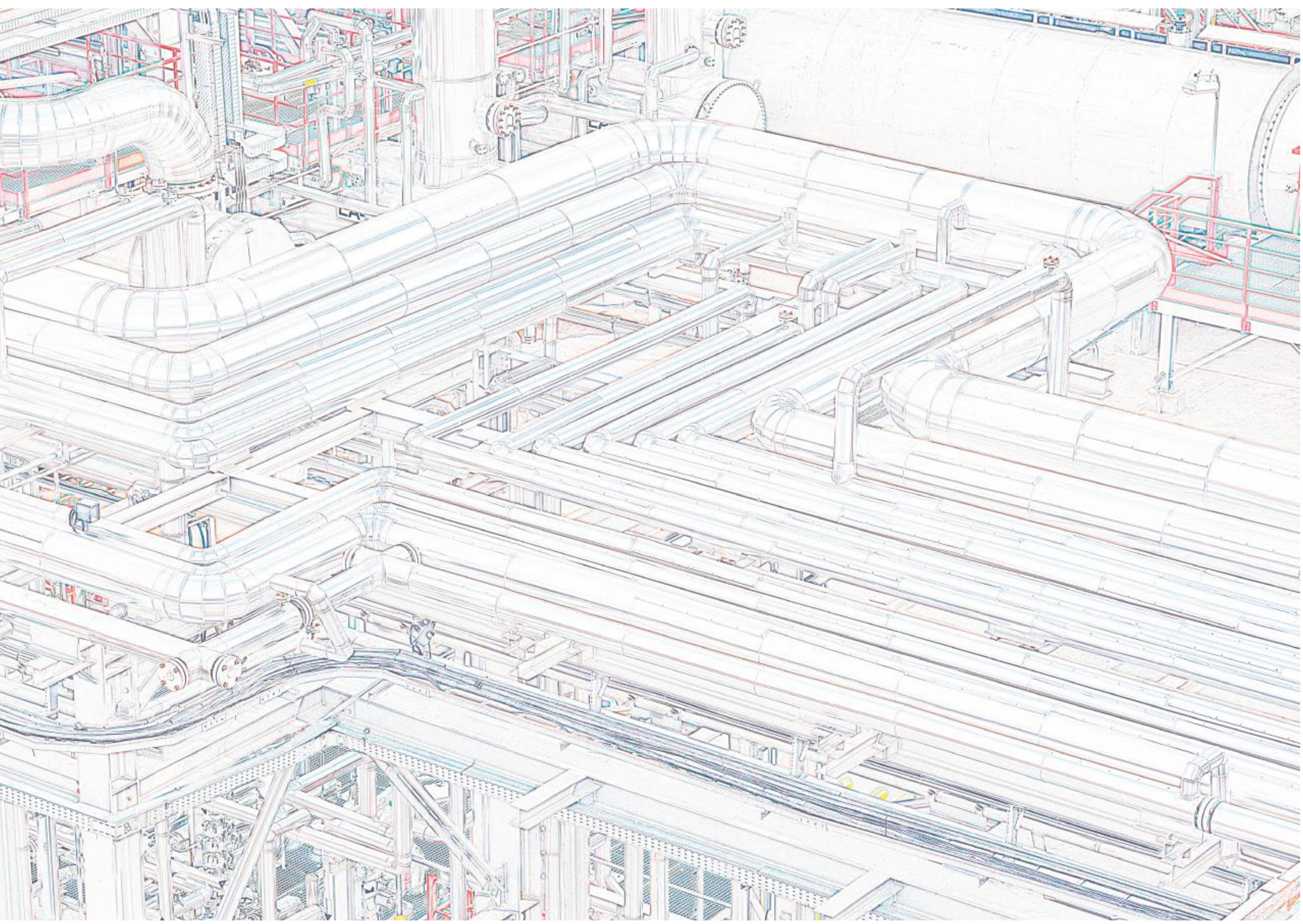
BIOFRONTIERS

Responsible innovation for tomorrow's liquid fuels



DISCLAIMER

The stakeholders who contributed to this study shared the aim of establishing a constructive and transparent exchange of views on the technical, economic and environmental issues associated with the development of advanced biofuels. The objective was to evaluate the boundaries under which advanced biofuels can contribute to mitigating carbon emissions from transport. Each stakeholder contributed knowledge and vision of these issues. The information and conclusions in this report represent these contributions, but should not be treated as binding on the companies and organisations involved.

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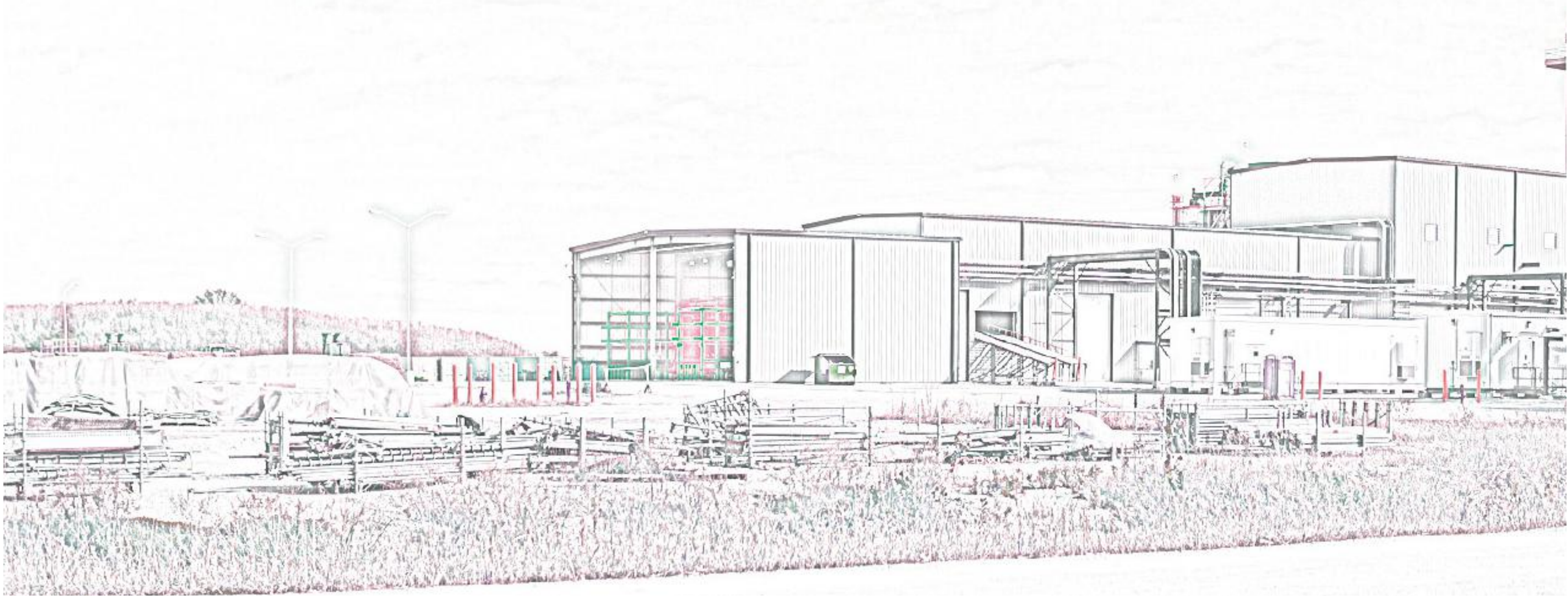

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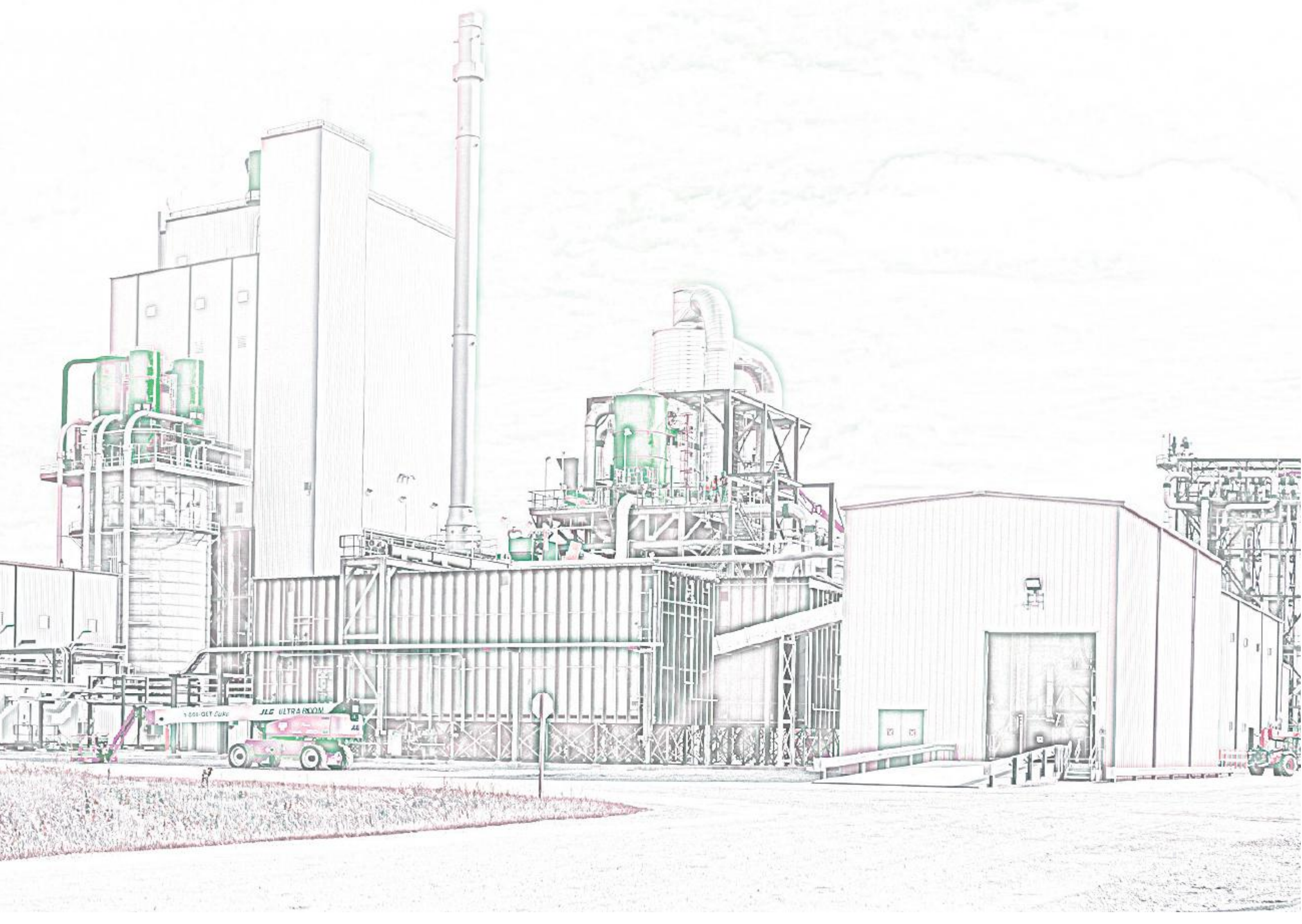


Foreword

Biofrontiers: Responsible innovation for tomorrow's liquid fuels.

Innovation will play a vital role in society's transition away from fossil fuels and towards less harmful energy sources. If done properly, innovation can harness the power of human ingenuity to deliver the low-carbon solutions that future generations will need to live in harmony with our planet.

A major change in energy use is necessary to deal with the challenge of climate change, but the transition creates a myriad of repercussions in other areas. Meeting climate objectives should not mean moving backwards on other important goals, such as sustainable development or nature protection. It is recognition of the need to manage such risks while moving forward that has led to the concept of Responsible Innovation. Responsible innovation has been defined as:

"A transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."[1]

Existing EU energy policy foresees an important role for bioenergy to 2030 as a means of reducing carbon emissions from heating, power and transport. On the other hand, some bioenergy pathways may have a higher carbon footprint than the fossil fuels they could replace.

If bioenergy is to continue to play a role in EU energy strategies for 2030, it seems wise to learn from the past to ensure that any use of bioenergy is done in a manner that is consistent with Europe's sustainability goals, including the 1.5-2 degrees objective. With this in mind, the European Climate Foundation has brought together stakeholders from industry and civil society to explore the conditions and boundaries under which supply-chains for low-carbon transport fuels might be developed sustainably and responsibly.

We have explored supply chains for low-carbon fuels, ranging from wastes and residues from households, forestry and agriculture to energy crops grown on land with low economic and environmental value. We have analysed the risks that investors face when developing these fuels and how policymakers might act to enable those investments. And we have examined sustainability issues that determine how far this finite resource can be used responsibly. This is Biofrontiers.

1. Von Schomberg,Rene (2011) 'Prospects for Technology Assessment in a framework of responsible research and innovation' in: Technikfolgen abschätzen lehren: Bildungspotenziale transdisziplinärer Methode, P.39-61, Wiesbaden: Springer VS

Executive Summary

Forged by world leaders in 2015, the Paris Agreement pledges to confront the threat to our planet from climate change. Governments and businesses must now develop strategies for achieving that goal, largely via efforts to curb deforestation and reduce the carbon intensity of the economy. It is hard to overstate the size of this challenge.

While climate goals are urgent, they will need to be met while avoiding negative impacts on other societal goals, such as biodiversity protection and development. The Paris Agreement expressly states that carbon mitigation should not come at the expense of food security.

This year in Europe, climate protection strategies are being shaped for meeting an intermediate target of reducing greenhouse gas emissions 40% by 2030, including measures to reduce the carbon-intensity of mobility. This strategy should be in line with the goal of deeply decarbonising the economy by 2050 and will involve a shift from the dominant role of fossil fuels in transport. Such a transition is likely to include significant roles for very low carbon, sustainable liquid fuels and electrification.

Innovation is advancing rapidly in this area. However, it is unlikely that the energy solutions that society needs will make the transition from the laboratory to commercialisation without a strong policy framework in place, allowing them to compete against fossil fuels, which have had more than a century head-start in driving down production costs. The challenge for EU policymakers is therefore clear: How to design a policy framework that mobilises investment to deliver such a fuel, while safeguarding sustainability and avoiding the policy mistakes of the past? It has already been widely recognised that EU energy policy for 2030 should phase out support for biofuels that do not deliver on our climate goals[2]. Within that, support for advanced alternative fuels should be prioritised.

The Biofrontiers project has set out to shed light on this challenge, bringing together stakeholders from industry and civil society to explore the conditions and boundaries under which such fuels might be developed in a sustainable manner. Within this project, we have considered only non-food feedstocks for alternative fuels. Each stakeholder has brought unique insight to the table, and where knowledge gaps have existed, we have sought to fill them through analysis.

Based on more than a year of exchanges, this report presents a vision of a path forward for European fuels policy. The challenges faced can be broadly grouped into two areas: Sustainability and Investment Security.

Sustainability

It has become clear that there is a wide range of carbon implications from alternative liquid fuels. Many advanced biofuels from wastes and residues have very low carbon emissions compared to fossil fuels, offering savings in the range of 60-90%. By contrast, some other biofuels offer little or no benefit, particularly where associated with large-scale deforestation. A recent study for the European Commission with the GLOBIOM model[3] and previous work by the International Food Policy Research Institute find that the carbon intensity of biodiesel from crops such as palm oil, soy oil and rapeseed oil are close to that of fossil diesel, or considerably higher. Ethanol from food and feed crops delivers a mix of impacts, ranging from minimal to beneficial levels of carbon savings for most pathways.

The European Union has proposed ambitious waste reduction policies, but even with these measures it is still expected that waste generation in Europe will be considerable within the timeframe considered in this project (2015-2030). Producing liquid transport fuels from such wastes could contribute to meeting targets for reduction of landfilling. Wastes such as unused food from restaurants and canteens are land-filled in many EU countries, often resulting in emissions of the potent greenhouse gas methane. Ensuring this waste is converted instead to liquid fuels, and thereby displacing the combustion of fossil fuel while avoiding the methane emissions, can potentially offer emissions reductions of over 100% (Pavlenko et al, 2016). While expanding the waste-to-fuel industry might in some cases impact existing uses of wastes, such as composting, in general the available resource is more than sufficient to meet current demand as well as support increased energy recovery, and hence the risks from such displacement effects are considered low. Where there may be competition between liquid transport fuel production from wastes and other waste management options, policy should "encourage the options that deliver the best overall environmental outcome", as required by the Waste Framework Directive.

2. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=EN
3. http://www.globiom-iluc.eu/

Residues from agriculture and forestry are not always truly wasted, as they have a market and ecological value. Cereal straw, for example, is often used for livestock bedding or horticulture, and allowing it to decompose in situ can return valuable nutrients to the soil and prevent erosion. Unconstrained residue removal would have ecological risks, but if the extraction of residues is kept within sustainable boundaries, these risks can largely be managed. For example, in many cereal production systems a substantial fraction of straw could be sustainably removed for conversion to cellulosic biofuel. This fuel would deliver GHG savings of more than 70%, according to a study conducted as part of this project (Pavlenko et al, 2016).

Low-carbon liquid fuels of non-biological origin or from biological conversion of non-biological inputs, for example those generated directly from the power grid, can contribute to our climate goals. For these fuel options, it will be important to undertake full life cycle assessment to ensure that the adoption of these new technologies is delivering climate benefits across the whole system.

Land-using feedstocks offer an entirely different proposition. Vegetation generated from the management of landscapes is generally a low-risk feedstock, for example scrub cleared during the management of nature reserves and roadsides. There is a developing knowledge base about the impacts of growing energy crops on land that has limited value for other agricultural production – such as marginal and abandoned land, if such land can be cultivated profitably. The long-term prospects for the industry would benefit from allowing expansion to proceed in a cautious manner, with regular monitoring. Perennial grasses and short-rotation coppice will generally increase soil carbon sequestration compared to annual crops, and will often improve carbon stock development on recently abandoned agricultural land.

The GLOBIOM study estimated that due to carbon sequestration in soils and biomass, biofuels from these energy crops could support an increase rather than reduction in overall carbon storage in persistent biomass and soils, even when indirect land use changes are included[4]. In many cases, these systems can harbour as much biodiversity as the systems they may replace, although the composition and ecological value of these species may be different. By contrast, abandoned land that has already gone a long way towards reverting to its natural state can be a haven for wildlife. Expansion of energy crops should only be undertaken having properly assessed and put in place safeguards for soil, water and biodiversity.

A first step in minimizing risks should be requiring a full environmental impact assessment.

Many of the sustainability impacts explored in this project are dependent on location, and on the scale and extent to which material is extracted for energy purposes. Ecologically sound extraction of residues is quite a different prospect to unrestrained high-intensity extraction. Moderate levels of energy cropping on underutilized land could add diversity to a landscape while intensive mono-cultures could impact food production and increase environmental burden.

Many impacts are highly location-specific. For example, the risk that extracting residues will lead to erosion is higher on steeper slopes and certain soil types, and many biodiversity risks are highly site-specific. The most effective way to identify these risks and pick the right locations to increase material extraction is through a bottom-up approach and on-site assessment. EU-wide guidelines should be established that will determine how specific sustainability criteria are set at a local level by qualified parties, rather than applying the exact same thresholds everywhere. Such a system would take advantage of local assessment and knowledge.

There is no question that sustainable energy cropping is possible in the right places, but it is also clear that identifying the right areas is challenging. Work undertaken for this project highlights the lack of reliable, pan-European, data that would allow a high level assessment of the available land suitable for biomass cultivation. Development of improved data resources that contain not only detailed information about land in agricultural production but also about land that is not agriculturally productive is therefore highly recommended.

Investment Security

Low-carbon liquid fuels will be sold in the same market-place as fossil fuels, which have been commercially extracted since the 1860s. The petroleum industry has had over 150 years of competition in which to drive down costs.

Many believe that low oil prices will become the norm in the future, as the market responds to improving energy-efficiency worldwide and reduced demand. If policymakers are to deliver the low-carbon liquids that are likely to be needed for some transport modes, they will need to put in place a policy framework that is robust under conditions of both high and low oil prices. The Biofrontiers project has explored the impacts of various policy options on the investment proposition for advanced fuels.

Europe's expansion of wind- and solar-power is a great success story, which only happened because policymakers were able to minimise investment risks by providing offtake guarantees. Through these, investors in renewable energy projects had confidence that they could sell the energy they produced over a timeframe long enough to ensure a return on their investment. That same confidence is now sought by potential investors in facilities to produce low-carbon liquid fuels.

Interviews with project developers established that the greatest challenge to investment in low-carbon liquid fuels is the offtake risk. For the advanced biofuel industry to be successfully commercialised, it will require the introduction of policy that guarantees long-term, secure value to project investors. This policy framework should be focused on fuels with low carbon intensity and should provide clear visibility around its goals in order to foster confidence and investment in the low carbon fuel industry. This value guarantee could be delivered through a variety of policy measures, including national blending targets, carbon intensity reduction targets – considering proper life-cycle carbon accounting, including for indirect land use change (ILUC) - and low carbon fuel use requirements on fuel suppliers. However, it is clear that carbon pricing at levels seen in the EU ETS today would not support the commercialisation of these new technologies. Building a successful second generation low-carbon fuels industry requires not only carbon pricing but committed support for innovation. Even having mitigated the offtake risk, project developers face a number of other investment challenges, such as regulatory or financing risks, which can be reduced via investment support, for example via the EU's NER400 or SET-Plan.

The technologies available today are not the only solutions that have a role in long-term transport decarbonisation. Therefore, any 2030 policy framework should be designed with flexibility to allow novel fuel technologies to be eligible for support as they arrive on the market, subject to life cycle analysis and sustainability assessment.

4. These findings are in agreement with several other studies that estimate low or negative indirect land use change emissions from dedicated energy crops (EPA, 2010; Wang et al., 2012; Dunn et al. 2013).

Recommendations for policy makers

If policymakers are to succeed in the challenges outlined above, they would do well to observe the following principles when crafting a 2030 policy for transport fuels:

- **Regarding Sustainability** - Sustainability-certainty and investment-certainty go hand in hand. The debate over ILUC and food versus fuel has demonstrated this. Energy and climate policy for 2030 should ensure deep cuts to lifecycle emissions and safeguard food, soil, water and biodiversity. Incentives should be linked to the availability of sustainable feedstocks. Site-specific assessments are needed to create confidence in feedstock supply chains.

- **Regarding Carbon-Intensity** - It has already been widely recognised that EU energy policy for 2030 should be focused around fuels with low carbon intensity and should phase out support for biofuels that do not deliver on our climate goals. Within that, support for advanced alternative fuels should be prioritised. In this regard, performance-based targets – founded upon full life-cycle analysis of direct and indirect emissions – offer one option for rewarding those fuels that deliver the greatest net greenhouse gas savings, and thereby growing the impact of sustainable biofuels in the marketplace.

- **Regarding Incentives** - With robust sustainability assurance, there is a compelling case for strong advanced alternative fuel incentives. This should take the form of a realistic and responsible binding target for fuel suppliers for advanced alternative fuels in 2025, with a higher target-range set for 2030. The level of the 2030 target would be conditional upon the outcome of a mid-term review to establish whether the 2025 target has been met in a sustainable manner and that a higher 2030 goal is achievable and can contribute to transport decarbonisation goals[5]. A higher target-range could also be set for 2035 during this 2025 review.

- **Regarding Competing Uses** - Alternative fuel policy will not be politically stable unless consistent with other EU policies. Policymakers should have regard to other objectives in forestry, climate, agriculture and waste management. Where there may be competition between liquid transport fuel production from wastes and other waste management options, policy should "encourage the options that deliver the best overall environmental outcome", as required by the Waste Framework Directive.

- **Regarding Innovation** - The technologies available today are not the only solutions that have a role in long-term transport decarbonisation, and many feedstocks may be able to contribute to very low carbon fuels. Therefore, any 2030 policy framework should be designed with flexibility to allow novel fuel technologies and different feedstocks to be eligible for support as they arrive on the market, subject to life cycle analysis and sustainability assessment.

5. The higher target-range for 2030 would start with the equivalent volume (not percentage of transport fuels) to the 2025 binding target.

Transport and the opportunity for low-carbon liquid fuels

Transport is currently the second largest sectoral contributor to European carbon emissions. In 2013, 25% of Europe's climate forcing pollution came from transport.

The European Union's 2011 White Paper on transport sets a goal for 60% emissions reductions from the transport sector by 2050, to support the overall EU target for 80% decarbonisation. The main tools to deliver this target are efficiency, electrification and modal shift. However, even with more efficient combustion engines, successful deployment of electric drive technologies and transfer of goods and passengers to more efficient modes, Europe will remain a consumer of liquid fossil fuels in 2050.

It is already clear that efficiency and electrification are not yet capable of fully tackling emissions from some modes, such as aviation at cruising altitudes. Decarbonising the transport sector in the 2050 timeframe may create an opportunity for low-carbon liquid fuels. Globally, it will take longer still to break the dependency of transport on fossil liquids.
This rump of liquid fuels demand represents a challenge, but it also represents an opportunity to develop truly low carbon alternative fuel technologies and feedstocks.

If Europe develops a low carbon alternative fuel industry, it will have available markets for the foreseeable future. Developing that capacity will not, however, be a trivial task. New technologies will allow us to turn low-value resources like agricultural residues, unrecyclable municipal waste and underutilized industrial waste streams into liquid energy. Power-to-liquids technology will allow us to turn excess renewable power generation into storable transport fuel. But these require research, development, investment and commercialisation.

Over the coming 35 years, Europe can take technologies that are in the lab and at demonstration scale today and turn them into new industries, delivering economic value and social benefit, but only with the right policy in place to support that change.

These embryonic and emerging technologies cannot yet be expected to compete on their own against an oil industry that is supported by explicit and implicit subsidies and which is not yet held accountable for the real cost of its climate impact. As Europe's 2030 climate and energy package takes shape, there is a once in a decade opportunity to build the right framework to support a low carbon fuels industry that can be vital in long term decarbonisation.

Assuring sustainability

Low-carbon fuels represent a valuable decarbonisation opportunity, but their production, especially at the level of feedstock collection or cultivation, has risks associated with it. At the most basic level, it is vital that we can be confident that the carbon emissions benefits associated with displacing fossil fuel use are not being undermined by carbon emissions elsewhere, such as through soil carbon depletion, forest carbon depletion or land use change. Beyond that, good public policy should seek to avoid undue negative impacts in other areas of environmental and social concern.

There is a limited quantity of land and biomass available in the EU, and it is already heavily utilised to meet global and European food, feed, timber and some existing energy requirements (e.g. Allen et al., 2014; Searle & Malins, 2016). These requirements are generally expected to grow over the next years, with an expanding and richer world population. There is already a well-established tension between these primary economic calls on the land and bioresource base and the protection of biodiversity, which is in decline in much of the world. In the EU there is a demanding policy goal to stop the decline of biodiversity and ecosystems by 2020. We believe that it is possible to produce low-carbon fuels without large-scale negative impacts on food security, biodiversity, water availability and so forth, but this will not be guaranteed by allowing the market to make decisions without guidance and if targets or demand outstrip sustainable feedstock supply.

For fuels produced from agricultural and forestry residues, the primary concern is to ensure that residue removal rates do not exceed what is appropriate to ensure preservation of soil quality and carbon, and to support good ecological function (erosion prevention, biodiversity). Appropriate removal rates will vary significantly depending on the precise conditions in the field or plantation, and thus while it is possible to set high-level guidelines (such as 'remove no more than 50% of material'), such guidelines represent a very coarse approximation of the reality of good practice. Far better would be to ensure that active measures are taken to assess appropriate removals, monitor soil quality, and to choose the right removal rates on a local basis. Regulatory requirements for this type of conservation planning represent a burden on producers, but are necessary to avoid the mistakes of the past. Furthermore, by helping producers develop knowledge and adopt good practice in areas like soil management they can actually support enhanced long-term productivity and profitability.

For fuels produced from other low-value materials that could be described as wastes or residues, it is important to understand the counterfactual scenario for how the material would be handled in the absence of support for biofuel production. This includes the possibility that material would otherwise be disposed of by landfilling or combustion; that material may be left in place (e.g. straw left in the field); or that there may be alternative economic uses for the material.

One example is used cooking oil (UCO) for biodiesel. It has been shown (Spöttle et al., 2013) that there is a large UCO resource available in the EU that can be collected and converted into biodiesel with minimal indirect emissions impact. On the other hand, when the impact of increasing use of animal fat for biodiesel has been assessed (Brander et al., 2009) it has been suggested that because animal fats in many regions are already more or less 100% utilized (e.g. in oleochemical and energy applications) there may be little or no environmental gain from using policy to drive a shift of uses from these existing applications to transport energy applications.

An effective alternative fuels policy should provide additional value for fuels produced from feedstocks that are truly being wasted, and avoid using public money to support changes in use that provide little or no net environmental gain. Part of this prioritization should be built on the principles of the waste hierarchy and the idea of cascading use, which refers to the efficient use of resources from the point of view of natural resource, material and land consumption. The waste hierarchy states that in general, preference should be given to recycling materials in ways that preserve embedded energy above energy recovery. It also recognizes that there may be many cases in which use of materials for energy recovery can provide greater social value than forcing inefficient recycling or the production of unwanted materials. Low-carbon fuel policy should support and reinforce both of these principles – it should avoid undermining the transition to increased cascading use of materials, but also recognize that displacing petroleum fuel is valuable in environmental and economic terms and should be supported.

For fuels produced from biomass cropping, the key concerns relate to land use and land use change. Policy should support the development of biomass cropping systems that complement rather than compete with existing production systems. This could mean utilizing land that cannot support alternative agricultural production, in which case the main concerns relate to direct land use changes. It could mean increased use of double cropping or improved rotations, in which case the main concerns relate to establishing what effect the new production systems have on productivity for other agricultural outputs. It could mean harvesting biomass from ecosystems as a complement to other ecological goals (as in the case of biomass from sustainable management of wetlands).

The sustainability framework imposed under the Renewable Energy Directive and Fuel Quality Directive set an important precedent for sustainability in biofuel policy, but it has been demonstrated over the last 5 years that these simple rules have not been adequate to provide the level of sustainability assurance required. For the period to 2030, European low-carbon fuels policy should look to examples from existing sustainability schemes like the Roundtable on Sustainable Biomaterials, from the Global Bioenergy Partnership and within Europe from national initiatives such as the Cramer Commission (Netherlands) and projects such as Biomass Futures[6] , as signposts towards the broader sustainability framework that will be vital to ensuring policy stability and policy success in the next decade. Sustainability standards are further discussed in Section 6.

The sustainably available resource

One resource that we know is available is underutilized waste and residual biomass. The report *Wasted: Europe's untapped resource*, published in 2014, demonstrated the potential to take agricultural and forestry residues, and municipal waste streams, and convert them into liquid fuels. This can be done without harming soil quality, and need not interfere with existing uses of these materials. The availability work undertaken as part of *Wasted* (Searle & Malins, 2013) and follow up work developing the *Wasted* methodology (Searle & Malins, 2016) show that most EU Member States are likely to have more than enough feedstock in 2020 to meet the 0.5% advanced biofuel blending sub-target in the ILUC Directive using sustainably available agricultural and forestry residues and biogenic wastes. With appropriate management systems for collection, this could be done without negative environmental impacts and without diverting feedstock from other uses.

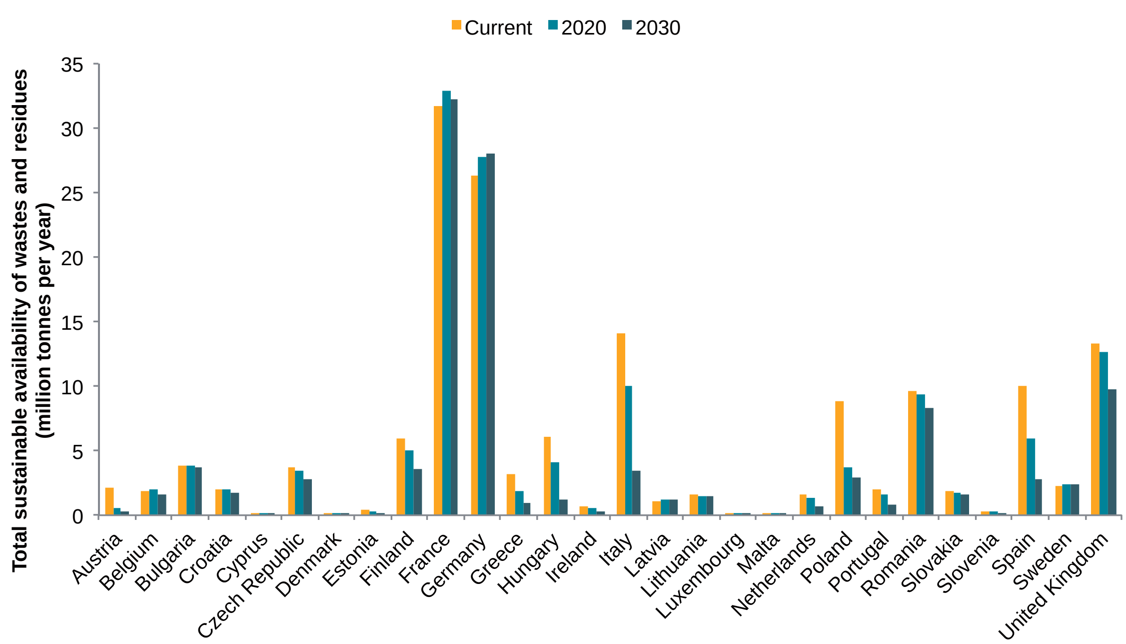
Overall, around 220 million tonnes of waste and residue feedstock are projected to be sustainably available in 2020, potentially delivering up to 41 million tonnes of advanced biofuel and displacing up to 11% of road transport fuel. However, it is already expected that a significant fraction of this resource will be committed to use for heat and power generation. Based on current expectations for heat and power, the remaining 140 million tonnes of waste and residue feedstock could provide up to 27 million tonnes of advanced biofuel (Searle & Malins, 2016). Tens of thousands of permanent and construction jobs could potentially be supported by biofuel production from available wastes and residues across the EU.

Wastes and residues are not the only potential biomass resource. Bioenergy cropping could potentially provide a contribution to low carbon fuel production alongside the use of wastes and residues. In the past, much harvesting of biomass for energy has been unsustainable, driving forest loss, ecosystem degradation, land use change, and climate change. Overharvesting of wood for bioenergy remains a major environmental issue in several world regions. Just as traditional biomass use for energy has a negative side, so modern bioenergy is associated with risks, and if these risks are not handled could lead to negative environmental impacts. The explosive growth in production of biofuels from agricultural commodity crops since the start of the 21st century has been associated with indirect land use changes, impacts on food prices and food security, and concerns about water use and biodiversity.

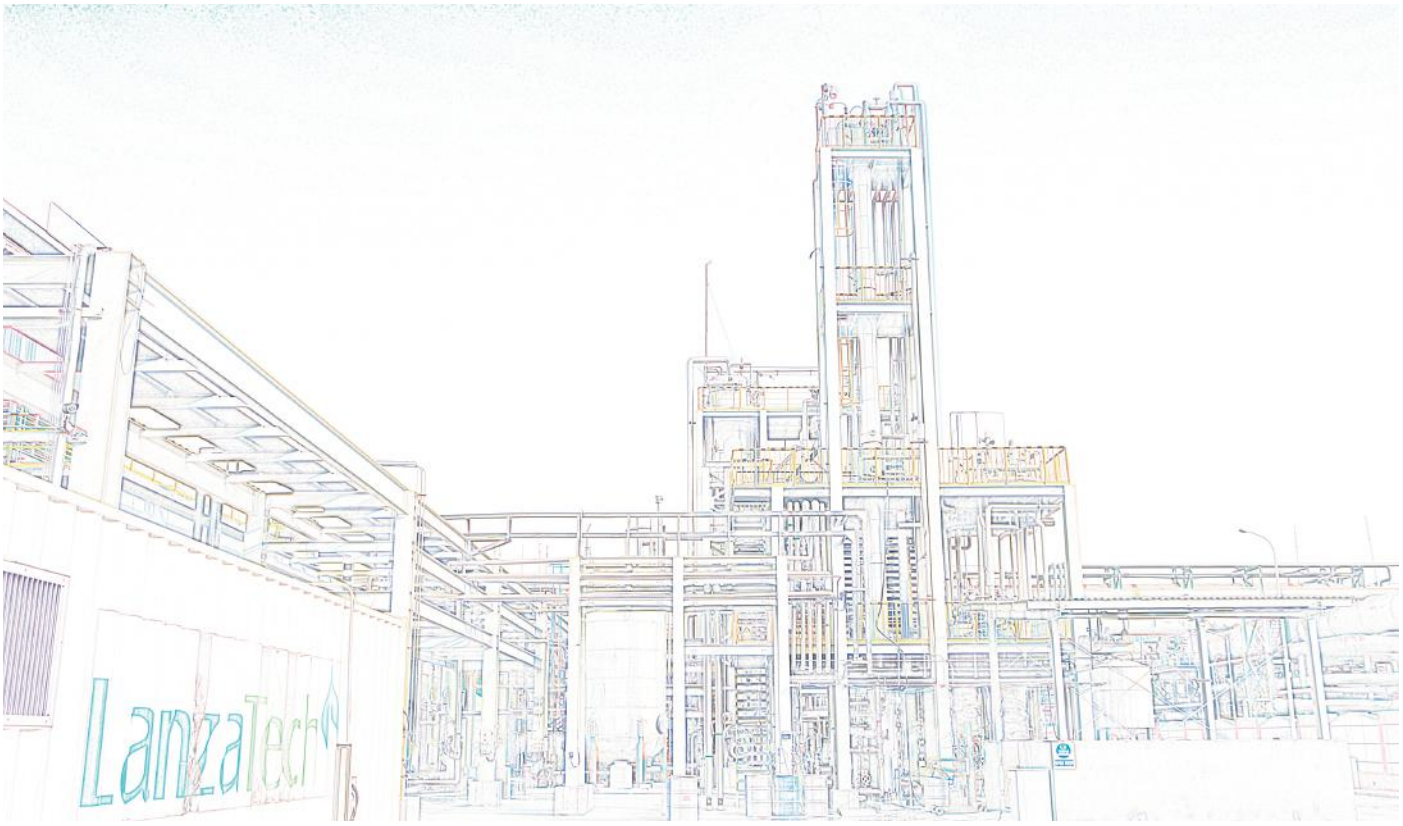
While the environmental and social risks associated with increasing demand for agricultural land are real, on the other hand sustainable biomass cropping represents an opportunity that cannot be lightly abandoned. We believe that there are many types of energy cropping systems that can be acceptable both to an industry seeking a reliable supply of low cost feedstock, and to a community of policy makers and civil society that has become cautious of land-based bioenergy. There are land areas that currently have very limited economic value, and where biomass harvest could be increased without undue impact on ecosystem services. There are also areas that are currently harvested but where biomass cropping could increase overall productivity.

Figure 1

National estimates of sustainably available waste and residual cellulosic material (from Searle & Malins, 2016)



6. http://www.biomassfutures.eu/



In such cases, options like double cropping, intercropping or improved rotations could increase biomass harvest without displacing existing production. There is reason to believe that energy crops could potentially deliver environmental benefits when grown on previously disturbed, abandoned agricultural land. While literature studies comparing biodiversity and carbon stocks in energy crop plantations to marginal land are scant, it is clear that in many cases perennial energy crops can improve agricultural land previously used for annual row crops. The literature suggests that growing perennial energy crops may also rehabilitate agricultural land faster than simple abandonment (Searle, Petrenko, Baz, & Malins, 2016).

While the potential for production of bioenergy from wastes and residues can be estimated based on already available data, it is much harder to make an authoritative estimate of the resource that could be produced from expanding biomass cropping. The types of land that would be most appropriate for expanding bioenergy are, by their nature, at the margins of production – abandoned areas, areas with low current productivity, areas that are contaminated or otherwise ill suited to food crops. Existing agricultural statistics and datasets are designed for the purpose of monitoring what is being produced by the European agricultural sector, not for monitoring what is not being produced (Allen et al., 2016). Identifying that one area would be a good candidate for bioenergy doesn't allow you to generalize to a conclusion that all such areas could be used sustainably (either in the economic or the environmental sense). Assessments of the current and future potential scale of suitable land in Europe to support production of biomass for energy supply have been limited by data availability in relation to the critical questions being asked, and compatibility.

As yet there remains a lack of consensus around this aspect of the bioenergy debate. There is therefore justification to proceed with a more detailed assessment particularly in relation to the nature, suitability, availability and scale of "marginal" farmland and near farmland that might be available in order to make more informed decisions around both EU policy development as well as more practical decisions around industry deployment potential.

This is an area for additional research and for an expansion of the data collected in European land use surveys. This uncertainty on the potential for biomass cropping in Europe need not be a barrier to developing the bioenergy industry though. The first billion litres of fuels produced from sustainable non-food resources in Europe do not require that there should be a central database of acceptable areas – they require dozens of individual projects, identified and assessed at the local level. Shifting the burden of sustainability assessment to the local level, based on principles laid down in regulation, is the right approach for an expanding industry that will be developing new bioenergy harvest systems, and can help lay the groundwork for larger scale potential assessment in future.

Novel feedstocks

Cellulosic and ligno-cellulosic biomass are not the only resources that can be used to produce low carbon fuels. Technologies are being developed that open the possibility of producing liquid fuels from a range of non-biomass resources. Just as with biomass, just because a resource is available does not automatically mean that liquid fuels produced from it will be sustainable, or indeed that they will be low carbon. 'Power-to-liquids' technologies, which

use electric power to generate building blocks such as hydrogen and carbon monoxide for synthesis into more complex fuel molecules, can be sustainable where the underlying energy generation is sustainable and where the economics support conversion of one useful energy source (electric power) into a higher value energy source (liquid fuels), although the competing uses of low carbon electricity will have to be considered.

Other technologies are based on available waste streams, such as carbon monoxide in flue gas, waste plastics or waste tyres. For such technologies, the overall carbon footprint is determined by whether the carbon in the waste in question would have been lost to the atmosphere in a counterfactual scenario. Carbon monoxide in flue gas that would have been flared or vented represents a 'free' carbon source, so these fuels can be very low carbon. In contrast, in cases where waste plastics would have gone to landfill, the carbon would be stored for the foreseeable future. In this second case, fuel production technology may have a role to play in a landfill minimization strategy, but full life cycle assessment would be needed to determine the net impact on atmospheric carbon.

Even though many of these Novel Fuel Technologies can deliver genuinely low-carbon fuels, there is currently a great deal of inconsistency in legal treatment of these fuels in low-carbon fuel support measures – with valid technologies being effectively excluded from support measures in the EU, U.S. and elsewhere.

The uneven treatment of Novel Fuel Technologies in regulatory frameworks can be addressed by moving toward a low-carbon fuel policy based directly on environmental performance. This could be in the form of a low-carbon fuel policy that promotes low-carbon fuels through eligibility criteria and levels of incentives that are based, at least in part, on carbon intensity. This is a departure from the historical focus by policymakers on proxy characteristics such as feedstocks or renewability. Given the lack of a universal definition of renewability, however, and the fact that renewability does not always guarantee carbon savings, as is often the case with biofuels that cause indirect land-use changes, Novel Fuel Technologies are better promoted on a level playing field where carbon intensity is the predominant consideration. Although there may be risks associated with large-scale development of Novel Fuel Technologies, in general these risks could be managed but will require development of a complementary regulatory framework of sustainability standards.

Commercially available waste feedstocks

In addition to the range of materials, such as cellulose, that can be utilized by next generation biofuel processing technologies, there are also materials already being used for biofuel production that can be processed with established technologies, and meet a standard of sustainability.

We note that not all materials that are referred to as wastes are actually truly wasted – many provide valuable ecosystem services, or already have value in the market. It is important that the alternate value and uses of these materials should be considered and compared when making policy choices about which technologies warrant support and which do not (ICF International, 2015). However, where established industries such as the European industry converting used cooking oil into biodiesel are taking real wastes and delivering significant environmental benefits, policy should continue to support these pathways. Indeed, it is estimated (Hillairet et al., 2016) that up to 800,000 tonnes of UCO can be collected from the professional food preparation sector in the EU for biodiesel production. In addition, EU households generate approximately 800,000 additional tonnes of UCO per year, although there are not currently programs in place to collect most of this. It is estimated that at maximum, 200,000 tonnes could be collected from households in 2030. Increasing collection beyond this point would require a marketing and infrastructure framework coupled with public support which seems unattainable at the moment.

These sustainable commercially available fuel technologies are worthy of on-going support, but should ideally be supported separately from less developed alternative fuel technologies, as the size and structure of incentives that are appropriate to sustain the established industry may not be appropriate for industries yet to be commercialised.

Balancing competing biomass demands

Transport is not alone in facing the challenge of decarbonisation by 2050 —all other economic sectors must be decarbonised in parallel. To meet its climate commitments, Europe must deliver an increasing fraction of its heat and power from low-carbon renewable resources. There is also a growing set of applications for biomass in producing biomaterials, in some cases (such as bioplastics) also displacing demand for petroleum. With a limited stock of sustainably available biomass feedstocks available in Europe, there is no possibility that biomass alone could satisfy the total needs for energy and material of all three of these sectors. While in the short term it is possible to develop all three options, there will come a point when policy makers must decide whether to prioritize one of these sectors over the others, or whether to let the market decide. While the discussion below is framed in terms of biomass, the same issues apply to utilization of all wastes and residues.

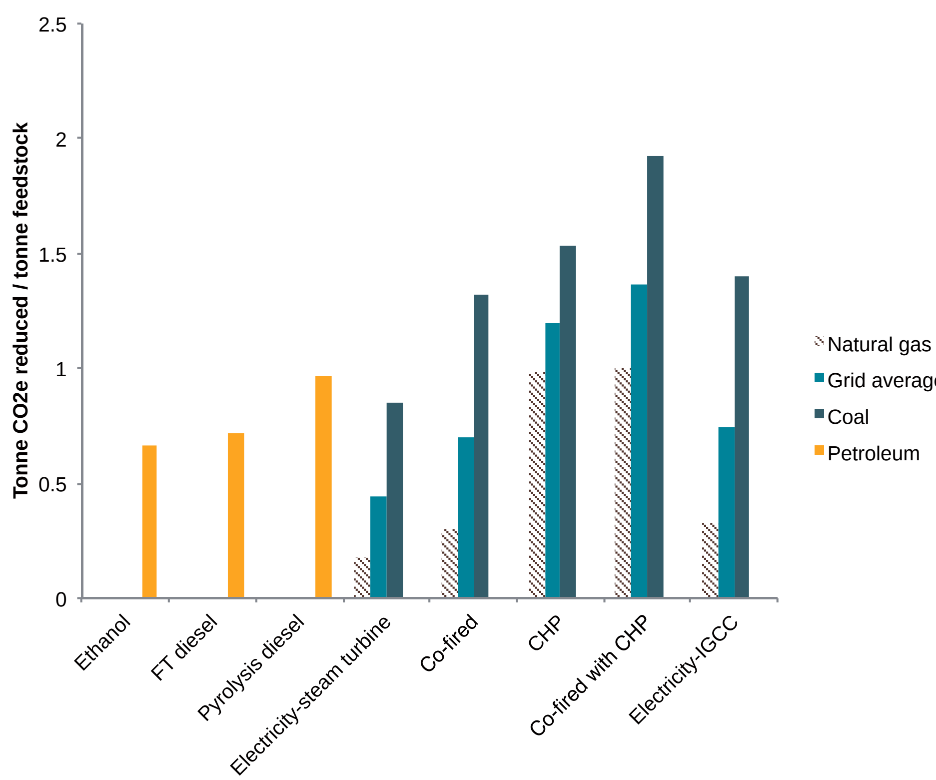
The greatest possible greenhouse gas benefits from biomass use for energy would come through displacing coal power generation, and in the past this has been presented as an argument to focus only on biomass for heat and power rather than on transport biofuels. Reality is not so simple however – the complexity of the electricity market makes solely displacing coal on an energy-equivalent basis unlikely in practice. The electricity grid relies on a diverse mix of energy sources—introducing a new source of energy would not only displace coal, but also natural gas, and potentially nuclear and renewable energy.

If we assume that increased biomass for heat and power displaces an average grid electricity mix, heat and power applications provide comparable carbon reductions to liquid biofuels, although the precise comparison depends on the choice of stationary combustion technologies (e.g., direct combustion or combustion with heat recovery) and biofuel technologies being compared (e.g. cellulosic ethanol, Fischer-Tropsch diesel, pyrolysis). As Europe continues to decarbonise its electricity grid, the grid average electricity mix will become less carbon intensive, and we anticipate that new biomass heat and power will have diminishing climate returns. In contrast, petroleum fuels are slowly getting more carbon intensive over time, so one could argue that looking into the future the case to use biomass resources for liquid fuels will only strengthen.

Biomaterials cover a much broader range of potential applications than bioenergy, and the emissions impacts of the use of biomass for biomaterials are not always so obvious as they are when displacing fossil energy use. Unlike with bioenergy, both biomaterials and their fossil fuel-derived counterparts generally sequester carbon throughout their useful lifetime, only releasing it at end-of-life if they are combusted, or if they biodegrade after disposal (e.g. for certain bio-plastics). Therefore, the primary climate benefit comes from the additional, upstream carbon sequestered where the biomass was grown, though in some cases this may be complemented by greater efficiency in the manufacturing process than for fossil alternatives. Currently, many biomaterials have

Figure 2

Comparison of GHG Reductions from Liquid Biofuels and Biomass Heat & Power (from Pavlenko et al., 2016)



comparable manufacturing and processing emissions to conventional materials, highlighting that only biomaterials produced from sustainably available feedstock with minimal indirect emissions are likely to offer significant climate benefits.

In addition to reducing climate pollution through the use of biomass, in several cases there are also opportunities to reduce conventional pollution. The greatest benefit, as with GHGs, comes from displacing coal in stationary combustion, followed by the displacement of diesel and gasoline in the transportation sector, but in general the value of the air pollution reductions from replacing fossil fuels with biomass is on a smaller scale than the climate benefit delivered. As bio-based materials are not combusted as part of their use, their associated air pollution impacts are comparable to the materials they displace, though as with climate impacts there may be some specific pathways that offer larger benefits.

In transport, there are also modes that will have few options beyond low-carbon liquid fuels. In aviation in particular, there is little prospect of a general shift away from liquid hydrocarbon fuels by 2050. Indeed, we expect there to be remnant liquid fuel demand in all transport modes, with heavy-duty road transport and shipping also likely to remain heavily reliant on liquid hydrocarbons in the medium term. The development of diesel-substitute fuels is therefore also a long-term priority, to be used alongside other solutions such as efficiency and electrification.

While stationary combustion for heat and power is a relatively mature technology sector, both liquid biofuels and biomaterials manufacturing from cellulosic biomass have only recently entered commercialisation. Both technologies require ongoing development support to improve the high cost of capital for these projects and take them to full commercialisation and cost-competitiveness. Commercialisation is not a simple challenge that can be delivered overnight. Even with bold policy action now, it will not be until approaching 2030 that production volumes for fuels produced with new technologies would start to replace first-generation biofuels and meet a more sizeable portion of the EU transport fuel demand. As the industry moves from a generation of first and second of a kind plants to true nth of a kind facilities, costs will come down and accelerated deployment will be possible, but only if the groundwork is already laid. This provides a clear case to develop low carbon fuel production technology for transport sooner rather than later but to manage supply to ensure the feedstock is genuinely sustainable – learning from the experience of first generation fuels.

Alongside the environmental benefit of sustainable biomass utilisation, a switch to renewable energy and materials also holds the promise of new jobs and of boosting the European economy. Biomass conversion generates both temporary jobs in construction and a smaller number of permanent jobs in operations, though there is a considerable range in the literature in estimates of the exact numbers of jobs that will be required for any given biomass use pathway. Overall, it is fair to conclude that the employment impact scales up with process complexity, with more labor-intensive efforts such as manufacturing industrial products or liquid fuels superseding the impact of more conventional biomass combustion. Still, while the end-use for biomass may have some employment impact, it is overshadowed by the job creation from feedstock collection and/or cultivation—jobs that will be created regardless of which biomass utilization pathway is given preference.

A more significant difference is seen between uses when considering the impact in terms of improving European energy security and increasing the EU balance of trade. Relative to other energetic biomass uses, liquid fuels offer greater expected import displacement due to the EU's high reliance on expensive imported petroleum. Similarly, some biomaterials applications could offer higher value import displacement. For instance, the use of bio-ethanol as a base molecule for the plastics sector could displace costly naphtha or ethane imports. Utilizing biomass resources in higher value markets such as transport fuels and chemicals rather than heat, power or compost could potentially also support higher feedstock prices, and thus higher rates of sustainable biomass use, although this will also be dependent on other costs associated with each process. The more products utilise biomass, however, the greater the competition for sustainable feedstock supply becomes. It may therefore be necessary to make choices.

Overall, there is no single option for biomass use that is clearly categorically preferable to others, as various technologies and conversion pathways offer varying benefits and drawbacks across a variety of policy priorities. The use of biomass for heat and power requires less capital and is more technologically ready than transport fuel production, but the economic benefits of a successful liquid fuels industry are likely

greater than in heat and power. The GHG emissions case could favour any of the three uses depending on the shape of policy and technology development for energy generation and material conversion. Benefits can also be highly sensitive to factors outside of the biomass sector; for example, if the heat and power sector decarbonises more quickly than anticipated or if vehicle electrification develops at a different pace than projections. Some technologies deliver environmental co-benefits, such as being more compatible with nutrient recycling, but such benefits must be weighed against differentiated costs and against the need to follow a path consistent with long-term deep-decarbonisation.

Perhaps the real solution at the moment to the challenge of balancing competing sources of demand is to focus not on competition, but on complementarity. For the period from now to 2030, the focus should be much more on developing sustainable biomass supply chains and on commercialising technologies than on trying to pick sectoral winners. Intervention at this stage has the potential to benefit all three pathways and allow the market to identify the optimal end-use at a later date when biomass supply becomes constrained. Heat and power applications could support scaling up of residue collection systems that can then start to supply growing biofuel and biomaterials industries. Transport biofuel plants may start to produce biochemicals as co-products, but equally high value biochemicals production could support the development of more efficient transport biofuel technologies. Liquid biofuel production, as a higher value industry, may be able to support sustainable biomass collection options that would not be viable in the case of heat and power. For now, the imperative is not to choose a single answer, but to say yes to all of the above.

Driving investment

The technologies that are needed to convert low-value waste and residual materials, electricity or sunshine into liquid fuels, whether cellulosic biofuel, flue gas fermentation, power-to-liquids or something else, require development, research and above all investment. Without investment, commercialisation will not happen, and without a commercial scale industry in action we will not see the technology improvements that will make advanced low carbon fuel production increasingly competitive with fossil fuels. Even for technologies such as cellulosic ethanol production, which have started to be deployed at commercial scale and which we believe have the most promising economics at the moment, mobilizing investment is a major challenge.

Currently, advanced biofuel projects both in the EU and U.S. have been mostly self-financed by the companies developing the technologies. This makes sense in a market with large regulatory and offtake risks, but in order to grow a thriving advanced biofuel industry at some point external investors will be needed to bring in more capital. Investors see these new technologies as high risk, and therefore require high expected-returns before committing money. Large institutional investors are generally not yet ready to bet on the sector, and investors of all shapes and sizes are waiting for a policy framework that will guarantee value and that will stay the course. Large Corporate Strategists, Investment Banks and Initial Public Offerings are identified as key funding sources for the developing industry (Peters et al., 2016).

Building the right investment climate requires a sense of policy certainty, but effective policy requires more than simply putting ambitious 2030 consumption targets for alternative fuels down on paper. The experience of the indirect land use change debate, which enshrined uncertainty at the heart of European biofuel support policy, shows that it is important to make sure that policy is really delivering the promised benefits. Allowing unsustainable biofuels, which have been associated with high ILUC emissions, to receive bioenergy support has undermined social and environmental goals and thus the credibility of all biofuels, as well as political support. A new start on a fundamentally more sustainable basis is needed to bring civil society and industry back together.

In order to develop the technological solutions that can deliver more sustainable outcomes, it is also important to support private investment. This is particularly important to help industry through the 'commercialisation valley of death', which "exists between the pilot/demonstration and commercialisation phases of the technological development cycle. This aligns with a gap between the traditional role of venture capital and the later stage investments of project finance and debt/equity investors" (Jenkins & Mansur, 2011). There is a reluctance among policy makers to be seen to be trying to 'pick winners', and the principle of technology neutrality therefore runs through European climate policy. Setting a truly level playing field, however, requires recognising that incumbent technologies have a head start. In the words of Breakthrough Institute in the U.S., "by failing to address the Technological and Commercialization Valleys of Death... the country is making the decision to pick winners in the energy sector—the conventional, incumbent, and dirty energy technologies that dominate the nation's energy supply today" (Jenkins & Mansur, 2011). That quote was written with fossil fuels in mind, but it's equally true for policies that set innovative new alternative fuel technologies against first generation biofuels in a competitive framework. Without active measures to bridge the valley of death to commercialisation, 2030 alternative fuel policy will implicitly, if not explicitly, be handing a massive advantage to incumbent technologies. This is why it is vital that new technologies should be given specific, well-targeted incentives.

One challenge that has been seen with existing policies to support the production of advanced alternative fuels has been the difficulty for investors in assessing the value of policy incentives over the lifetime of an investment. In the U.S., we have seen that some policies that offer generous incentives to fuel producers have been handicapped by a lack of long-term guarantees (for example the second generation biofuel producers tax credit), (Miller et al., 2013), or by a lack of confidence among investors in the value of future credits (for example RIN values in the Renewable Fuel Standard). Policy makers should develop instruments that are not excessively vulnerable to market fluctuations, and that provide a degree of insurance to producers against normal fluctuation in prices of alternative fossil fuels and of feedstocks.

A low carbon fuel support policy that really works should therefore have the following characteristics:

- Provide effective offtake support for producers;

- Not make high cap-ex advanced technology fuels compete directly for market access with low cap-ex first generation technologies, even where those first generation technologies may be sustainable;

- Give a clear and binding value signal through to 2025 and higher target range set for 2030;

- Be embedded in a policy narrative that provides confidence beyond 2030;

- Not exclude low carbon fuel options that fall outside traditional categorizations of ‘renewable’ or ‘biomass-based’;

- Deal upfront with key sustainability challenges in a way that provides assurance to civil society;

- Foster the development of a robust and sustainable feedstock supply chain.

There is not one single answer about the best policy framework to deliver support. Both volumetric targets and carbon reduction targets can provide a clear market for produced fuel, provided advanced fuel technologies are clearly carved out for a specified level of support. A fundamental challenge for designing policy built around either volumetric or carbon intensity targets is setting the right level of aspiration. Set too low, targets will fail to provide the value signal to get investment moving. Set too high, targets may be missed, as the cellulosic biofuel target has been in the U.S. Renewable Fuel Standard; or will drive the supply of unsustainable feedstock in order to meet overambitious goals. When targets are subject to serial supply shortfalls, it can create just as much uncertainty as if targets were set too low, and can lead to fundamental challenges to continuation of the program. Good policy should have systems built in to handle the case that supply falls short of expectations in a way that preserves the pull for additional fuel production without placing unreasonable burden on fuel suppliers acting in good faith. It must also have exemplary sustainability standards to avoid feedstocks causing ILUC entering the market for future generation fuels.

Investment incentives can provide a valuable complement to production incentives by providing value in the challenging phase before plants become operational. In both Europe and the U.S., the development of cellulosic biofuel technology to date has been underwritten with a combination of complementary policies, and this pattern of complementary incentives should continue if we are to maximize the benefits from low carbon fuels.

Finally, providing effective support to new technologies does not mean abandoning technologies or pathways that are already delivering positive outcomes. For instance, work for this project (Hillairet et al, 2016) has shown that there is potential to increase the collection and supply of used cooking oil for biodiesel feedstock, and it has been shown that in the European market these resources have little alternate value or risk of causing indirect emissions (Spöttle et al., 2013). European policy should continue to support these existing industries and investments alongside developing new ones.

Investing sustainably:
an outline for regulatory sustainability principles

Above, we have made the case that regulatory sustainability assurance for the new generation of advanced alternative fuels is necessary not only to protect the environment, but also to protect investments. As part of the Biofrontiers project, the Institute for European Environmental Policy (IEEP) was therefore asked to propose a set of basic sustainability principles that could, in principle, be applied through regulation as a condition for advanced fuels to be eligible to receive incentives (Allen et al., 2016). The aim of this exercise was to propose rules that would provide real assurance on the environmental side, without implying a level of burden for business that could itself become a barrier to development. In parallel to this initiative, the European Commission is developing proposals for biomass sustainability rules, and indeed held a public consultation that closed in May 2016.

The proposed principles are intended to guarantee that bioenergy policy truly delivers significant greenhouse gas emissions reductions across the whole system, while protecting biodiversity and other ecosystem services and minimising any potential negative impact of bioenergy production on other parts of the economy.

The principles suggested by the IEEP are qualitatively different to the requirements in the existing Renewable Energy Directive, both in their wider scope, and because they are built on a recognition that different agricultural, industrial and forestry systems have their own characteristics and challenges, that cannot always be easily addressed through simple centrally determined metrics. The principles therefore go beyond the binary conditions set in existing policy and imply a requirement for local assessment of ecological conditions and impacts as a central element of the system.

The sustainability criteria suggested by IEEP are as follows:

- The greenhouse gas emission intensity from the production and use of biofuels and bio-liquids shall be no more than [27] gCO_2 MJ-1[7].

(This criterion is designed to ensure that the feedstock and biofuel production process are not unduly energy intensive or associated with excessive non-CO_2 GHG emissions. It does not address indirect emissions such as ILUC, which are dealt with by the next criterion. The precise number that would be appropriate, shown here in square brackets, would need to be developed on the basis of more detailed assessment).

- The use of feedstocks should not cause the displacement of food, feed or timber production either directly or indirectly within a specific area or project.

(This criterion aims to prevent biofuels from causing significant indirect emissions. It is related to the idea of low-ILUC-risk biofuels, as framed in the ILUC Directive).

- The use of land-based biomass produced in an agricultural context for the express purpose of biofuel production should be limited to a sustainability ceiling set for the EU as a whole, with appropriate mechanisms for dividing it between Member States.

(This criterion has been developed in the recognition that the deployment of land-based biomass for energy production can be sustainable at specific scales and in specific contexts. Where these scales and contexts are exceeded, there is a risk to sustainability).

- The use, collection and harvesting of feedstocks should be in compliance with international, national, regional and local environmental legislation.

(This creates a requirement that if it is to be incentivised in Europe, feedstock production must respect local and regional environmental laws).

- Biofuels and bio-liquids should not be made from material obtained from land with high biodiversity value, except where the material can be harvested in compliance with conservation objectives.

(This rule continues the prohibition set in the RED on conversion of high biodiversity land for biofuel production, while making allowance for projects where harvesting material is consistent with or required for achieving conservation goals (cf. example of paludiculture given in Searle et al., 2016).

- Biofuels and bio-liquids should not be made from material obtained from high carbon stock land except where the material can be harvested in compliance with conservation objectives.

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7. This criterion refers to direct attributional analysis. Accounting of ILUC emissions would not be necessary under this framework as the possibility of ILUC is excluded by the next criterion.

(This rule continues the prohibition set in the RED on conversion of high carbon stock land for biofuel production, with an exception for harvest consistent with conservation objectives, as for the biodiversity criterion above).

• Biofuel and bioliquids should not be made from material where its extraction or cultivation will result in significant negative impacts on biodiversity or ecosystem function.

(This rule expands protection of biodiversity and ecosystem services beyond just the highest value systems, and applies it to all feedstock production areas).

• Where biofuels and bio-liquids are produced from novel non-native or invasive alien species (e.g. certain species of algae, tropical plants, etc.), their cultivation should be subject to an initial risk assessment and on-going monitoring in order to ensure that sufficient safeguards are in place to prevent escape to the environment.

(Given that many of the characteristics of a good biofuel crop are the same as those of invasive species, it is important that energy crops should be deployed responsibly).

• Biofuels and bio-liquids shall not be made exclusively from whole trees above a stem diameter… that should be determined within the context of regional sustainable forest harvesting strategies.

(This criterion contrasts with the others by setting a top-down maximum value on size of trees used for bioenergy. While it may often be appropriate to use smaller whole trees for bioenergy, a flat threshold is proposed to provide additional assurance that EU bioenergy demand cannot be met by clear cutting established tree plantations or forests).

The work by the IEEP is not the last word on sustainability rules for 2030, but a contribution to a conversation between the European institutions, Member States, civil society and industry. We believe that it provides an excellent starting point to talk seriously about a new era of sustainability governance that will be a cornerstone of future fuel development in Europe. The nature of the criteria means that local environmental impact assessments will be required on sites from which biomass is collected to account for local conditions.

Conclusions – Taming the Biofrontier

The Biofrontiers project has brought together partners from environmental NGOs, technology developers, advanced low-carbon biofuel producers and research institutions in order to identify what is needed in Europe to commercialise an advanced low-carbon fuels industry that is environmentally, economically and socially sustainable. We know that 2050 European transport will be much less dependent on petroleum fuels, due to a spectrum of measures from vehicle efficiency to green driving to electrification. Despite this, we can also be sure that even while overall oil dependency is reduced, a significant fraction of European transport is likely to rely on sustainable liquid fuels. Developing a sustainable low carbon fuels industry is the only way to achieve further decarbonisation in this rump of demand.

From the *Wasted* report, and through the energy crop case studies undertaken for this new project, we know that sustainable feedstock production is possible, and that there is not one single answer to the question of what a sustainable low carbon fuel feedstock looks like. Our cost modelling of key cellulosic biofuel technologies confirms that for the first generation of facilities, firm policy support will be needed to convince investors to participate in the industry.

The European Commission has already stated that it has the confidence in the promise of advanced low carbon fuels to make them part of the long-term decarbonisation agenda, saying that:

> *The focus of policy development should be on second and third generation biofuels and other alternative, sustainable fuels as part of a holistic and integrated approach[8].*

The European Council has also emphasized the importance of technology neutrality in delivering transport sector emissions reductions to 2030. It must be understood that delivering a holistically technology neutral approach to transport sector decarbonisation is not the same as trying to shoehorn a range of different solutions into a single policy instrument. Vehicle efficiency improvements will continue to require vehicle efficiency standards. Expansion of the electric vehicle market will continue to require infrastructure support and fiscal incentives. Maintaining the production and supply of already-commercialised sustainable biofuels such as used cooking oil biodiesel requires continued production support. And commercialising innovative new low-carbon fuel technologies requires policy that is designed to support investment in high capital expenditure projects.

Driving investment is crucial, but investment is not enough on its own to guarantee the creation of an industry that meets society's expectations of environmental and social responsibility. There is no single off-the-shelf example that Europe can look to for effective regulatory assurance of sustainability for these advanced alternative fuel technologies. Europe has to develop these tools itself.

The advanced alternative fuels industry is one that will grow over the coming decades. The only question is how fast and how well governed this growth will be. Europe can be a true leader in this field, and has an opportunity between now and 2020 to set a policy that combines investment support and sustainability in a way that can be a model for the rest of the world.

8. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A policy framework for climate and energy in the period from 2020 to 2030

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List of contributing studies to Wasted and Biofrontiers

ICCT – Availability of cellulosic residues and wastes in the EU

ICCT – Assessing the climate mitigation potential of biofuels derived from residues and wastes in the European context

NNFCC – Use of sustainably-sourced residue and waste streams for advanced biofuel production in the European Union: rural economic impacts and potential for job creation

ICCT – Waste and residue availability for advanced biofuel production in EU Member States

ICCT – Crops of the biofrontier: sustainable opportunities for sustainable energy cropping

Ecofys – How to advance cellulosic biofuels: Assessment of costs, investment options and policy support

ICCT – Beyond the biofrontier: balancing competing uses for the biomass resource

IEEP – Data sources to support land suitability assessments for bioenergy feedstocks in the EU – A review

IEEP – Sustainability criteria for biofuels made from land and non-land based feedstocks

Defense Terre – Leveling the Playing Field for Novel Fuel Technologies

GreenEA – Analysis of the current development of household UCO collection systems in the EU

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