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NEW ENERGY FINANCE

Next-generation ethanol and biochemicals: what's in it for Europe?

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Executive Summary

Europe has a unique opportunity to develop a EU27 next-generation bioproducts industry over the next decade, with major benefits for job creation, the economy, reduction of Greenhouse Gas Emissions, and energy security. In this report Bloomberg New Energy Finance explores the outcomes, barriers and policies required to develop a bioproducts industry in EU27 over the next decade.

Outcomes

- ***Job creation****:* The development of Europe's next-generation ethanol industry could create up to ***a million man-years of employment in Europe between 2010 and 2020***. These jobs will predominantly be in rural areas, and therefore difficult to outsource overseas. It is estimated that ***230,000 man-years of employment would be generated in new EU27 member states.***

- ***Economic impact****:* The development of this new industry will stimulate innovation and spur economic growth - generating up to ***EUR 31bn of revenues internally in the EU27 per year by 2020***.

- ***Natural resources****:* A conservative forecast suggests that between 225m and 270m tonnes of biomass residues will be annually available in EU 27 for bioproduct conversion by 2020, ***without changing today's agricultural land use patterns or cultivating new energy crops***.

- ***Environmental benefits***: By 2020 most of this available biomass residue resource could be annually processed into between 75bn and 90bn litres of next-generation ethanol, ***displacing between 52% to 62% of EU27 forecast fossil gasoline consumption***. The EU Renewable Energy Directive (2009) requires 10% of renewable energy in transport and the Fuel Quality Directive, a minimum 6% GHG emissions reduction from the EU27 road transport sector by 2020. Next-generation ethanol consumption in the EU 27 by 2020 on the scale foreseen in this report could alone ***reduce road transport GHG emissions from gasoline by 42% to 50% by 2020***.

- ***Energy security****:* The EU27 will spend EUR 40bn a year importing crude oil and converting it into gasoline by 2020, assuming oil at $100 a barrel. The EU27 could alternatively generate up to EUR 31bn internally by displacing 62% of its fossil gasoline consumption with next-generation ethanol, which would allow the region ***to move from high dependence on foreign oil towards greater transport fuel self-sufficiency***.

Barriers

- The main barrier to the development of Europe's bioproducts potential is the perceived investment risk in ***an uncertain policy environment with no clear incentives***.

Policy requirements

- The first priority for EU27 policy-makers is to introduce ***an EU-wide mandate for next-generation ethanol***, along the lines of the one in the US covering the 2009-22 period.

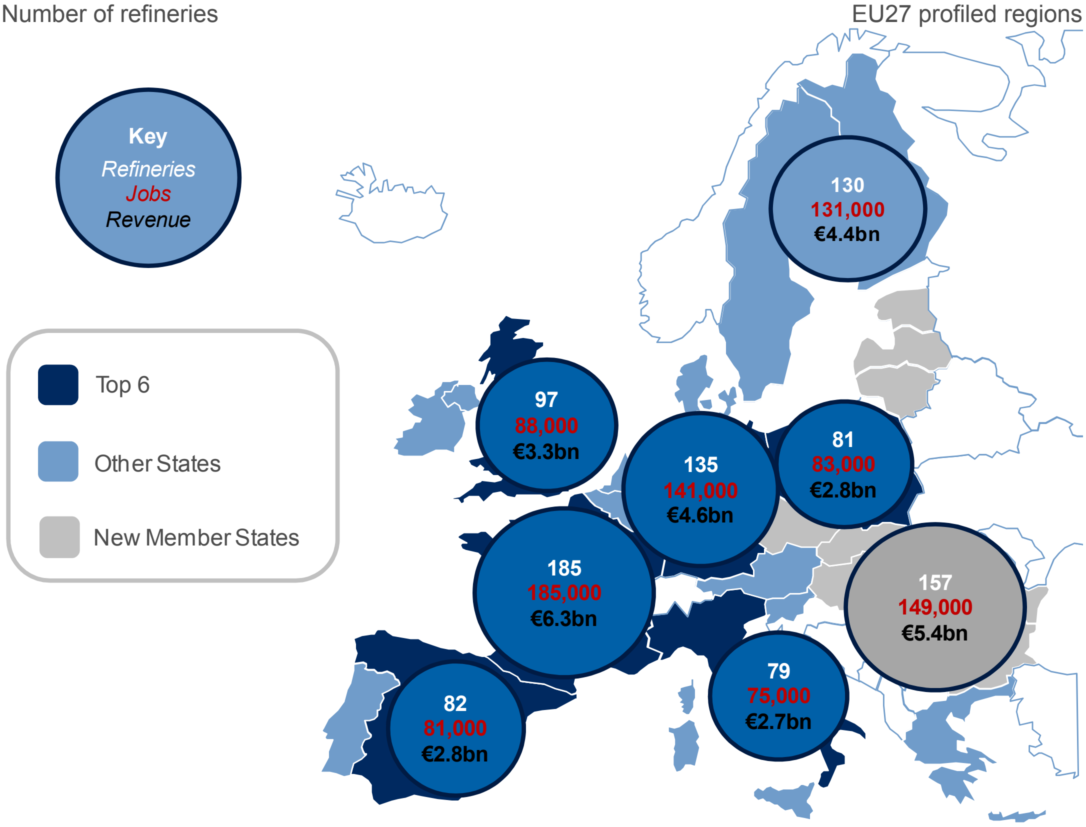
- European policy-makers must also introduce ***incentives for the collection of the biomass***, through biomass assistance programmes and the Common Agricultural Policy.

The map below illustrates how the European Union could benefit from developing its next-generation ethanol and biochemicals industry to its optimum potential. The benefits are spread among all its member states. The figures in white are the potential number of biochemical refineries with the figures in red denoting the number of jobs created. The figures in black represent the annual revenues generated from the sale of ethanol.

Figure 1: Potential number of refineries, employment and revenue in next-generation ethanol to 2020 (bull scenario)

Number of refineries

EU27 profiled regions



***Source**: Bloomberg New Energy Finance*

***Note**: The numbers of biorefineries is determined by the ability of each region or member state within the EU27 to supply bioproducts. Jobs in the chart represent the total man-years of employment between 2010 and 2020, not the number of jobs in 2020 alone.*

Section 1. Introduction

This report by Bloomberg New Energy Finance explores the potential results of the development of a next-generation ethanol and biochemicals industry in the European Union in the next decade, and also the barriers standing in the way of this important new industry.

The bioproducts industry of the future will harness a modest and sustainable proportion of available European biomass - agricultural and forestry residues and municipal solid waste - and use new technological processes to convert these into next-generation ethanol for transport fuel and biochemicals.

The report presents two scenarios – a “base case” and a “bull case” – for the development of a bioproducts industry and compares them with the current development path. Those benefits range from spurring economic growth and job creation to reductions in greenhouse gas emissions and increases in energy security in the countries of EU27.

Bloomberg New Energy Finance was commissioned by Novozymes and DSM to research and write this report. The content and conclusions are those of Bloomberg New Energy Finance alone, based on its own independent analysis.

Section 2. Biomass residue resources

2.1. Conservative methodology uncovers substantial resource

Within the EU27 today there are already considerable biomass resources, in Section 2 we explore how much could theoretically be supplied in the next decade. As we will go on to demonstrate, we believe these are comparatively conservative biomass potential forecasts. The study does not include energy crop cultivation and it assumes the amount of agricultural crop land will remain constant for the next decade. It represents a technical assessment of biomass residue availability.

Following the recommendations of the International Energy Agency's study on Sustainable Production of Second-generation Biofuels Potential and Perspectives in Major Economies and Developing Countries, only 25% of the agricultural residue is collected from the field. Other technical and economic biomass residue availability studies frequently assume that 50% of the residues are removed (see Table 5).

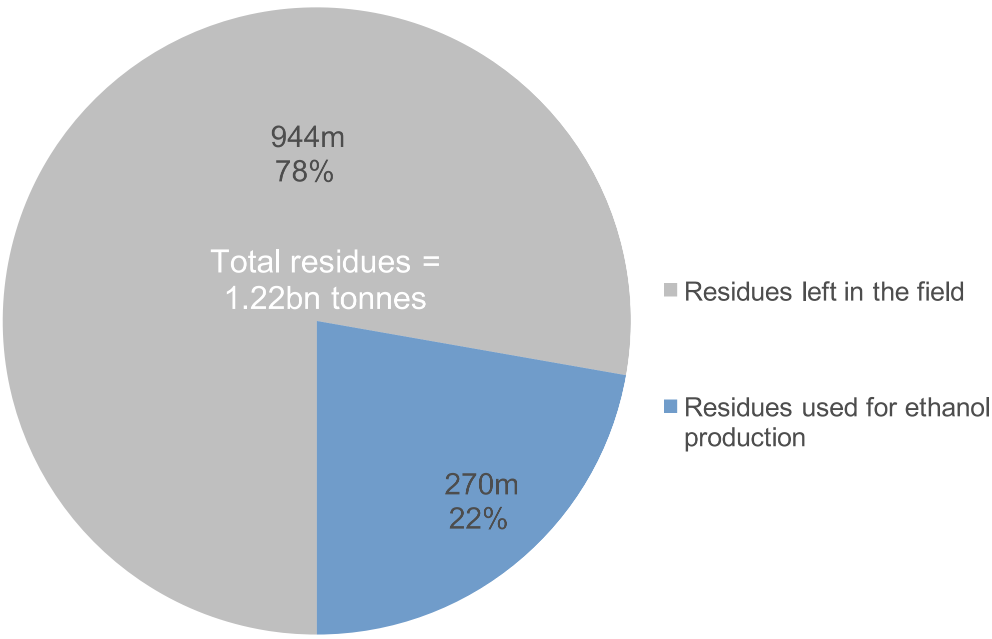
Bloomberg New Energy Finance acknowledges that a sustainable use of biomass must take into account the individual characteristics of each residue and land/soil variations and the sustainability criteria should be addressed at the EU level.

The study was keen to avoid taking too much crop residue from the field. Our literature review shows that the biomass residue availability sits at the lower end of the spectrum (see Table 5). For example, De Witt and Faaij estimated the EU27 maximum potential, excluding energy crops, of 9.3 Exajoules, and the European Environment Agency estimated it at 7.95 Exajoules while our maximum potential estimates is 4.8 Exajoules (see Table 5). As a reference, 100m tonnes contain approximately 1.8 Exajoules of energy.

Bloomberg New Energy Finance has analysed agricultural, forestry and municipal solid waste (MSW) resources to determine how much biomass will be available between 2010 and 2020. Using the historic trends from 1990 to 2008, we projected a linear forward curve to 2020. We found approximately 225m tonnes of biomass should be annually available by 2020 under our base case scenario for bioproduct conversion. This total annual European biomass resource jumps to 270m tonnes by 2020 under our bull scenario (see Figure 2).

Figure 2: Total EU27 biomass residue availability under bull scenario for next-generation ethanol, 2020

Billion tonnes 2020



***Source**: Bloomberg New Energy Finance (BNEF), European Environment Agency (EEA) and UN Food and Agriculture Organisation (FAO)*

***Note**: biomass potential comes from three distinct categories – agricultural residues, forestry residues and MSW* *cellulosic material. Agricultural residues are derived from the biomass left after the harvesting of apples, barley, grapes, maize, oats, olives, potatoes, rapeseed, rye, sugar beet, tomatoes and wheat; we have assumed 75% of the residues are left on the field and 25% are collected. 10% of the collected agricultural residues are used for power production; 20% are used for animal husbandry; we have assumed therefore that the remaining 70% can be converted into bioproducts. Under our base case scenario yields grow at the same rate as between 1990 to 2008 and under our bull scenario crop yields grow at a 5% higher rate – the intention is to show how yield improvement increases agricultural residue biomass supply potential. Forestry residues are the by-product from the wood panel and paper and pulping industries; we have assumed 80% are used for power production. In the EU27 MSW is currently either recycled, landfilled or incinerated for power production; we have assumed only 57% of the landfilled MSW is organic – under the base case scenario we assume 75% of the organic component can be converted to bioproducts and 100% can be converted in the bull scenario.*

In the EU27, under the base case scenario, the top five agricultural contributors to the 2020 total biomass potential are wheat straw from the field (74m tonnes), sugar beet residues (38m tonnes), barley straw (26m tonnes), maize stover (18m tonnes) and rye residues (6m tonnes). Agricultural residues contribute to 80% of the 2020 biomass residues supply; forestry and MSW biomass residues contribute 3% and 17% in the base case scenario. Under the bull biomass potential scenario these proportions change to 79%, 2% and 19%. Today next-to-none of this biomass resource is harvested for bioproduct conversion; the challenge for European policymakers will be to incentivise the collection of this biomass resource.

2.2. Base case: limited agricultural residue collection

The base case scenario assumes the yield per hectare – for the agricultural crops considered – grows at the same linear rate as between 1990 and 2008. It essentially illustrates a business-as-usual case. We also assume that only 75% of the organic component of an average tonne of MSW can be converted into various bioproducts.

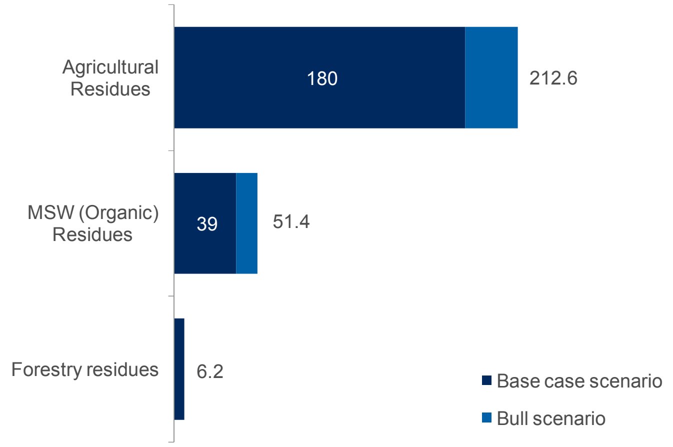
In terms of potential, under our base case scenario there is no significant resource growth from 2010 to 2020. Biomass potential grows from approximately 217m tonnes in 2010 to 225m tonnes in 2020, which represents growth of less than 0.5% per annum. EU27 farmers and the broader agricultural community must be financially incentivised with forward thinking legislation to harvest, transport and store this biomass resource. In August 2009 the US government introduced the Biomass Crop Assistance Program (BCAP) which provides a matching payment of up to approximately $50 per dry tonne for producers harvesting biomass. A similarly clear and supportive policy would greatly assist EU27 biomass producers and help unlock some of this resource.

2.3. Bull scenario: higher yields provide more residues

The bull scenario assumes a higher proportion of the landfill biomass resource will be made available for bioproduct conversion. To illustrate how crop yield improvements can positively affect biomass availability we have increased the yield growth rate, for the considered agricultural crops, by 5% above the recent historic trend. As a result, the total 2020 biomass supply potential jumps from 225m tonnes in the base case scenario to 270m tonnes in the bull scenario. We have deliberately increased agricultural crop yields beyond the historic norm to illustrate how improved farming practices and investment in the Eastern European countries will improve biomass supply availability. Lifting yields – as opposed to increasing the amount of agricultural crop land or area under energy crops – should negate the politically sensitive indirect land use change (ILUC) issue.

Figure 3: Total biomass residue scenario availability by category, 2020

Million tonnes Scenarios

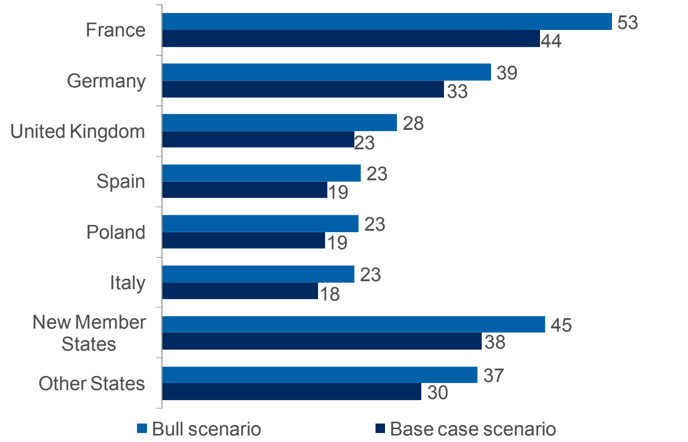


***Source**: Bloomberg New Energy Finance*

***Note**: see Figure 2 notes as the same methodology applies.*

Figure 4: Total biomass residue scenario availability by countries and regions, 2020

Million tonnes Select countries



***Source**: Bloomberg New Energy Finance, European Environment Agency (EEA) and UN Food and Agriculture Organisation (FAO*

***Note**: see Figure 2 notes as the same methodology applies. The top six member state producers have been listed; "New Members" include all the countries which have joined the EU since 2004, with the exception of Poland; "Other States" refer to all the remaining EU27 member states.*

2.4. Profiled regional biomass potential

The European agricultural powerhouse countries of France and Germany have the greatest 2020 biomass supply potential under both the base case and bull scenarios. This is primarily because France and Germany harvest a much larger area of land for all the considered agricultural crops compared with other countries – 426,000 hectares and 477,000 hectares respectively. However, when it comes to wheat cultivation France cultivates a considerably larger area than Germany. The other profiled countries do not come close to matching this figure, which partially explains why France and Germany outperform the other remaining six regions.

In France, 2010, an average hectare of wheat yields about 7.5 tonnes; in contrast an average Polish hectare of wheat yields about 4 tonnes. If the Central and Eastern European countries can lift food crop yields through better farming practices in the next decade then there will be a two-fold benefit – more domestically produced food and larger volumes of agricultural residues. Poland and Romania appear to have the most potential for advancement.

The story behind our profiled regions is quite interesting, as it shows that though individually new member states may not contribute much in terms of 2020 EU27 biomass potential, the new member states as a group, contribute a significant amount to the overall biomass potential supply. The grouped new member states and Poland contribute approximately 25% of the total 2020 biomass potential.

Table 1: Indirect land use change and the BNEF approach

Indirect land use change (ILUC) occurs when there is pressure on agriculture due to the displacement of previous activity, or when biomass use induces land use changes. The environmental effects of ILUC are known as leakage – essentially the result of an action occurring in a system that induces indirect effects outside the system boundaries. The displacement of current land use to produce biofuels can therefore generate more intense land use elsewhere.

A certain amount of feedstock is needed to meet a given demand of first-generation biofuels. These feedstock quantities can be obtained by biomass use substitution, crop area expansion, shortening the rotation length, and yield increments in the same land. But next-generation technologies open the opportunity to avoid ILUC altogether by efficiently using all the hectares of land already used in food production and by using a small part of the residues produced in the process instead of using the food part of the crop.

Our methodology assumes agricultural land use patterns will not change between 2010 and 2020 either in our base or bull scenarios, which does not therefore bring the ILUC subject into play. The increase in biomass potential in our analysis only comes from yield increments, and therefore does not produce any changes in the carbon stocks and does not affect other valuable ecosystems. In our base scenario we reflect what happens if the current agricultural system is not altered. The increase in biomass availability comes solely from annual yield increases conforming to the yield increments seen between 1990 and 2008.

In our bull scenario we have deliberately increased agricultural crop yields beyond the historic norm to illustrate how improved farming practices and investment in the Eastern European countries will improve biomass supply availability. Lifting yields – as opposed to increasing the amount of agricultural crop land or area under energy crops – should negate the politically sensitive ILUC issue.

Source: Bloomberg New Energy Finance

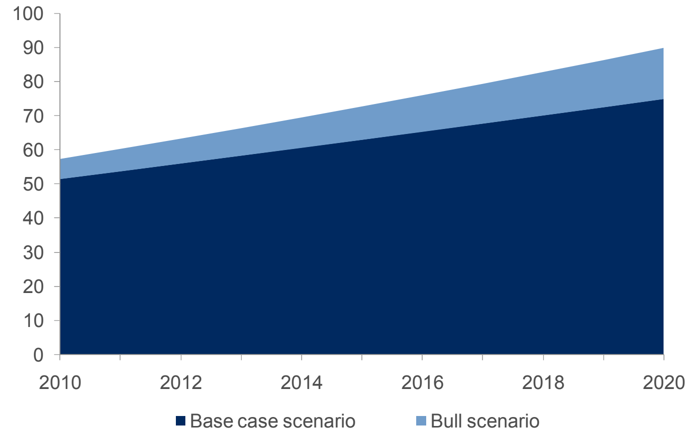
Section 3. Bioproduct potential

3.1. EU27 could produce up to 90bn litres of next-generation ethanol

It is important to emphasise that our next-generation ethanol scenarios, from 2010 to 2020 (Figure 5), are not an actual supply forecast. We are simply illustrating how much ethanol could potentially be supplied in the next decade, in the context of EU27 biomass availability. In our base case scenario next-generation ethanol supply could grow from 63bn litres in 2015 to 75bn litres in 2020. Due to greater biomass availability, in our bull scenario next-generation ethanol supply could grow from 73bn litres in 2015 to 90bn litres in 2020. The potential to generate low emission gasoline substitutes from the available EU27 biomass resources is therefore considerable. The purpose of the next-generation ethanol projections in Figures 5 and 6 are to show how much could be supplied. The 2020 base case and bull scenarios should provide reasonable targets for the policymakers and the industry to aim towards.

Figure 5: Next-generation ethanol potential from biomass residue scenarios, 2010 to 2020

Billion litres 2010 to 2020

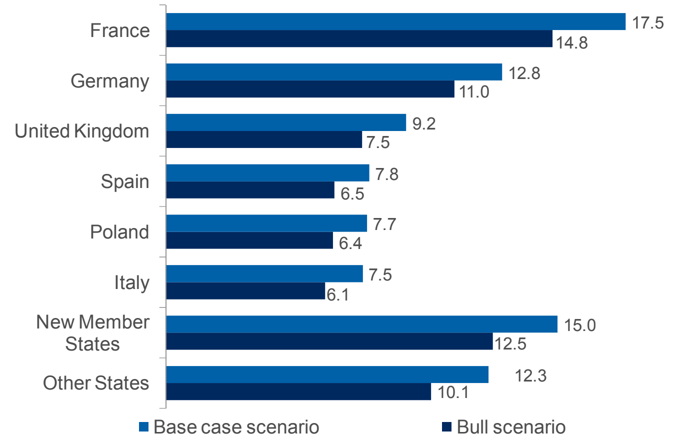


***Source**: Bloomberg New Energy Finance, European Environment Agency (EEA) and UN Food and Agriculture Organisation (FAO)*

***Note**: ethanol potential is directly derived from the biomass supply potential in Figure 2; we assume ethanol yields from a tonne of biomass will improve from 250 litres in 2010 to 300 litres in 2015 to 350 litres in 2020; and we assume 95% of the biomass resource will go towards ethanol production, with 5% going towards biochemicals production.*

Figure 6: Next-generation ethanol potential from biomass residue scenarios by profiled region, 2020

Billion litres Profiled regions



***Source**: Bloomberg New Energy Finance, European Environment Agency (EEA) and UN Food and Agriculture Organisation (FAO)*

***Note**: see Figure 5 note as the same methodology applies. The top six member state producers have been listed; "New Members" include all the countries which have joined the EU since 2004, with the exception of Poland; "Other States" refer to all the remaining EU27 member states.*

The conversion yields for turning lignocellulosic biomass into ethanol, using the enzymatic hydrolysis technology, have improved dramatically in the past five years. Between 2010 and 2020 we expect ethanol production to increase by 45% in the base case scenario and 57% in the bull scenario. This is an interesting result, as the actual underlying biomass potential availability only increases by 3.9% and 11.9%, in the same 10-year time period. This outcome can be explained by our assumptions regarding ethanol yields from a tonne of biomass, which will improve progressively from 250 litres in 2010 to 300 litres in 2015 to 350 litres in 2020 due to further process efficiency improvements (see Figure 5). Technology and efficiency improvements in the next decade will therefore magnify any small growth in biomass supply potential.

We have assumed that 95% of the biomass potential will be converted into next-generation ethanol and the remaining 5% of the biomass potential will go towards biochemical production. Bioproduct diversification should lower the overall biorefinery operating economics. The ability of a biorefinery to alter the quantity of its outputs – in a similar fashion to Brazilian sugarcane mills – should reduce some of the project risk, as it can cater for different markets depending on the current price of the product.

3.2. France can lead the way

In terms of next-generation ethanol supply potential, the top six countries have been represented in Figure 6. Under a conservative scenario, France could produce 15bn litres of ethanol from its biomass resources by 2020. France will consume about 12bn litres of gasoline annually by 2020 if it has reached its demand floor. However, if consumption continues to decline at the historic rate then annual demand could sink as low as 8bn litres. France could therefore comfortably replace – on an energy equivalent basis – its fossil gasoline requirements with next-generation ethanol. The EU27 biomass potential suggests most countries could begin to partially move away from fossil fuel dependence if the region supports the development of a next-generation bioproducts industry.

Table 2: Country groupings

Top Six	France, Germany, Spain, United Kingdom, Italy and Poland
New Member States	Includes all the countries that joined the EU in 2004 or after, excluding Poland: These are: Estonia, Latvia, Lithuania, Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Cyprus and Malta
Other States	All the member states that were part of the EU before 2004 and are not part of the Top Six

Section 4. Bioproduct industry upsides

4.1. Business as usual: demand will be very limited under current legislation

The road transport section of the Renewable Energy Directive (RED) effectively mandates the consumption of next-generation biofuels. However, mandated next-generation ethanol demand under this legislation represents a very small figure – especially when compared with the US renewable fuels standard or RFS2 (see Table 4). Under the most optimistic 2020 scenario the EU27 region will replace 2.8bn litres of its annual fossil gasoline demand with next-generation ethanol. By contrast if RFS2 demand is fulfilled then the US could annually be consuming between 40bn and 57bn litres of next-generation ethanol by 2020, representing up to 11% of its yearly transport fuel requirements. The US government has definitively supported the development of its next-generation biofuels industry; the challenge will be for the EU27 member states to do something similar in the coming decade.

Under the current legislation, the central driver for renewables-in-transport for the next decade will be the RED. EU27 member state governments are required to use 10% renewables – in the form of either biofuels or green electricity in hybrids and electric vehicles – in its transport sector by 2020 under the RED. There is also another important European biofuel driver though – the Fuel Quality Initiative, which requires an increase in vehicular fuel efficiency and total transport fuel carbon dioxide mandated savings of 6% by 2020, with an additional 4% left as a voluntary programme. Both legislative drivers support greater biofuel penetration in the EU27 region; However, neither directly mandates next-generation ethanol consumption unlike in the US.

The current legislation leaves very limited room for ethanol supply growth in the next decade – especially for the next-generation ethanol industry. We project annual ethanol demand to grow from 0.64bn litres in 2013 to 1.44bn litres in 2020 (see Figure 7).

Ethanol consumption is constrained by negative growth in gasoline demand and by technical limitations which impede high ethanol-gasoline blending proportions. We project there will be relatively measured fall in gasoline consumption from 125bn litres in 2010 to 101bn litres in 2020 due to a decreasing EU27 gasoline car fleet. This trend is unlikely to change before 2020 due to competitive European diesel prices. Ethanol consumption is pegged to gasoline consumption; therefore, any movements in the gasoline market will have an impact on ethanol demand. We anticipate that the primary US car transport fuel in 2020 will be gasoline, in the EU27 region it will be diesel.

The current EU27 legislation also puts a technical 10% ceiling on the amount of ethanol that can be blended with gasoline. If next-generation ethanol is to have a significant impact in the transport fuel market then the 10% blending ceiling must first be increased. There are two means of facilitating the penetration of higher ethanol-gasoline blends in the transport fuel market: either the car market absorbs a greater proportion of flex-fuel vehicles (FFV) as Brazil has done successfully in the last decade, or the blending ceiling for regular gasoline cars is lifted to 15% and above as is being mooted in the US. Macro-economic conditions, regulatory and technical impediments are currently limiting the potential development of a EU27 next-generation ethanol industry; with foresight it should be possible to overcome some of these hurdles.

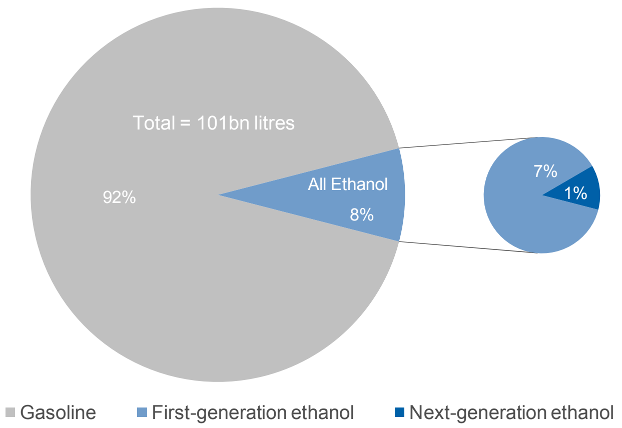
In addition, currently next-generation biofuels also count twice, relative to first-generation ethanol volumes, to the 2020 renewables-in-transport target which effectively halves mandated demand.

The room for next-generation ethanol mandated demand growth is therefore severely constrained. The current legislation does not contain any fixed target for next-generation ethanol because of the current broader 10% renewables-in-transport ambition. The RED does open the possibility of adding a 2% next-generation biofuels target to the mandated demand but this is at the discretion of the EU Commission. However, this clause will not result in a large demand for next-generation biofuels, especially when compared with the US.

EU 27 forecast gasoline market demand, 2020

Figure 7: "Business-as-usual"

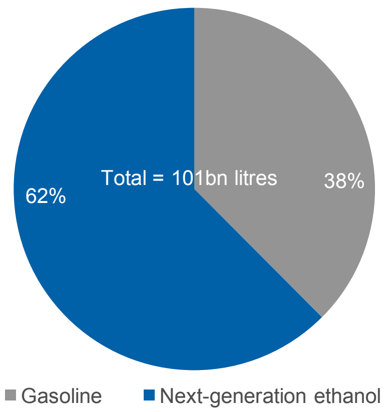
% Billion litres



***Source**: Bloomberg New Energy Finance*

Figure 8: : "Bull scenario"

% Billion litres



***Source**: Bloomberg New Energy Finance*

***Note**: The model projects the amount of biofuels which must be supplied to the EU27 market under the Renewable Energy Directive (2009) between 2010 and 2020. It firstly forecasts the amount of fuel needed by the road transport sector. To make this calculation, we divided the market into four categories: personal diesel, personal petrol, freight consumption and electric vehicles. We projected fuel demand for each of these four groups based on historical trends accounting for variables like fleet size,fleet average consumption, kilometres travelled, vehicle turnover rate, oil price and economic growth. After calculating the total demand for all transport fuels, we factored in the current regulatory framework to deduce how much could be replaced by renewable alternatives.*

4.2. Economic benefits: replacing crude imports

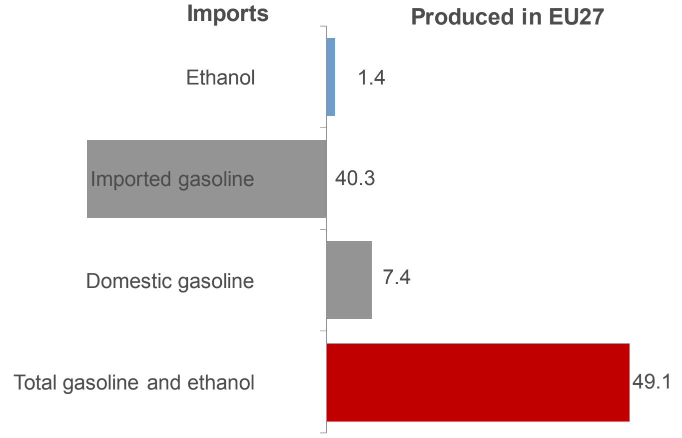
The EU27 could theoretically replace between 52% and 62% of its annual gasoline consumption by 2020 with next-generation ethanol (see Figures 8). We project the EU27 region will spend approximately EUR 49bn on importing gasoline by 2020, or 85% of its annual gasoline requirements (see Figure 9). Hypothetically, if the EU27 region built the biorefinery capacity to annually produce the 75bn to 90bn litres that could be supplied by 2020 – see Section 4 for further details – then it would internally be generating yearly revenues of between EUR 26bn and EUR 31bn. Added value in the sector would, on our estimates, be likely to be equivalent to around 0.2% of total EU27 GDP, which was reported by Eurostat at EUR 12.25 trillion – annualised – in the second quarter of 2010.

4.3. Economic benefits: generating new EU27 sales revenues

There will therefore be two clear benefits of backing a EU27 next-generation bioproduct industry: firstly, the region could replace its gasoline demand with a low carbon biofuel alternative; and secondly, it could annually internally generate EUR 26bn to 31bn rather than spending EUR 49bn externally. It would also allow the region to become less crude oil dependent, lower its fossil fuel emissions, raise its internal revenue stream and increase its energy self-sufficiency. The potential upside of a next-generation bioproduct industry is very encouraging.

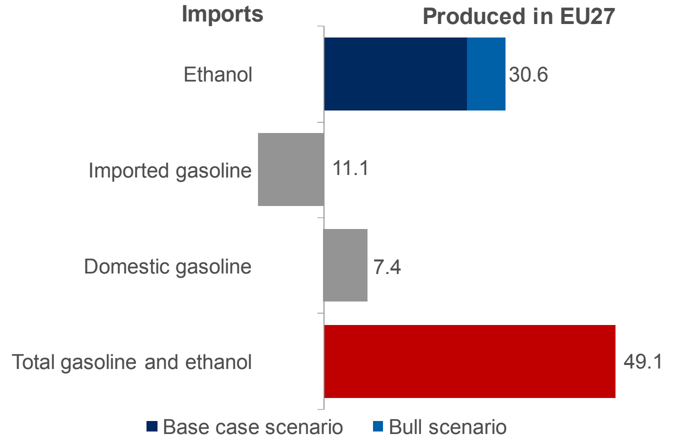
Gasoline and ethanol consumption costs and sales revenues, 2020

Figure 9: "Business-as-usual"
EUR bn



***Source**: Bloomberg New Energy Finance and European Commission (Energy)*

Figure 10: "Bloomberg New Energy Finance scenario"
EUR bn

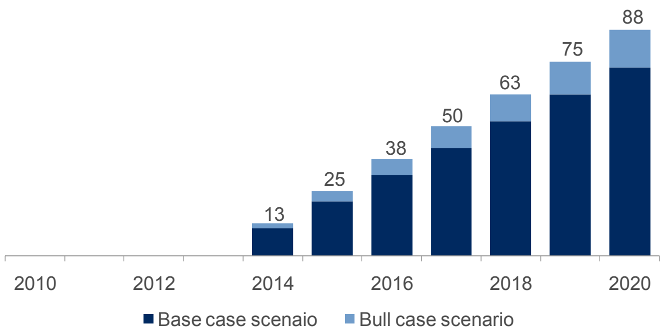


***Source**: Bloomberg New Energy Finance and European Commission (Energy)*

***Note**: "Total gasoline" accounts for production costs when crude is at $100 a barrel, multiplied by our 2020 gasoline demand forecast; "Ethanol" revenues assume ethanol represents 70% of the gasoline cost, adjusting for its lower energy MJ content, multiplied by our base case and bull ethanol potential scenarios; "Imports" assume 85% of the gasoline cost – based on historical trends for crude oil.*

We have assumed next-generation ethanol revenues will grow progressively towards the projected 2020 range of EUR 26bn to EUR 31bn as more biorefineries come online (see Figure 11). Our methodology takes 2020 base case and bull scenario ethanol volumes – from Section 4 – as an industry decadal target: we have therefore assumed biorefinery capacity will build towards the 75bn to 90bn litres of ethanol potential between 2012 and 2020. When accounting for the current state of technology development, the study has projected the first handful of biorefineries will be commissioned by 2014. Construction on this first group of biorefineries should therefore begin around 2012. All our assumptions regarding capacity and revenues are based on the current state of bioproduct technology development and a 2020 crude oil price of $100 per barrel.

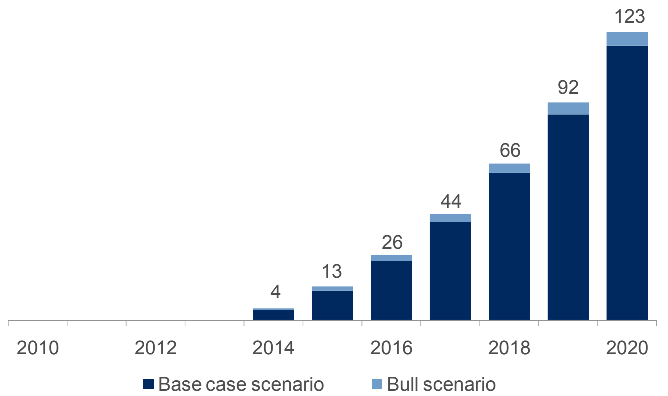
Figure 11: Total cumulative next-generation ethanol capacity investment, 2010 to 2020
EUR bn



***Source**: Bloomberg New Energy Finance*

***Note**: in both scenarios we assume total facility costs will be approximately $1.25 per litre of annual capacity; we project there could theoretically be 788 biorefineries online by 2020 under our base case scenario according to our biomass potential forecast, under our bull scenario there could be 946 biorefineries online in the EU27.*

Figure 12: Total cumulative next-generation ethanol revenues
EUR bn



***Source**: Bloomberg New Energy Finance*

***Note**: This chart represents the revenues achieved from the operational new biorefineries, when crude is at $100 a barrel; construction starts in 2012 and two years later (2014) the first biorefineries come online.*

Using the biomass potential scenarios outlined in Sections 3, we project 788 biorefineries should be commissioned under the base case scenario and 946 under the bull scenario by 2020 to fulfil the next-generation ethanol potential of the EU27 region. If, hypothetically, this capacity was built between 2012 and 2020, it would require investment of approximately EUR 74bn under the base case scenario and EUR 88bn under the bull scenario. This calculation assumes it will cost on average EUR 0.98 per litre of installed capacity to build a freestanding biorefinery. Under the base case scenario an annual capacity investment of approximately EUR 10.5bn from 2015 and 2020 should generate cumulative revenues of EUR 13bn in 2015 rising to EUR 123bn in 2020 (see Figure 12). The internally generated EU27 next-generation ethanol could also theoretically replace the money spent on crude oil imports; thus, the net benefit would be higher.

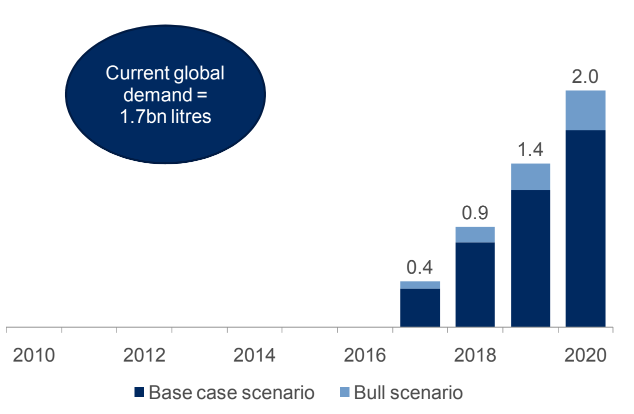
But the potential of bioproducts does not end with ethanol. There are several paths that the sugars extracted from the residues can follow. The one that offers the highest value is the production of biochemicals. For example, while a litre of ethanol averaged around EUR 0.52 per litre in August 2010, maleic anhydride, one of the chemicals that can be easily replaced with biochemicals such as succinic acid, trades at EUR 1.12 per litre.

In this analysis, we allocated 5% of the used residues for biochemicals production. The technology to produce biochemicals is already in development and we expect the first plants to appear around 2017. We calculated the total potential of the EU27 at 5% of the total used residues to be 1.7bn in our base scenario and 2bn litres in our bull scenario but we do not expect the EU27 to achieve its potential within the timeframe of this analysis. Our estimates are closer to 30% of the total potential by 2020, or 500m litres for our base scenario and 600m for our bull scenario.

We estimate that the EU27 can generate revenues from biochemicals of around EUR 5.2bn between 2017 and 2020 taking the price of maleic anhydride as a proxy (see Figures 13 and Figure 14).

Figure 13: Total cumulative biochemical capacity, 2010 to 2020

EUR bn Scenarios

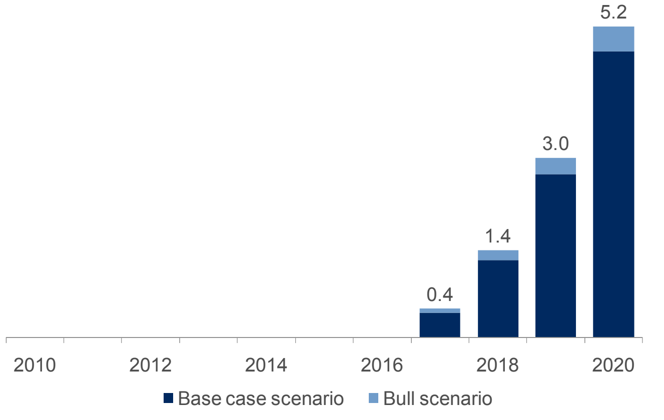


***Source**: Bloomberg New Energy Finance*

***Note**: in both scenarios we assume that the first biochemical plant will be online in 2017and that the EU27 could reach 100% of its potential by 2020.Current global demand is the demand for maleic anhydride*

Figure 14: Total cumulative biochemical revenues

EUR bn 2010 to 2020



***Source**: Bloomberg New Energy Finance*

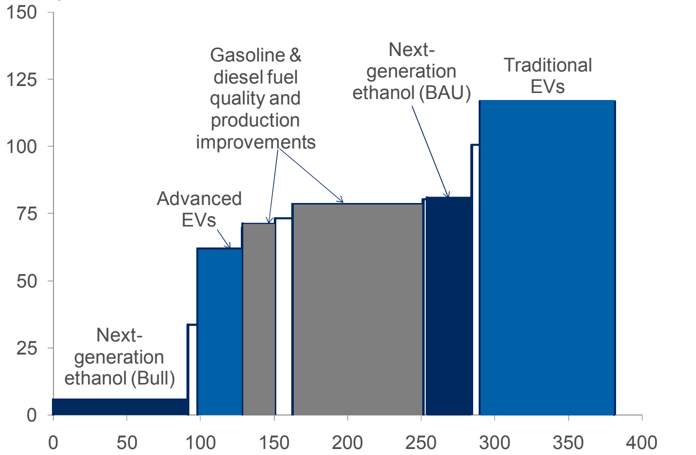
***Note**: This chart represents the revenues achieved from the operational new biorefineries, when maleic acid is at EUR 1,600 per tonne (1.12 per litre), the price in September 2010 according to ICIS pricing.*

4.4. Environmental benefits: road transport sector reductions

Next-generation ethanol has the potential to annually save between 101m and 122m tonnes of CO2e when compared with fossil gasoline. To put these figures into context, this could help the EU27 gasoline-based transport sector annually reduce its total emissions by 42% under our base case scenario and by 50% under our bull scenario. The RED mandates the use of 10% of renewable energy in transport by 2020, but this target includes first-generation biofuels, hybrids and electric vehicles consuming green electricity.

According to the annex V of RED, next-generation ethanol saves on average between 80% and 90% in lifecycle greenhouse gas emissions when compared with fossil gasoline – discounting any ILUC issues. Our methodology assumes agricultural land use patterns will not change between 2010 and 2020, which does not therefore bring the ILUC subject into play. We also assume lifecycle greenhouse gas emissions for next-generation ethanol are only 80%, which is the lower point in RED's range. Under conservative conditions, a minimum of 101m tonnes of CO2e will be saved if the EU27 replaces 52% of its gasoline demand with next-generation ethanol.

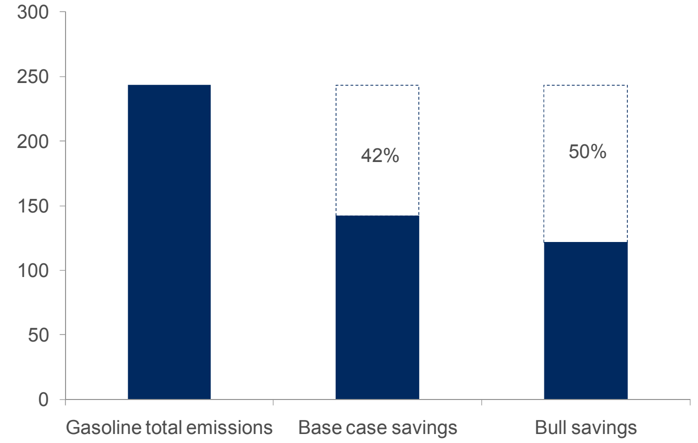
Figure 15: EU27 road transport greenhouse gas emissions abatement curve



***Source**: Bloomberg New Energy Finance*

***Note**: This curve represents the cost of reducing the emissions in transport at an oil price of $100 per barrel. Next-generation ethanol (BAU) represents the abatement cost if the industry develops following the business as usual scenario. Next generation ethanol (Bull) represents the abatement cost if the industry develops following our bull scenario. The reason why the Bull scenario is lower than BAU is because of a significant reduction in conversion and capital costs due to different economies of scale. Traditional EVs represent the current technology and advanced EVs represent those that will be available in the future.*

Figure 16: Next-generation ethanol 2020 greenhouse gas and gasoline emissions



***Source**: Bloomberg New Energy Finance*

***Note**: Data from the EU sustainable transport group shows a litre of gasoline has a well-to-wheel emissions footprint of 2.42kg / CO2e. Following RED indications the study assumes next-generation ethanol, using the enzymatic hydrolysis technology, will reduce GHG emissions by 80%.*

To reach the base case ethanol potential target of 75bn litres by 2020, it will cost approximately EUR 53bn per annum in total production costs. We calculate it currently costs EUR 0.71 to produce a litre of next-generation ethanol (see Figure 26), which means the 2020 abatement cost would be EUR 157 per tonne of CO2e. If production costs fell to EUR 0.60 per litre then the annual abatement cost would fall dramatically to 81 per tonne. We estimate that in 2020, when production cost will be close to EUR 0.50, the abatement cost will only be EUR 6 per tonne if the oil price is $100 per barrel. Small reductions in next-generation ethanol costs will result in considerable abatement cost reductions, presenting a case for improving the economics of the industry and increasing production volumes.

Table 3: BNEF Abatement curves

Our business-as-usual abatement curve includes the natural uptake of cost effective changes in capital stock; it gets more efficient over time (competitor curves do not).
There are no negative cost abatement measures because the model assumes the natural uptake of abatement measures is "theoretically optimal". Any deviation from this natural uptake rate diverts resources from more productive uses and therefore incurs a cost.

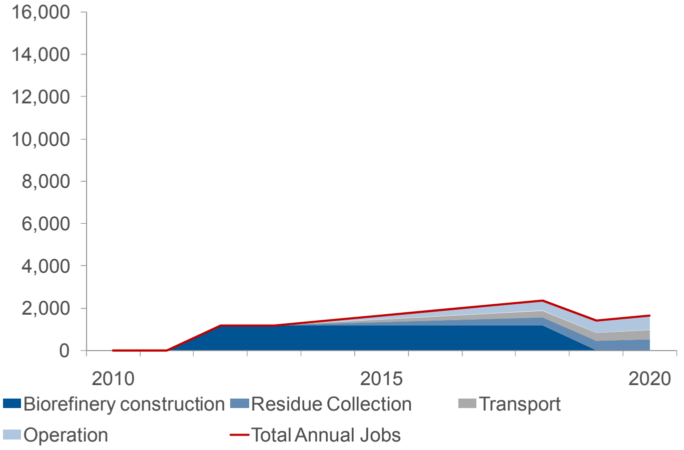
4.5. Job creation: bioproduct industry brings EU27 jobs

A new industry will be created, in unlocking the EU27 biomass potential, to build and produce next-generation bioproducts. Under the base case scenario about 782,000 aggregated jobs will be created between 2010 and 2020; under the bull scenario this figure soars to 934,000. Even if you move away from decadal aggregated job creation, then under the base case scenario 87,000 more people will be employed in the bioproduct industry in 2015 in the EU27 than there are today, this is a significantly higher figure than the 15,000 new jobs in the business as usual case. The number of jobs peaks at 124,000 in 2018 before falling back to a still encouraging total of 87,000 by 2020. The reason for this drop is that some of the jobs created by the industry come from the construction of the biorefineries.

Annual jobs created by the bioproduct industry sector

Figure 17: "Business as usual"

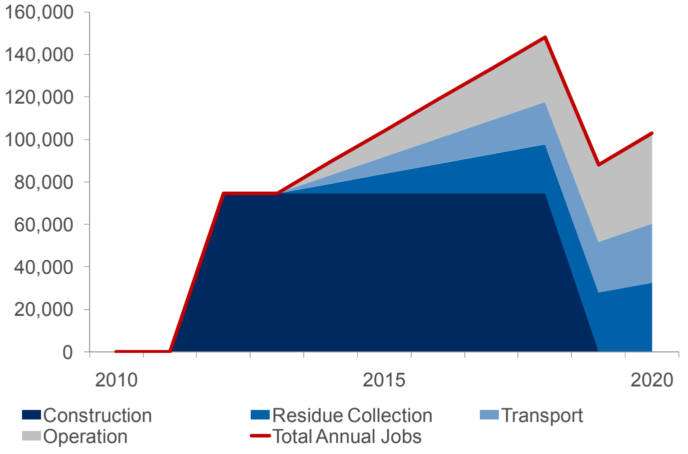
People in employment 2010 to 2020



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

Figure 18: "Bull scenario"

People in employment 2010 to 2020



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

***Note**: total annual jobs, or one man year, from the bioproduct industry come in two parts – firstly from biorefinery construction and operation, and secondly from the biomass residue supply chain. We have taken the sum of the total annual jobs created between 2010 and 2020. For further details see the Appendix.*

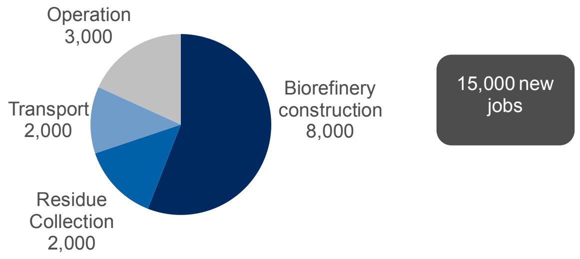
Collecting the biomass residues from the field, transporting it to the biorefinery and converting it into bioproducts should nevertheless still keep 87,000 people in annual employment for the 20-year lifetime of each biorefinery – essentially between 2020 and 2040. Under the bull scenario, 104,000 people in the EU27 will be employed annually in 2015, with this figure again peaking at 148,000 in 2018, before falling back slightly to 103,000 two years later. Whether it is decadal aggregated job creation or annual job creation, the employment opportunities created by a bioproduct industry are cause for great optimism.

There are other additional results from the employment opportunities created by the construction and operation of a bioproduct industry that are worth noting. Most of the decadal aggregated job creation – and annual job creation – is low skilled work. It is important to visualise the bioproduct production process to understand this. Firstly, the biomass feedstock must be collected from the field, as it is not currently, which will involve farmers, innovative machinery and farm labourers. Secondly, the biomass feedstock must be bailed – or bundled – and transported to the biorefinery gates. We have estimated the average distance travelled per tonne of biomass from the field to the biorefinery gate will be 50km; if the biomass feedstock travels distances greater than this the project economics become less feasible. Thirdly, the biomass feedstock is then converted at the biorefinery into biochemicals and next-generation ethanol, which would require on-site operators, research and development employees and support personnel. The final bioproducts would then enter the traditional fossil infrastructure supply chain.

Direct and indirect jobs will also be created in the construction of the biorefineries. Under the base case scenario 787 biorefineries must be commissioned by 2020, which creates about 435,000 decadal aggregated jobs: under the bull scenario, this figure shoots to 522,000 direct and indirect construction jobs. In accounting for the current developmental state of the enzymatic hydrolysis technology, which produces the next-generation bioproducts, we have assumed pan-EU27 biorefinery construction will begin in 2012 and will then begin falling in 2017. The projected construction timeline will allow the bioproduct industry to fulfil its potential by 2020.

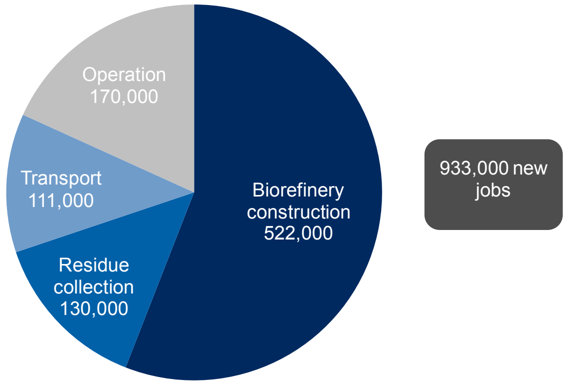
Total next-generation bioproduct job creation, 2010 to 2020

Figure 19: "Business as usual"
Number of jobs



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

Figure 20: "Bull scenario"
Number of jobs



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

***Note**: total annual jobs, or one man year, from the bioproduct industry come in two parts – firstly from biorefinery construction and operation, and secondly from the biomass residue supply chain. We have taken the sum of the total annual jobs created between 2010 and 2020. For further details see the Appendix.*

On visualising the bioproduct value chain, it becomes clear that these jobs cannot be outsourced. Project economics become less feasible and viable if biorefineries move too far away from the biomass residue feedstock. The biomass residue feedstock supply chain is also completely dependent on the agricultural sector. A new bioproduct industry could therefore drive job creation in rural communities – jobs which cannot be outsourced from the EU27 region. The nature of the bioproduct business will create jobs for divergent communities across the value chain from farmers to farm labourers to short-haul drivers to engineers to the scientific community.

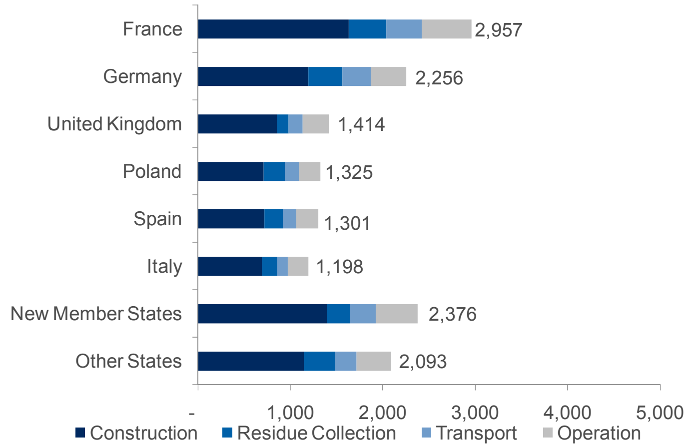
4.6. Job creation: new member state opportunities

Due to the relatively even distribution of the biomass potential across the EU27 region, biorefineries will most likely be required in most member states. According to the scenarios, France could theoretically create between 156,000 and 185,000 jobs in the next decade from a bioproduct industry; it is therefore the EU27 member state with the most to gain in employment terms from this vision. For EU27 member states acceding after 2004 (new member states) - essentially the Czech Republic, Hungary, Slovenia, Slovakia, Lithuania, Estonia, Latvia, Cyprus, Malta, Romania and Bulgaria — with the notable exception of Poland, which we analysed individually— a bioproduct industry will also create a wealth of employment opportunities, predominantly in the agricultural sector. Under the base case scenario, 124,000 decadal aggregated jobs will be created in the new member states and in the bull scenario 148,000. Eurostat recently announced total EU27 unemployment rates increased 1.5% between 2008 and 2009, with some unemployment rates in the rural areas hovering at over 20%. But there could be promising bioproduct employment opportunities for the new member states in the next decade.

Total next-generation job creation by profiled region, 2010 to 2020

Figure 21: "Business-as-usual"

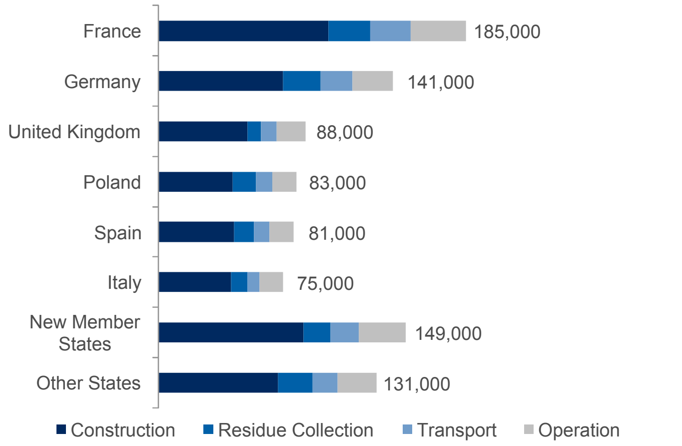
Number of jobs EU27 profiled countries



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

Figure 22: "Bull scenario"

Number of jobs EU27 profiled countries



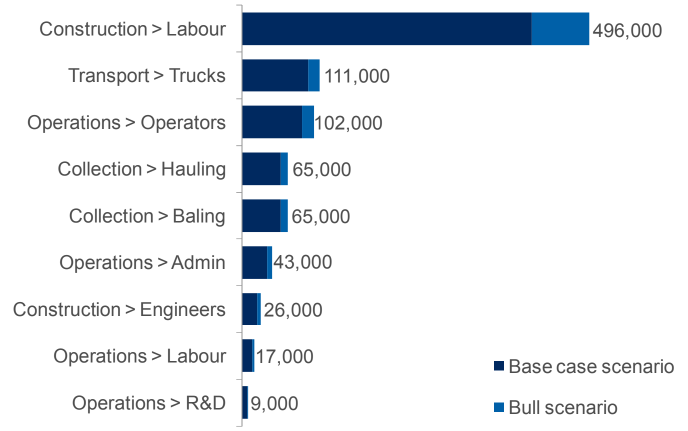
***Source**: Bloomberg New Energy Finance & Danish Construction Association*

***Note**: total annual jobs, or one man year, from the bioproduct industry come in two parts – firstly from biorefinery construction and operation, and secondly from the biomass residue supply chain. We have taken the sum of the total annual jobs created between 2010 and 2020. For further details see the Appendix.*

Poland is analysed separately from the other new EU27 member states because of its impressive potential biomass residue resources. Under the two scenario conditions, Poland could hypothetically create between 69,000 and 83,000 aggregated decadal jobs with the construction of 67 to 81 biorefineries. Total employment in Poland in 2009 was 59.3%, which was some way short of the EU27 regional average of 64.9%. Poland could also significantly increase its per hectare agricultural productivity in the next decade – wheat is the best example. Greater wheat yields will simultaneously increase wheat straw availability, which may enable Poland to easily surpass the bull scenario 2020 biomass total of 23m tonnes per annum. Ultimately, greater Polish agricultural productivity should provide even more bioproduct job opportunities.

Figure 23 Decadal next-generation bioproduct job creation by employment type

Number of jobs

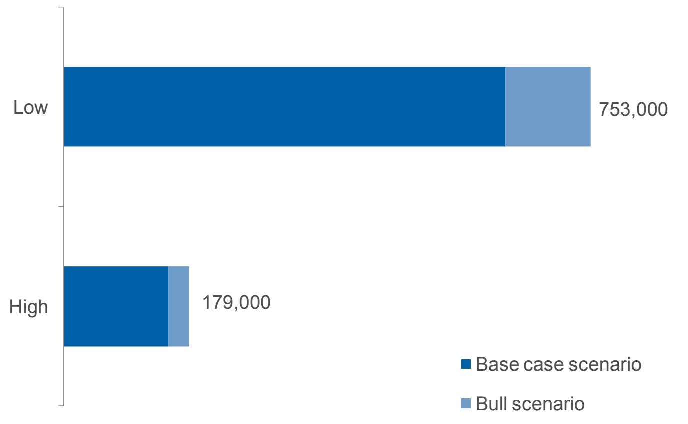


***Source**: Bloomberg New Energy Finance & Danish Construction Association*

***Note**: total annual jobs, or one man year, from the bioproduct industry come in two parts – firstly from biorefinery construction and operation, and secondly from the biomass residue supply chain. We have taken the sum of the total annual jobs created between 2010 and 2020. For further details see the Appendix.*

Figure 24: Decadal next-generation bioproduct job creation by skill type

Number of jobs



***Source**: Bloomberg New Energy Finance & Danish Construction Association*

***Note**: Low-skilled jobs represent those that do not require any specific skill or previous extensive experience besides basic education. High skilled jobs, on the other hand, are those that require extensive education or technical training before they can be performed. For further details see the notes in Figure 23 and Appendix.*

Section 5. Developmental barriers

5.1. No market for residues

In 2010 there is currently little or no financial incentive for farmers, and the broader agricultural community, to collect and transport agricultural residues from the field to the biorefinery gate. Of the total 2020 biomass supply potential in both base case and bull scenarios, 80% comes from agricultural residues. There is therefore limited incentive to build the infrastructure to harvest, transport and store large volumes of agricultural biomass residues. EU27 farmers are therefore still inclined to simply leave the agricultural residues on the field. By contrast, in August 2009 the US government provided a matching payment of up to $50 per dry tonne for biomass producers to overcome this problem. The introduction of similar EU legislation would drive forward the development of an agricultural residues supply chain.

5.2. Biomass residue infrastructure required

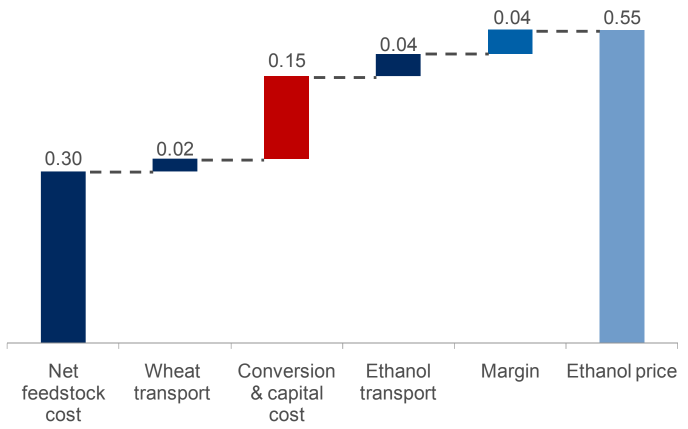
The specialised equipment to harvest and transport agricultural residues is also absent today. The US maize ethanol producer POET is looking innovatively at this issue. It is attempting to retrofit its combine harvesters to simultaneously collect maize stover and maize cobs, which it will then convert into next-generation ethanol. Farming practices vary across the EU27 member states and mechanised farming is not prevalent. Raising the collective standard of farming across the EU27 region – particularly in the new member states – will increase food yields and the availability of agricultural residues. The improvement in farming practices should simultaneously drive the development of additional equipment to collect agricultural residues from the field.

5.3. Conversion economics

The economics of both first-generation and next-generation biofuel production will ultimately determine how much next-generation ethanol is consumed in the next decade. Bloomberg New Energy Finance estimates it costs EUR 0.51 per litre to produce a litre of first-generation ethanol in August 2010, when wheat is at EUR 140 per tonne. It is worth noting however that wheat began the year at EUR 100 per tonne. We likewise estimate it costs approximately EUR 0.71 to manufacture a litre of next-generation ethanol in August 2010; these costs will fall in the next decade. As Figure 26 shows, if agricultural residues can be delivered to the biorefinery gate for approximately EUR 77 per tonne, then next-generation ethanol is close to being cost competitive with wheat ethanol production today.

Figure 25: First-generation wheat ethanol production costs, August 2010

EUR per litre — Supply chain costs

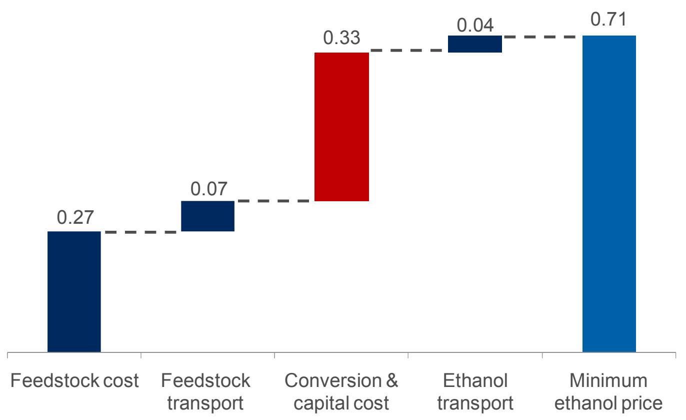


***Source**: Bloomberg and Bloomberg New Energy Finance*

***Note**: "Net feedstock cost" includes revenues generated from the sale of distillers grains by-products; "Net feedstock cost" also accounts for wheat at EUR 140 per tonne; "Conversion & capital cost" accounts for a 10% IRR*

Figure 26: Next-generation ethanol production costs, August 2010

EUR per litre — Supply chain costs



***Source**: Bloomberg and Bloomberg New Energy Finance*

***Note**: "Feedstock cost" accounts for one tonne of dry biomass at EUR 77 per tonne, if this cost could be reduced to EUR 25 per tonne then the feedstock cost would fall to EUR 0.07 per litre. This chart excludes possible supplier margins.*

It is therefore not feedstock costs which are holding back the development of next-generation ethanol production, which is promising news. The pressing industry concern should therefore be the reduction of the capital and conversion costs of next-generation ethanol production; although, some of these reductions will happen naturally as the technology scales up. Agricultural residue costs for next-generation ethanol production, of between EUR 70 and EUR 100 per tonne, should not hold back the development of the enzymatic hydrolysis technology in the next five years. Delivering large quantities of feedstock in this cost range however is not technically feasible today. Policymakers must work to incentivise the delivery of large quantities of biomass in the EUR 50 to 100 tonne cost range.

5.4. Technical blending hurdles

It will be technically impossible, under the current EU27 legislation, for ethanol to replace more than 10% of the total annual gasoline supply. If the EU27 region wants to reduce greenhouse gas emissions, facilitate the development of a new industry, create new job opportunities and reduce its dependency on foreign oil it is vital to ensure that ethanol can technically substitute more than 10% of the fossil gasoline supply by 2015. That can be achieved in several ways, for example, the US is working towards tightening vehicle specification so they can use a 15% blend. Another way to achieve it is by promotion of the production of flex fuel vehicles. Two great examples of what can be done are Brazil and Sweden, where 90% and 25% of the new vehicles are FFV.

5.5. Capital shortage

According to analysis we have recently conducted, there are 31 next-generation biofuel projects in the EU27 region that are currently commissioned or in the pipeline. By contrast, in the US in 2010 there are 74. In the past five years, the US government has been very proactive in its support of the next-generation biofuels industry. Developers have responded positively to this government initiative, which has resulted in twice as many projects being on the drawing board as in EU27. The US government, however, has not yet successfully driven private capital towards the industry; so some of these projects may not get commissioned. Another important barrier to the development of a EU27 next-generation bioproduct industry – as in the US – is therefore the unavailability of private capital. Investors are not comfortable with next-generation ethanol project risk. This risk aversion should be surmountable once the first ten EU27 biorefineries are commissioned. The reduction in risk will open the doors to a wider investor base, which at the same time will bring the capital cost of plants closer to those now achieved by the first generation industry.

Section 6. The bioproduct roadmap

6.1. Remove technical impediments

Our analysis has shown there are biomass residue resources in the EU27 region to create an exciting new bioproduct industry in the next decade. The first and most important step in facilitating the creation of this industry must be to allow ethanol, both first and next-generation, to replace more than 10% of the fossil gasoline supply.

6.2. Create a new next-generation biofuels mandate

If the EU27 region is to realise some of its next-generation bioproduct potential then it will be very important to create an aggressive next-generation biofuels mandate. As Table 4 shows, the US renewable fuel standard mandates the annual consumption of 40bn litres of next-generation ethanol by 2020. EU27 for next-generation ethanol, through the RED, suffers by comparison. US governmental unequivocal and clear support of, firstly, its corn ethanol industry, and secondly, its next-generation biofuel production sent a powerful message to investors and technology developers. Directly subsidising next-generation biofuel production in tandem will also push the industry forward in this critical stage between the demonstration and commercial scale. In 2010 next-generation ethanol production is not cost competitive with current gasoline prices, an aggressive 2020 blending mandate and a tax break – similar to the US blenders tax credit – will help to reduce these costs considerably in the next decade.

Table 4: US renewable fuel standard for next-generation biofuels, 2010 to 2020: billion litres

Year	Cellulosic biofuels	Biomass-based diesel	Other advanced biofuel	Total advanced biofuels
	All advanced biofuels			Total
2010	0.02	2.46	N / D	3.60
2011	0.06	3.03	N / D	5.11
2012	1.89	3.79	N / D	7.57
2013	3.79	N / D	N / D	10.41
2014	6.62	N / D	N / D	14.19
2015	11.36	N / D	N / D	20.82
2016	16.09	N / D	N / D	27.44
2017	20.82	N / D	N / D	34.07
2018	26.50	N / D	N / D	41.64
2019	32.17	N / D	N / D	49.21
2020	39.74	N / D	N / D	56.78

***Source**: US Environmental Protection Agency*

***Note**: N / D means "not disclosed" as of August 2010*

A new next-generation biofuels mandate will have a series of important knock-on effects. Firstly, it will incentivise farmers to collect agricultural residues and provide a long-term stable demand for their product. And then, if farmers can see the merit in supplying large quantities of agricultural residues across all the EU27 member states, investment in biomass supply chain infrastructure will follow.

A mandate will also help to drive investment in the EU27 agricultural sector in the next decade. This is an important consideration as the sector has struggled in recent years to attract the necessary capital. This investment will help drive innovation in equipment and machinery required to collect, transport and store large quantities of agricultural residues. Agricultural investment, particularly in the new EU27 member states, will also help increase crop productivity per hectare. Barley, maize, wheat and sugar beet yields in the new member states can – and should – be driven towards French and German levels in the next five years, but machinery and land management investment is required. There will be two clear benefits to stimulating this type of investment: firstly, it will increase the actual food yield from each hectare, which will, in turn, lift the amount of residues available. The greatest room improvement, in yield per hectare terms, is in the new member states. If a new next-generation biofuels mandate can stimulate investment in the agricultural sector, this fresh capital should logically flow towards the new member states.

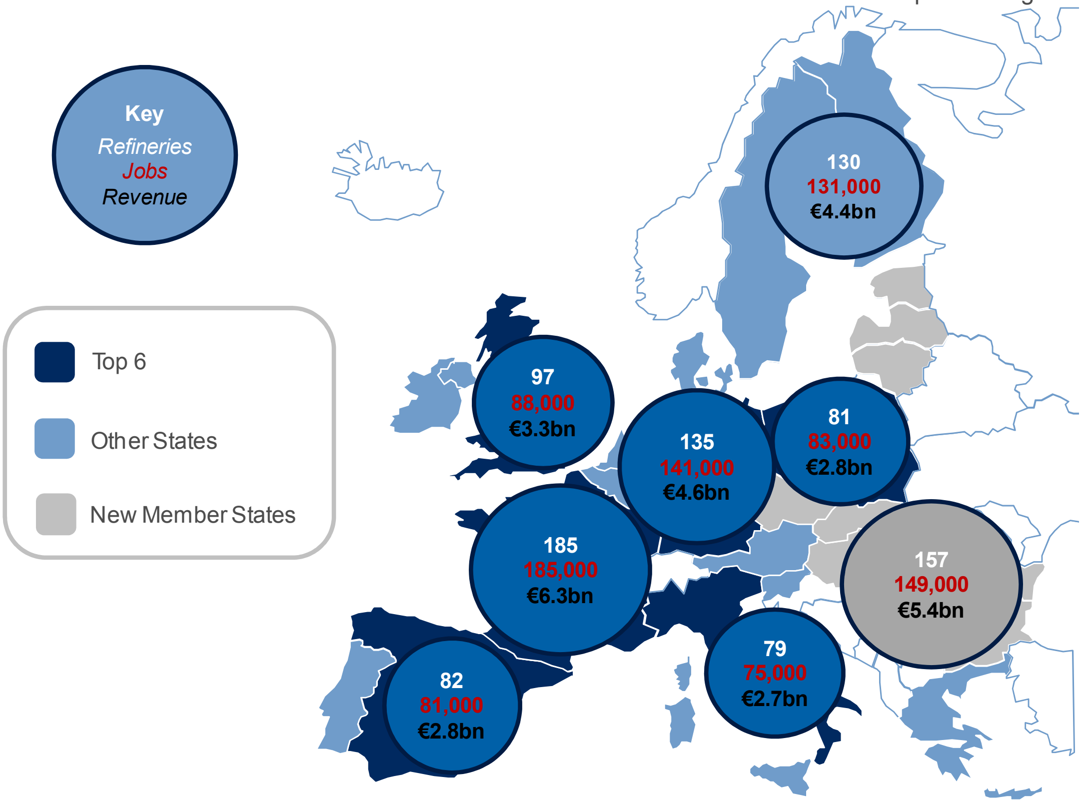
6.3. Jobs will follow biomass residue supplies

Biorefineries will have to be built close to the main biomass residue supply points. As our analysis has illustrated, it is logical to assume countries like France, Germany, Italy, Spain, Poland and the United Kingdom will require the most biorefineries. The construction and operation of these biorefineries will create jobs. However, most countries in the EU27 have the ability to supply agricultural residues, so there is the motive to build biorefineries in each of the 27 member states.

Figure 27: Potential number of refineries, employment and revenue in next-generation ethanol to 2020 (bull scenario)

Number of refineries

EU27 profiled regions



***Source**: Bloomberg New Energy Finance*

***Note**: The numbers of biorefineries is determined by the ability of each region or member state within the EU27 to supply bioproducts. Jobs in the chart represent the total man-years of employment between 2010 and 2020, not to the number of jobs in 2020 alone.*

6.4. Drive capital towards the industry

A next-generation biofuels mandate will also give the financial and investment community a long-term market demand perspective, which will help drive debt and equity capital towards the first 10 projects. The financing of these biorefinery projects is critical to the development of the industry. A new aggressive mandate will not only guarantee demand, but will also send a strong signal of encouragement and support from the government to the bioproduct industry. Most of the initial projects will be equity financed in the beginning. As the financial community becomes more comfortable with the project risk involved, the debt-to-equity ratio will become more balanced. A mandate and a short-term production cost subsidy would help pull capital towards the nascent bioproduct industry, which will drive the construction of the first 10 biorefineries.

6.5. Making the EU27 bioproduct industry happen

Freeing ethanol restrictions in the EU27 gasoline market will allow for greater substitution potential. A firm and long-term next-generation biofuels mandate will guarantee demand, which will increase investor confidence in the sector. Greater investor confidence will attract more capital towards the first 10 – and most vital – biorefinery projects. The construction of these biorefineries will test the technology and hopefully reduce project risk concerns. And if technology and project risks can be lessened, the industry can move quickly towards a commercial biorefinery capacity roll-out, which will create job opportunities. A commercial capacity roll-out will also importantly drive down the cost of producing a litre of next-generation ethanol, which will bring it closer to becoming cost competitive with gasoline at $100 a barrel without subsidies. Guaranteed demand for next-generation biofuels will in turn drive biomass residue production, which will lead to innovation and investment all along the agricultural supply chain. The EU27 region has a clear opportunity to learn, and improve, from the initiative of the US renewable fuel standard; it can also now seize the reins in the creation of a new bioproduct industry.

Section 7. Appendix

7.1. Agricultural residue potential methodology

7.1.1. Summary

To visualise how we derived our base case agricultural residue potential scenario, we firstly measure the ratio between the total harvested crop weight and the food component weight. Typically, a third of the total harvested crop weight is the food component, the remaining two-thirds are classified as agricultural crop residue – we refer to this variable as the "harvest index". Essentially, in a wheat harvest one-third is wheat grain and two-thirds are wheat straw. The harvest index is in part dependent on technology and how each crop is harvested.

Not all of this agricultural residue can, or should, be used as a bioenergy feedstock though. Most academic literature on biomass resources in the past decade assumes 75% of the total agricultural crop residue will be left on the field because of scattered production, limited size and high moisture content. In our base case agricultural residue potential scenario, we have also assumed only 25% of the biomass is actually physically recoverable – we refer to this variable as the "recoverability index". The 75% biomass that is not recovered will be left on the field to return nutrients to the soil. After we have accounted for the harvest and recoverability indices in our base case biomass potential scenario, we assume that a further 30% of the total agricultural crop residue will go towards animal husbandry and 10% will go towards power production.

In our base case scenario, we have therefore assumed only a proportion of the crop residues can be used as bioenergy feedstock; 75% of these residues will be left on the field; from the remaining residues 20% will go towards animal husbandry; and another 10% will go towards power generation.

7.1.2. Detailed calculations

For all the EU27 countries we obtained historical annualised data from 1990 to 2008 for the area harvested, in hectares (H_{Area}), and the yield, in hectograms per hectare (H_{Yield}), from the FAO database for the following agricultural crops: apples, barley, grapes, maize, oats, olives, potatoes, rapeseed, rye, sugar beet, tomatoes and wheat. We selected these 12 crops because they are the most widely produced food crops in the EU27 and should therefore be the principle sources for agricultural biomass residues. The multiple of these two items equals the amount of crops produced; see the equation below for further details. Where P_{Crop} is the total production of food or grain.

$$P_{Crop} = H_{Area} H_{Yield} \quad \dots (1)$$

We can calculate from the amount of crops produced, using the literature available ("A bottom-up assessment and review of global bioenergy potentials to 2050" by Edward Smeets, Andre Faaij, Iris Lewandowski and Wim Turkenburg), the volume of agricultural residues produced in the harvesting of these 12 crops.

$$H_{Residues} = P_{Crop} H_{Recoverability} \left(\frac{1}{H_{Index}} - 1 \right) \quad \dots (2)$$

Where $H_{Residues}$ is the amount of residues produced in harvesting these crops for food. The recoverability fraction $H_{Recoverability}$ is defined as the percentage of the crop weight that can realistically be recovered after harvesting. Most academic studies on the energy potential of biomass residues assume a recoverability fraction of 25%; we therefore assume the same for all crops in our study. The harvest index H_{Index} is therefore defined as the ratio between the food weight (W_{Food}) and the total crop weight (W_{Crop}). The harvest index calculation however is dependent on the agricultural technology level and the crop type. These ratios have been defined for all crops (see methodology source). To see how equation (2) works, the following equation breaks down the harvest index.

$$H_{Residues} = P_{Crop} H_{Recoverability}\left(\frac{W_{Crop} - W_{Food}}{W_{Food}}\right) = P_{Crop} H_{Recoverability}\left(\frac{W_{Residues}}{W_{Food}}\right)$$

After calculating the amount of agricultural residues that would have been available between 1990 and 2008, we fit a linear regression line to forecast a forward 2020 projection based on historic trends.

7.2. Forestry residue potential methodology

For all countries in the EU27 we obtained historical annualised data from 1990 to 2008 on the production of sawn wood (sawn timber), plywood, fibreboard, chemical wood pulp, mechanical wood pulp and pulpwood. All these production numbers allow us to calculate the amount of wood and residues produced in the harvesting of industrial round wood using defined “conversion factors” or “harvest indices” (see methodology source). The figure below visually represents the methodology and demonstrates how we have calculated our conversion factors and harvest indices.

Using the methodology in the above illustration, we subtract the amount of wood residues used in both the wood panel industry and the paper industry. Forestry residue production is illustrated in the equation below. Sawn wood and plywood are processed through saw mills and plywood mills to produce industrial round wood, which can then be used in other industries:

$$P_{Residues}(Available\ from\ Ind.Round\ Wood) = P_{Residues}(Sawnwood)\left(\frac{1}{P_{Efficiencyx}(Sawnwood)} - 1\right) + P_{Residues}(Plywood)\left(\frac{1}{P_{Efficiencyx}(Plywood)} - 1\right) \dots (3)$$

Using this equation we can calculate the amount of residues remaining – for potential use as a bioenergy feedstock – after consumption in the wood panel and paper industries has been accounted for (see equation below):

$$H_{Residues}(Remaining) = H_{Residues}(Available\ from\ ind.round\ wood) - H_{Residues}(Used\ in\ wood\ panel\ industry) - H_{Residues}(Used\ in\ paper\ industry)$$

To estimate the amount of wood residues used in the industrial round wood business, we assume the wood based industry uses all the fibreboard produced and that the paper industry uses all the chemical wood pulp and the mechanical wood pulp – less the pulpwood and particles. This is illustrated by the following two equations:

$$H_{Residues}(Used\ in\ Woodbased\ Panel\ Industry) = P_{Fibreboard}$$

$$H_{Residues}(Used\ in\ Paper\ Industry) = P_{Chemical\ Wood\ Pulp} + P_{Mechanical\ Wood\ Pulp} - P_{Pulpwood}$$

7.3. MSW residue potential methodology

Our municipal solid waste (MSW) forecasts are based on European EEA data on MSW generation from 1995 until 2007 and Eurostat population data from 1999 until 2007. The EEA data shows the amount of MSW generated in each EU27 country in kilograms per capita per year; in our analysis we converted the data to an annual amount of MSW generated into tonnes using Eurostat population data. We have used Austria as an example:

- Austrian MSW generation per capita in 1999 – 563 kg per capita;
- Population in Austria in 1999 – 7,982,461;
- *MSW_{1999} = (563 kg per capita) x (7,982,461 capita) = 4,494,125,543 kg*

We used the FORECAST function in Microsoft Excel to project the amount of MSW generated after 2007 – our forecasts therefore run from 2007 until 2020 on a country by country basis. We have aggregated the country data in this report.

After calculating our total MSW generation (by country) forecast, we deduced what proportion of the MSW total would be disposed at landfill sites. There are three methods for disposing of household MSW – it is either used for power generation or recycled or sent to a landfill site. In our base case

MSW residue potential scenario, we assume the biomass fraction will only come from MSW that is sent to a landfill site.

In a paper published by the Confederation of European Waste-to-Energy Plants (CEWEP), we found the MSW proportion which went to landfill sites for each country in 2006. These values ranged from 0.7% for Germany to 91% for Poland. In light of this information, to determine the 2020 proportion of MSW which will be landfilled we have assumed:

- All countries which sent less than 10% to landfill sites will maintain those specific proportions until 2020;
- The remaining EU27 countries, which in 2006 landfilled between 11% and 100% of their MSW, will individually reduce this proportion by 2.14% annually out until 2020 due to limited capacity.

To estimate how much of the MSW generated would be available for ethanol production Bloomberg New Energy Finance assumed that only three fractions of the landfilled MSW stream could be used:

In projecting our MSW biomass residue potential scenarios, we assumed that only three categories of landfilled waste would be used in the production of bioproducts – organics, paper and paper board, and wood waste. The maximum threshold for the biomass residue potential – using the organic, paper and paper board and wood waste components – therefore amounted to 57% of the total landfilled MSW.

Table 5: Biomass residue availability literature review, 2000 to 2030

Reference	Modelling type	Potential type	Area type	Geographical scope	Year	Min Potential (EJ)	Max Potential (EJ)
Campbell et al., 2008	GEO	SUS	Abandoned agriculture (crops and pasture)	World	2030	0.032	0.041
de Wit and Faaij, 2010	TECH + ECON	ECON	Energy crops	EU27+Ukraine	2010	1.7	12.8
			Agriculture residues			3.1	3.9
			Forest residues			1.4	5.4
Ericsson and Nilsson, 2006	TECH	SUS	Forest residues	EU15	2015 to 2025	0.44	0.88
				EU10		0.15	0.29
			Forest industry residues	EU15		0.83	NA
				EU10		0.22	NA
			Agricultural residues	EU15		0.47	0.67
				EU10		0.15	0.26
				Ukraine		0.06	0.15
			Energy crops (10% of arable land)	EU15		1.15	NA
				EU10		0.39	NA
Smeets et al., 2007	GEO	TECH	Energy crops + agricultural and forest residues + surplus forest increment	W. Europe		13	30
				E. Europe		5	29
				CIS + Baltic		83	269
Doornbosch and Steenblik, 2008	TECH	TECH	Total	EU27 region+ Russia		33.9	NA
Dornburg et al., 2008	TECH	ECON	Agriculture residues + waste	World	2050	40	170
European Environment Agency, 2007	TECH	SUS	Agriculture residues + waste	EU25	2010	7.95	NA
					2030	12.35	NA
Fischer et al., 2010	TECH	TECH	Agriculture residues	EU15	2000 to 2002	1.427	NA
				EU12		0.569	NA
				Ukraine		0.292	NA
				EU15	2030	1.206	NA

Reference	Modelling type	Potential type	Area type	Geographical scope	Year	Min Potential (EJ)	Max Potential (EJ)
				EU12		0.331	NA
				Ukraine		0.146	NA
Felby and Bentsen, 2010	TECH	TECH	Agriculture residues	EU27	2007	4.8	6.8
Bloomberg New Energy Finance 2010	TECH	TECH	Agriculture residues	EU27	2020	3.3	3.9
			Forest residues			0.10	0.10
			MSW (Organics)			0.61	0.81

7.4. Job creation methodology

7.4.1. Introduction

To visualise how we came to our biomass residue and biorefinery job creation conclusions, one must first consider the jobs created directly from the biomass residue supply chain and second biorefinery construction and operation jobs, as two separate entities. Between 2010 and 2020, our aggregated EU27 2020 potential agricultural residue supply forecast creates transport jobs and residue collection jobs. Residue collection will help create jobs in baling and hauling the biomass from the field to a central collection point.

The potential 2020 bioproduct forecasts then allows us to project the number of biorefineries that will require construction. We assume that throughout the next decade, the average annual plant capacity will be 100m litres. The capacity roll-out creates temporary construction jobs, which we assume will last for 24 months per biorefinery and fixed-term permanent operational jobs including administrative, labour and research and development work.

7.4.2. Biorefinery module

Direct construction jobs source: Danish Construction Association and Inbicon and 3F (assuming DKK 1 = EUR 0.1342)

Operational jobs source: NREL "25m Annual Gallons Fuel Ethanol from Corn Stover Operating Costs"

The methodology interpolates from zero production capacity in 2010, 2011, 2012 and 2013 towards the target production volume in 2020. This provides an annual capacity which builds towards the 2020 next-generation ethanol target. We assume next-generation biorefinery capacity construction starts in 2012 and that construction will last two years. We expect the first biorefineries will therefore be operational by 2014. To meet the 2020 bioproduct target of 75bn litres (base case) or 90bn litres (bull); 100m litre biorefineries must become operational each year from 2014 to 2020. This leaves us with a total of between 788 and 946 new build biorefineries by 2020. We assume it costs EUR 98m to build each 100m litre biorefinery; it is therefore possible to calculate the aggregated capital costs for the annual construction of this biorefinery capacity.

The Danish Construction Association projects that for every EUR 1bn spent in the construction industry 5665 direct construction jobs are created in the EU27. The total annual amount annually spent on biorefinery construction between 2012 and 2020 thus provides the number and timeframe of construction jobs created.

It is commonly understood that each biorefinery of 100m litre capacity will create approximately 45 operational jobs. Therefore, the cumulative commissioned end-of-year capacity multiplied by 45 gives the annual and aggregated amount of operational jobs created. NREL projects 10 operators and 4 maintenance workers will be required per shift; these jobs make up 70% of the operational jobs (excluding senior management). We assume that in any given day there are two shifts. There are therefore 20 operators and 8 maintenance workers required per shift. 28 workers make up 70% of the total operational jobs hence there are a total of 40 non-senior operational jobs. We have assumed 5 jobs for senior management, 1 overall plant manager and 4 supervisors. This totals the operational jobs to 45.

7.4.3. Biomass supply chain module

Straw harvest and transport

Source: NRG Consultants

(http://www.nrg-consultants.com/chppowerplantscogeneration/wholestrawbalegasifiers/handlingofstraw/index.html)

We first found the number of hours per hectare that were required to harvest and transport agricultural straw from the field to the biorefinery gate. Straw yields three tonnes per hectare, from a four-hectare size field, with a transport distance of 1km from the field to the storage. Large bails are currently moved from an agricultural storage centre to biomass power facilities; our methodology repeated this process. The large bale is the only bale size accepted by biomass district heating and power plants. Its average size is normally 240cm (adjustable) x 120cm; and the average weight is about 523kg, with a density of 139kg per cubic metre. The manpower required for bailing and transportation to an agricultural storage centre is 4 minutes per tonne for loading, 9 minutes per tonne for baling and hauling and 13.5 minutes per tonne for transportation.

We project 15 tonnes can be baled each hour. We assume the large bales are loaded and then unloaded from a tractor, assuming 24 bales can be transported per trail and that the trailing distance is 50km at all times. The manpower required in the collection, bailing, hauling and transportation of a generic tonne of straw has been applied to the agricultural residues from six crops; barley, maize, oats, rapeseed, rye and wheat.

Potato harvest and transport

Source: FAOSTAT (http://faostat.fao.org/) and pellet transportation data.

Using pellet transportation data it is safe to assume a 13 tonne load truck will be used to move the residues from an agricultural storage centre to the biorefinery. The biomass residue loaded truck will on average travel 50km from an agricultural storage centre to the biorefinery gate as with straw residues. The combine harvester is assumed to have an efficiency of approximately 15 hectares per day. We assume a 10 hour working day for all the agricultural residues.

We also assume that 1 tonne of potatoes produces 68kg (0.068 tonnes) of residues and an average potato yield of 53 tonnes per hectare in the EU27 region – which essentially equates to 3.6 tonnes of potato residues per hectare. The study only takes 25% of the residues for bioproduct conversion, which leaves us with 0.9 tonnes of residues per hectare. 15 hectares can be covered per day (10hrs) or approx 15 tonnes of residues per day, but 1 truck load is 13 tonnes. So in 1hr we can cover 1.5 hectares or tonnes. So in order to cover 13 tonnes (the truck load), we need 8.6 hours. So it takes 0.66 (8.6/13) hrs/tonne (or 39.6mins/tonne) to harvest a tonne of potato residues.

Now we know how many minutes per tonne it takes to bale, haul and transport our biomass residues. And from our cumulative EU27 agricultural residues actual production figures (starting in 2014), we also know how many tonnes are collected and transported per year. Multiplying these two factors we get the number of minutes or "manpower" it took to complete these processes. If we assume 96,000 minutes in a "working year" (200 days x 8hrs x 60 minutes) then it is possible to calculate the number of jobs created. We assume the manpower required for harvesting potato residues is the same for five of the agricultural residues; apples, grapes, olives, sugar beet and tomatoes.

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