and Investment, OECD Publishing, Paris.

OECD (2015a), "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry", Report of the joint HUGO-OECD workshop, Saturday, March 14th 2015, Kuala Lumpur, Malaysia. OECD Publishing, Paris.

OECD (2015b), "Greening steel: innovation for climate change mitigation in the steel sector", OECD Publishing, Paris.

OECD (2014a), "Biobased chemicals and plastics. Finding the right policy balance", OECD Science, Technology and Industry Policy Papers No. 17. OECD Publishing, Paris.

OECD (2014b), "Present and future policy for bio-based production", Report of an OECD Workshop held in Turin, Italy, 09 October 2014.

OECD (2013), "Policies for bioplastics in the context of a Bioeconomy", OECD Science, Technology and Industry Policy Papers No. 10. OECD Publishing, Paris.

OECD (2011), "Towards green growth: monitoring progress", OECD Indicators. OECD Publishing, Paris.

OECD (2010), "OECD environmental performance reviews: Japan 2010", OECD Publishing, Paris.

OECD (2007), "OECD environmental data, compendium 2006–2008", OECD Publishing, Paris.

OECD (2003), "Entrepreneurship and local economic development programme and policy recommendations", OECD Publishing, Paris. ISBN 92-64-19978-0

Orts, W.J. and C.M. McMahan (2016), "Biorefinery developments for advanced biofuels from a sustainable array of biomass feedstocks: survey of recent biomass conversion research from Agricultural Research Service", *BioEnergy Research* 9, 430-446.

Paillard, H. (2016), "Ever decreasing circles", *The Chemical Engineer* 899, 38-40.

Panoutsou, C. (2015), Presentation at the EC workshop *Integrated biorefineries and innovations in the optimal use of biomass*, Brussels, December 10, 2015.

Parajuli, R., T. Dalgaard, U. Jørgensen, A.P.S. Adamsen, M.T. Knudsen, M. Birkved, M. Gylling and J.K. Schjørring (2015), "Biorefining in the prevailing energy and materials crisis: a review of sustainable pathways for biorefinery value chains and sustainability assessment methodologies", *Renewable and Sustainable Energy Reviews* 43, 244–263.

Pavanan, K.C., R.A. Bosch, R. Cornelissen and J.C. Philp (2013), "Biomass sustainability and certification", *Trends in Biotechnology* 31, 385-387.

Peplow, M. (2014), "Cellulosic ethanol fights for life. Pioneering biofuel producers hope that US government largesse will ease their way into a tough market", *Nature* 507, 152

Peters, D. (2011), "The German biorefinery roadmap; presentation at the expert forum conference on biorefineries", Budapest, April 2011.

Pickin, J. (2009), "Australian landfill capacities into the future", Report prepared for the Department of the Environment, Water, Heritage and the Arts, Hyder Consulting Pty Ltd, report ABN 76 104 485 289.

Pienkos, P.T. (2009), "Algal biofuels: ponds and promises", Presented at the13th Annual Symposium on Industrial and Fermentation, May 01, 2009, NREL/PR-510-45822.

Pienkos, P.T. and A. Darzins (2009), "The promise and challenges of microalgal-derived biofuels", *Biofuels, Bioproducts and Biorefining* 3, 431-440.

Randolph, K. and S. Studer (2013), "Biological hydrogen production workshop summary report", US Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office.

Renewable Waste Intelligence (2014), "Is the conversion of municipal solid waste to biofuels and bio-products a truly sustainable and economic business model in the USA?", An analysis of the USA market and the state of play for MSW to biofuels and bio-products projects. http://www.renewable-waste.com/biofuels/pdf/Whitepaper1.pdf

Sayre, R., W. Henley, W. Litaker and L. Novoveská (2013), "Initial risk assessment of genetically modified (GM) algae for commodity-scale cultivation", *Algal Research* 2, 66–77.

Scarlat, N., J.-F. Dallemand, F. Monforti-Ferrario and V. Nita (2015), "The role of biomass and bioenergy in a future bioeconomy: Policies and facts", *Environmental Development* 15, 3–34

Scharff, H. (2014), "Landfill reduction experience in The Netherlands", *Waste Management* 34, 2218–2224.

Schieb, P.-A., H. Lescieux-Katir, M. Thénot and B. Clément-Larosière (2015), "Biorefinery 2030: Future prospects for the bioeconomy", Springer-Verlag. ISBN 978-3-662-47374-0.

Schieb, P.-A. and J.C. Philp (2014), Biorefinery policy needs to come of age, *Trends in Biotechnology* 32, 496-500.

Scottish Enterprise (2014), "National plan for industrial biotechnology", Scottish Enterprise, Glasgow, UK.

Scottish Enterprise (2015), "The Biorefinery Roadmap for Scotland", Scottish Enterprise, Glasgow, UK.

Siegmeier, T., B. Blumenstein and D. Möller (2015), "Farm biogas production in organic agriculture: System implications", *Agricultural Systems* 139, 196–209.

Sjostrom, E. (1993), "Wood chemistry (second edition). Fundamentals and applications", Elsevier. ISBN: 978-0-08-092589-9.

Star-COLIBRI (2011), "Joint European biorefinery vision for 2030. Strategic targets for 2020 – collaboration initiative on biorefineries".

Subba Rao, P.V. and V.A. Mantri (2006), "Indian seaweed resources and sustainable utilization: scenario at the dawn of a new century", *Current Science* 91, 164-174.

Sudhakar, M.P., R. Merlyn, K. Arunkumar and K. Perumal (2016), "Characterization, pretreatment and saccharification of spent seaweed biomass for bioethanol production using baker's yeast", *Biomass and Bioenergy* 90, 148-154.

Suurs, R. and E. Roelofs (2014), "Biobased investment climate in the Netherlands and Europe. Summary results quick scan", https://www.tno.nl/media/3387/quickscan_biobased_investment_climate_executive_summary.pdf.

Szollosi, A., Q.D. Nguyen, A.G. Kovacs, A.-L. Fogarasi, S. Kun and B. Hegyesne-Vecseri (2016), "Production of low or non-alcoholic beer in microbial fuel cell", *Food and Bioproducts Processing* 98, 196–200.

Tan T, Yu J and Shang F (2011), "Biorefinery engineering", Chapter 2.58 in: Comprehensive Biotechnology (Second Edition), ed. M. Moo-Young. ISBN: 978-0-08-088504-9, pp. 815-828.

Tanaka, K., A. Ishizaki, T. Kanamaru and T. Kawano (1995), "Production of poly(D-3-hydroxybutyrate) from CO_2, H_2 and O_2 by high cell density autotrophic cultivation of *Alcaligenes eutrophus", Biotechnology and Bioengineering* 45, 268–275.

Taylor, P. (2010), "Biosuccinic acid ready for take off?", Royal Society of Chemistry, January, 2010, http://www.rsc.org/chemistryworld/News/2010/January/21011003.asp.

Timmer, P.C. (2008), "Causes of high food price", plus Technical Annexes. ADB Economics Working Paper Series No. 128 (October), Asian Development Bank, Manila.

Tsakalova, M., T.-C. Lin, A. Yang and A.C. Kokossis (2015), "A decision support environment for the high-throughput model-based screening and integration of biomass processing paths", *Industrial Crops and Products* 75, 103–113.

UK Bioenergy Strategy (2012), Department of Energy & Climate Change, London. www.decc.gov.uk. 83 pp.

USEPA (2014), "Municipal solid waste generation, recycling, and disposal in the United States: facts and figures for 2012", EPA-530-F-14-001, February 2014, Washington DC.

UN FAO (2011), "Global food losses and food waste – Extent, causes and prevention", FAO, Rome.

UN FAO (2013), "Food wastage footprint: impacts on natural resources", Rome, FAO, ISBN 978-92-5-107752-8 http://www.fao.org/docrep/018/i3347e/i3347e.pdf.

UN FCCC (2015), "Adoption of the Paris agreement", FCCC/CP/2015/L.9/Rev.1. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

UN-Water (2015), "Wastewater management", A UN-Water analytical brief. http://www.unwater.org/publications/publications-detail/pt/c/275896/

USDA News Release (2014), "USDA announces loan guarantee to help innovative company turn waste into renewable jet fuel", USDA Office of Communications Release No. 0195.14

Van Stappen, F., I. Brose and Y. Schenkel (2011), "Direct and indirect land use changes issues in European sustainability initiatives: State-of-the-art, open issues and future developments", *Biomass and Bioenergy* 35, 4824–4834.

Velis, C.A. (2015), "Circular economy and global secondary material supply chains", *Waste Management Research* 33, 389–391.

Wasted (2014), "Europe's untapped resource. An assessment of advanced biofuels from wastes & residues", http://europeanclimate.org/wp-content/uploads/2014/02/WASTED-final.pdf

Wei N, Quarterman J and Jin Y-S (2013), "Marine macroalgae: an untapped resource for producing fuels and chemicals", *Trends in Biotechnology* 31, 70-77.

World Economic Forum (2010), "The future of industrial biorefineries", WEF ref 210610.

Wright, M. and R. Brown (2007), "Comparative economics of biorefineries based on the biochemical and thermochemical platforms", *Biofuels, Bioproducts, and Biorefining* 1, 49-56.

Yamashita, M. and S.-I. Matsumoto (2014), "Status of recycling plastic bottles in Japan and a comparison of the energy costs of different recycling methods", *International Journal of Environmental Protection and Policy* 2, 132-137.

Zelenovskaya, E. (2012), "Green Growth policy in Korea: A case study", International Center for Climate Governance, Venice, Italy.

Zeng, X., A.P. Borole and S.G. Pavlostathis (2015), "Biotransformation of furanic and phenolic compounds with hydrogen gas production in a microbial electrolysis cell", *Environmental Science and Technology* 49, 13667–13675.

Zhang, Y., M. Goldberg., E. Tan and P.A. Meyer (2016). "Estimation of economic impacts of cellulosic biofuel production: a comparative analysis of three biofuel pathways". *Biofuels Bioproducts and Biorefining* 10, 281-298.

ANNEX 1: GLOSSARY OF BIOREFINERY TERMS

Agricultural residue: Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fibre product. Examples include corn stover (stalks, leaves, husks, and cobs), wheat straw, and rice straw.

Algal lipid biorefinery: component separation in primary refining results in algal lipids and algal biomass. They generally refer to microalgae, which are often single-celled organisms. Having been grown in a reactor under conditions that allow accumulation of lipids, the lipids are then extracted. The product is an algal oil rich in triglycerides, but also in higher value materials such as carotenoids and phytosterols. Triglycerides form the basis of biodiesels and are also a potential raw material for the chemical industry.

Aromatic: A chemical with flat ring or rings in its molecular structure held together by alternating single and double bonds (for example benzene, toluene, xylene).

Bagasse: Residue remaining after extracting a sugar-containing juice from plants like sugar cane.

Biodiesel: Conventionally defined as a biofuel produced through transesterification, a process in which organically- derived oils are combined with alcohol (ethanol or methanol) in the presence of a catalyst to form ethyl or methyl ester. The biomass- derived ethyl or methyl esters can be blended with conventional diesel fuel or used as a neat fuel (100% biodiesel). Biodiesel can be made from soybean or rapeseed oils, animal fats, waste vegetable oils, or microalgae oils. *Note: Biodiesel can in certain circumstances include ethanol-blended diesel.

Biocoal: This is a solid fuel made from biomass by heating it in an inert atmosphere. The result is either charcoal, or if the process temperature is mild, a product called ‘torrefied wood’. Charcoal and torrefied wood can be called by common name biocoal. Compared to untreated biomass, biocoal has several advantages. It has high energy content, uniform properties and low moisture content. Biocoal can be used in coal-fired power plants, which have difficulties with other biomass based fuels, such as wood chips.

Biocrude: A crude oil similar to petroleum which can be produced from biomass under high pressure and temperature.

Bioenergy: Useful, renewable energy produced from organic matter. The conversion of the complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel processed into liquids and gases, or be a residual of processing and conversion.

Biofuels: Fuels made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

Biogas biorefining: here there is no separate component separation in primary refining. The organic materials present in the feedstock are anaerobically decomposed in a complex microbiological process to biogas, comprised mainly of methane and CO_2. The gas is flammable and can be burned to produce heat and electricity. In wastewater treatment plants this is traditionally called anaerobic digestion, and can in many cases meet the electricity needs of the entire plant.

Biomass: Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues, fibers, animal wastes, and segregated municipal waste, but specifically excluding unsegregated wastes;

painted, treated, or pressurized wood; wood contaminated with plastic or metals; and tires. Processing and conversion derivatives of organic matter are also biomass.

By-products: that occur as a result of primary- and/or secondary refining are used to supply process energy or, where applicable and in compliance with statutory requirements, they are further processed into food or feed.

Energy crops: Crops grown specifically for their fuel value. These crops may include food crops such as corn and sugarcane, and non-food crops such as poplar trees and switchgrass.

Feedstock: Any material converted to another form or product. The starting material for a process. In a biotechnology-related process, this could be wood, switchgrass, waste paper, agricultural residues, corn, soybeans, and so forth.

Fermentation: the term is used generally in bio-based production, and more widely in society, to mean the microbial conversion of carbon sources (such as sugars) into bio-based products. More strictly it is the anaerobic catabolism of sugars to (usually) ethanol and short chain fatty acids (such as acetate), CO_2 and H_2. The substrate acts as both the carbon source and the electron acceptor (instead of oxygen). This does not adequately describe fermentation scientifically but it covers most eventualities in bio-based production.

Fischer-Tropsch: The Fischer–Tropsch process is a set of chemical reactions that converts a mixture of carbon monoxide gas and hydrogen gas into liquid hydrocarbons (fossil fuels like gasoline or kerosene).

Forest residue: Materials generated from timber harvesting operation other than sawlogs that are typically of lesser or no economic value.

Fuel cell: A device that converts the energy of a fuel directly to electricity and heat, without combustion.

Gasification: The process that converts organic or fossil fuel based carbonaceous materials into CO, H_2 and CO_2, and possibly hydrocarbons such as CH_4. This is achieved by reacting the material at high temperatures without combustion, with a controlled amount of oxygen and/or steam. It can therefore be viewed as a ‘partial oxidation’ process.

Hydrogenation: This means to treat with hydrogen. It is a chemical reaction between molecular hydrogen (H_2) and another compound or element, usually in the presence of a catalyst. The process is commonly employed to reduce or saturate organic compounds. Hydrogenation is becoming an important tool in the efficient conversion of biomass to value-added products.

Hydrolysis: In relation to biorefining, the hydrolysis of biomass is usually taken to mean the hydrolysis of cellulose present in biomass to produce sugars and other organic compounds that can be subsequently fermented. In chemistry it literally means the chemical breakdown of a compound due to reaction with water.

Hydrothermal: Hydrothermal processing of biomass is similar to torrefaction but uses milder treatment conditions. Hydrothermally processed biomass is commonly referred to as ‘biocoal’.

Industrial ecology: The analogy between ecosystems and industrial systems is stressed by the discipline of industrial ecology. The concept that "in nature there is no waste" is particularly pertinent here because of a focus on the re-use of industrial waste streams as feedstocks for other products.

Lignin: An amorphous aromatic polymer, together with cellulose, forms the cell walls of woody plants.

Lignocellulosic biorefining: in dry biomass-based lignocellulosic biorefining, the component separation in the primary refining produces the lignocellulosic components cellulose, hemicelluloses, and lignin, extremely common components of plant and woody materials. The feedstocks are various e.g. straw, forestry trimmings, other agricultural residues, and dedicated energy crops.

Primary refining: in a biorefinery involves the separation of biomass components into intermediates (e.g. cellulose, starch, sugar, vegetable oil, lignin, plant fibres, biogas, synthesis gas), and usually also includes the pre-treatment and conditioning of the biomass. While component separation takes place at the biorefinery, one or more pre-treatment/conditioning processes can also be decentralised where need be.

Secondary refining: further conversion and processing steps create a larger number of products from the intermediates. Thereby, in a first conversion step the intermediate materials are fully or partially processed into precursors, as well as into more intermediates; in further value creation at the site of the biorefinery, these are then fully or partially refined into products. The products from biorefineries can be both finished or semi-finished.

Slash: The component within the forest residues generated from sawlog processing typically consisting of chunks, foliage, branches and other broken material not appropriate to be comminuted by a chipper.

Starch biorefinery: The component separation in primary refining results in starch, which thus constitutes the platform of the starch biorefinery. Typical feedstocks are cereals or potatoes.

Steam explosion: This is a pre-treatment process in which biomass is treated with hot steam under pressure followed by an explosive decompression of the biomass that results in a rupture of the biomass fibres rigid structure, literally ‘exploding’ the biomass to pulp. It makes the biomass polymers more accessible for subsequent processes, such as fermentation, hydrolysis or densification.

Sugar biorefinery: sucrose, commercially available sugar, results from separation processes, and the sugar is then converted, usually through fermentation, to products such as ethanol. Typical feedstocks are sugar cane and sugar beet.

Synthesis gas (syngas): The product of gasification i.e. CO, H_2 and CO_2 a mixture of which is in itself a fuel.

Synthesis gas biorefining: here there is no separate component separation during primary refining; instead, all organic constituents (e.g. solid domestic waste) and biomass components are broken down in such way to produce the raw product synthesis gas. This makes amenable for biorefining materials that would otherwise be unsuited. Products range from fuels, such as Fischer-Tropsch diesel and methanol, to higher alcohols and chemicals, and chemicals.

Torrefaction: Torrefaction of biomass is a mild form of pyrolysis at temperatures typically between 200 and 320°C. It changes biomass properties to provide a much better fuel quality for combustion and gasification applications. It leads to a dry product that is stable on storage as rotting can no longer occur. It can also result in much higher energy density, useful to improve transportation efficiency.

Transesterification: Biodiesel can be produced from straight vegetable oil (SVO), animal oil/fats, tallow and waste oils. SVO creates fairly severe engine problems such as poor atomisation. Transesterification is the reaction of a triglyceride (fat/oil) with an alcohol to form esters (the biodiesel) and glycerol. The glycerol is relatively simple to separate, and the biodiesel has much enhanced properties as a diesel fuel.

Vegetable oil biorefinery: one in which the feedstock is various oil seeds and -fruits, whereby oil is present together with other lipids.