POLICY BRIEF NO. 2, NOVEMBER 2015

PRODUCING BIO-ETHANOL FROM RESIDUES AND WASTES

A TECHNOLOGY WITH ENORMOUS POTENTIAL IN NEED OF FURTHER RESEARCH AND DEVELOPMENT

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Key messages

I Waste-based bio-ethanol helps mitigating climate change while at the same time reducing land competition between energy and food crops

II Waste-based bio-ethanol production offers promising economic potential through diversified value chains and low feedstock costs

III Partly immature technologies, challenging logistics for sourcing waste, and hesitating investors pose barriers to using this potential

IV Targeting research and innovation funding at developing and demonstrating cost-competitive waste-based ethanol production, and setting ambitious targets for the use of biofuels in transport would provide needed policy support

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 308680.

What to find in this policy brief?

RECREATE is a 5-year project running from 2013 to 2018, funded by the European Commission. It is carried out by a consortium consisting of 16 key partners from European research and industry and is led by the Joint Institute for Innovation Policy (JIIP). The overall objective of the project is to support the development of the European Union's research and innovation funding programme Horizon 2020, with a specific focus on the part *Societal Challenge 5: Climate Action, Resource Efficiency and Raw Materials*.

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Policy support needed to unlock the potential of waste-based bio-ethanol

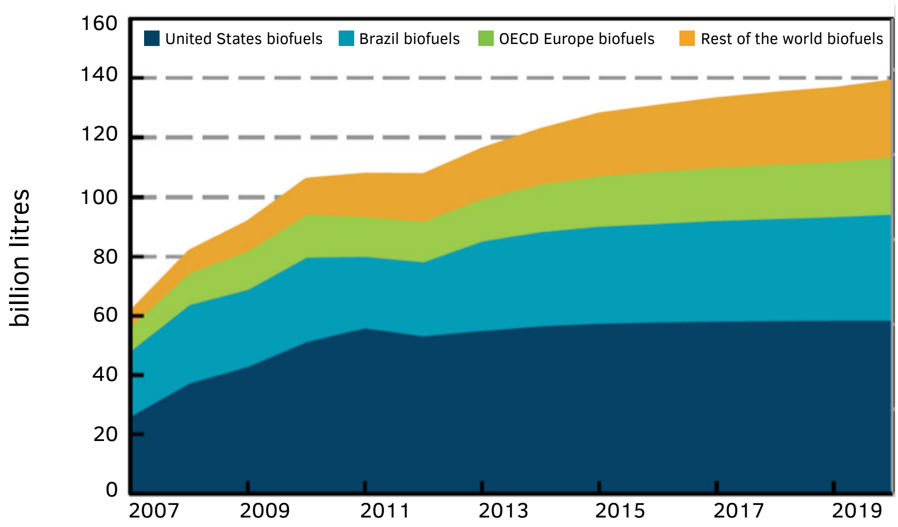
Waste-based bio-ethanol has the potential to both fight climate change and reduce land competition. However, in order to unlock its potential, support for research and development, as well as an enabling political framework, are needed.

I What is the problem? What is the suggested innovative solution?

Biofuels: A puzzle piece for fighting climate change

Ethanol and other alcohols have been considered transport fuels since some of the earliest engine designs. However, they have long been limited to niche applications (e.g. as a racing fuel). In recent years, interest in ethanol from renewable biomass as a motor fuel is surging globally, because of its potential to reduce both fossil fuel dependency and environmental impacts. Global biofuel production increased from around 16 billion litres in 2000 to around 120 billion in 2013; and is projected to rise to some 140 billion towards 2020 (see Figure 1).[1] Main production and consumption markets are the US and Brazil, followed by the EU – in 2008, almost ¼ (21%) of Brazil's road transport fuel demand was met with biofuels, while this share was only 4% in the US and around 3% in the EU.[1]

Figure 1: World biofuels production, historical and projected



Source: OECD/IEA 2014[2]: 10

II Environmental and economic potential of the solution

Biofuels and sustainability: Looking to waste-based bio-ethanol

Ethanol is produced either through fermentation of sugar or starch (first generation), or through hydrolysis and subsequent fermentation of ligno-cellulose, i.e. cellulosic material forming the basic structural components of plant dry matter (second generation bio-ethanol). Currently, bio-ethanol is produced mainly from sugar or starch rich food crops; i.e. corn in the US, sugar cane in Brazil and a mix of wheat, sugar beets, barley and corn in the EU.[3]

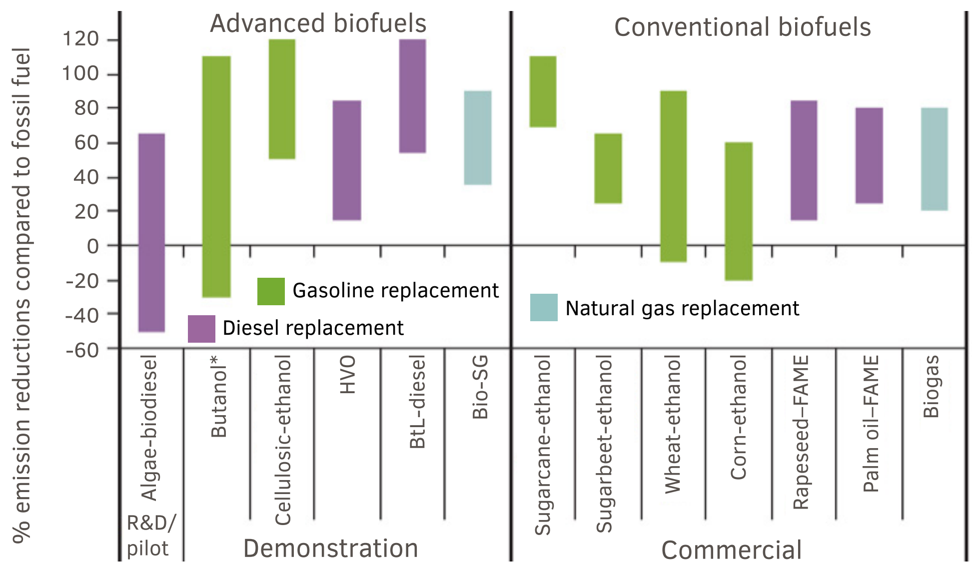
Crop-based bio-ethanol has proven somewhat controversial due to concerns about energy balances, life cycle CO_2 emissions and competition with food production. To address these concerns, bio-ethanol can be derived from a large variety of residue and waste streams – either by capturing sugar or starch rich waste streams or by using waste fractions of crops (so-called ligno-cellulosic biomass). The former is significantly easier to ferment and has more mature required processing technologies. The latter is much more difficult to process, but has a far larger potential feedstock supply available at lower cost.

Figure 2 shows a larger greenhouse gas (GHG) emission reduction potential for advanced biofuels, in particular cellulosic ethanol, than for conventional (first generation) biofuels.

Utilising ligno-cellulosic biomass is still in a relatively early stage of development, but waste-based ethanol can be refined from a number of industrial and municipal wastes and residues at commercial scale today. There are a number of important benefits associated with using waste-based ethanol, including:

- lifecycle CO_2 emissions are far lower than for fossil fuels or crop-based biofuels; comparing well-to-wheel fossil energy use in the case of maximum feedstock use waste-based ethanol allows potential GHG emission savings[5] of 75.5 Mt CO2-eq when compared with wheat based ethanol and 110 Mt CO_2-eq when compared with gasoline;[6] this is equal to circa 6.4 or 9.3% respectively of all GHG emissions from transport in the EU.[7]

Figure 2: Life-cycle GHG balance[4] of different conventional and advanced biofuels and their current state of technology;



Source: OECD/IEA 2014[1]: 16; Bio-SG = bio-synthetic gas; BtL = biomass-to-liquids; FAME = fatty acid methyl esthers; HVO = hydrotreated vegetable oil

- it offers a high value utilisation of low value waste streams, improving revenue for the industries that produce and process these residue streams;
- capturing additional value from the circulation of biogenic materials and promoting eco-industrial networks aligns with the circular economy agenda.

Waste-based bio-ethanol: Estimating production, demand and turnover

The market size for biofuels has largely depended on EU directives, which mandate minimum levels of consumption to be attained by each Member State. The revised Biofuel Directive 2009/28/EC[8] sets a 10% target for 2020. Current EU policy for 2020 aims for a 20% share of renewables for all energy, with a 10% contribution of renewables in all transport energy consumption. The suggested target for 2030 is a 30% share of renewables for all energy, currently with no specification of a target for transport fuels.[9]

To estimate EU waste-based bio-fuel demand and turnover potential by 2030 (see Table 1), the assumptions made were:[10]

- a 20% contribution in transport fuels, differentiating between a 'low' and 'high' demand scenario (see below); and
- that all available biomass feedstocks are utilised; this is included to check that demand does not exceed the maximum technical production potential.

Waste streams that are sustainably harvestable and not used for competing recycling purposes could have a production potential of about 10% of all current EU transport fuel energy consumption.[12] Using all these resources would

> 'Low' demand scenario: crop-based biofuels supply a maximum of 7% of all transport energy[11]
>
> 'High' demand scenario: all biofuel demand will be fulfilled with advanced biofuels

yield a maximum level of production of waste-based bio-ethanol of 65,000 million litres (Ml), far more than the 'high' demand potential for 2030. The average bulk purchase price of bio-ethanol in the EU was 0.55 € per litter (€/l) in 2011[13]; the long term expected average is approximately 0.65 €/l.[14] In addition, EU firms could potentially develop export markets for waste-based ethanol production technologies. The size of this market is far more difficult to estimate in turnover volume.

Environmental and employment effects and required investments

Compared to wheat (crop)-based ethanol and regular gasoline, in the 'high' demand scenario of maximum feedstock supply of 65,000 Ml, waste-based bio-ethanol would save 1,405 Petajoule (PJ) of energy, equivalent to saving 9.3% of all current EU transport energy use.[17] GHG emission savings would be equal to 110 million tonnes (Mt) CO_2-eq when compared with gasoline, and 75.5 Mt CO_2-eq when compared with wheat-based ethanol. This is equal to roughly 9.3 or 6.4% of all GHG emissions from transport in the EU.[14]

Additional benefits of waste-based fuel production are that feedstock collection and fuel conversion tend to be highly localised and, therefore, provide local employment opportunities. At about 3 employees per Ml of fuel production,[18] an estimated 195,000 jobs could be created to meet the demand potential by 2030 with maximum feedstock supply (see Table 2). These numbers

Table 1: EU waste based bio-ethanol demand and turnover potential through 2030[15,16]

Scenario	2020		2030	
	Demand potential (Ml)	Turnover potential (M€)	Demand potential (Ml)	Turnover potential (M€)
Low demand	4,831	3,140	20,933	13,606
High demand	16,103	10,467	32,205	20,933
Maximum feedstock supply	65,000	42,250	65,000	42,250

Ml = million litres, M€ = million €

Table 2: EU waste to ethanol job potential and cumulative required investment through 2030

Scenario	2020		2030	
	Job potential	Investment requirement (M€)	Job potential	Investment requirement (M€)
Low demand (FTE)	14,493	4,831	62,799	20,933
High demand (FTE)	48,309	16,103	96,615	32,205
Maximum feedstock supply (FTE)	195,000	65,000	195,000	65,000

FTE = Full Time Equivalent

are focused on the employment at the production facilities. Export markets for knowledge and turn-key business should be expected to result in additional job potential, although comparable in scale of that required in fuel production.

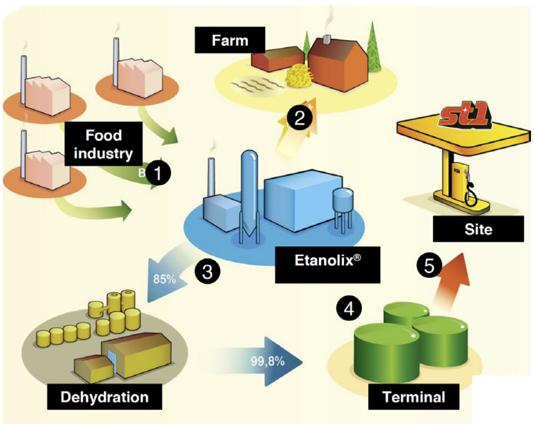
The investment required for the suggested production capacity is significant. Facilities between demonstration and commercial size (several to several dozen Ml) typically required investments of circa 1 million € per Ml of annual production capacity.[19] It is difficult to extrapolate investment requirements, as current projects are still relatively small compared to expected commercial scale plants (approximately 100 Ml and over), and it is uncertain by how much production costs could be reduced trough scaling and process efficiency improvements. Therefore, the suggested investment volume in the following table should be considered very rough estimates, and likely on the high end of actual required investment.

III Good practice examples

Towards business cases for waste-based bio-ethanol: Learning from the case of St1

Pilot and (commercial) demonstration plants for waste-based bio-ethanol are springing up across Europe. St1 Biofuels Oy's bio-ethanol production plant in Gothenburg, Sweden, is a good practice example. The plant produces ethanol utilising ligno-cellulosic biomass from three different waste streams, collected at smaller scale sites for conversion to ethanol to both minimise bulk feedstock resource transport and allow better utilisation of process waste heat. St1 utilises the Etanolix® processing concept for sugar and starch-rich waste streams, e.g. from breweries and beverage industries, bakeries, potato processing factories (see Figure 3). In addition, St1 uses two further feedstocks through different processing technologies: the Bionolix® concept for biological fractions of municipal solid

Figure 3: Etanolix—dispersed ethanol production concept.



I Process residue and/or wastes are sources from nearby industries

II Residues from ethanol production are used as animal feed, fertilizer or solid biomass fuel

III 85% pure ethanol is centrally collected for dehydration in Hamina

IV Storage and blending with gasoline

V Distribution to over 1.200 fuel stations in Scandinavia

Source: St1, captions edited by Gosens, J.

waste and the Cellunolix® concept for forestry industry wastes (saw dust, wood chips, waste wood) and straw.

St1 started ethanol production in Gothenburg in June of 2015, with an annual production capacity of around 5 Ml. Collection of waste from bakeries and bread products past their sell-by date from retailers is facilitated through the bakeries, other intermediaries, or set up by St1 specifically for the purpose of use in the Etanolix plants.

To assess potential business cases, a model project plant was built that closely resembles St1's Gothenburg plant. This enables the consideration of costs and revenues, risks and other business concerns, and comparison with alternative biofuels and conventional fuels.

Estimated production costs and revenues

Based on data from St1 and literature, production costs for such a medium-scale production facility amount to 530€/m³ of 100% ethanol, or 459€ when accounting for an average co-product value of stillage,[20] which can be used as an input for animal feed (see Figure 4).

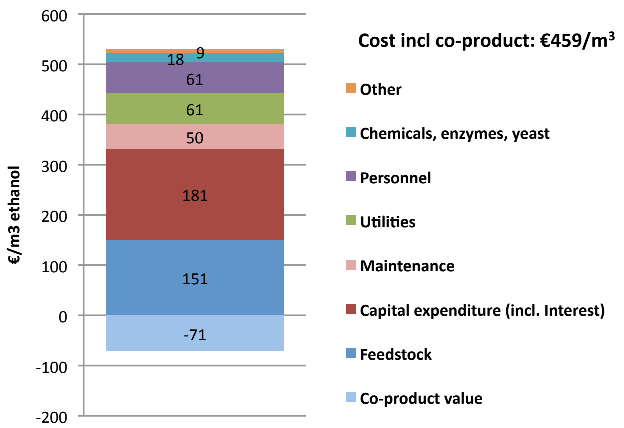
Production costs include investment costs and feedstock costs, as well as costs for electricity, steam and heat (utilities) and for needed chemicals, yeast and enzymes. Feedstock cost is one of the key considerations in a business case for biofuels, because they make up a considerable portion of total production cost and because of the high volatility in feedstock prices. The price for bread and bakery waste is not well reported, but one recent study put it between 60 and 150€ per tonne.[21] Although these prices are well below those of wheat, price volatility is comparable in level.[22] An attractive feature of many waste-based ethanol is that feedstock-related production costs are lower and also subject to less price volatility than for some other biofuels (see Figure 5 below).

The expected revenue is estimated to move between 450 and 600 €/m³, with an average of around 650 €/m³ expected in the longer term.[11] Assuming a 'green premium' of approximately 50 €/m³ between fuel supplier and distributor, this model project would generate an internal rate of return of approximately 7.7%, with a payback period of around 9 years.

In addition to St1's plant there are other refineries using other food industry waste streams, e.g. biological fractions of household waste, crop residues and forestry industry wastes. However, the technological processes are not radically different and the production costs in terms of Operations and Maintenance costs (O&M) per litre are very similar to conventional ethanol (e.g. corn and sugar beet).

There are, however, a number of risks regarding feedstock cost and supply security, as well as risks regarding revenue, including uncertain demand levels, competition with alternative biofuels and policy stimulus, discussed in the following sections.

Figure 4: Estimated production costs in a medium scale (5 Ml/year) refinery for bread and bakery waste-based ethanol, by cost component



Fischer et al. (2015)[7]

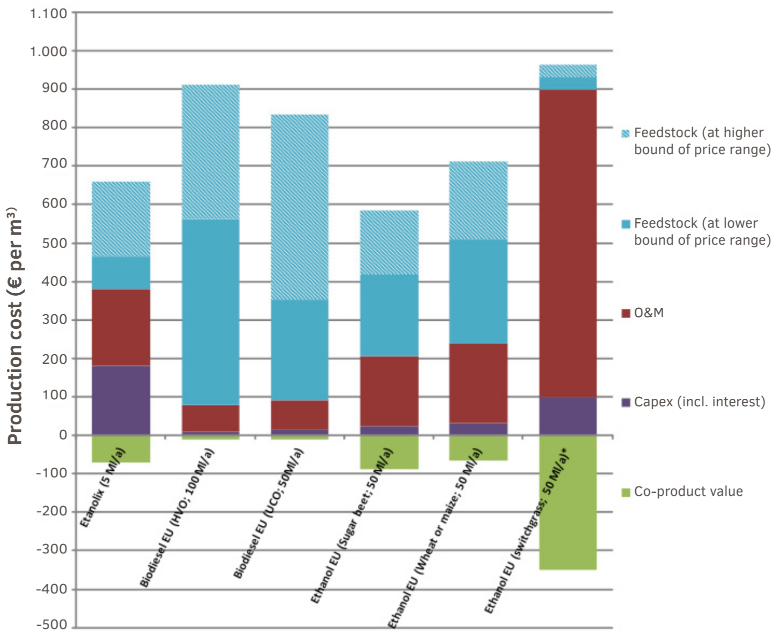


Figure 5: Comparison of Production Cost Components in Selected Biofuels (€/m³); Source: Fischer et al. (2015)[10]

Notes: authors calculations based on Fischer et al. (2015) and De Wit ; HVO: hydrogenated vegetable oil; UCO: used cooking oil; *) note that the estimate for switchgrass based ethanol is largely hypothetical and quite uncertain; there are no known commercial demonstration plants of this type.

IV Barriers to implementation

Barriers and challenges to creating a business case for waste-based bio-ethanol

Availability of and access to waste as feedstock supply	• Competing uses of waste may limit availability of feedstock for waste-based bio-ethanol plants; e.g., forestry industry waste has a competing use in heat and power generation, whereas much biowaste is used in biogas production • Organic waste streams from breweries or potato processing factories are watery solutions of starch or sugars, which do not lend themselves to economically feasible transport • Small scale and localised plants to convert organic waste into bio-ethanol require connection networks to waste providers • To ensure economic viability of the bio-ethanol plant, waste providers must be willing to: » have a localised conversion facility set up on or close to their premises, » provide the feedstock both continuously and at a reasonable price • Collecting bread and bakery waste requires considerable organisational effort for using existing or establishing new connection networks[20] • Ensuring the supply with bread and bakery waste needed for bio-ethanol plants with an annual production capacity of 5–10 Ml requires cities of at least 500,000 inhabitants
Technological and economic issues	• Waste-based feedstocks are more attractive in price and price stability, but competitiveness vis-à-vis other biofuels or conventional fuels seems currently limited by » less mature conversion technologies, and » much higher capital expenditure (CAPEX) and operational expenditure (OPEX) than for crop-based ethanol production • Oil price (development) matters too, because » it determines production cost of biofules' primary competitor, fossil transport fuels, and » production costs of agricultural commodities strongly depend on and move with oil prices • High-blend ethanol fuels require changes to fuelling infrastructure and vehicle fleets; there is a lack of stimulus for the development of high ethanol blend fuelling infrastructure • Difficulties in developing upscaled and advanced biofuel refineries when private investors are hesitant, while government participation is limited
Policy and politics	• Lobbying influence from fossil fuel, automobile and food industries highlights the potential for damage to fuel systems and engines at 10% fuel blends, thus contributing to blocking legislation on 10% blends in a number of European countries • Remaining lack of clarity on financial stimulus and further competition with first generation biofuels; • Lack of stimulus for the development of high ethanol blend fuelling infrastructure; • Limited commodification (and trading possibilities) of blending mandate credits; investors lack price signals for the value of their waste-based biofuels, in particular

V Policy support needs

Need for actions in European Research and Innovation Policy

Waste-based bio-ethanol production remains under technical development, with a number of plants in operation across Europe, typically with scales between demonstration (up to several Ml) and commercial sizes (approximately 100 Ml or more). This is exactly where the classic 'valley of death'[25] in the innovation chain occurs; government funding for basic research is no longer applicable nor sufficient, while private investors are deterred by the limited technological track record.

Considering waste feedstocks research programmes are most important for the development and demonstration of processes utilising cellulosic ethanol. Here, several research funding activities on the European level are already under way.[26] Very importantly, under Horizon2020, the Bio-Based Industries Public-Private Partnership BBI PPP (between the European Commission and the Bio-based Industries Consortium (BIC)) has been set up, which already funds both Research & Innovation Projects and Innovation (Demonstration) Projects that research into generating advanced biofuels from lignocellulosic feedstock (see http://bbi-europe.eu/projects) and aim also to demonstrate future competitiveness of production processes using such feedstock. Furthermore, the 2016/2017 Horizon 2020 Work Programme for SC3 invites submissions in 2016 for projects fostering International Cooperation with Brazil on advanced lignocellulosic biofuels (LCE-22-2016). However, there is only a small number of Horizon calls that appear targeting the need to build capacities through training of researchers, entrepreneurs, process operators, service providers and policy makers to enable innovation within the bio-based economy: BB-06-2016: The regional dimension of bio-based industries; and BB-05-2017: Bio-based products: Mobilisation and mutual learning

Therefore, European research and innovation policy should

a) consider assigning scores in the evaluation of the proposals submitted in response to relevant calls under future Framework Programmes for Research and Innovation (to the extent possible in the upcoming Horizon 2020 Work Programmes or alternatively in FP9) in relation to

- **i)** the importance that the applicants give to linking existing research projects from different regional or local contexts, different feedstocks and different policy frameworks;
- **ii)** project proposals ensuring or outlining credible mechanisms for combining Horizon 2020 funding with funding from European Structural and Investment Funds (ESIF) (such as the European Regional Development Fund (ERDF), the European Social Fund (ESF) or from Cohesion Fund (CF)) in order to link excellent scientific research to and hence increase its relevance and applicability for regional contexts, thus promising potentially more ambitious (demonstration) projects and enhancing innovation impacts for the local economy.

b) strengthen in upcoming Horizon 2020 Work Programmes calls that

- **i)** compare different technologies and demonstration plants in terms of the sustainability of biofuels production from different waste-based feedstocks (including linking to ongoing Horizon 2020 projects dealing with sustainability schemes (BB-01-2016: Sustainability schemes for the bio-based economy) and under the BBI PPP);
- **ii)** compare different supply and demand side policy frameworks on regional and national levels in terms of potential effects for fostering and commercialising biofuels production from different waste-based feedstocks (including linking to ongoing Horizon 2020 projects dealing with sustainability schemes (BB-01-2016: Sustainability schemes for the bio-based economy), regional support issues (BB-06-2016: The regional dimension of bio-based industries) and establishing a mobilisation and mutual learning action plan for bio-based products (BB-05-2017));
- iii) analyse societal support for waste-to-fuel compared to other alternative fuels, including public understanding of global- versus locally-produced biofuels, and crop-based versus waste-based fuels. Where appropriate, such project should include information campaigns/study tours to waste-based bio-ethanol plants for societal groups, in an effort to improve societal knowledge about the potential benefits of ethanol from waste streams.

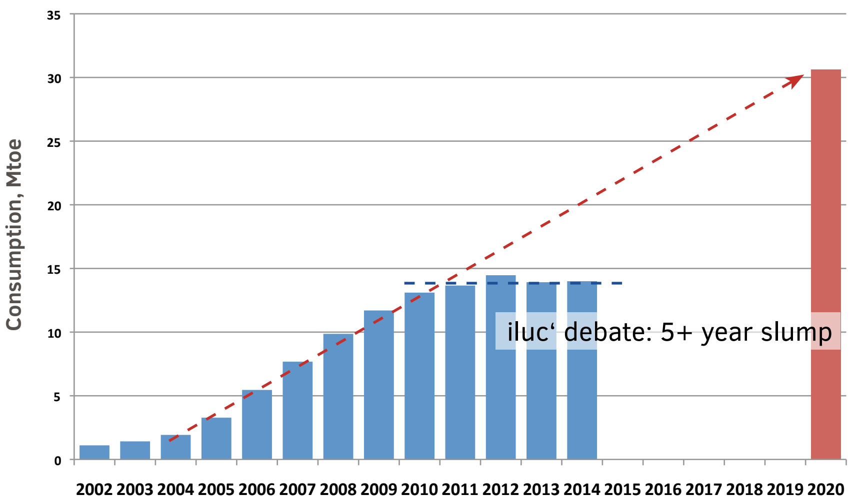
action plan (both 2016/2017 Horizon2020 Work Programme for SC2).[27]

Fostering the use of food-waste based bioethanol requires demand-side policies in the context of European biofuels policy.

Need for action in European biofuels policy

As with other biofuels and renewable energy solutions, waste-based bio-ethanol is dependent on a clear post-2020 framework for climate and renewable energy policy. The recent Indirect Land Use Change (LUC) Directive, 2015/1513,[28] has finally provided the cap on land-based fuels and indications on how emissions from indirect land use change would be incorporated into biofuel GHG accounting. This debate, however, has taken considerable time to be settled, with discussions started in 2009 and extensive adjustments during the discussion process. An initial cap on land-based fuels of 5% was suggested by the European Commission (EC). This was subsequently changed to 6% by the European Parliament, and ended up as a 7% cap in the final text. Rules on 'double-counting' too have changed throughout the negotiation process. The lack of clarity in what future biofuel policy would look like has deterred investors from building new production capacity. The result has been virtually no growth in biofuel consumption between 2009 and 2014 (see Figure 5). Although the debate has now been finally settled, clarity remains absent on post-2020 targets, which are needed soon to provide any long term prospect for investment made in the following years.

Figure 5: EU biofuel market development under policy uncertainty.



When asked about preference for either tax exemptions or mandates, industry representatives indicated that long term perspective mattered most. Mandates, in this sense, were preferable, because these may be implemented with a very long term time horizon; tax exemptions, on the other hand, are subject to repeated renewal of approval from the EC due to EU State Aid regulations.

Source: Fischer et al. (2015)[7]

A clear post-2020 framework for climate and renewable energy policy should:

- set ambitious targets for the use of biofuels in transport to foster demand for and consumption of biofuels in road transport;
- set standards for feedstock acceptability based on true CO_2 and resource savings to strengthen the use of waste and residues as feedstock;
- allow Member States more flexibility in utilising mandates or tax exemptions; the limited exemptions allowed by the guidelines on Stated Aid are unlikely to be sufficient to foster high-blend markets and infrastructure; a necessity for post-2020 targets.

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4. "The assessments exclude emissions from indirect land-use change. Emission savings of more than 100% are possible through use of co-products" IEA (2011): 16.

5. The estimated GHG savings, however, strongly depend on assumptions and system boundaries, e.g., what would have been the alternative fate of the waste streams, and what type of energy is used in ethanol and enzyme production. See for example Wang, M.Q., et al., Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes. Biomass and Bioenergy, 2011. 35(5): p. 1885–1896; and Slade, R., A. Bauen, and N. Shah, The greenhouse gas emissions performance of cellulosic ethanol supply chains in Europe. Biotechnology for Biofuels, 2009. 2(1): p. 1–19.

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18. We arrived at this figure by looking at the Gothenburg St1 plant, with a current production of circa 13 Ml of ethanol, and some 80 employees, and the plans of North European Bio Tech Oy (NEB) to build a bioethanol plant in Kajaani, Finland, based on the St1 Cellunolix concept, with a capacity of circa 10 Ml annually. Once in operation, the plant will employ 15–20 people directly, and about 15 people indirectly.

19. Bacovsky, D., et al., Status of Advanced Biofuels Demonstration Facilities in 2012 – report to IEA bioenergy task 39. 2013.

20. See Wit, M.d. (2011). Bioenergy development pathways for Europe. Potentials, costs and environmental impacts. PhD Dissertation. Science, Technology and Society Group of Utrecht University and Policy Studies Unit of the Energy Research Centre of the Netherlands; see also SAC Consulting, Distillery feed by-products briefing. Report commissioned by the Scottish Government. 2012.

21. Project, B.P., Demonstration plant project to produce Poly-Lactic Acid (PLA) biopolymer from waste products of bakery industry. Project nr LIFE10/ENV/ES/479. 2014.

22. Food crops, the predominant basis for biofuel production, are subject to considerable price volatility: For instance, over the last ten years, prices for wheat and maize have moved, roughly, between 120€ to 250€/tonne (Committee for the Common Organisation of Agricultural Markets (2015). Market situation Cereals - AGRI C 4 - 30 July 2015).

23. Wit (2011).

24. St1 (n.d.), St1 opens its fifth Etanolix® bioethanol plant next to the Hartwall brewery in Lahti, Finland. URL: http://www.st1biofuels.com/company/news/st1-opens-its-fifth-etanolix-bioethanol-plant-next-to-the-hartwall-brewery-in-la, accessed 23 October, 2015.

25. In order to move from a pilot, demonstration or test-series to up-scaling and commercialisation of production, a firm has to invest considerable financial resources. However, this stage in the innovation process usually is hardly funded through public support, hence creating a high risk profile for the companies that is sometimes referred to as "The Valley of Death" for innovations. COWI (2009). Bridging the Valley of Death: public support for commercialisation of eco-innovation. Final Report for DG Environment, May 2009.

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28. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=EN, accessed 23 October, 2015.

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Producing bio-ethanol from residues and wastes

A technology with enormous potential in need of further research and development

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