Sustainable Jet Fuel for Aviation

Nordic perspectives on the use of advanced sustainable jet fuel for aviation - Update 2019

NORDIC ENERGY RESEARCH

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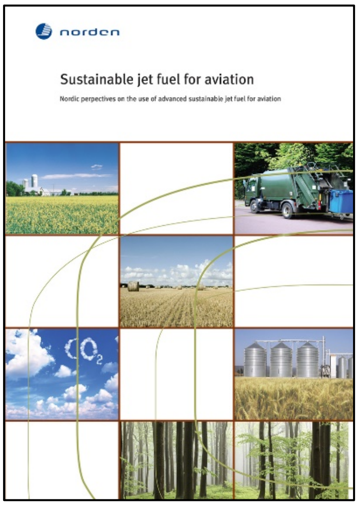
1 Introduction



In the effort to meet its international commitments in reducing its share of the global GHG emissions, the aviation sector in the Nordic countries have initiated a series of developing processes towards new sustainable jet fuel solutions.

In 2016 Nordic Energy Research published the report "Sustainable jet fuel for aviation – Nordic perspectives on the use of advanced sustainable jet fuel for aviation" where the potential to develop and use sustainable aviation fuel (SAF) in the Nordic countries, including Denmark, Finland, Norway, Iceland and Sweden was examined.

The main purpose of the report was to assess, to what extend the use of SAF may contribute to GHG mitigation in the sector at both European and global level; and to assess the commercial potential for initiating and upscaling production at a Nordic level, making use of Nordic know-how, feedstock and production facilities, as well as identify barriers and how to remove these barriers.

Since 2016, there has been an increased international focus on the climate impact of aviation, which calls for a progress update of the original report. The update reflects the development since 2016, with a focus on the most important developments and activities, including new policies, stakeholder initiatives and technical advancements.

1.1 Executive Summary

In the past 3 years a lot of initiatives and projects has been launched to promote the use of SAF. Sweden and Norway have implemented an aviation tax and all of the Nordic countries acknowledge the need for action in the aviation sector. On an international scale the International Civil Aviation Organisation (ICAO) has developed a new global marked-based measure scheme for aviation to help with achieving the goal of a carbon-neutral growth from 2020 and 50% reduces emissions in 2050. However, there is still a lack of a global congruent sustainability requirements.

Six biofuels for aviation production pathways have been certified, and other pathways is in the qualification process. There is an increased interest in electro fuels which is introduced as a zero-emission aviation fuel. However high production cost is a big barrier and there are only a few demonstration facilities.

The market for SAF is minimal and is likely to stay this way in the short term. There is still a significant price gap between sustainable and conventional jet fuels which is primarily because of the high production cost of SAF. However, SAF still have the potential to make an important contribution to mitigating the environmental impacts of aviation, and recent policy and industry initiatives are likely to have a positive impact on the development.

The ongoing discussion of biomass as a feedstock to SAF has increased especially regarding LUC and ILUC (land use change and indirect land use change) in the agricultural sector and partly within sustainability in the wood production from forest. The international demands by NGO´s goes towards strengthening the criteria for sustainability which leads to a preference to avoid agricultural products being used for SAF.

New analysis shows the potentials for producing SAF based on synthetic pathways based on a combination of green power, biomethane and carbon dioxide captured from biogas or flus gasses (cement production, waste incineration etc.). thus, is the carbon source not competing with food and feed similar to the utilization of wooden materials from the forest in the Nordic countries (Sweden, Norway and Finland). In all processes of SAF there is a need to upgrade the base product by hydrogenation due to the contend of oxygen in the biomass, SAF needs to have the same high burning value as fossil-based materials and the contend of oxygen lowers the value and has to be removed.

The Nordic countries are front runners in the transition of fossil-based energy towards renewables leading to energy systems of electric power based on non-fossil material. (Hydro, biomass, wind, sun and nuclear). The potential for producing SAF – pure synthetic or by upgrading biomass-based fuels by hydrogen made by electrolysis has thus a great potential to be realized. Projects are on their way in all these fields.

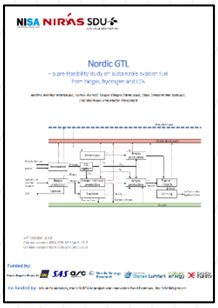
The barriers and recommendations are still the same as in the 2016 report. Thus, a new bigger demand from the aviation sector is leading the way for a greener aviation.

1.2 Process and structure

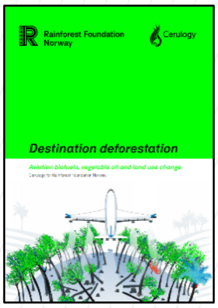
The progress update has been developed based on desk studies and follows, to some extent, the structure of the original report. The report also make reference to recent developments in electric aviation.

1.3 Studies on sustainable aviation fuel

In this section some of the Nordic studies published since 2016 are described.

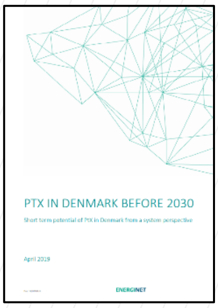


Nordic GTL – a pre-feasibility study on sustainable aviation fuel from biogas, hydrogen and CO_2, Denmark 2019: In 2019 NISA, NIRAS and SDU published a pre-feasibility study that identified technological pathways and processes for producing SAF based on renewable feedstock such as: biogas, bio-methane, electro-methane, hydrogen and CO_2. Based on this, a preliminary assessment of their feasibility including their economic/commercial viability was made. The outcome of the study was promising. The key stakeholders of the supply and demand chain express interest in looking more into the possibilities, including a more in-depth feasibility study. The study was funded by: CPH Airport, SAS, Amager Ressource Center (ARC), Nordic Energy Research, Danish Aviation (BDL), Nature Energy and Danish Energy (NISA et al. 2019).



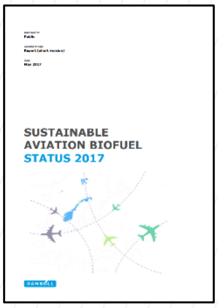
Destination deforestation – aviation biofuels, vegetable oil and land use change, Norway 2019: Rainforest Foundation Norway published in 2019 a report about the risk of deforestation with an increased biofuel demand. They recommend excluding HEFA fuels from the highest ILUC-risk feedstocks in any targets for aviation fuel and limit support for HEFA from food oils in general. Additionally, the report recommends that the political ambitions (ICAO) should be evaluated and focus should be on electro fuels, cellulosic biofuel and the electrification of aviation.

Large scale Bio-Electro-Jet fuel production integration at CHP-plant in Östersund, Sweden: Swedish Environmental Research Institute (IVL), Jämtkraft, University of Lund, Chalmers University, NISA and FGF, among others, were allocated funding from the Swedish Energy Agency to conduct a feasibility study for the establishment of a production facility for fossil free Bio-electro-Jet fuel at an exciting CHP plant. The facility will produce both electricity, heat and jet fuel, in a new process where they split H_2O by electrolysis and add the Oxygen to the combustion to create a cleaner flue gas, then the CO_2 is isolated from the rest of the flue gasses and the gas is hydrogenated to create liquid fuel.



PTX IN DENMARK BEFORE 2030: Potential for PtX in Denmark in the short-term from a system perspective, Denmark 2019: A report from the Danish TSO Energinet summarizing the potential for making Power-to-X (PtX) in Denmark before 2030. It finds that PtX could be economically relevant within a 5-10 years and the electricity tariff is one of the key elements to the profitability of electrolysis/PtX.

The Potential for electrofuels Production in Sweden Utilizing Fossil and Biogenic CO_2 Point sources, Sweden 2017: The purpose of this paper was to estimate the Swedish technical potential for electro fuels. It maps, categorizes and quantifies the major point sources of CO_2 emissions from industrial and combustion processes in Sweden. It concludes that the Swedish potential for electro fuels is currently limited by the electricity available and production costs, rather than the amount of recoverable CO_2.



*SUSTAINABLE AVIATION BIOFUEL STATUS 2017, Norway 2017: I*n 2013, Ramboll published a report for the Norwegian aviation sector about SAF. In 2016 an update was requested with a focus on the sustainable feedstock supply, new certified biofuels and policy instruments for implementation of sustainable aviation biofuel at Norwegian airports. The conclusion of the update is that 30 percent sustainable aviation fuel in all Avinor airport is possible by 2030. However, this require political involvement since the market does not exist due to high cost and limited offtake. and must be created. Two solutions were proposed: blending requirements or establishment of a fund to support the market. The Norwegian Parliament decided to establish blending requirements.

2 Global Status of Sustainable Aviation Fuel

Efuel, PtX and power-to-Met are different notions for electro fuels used in this report.

The use of SAF is still, in 2019, very limited because of the significant price gap between sustainable and conventional jet fuels which is primarily because of the high production cost of SAF. However, it has great potential to have a positive effect on the further environmental impact of aviation. There is a general interest in developing electro fuels, because of its huge potential as a zero-emission alternative fuel. However, high production costs have minimized the efforts in this area (European Union Aviation Safety Agency (EASA)).

2.1 Approved technology pathways

There have been some updates to the Amercian Society for Testing of Materials (ASTM) certified production pathways for SAF (cf. table 2.1).

Table 2.1: ASTM certification of sustainable jet fuel pathways (EASA)

Production Pathway	Max. Blend	Feedstock
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	50%	Biomass
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK/A)	50%	Biomass
Hydroprocessed Fatty Acid Esters and Free Fatty Acid (HEFA)	50%	Lipid feedstocks
Hydroprocessing of Fermented Sugars - Synthetic Iso-Paraffinic kerosene (HFS-SIP)	10%	Sugars
Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	50%	Alcohol
Co-processing	5%	Lipidic

2.1.1 Fischer-Tropsch Synthetic Paraffinic Kerosene FT-SPK/A

FT-SPK/A is a variation of FT-SPK. In this process alkylation of light aromatics creates a hydrocarbon blend that includes aromatic compounds, meaning that it is closer to the composition of conventional jet fuels, which also contain aromatics (EASA).

2.1.2 Alcohol-to-Jet Synthetic Paraffinic Kerosene (AtJ-SPK)

For AtJ-SPK, ASTM has increased the approved blend in ration from 10 percent to 50 percent (EASA). This means that fuel produced via this pathway may be blended with jet fuels up to 50 percent.

2.2 Emerging technologies

There are different pathways for SAF in the testing process. Commercial Aviation Alternative Fuels Initiative (CAAFI) have listed the pathways currently in pursuit of a certification through their qualification process (CAAFI).

Table 2.2: List of current Fuels in the D4054 Qualification Process

ASTM Progress	Production pathway	Feedstock	Task Force Lead
Phase 2 testing	Hydro-deoxygenation Synthetic Kerosene (HDO-SK)	Sugars and celluloses'	Virent (inactive)
	Catalytic Hydro thermolysis Synthetic Kerosene (CH-SK)	Renewable Fat, Oil and Grease	ARA
Phase 1 OEM Review	High Freeze Point Hydroprocessed Esters and Fatty Acids Synthetic	Renewable Fat, Oil and Grease	Boeing

	Kerosene (HEP HEFA-SK)		
Phase 1 Research Report	Hydro-deoxygenation Synthetic Aromatic Kerosene (HDO-SAK)	Sugars and cellulose's	Virent
Phase 1 Testing	Alcohol-to-Jet Synthetic Kerosene with Aromatics (ATJ-SKA)	Sugars and lignocellulosic	Byogy, Swedish Biofuel
	Integrated Hydro pyrolysis and Hydro conversion (IH^2)	Multiple	Shell
	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	Hydrocarbon rich algae oil	IHI
	Hydrotreated Depolymerized Cellulosic Jet (HDCJ)	Forest residues	KiOR (inactive)

In addition, a number of other pathways are being examined, but they are not yet in the ASTM Certification Process (CAAFI).

The ASTM D4054 process of getting SAF approved for commercial use includes three phases: Initial Screening, Follow-on Testing and Balloting and Approval.

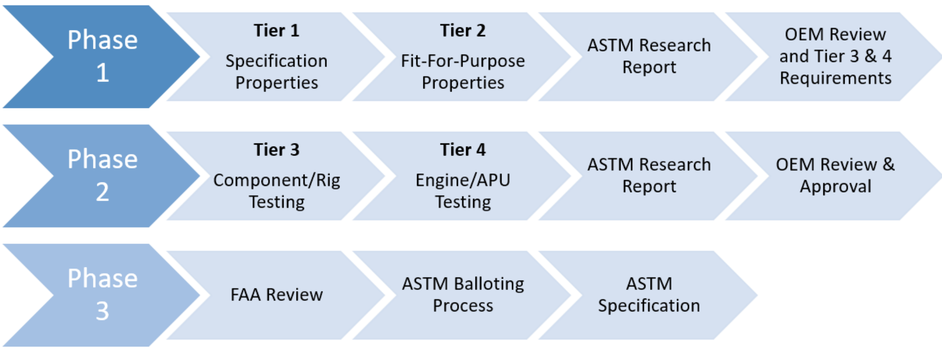


Figure 2.1: ASTM D4054 Evaluation Process (CAAFI)

If the data and specification properties of the SAF investigated through the four tier process is approved as an equivalent (either neat or as a blend) to conventional jet fuel an annex with the new aviation jet fuel (including any required blending level) is added to the D7566 Drop-In Fuel Specification (CAAFI).

2.3 Nordic stakeholder initiatives

This section will highlight initiatives towards development and production of SAF from the Nordic countries arising since 2016.

At the Technical University of Denmark (DTU) a concept project, Energy-X is addressing the systems and technologies to replace fossil fuels. They are examining the whole system of carbon capture from biogas and flue gas, production of biomethane, bio-methanol and bio-crude oil by Power to X (PtX) and utilization of all excess energies in the system to reduce costs (NISA et al. 2019).

At the VTT Technical Research Centre of Finland and Lappeenranta University of Technology (LUT), a demo plant has been developed using carbon dioxide to produce renewable fuels and chemicals. The pilot plant with a production capacity of up to meagre 80 litres of gasoline per day is coupled to LUT's solar power plant in

Lappeenranta. The aim of the project is to demonstrate the technical performance of the overall process and produce 200 litres of fuels and other hydrocarbons for research purposes. The demo plant comprises four separate units: a solar power plant; equipment for separating carbon dioxide and water from the air; a section that uses electrolysis to produce hydrogen; and synthesis equipment for producing a crude-oil substitute from carbon dioxide and hydrogen. Pilot-scale plant units have been designed for distributed, small-scale production (NISA et al. 2019:18).

Danish Aviation Association (BDL) is an association consisting of; Copenhagen Airport, SAS, Atlantic Airways, Air Greenland, Alsie Express, DAT and regional airports etc. BDL have on behalf of their members formulated a strategy to reduce their carbon footprint. The strategy includes a full offset on domestic flights from 2020, fulfillment of the Paris-agreement to become carbon natural by 2050 and to strengthen research and development regarding SAF (BDL 2019).

The airlines SAS and Braathens Regional Airlines (BRA), offer passengers an opportunity to pay extra to promote biofuels when booking their tickets (SAS 2019 & traveldailynews 2018). SAS have a vision to use renewable jet fuels for all domestic flights by 2030 (SAS 2019). Finnair and Icelandair has made it possible for their customers to offset their CO_2 emissions, by CO_2 reduction projects or buying biofuels (Finnair 2019 & Icelandair 2019).

Different Nordic airports are also taking initiatives to implement SAF, some examples:

- Avinor's Oslo Airport became in 2016 the first major airport to provide biofuel on a regular basis to the airlines refuelling in Oslo. Bergen Airport followed suit in 2017. In 2019 Avinor entered an agreement with Quantafuel to buy bio-based fuel through pyrolysis and based on Norwegian biomass. The plant will by partly funded by ENOVA and Avinor has committed to purchase fuel for EUR 784.000 (renewableenergymagazine 2019).
- Swedavia provided SAF for a couple of days to Stockholm Arlanda Airport, Göteborg Landvetter Airport, Bromma Stockholm Airport, Visby Airport and Luleå Airport in 2018. The fuel was produced by World Energy and delivered by SkyNRG in partnership with Shell. Swedavia have since 2016 purchased biofuel equivalent to the fuel used in the company's flights for business purposes. Which is around 450 tonnes of fuel annually (Swedavia 2018).
- Kalmar Airport buy biofuels equivalent to their own business travels, and they finance and offer biofuel to air carriers (Kalmar Öland Airport).
- Copenhagen airport (CPH) are taking steps towards facilitating solutions to provide SAF. This move is part of a wider ambition to achieve fossil free operations of both the airport and the aircraft flying in and out.

Besides the need for SAF most airports in the Nordic Countries have plans for the ground operations to be based on non-fossil materials such as the vehicles, lightning, heating and cooling capacities. It is likely that they will come close to a zero emission within the next decade excluding the aviation fuel. Some airport include LTO (fuel for the operations on and close to the airport – Landing and take-off) in their annual climate reports (Copenhagen Airport, CPH). The potential for electrification of some of these operations is due to the development of electric and/or hybrid aircrafts and it is expected, that smaller domestic aircraft to be in operation with the next decade.

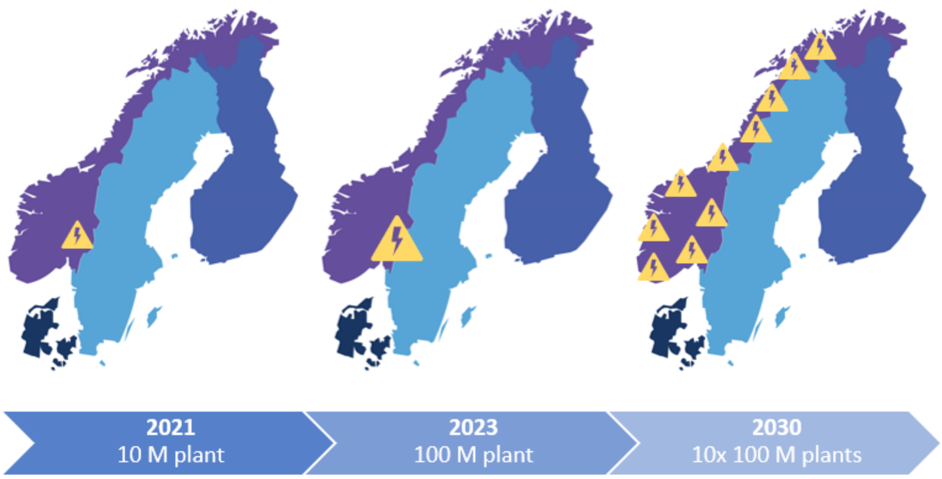
Quantalfuel is building a full-scale plant in the Danish business park GreenLab Skive. The park will become a platform for various forms of energy storage including power-to-hydrogen, power-to-ammonia and other PtX technologies as well as methanization of biogas, thermal and electrical storage. Quantafuel is expecting that their plant will produce 15 million liters of fuel a year from plastic waste by pyrolysis. The plant is ready for production in 2019 (Quantafuel & Greenlab).

The Danish company Topsøe has a full-scale technology ready, HydroFlex, for processing renewable feedstocks to existing refineries. Furthermore, Topsøe is building a demonstration plant to produce CO_2-neutral methanol from biogas and green electricity, located at Foulum, Denmark. The demonstration plant is scheduled to be fully operational in the beginning of 2022. The eSMR MethanolT technology will produce methanol from Topsøe's syngas eSMRT technology. In addition, Topsøe manufactures solid oxide electrolyzer cells (SOEC) that use electricity to produce hydrogen from steam at high temperatures. Finally, Topsøe is exploring how to reduce CO_2-emissions from traditional steam methane reforming by using electric heating in smaller reactors. These different technologies promise to reduce costs of several pathways and are particularly relevant to the PtX / GTL approach. (NISA et al. 2019). Methanol can be upgraded to SAF afterwards.

The Finnish company Neste is still a global frontrunner in developing advanced technologies for biofuel production and demonstrated their ability to produce bio-kerosene in large scale already in 2011. Neste have since 2016 expanded and have established additional production capacity in Singapore (Neste 2018). In 2019, Neste MY Renewable Jet Fuel won an award for its role in reducing black carbon emissions in a competition jointly organized by the Climate Leadership Coalition, the Bioenergy Association of Finland, the Finnish Innovation Fund Sitra, the Finnish Environment Institute, and the Central Association of Chimney Sweeps (Neste 2019).

Nordic Blue Crude together with Sunfire and Climeworks aims to produce high quality synthetic fuels from water, CO_2 from direct air capture (DAC) units, and renewable electricity. A demonstration plant of 20 MW will be established in 2022 and a full scale 200 MW facility is planned for 2025 (NISA et al. 2019:17).

Figure 2.2: showing the plans for the development of local plants in Norway situated at airports



The Danish-Canadian company Steeper Energy is partnering with Silva Green Fuel to construct a 50 MW industrial-scale demonstration plant at Tofte, Norway. The plant will convert woody residues into renewable crude oil that subsequently will be upgraded to renewable to transport fuels (SteeperEnergy 2017).

Preem and Vattenfall have recently announced that they are planning to build Europe’s largest electrolysis plant (20 MW) for the refinery sector. Their plan is to use the hydrogen to produce fossil-free fuels. The power used for the electrolysis comes from hydropower (NISA et al. 2019:17).

St1 is building a new biorefinery in Gothenburg to produce jet fuels, naphtha and HVO-diesel. The biorefinery will also produce hydrogen from electrolysers (St1 2019).

Furthermore, Chalmers Tekniska Högskola (CTH) has examined the production cost of electrofuels for the transport sector. The study covers methane, methanol, dimethyl ether, diesel and gasoline processes. It shows that the two most important factors affecting the production cost of all electrofuels are the capital cost of the electrolyser unit and the electricity price, i.e. the aggregated hydrogen production cost (NISA et al. 2019).

2.3.1 Multi-stakeholder initiatives

2.3.1.1 *NISA, Nordic Initiative for Sustainable Aviation*

Partners: SAS, Finnair, Norwegian, Icelandair, Air Greenland, Malmo Aviation, Atlantic Airways, Copenhagen Airports, Swedavia, Avinor, Finavia, Isavia, Airbus, Boeing, Brancheforeningen Dansk Luftfart (BDL), Svenskt Flyg, Svenska FlygBranschen, NHO Luftfart, International Air Transport Association (*IATA) and transport authorities of Denmark, Sweden and Finland.* The object of the partnership is to facilitate the development and uptake of SAF in the Nordic region (Cleancluster).

2.3.1.2 *Conference on sustainable aviation*

Partners: Nordic Initiative for Sustainable Aviation (NISA) and Nordic Energy Research (NER). NISA and NER hosted a conference to explore how various initiatives and policy frameworks can enable increased use of SAF. The conference was held the 10th October 2017 in Copenhagen Airport (Nordic Energy Research).

2.3.1.3 *The Nordic Network for Electric Aviation (NEA)*

Partners: RISE, SAS, Heart Aerospace, El-fly AS, Air Greenland, Avinor, BRA, Finnair, NISA, Swedavia Airports, Fossilfritt Flyg 2045 and Icelandair. The twelve partners have come together to develop a platform where Nordic actors can work together to accelerate the introduction of electric aviation in the Nordic countries. The project has four overall objectives: standardize electric air infrastructure on the Nordic countries, develop business models for regional point-to-point connectivity, develop aircraft technology for Nordic weather conditions and create a platform for European and global collaboration (Nordic Network for Electric Aviation).

2.3.1.4 *EUDP (a Danish Energy Technology Development and Demonstration Program), Power2Met*

Partners: GreenHydrogen, Aalborg University, Integrate ApS, Process Engineering A/S, Cemtec Fonden, Holtec Automatic – Nord A/S, Lillegården el A/S, Drivkraft Denmark, Rockwool A/S, NGF Nature Energy Biogas A/S and E.ON Denmark A/S. The aim of the Power2Met project is to develop, design and build a pilot plant for a complete standardized and modular power-to-methanol plant. The projects has a budget of EUR 3,5 million and runs from 2019 to 2021 (Energiforskning [1]).

2.3.1.5 *Electro fuel from a bio-trickling filter (e-Fuel)*

The purpose of the e-Fuel project is to develop a new and better way to produce electro-fuels, building on a well-known technological basis. The project will develop and build a large-scale prototype bio-trickling filter that converts CO_2 and hydrogen form biogas to methane. The project is supported by the Danish Energy Agency and will contribute to the Danish government's energy strategy. The projects budget is EUR 3 million and runs from 2019 to 2022 (Energiforskning [2]).

2.3.1.6 Innovation Fund Denmark, SYNFUEL project

Partners: Danmarks Tekniske Universitet (DTU), Aalborg University, Haldor Topsøe A/S, Chalmers University of Technology, Ørsted A/S, Energinet, Institut National des Sciences Appliqués (INSA), Technische Universität Berlin, Northwestern University, Chinese Academy of Science, MIT and AVL GmbH. DTU have the lead on the SYNFUEL project, which objective is to examine how to combine electrolysis and gasification of biomass to produce more biofuels from the same volume of biomass. The project budget is EUR 3,5 million and runs from 2015 to 2019 (Energiforskning [3])

2.3.1.7 EUDP Electro fuel from a bio-trickling filter (e-Fuel)

Partners: NGF Nature Energy Biogas A/S, Syddansk University, DTU, Biogasclean A/S, Biogasclean Asis Co. Ltd and Erhvershus Fyn P/S. The object of FLABBERGAST is to develop a sustainable production of bioethanol that also fulfills the physical-chemical requirements for jet-fuel. The project had a budget of EUR 3,9 million and it was completed in 2018 (Energiforskning [4]).

2.3.1.8 Green hydrogen and electrofuels in Sweden

Partners: Nouryon, RISE, Södra and BillerudKorsnäs. In 2018 Nouryon joined a partnership with RISE, Södra and BillerudKorsnäs, supported be Swedish Energy Agency, to explore the opportunities for producing chemicals, green hydrogen and electrofuels using renewable energy. The project budget was EUR 76.000 and it was completed in 2019 (Energimyndigheten, Sweden).

2.3.1.9 Future Liquid Aviation Biofuels Based on Ethers for Gas Turbine Engines (FLABBERGAST)

Partners: DTU, Copenhagen University, Aalborg University, NOVOZYMES A/S, Cumulus Bio ApS, Niels Clauson-Kaas A/S, Airbus Operations Lmt., RWTH Aachen and Lawrence Berkeley National Laboratory (US). The FLABBERGAST project goal was to develop a sustainable production of bio jet fuel that is fully compatible with current gas-turbine engine-technology. The project was funded by Innovation Fund Denmark and had a budget of EUR 1,2 million. The project was completed in 2018 (Aalborg University).

2.3.1.10 Partnership Fossilfria Flygtransporter

Partners: SAS, Swedavia and RISE. The Swedish Energy Agency allocated EUR 3,2 million to an innovation cluster called Fossilfria Flygtransporter 2045, which goal is to create a Swedish fossil free aviation sector. Fossilfria Flygtransporter will help fund 11 research projects that focus on SAF produced from either biomass or PtX. Three projects will examine jet fuels from bio-methane, CO_2 and hydrogen, and the remaining eight projects will explore the production of jet fuels from biomass such as wood chips and lignin (NISA et al. 2019:16).

One of the other projects, a partnership between Research Institute of Sweden (RISE), SAS and Swedavia aim to gather actors from the entire value chain and develop a joint plan, both in terms of technical innovations, business models and services that will make it more attractive to invest in the production of bio-jet fuels. The second project is from Chalmers Tekniska Högskola, where they are looking at the process of making methanol from hydrogen and CO_2 and then transform methanol into jet fuels. The hydrogen will be produced from electrolysis, and CO_2 will be captured from biomass power plant. The main focus of the research project is to develop and test various kinds of catalysts. Another research project led by Lund University with Kiram AB as partner are developing a process for production of electrofuels, that can be integrated with biofuels (NISA et al. 2019:16-17).

2.3.1.11 *Flying on forest residues in Småland, Sweden*
Partners: Södra, KLM, Växjö Kommun, Småland Airport, Fores, RISE Research Institutes of Sweden, Luleå University of Technology, Växjö Energi, SkyNRG. The flying on Forest residues in Småland is a feasibility study about local production of sustainable aviation fuel in Småland and the most profitable supply chain set up. A quantitative and site-specific analysis of production technologies, including integration opportunities, feedstock supply and logistics, is employed (SkyNRG).

2.3.1.12 *Validation and demonstration of forest-based bio jet fuel*
Partners: Luleå University of Technology, RISE Research Institutes of Sweden, SkyNRG, INERATEC, SCHMIDTSCHE SCHACK | ARVOS, Smurfit Kappa, Sveaskog, Svebio, SAS, BRA and Fly Green Fund. The objective of this project is to build a demonstration plant that can produce SAF from black liquor a residue from the kraft (Carboard/paper) pulping process. The project includes engineering the plant, presenting a business case and establishing a downstream supply chain (SkyNRG).

2.3.1.13 *The Roundtable on Sustainable Biomaterials (RSB)*
The Nordic members of RSB includes: Neste, Quantafuel, UPM-Kymmene Corporation, Eco-1, Maersk, SAS Tech AB. RSB is a global independent multi-stakeholder organisation that develops sustainable solutions through certification, innovation and collaborative partnerships. The RSB supports the development of alternative aviation fuels that secure social and environmental sustainability, including promoting food security and water stewardship. RSB tools includes a greenhouse gas calculator that covers the full scope of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) methodology and is adapted for the CORSIA calculation rules.

The RSB Standard is recognised by the World Wildlife Fund for Nature (WWF), International Union for Conservation of Nature (IUCN) and Natural Resources Defence Council (NRDC) (RSB 2018).

3 Production capacity and price estimates.

Today Neste in Finland is the only commercial producer of SAF in the Nordic countries that are approved by ASTM as a blend in. The SAF is based mainly on used cooking oil. Several producers have plans for a production in the future (Preem and others) but in grand total the plans are at a limited capacity for the next five years.

In Europe several projects are in the execution phase (The Nederland`s) and a lot of plans are under development. In grand total it is expected that with the next five years the total production capacity will be several hundred thousand tons per year, but still a relative low percentage of the demand for aviation fuel.

In the Nordic countries a full-scale GTL plant might be a reality within the next 10 years with a capacity larger than the total demand for SAF in domestic flying.

Figure 3.1: model of a GTL production facility

At present most of the plans for SAF have revealed a price level of SAF in the magnitude of 3-4 times the price of fossil-based fuel. However, the recent GTL study in Denmark indicates a future price level for SAF in the magnitude of 1,5-2 times fossil fuel (NISA et al. 2019).

A refinery has indicated that they might produce SAF utilizing hydrogen based on electrolysis with green power in a combination with the existing refining operation. The resulting fuel would each a "green" component of about 5 percent. The potential of such production might lead to a production of up to 1 mill. t/year of SAF within the next 3 to 5 years.

Equinor I Norway are planning to create "blue" hydrogen to be used in the same manner. The "blue hydrogen" comes from a combination of producing hydrogen the usual way with steam reforming at the refinery in a combination with equivalent carbon capture and storage deep in the ground in the North Sea (that's why named Blue Hydrogen).

4 Criteria for sustainable jet fuel

4.1 Sustainable Development Goals (SDG's)

In 2015 the Sustainable Development Goals (SDG's) were adopted by world leaders in the United Nations. The 17 SDG's offer a framework to discuss, structure and set goals on sustainable development. Since it was introduced in 2016, the SDG's have become a popular and useful tool that organizations, businesses and authorities use when working on their sustainability agenda. Aviation's responsibility is primarily aimed at SDG 13 Climate action, but several of the other SDGs call for aviation involvement, directly or indirectly.

Figure 4.1: The 17 Sustainable Development Goals from UN.

4.2 Other global warming effects

Studies by the German Aerospace Centre show that both airstrips and clouds generated by airplane combustion in the short term has a serious impact on the GHG effect. The study suggests that in worst case the climate impact of vapor, particles and NOx can be up to 4,5 times higher than the CO_2 emission alone (Dahlmann et al. 2016). This is therefore a further challenge in the development and use of SAF. Some studies show that using SAF can reduce cloud formation and airstrips (contrails) because they are cleaner than fossil fuels and therefore emit fewer particles (Ingeniøren DK 2019).

4.3 Direct and indirect land-use change (LUC and ILUC)

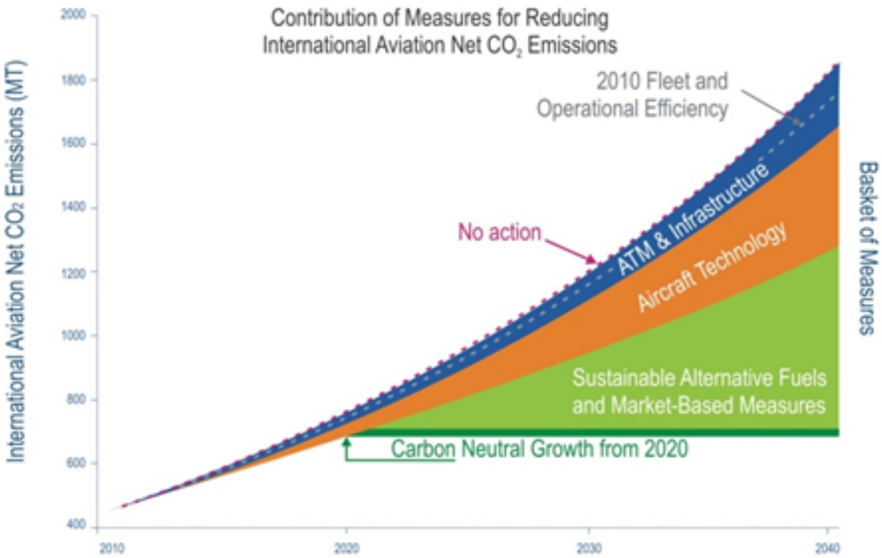
The ongoing discussion of biomass as a feedstock to SAF has increased especially regarding LUC and ILUC in the agricultural sector and minor within sustainability in the wood production from forest. The international demands by NGO's goes towards strengthening the criteria for sustainability which leads to a preference to avoid agricultural products to be used for SAF.

5 International governmental policy frameworks

5.1 International Civil Aviation Organisation (ICAO)

At the ICAO 39th assembly in 2016 it was requested that member states coordinated policy actions to accelerate the development and use of SAF. In 2017, a 2050 vision for SAF were adopted CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) which meant that all stakeholders had to ensure that a significant proportion of their fuel were substituted SAF by 2050 in order to secure carbon-neutral growth. Quantified targets for individual countries are first to be agreed upon at the next conference in 2025 (EASA).

Figure 5.1: CAEP International Aviation Net CO_2 Emissions Trend (ICAO [1])



The ICAO have developed a new global marked-based measure (MBM) scheme for aviation, called CORSIA. The purpose of CORSIA is to provide a broader variation of measures to achieve the global goal of a carbon-neutral growth from 2020 and 50% reduces emissions in 2050.

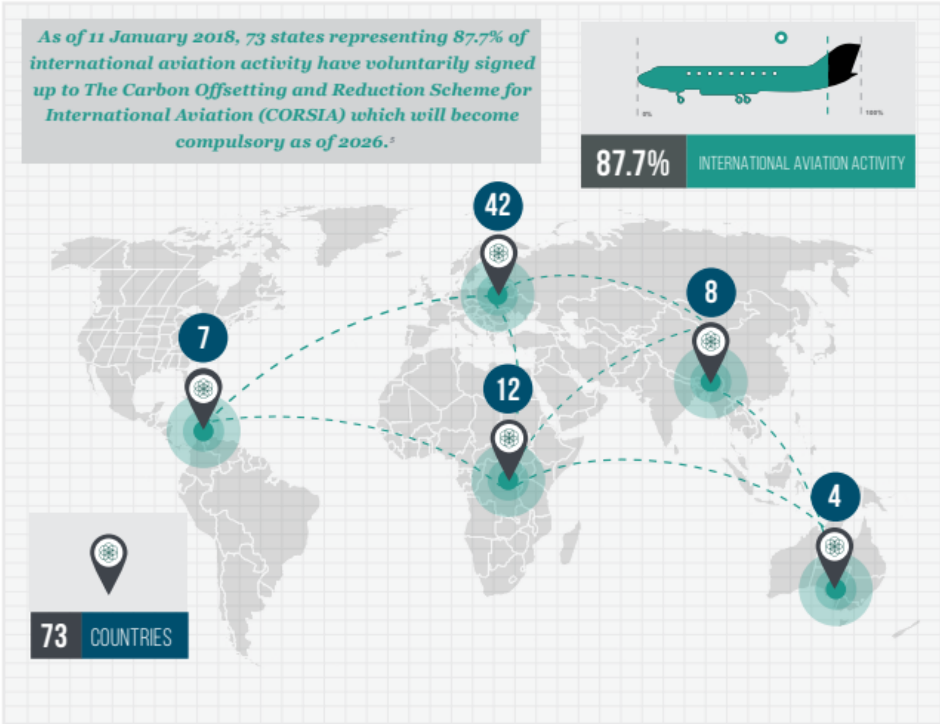


Figure 5.2: Overview of countries signed up for CORSIA

CORSIA will address annual increase in the total CO_2 emissions from international civil aviation. The baseline is based on emissions in 2019 (EASA). CORSIA will allow air carriers to reduce their offsetting obligations by increasing their use of low carbon aviation fuels instead. These fuels must comply with sustainability criteria, which are still under discussion internationally (EASA).

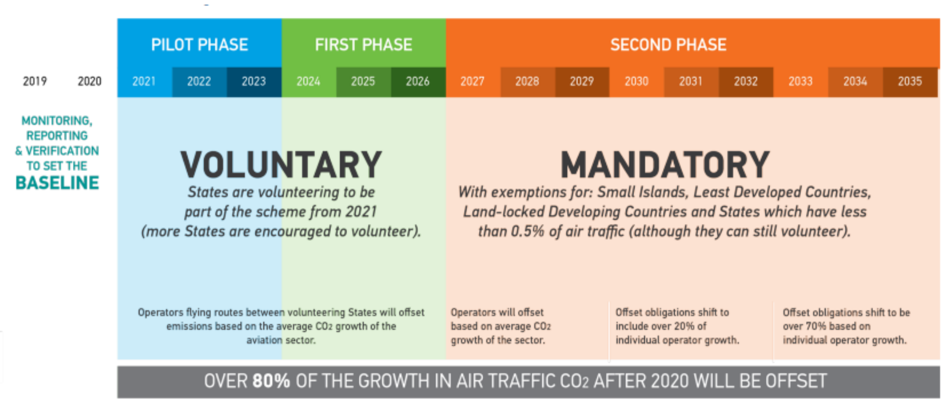


Figure 5.3: CORSIA Emissions Monitoring Plan (IATA 2018).

5.2 The EU Renewable Energy Directive II (RED II)

In December 2018, the revised renewable energy directive 2018/2001/EU (RED II) entered into force and is to be implemented in 2020. In RED II, new overall EU targets for Renewable Energy Sources consumption are set. By 2030, renewable energy should represent 32 percent of total energy consumption and member-states are required to supply 14 percent renewable energy/fuel to the transport sector. Fuels used in the aviation and maritime sectors can opt in to contribute to the 14% transport target but are not subject to an obligation. Sustainable fuel is referred to as advanced fuel. Fuel producers must deliver at least 0.2 percent in 2022, at least 1 percent in 2025 and at least 3.5 percent by 2030”. Aviation is a relatively small part of the overall transport sector. Moreover, the advanced fuels count 1.2 times their energy content (EU Science Hub 2019).

RED have defined some sustainable criteria:

- Greenhouse gas emissions from biofuels must be lower than from the fossil fuels they replace by at least 50 percent for installations established prior to 5th October 2015, increasing to 60% for installations after that date until end of 2021, and 65% for biofuels produced in installations starting operation after 2021.
- Carbon stock and biodiversity: raw materials for biofuels production cannot be sourced from land with high biodiversity or high carbon stock (i.e. primary and protected forests, highly biodiverse grassland, wetlands and peatlands) (European Aviation Environmental Report 2019).
- Limit on high ILUC-risk biofuels, bioliquids and biomass fuels with a significant expansion in land with high carbon stock. These limits will affect the amount of these fuels that Member States can count towards their national targets when calculating the overall national share of renewables and the share of renewables in transport (EU Science Hub 2019).

6 Legislation and priorities in the Nordic countries

6.1 Denmark

The goal for the transport sector is to be independent of fossil fuels by 2050. In addition, the ambition of the Danish government is to reduce the overall national carbon footprint with 70 percent by 2030. The Danish government has established a number of climate partnerships. Airline industry players have taken on the task to develop a plan for how the sector can meet the national targets.

This have an impact on the political discussion about aviation and how to regulate the carbon footprint. The government are considering different types of taxes on air travel/air carriers but has not reach a decision yet (Engelbrecht 2019).

BDL (Danish Aviation Association) has proposed a Climate Fund instead of a carbon tax, that will be earmarked the development and production of SAF in Denmark. The funding will be provided by an increased price pr. ticket and BDL estimates an annual amount of about 65,000 € to be used for the development and purchasing of SAF (BDL).

6.2 Finland

The Finnish Government have included a 30 percent target for "sustainable biofuels" in aviation by 2030 through a blending obligation (Government of Finland, 2019). This is equal to the targets set in Norway.

Finland have no aviation tax but over 50.000 citizens have voiced their support for an aviation tax (Helsinki Times 2019).

6.3 Iceland

The Icelandic Government have published a new Climate Action Plan for 2018-2023. In this plan one of the main goals is to phase out fossil fuels in the transport sector. In addition to electrification the plan also introduces government support for biofuels production (Ministry for the Environment and Natural Resources 2018).

6.4 Norway

The Norwegian Parliament introduced an Air Passenger Tax in 2015, which took effect in 2016. The tax rate depends on the final destination of the passenger. A flight within Europa will incur a taxation around 7,5 EUR and around 20 EUR if it is outside of Europa (FCC Aviation).

The Ministry of Climate and Environment announced I 2018 that airlines operating in Norway have to use a jet fuel mix that contains 0,5 percent biofuel by 2020. The government's goal is that 30 percent of jet fuel will be sustainable in 2030 (Reuters 2018). It is up to the Manufacturers to secure the deliveries.

6.5 Sweden

The Swedish Government have issued an aviation strategy in 2017 where biofuel is mentioned as one possible solution to reach the 2035 and 2050 climate goals. The Swedish Government support research that aim to reduce production cost on biofuel in the transport sector (Näringsdepartementet 2017).

To help with developing a strategy the government appointed a commission to investigate the possible use and regulation of biofuel. The commission proposed a GHG intensity reduction obligation in Swedish aviation with a penalty to airlines which does not comply (Statens Offentliga Utredninga 2019). In 2018 the Swedish Government gave EUR 9,5 million to the Swedish Energy Agency with the purpose of supporting initiative that makes it more profitable to develop and produce biofuel (RISE 2018).

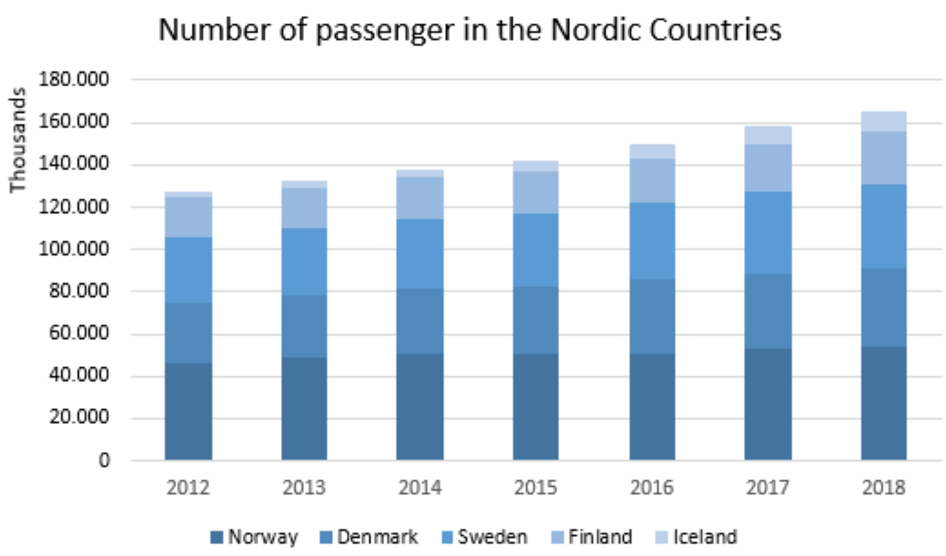
In 2018 Sweden introduced a new aviation tax where the air carrier has to pay approximate 5,5 EUR for domestic flights and flights in the EU, 23,5 EUR for medium-long flights and 37,5 EUR for long flights (Skatteverket).

7 Jet fuel Demand

7.1 Jet fuel demand in the Nordic countries

In the last couple of years Nordic aviation has increased from 127,5 million passengers to 165,5 million. An increase of 29,5 percent.

Figure 7.1: Number of passengers in aviation in the Nordic countries



It is expected that this trend will continue and the need for jet fuel will increase in the future. A projection of the jet fuel demand in the Nordic countries can be seen from the table below:

Table 7.1: Aggregated and projected Nordic demands for jet fuel

Year	2014		2025		2050	
Unit	*Million iters*	*Petajoule*	*Million litres*	*Petajoule*	*Million litres*	*Petajoule*
Norway	1200	44	1500	55	1400	50
Denmark	1200	45	1300	50	1900	70
Sweden	1000	38	1300	45	1200	45
Finland	900	34	1100	40	1100	40
Iceland	240	9	300	10	300	10
Total	4540	170	5500*	200*	5900*	215*

*For Denmark the projected demand for jet fuel has been updated, taking into account the newest consumption from 2017 and with 1,5% pa. projection. The projection for the rest of the Nordic countries are from 2014. For 2030 the projected jet fuel demand is 53 PJ for Denmark.

As can be seen from Table 8.1, the demand for jet fuel in the Nordic countries is projected to increase from around 170 PJ in 2014 to around 210 PJ in 2025 and then decrease slightly towards 2050 to around 200 PJ.

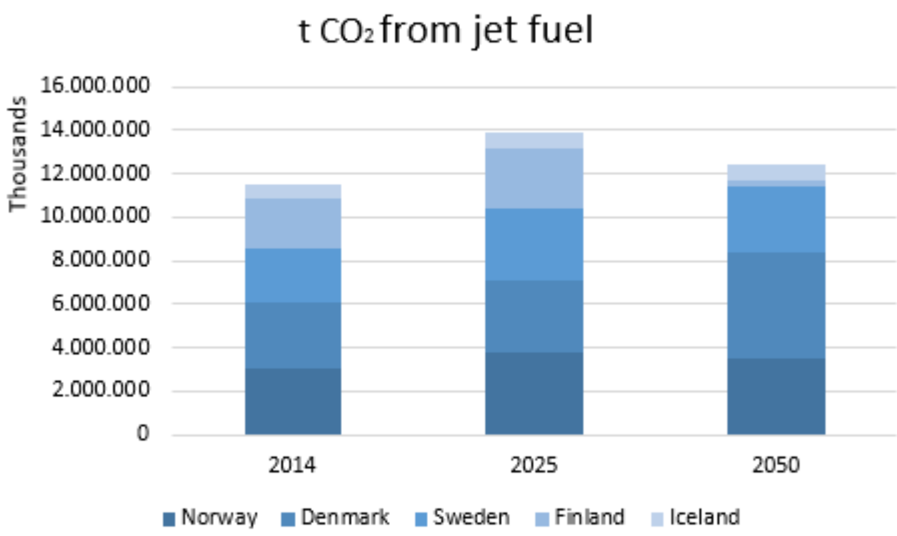


Figure 7.2: Aggregated and projected Nordic CO_2 emissions from jet fuel

Producing 200 PJ of SAF is, of course, a challenge. But with a pathway based on biomethane, hydrogen and CO_2, all technologies in the supply chain needed to produce such jet fuel already exists even without any need for change of the current jet engine technology. Technologies for jet fuel production based on bio-methane already exist in full scale in terms of the well-established gas-to-liquid, GTL technology. Some of the processes based on the feedstock of hydrogen and CO_2 exist only in smaller scale and need to be scaled-up, but many projects are presently ongoing and companies working in this field aiming at producing e.g. methane (electro-methane) or carbon monoxide or syngas from CO_2 and hydrogen. A full-scale production of jet fuel from bio-methane is, thus, already available for implementation, and a supplementing production based on CO_2 and hydrogen is judged to be so in a few years from now.

The reason for choosing a pathway based on feedstock of bio-methane, hydrogen and CO_2 is that this is judged to be the most feasible and sustainable pathway based on the criteria described in the next section.

8 Promising pathway (update)

8.1 Electric Aviation

In the past couple of years, the focus on electric aviation has increased and different activities and development projects has been initiated. Concrete projects include:

- In March 2018, Avinor and others commissioned a feasibility study on electric aviation in Norway. The study found that more than 20 destinations/routes in the Norwegian short airfield network have distances ranging from 38 – 170 km. all of which can easily be flown by a battery-powered electric aircraft.
- In November 2919, Green Flyway was launched. This is an international test arena in a sparsely populated area between Røros and Öresund airport to be used for testing electric aircrafts and drones in Nordic conditions.
- The American aircraft manufacturer ZUNUM who is funded by Boeing and JetBlue, strives to have a 12. persons hybrid airplane ready in 2022.
- Easyjet is collaborating with the aircraft manufacturer Wright Electric to produce electric aircrafts that can be implemented on shorter routes (up to 500 kilometer) in 2027.
- A Swedish startup - Heart Aerospace - claims to have their first aircraft ES-19 will take 19 passengers certified for passenger traffic in 2025. It will have an operating range of 250 miles on batteries cert enough to cover a third of domestic traffic in Sweden, and 14 percent of departures worldwide.
- Widerøe – a regional air carrier in Norway - wants to replace its aging fleet of Dash 8 turboprops operating in short-haul network with zero-emissions aircraft by 2030. They have teamed up with Rolls-Royce and received government funding to meet this target (Rolls-Royce 2019).
- Another interesting startup is Zeroavia that aims to have aircraft equipped with fuel cells powered by hydrogen market-ready by 2022 (Forbes 2019).

It is estimated that the first commercial electric aircrafts will be ready by 2022. These aircrafts will be smaller (9-12 passengers) and have a limited range. Bigger fully or partially electric aircraft (50-100 passengers) are expected to be a reality in 2030. The challenge with electric aviation is the low energy density of batteries. Extensive research is focusing on solving this problem.

Figure 8.1: Electric Aircraft (Avinor)

Electrification of aviation can be done in various degrees: Increased use of electrical components, a hybrid solution or full electrification of aircraft engines. The benefits of electric aviation are a reduction in the aircraft's climate impact, noise and potentially a reduction in operating and maintenance costs.

8.2 Power-to-jet fuel

A lot of developments have happened over the past few years to produce SAF. New developments on Power-to-fuel based on methane from biogas in combination with hydrogen based on renewable power and CO_2 captured from various industries and incineration plants is presented in the GTL-report (NISA et al. 2019).

Increasing investments in wind energy could lead to excess electricity that be transformed into hydrogen through electrolysis. Investors are increasingly interested in utilizing part of the excess production capacity to the produce of hydrogen. Hydrogen from renewable energy can together with captured CO_2 from biomass combustion could produce SAF.

Ørsted – Danish offshore wind developer has just announced the possibility of such a scheme in the Baltic sea up to 5 GW capacity.

Figure 8.2: Lillgrund Wind Power Plant

A study made by the municipalities of five major cities; Amsterdam, Oslo, Stockholm, Helsinki and Copenhagen point out, that Carbon Capture, Utilisation and Storage (CCUS) will be necessary for the cities in order to meet their goals of being CO_2 neutral within the next decade. Such a process could production fuels without any conflicts to Land use, land-use change and forestry (LULUCF) what-so -ever.

Figure 8.3: Picture 1: ARC-CC Carbon Capture in planning

Picture 2: Test of carbon Capture on waste incineration at Klementsrund, Oslo Norway

It also an increasing interest from the refining industry to consider co-processing and the transition from fossil-based crude oil to green alternatives.

The Shell refinery in Denmark has just revealed they aim to abandon fossil fuel refining and only have non-fossil production from 2035.

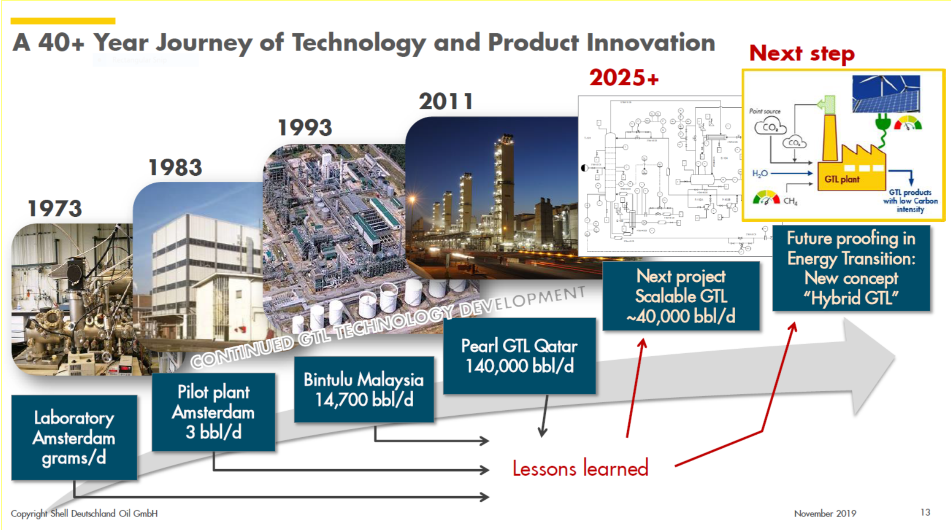


Figure 8.4: A 40+ Year Journey of Technology and Product Innovation (Shell)

Equinor are also considering production of Hydrogen from Natural Gas with CO_2 capture and storage. The company requests government support to cover the cost of capturing CO_2. Provided that the energy use is based on renewable energy the hydrogen could be considered "green" (Energiogklima 2019).

9 International actors

There is a big international focus on the environmental impact of aviation and the need for action is compounded by the fact that the sector is in strong growth. A lot of different actors are therefore working on developing and producing SAF. The maps below show some of the emerging actors around the world.

Figure 9.1: Map of Emerging SAF-production 2018 (Nordic Energy Research)

While no major breakthroughs have occurred yet when it comes to deployment, several projects are expected to be in operation on a commercial scale within 5 years' time.

Shell is supports SkyNRG in developing one of the first dedicated European SAF production plant. The plant will be located in Delfzijl, Netherland and is schedule for commissioning in 2022. The plant will produce 100.000 tons of SAF a year (SkyNRG [2]).

International Airlines Group (IAG) and Velocys is a part of a UK project that want to establish a production of aviation fuel from household waste. Production is scheduled to start in 2022. The plant will produce around 30,000 tonnes a year – delivering CO2 savings of some 60,000 tonnes annually. The UK government is supporting the project by awarding Velocys a grant on the grounds of SAF's potential to help meet the UK's low-carbon vision (EASA 2019:49).

10 Abbreviations

ADAM - Annual Danish Aggregate Model

ASTM - American Society for Testing and Materials

ATAG - The Air Transport Action Group

ATM - Air Traffic Management

AtJ - Alcohol to Jet

BDL - Brancheforeningen Dansk Luftfart (Danish Aviation)

BIOCCS - CCS applied to a biogenic source of CO_2 (bio-based power-plant)

CAAFI - Commercial Aviation Alternative Fuels

CCS - Carbon Capture and Storage

CCUS – Carbon Capture Utilization and Storage

CHP - Combined heat and power

CH - Catalytic Hydro thermolysis

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

DAC – Direct Air Capture (of CO_2)

DCA - *Danish Centre for Food and Agriculture*

DSHC - Direct Sugar to Hydrocarbons

EASA – European Aviation Safety Agency

EOF - Energi- og Olieforum

EPA - Environmental Protection Agency

ETS - Emissions Trading System

EU RED - European Union Renewable Energy Directive

FAME – Fatty Acid Methyl Esters

FAO - Food and Agriculture Organization of the United Nations

FCC - Fluid Catalytic Cracking

FRL - Fuel Readiness Level

FSC - Forest Stewardship Council

FSRL - Feedstock Readiness Level

FT- Fischer-Tropsch

FTE - Full Time Equivalents

GHG - Greenhouse Gas

GFAAF - Global Framework for Aviation Alternative Fuels

GWP - Global Warming Potential

HDCJ - Hydrotreated Depolymerized Cellulosic Jet

HEFA - Hydrotreated Esters and Fatty Acids

HTL - Hydrothermal Liquefaction

IAG - International Airlines Group

IATA - The International Air Transport Association

ICAO - International Civil Aviation Organization

ILUC - Indirect Land Use Change

IPCC - Intergovernmental Panel on Climate Change

ISO - The International Organization for Standardization

LCA - Lifecycle Assessment

LHF – Liquid hydrocarbon fuels

LUC - Land Use Change

LULUCF - Land Use, Land Use Change and Forestry

MASBI - Midwest Aviation Sustainable Biofuels Initiative

MEC - Maabjerg Energy Concept

NISA - Nordic Initiative for Sustainable Aviation, Nordic Countries

NREL - National Renewable Energy Laboratory

OECD - Organization for Economic Co-operation and Development

PEFC - Programme for the Endorsement of Forest Certification schemes

PJ - Petajoule (equivalent to 10^{15} Joule or $2.78 \cdot 10^{5}$ MWh)

RSB - Roundtable of Sustainable Biomaterials

SAFUG - Sustainable Aviation Fuel Users Group

SARPs – Standards and Recommended Practices

SAF – Sustainable Aviation Fuel

SAK - Synthetic Aromatic Kerosene

SES - Single European Sky

SESAR - Single European Sky ATM Research

SK - Synthetic Kerosene

SKA - Synthetic Paraffinic Kerosene with Aromatics

SMEs - Small and Medium sized Enterprises

SPK - Synthetic Paraffinic Kerosene

TJ - Terajoule (equivalent to 10^{12} Joule or 278 MWh)

USGS - United States Geological Survey

WWF - World Wildlife Fund

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