Nordic Energy Research

NORDIC PERSPECTIVES ON THE USE OF ADVANCED SUSTAINABLE JET FUEL FOR AVIATION

Erik C. Wormslev, ecw@niras.dk
Jakob Louis Pedersen, jlp@niras.dk

THE TEAM

- NIRAS A/S: Erik C. Wormslev (Project owner and responsible), Jakob Louis Pedersen (Project manager), Christian Eriksen, Rasmus Bugge, Nicolaj Skou, Camilla Tang, Toke Liengaard, Rasmus Schnoor Hansen, Johannes Momme Eberhardt and Marie Katrine Rasch.

- ÅF: Jonas Höglund and Ronja Beijer Englund

- SINTEF ENERGY RESEARCH: Judit Sandquist, Berta Matas Güell and Jens Jacob Kielland Haug

- GAIA CONSULTING OY: Päivi Luoma, Tiina Pursula and Marika Bröckl

APPROACH

1. BACKGROUND

2. DEMAND

3. PRODUCTION

4. MOST PROMISING SCENARIOS

5. IMPACT

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7. CONCLUSION

BACKGROUND AND MOTIVATIONS

NIRAS

THE MARKET TODAY

- No fully functioning commercial supply chain for sustainable jet fuel.
- Increasing number of commercial flights operate worldwide on a blend of commissioned biofuels.
- Nordic countries: leader on this field in Europe.
- US: Likely stable commercial production in the near future.
- A number of companies are supplying and developing technologies that are either commercially used to some extent or could see increased future potential given technological development. While such technologies may seem to offer promising new solutions, they are generally on a lower level of maturity.
- In the last decade: 80 multi-stakeholder initiatives. Some terminated, due to various challenges facing the commercial markets.

TODAY'S COMMERCIAL PRODUCERS OF ALTERNATIVE JET FUEL

- Since January biofuel has been available on the Oslo airport in Norway and the delivered fuel produced at a refinery in Porvoo, Finland.

- US: Fulcrum Bioenergy, GEVO, Red Rock Biofuels and AltAir, have agreements with airlines for the supply of larger fuel amounts -> Likely stable commercial production in the US in the near future.

PRODUCER, COUNTRY	Production pathway	Capacity	Feedstock	Example of airline agreement
NESTE FINLAND	HEFA	-	Natural oils and animal fats	Lufthansa
AMYRIS/TOTAL US/FRANCE	SIP	47 mio l/yr	Sugarcane	GOL, AirFrance
FULCRUM BIOENERGY USA	FT	35 mio l/yr*	MSW	Cathay Pacific
GEVO USA	AtJ	68 mio l/ yr*	Lignocellulosic (straw, wood residuals)	Alaska Airlines
RED ROCK BIOFUELS USA	FT	11 mio l / yr*	Wood residuals	Southwest Airlines
ALTAIR USA	HEFA	113 mio l/yr	Camelina, agricultural residues	United Airlines
UOP HONEYWELL USA	HEFA	-	Natural oils (Camelina)	GOL, LAN
SINOPEC CHINA	HEFA	-	Waste oils	Hainan
SOLAZYME USA	HEFA	-	Microalgae	United Airlines

'*' denotes that the capacity is planned rather than existing. '–' denotes that the production capacity (of jet fuel) is unknown.

CRITERIA FOR SUSTAINABLE JET FUEL

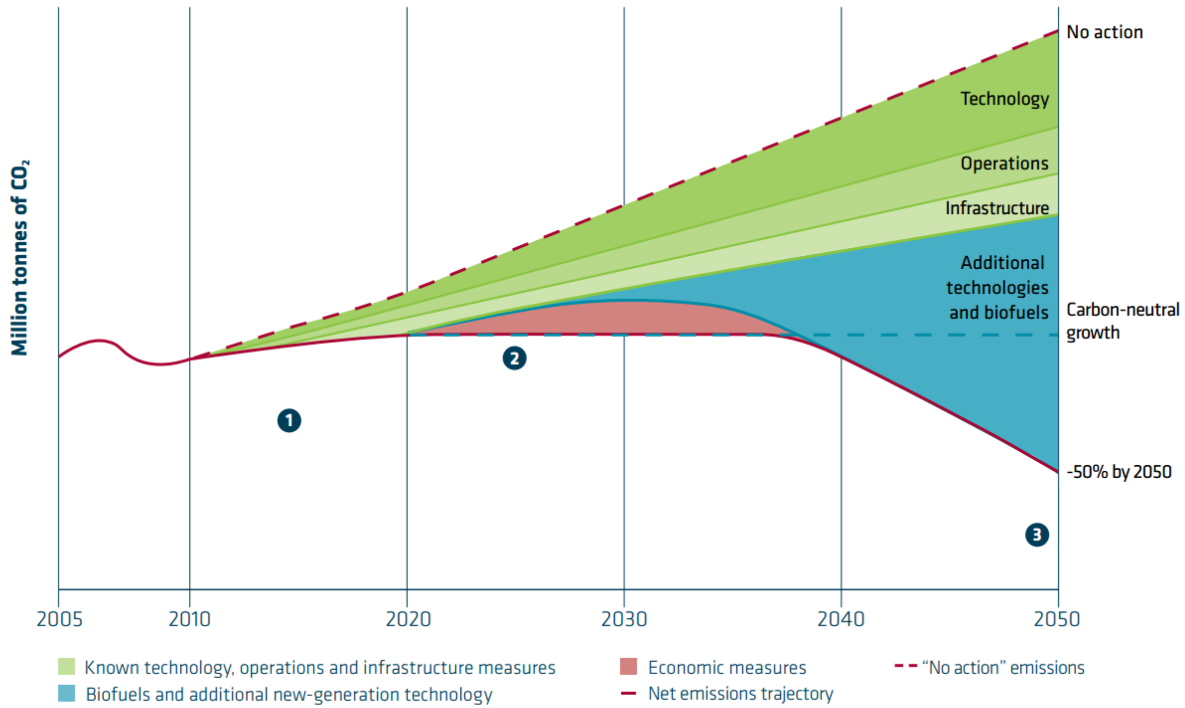
- No common definition in the Nordics
- Several internationally agreed upon criteria of what defines *sustainability*, in sustainable jet fuel.
- Common criteria aim on accountable GHG-emissions reductions, biodiversity and land usage
- EU/RED: sustainability jet fuel must fulfill a number of land-use criteria and has at least 35% less direct GHG emissions over the full life cycle as compared to the fossil fuel. Indirect land-use changes not included.
- ICAO: similar definition, as it is planning to launch a global, market-based mechanism to promote reductions in GHG emissions from civil aviation.
- Private business engagement: IATA, SAFUG and NISA
- In the debate the question is not as much whether the fuel is sustainable, but whether it also is *advanced.*
- Dividing feedstock into generations is largely historical, based on the progression of technology.

MAPPING OUT THE INDUSTRY COMMITMENTS

Air Transport Action Group (ATAG) targets:

- Fuel efficiency improvements averaging on 1.5% per annum from 2009-2020
- A cap on net CO_2 emissions from aviation from 2020, i.e. carbon-neutral growth
- A reduction in net CO_2 emissions from aviation of 50% in 2050, compared to 2005
- Four-pillar approach:
  - Technologic improvements (including biofuels)
  - more efficient aircraft operations
  - Improve infrastructure
  - market-based measure to close remaining emission gaps

MAPPING OUT THE INDUSTRY COMMITMENTS



Source: ATAG, 2013

NORDIC POLICY FRAMEWORK

- Nordic policy framework for sustainable jet fuels is fragmented.
- Ambitious environmental policies
- Leading position in the fight against climate change
- Finland and Norway have introduced national initiatives aimed at the promotion of sustainable jet fuel, and Norwegian domestic aviation is also subject to CO_2 taxation
- Sweden is working on a national aviation strategy

EU POLICY FRAMEWORK

- Renewable Energy Directive (RED) emission reduction targets includes aviation.
- 2020 goal: 10% of the total energy used in transportation (in comparison to 2005)
- Excludes aviation emissions exceeding 6.18 % of total national emissions
- EU ETS: Emissions from aviation included from 2012. Sector cap 5% below 2004-06 level, annually 2013-2020
- 82% of emissions are allocated as “free allowances” to the aviation sector and the remaining 18% have to be offset with carbon certificates.
- Probably linked to the ICAO induced Global Market Based Measures this year.

POLICY FRAMEWORKS *CONTINUED*

- Nordics have all implemented mandatory ratios of biofuels in road based transport
- Comprehensive support schemes for renewable energy production
- *May* incentivize the use of biomass in road transport and energy production over the production of sustainable jet fuel.
- Norway includes sustainable jet fuel in the support schemes

BACKGROUND – NATIONAL REPORTS




- In 2013-2014, the Nordic countries individually conducted analyses into the potential for sustainable aviation fuels
- The reports highlight FT, AtJ and HEFA as the most appropriate production pathways, given the feedstock available in the region

  The region hosts an abundance of forests and fields, which can supply biomass in the form of wood and straw
- The reports also highlight the need for incentives to invest in sustainable aviation fuels development and deployment, as well as the need for political attention

DENMARK

- 2020 goal: RES is 30% of gross final consumption of energy, 10 % share of RES in energy for transportation
- 2050 goal: follows EU, but transport sector independent of fossil fuels
- No national initiatives targeting the advancement of sustainable jet fuel.
- A range of private and public Danish entities are members of transnational initiatives, such as NISA.
- Spends DKK 1 bn on research, development and demonstration-projects within the energy sector
- Assigns a significant proportion of biofuel energy inputs to the aviation sector in its future plans for the Danish energy system.
- Danish Resource Strategy: Explicitly mentions the use of organic waste to increase bioenergy production.

FINLAND

- 2020 goal: 38 % of gross final consumption of energy, 10 % share of RES in energy for transportation. Has unilaterally increased the target share of RES in transportation to 20 % by 2020
- Establish distribution infrastructure for alternative power sources in aviation by 2020
- Innovations in fuel technology plays an important part of lessening the outflow of capital to oil producing countries and boosting export of Finnish clean tech
- Finland is ”*extremely well-positioned to be among the first in the world to start extensive, continuous use of biofuels in aviation*” (MTC, 2014)
- Issue of covering incremental costs of biojet production - 3 year model: Public subsidies cover 45% of incremental costs for “frontrunner companies”

SWEDEN

- 2020 goal reached. 50% renewable energy, 10% in road transport by 2020 (aviation exempted)
- 2030 goal: A vehicle fleet independent of fossil fuels. 2050: No net emissions
- Working on a national strategy towards sustainable aviation

- 2005: adopted act on the obligation to supply renewable fuels.
- Related tools: carbon and energy taxes, electricity certificate system, the "pump act", car taxation measures and subsidies promoting sustainable fuels and vehicles using renewable fuels or electricity

- Large number of potential actors, but only a few are actually involved

NORWAY

- 2020 target: 67.5 % share of RES of gross final consumption of energy. 10 % share of RES in energy for transportation.

- Identifies FT and AtJ as suitable pathways for a Norwegian production of sustainable aviation fuels
- Study projects that the FT pathway could be price competitive (on a commercial scale) by 2021, however dependent on commercializing the byproducts of sustainable aviation fuels production
- Conversion rate is one of the main drivers for profitability in the processes

- Projections imply that AtJ will not be costs competitive vs. fossil jet fuels until after 2030

ICELAND

- 2020 goal: share of 73% of gross final consumption of energy, 10 % share of RES in energy for transportation

- No national initiatives with regards to sustainable jet fuel in Iceland
- Lack of feedstock production
- Access to low-cost energy
- Potential for hydrogen-production

- Icelandic National Renewable Energy Action Plan aims to enable Iceland to lead the way in coming years in experiments and production of sustainable energy sources, in part by supporting research and development and building up infrastructure

MARKET DEMAND

NORDIC DEMAND FOR JET FUEL

- Only one facility exists capable of producing sustainable jet fuel.
- Dedicated refineries for biofuels and intermediates exist. Most producers of either bioethanol and renewable diesel, but also other fuels such as DME or gaseous fuels.

- 11 Nordic petroleum refineries -> Likely to experience an increasing factor overcapacity
- Rest is covered through maritime imports from overseas producers.

NORDIC DEMAND FOR JET FUEL

- Nordic countries aggregate consumption: from roughly 4 million m^3 in 2010 to 4.5 million m^3 in 2014
- Gradual increase up until 2025, where the Nordic demand for jet fuel peaks at roughly 5.7 million m^3.
- After 2025, the demand stagnates reaching a steady state of an aggregate annual demand of 5.4 million m^3 in 2030 and onwards.

MILLION L	**2014**	**2020**	**2025**	**2035**	**2050**
DENMARK	1,196	1,414	1,487	1,414	1,414
SWEDEN	1,014	1,199	1,260	1,199	1,199
NORWAY	1,184	1,400	1,471	1,399	1,399
FINLAND	906	1,072	1,126	1,071	1,071
ICELAND	243	287	302	287	287
TOTAL	**4,543**	**5,372**	**5,646**	**5,369**	**5,369**

PROJECTION OF NORDIC DEMAND FOR JET FUEL UP UNTIL 2050

NORDIC DEMAND FOR JET FUEL

- Market for sustainable jet fuels has yet to emerge, both in the Nordic region and globally.
- Sustainable jet fuel currently exhibits costs ranging from 0.8-2.2 EUR/l, compared to a fossil reference of 0.25 EUR/l.

Reasons for price gap:

- High production costs of sustainable jet fuel
- Historically low contemporary oil prices

FEEDSTOCK PRICES

- Estimates shows that feedstock prices make up 50-90% of sustainable aviation fuel production costs -> 70% on average
- Straw and wood are particularly expensive feedstock
- High cost of hydrogen. Hydrogen is used in certain pathways (e.g. FT and HEFA) to deoxidize bio oils (upgrade to jet fuel quality). (The higher the oxygen content, the more hydrogen is required)

- Makes production of sustainable jet fuels vulnerable to fluctuations in market prices -> Need to secure market conditions for investors

NORDIC DEMAND FOR JET FUEL

- Because of the price gap, demand will be led by the global aviation industry's GHG emission targets and the industry's four pillar strategy for meeting set targets
- Initial Nordic annual demand for sustainable jet fuel could reach 65 million l in 2020, reaching 2 billion l in 2050, corresponding to 37.5 % of total demand.

A 3% blend-in of sustainable jet fuel corresponds to a 2% reduction in GHG emissions. Thus, in order to reach a GHG emission reduction of 25% through the use of biofuels, a blend-in ratio of 37.5% is required by 2050.

FUTURE DEMAND FOR SUSTAINABLE JET FUELS IN THE NORDIC COUNTRIES

MILLION L	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
DENMARK	17	108	188	274	359	445	530
SWEDEN	15	91	160	232	305	377	450
NORWAY	17	107	186	271	355	440	525
FINLAND	13	82	143	207	272	337	402
ICELAND	3	22	38	56	73	90	108
TOTAL	**65**	**410**	**714**	**1,039**	**1,364**	**1,689**	**2,014**

Source: Own estimates, based on extracts from Eurostat.

FEEDSTOCK DEMAND

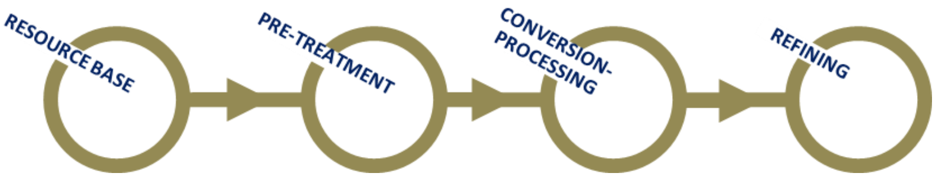
- Sustainable jet fuel demand will lead to a demand on 19-93 tons of feedstock, depending on production efficiency

	2020	2025	2030	2035	2040	2045	2050
FEEDSTOCK DEMAND [PJ]							
Low efficiency: 5 %	45	285	497	723	949	1,175	1,401
Medium efficiency: 15 %	15	95	166	241	316	392	467
High efficiency: 25 %	9	57	99	145	190	235	280
FEEDSTOCK DEMAND ['000 TONS]							
Low efficiency: 5 %	3,015	19,015	33,152	48,220	63,289	78,358	93,427
Medium efficiency: 15 %	1,005	6,338	11,051	16,073	21,096	26,119	31,142
High efficiency: 25 %	603	3,803	6,630	9,644	12,658	15,672	18,685

Feedstock demand for sustainable jet fuel from 2020-2050

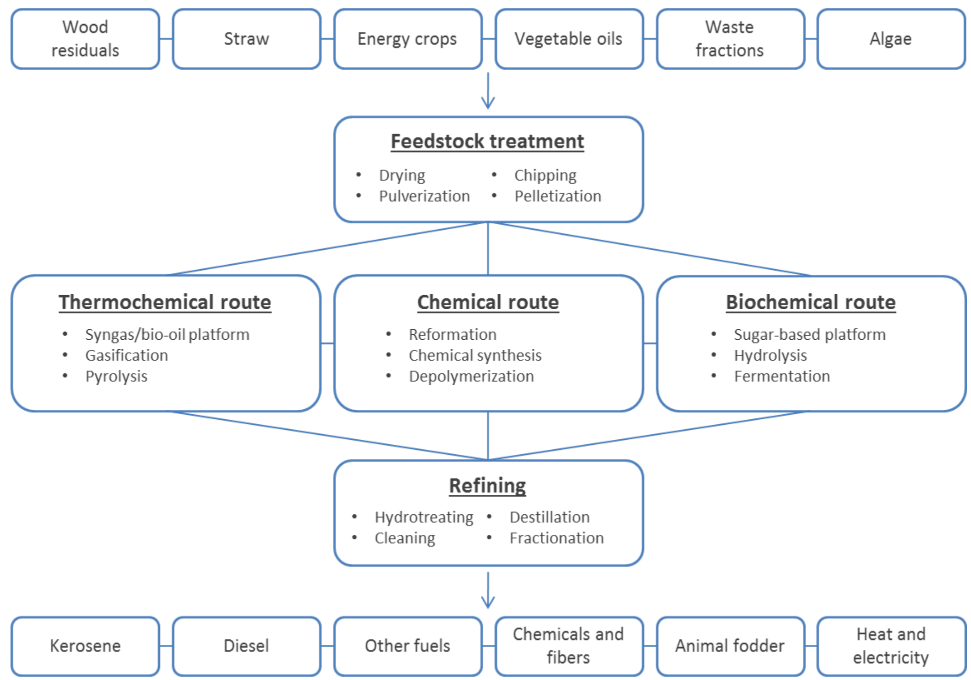
PRODUCTION PATHWAYS

BIOFUEL PRODUCTION STEPS



The four basic steps in a feedstock to fuel pathway.

Different routes to produce biofuels and other products



RECOGNIZED PATHWAYS

ASTM certification of sustainable jet fuel pathways

PATHWAY	Certification status	Feedstock
FISCHER-TROPSCH (FT)	✓ 50 % blend	Any biomass or carbon source
HYDROPROCESSED ESTERS AND FATTY ACIDS (HEFA)	✓ 50 % blend	Vegetable oils, animal oils, and any other bio-oils containing tri-glycerides
SYNTHETIC PARAFINIC KEROSENE (SIP)	✓ 10 % blend	Any sugar containing feedstock
ALCOHOL TO JET (ATJ) (based on isobutanol)	✓ 30 % blend	Any sugar containing feedstock
FT SYNTHETIC KEROSENE WITH AROMATICS (FT-SKA)	under review (100 % blend)	Any biomass
HYDROPROCESSED DEPOLYMERIZED CELLULOSIC JET (HDCJ)	under review	lignocellulosic
HEFA+ (OR HEFA+)	testing (as annex to HEFA, around 10 % blend)	Same as HEFA
ATJ SYNTHETIC KEROSENE WITH AROMATICS (ATJ-SKA)	testing (100 % blend)	Same as AtJ
CATALYTIC HYDROTHERMOLYSIS (CH)	testing	Vegetable oils, animal oils, and any other bio-oils containing tri-glycerides
HYDROTHERMAL LIQUEFACTION (HTL)	-	Any biomass
PYROLYSIS TO JET (PTJ)	-	Any biomass
POWER TO LIQUID (PTL)	-	Concentrated CO_2
MICROBIAL CONVERSION OF CO_2	-	Concentrated CO_2

FEEDSTOCK PRODUCTION

- The most ideal candidates in the foreseeable future, with respect to availability and price, are **wood residuals**, **wheat straw** and **organic waste fractions**.
- Heavy competition from alternate uses in production of heat and power and biofuels for road transport.
- Other sources of feedstock are also possible, but not currently available in any significant amount in the region. (energy crops and marine resources, such as seaweed and algae. May later become available, given developments)
- Many of the feedstock candidates can potentially be imported from countries outside the Nordics, though the same issues of competing markets are expected to limit availability.

WOOD RESIDUALS

- Wood residuals from logging-, pulp, paper and timber industries are used in vast amounts in Finland, Norway and Sweden. Estimates of the total potential range well over 250 PJ annually.
- The price for wood residuals range between 5-8 EUR/GJ and is highly dependent on the specific source and region of origin.

WHEAT STRAW PRODUCTION

- Wheat straw is left to compost at fields in large amounts in Denmark and Sweden amounting to a potential of 37 PJ annually.
- The price for wheat straw ranges between 5-6 EUR/GJ.

ORGANIC WASTE PRODUCTION

- All organic waste fractions can in theory be used in sustainable jet fuel production, in particular vegetable and animal waste oils are highly suited.
- Total potential is complex to estimate.
- Prices are highly variable, with negative estimates for fractions with a gate-fee and up to 5 EUR/GJ.
- There exist no available data on the cost
- Import of waste fractions from outside the Nordic countries may even show to be a cost effective solution (including transportation costs) and is therefore also considered as an option.

FEEDSTOCK AVAILABILITY

	Denmark	Finland	Norway	Sweden
ENERGY CROPS	Low potential (short term) Limited cultivation of willow and poplar, corresponding to less than 1 PJ/yr	Not available in significant amounts	Not available in significant amounts	Low potential (short term) Cultivation of around 11,000 ha of willow, corresponding to 1.5 PJ/yr
STRAW	Promising potential Up to 1.5 million tons, corresponding to 22 PJ may be available Competition with heat and power production.	Not available in significant amounts	Not available in significant amounts	Some potential Around 1 million tons (15 PJ) may be available, though in competition with other uses.
WOOD RESIDUALS	Not available in significant amounts	Promising potential 8 million m^3 of logging residues was used in 2014 for energy production. A part of this fraction could be diverted towards biofuel production, along with other logging residues which are not currently harvested from forests.	Promising potential Around 69 PJ of logging residues is technically available. Large amounts of secondary wood residuals could be diverted towards biofuel production	Promising potential Between 54-130 PJ of logging residues are technically available. Over 86.4 PJ of secondary wood residuals was used in energy production, some of which could be diverted towards biofuel production.
TALL OIL AND BLACK LIQOUR	Not available in significant amounts	Some potential Most tall oil is used for chemicals and renewable diesel production, but use may be diverted to jet fuel production. Most black liquor is used for heat and energy production but use may be diverted to jet fuel production	Not available in significant amounts	Some potential Most tall oil is used for chemicals and renewable diesel production, but use may be diverted to jet fuel production. Most black liquor is used for heat and energy production but use may be diverted to jet fuel production
WASTE FRACTIONS **WASTE**	Low potential (short term) Total production of 11 million tons in of waste in 2014, with 93 % either incinerated or recycled. Improved sorting technology may free up a part of the organic fraction for jet fuel production.	Some potential Total production of around 9.5 million tons waste in 2013. No large-scale incineration of waste. Some organic fractions are already utilized for biofuel production Long transportation distances limits the total potential	Low potential Large use of waste in inceration, including import from Norway Long transportation distances limits the potential	Low potential Total production of 11.2 million tons in 2013. Large export of MSW to Sweden. Long transportation distances limits the total potential
MARINE FEEDSTOCK	Not available in significant amounts	Not available in significant amounts	Low potential (short term) Some sea-weed harvest today, though not for biofuel production. Large scale cultivation increases the potential in the longer term	Not available in the short term

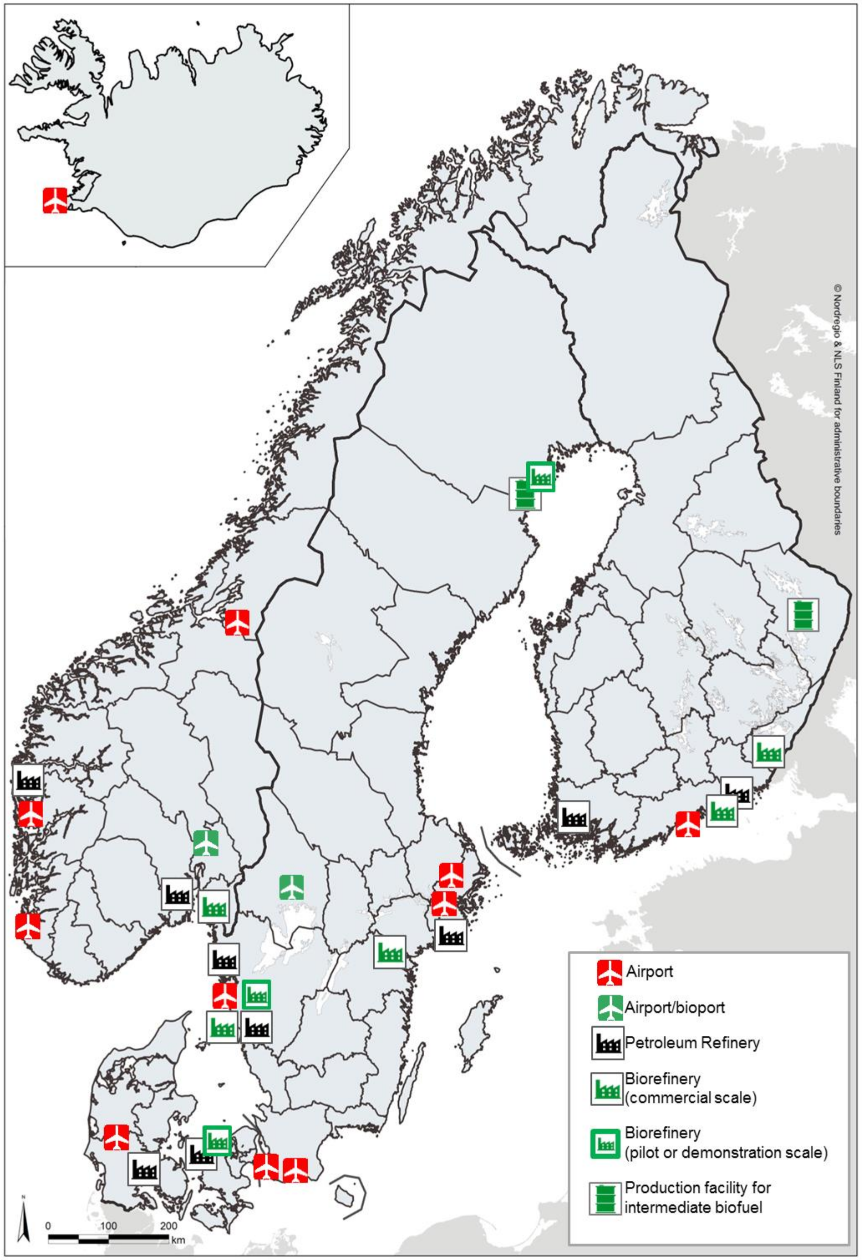
TECHNOLOGY AVAILABILITY

- Nordic countries have strong competencies in biorefining technology.
- Within a biochemical conversion route, this includes suppliers for pre-treatment of lignocellulosic biomass by enzymatic hydrolysis, as well as yeast cultures for fermentation, and within a thermochemical route it includes gasification of biomass and reforming of syngas.
- A range of suppliers also provide technologies for producing intermediates, currently used in Nordic production of other biofuels such as renewable diesel, which can potentially also be used for sustainable jet fuel production.
- Refining technologies, relevant for all biofuels are also part of the Nordic technology portfolio.

TECHNOLOGY AVAILABILITY

- A handful of firms are currently in active pursuit of a sustainable jet fuel production.
- With the exception of Neste, who has the capacity and technology to produce sustainable jet fuel, all of these actors are at a lower technological maturity and require significant development before they can be considered part of a possible commercial scale production.

NORDIC ENERGY INFRASTRUCTURE



	Capacity million t. crude oil/yr	Production of jet fuel	Other remarks
DENMARK			
KALUNDBORG REFINERY STATOIL	5.5	None (has previously produced jet fuel)	
FREDERICIA REFINERY SHELL	3.4	None (has previously produced jet fuel)	In 2014 Shell announced plans to sell the refinery, but as of mid-2016 no buyer has been found
FINLAND			
PORVOO REFINERY (NESTE)	12	Yes	The refinery also has the capacity to produce sustainable jet fuel from waste vegetable and animal oils
NAANTALI REFINERY (NESTE)	3	Yes	
NORWAY			
MONGSTAD REFINERY, STATOIL	12	Yes	
SLAGENTANGEN REFINERY, STATOIL	6	None	
SWEDEN			
LYSEKIL REFINERY (PREEM)	11.4	Yes	
GOTHENBURG REFINERY, PREEM	6	Yes	A hydrotreatment unit of the refinery has been retrofitted to co-process tall oil into diesel with renewable content
GOTHENBURG REFINERY, ST1	4	None	An ethanol plant running on organic waste has been integrated within the refinery complex
NYNÄSHAMN REFINERY, NYNAS	2	None	

Nordic petroleum refineries

SUPPLY-CHAIN STAGE

	Existing infrastructure	Challenges
UPSTREAM		
FEEDSTOCK	Nordic forestry/pulp and paper industry (wood-biomass) Various industries for sources of waste fractions (oils and animal fats, organic waste) Danish/Swedish farmers (straw)	Complex coordination with many feedstock suppliers New facilities for pre-treatment of feedstock competing uses for many feedstock
TRANSPORTATION	Trucks for short distances Trains for longer distances	Complex logistics for transportation Long transportation distances
MIDSTREAM		
CONVERSION	Neste's biorefinery in Finland can produce sustainable jet fuel Renewable diesel production can serve as inspiration for integration with forestry industry Bioethanol production can be diverted towards further processing into jet fuel	New facilities and production capacity required Location of facilities, close to feedstock source and in connection with industry infrastructure Economic incentives for biofuel producers before sustainable jet fuel is considered an attractive option
REFINING	Petroleum refineries can be retrofitted/revamped to refine renewable feed into jet fuel	New refining capacity likely required
DOWNSTREAM		
DISTRIBUTION	Jet fuel producing petroleum refineries may have existing distribution infrastructure to airports	
STORAGE	Off-field and on-field storage facilities at the largest airports	Blending ratios of sustainable jet fuel with fossil jet can be restricted depending on composition of existing fossil based supply and the type of sustainable jet fuel New storage tanks may have to be constructed (at airports or off-field) Airport fueling system may have to be expanded

TECHNOLOGY AND FEEDSTOCK MATURITY OF NORDIC PRODUCERS

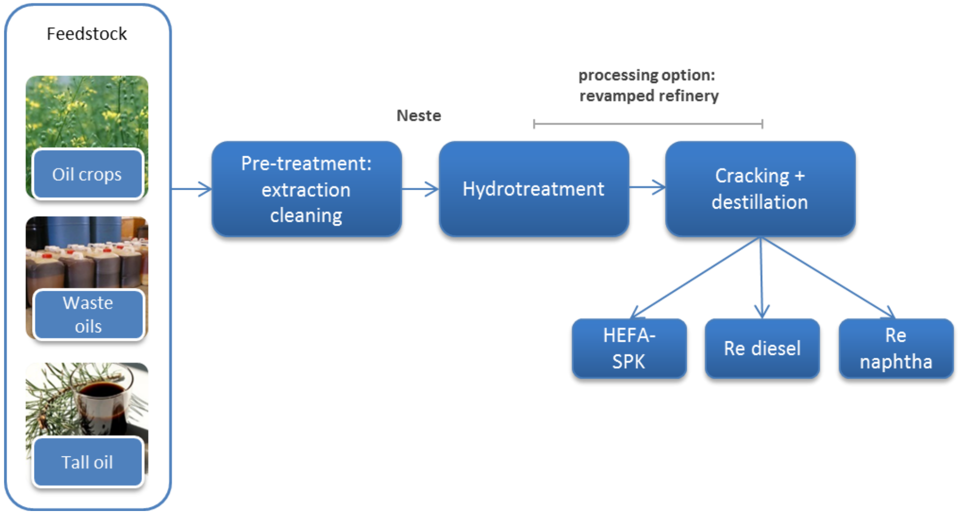
PRODUCERS OF BIOFUELS	Technology and role in pathway	Relevant in pathways	Fuel and feedstock readiness level
FINLAND			
NESTE OIL (DIESEL)	Production of renewable diesel from vegetable oils, can potentially produce HEFA+ for aviation if certified	HEFA/HEFA+	FRL: 9 FSRL: 9
UPM	Production of renewable diesel from tall oil. Know-how on biorefining and integration with forest industry and use of tall oil as a feedstock	HEFA/HEFA+	FRL: 9 FSRL: 9
ST1	Production of bioethanol from wastes and residues to the transportation sector. Potential for further processing into jet fuel.	AtJ, SIP	FRL: 6 FSRL: 4
DENMARK			
EMMELEV	Production of biodiesel from rapeseed oil. Know-how on large scale hydrotreating and refining of vegetable oil	HEFA/HEFA+	FRL: 9 FSRL: 9
DAKA	Production of biodiesel from animal fats and wastes. Know-how on large scale hydrotreating and refining of animal fats and wastes	HEFA/HEFA+	FRL: 9 FSRL: 9
SWEDEN			
LANTMÄNNEN AGROETANOL	Production of bioethanol from grain and wastes. Potential further processing into jet fuel and know how on large scale production of bioethanol	AtJ, SIP	FRL: 9 FSRL: 9
PREEM BIOREFINERY, GOTHENBURG	Produces diesel with renewable content from tall oil. Know how on retrofitting concepts and utilization of existing fossil refining capacity for biofuel production	Multiple pathways, relying on fossil retrofitting concepts for refining	FRL: 9 FSRL: 9
CHEMREC	Gasification of black liquor to produce syngas and further processing into DME and biomethanol. Know-how and technology for black liqour gasification	FT	FRL: - FSRL: -
SEKAB BIOREFINERY	Know-how, technology and production of bioethanol from wastes and residues. Potential for further processing into jet fuel.	AtJ, SIP	FRL: - FSRL: -
NORWAY			
BORREGAARD	Production of bioethanol from wood residues. Potential further processing	AtJ, SIP	FRL: 9

PRODUCERS OF INTERMEDIATES AND OTHER SUPPLIERS OF TECHNOLOGY COMPONENTS BIOFUEL PRODUCTION

	Technology and potential role in pathway	Relevant in pathways
DENMARK		
NOVOZYMES	Enzymes for hydrolysis of lignocellulosic biomass	AtJ, SIP
ESTIBIO	Microorganisms for catalysing anaerobic fermentation of sugars to ethanol	AtJ, SIP
BIOGASOL	Pretreatment technology for enzymatic hydrolysis of lignocellulosic biomass	AtJ, SIP
TERRANOL	Yeast cultures for ethanol fermentation	AtJ, SIP
INBICON/MEC	Biorefinery for production of bioethanol from straw	AtJ, SIP
HALDOR TOPSØE	Catalysts and refining technology, including hydrotreatment, cracking and reforming/conditioning of syngas	potentially all pathways
STEEPER ENERGY	Production of bio-oil by hydrothermal liquefaction for further processing	HtL
GREEN HYDROGEN	Technology for hydrogenproduction by electrolysis	potentially all pathways
TK ENERGY	Technology for feeder systems in gasification	FT
FINLAND		
FORTUM	Production of pyrolysis oil from wood residuals for further processing and refining	PtJ and other new pathways
FORCHEM	Processesing and refinering of tall oil to further products	HEFA
METGEN	Enzymes for biofuels and biochemicals production from lignocellulosic feedstock.	AtJ
GREEN FUEL NORDIC	Production of pyrolysis oil from wood residuals for further processing and refining	PtJ and other new pathways
ANDRITZ	Gasification technology and pre-treatment technology for wood biomass	FT
VALMET	Gasification technology, various technology components for bioethanol production, pre-treatment technology for wood biomass, pyrolysis technology for bio-oil production	FT, AtJ, SIP, PtJ and other new pathways
FOSTER WHEELER	Technology component for various refining steps, including hydrotreatment and hydrocracking	potentially all pathways
NESTEJACOBS	Various technology components for both thermochemical and biochemical biorefinery concepts	potentially all pathways
SWEDEN		
GOBIGAS	Technology and know-how for gasification of forest residuals	FT
SUNPINE	Production of tall oil diesel from tall oil for further processing and refining into biofuels	HEFA
RENFUEL 2KB AB	Production of catalytic lignin oil for further processing and refining into biofuels	PtJ and other new pathways

MOST PROMISING PATHWAY SCENARIOS

SCENARIO 1: HEFA/HEFA+

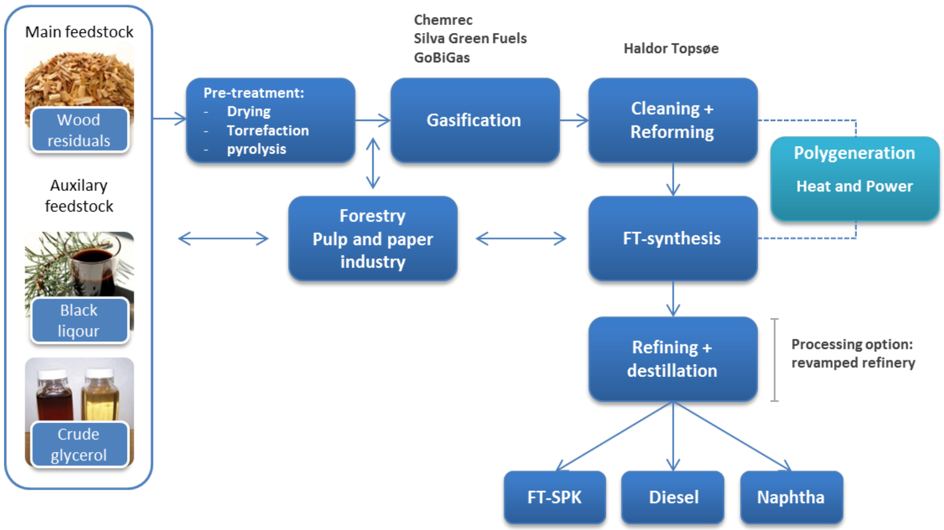


SUPPLIERS/ACTORS	Possible roles
NESTE (FI)	Producer of sustainable jet fuel, know-how and technology for hydroprocessing of bio-oils and refining capacity and infrastructure
UPM BIOFUELS (FL)	Technology and refining capacity of crude tall oil into an intermediary product suited for jet fuel production + integration of forestry and biorefining
SUNPINE (SWE)	Technology and refining capacity of crude tall oil into an intermediary product suited for jet fuel production
RENFUEL 2KB AB (SWE)	Technology and production for lignin oil for further processing into biofuels
PREEM REFINERY GOTHENBURG (SWE)	Know-how on retrofitting of hydrotreatment units to handle renewable feed
HALDOR TOPSØE (DK)	Catalysts and technology for hydroprocessing of bio-oils
GREEN HYDROGEN (DK)	Hydrogen production for refining steps
NORDIC PETROLEUM REFINERIES (SWE, DK, NO, FI)	Production integration, refining in retrofitted units and infrastructure for storage and distribution to airports

HEFA COMPARATIVE ADVANTAGES

- The HEFA-based scenario is superior to the two other scenarios when it comes to maturity and cost efficiency. Also, it has the lowest production complexity and is therefore most attractive as an initial technology.
- This scenario is thus likely to be initiated first, from around 2020 (provided that the demand is increased), while the FT and the AtJ scenario are expected to be initiated towards 2025-2030.
- The downside of HEFA is the limited availability of waste oils as a feedstock in the Nordic countries and generally poorer conditions for cultivating oil crops like jatropha or camelina compared to warmer countries.

SCENARIO 2: FT FOREST INDUSTRY INTEGRATION

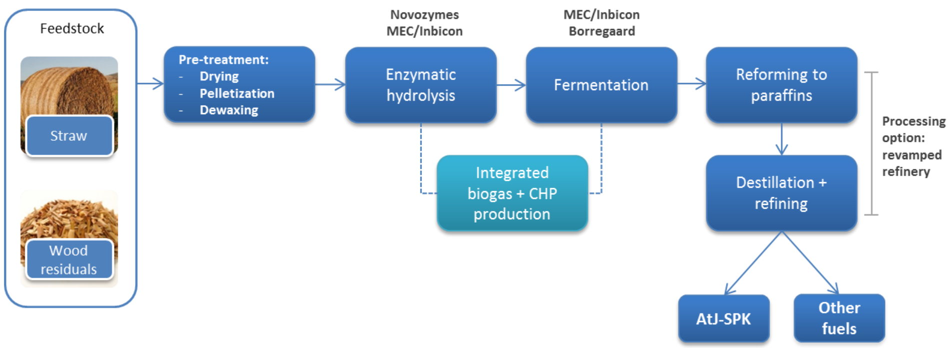


SUPPLIERS/ ACTORS	Possible role
ANDRITZ CARBONA (FL)	Technology for gasification and pre-treatment of wood biomass
VALMET (FL)	Technology for gasification and pre-treatment of wood biomass
GOBIGAS (SWE)	Know-how on gasification of wood residuals to produce synthesis gas (currently only aimed at generating gas-fuel for road transport)
CHEMREC/LTU GREEN FUELS (SWE)	Technology and know-how on gasification of black liquor
SILVA GREEN FUELS/STATKRAFT AND SÖDRE (NO)	Know-how and technology on gasification and possibly opportunities for biorefining of high-value products from wood residuals
T/K ENERGY (DK)	Technology for gasification, in particular energy efficient feeder systems
HALDOR TOPSØE (DK)	Catalysts and technology for refining processes and cleaning/reforming of syngas
NORDIC PETROLEUM REFINERIES (SWE, DK, NO, FI)	Refining in retrofitted units + infrastructure for storage and distribution to airports
GREEN HYDROGEN (DK)	Hydrogen production for refining steps

FT COMPARATIVE ADVANTAGES

- The FT scenario has an international comparative advantage, as it utilizes the forest biomass in Finland, Norway and Sweden, which represents the largest forest resource in Europe, with an existing, well-established industry and infrastructure for collection and utilization of the feedstock.
- Most Nordic forests are also in a state of net growth, and this extraction can be increased if economically and sustainably viable.
- In terms of life cycle GHG reductions, the FT-scenario is most likely to achieve the highest performance out of the three scenarios.

SCENARIO 3: LIGNOCELLULOSIC ATJ



SUPPLIERS/ACTORS	Possible roles
LANTMANNEN AGROETANOL (SWE)	Know-how on large scale ethanol production and CO2 capture, knowledge on logistics of agricultural feedstock sourcing
SEKAB (SWE)	Know-how and technology for bioethanol production and biorefining opportunities
ST1 (FI)	know-how on integration of ethanol production and dehydration with petroleum refinery infrastructure
METGEN (FI)	Enzymes for hydrolysis of lignocellulosic feedstock
BORREGAARD (NO)	Know how on biorefining and co-production of high-value products
NOVOZYMES (DK)	Enzymes for hydrolysis of lignocellulosic feedstock
INBICON/MEC (DK):	existing ethanol from straw demo plant and planned full scale production facility
BIOGASOL (DK)	Straw pre-treatment and enzymatic hydrolysis technology
ESTIBIO (DK)	Microbial catalysts for ethanol fermentation
TERRANOL (DK)	Yeast cultures for ethanol fermentation
HALDOR TOPSOE (DK)	Catalysts and technology for refining processes of ethanol to jet
GREEN HYDROGEN (DK)	Hydrogen production for refining steps
NORDIC PETROLEUM REFINERIES (SWE, DK, NO, FI)	*Production integration, refining in retrofitted units and infrastructure for storage and distribution to airports*

COMPARATIVE ADVANTAGES

- The AtJ scenario is in comparison the most immature technology, as well as the most expensive production process.

COUNTRY PRODUCTION FOOTPRINTS

- The downstream of the HEFA-based scenario likely be physically located in Finland, due to the already existing infrastructure. Long term expansion could in principle be located in any of the Nordic countries.
- The FT based scenario is likely to be produced in Norway, Sweden or Finland, close to available forest biomass and forestry/pulp and paper production infrastructure.
- The AtJ scenario will especially benefit Denmark or Sweden, due to the utilization of straw.
- Iceland has large access to low cost energy, which could be utilized for hydrogen production, though any other production processes are unlikely to be located physically in Iceland.
- The final processing steps of refining for all scenarios can, theoretically, also be located in any of the Nordic countries

NORDIC COMPARATIVE ADVANTAGES

- Commercial scale production facilities already exist.
- Availability of an increasing over-capacity in refining caused by placing the refining steps of biofuel production in retrofitted units or integrated close by.
- Knowledge and feedstock capacity to let the three most promising scenarios exist in parallel.
- The biorefinery concept is already well-established in Nordic energy production and is closely linked to an increasing awareness of circular economy and the utilization of by-products.

NORDIC AVAILABLE COMPETENCIES

- Advanced utilization of forest biomass, such as gasification and extraction of higher value products in biorefining
- Production synergies and increasing the production differentiability between biofuels and biochemicals
- Fermentation and enzymatic hydrolysis technologies, with similarly strong technological competencies and know-how. Impact on climate mitigation and socio-economy
- Catalytic technology for refining of fuels and reforming/conditioning of syngas
- The HEFA-based scenario can potentially achieve equally high GHG reductions if based only on waste oils.

COMPARISON OF THE THREE SCENARIOS

	Scenario 1: HEFA/HEFA+ (waste oils and oil crops)	Scenario 2: FT (wood residuals)	Scenario 3: AtJ (straw and wood residuals)
ASTM CERTIFIED	Yes, 50 % blend in (HEFA+ expected in 2016/2017)	Yes, 50 % blend in	No, expected in 2016
ESTIMATED PRICE RANGE OF JET FUEL PRODUCED	0.8-1.5 EUR/l (HEFA+ price expected in the lower range)	1.5 – 2.2 EUR/l (lower range if sale of byproducts is included)	1.7-2 EUR/l (lower range if sale of byproducts)
FEEDSTOCK AVAILABILITY	Uncertain availability of waste oils and oil crops. Depends largely on import and availability in other countries Competition with diesel production for road transport	Promising availability of wood residuals in general in Norway, Sweden and Finland. Prices and availability are likely to be highly variable on a regional basis Competition with CHP production	Promising availability of straw in Denmark and wood residuals in Sweden, Norway and Finland. Competition with heat and power production
INFRASTRUCTURE	Existing infrastructure capable of producing sustainable jet fuel New production capacity required after demand increases beyond existing capacity. Can potentially utilize existing petroleum refinery infrastructure	Some biomass gasification plants exist, though not for syngas production for biofuels at large scale Requires new production facilities from start. Can potentially utilize existing petroleum refinery infrastructure	Some bioethanol production plants exist, though mostly for road transport fuel. Requires new production facilities from start Can potentially utilize existing petroleum refinery infrastructure
CO_2 REDUCTION COMPARED TO FOSSIL ALTERNATIVE	63-90 % (High savings if using waste-oils, lower if using cultivated oil crops)	80-90 %	45-66 %

IMPACT ON CLIMATE CHANGE

IMPACT ON CLIMATE CHANGE

Framework:

- Aviation is globally responsible for about 11% of all transport associated CO_2 equivalent emissions
- Equivalent to 2% of all anthropogenic CO_2 equivalent emissions
- Aviation growth will cause emissions to almost triple by 2050 with over 2.6 Gt/yr in a baseline scenario (ICAO, 2013)
- The aviation industry has set forth voluntary emission-targets

IMPACT ON CLIMATE CHANGE

How to measure the climate impact of aviation fuel?

- LCA of sustainable jet fuel production identify GHG emission sources from the entire supply chain
- However - studies ends up with different results due to different system boundaries and sensitivity of assumptions
- Currently no consensus on how to quantifying those effects
- ILUC - not considered in most studies
- LCA may include substitution effects (if a byproduct of the process is considered to displace another product)

IMPACT ON CLIMATE CHANGE

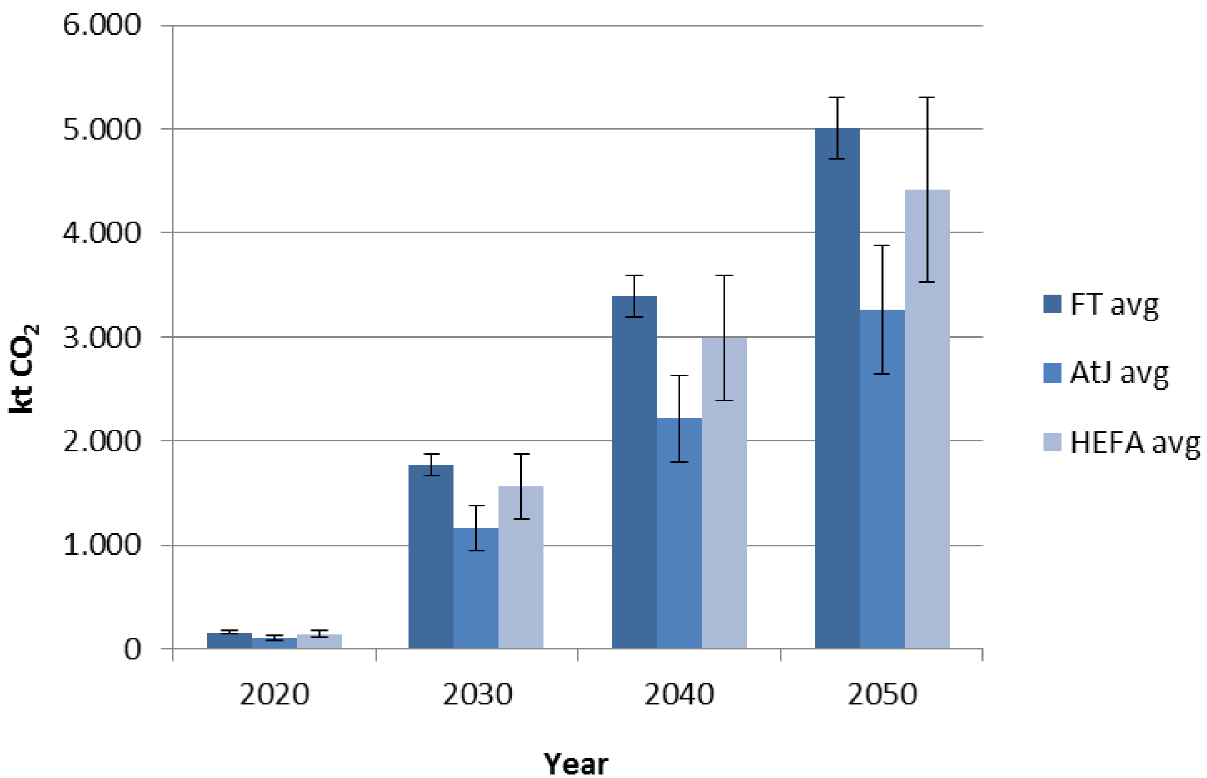
GHG-intensity in comparison to fossil jet A-1

- HEFA-SPK (scenario 1): 63 – 86 % reduction, with the highest estimate attributed to a high yield of camelina per hectare.
- FT-SPK (scenario 2): With forest residuals. 80 % CO_2 (Avinor 2013) - no LUC or ILUC included. Based on energy crops: Willow or switchgrass estimates are comparable in the range of 80-90 % reduction (SWAFEA 2011, Partner 2010)
- AtJ pathway (scenario 3): 66 % GHG-reduction

CLIMATE CHANGE MITIGATION IMPACT

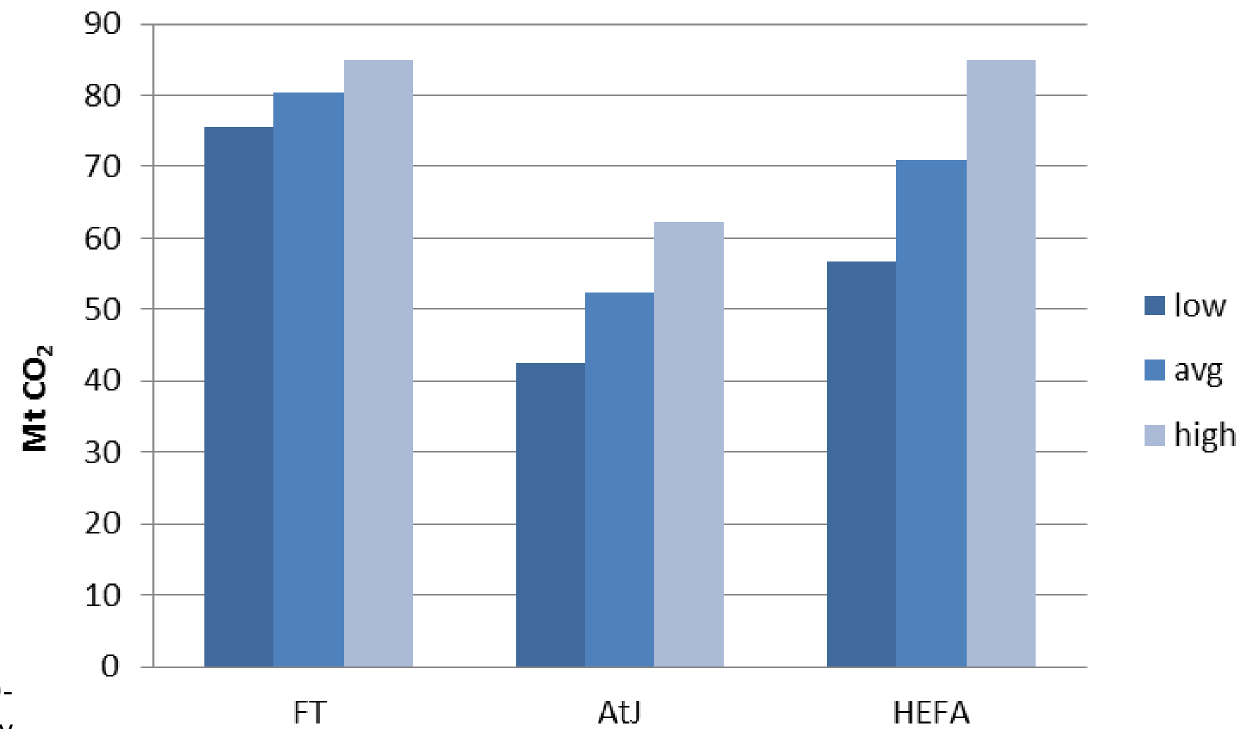
The GHG mitigating impact from 2020 - 2050

Annual GHG savings by pathway scenario



CLIMATE CHANGE MITIGATION IMPACT

Aggregate GHG mitigation impact in 2050
(in Million ton CO2e):
FT: 76-85
AtJ:43-62
HEFA: 57-85

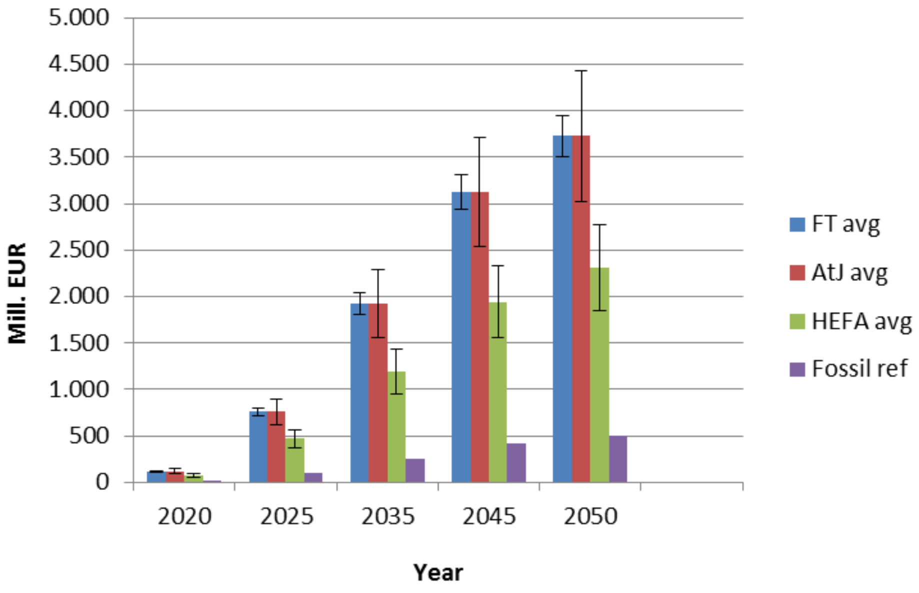


Total GHG savings from 2020-2050 by pathway

IMPACT ON ECONOMY AND BUSINESS

COST OF PRODUCING SUSTAINABLE JET FUELS

Million EUR	**Min**	Max
HEFA	25,853	48,474
FT	48,474	71,095
AtJ	54,937	64,632
FOSSIL REFERENCE	8,079	8,079



Cumulative costs 2020-2050

SOCIO-ECONOMIC AND BUSINESS IMPACT

- Given the high ratio of feedstock production in each of the pathway scenarios, the effect of biofuel products is primarily generated through their direct effect on agriculture and forestry production.
- Further effects could be generated through the multiplication effects to other businesses within and outside the agricultural sector.
- An illustrative example indicates that in 2050 of production socio-economic net impact could annually reach 5.2 – 8.8 billion EUR

ECONOMIC AND BUSINESS IMPACT

Illustrative example, based on former research results key indicators:

ANNUAL EFFECT (EUR/LITER)	Scenario 1a: HEFA	Scenario1b: HEFA (imported)	Scenario 2: FT	Scenario 3: AtJ
GROSS SOCIO-ECONOMIC BENEFIT	3.0	0.2	3.9	4.8
• AGRICULTURE, FORESTRY ETC.	1.4	-	1.6	2.6
• ENERGY AND WATER SUPPLY	0.3	-	0.4	0.4
• INDUSTRY AND CONSTRUCTION	0.7	-	1.2	1.0
• TRANSPORT ETC.	0.3	0.1	0.3	0.3
• OTHERS	0.3	0.1	0.4	0.5
• ENVIRONMENTAL BENEFIT	0.016	0.016	0.019	0.012
GROSS SOCIO-ECONOMIC COST	0.4	-	0.4	0.4
NET SOCIO-ECONOMIC BENEFIT	2.6	0.3	3.5	4.4

Source: Own estimates, based on Department of Food and Resource Economics, 2012, Blooberg 2012 and Larsen et. al. 2008

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BUSINESS IMPACT ON INCREASED SUSTAINABLE FUEL PRODUCTION

	Scenario 1: HEFA	Scenario 2: FT	Scenario 3: AtJ
CONSTRUCTION AND PLANNING	Construction and engineering industry (and expansion of existing) Advisory services from the engineering industry	Construction and engineering industry Advisory services from the engineering industry	Construction and engineering industry Advisory services from the engineering industry
FEEDSTOCK PRODUCTION	Oil residual industry to be expanded in all Nordic countries For the imported share, no impact will be traced in the Nordic economy.	Wood residual industry to be expanded in general in Norway, Sweden and Finland. Current demand of biofuel from wood residues to CHP will shift into renewable electricity (wind and water-based energy production).	Straw production in the agricultural sector in Denmark and to some extent Sweden. Wood residual production in Norway, Finland and Sweden. Current demand of biofuel from ethanol to CHP will shift into renewable electricity (wind and water).
TRANSPORTATION INFRASTRUCTURE	The Nordic tankships are likely to have a large share in transportation of the imports from Central- and Southern Europe.	Transportation, including feedstock collection and fuel distribution via railways, trucks and tankships.	Transportation includes feedstock collection and fuel distribution via railways, trucks and tankships.
CONVERSION AND BIOREFINERY	Hydrotreatment and refinery plants in Finland and possibly the other Nordic countries	Gasification and refinery plants in the Energy sector in Norway, Sweden and Finland	Enzyme and biomass pre-treatment, gasification and refinery plants in the Energy sector in Denmark, Norway, Sweden and Finland
BLENDING AND DISTRIBUTION	Nordic petroleum refinery plants close to the Nordic Airports	Nordic petroleum refinery plants close to the Nordic Airports	Nordic petroleum refinery plants close to the Nordic Airports

BUSINESS IMPACT ON REDUCED FOSSIL FUEL PRODUCTION

SECTOR	EFFECT
PRODUCTION	The production is fully imported. The Nordic oil producers will not be affected
TRANSPORTATION	The Nordic Tankships value chain will lose their current import shipping of oil, between the Nordic countries as well as from abroad
CONVERSION AND BIOREFINERY	Minimal effect
BLENDING AND DISTRIBUTION	Nordic petroleum refinery plants close to the Nordic Airports

EMPLOYMENT

Nordic region annual employment impact in 2050 (at 37.5 % blend-in requirement), by business sector and highest education

	Secondary/ Unskilled	Vocational training	Short/medium-term higher education	Long-term higher education	Total
SCENARIO 1: HEFA					
AGRICULTURE, FORESTRY ETC.	1.800	3.400	600	200	6.000
ENERGY AND WATER SUPPLY	200	300	100	-	600
INDUSTRY AND CONSTRUCTION	700	1.200	700	400	3.000
TRANSPORT, POST AND TELECOMMUNICATIONS	400	1.600	200	-	2.200
OTHERS	1.400	100	800	100	2.400
SCENARIO 2: FT					
AGRICULTURE, FORESTRY ETC.	2.300	4.400	800	200	7.800
ENERGY AND WATER SUPPLY	200	400	100	100	700
INDUSTRY AND CONSTRUCTION	900	1.600	900	500	3.900
TRANSPORT, POST AND TELECOMMUNICATIONS	600	2.000	300	-	2.900
OTHERS	1.800	100	1.000	100	3.000
SCENARIO 3: ATJ					
AGRICULTURE, FORESTRY ETC.	2.900	5.400	1.000	300	9.600
ENERGY AND WATER SUPPLY	200	400	200	100	900
INDUSTRY AND CONSTRUCTION	1.200	1.900	1.100	600	4.800
TRANSPORT, POST AND TELECOMMUNICATIONS	700	2.500	300	-	3.500
OTHERS	2.200	100	1.300	200	3.800

Source: Own extrapolated estimates, and crossed with branch statistics data

BARRIERS

CHALLENGE 1: HIGH PRICE GAP BETWEEN FOSSIL AND SUSTAINABLE JET FUELS

- A main barrier is the cost of sustainable jet fuel, which falls within a price range that is currently roughly 2.5 - 8 times higher than conventional jet A-1.
- This price gap is likely to diminish step-by-step in the future, following the annual reduction of the implementation of the ETS system’s free allocated allowances.
- An agreement on ICAO’s Global Market-Based Mechanism as a globally extended compatible ETS system will further contribute to this development, as it can reduce the carbon leakage potential of the current ETS market as well as establishing a global price on fuel.

CHALLENGE 2: LACK OF CONGRUENT SUSTAINABILITY REQUIREMENTS

- The current lack of global consensus with regards to what constitutes sustainability creates hesitation and disincentives for the industry to commit to certain technology pathways.
- It is a necessity for producers of sustainable jet fuel worldwide to have an internationally agreed upon standard to adhere to, in order to ensure the production of truly sustainable jet fuels.
- Regional asymmetries with regards to the sustainability standards that producers should achieve could result in an asymmetrical competitive situation. Thus, producers of sustainable jet fuel within the EU could face unfair global competition.

CHALLENGE 3: LACK OF COHERENT POLICY ACROSS NORDIC REGION

- The Nordic policy framework for sustainable jet fuels is fragmented.
- The unaligned support schemes cause different levels of incentive/disincentive in different countries.

CHALLENGE 4: LOW ACCESS TO RISK-CAPITAL

- Many businesses fail in making the transition from demonstration to commercial scale production, due to the commercial risks and difficulties in attracting investors.
- The lack of explicit policy goals for sustainable alternatives for aviation fuels reduces investor confidence in the future market.
- The uncertain future demand forms the basis of an environment which is detrimental to investments for first-movers.
- As a consequence, it becomes necessary to find a way to pool risk between the various stakeholders of the industry.

CHALLENGE 5: COMPETING USES FOR FEEDSTOCK

- Feedstock constitutes at least part of the substantial production cost of sustainable jet fuels.
- This makes the production highly vulnerable to fluctuations in feedstock prices and thereby demotivation for investments.

CONCLUSIONS

MAIN CONCLUSIONS

Nordic production of sustainable bio jet fuels has potential benefits stemming from the reduction of GHG emissions and negative environmental impacts, the development of new technology, as well as economic growth and job creation.

Furthermore, the Nordic countries possess a series of comparative advantages with regards to producing sustainable jet fuels, including:

- The vastest forest resource in Europe, with a well-established industry and infrastructure
- Strong competencies and technical know-how with regards to utilization of forest biomass
- Strong competencies in fermentation and enzymatic technologies, relevant for production under e.g. the AtJ pathway
- Already existing commercial scale facilities for production under a HEFA pathway, combined with technical expertise in converting lipids to jet fuel
- Strong competencies in refining technology, relevant for all pathways
- Existing infrastructure poised for retrofitting to production of sustainable jet fuels
- Airlines companies show a high willingness to introduce biofuel in aviation

RECOMMENDATIONS TO NATIONAL POLICY MAKERS

- Recognize that focused jet fuel targeted strategies are needed to kick start and develop a market for sustainable fuel alternatives in the Nordic countries.
- Launch national and international initiatives which can kick-start and stimulate the maturing and upscaling of the market for sustainable jet fuel. *An example could be to tie economic benefits to the use of sustainable jet fuel in order to reduce the cost differential.*
- Explore possibilities to make specific targets for the share of RES in aviation on global, European and Nordic level in order to create a strong signal value to private investors and design a more streamlined incentive structures.
- Explore and stimulate possibilities for co-processing with existing facilities, especially oil refineries.

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RECOMMENDATION TO POLICY MAKERS AND PRIVATE SECTOR IN TERMS OF ENHANCING PUBLIC-PRIVATE COLLABORATION

- Organize the individual technologies and their developers in collaboration around specific production pathways throughout the value chain and with a strong lead partner to facilitate and drive the development.
- Intensify innovation and research on sustainable jet fuel across the Nordic countries.
- Promote public-private partnership, between airline carriers, jet fuel producers, universities and other public entities, in order to increase transparency and lower the risk in investing in sustainable business models.
- Explore new, sustainable business models in support of the development of sustainable jet fuel supply chains, such as the Fly Green Fund and the multi-stakeholder initiative BioPort.
- Policy makers should explore possibilities for establishing a loan guarantee mechanism for producers of sustainable jet fuels, in order to secure transition investment capital.

RECOMMENDATIONS FOR POLICY MAKERS DIRECTED TOWARDS INTERNATIONAL COLLABORATION

- Nordic collaboration and policy makers should work on the international level through ICAO and other channels, towards an incentive structure for the use of sustainable jet fuel.
- Nordic collaboration and policy makers should continue work towards globally applicable standards for sustainability, in line with current policies for climate change mitigation.
- Explore the possibility to develop globally accepted mandatory blending levels.
- Support and advocate for more streamlined and time-efficient ASTM acceptance processes of new pathways in support of sustainable jet fuel.

THANKS FOR YOUR ATTENTION

CONTACT

Erik C. Wormslev
NIRAS A/S
ecw@niras.dk
+ 45 4810 4735

Jakob Louis Pedersen
NIRAS A/S
jlp@niras.dk
+ 45 6011 4285