Feedstocks for Sustainable Aviation Biofuels in Norway

Executive Summary

Report for:

Avinor
Oslo

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Executive Summary

Aim

The aim of this study is to identify the lowest cost and most sustainable feedstocks for import into Norway for the production of aviation biofuels. We provide feedstock availability and supply prices for 2020+. We consider the cost of producing aviation biofuels in Norway and compare this with the cost of producing aviation biofuels at origin. Finally, we consider whether aviation biofuels can be produced in the future competitively with fossil jet A1 without the need for subsidies.

Assumptions

Raw material prices are expressed both per tonne of raw material (on a bone dry basis for biomass) and per KWh. Our forecasts are initially expressed in US dollars and then converted into Norwegian Krone using an exchange rate[1] of 5.72 NOK per US dollar. We provide transport costs from the country of origin to Norway.

For biomass feedstocks, we start with the price of the wet feedstock and then convert prices either into pellets or on to a bone dry basis using the assumptions for moisture and energy content given in Table EXEC.1. Where a range is given, we use the average moisture content in our calculations.

Table EXEC.1: The energy and moisture content of biomass feedstocks

Feedstock	Moisture Content (%)	Energy Content (kWh/kg)
Harvest residues/thinnings (S1)	50-60	2.45
Saw mill residues (S2):		
Bark	*30-60*	*2.99*
Planer shavings	*8-19*	*4.71*
Saw dust	*25-55*	*3.27*
Urban wood waste (S3)	12-25	4.44
Dry wood chips	40	3.27
Fresh wood chips	55	2.45
Wood pellets/residue briquettes	6-10	5.04
Wheat straw	15	4.63
Corn stover	15	4.63
Bagasse	50	2.72
Switchgrass	15	4.63
Miscanthus	15	4.63
SRC (eg. poplar, willow, eucalyptus)	40	3.27
Palm biomass:		
Empty fruit bunch	*65-75*	*1.63*
Palm mesocarp fibre	*35-48*	*3.18*
Palm kernell expellent	*2.6-2.9*	*5.29*
Palm kernel shell	*11-13*	*6.01*
Bone dry tonne woody biomass	0	5.44

In calculating production costs we assume that production takes place in a plant producing 625 million litres of bio-jet A1 per annum. This requires one million tonnes of bone dry feedstock. We consider four different processing technologies:

- Biomass Gasification and Fischer Tropsch (FT) Synthesis.

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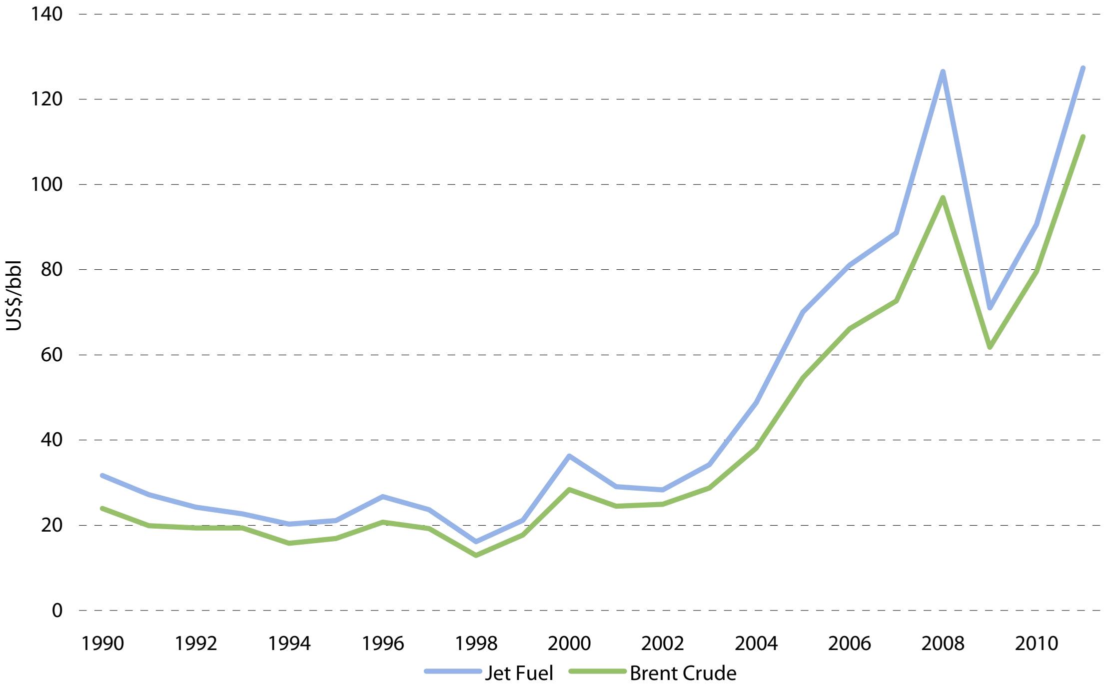
[1] Rate provided by Avinor.

- Pyrolysis of Biomass.
- "Alcohol to Jet" — the production of alcohols from hydrolysed biomass followed by conversion to jet fuel; and
- Hydro-treatment of Vegetable Oils, particularly non-food oils.

Background

Demand for bio-jet fuels is being driven by a need to reduce CO_2 emissions and mitigate climate change. In addition, fossil fuels are becoming increasingly expensive, a trend which is highlighted in Diagram EXEC.1.

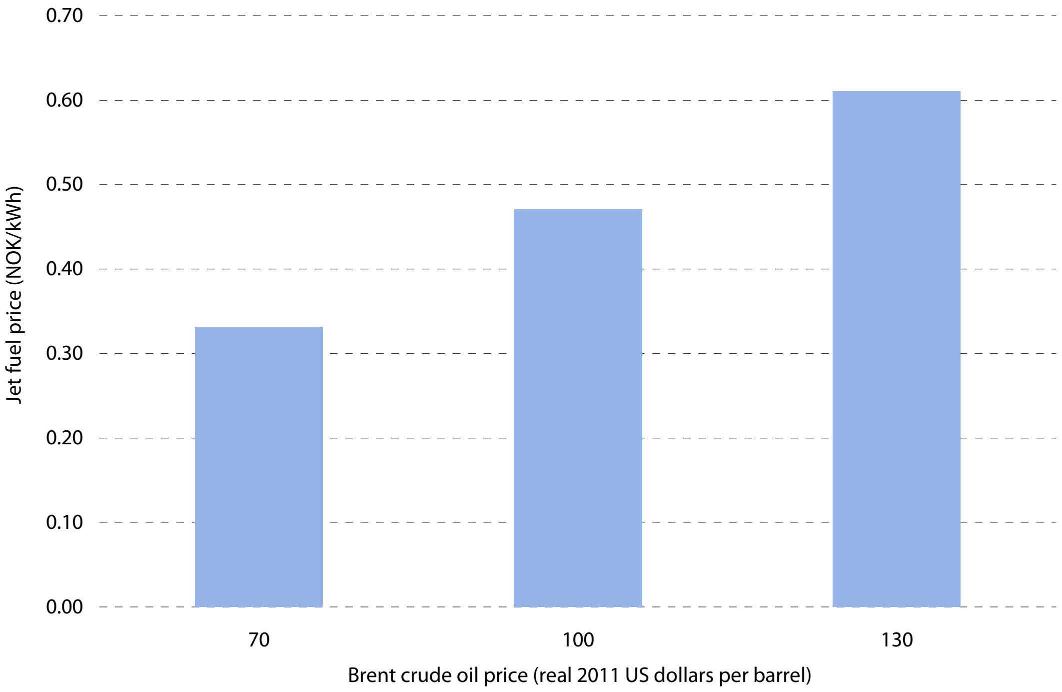
Diagram EXEC.1: Annual nominal fossil jet fuel prices and crude oil prices



Fossil jet fuel prices have risen unremittingly over the past decade, pausing only in 2009 when the global economic crisis had a temporarily negative impact on crude oil prices.

In Diagram EXEC.2 we present real 2011 fossil jet fuel prices at crude oil price of 70, 100 and 130 US dollars per barrel. This represents a benchmark against which to compare our feedstock prices.

Diagram EXEC.2: Real (2011) jet fuel prices at oil prices of 70, 100 and 130 US$ per barrel in NOK per kWh



Feedstock Coverage

The focus of the report is biomass feedstocks. We include food crops only for the purpose of comparison with biomass. The second generation (non-food) feedstocks are given in Table EXEC.2. Table EXEC.3 lists the first generation feedstocks. In addition to grain and sugar, we also consider their derivatives: starch, glucose; and ethanol. There is as yet no market for pyrolysis oil and therefore this is considered only in the section on production costs.

Table EXEC.2: Second generation feedstocks considered for aviation biofuels

Feedstock	Type	Origin
Forest biomass	S1 (harvest residues)	USA, Canada and EU
	S2 (saw mill processing residues)	USA, Canada and EU
	S3 (waste wood)	USA, Canada and EU
	Wood chips	USA
	Wood pellets/briquettes	USA
Agricultural residues	Straw	USA and EU
	Bagasse	Brazil
	Palm biomass	Indonesia/Malaysia
Energy crops	Grasses	USA and EU
	Short rotation coppice i.e. poplar	USA and EU
Non food oils	Camelina	USA and Canada
	Jatropha	Africa
Cellulosic ethanol	Semi products	USA and EU
Pyrolysis oil	Semi products	USA and EU

Table EXEC.2: First generation feedstocks considered for aviation biofuels

Feedstock	Type	Origin
Food oils	Palm oil	Malaysia & Indonesia
	Rapeseed oil	Europe, Canada
	Soyabean oil	Brazil, USA and Argentina
Sugar	Sugarcane	Brazil
	Sugarbeet	EU
Grains	Corn	USA and Argentina
	Wheat	USA, Canada and Australia

Sustainability

Sustainability is a key issue for aviation biofuels. We list below the key aspects of sustainability with regard to biofuels:

- Climate change mitigation — a need to reduce greenhouse gas emissions relative to fossil fuels through the efficient use of feedstock and reduction of emissions throughout the bio-fuel supply chain.
- Protection of natural habitats and land with high carbon stock — a need to prevent de-forestation, prevent peat land from being used to grow crops or protect land with high conservation value.
- Promotion of good agricultural practice — in order to protect soil fertility, air quality and the provision of sustainable water supplies.
- Respect for the law — an obligation to obey all national and regional laws together with relevant international treaties.
- Labour rights — compliance with international labour standards such as the ILO which prohibits child labour, forced labour, and discrimination. Provision of employees with the minimum wage and safe working conditions.
- Land rights — a respect for land ownership, protection of indigenous peoples and good community relations.
- Economic sustainability — biofuels should be produced competitively with fossil alternatives without the need for subsidies.

The Renewable Energy Directive (RED) has a narrower definition of sustainability than that given above and focuses on environmental sustainability.

In October 2012, the Commission proposed the following amendments to the RED:

- 5% limit on use of food crops - biofuels from food crops would be limited to 5% (by energy) of consumption in transport in 2020. The 2011 share was 4.5%.
- ILUC penalties — penalty co-efficients which aim to incorporate indirect land use change (ILUC) impacts. For starch-based ethanol this is set at 12gCO_2eq/MJ, for sugar ethanol at 13g and for oilcrops at 55g. These will need to be reported but will not be taken into account for calculating GHG savings until 2021 at the earliest depending on the review set for 2017.

- Quadruple counting for biomass — this includes MSW, aquatic material, agricultural, acquacultural, fisheries, and forestry residues, renewable liquid and gasesous fuels of non-biological origin.
- End to public subsidies — a promise to end all public subsidies for crop-based biofuels after the current legislation expires in 2020.
- Higher GHG savings — new biofuel plants (>July 2012) must generate GHG savings of 60%. Existing plants must generate GHG savings of 50% from 2018.

The EU has approved a number of voluntary schemes to certify sustainability for the RED. These have been subject to a number of criticisms:

- Most schemes are designed to certify first generation feedstocks and few schemes are suitable for biomass. The recently approved Dutch scheme (NTA8080) is an exception.
- The volume of certified product is small relative to global output. Having said that, current demand does not outstrip supply and the additional cost of certified product is currently less than the cost of certification.
- Environmental criteria are often weak — schemes such as the RTRS have been criticised for sanctioning unsustainable farming practices.
- The treatment of social criteria differs widely across schemes — as a rule, schemes used to certify EU feedstocks typically have weak or absent social criteria. Schemes used to certify foreign feedstocks have stronger social criteria.
- There is often insufficient enforcement of sustainability criteria — for example, the ISCC scheme allows growers to fill-in a self declaration that their feedstock is sustainable.
- Certificates have been used fraudulently — this seems to have been a particular problem in the market for used cooking oil.
- ILUC is ignored — none of the certification schemes currently in operation address the problem of ILUC.

Woody Biomass

The US and Canada are the world's largest and lowest cost producers of forest products and woody biomass. Diagram EXEC.3 provides the cost of US woody biomass delivered into Oslo in 2020. The first three bars represent access to biomass "at cost" whereas the last two bars represent the purchase of biomass at the prevailing market price. Market prices are significantly higher than residues "at cost". This is because traders demand a high margin for setting up the supply chain.

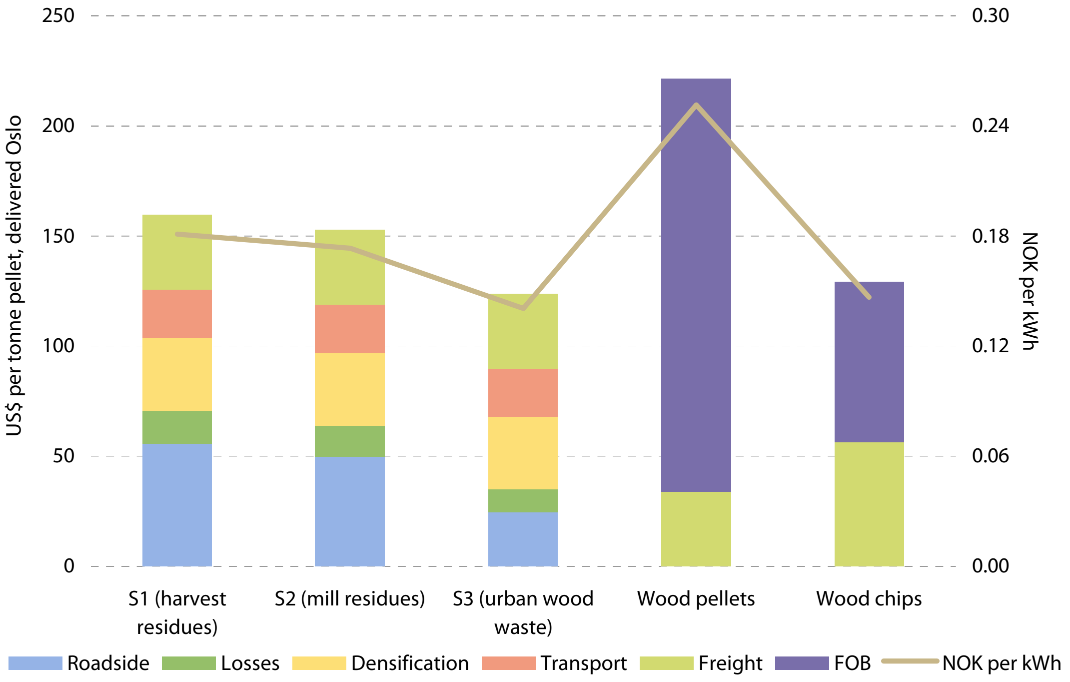
The first three bars disaggregate the supply chain into the following elements: roadside, at-the-mill or point-of-collection cost; losses; densification into pellets or briquettes; transport to a port, and ocean freight to Oslo.

Key points to note are:

- The lowest cost potential woody biomass resource is urban wood waste. This benefits from an established collection system and low opportunity cost (most is land-filled and subject to high tipping fees). However, contamination issues may make this feedstock difficult to use. Urban wood waste is not being exported at present. However, there are millions of tonnes available close to deep sea ports and growing demand for biomass from the European power sector is likely to stimulate investments in pelleting plants over the course of the decade.

- The projected market price for US wood chips is also competitive with urban wood waste. US wood chips are not being exported to Europe at present because the power companies prefer pellets. However, there is no reason why this supply chain could not be established if there was sufficient demand. Wood chips can come from harvest residues, mill processing residues or represent whole tree chips (from thinnings and poor quality or infected trees unsuitable for wood processing).
- Logistics comprise a large proportion of the final delivered cost, ranging from three quarters to two thirds depending on the feedstock.

Diagram EXEC.3: Cost of US woody biomass delivered Oslo in 2020



Residue and Energy Crop Biomass

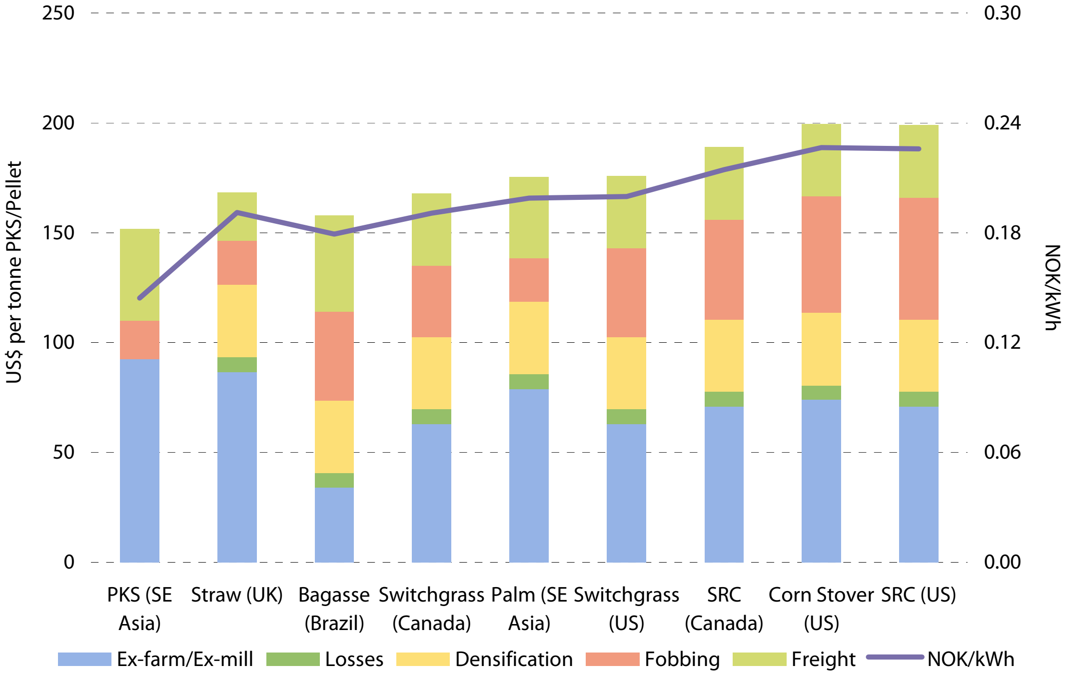
Diagram EXEC.4 summarises our results for agricultural residues and energy crop biomass (grasses and short rotation coppice). The diagram reveals:

- The lowest cost agricultural residue available for import is palm kernel shell (PKS). PKS is a naturally occurring pellet, and is the shell that remains after the nut has been removed from the kernel. PKS is attractive as it does not require densification and it "collects itself" i.e., is already available at the mill.
- No firm figures exist as to the quantity of PKS that is currently traded, although it is thought to be in the order of hundreds of thousands of tonnes. We have ruled out PKS as a potential raw material because it is unlikely to be available in sufficient quantities. Much is consumed by the mills themselves for electricity production and palm oil mills in Malaysia and Indonesia are typically small, which would raise collection costs.

- Sugarcane bagasse is another low cost option which like PKS is available at the mill. All mills burn bagasse for power generation, consuming 80% of each mills output on average. This means that in order to acquire sufficient supplies, the output of several mills must be pooled. There has been interest in bagasse from the European power sector and talk of building pellet mills in Brazil. However, very few bagasse pellets from Brazil or elsewhere are being traded on the international market.

- A major hurdle to developing an international trade in residues is logistics. Many of these residues i.e., stover and straw are not collected. Moreover, they are far from pelleting plants which are traditionally located in forested areas.

Diagram EXEC.4: Cost of residue and energy crop biomass delivered Oslo in 2020



Note: The residue prices are based on current prices, except for PKS which is forward looking to 2020.

Food and non-food oils

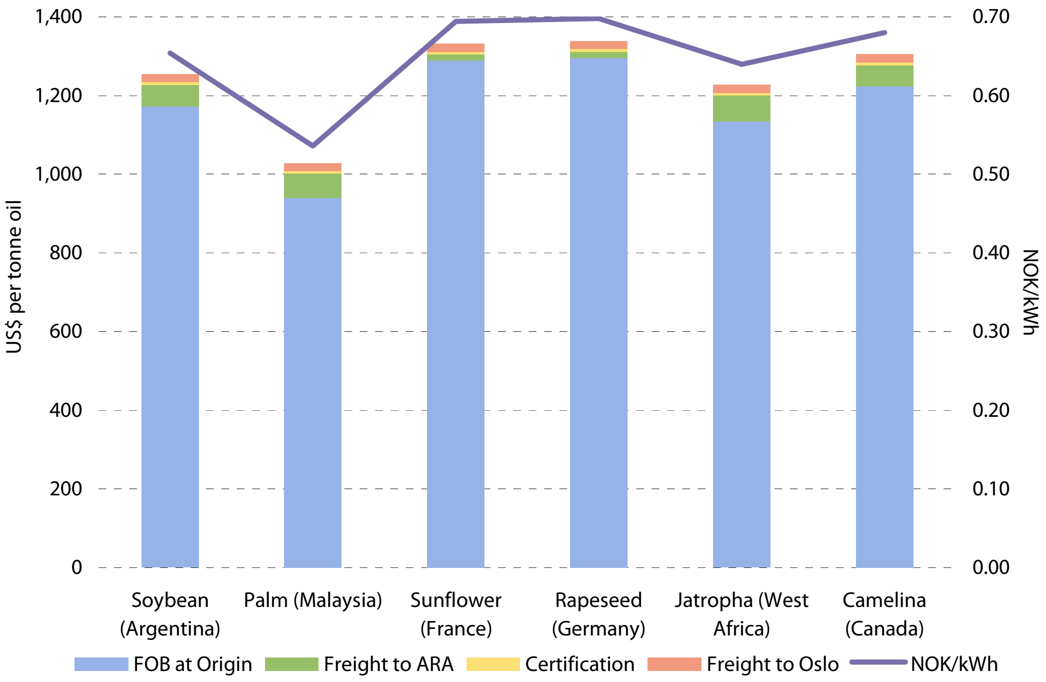
Diagram EXEC.5 presents our estimates of the cost of vegetable oils delivered into Oslo in 2020 at a Brent crude oil price of US$100 per barrel. The key points to note are:

- Unlike biomass feedstocks where logistics are a major component of the delivered cost, most of the cost of food and non-food oils is in the ex-mill price. The cheapest vegetable oil is palm oil. This is because oil yields for palm are much higher than those for soybean and rapeseed. Typical oil yields for palm are 3.0-3.5 tonnes per hectare compared with less than 0.5 tonnes for soybean oil and 0.7 tonnes for rapeseed oil. Moreover, palm oil output is expanding at a much faster rate than other oils, and the need to capture new markets is driving an increasing price discount to other oils.

- As there are no market prices for jatropha oil or camelina oil, we have valued these oils at the opportunity cost of producing biodiesel. This places these non-food oils at a slight discount to sunflower and rapeseed oil and at a similar level to soybean oil.

- A good deal of uncertainty surrounds the future potential supply of jatropha oil and camelina oil. As jatropha requires a high level of manual inputs in its production, it will only be viable in countries with very low labour costs. This will confine production to a handful of poor African and Asian countries. There has been much interest in camelina oil as a raw material for aviation biofuel in the US. However, the recent US government announcement that it would be unwilling to continue subsidising the production of aviation biofuels casts doubt over future supplies.

Diagram EXEC.5: Cost of vegetable oils delivered Oslo in 2020 (US$100/bbl oil)



Carbohydrates

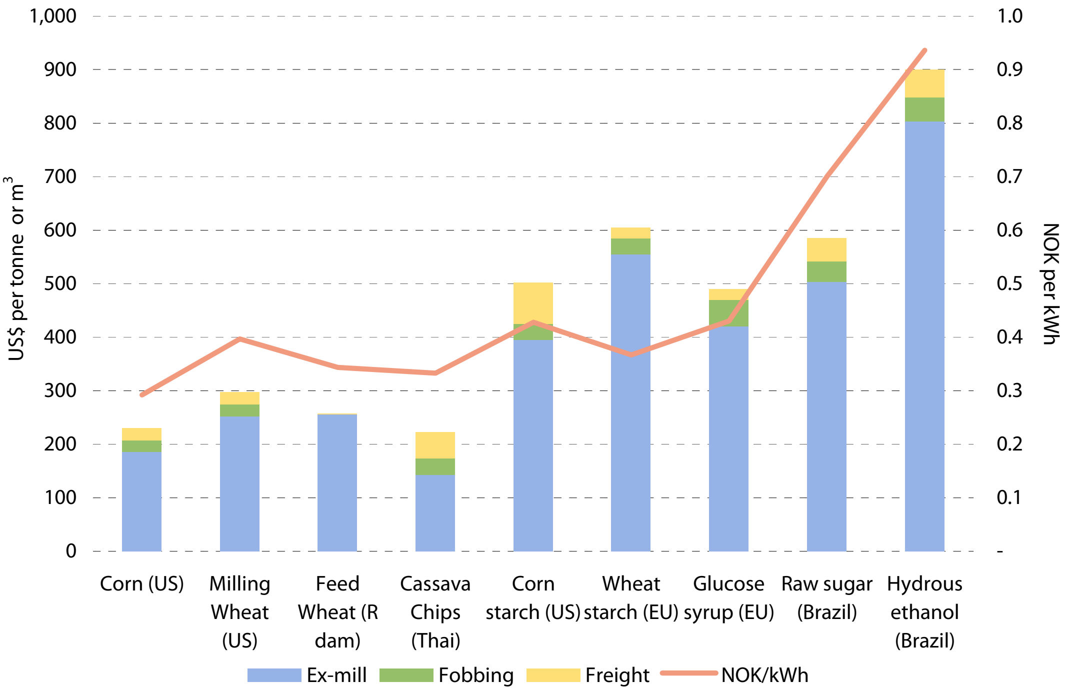
Diagram EXEC.6 summarises the cost of carbohydrates delivered to Oslo in 2020 at a Brent crude oil price of US$100 per barrel. The diagram reveals:

- US corn is the lowest cost carbohydrate source, followed by Thai cassava chips and European feed wheat. Concern over rising food prices has prompted national governments to limit the use of food for biofuel production. In the US, the quantity of corn ethanol under the Renewable Fuel Standard (RFS) is capped at 15 billion gallons (57 billion litres). In the EU, the Commission is proposing to cap the use of food based biofuels at 5% of transport fuels (by energy).

- Starch and glucose syrups are expensive carbohydrate sources. Glucose syrup is costly to transport as it contains 30% water and has to be shipped in heated containers. For these reasons, glucose is not traded in significant volumes on the international market. Commercial starch is dried prior to shipping, an expensive, energy intensive process.

- Brazilian raw sugar and hydrous sugarcane ethanol are the most expensive carbohydrate raw materials, as their production requires extensive processing from sugarcane.

Diagram EXEC.6: Cost of carbohydrates delivered Oslo in 2020 (US$100/bbl oil)



Ranked Feedstock Costs

Diagram EXEC.7 and Table EXEC.3 rank all of the feedstock costs delivered to Norway, from lowest to highest. The prices are presented in NOK per kWh, to enable a comparison on an energy equivalent basis. The output figures represent national totals whereas the prices are based on the lowest cost supply region within each country. We therefore overstate the volume of raw material that could be obtained at the given price as there is a supply curve with more distant resources being more costly to obtain. Food and biomass volumes are given in tonnes (dry tonnes for biomass) while ethanol and bio-butanol are given in billion litres. The key points to note are:

- Biomass raw materials appear primarily on the left-hand side of the curve, as these are generally lower in cost than food based raw materials.
- We see that the lowest cost biomass raw materials are US wood waste, US wood chips, US saw mill residues and Brazilian bagasse. These residues are available at a cost delivered to Norway of NOK 0.14-18 per KWh.
- In theory there is ample availability of low cost biomass resources. However, all of the lowest cost resources require investment in the supply chain. To obtain US wood waste, it would be necessary to invest in a pelleting plant on the east coast of the US or in Toronto Canada (another low cost source of wood waste). Wood chips from the US are not exported today as there is no demand. However, it is possible that chips could be sourced from elsewhere at similar prices as biomass supplies from the east coast of the US and Canada tend to drive prices in Rotterdam. A handful of companies are looking into building bagasse pelleting plants in Brazil and there is interest from European power companies in sourcing bagasse pellets. However, there appears to be nothing concrete in the pipeline. If Avinor wanted to source bagasse pellets it would

therefore need to invest in a pelleting plant as well as negotiate supply agreements with a cluster of mills.

- The easiest biomass resource to obtain is wood pellets. Over 3 million tonnes of pellets are currently imported into Rotterdam, a figure that is expected to grow strongly in the future. The projected Oslo delivered price of wood pellets from US Georgia, is NOK 0.25 per KWh, rather higher than the untapped, lowest cost raw materials.

Diagram EXEC.7: Ranked feedstock costs delivered Norway in 2020

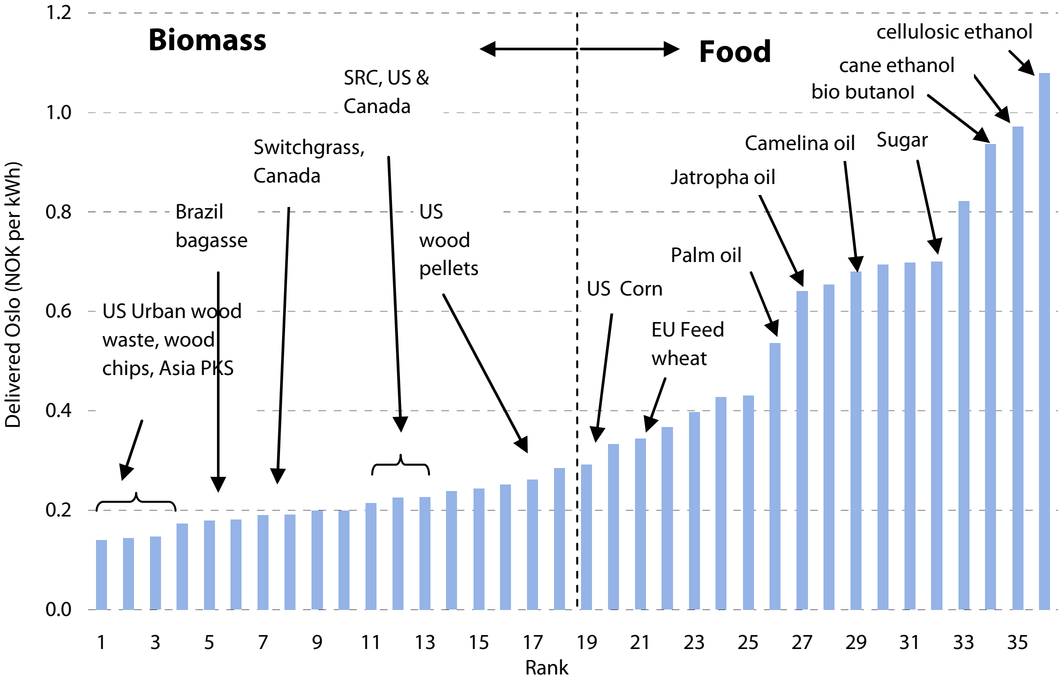
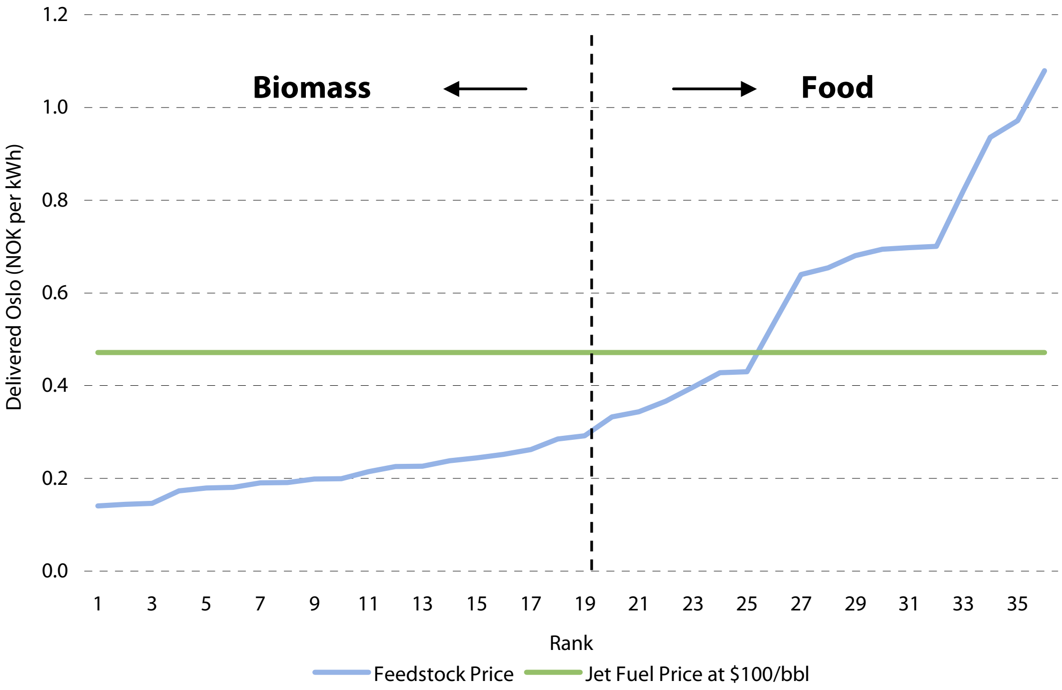


Table EXEC.3: Top 20 Ranked feedstock costs delivered Norway in 2020 (NOK per kWh)

Rank	Feedstock	Price NOK/kWh	Output mn mt / bn lts
1	Urban wood waste (S3) - briquetted, Average for US	0.14	58.2
2	Palm kernel shell, SE Asia	0.14	4.0
3	Wood chips (bone dry basis), US southeast	0.15	0.0
4	Saw mill residues (S2) - pelletised, US east coast	0.17	22.0
5	Bagasse, S America	0.18	40.0
6	Harvest residues/thinnings (S1) - pelletised, US east coast	0.18	130.2
7	Switchgrass, Canada	0.19	24.0
8	Wheat straw, UK	0.19	125.0
9	Palm biomass, SE Asia	0.20	53.0
10	Switchgrass, US	0.20	143.0
11	SRC woody crops, Canada	0.21	6.0
12	SRC woody crops, US	0.23	57.0
13	Corn stover, US	0.23	125.0
14	SRC woody crops, Southern Europe	0.24	28.0
15	Energy grasses, Northern Europe	0.24	7.0
16	Wood pellets, US, Georgia	0.25	0.3
17	SRC woody crops, Baltic & Scandanavia	0.26	7.0
18	SRC woody crops, Central Europe	0.28	18.0
19	Corn, US	0.29	429.1
20	Cassava Chips, Thailand	0.33	9.8

Diagram EXEC.8 reveals that many of the raw materials are available at a price that is well below the price of fossil Jet A-1 at a crude oil price of US$100 per barrel. A key question for the project is whether sufficient margin exists for bio-jet fuels to compete directly on price with fossil jet fuel. This is an issue to which we now turn.

Diagram EXEC.8: Comparison of ranked feedstock costs with fossil jet fuel at a Brent crude oil price of US$100 per barrel



The cost of producing bio-jet fuel

Diagram EXEC.9 presents the underlying costs of the three technologies for processing cellulosic biomass. The costs displayed are based on the use of wood pellets from the USA, transported to Oslo and processed in Norway.

- The lowest cost technology is Pyrolysis with FT & ATJ being the same within the uncertainty of the estimates. This reflects the fact that pyrolysis recovers the hydrocarbons in a state very close to the chemical structure of the biomass — viz minimum processing losses. The consequence of this is the fact that the yield of jet fuel is relatively low.

- The other two processes break down the biomass extensively and then “re-assemble” the molecules into the chosen product mix giving significantly higher yields of jet fuel than pyrolysis. The consequence is that the efficiency of producing liquid from biomass via pyrolysis is significantly higher than the other two technologies leading to the cost of the raw material being lower by around a third. The higher efficiency and the simpler process also results in lower capital costs (and hence depreciation and interest) and fixed operating costs.

Diagram EXEC.9: Breakdown of bio-jet processing costs for wood pellets processed in Oslo

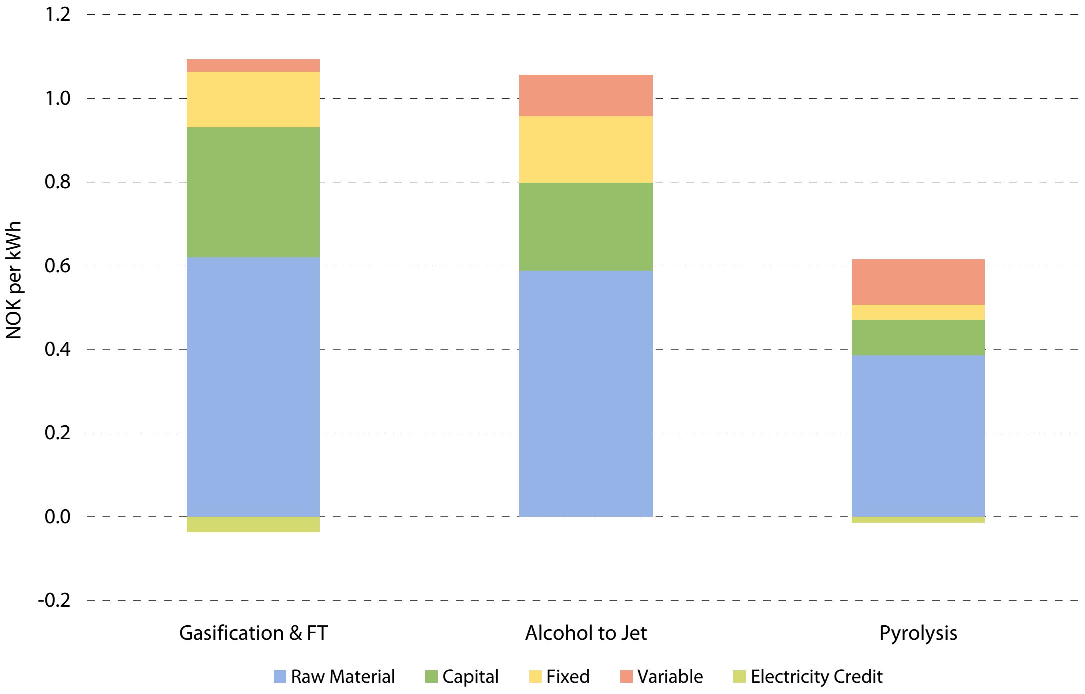


Diagram EXEC.10 compares the cost of producing finished jet fuel at origin (leftmost three bars) with the equivalent cost of production of jet fuel from an intermediate product in Norway.

- Comparing the leftmost three bars with Diagram EXEC.9 reveals that it is approximately 10% cheaper to produce directly from biomass at origin than in Norway. This is a consequence of the fact that the processes all recover no more than a third of the mass of the raw material as liquids and given that transporting liquids is more cost effective than bulk solids, the transport cost element is greatly reduced. Added to this is the fact that in most of the origin countries production costs are lower than in Norway.

- The three right-hand bars show that in the case of US based wood pellets the production costs of bio-jet fuel when shipping an intermediate for finishing in Norway is no different from production of the fuel at source. In the cases where the source countries have much lower labour costs and are further from Europe, the cost of producing an intermediate at source and then transporting this to Norway for finishing produces products at costs that fall between the cases of production at source and production in Norway.

Diagram EXEC.11 presents the hydro treating of vegetable oils.

- The cost of the bio-jet fuel is very largely determined by the cost of the raw material. The other costs contribute less than 20% of the full cost, split almost equally between capital related charges and the cost of the hydrogen required.

- The two non-food oils (camelina and jatropha) have costs that fall between European oils and oils from developing countries (Malaysia and Argentina).

Diagram EXEC.10: Breakdown of bio-jet processing costs for wood pellets processed at origin and an intermediate or the finished fuel shipped to Oslo

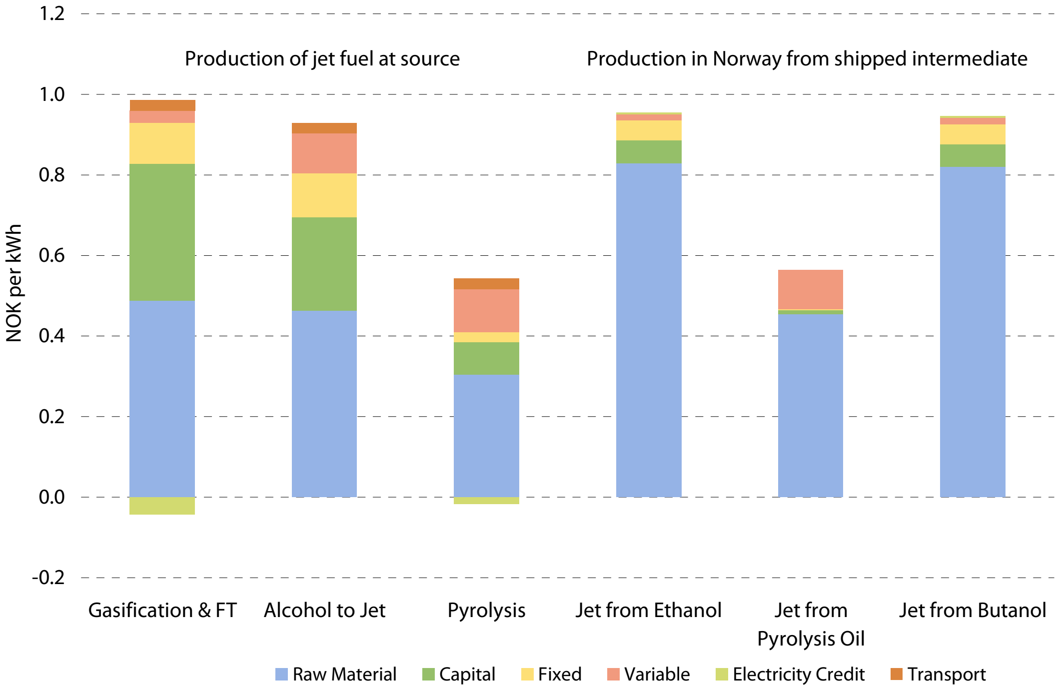
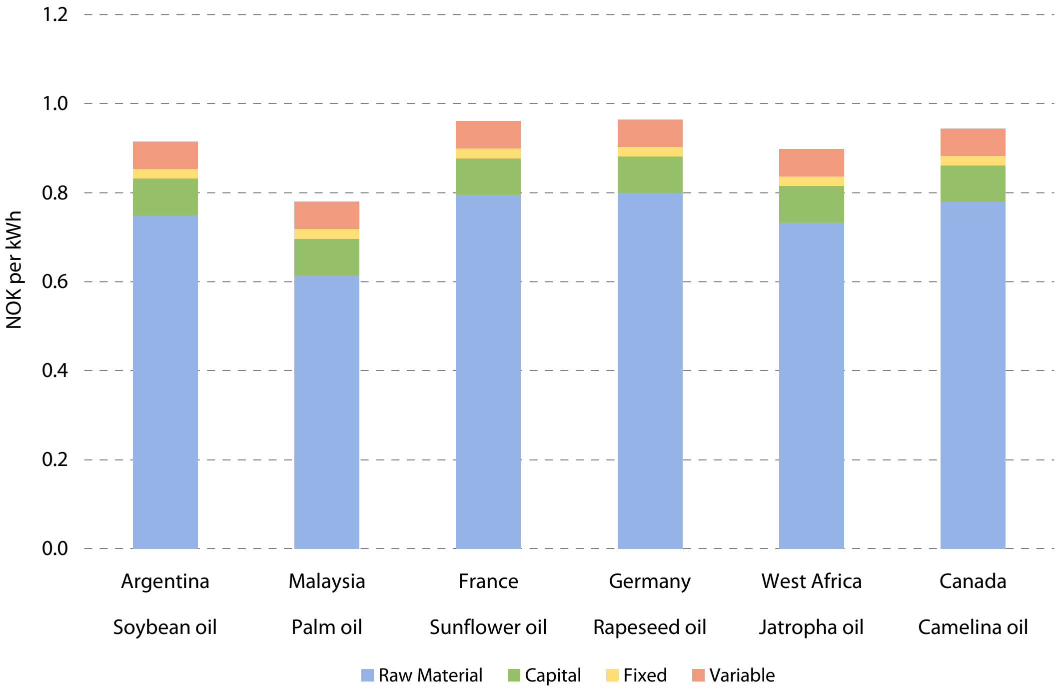


Diagram EXEC.11: Breakdown of bio-jet processing costs for hydro-treatment of vegetable oils (raw material costs basis US$100 per barrel crude oil)



Finally, we consider the option of importing ethanol (or butanol) made from food crops produced at the countries of origin, shown in Diagram EXEC.12 below.

- Based on our view of likely costs for the various carbohydrate costs in 2020+ and the development of ethanol production costs over the next decade, we calculate that bio-jet produced in Norway from imported ethanol would range from around NOK0.7/kWh to over NOK1.0/kWh, the largest cost element being that of the imported ethanol.

Diagram EXEC.12: Breakdown of bio-jet processing costs for food crops based on producing bio-jet from imported ethanol

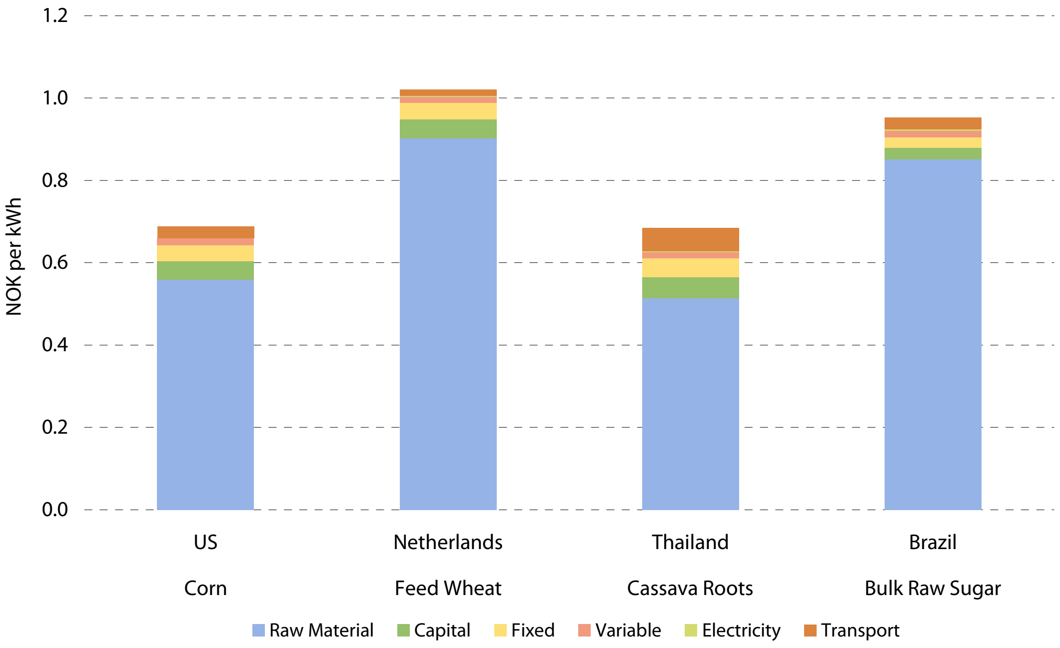
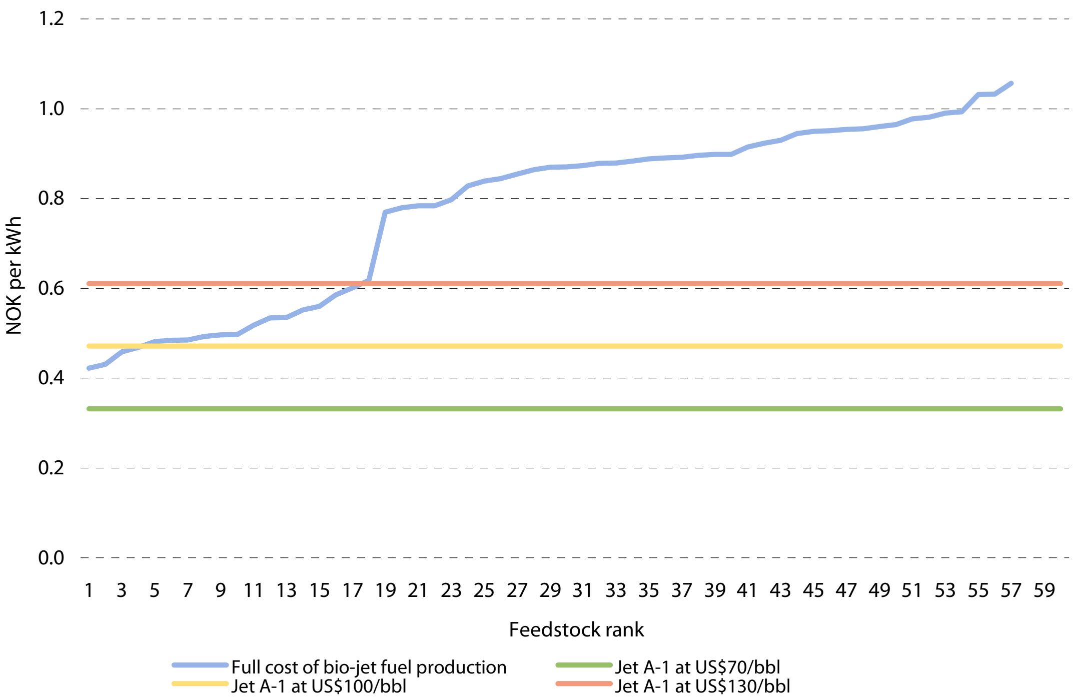


Table EXEC. 4: Ranked bio-jet A1 produced Norway (delivered Oslo), NOK per kWh

Rank	Feedstock	Technology	Price NOK/kWh
1	Wood chips (bone dry basis), US southeast	Pyrolysis	0.42
2	Urban wood waste (S3) - briquetted, Average for US	Pyrolysis	0.43
3	Palm kernel shell, SE Asia	Pyrolysis	0.46
4	Bagasse, S America	Pyrolysis	0.47
5	Saw mill residues (S2) - pelletised, US east coast	Pyrolysis	0.48
6	Switchgrass, Canada	Pyrolysis	0.48
7	Wheat straw, UK	Pyrolysis	0.48
8	Harvest residues/thinnings (S1) - pelletised, US east coast	Pyrolysis	0.49
9	Palm biomass, SE Asia	Pyrolysis	0.50
10	Switchgrass, US	Pyrolysis	0.50
11	SRC woody crops, Canada	Pyrolysis	0.52
12	SRC woody crops, US	Pyrolysis	0.53
13	Corn stover, US	Pyrolysis	0.53
14	SRC woody crops, Southern Europe	Pyrolysis	0.55
15	Energy grasses, Northern Europe	Pyrolysis	0.56
16	SRC woody crops, Baltic & Scandanavia	Pyrolysis	0.59
17	Wood pellets, US, Georgia	Pyrolysis	0.60
18	SRC woody crops, Central Europe	Pyrolysis	0.62
19	Wood chips (bone dry basis), US southeast	FT	0.77
20	Palm oil, Malaysia	Hydro-treatment	0.78

Diagram EXEC.13 highlights that bio-jet fuel could be produced in Norway competitively with fossil jet fuel if the Brent crude oil price remains at a relatively high level i.e., at or above US$100 per barrel. At lower oil prices, subsidies would most likely be required.

Diagram EXEC.13: Comparison of cost of bio-jet A1 produced in Norway with fossil jet at different crude oil prices

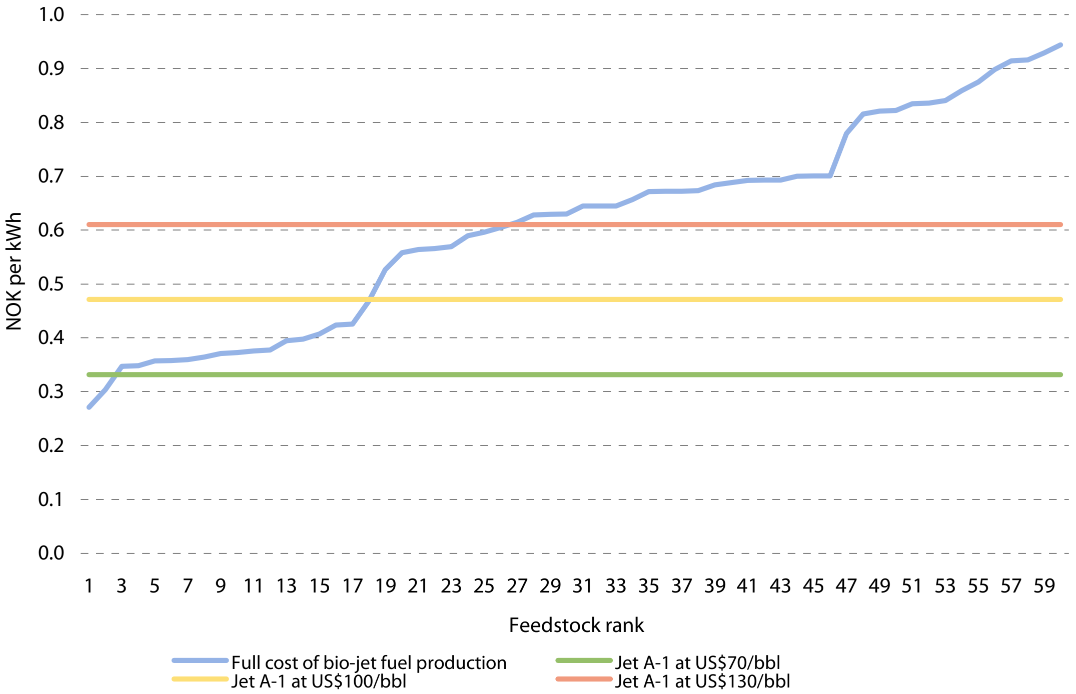


Long term sustainable market price of bio-jet fuel

The long term market price of aviation biofuel will be determined by the lowest cost producers. We estimate that the largest competitive suppliers of aviation biofuels are likely to be Brazil, US, Canada and Europe using bagasse, wood waste, saw mill residues, straw, wood chips and possibly energy grasses. **A sustainable long term market price for aviation biofuels is NOK 0.27–0.36 per kWh, delivered Norway.** This is lower than the price of fossil jet fuel which equates to NOK 0.47 per kWh at US$100 per barrel.

This is based on the cost of producing aviation biofuels at origin using pyrolysis, the lowest cost conversion technology. As outlined above, this assumes production takes place in a large scale nth plant in a commercially competitive environment.

Diagram EXEC.14 Ranked bio-jet A-1 produced at source (delivered Oslo), NOK per kWh



Conclusion

Our conclusion is that the most sustainable, lowest cost feedstock for the production of aviation biofuels in the period 2020-2025 will be biomass. Woody biomass and agricultural residue biomass benefit from good sustainability credentials. Both types of biomass do not require the use of agricultural land and therefore do not have problems with indirect land use change (ILUC). Much of the forest biomass available from North America is already covered by existing sustainability schemes. Moreover, millions of tonnes of feedstock are potentially available, even allowing for the use of agricultural residues to maintain soil fertility.

However, there remain significant barriers and risks to the production of aviation biofuels from biomass feedstocks. Waste wood has technological as well as supply chain issues that make it difficult to be used as a feedstock, despite its abundance and apparent low cost. In the US, prices for woody biomass and corn stover are vulnerable to demand for the production of cellulosic ethanol. This means that the cost of procuring these residues (which we calculate using collection costs) could rise to the opportunity cost of producing cellulosic ethanol. This is a particular risk for stover which is being eyed as a feedstock for ethanol by many first generation ethanol producers. As cellulosic ethanol benefits from generous subsidies, this places the aviation sector at a disadvantage in terms of its ability to pay for feedstocks.

The lowest cost biomass resources (wood waste, wood chips, straw and bagasse) require investment in the supply chain to enable imports in the volumes needed by the project. As most biomass resources have a low energy density, they can only be exported economically if they are densified. This means that investments in pelleting facilities may be needed. We have ruled out PKS as a feedstock as this is unlikely to be available in sufficient quantities. It is also worth noting that agricultural residues are only available during the harvest period and therefore must be stored whereas woody biomass is available all year round. To mitigate risk, the project is advised to obtain a mix of local and imported feedstocks.

Our comparison of the economics of production at origin versus destination suggests that it will be cheaper to import aviation biofuels than produce them in Norway. However, as the market is still in its infancy, it is far from clear that sufficient supplies will emerge for export. Most projects are for local use and it seems likely that potential demand will exceed supply**. If Norway is to guarantee future supplies, it will have to produce its own fuel from either local or imported feedstock**.