



IEA Bioenergy, Task 33 –Gasification of Biomass and Waste

Workshop

Aviation Biofuels through Biomass Gasification

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Introduction

Traditional jet fuel is a hydrocarbon, almost exclusively obtained from the kerosene fraction of crude oil.

Worldwide, flights produced 770 million tonnes of CO₂ in 2015, aviation was responsible for 12% of CO₂ emissions from all transport sources. A third of the operating costs of airlines is spent on fuel: 33%, which is up from 13% in 2001. The proportion is likely to rise further as fuel prices go up. So this alone is a major incentive for the whole industry to focus on fuel efficiency (source: www.atag.org).

For aviation, advanced liquid biofuels are the only low-CO₂ option for substituting kerosene, as they have a high specific energy content. Gaseous biofuels and electrification are definitely not options for air transportation. Advanced biofuels for aviation should use a sustainable resource to produce a fuel that can be considered as substitute for traditional jet fuel (Jet A and Jet A-1), while not consuming valuable food, land and water resources.

A big challenge facing the use of biofuels in aviation is the stringent quality standards for jet fuel. Safety and fuel quality specifications are of tremendous importance in the aviation sector, however, these are not limiting the use of biofuels. The technical requirements for aviation biofuels are:

- high performance fuel, that can withstand a range of operational conditions
- fuel that does not compromise safety
- fuel that can directly substitute traditional jet fuel aviation
- fuel that meets stringent performance targets

Fuels from biomass have a great potential: In the short term, they will be able to replace part of our fossil energy sources and will contribute to an efficient mix of renewable energies. Covering a wide range of different fuels such as kerosene, diesel, and gasoline, BTL (biomass-to-liquid) fuels of the second/third generation offer various advantages over bioethanol or biodiesel. Almost any kind of biomass, whose origin and use do not collide with those of plants grown for the food industry, can be used for biofuel production. Dry, cellulose-rich residual biomass from agriculture, forestry production, and landscaping is particularly suited for use in fuels.

Aviation Biofuels through Biomass Gasification

workshop presentations

Presentation of GAFT for Aviation Biofuels through Biomass Gasification GAFT/IEA workshop

Roger A. Khalil

GAFT is a competence building project, which is financed by the Research council of Norway and industry partners. The project duration is 4 years (2015-18) and total budget is 20 MNOK.

The partners of the project are:

- SINTEF Energi AS – project leader
- NTNU
- Stiftelsen SINTEF
- SP Energy Technology Center AB
- Johnson Matthey
- Avinor
- Silva Green Fuel AS
- Viken Skog
- CAMBI ASA
- ECOPRO AS
- The Research Council of Norway

The **objective** is to contribute to accelerated implementation of liquid biofuels production in Norway.

Sub-objectives:

- Support implementation of pre-treatment methods, with particular attention to feedstock mixing and torrefaction that allow the use of challenging biomass in entrained flow (EF) gasification
- EF gasification technology improvement through lab experiments and modelling
- Fischer-Tropsch synthesis development for medium scale (150 – 500 MW thermal input)
- Techno-economic assessment of the overall biofuels production process with integration of heat recovery for relevant Norwegian business cases (Follum and Tofte sites)
- Education of highly skilled candidates within this area and training of industry partners

GAFT: Value chain model for production of liquid biofuels from co-processing low grade woody biomass and organic waste

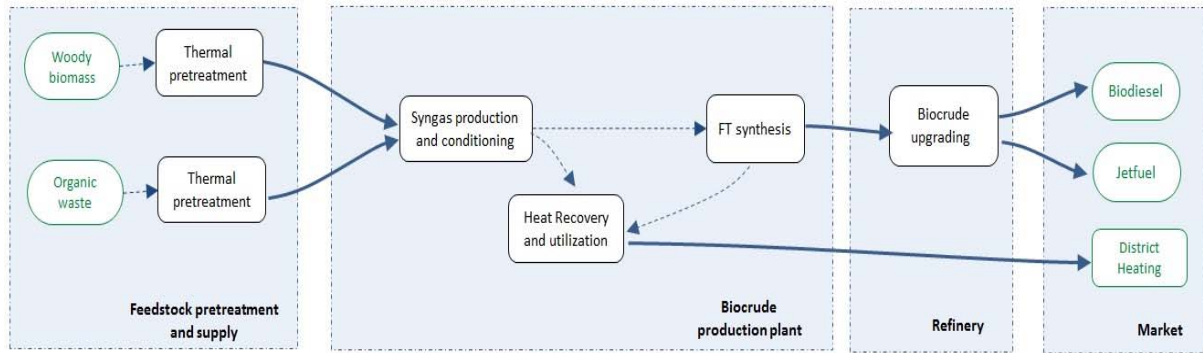


Figure 1: Value chain model - GAFT

Feedstock:

- Stem wood (debarked)
- Stump wood (shredded into pieces)
- Bark (chipped)

Thermal pretreatment – torrefaction

- Temperature 225, 275 and 300°C
- Residence time 30 and 60 min.

The reactor will primarily be use to

- Study if a fuel is suitable for gasification
- Study soot and tar formation from gasified biomass
- Provide validation data to numerical models

The test parameters

- Fuel flow rate: 2 kg/h ~10-15 kW
- Number of operators: 2
- Pressure: 10 bar(g)
- Wall heater temperature: 1500 °C
- Fuel particle size distribution: 50 µm-
- Continues operating time: 6 h

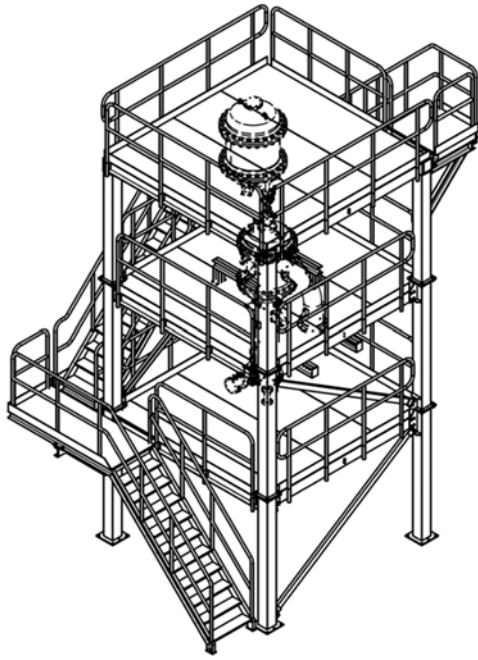


Figure 2: The reactor



Figure 3: Advanced testing facilities

The role and importance of aviation biofuels

Sierk de Jong, Utrecht University and SkyNRG

SkyNRG's mission is to play a pioneering role in creating a long-term sustainable future for aviation. SkyNRG is the global market leader for sustainable jet fuel, supplying more than 20 carriers across 5 continents in the world.

SkyNRG: the market maker for biojet fuel



Today, EU aviation causes 180 Mt CO₂, without any action it could increase to about 580 Mt CO₂ in 2050. A possibility of CO₂ reduction is through renewable fuel from biomass, so-called biojet.

To date, the uptake of biojet has been limited by the absence of production capacity and high price premiums. But that is about to change:

- Dedicated production capacity. The AltAir refinery will be the first biojet factory in the world.
- Certification of Hydrotreated Renewable Diesel (HRD). Unlocking 3 million tonnes of production capacity.
- Government incentives that apply to aviation, mainly in the EU and the US. Decreasing the biojet premium.



Figure 4: Overview of HEFA jet fuel and HRD biorefineries

The development of additional conversion pathways in the coming decades is essential to reach scale.

Pathway	ASTM certified	Description	Target feedstock
<u>Hydrotreated Esters and Fatty Acids (HEFA)</u>	✓	Converts oil to jet via <u>deoxygenation</u> with hydrogen and cracking	Oils and fats
Gasification and Fischer-Tropsch (FT)	✓	Converts any carbon-rich material (e.g. biomass) into sugars which is then catalytically converted to jet	All biomass & MSW
Alcohol to Jet (ATJ)	✓	Uses alcohols derived from sugars and starches and converts them to jet via <u>dehydration</u> , <u>oligomerization</u> and hydrogenation	All biomass, MSW and waste gasses
Direct sugars to hydrocarbons (DSHC)	✓	Ferments plant sugars and starches to hydrocarbons which are subsequently upgraded to jet fuel	Sugars (also cellulosic sugars)
Hydrotreated Depolymerized Cellulosic Jet (HDCJ)		Converts any carbon-rich material into a bio-crude oil via thermochemical <u>depolymerization</u> which can then be upgraded to jet	All biomass
Hydrotreated Renewable diesel (HRD/Green Diesel)		Converts oil to deoxygenated diesel using <u>hydroprocessing</u>	Oils and fats

And some more in the pipeline, including catalytic hydrothermolysis, aqueous phase reforming, co-processing of oils and fats in existing refineries

Impact of torrefaction on fuel properties of woody biomass

Liang Wang, SINTEF

Torrefaction improves properties of woody biomass for more efficient gasification processing.

Experiment and method at SINTEF:

Feedstock

- Stem wood (debarked): 1 x 1 cm cubes
- Bark: chipped into pieces (~5-7 cm)
- Stump: shredded into pieces (~3-5 cm)

Torrefaction experiment

- Batch reactor with around 80 grams sample for each run
- Torrefaction temperature: 225 °C, 275 °C and 300 °C
- Residence time: 30 and 60 min
- Heating rate 10 °C/min
- Continuous nitrogen purge

Measuring of mass yield

Assessment of physical properties of raw and torrefied residues

- Energy consumption for grinding (IKA MF 10 mill) + energy consumption logger
- Particle size distribution of ground samples (FRITSCH vibration sieve shaker)
- Morphology investigation of ground samples (Scanning electron microscopy)

Results and discussion

Torrefaction mass yield

- Decrease of mass yield with increase of torrefaction temperature and residence time
- Differences of mass yield of three woody biomasses



Figure 5: Preliminary assessment of raw and torrefied woody biomasses

Grindability of raw and torrefied woody biomasses

- Significant reduction of energy consumption for grinding torrefied stem wood and stump
- Minor effects of torrefaction treatment on energy consumption for grinding bark
- Loss of tenacious nature of tested fuels after torrefaction

Particle size distribution of ground raw and torrefied stem wood

- Evident particle size reduction of the torrefied stem wood
- More uniform and narrower particle sizes of ground stem wood torrefied at 275 and 300 °C

Particle size distribution of ground raw and torrefied bark

- Significant reduction of particles with size in the range of 600-1000 µm
- Increase of fraction of particles smaller than 63 µm
- Small effect of torrefaction on ground bark size distribution as torrefaction temperature higher than 275 °C

Particle size distribution of ground raw and torrefied stump

- Better grindability compared to stem wood
- Minor fraction of particles with size in range 600-1000 µm
- Pronounced increase of particles with sizes smaller than 63 µm

Compositional analysis of raw and torrefied woody biomass

- Different compositions of raw stem wood, bark and stump
- Decrease of hemicellulose along increase of torrefaction temperature
- Substantial decomposition of cellulose for bark sample at 275 °C
- Significant decrease of hemicellulose and cellulose content at 300 °C

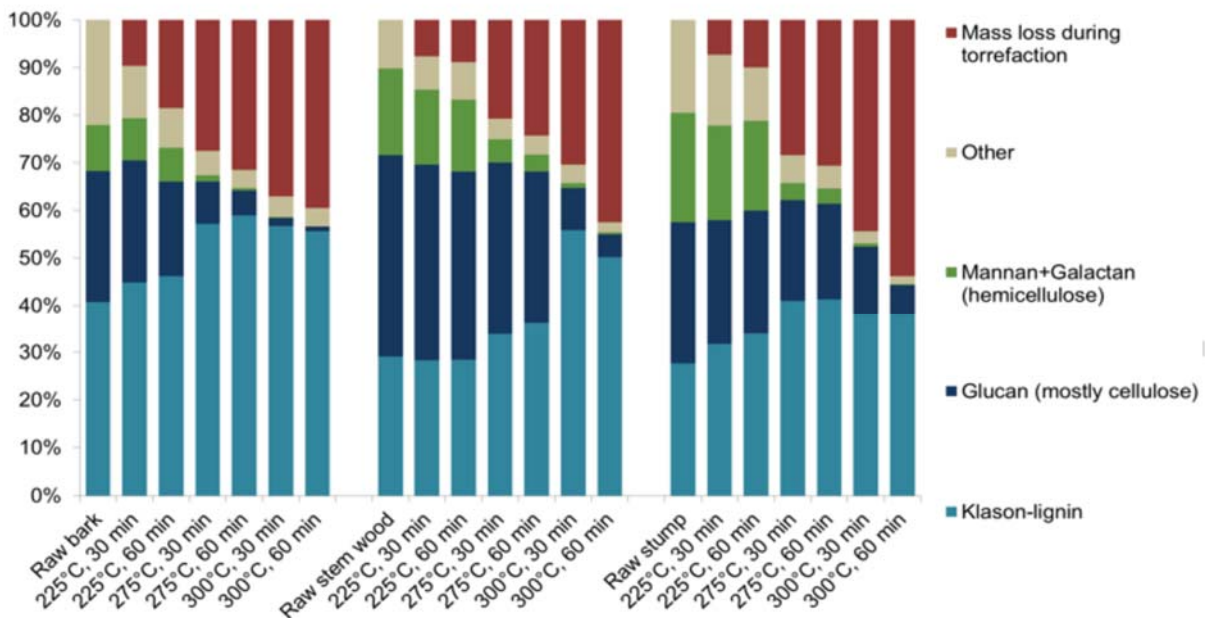


Figure 6: Compositional analysis of raw and torrefied woody biomass

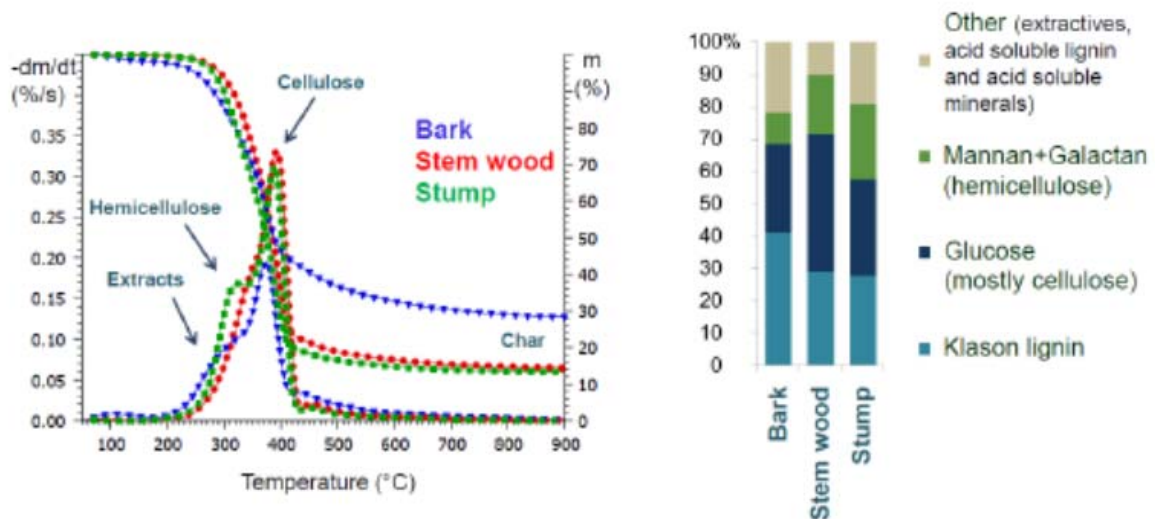


Figure 7: Compositional and TG-MS analysis of raw and torrefied woody biomass

Conclusions:

Torrefaction operation conditions and biomass properties have significant effects on amounts of remaining solid residues (mass yield)

- Grindability of stem wood and stump can be significantly improved via torrefaction treatment
- The energy consumption for grinding torrefied stem wood and stump are dramatically reduced compared to non-torrefied material
- Torrefaction significantly influences particle size distribution of ground stem wood and stump
- Energy used for grinding samples and sizes of ground samples can be further decreased with high temperature torrefaction process or/and longer torrefaction time
- Torrefaction causes considerable reduction of hemicellulose content and partial decomposition of cellulose
- At high conversion temperature, torrefied feedstocks have evidently different conversion behaviors, due to change of chemical compositions of the stem wood, bark and stump during the torrefaction process

Bioliq® - BtL pilot plant

Thomas Kolb, KIT

Bioliq® is one solution for high quality fuels or fuel components produced from sustainable biomass. The problem to be solved is the widely distributed availability of biomass versus the need of large scale, centralized fuel production plants required by economies of scale. The solution is the de-centralized pre-treatment of biomass to obtain an intermediate energy carrier of high energy density (bioliqSyncrude), which can be transported economically over long distances to supply an industrial plant of reasonable size for synthetic fuel production. By chemical synthesis fuels will be produced which can be used as drop-in fuels or as stand-alone products completely compatible to exiting diesel or gasoline type fuels. Nearly any type of dry biomass can be utilized for this process; focus is set on by-products and residues of agriculture, forestry or landscaping.

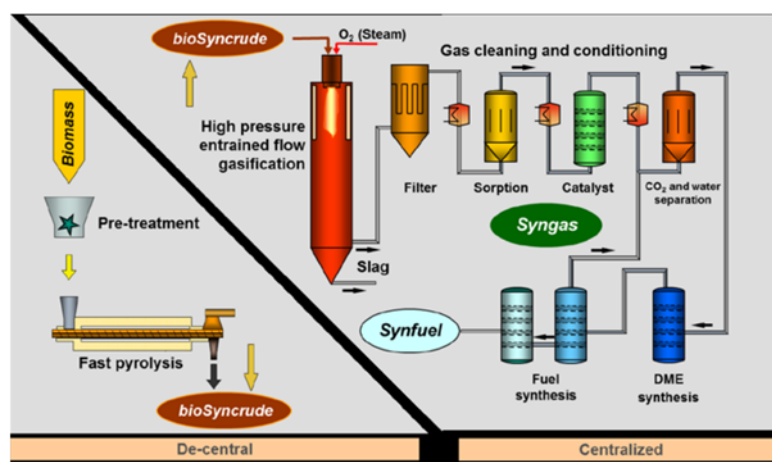


Figure 8: The Bioliq® BtL Process

BtL residual biomass to gasoline

- de-central feedstock pretreatment
- central gasification / synthesis
- pilot plant with 500 kg/h straw pyrolysis, 5 MW gasification
- fast pyrolysis for slurry production from straw
- entrained flow gasification
- high temperature gas upgrading
- direct DME gasoline synthesis

	Stage I	Stage II	Stage III	Stage IV
Process	Fast pyrolysis	High pressure entrained flow gasification	Gas cleaning and Synthesis I	Synthesis II
Product	BioSyncrude	Synthesis gas	Dimethyl ether	Gasoline
Capacity	2 MW (500 kg/h)	5 MW (1 t/h)	150 kg/h	< 100 l/h
Realization	2005 - 2008	2008 - 2013	2009 - 2011	
State	In operation	In operation	In operation	

Table 1: Status of the bioliq project

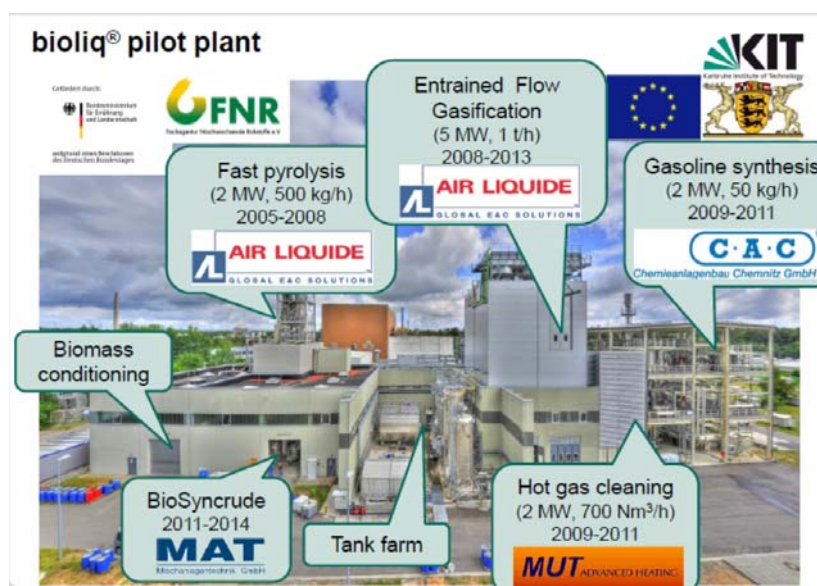


Figure 9: Bioliq plant

Helmholtz Virtual Institute for Gasification Technology – HVIGasTech

HVIGasTech represents a new level of scientific collaboration in the field of thermo-chemical processes for fuel conversion at high pressure. The research work is primarily focused on the modeling of the oxygen-blown, high pressure gasification process of solid/liquid fuel in an entrained flow reactor.

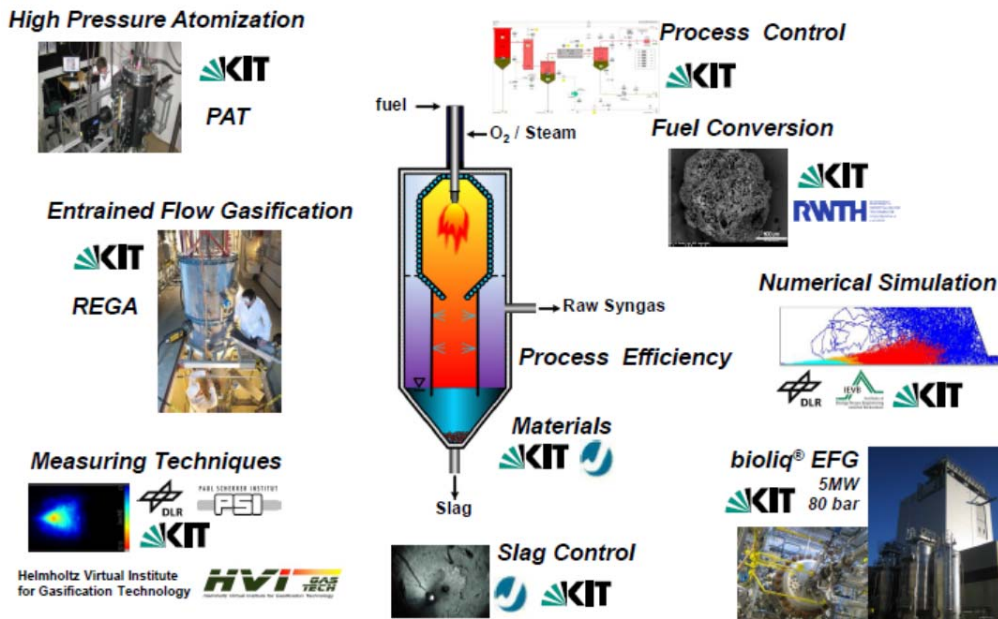


Figure 10: Integrated research on gasification

Güssing: Small scale gasification-FT


Reinhard Rauch, Vienna University of Technology, bioenergy 2020+

Project GreenFly

- R&D project on kerosene from biomass, with focus on usage in Wankel engine

Partners:



Funded by:  FFG

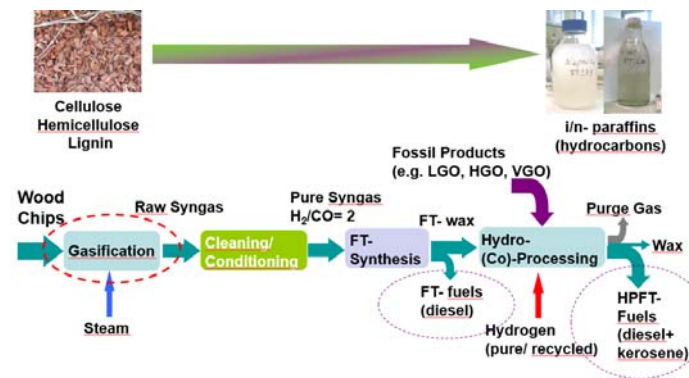


Figure 11: Synthetic biofuels (FT- route)

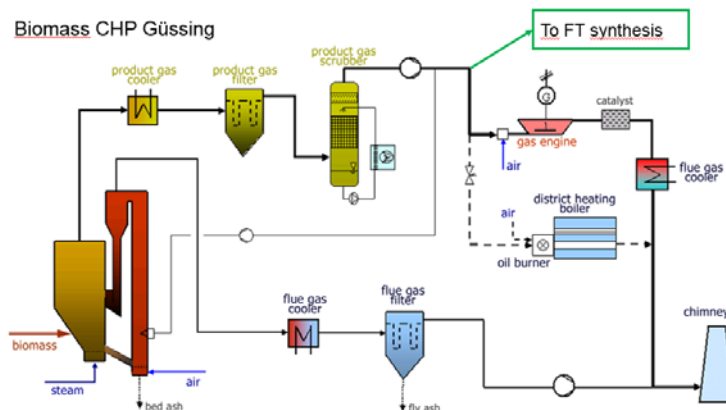


Figure 12: Experimental work (gasification plant in Güssing)

FT lab scale plant

- In operation since 2005
- 5-10 kg/day of FT raw product
- Slurry reactor, because of excellent heat transfer and easy scaling up
- Gas treatment removes Sulphur to below 10 ppb

- Cobalt and Iron- based catalyst were tested
- Fully automatic

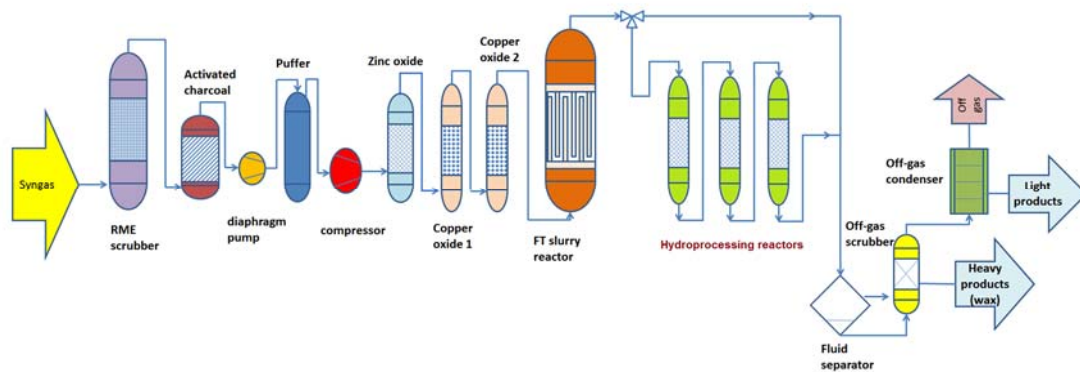


Figure 13: FT lab scale

Value of raw FT products:

- Naphtha: worse than gasoline (~300-500 EUR/t)
- Diesel: excellent quality, competes with NextBTL on the market (~800-1000 EUR/t)
- Waxes: valuable chemicals, where a market already exists

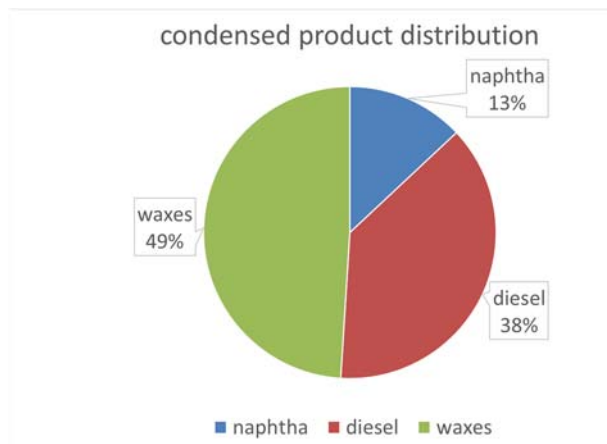


Figure 14: Condensed product distribution

- Waxes can be converted to kerosene with a conversion efficiency of about 20-50% (boiling range 150-300°C)
- Cold flow behaviour in the range of -30 to -60°C freezing point (-40°C is the limit of ASTM)
- Most samples of kerosene fulfil ASTM D7566, Annex A1 for F-T SPK* (F-T SPK have been approved as maximum 50% blend stock in jet fuel)
- On Hydroprocessing more catalysts with different isomerisation behaviour should be tested

Work planned – 1 barrel/day

- Economic optimisation of gas treatment
- Scaling up of Slurry FT reactor
- Long term tests for FT synthesis with wood based synthesis gas
- Upgrading of the raw FT products
- Testing of FT products

Actual reactor setup in the pilot plant:

- *Once through flow* without recycling of offgas.
- Ratio height diameter H/D \approx 20.
- Coupled heating devices.
- Conical gas distributor geometry.

The aim is:

- Evaluation of different flow configurations:
 - Once Through Flow
 - With Recycling of Offgas
 - Recycling + Steam Reforming
- Height/Diameter \approx 7.
- Integration of a heat exchanger system.
- Flat gas distributor geometry

Status and Developments in Fischer-Tropsch Synthesis

Erling Rytter, NTNU

Key Challenges in Biomass-to-Fuels

- There are significant implications on the Fischer-Tropsch synthesis and on overall process design

Challenging feedstock

- High water content
- High oxygen content
 - Very low energy efficiency
 - Low carbon efficiency
- Moderate H₂/CO ratio
 - Need to import hydrogen or release CO₂
- Distributed feedstock
 - Optimal process integration is difficult
- High level of impurities
 - Requires intensive impurity removal and control

Catalyst

- Iron or cobalt
 - The hydrogen issue
 - Iron will produce needed hydrogen in-situ by the water-gas-shift reaction
$$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$$
 - Cobalt needs a separate WGS reactor
 - *The best choice is not obvious. Need process simulations.*
 - Cobalt has significantly lower deactivation rate
 - Cobalt provides more desired product/less byproducts (oxygenates)
 - Iron is cheap

Reactor technology

- Fixed-bed
 - Long established scale-up methodology
 - Strong economy of scale to maximum size
 - Plug flow behavior
 - “Simple” operations
 - Very high strength catalyst not required
 - Generally excellent catalyst/wax separation
 - Bed inlet acts as poison removal zone
 - Simple, in-situ catalyst regeneration process
- Slurry
 - Isothermal behavior – thermally stable
 - Generally robust to upsets
 - Very strong economy of scale
 - Accommodates high activity catalysts
 - Low DP (liquid head and gas distributor)
 - Small particles not mass transfer limited
 - Catalyst replacement on line

- High on-stream factor
- Tail gas recycle only to achieve high conversion
- Microchannel
 - Isothermal behavior – thermally stable
 - Extremely robust to upsets
 - Strong economy of mass manufacturing
 - Accommodates high activity catalysts
 - Installed spares relatively cheap
 - High on-stream factor
 - Tail gas recycle only to achieve high conversion
 - Extremely high volumetric productivity
 - Ease of modularization

Property	Tubular fixed-bed	Slurry bubble column	Microchannel
Flow pattern	Plug flow	Back-mixed	Plug-flow
Reactor design maturity	Known	Known by licensors	Novel
Heat transfer limitations	High	Low	Low
Mass transfer limitations	High	Low	Medium
Thermal stability	Poor	Excellent	Excellent
Catalyst activity	Low	High	High
Global reactor reaction rate	Low	Low	Medium
Differential pressure	Moderate	Low	High
Gas recycle	High	Moderate	Moderate
Catalyst-wax separation	Excellent	Known by licensor	Excellent
Catalyst strength requirement	Moderate	High	Moderate
Regeneration equipment (ease)	Minimal	Needed	Minimal
Regeneration efficiency	Moderate	High	Moderate
Catalyst replacement	Off-line	On-stream	Off-line
On-stream factor	Moderate	High	Moderate
Upset robustness	Low	Moderate	Low
Modularization	Medium	Medium	High
Economy of scale	Moderate	High	Low
Boiler feed water quality	Low	Low	Moderate
Capital cost	High	High	High
Overall technology readiness	Excellent	Moderate-proven	Demo-scale

Table 2: Rytter’s provisional FT reactor scorecard

Process design FT

- The H₂/CO ratio
 - Consumption ratio is ca. 2.1
 - Feed to the FT reactor should, however, be significantly lower than 2.
 - Composition of the syngas depends heavily on the gasification technology and operation.
 - The syngas composition needs to be predictable within reasonable ranges.
- Conversion and recycle
- Product separation and upgrading
 - Jetfuel
- Overall process design
 - FT integration with biomass treatment and gasification
 - Water management

Recommendations – conclusions

- a. Select cobalt catalyst
 - b. Select slurry reactor
- but most importantly:*
- c. Select gasification technology compatible with FTS
 - d. Develop an integrated and optimized process design
 - Basic flow-sheet
 - Energy efficiency
 - Carbon efficiency
 - Water management
 - e. Consider hydrogen added from other energy sources
 - Water electrolysis most realistic in short term

FT- Catalysts for aviation fuel from biomass

Rune Myrstad

Influence of FT operating conditions on product selectivity				
Selectivity parameter	Operating parameter being increased			
	Temperature	Pressure	Space velocity	H ₂ :CO ratio
Carbon number distribution	Lower α -value	Higher α -value	No change ²	Lower α -value
Methane selectivity	Increases	Decreases	Decreases	Increases
Syngas conversion	Increases	Increases	Decreases	complex

Table 3: Influence of FT operating conditions on product selectivity

Parameter	Co catalyst	Fe catalyst
Operating temperature	190–240 °C Used only in LTFT reactors High temperature increases CH ₄ selectivity and causes catalyst deactivation	200–350 °C. Operates both in HTFT and LTFT reactors
Feed gas	Syngas with H ₂ :CO ratio in the range of 2.0–2.3, due to very low WGS activity	Flexible H ₂ :CO ratio in the range 0.5–2.5, due to high WGS activity
Activity	More active at higher CO conversions i.e., lower space velocities	More active than Co at higher space velocities
Product spectrum	Primary products are n-paraffins with marginal production of α -olefins Higher paraffin/olefin ratio $\alpha=0.85-0.92$	Primary products are n-paraffins with considerable production of α -olefins Lower paraffin/olefin ratio $\alpha=0.65-0.92$
Operating plants	Shell Middle Distillate Synthesis, Oryx-GTL facility-Sasol	Sasol Slurry process (LTFT), Sasol-SAS (HTFT), Mossgrass facility
Promoters	Noble metals (Ru, Rh, Pt, Pd); Oxide promoters (ZrO ₂ , La ₂ O ₃ , CeO ₂)	Alkali metals (Li, Na, K, Rb, Ca)
Life & cost	Longer life time, more expensive	Lower life time, less expensive

Table 4: Comparison of Co and Fe catalysts

In situ hydrocracking

- Upgrading of FT-wax commonly performed *ex situ* by hydrocracking
- Extensive studies in literature on *in situ* hydrocracking. Combinations of Co- and Fe-catalyst with zeolites as mixed or bi-functual catalysts are investigated
- + Selectivity control possible
- Zeolites deactivates much faster than FTS-catalyst

BtL installations.				
Organization	Year	Gasifier	Scale	Details
Solena Fuels, <i>Green Sky</i> (Essex, UK)	2015	Solena plasma gasification	Commercial • 1157 bpd jet fuel • Co catalyst • Velocys micro-channel reactor	• Municipal & commercial waste
Red Rock Biofuels (Oregon, USA)	2017	TRI steam reformer	Commercial • 460 t/d biomass feed • 1100 bpd liquid fuel • Co catalyst • Velocys reactor	• Forest & saw mill waste
Sierra Biofuels, <i>Fulkrum Bio-energy</i> (Nevada, USA)	2016	TRI steam reformer	Commercial • 400 t/d MSW feed • 657 bpd liquid fuel • Co catalyst • Velocys reactor	• Municipal solid waste
SYNDIESE, <i>CEA</i> (Nevada, USA)	2015	Entrained flow, O ₂ blown, high pressure gasifier	Commercial	• Forest & agricultural waste • 205 t/d biomass feed • 530 bpd liquid fuel
CHOREN, [183,184] <i>Sigma Plant</i> (Freiberg, Germany)	2010	Carbo-V gasification	Commercial • 5000 bpd liquid fuel • Co catalyst • Fixed bed reactor • temporarily discontinued	• 3044 t/d dry biomass
Velocys [185] (Gussing, Austria)	2010	Dual Fluidized bed gasifier	Pilot • 1 bpd FT products • Micro channel reactor • Co catalyst	• 150 t/d dry biomass
CUTEK [185] (Germany)	2010	CFB, steam-O ₂ gasification	Laboratory • Fixed bed, Co catalyst • 2500 hours of gasifier operation • 900 hours of FT operation • 150 ml/day FT products	• 2.7 t/d dry biomass

Table 5: Current BtL installations

GAFT: SP3 FT synthesis

Background

- EF of biomass yields synthetic gas with $H_2:CO \leq 1$
- For FTS ideally $H_2:CO \approx 2$, achieved by WGS step after EF ($CO + H_2O \leftrightarrow CO_2 + H_2$)
 - For $H_2:CO = 2$, Cobalt based catalysts normally preferred, maximising wax yield before cracking into diesel fraction
 - Co based FT catalysts, low tolerance for impurities (catalyst poisons) in synthetic gas
- $H_2:CO$ adjustment avoided by use of Fe-based catalysts (intrinsic WGS activity)
 - Eliminate a process step
 - Fe based FT catalysts, higher tolerance for impurities in feed gas
- Fe-based FTS, typical > 300 °C, yielding light hydrocarbons and chemicals

GAFT: Fe based medium to high temperature FTS (240 – 270 °C)

- Aims to tune product into diesel range
- Simplified product upgrading (eliminate cracking step?)
- Promoted Co-based catalyst included in screening phase (after discussions with JM)

Experimental

- 4 parallel Fixed-bed reactors, ½" o.d, ca. 30 cm long
- Currently, on-line GC for light gases. GC for wax analyses are in progress.

Preliminary results from 4 catalysts

Fe-Cu/TiO₂

Fe-Cu-K/SiO₂

Co/TiO₂/Al₂O₃

CoMn/TiO₂

H₂:CO = 1.0, H₂:(CO+CO₂) = 1.7 (with 0 and 5 % CO₂) and H₂:CO = 2.1, 20 bar,
210-270 °C

Summary and further work

- From the Fe catalysts, Fe-Cu-K-SiO₂ most promising
- Both Co-catalysts interesting performance and apparently better selectivity than the Fe catalysts.
- Considering to include some supported Fe-catalysts
- Modified versions of the Co-catalysts are upcoming
- Tests with higher (up to 20%) CO₂-content and low H₂:CO to be performed on selected Fe and Co catalysts
- Analyses of wax fractions is prerequisite for deciding catalyst choice
- Further process conditions to be included on selected catalyst(s)

The viability of renewable jet fuel – a general overview

Sierk de Jong, Utrecht University

The viability of renewable jet fuels (RJF) depends on on its

- Technological viability
- Sustainable viability
- Economic viability

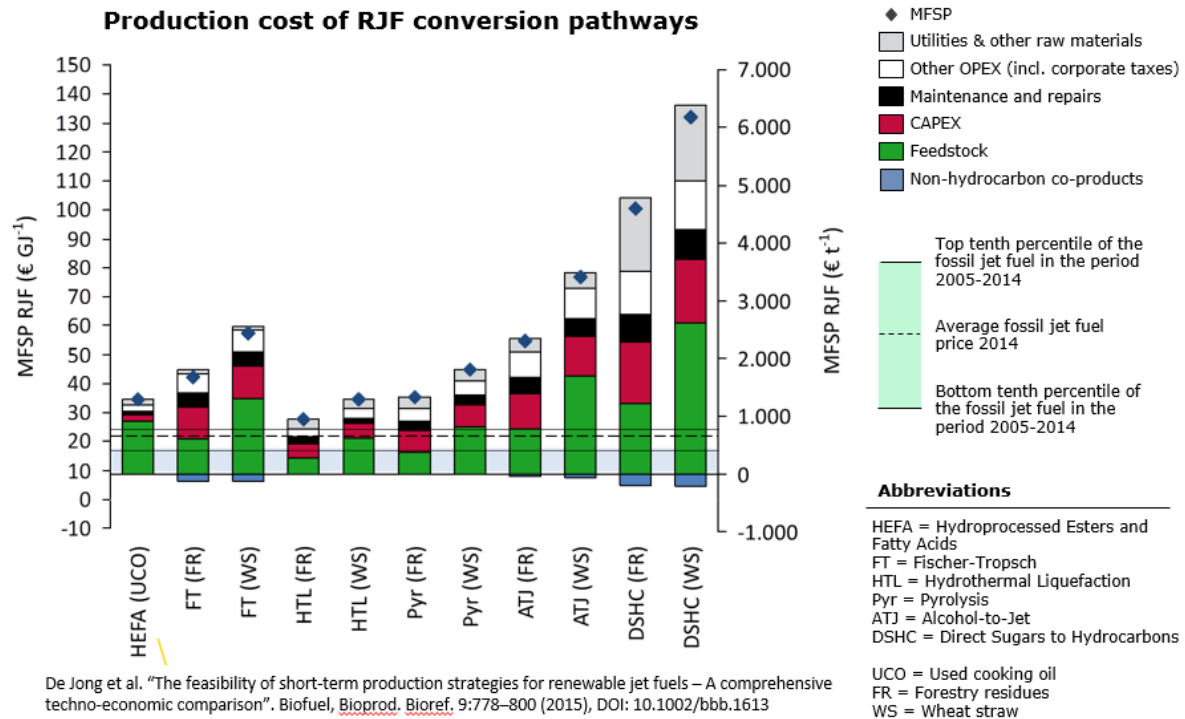


Figure 15: Comparison of production costs of renewable jet fuel conversion pathways

As can be seen in the figure above, at the moment, none of the assessed conversion pathways can reach fossil jet fuel prices. That is why, in the future a cooperation of multiple stakeholders will be necessary.

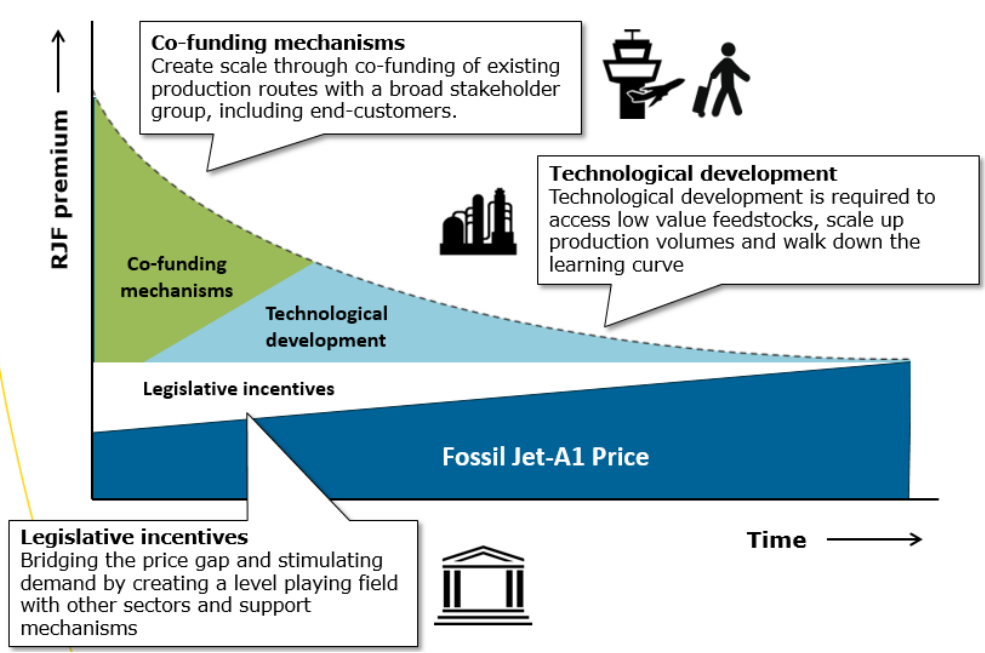


Figure 16: Future scenario of renewable and fossil jet fuel prices

Strategies for production of jet-biofuels via EF gasification and FT Synthesis

Gonzalo del Alamo & Rajesh S. Kempegowda, SINTEF

Usage of local biomass, decentralized conversion to biocrude and centralized upgrading liquid fuels in existing oil refineries can be seen as an optimal strategy for production of jet biofuels.

Feedstock	Feedstock kTons/year	Jet biofuel GWh/year	Jet biofuel Mill. liters / year
Forest wood for logs and chips	1380	5175	542
Forest residues (thinnings, top and branches)	960	3600	377
Wood from cultivated landscape	210	862,5	90
Straw and cereal residues	225	1035	108
Sludge	4800	2925	306
MSW	1800	1120	117

Table 6: Norwegian biomass potential

Norwegian biomass potential enables production of 1,5 millions liters of aviation fuel per year, which means 300% of total aviation fuel in Norway and about 5% total consumption of aviation fuel in Europe.

The value chain model presented included feedstock supply, biocrude production, gasification and syngas cooling and quench, CO₂ capture and compression, FT synthesis, biocrude production and costs.

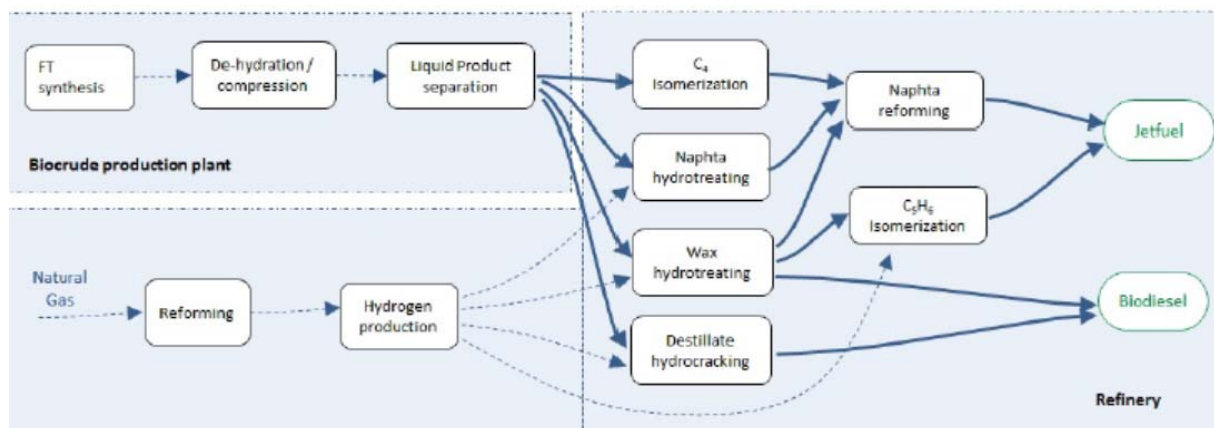


Figure 17: Biocrude upgrading

Recent developments in gasificationbased aviation biofuels in the U.S.

Zia Haq, Borislava Kostova, U.S. Dept. Of Energy, Craig Brown, NREL

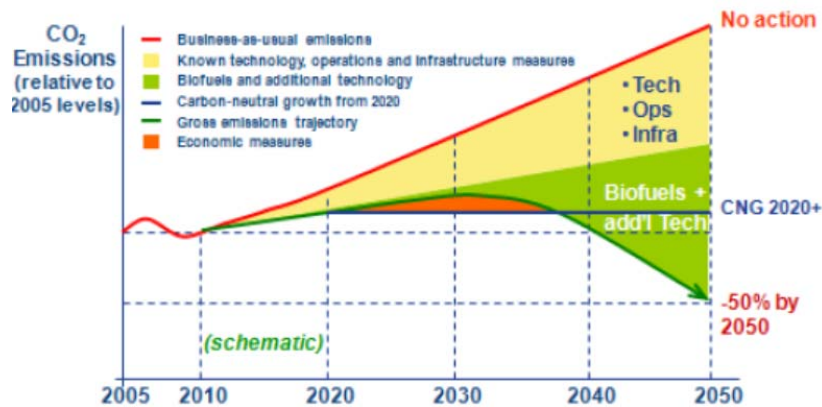


Figure 18: Aviation's emissions reduction roadmap

National Academies of Sciences, Engineering, and Medicine published May 24, 2016 a report on Commercial Aircraft Propulsion and Energy Systems Research Reducing Global Carbon Emissions www.nap.edu/catalog/23490

Recommendation was to implement a national research agenda that places the highest priority on the following approaches:

- Advances in aircraft and propulsion integration
- Improvements in gas turbine engines
- Development of turboelectric propulsion systems
- Advances in sustainable alternative jet fuels (SAJF)

In 2013, USDA and FAA made a commitment to the aviation industry to help meet their goals with the Farm to Fly 2.0 agreement. This effort seeks to enable the use of commercially viable and sustainable renewable jet fuel in the United States.

In July 2014, Secretary Moniz signed an amendment officially making DOE the newest partner agency in this significant initiative.

Senate FY16 appropriations language requests DOE to indicate commitment to Farm to Fly 2.0.



Figure 19: Airline offtake agreements (more in process)

BETO (Bioenergy Technologies Office) reduces risks and costs to commercialization through RD&D, the main tasks are to:

- Accelerate the commercialization of advanced biofuels and bioproducts through RD&D of new technologies supported by public-private partnerships
- Develop technologies to enable the sustainable, nationwide production of biofuels compatible with today's transportation infrastructure
- Validate at least one pathway for \$3/GGE* hydrocarbon biofuel with ≥50% reduction in GHG emissions relative to petroleum by 2017

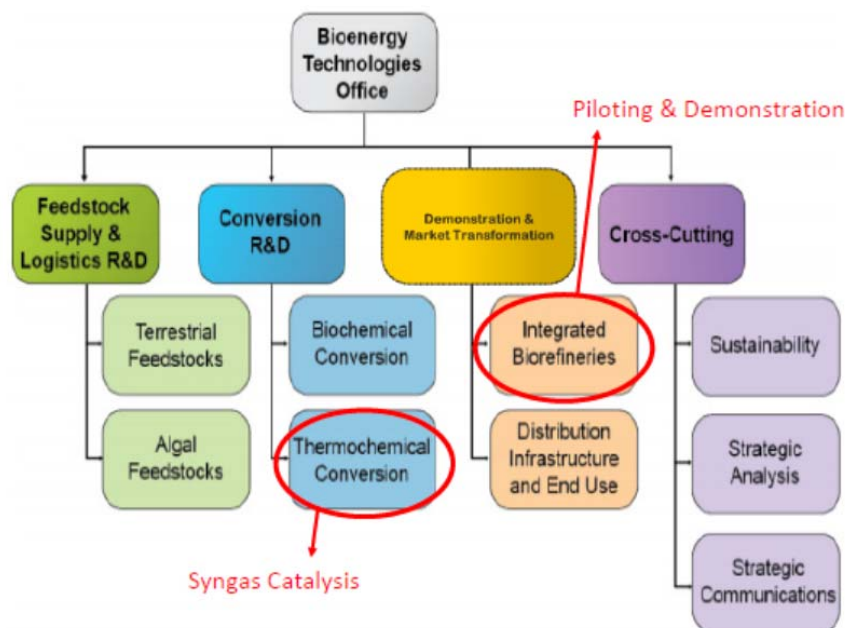


Figure 20: BETO program – biomass gasification RD&D

Conversion activities include continued efforts in both core and competitive R&D.

R&D focuses on gaseous intermediates and mixed oxygenate upgrading to produce gasoline, distillate, and jet range hydrocarbons from biomass in support of the programmatic goal of \$3/GGE by 2022.

Continued efforts in core and competitive R&D support the 2022 programmatic goal of \$3/GGE:

- Catalytic upgrading of gaseous and liquid intermediate to produce gasoline, distillate, and jet range hydrocarbons from biomass, e.g.:
 - o Conversion of syngas to mixed oxygenates followed by conversion to hydrocarbon fuels and oxygenate blendstocks
 - o Syngas fermentation to ethanol followed by chemical catalytic conversion to hydrocarbon blendstocks – e.g. **Lanzatech-PNNL ATJ**
 - o Conversion of Methanol /DME to high octanegasoline (Triptane – C₇H₁₆) and/or **dimerization to distillate/jet.**
- Develop techno-economic analysis (TEA) and associated design cases that include cost projections and technical targets for indirect liquefaction pathways to make gasoline, diesel, or jet fuels

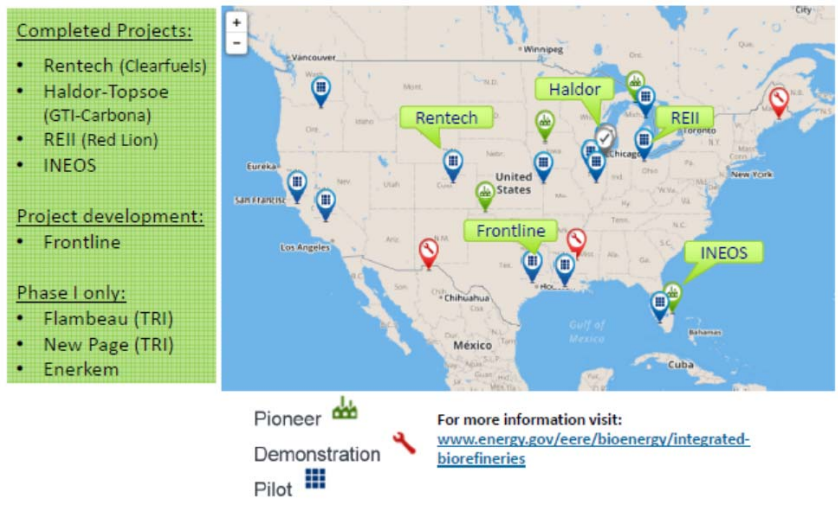


Figure 21: BETO demonstration portfolio

Introducing aviation biofuels into OSL's fuel distribution infrastructure

Olav Mosvold Larsen, Avinor

Avinor is responsible for Air Navigation Services (ANSP) and operates 46 airports in Norway.

Long term approach and activities:

- The Norwegian aviation industry have been looking into sustainable biojet since 2007
- Biofuel certified for use in civil aviation since 2009
- Major study in 2011-2013. Conclusion: Possible, but risky
- Avinor to invest up to MNOK 100 in jet biofuels (2013-2022)
- Demoflights to the ZERO conference 11 NOV 2014
- Fruitful collaboration with AirBP and airlines
- OSL world's first to offer jet biofuel to all airlines on a commercial basis
- KLM/Embraer OSL-AMS campaign Q2 2016
- Several ongoing R&D projects

From January 2016, OSL became the world's first hub to offer jet biofuel to all airlines on a commercial basis, in cooperation with Air BP, SkyNRG, Neste and airlines.

First batch:

- Approx 600.000 litres
- Based on Camelina from the ITAKA project in Spain
- Refined by Neste in Finland
- Shipped to Gävle in Sweden blended with fossil JetA1 (50/50) and stored there
- Transported to OSL by lorries
- Dropped into the fuel farm at OSL
- Distributed in the dispenser system
- Works very well
- No issues technically
- No issues with other airlines
- No issues with passengers

The project evoked political interest and process, jet biofuel was firmly placed on the political agenda in Norway.

Way forward:

- Avinor 2030 goal: 30 % of aviation fuel in Norway should be sustainable biofuel = Approx 400 million litres
- Ramp up supply at OSL
- Support local/national production of sustainable jet biofuel
- Push for jet biofuel in Norway on several arenas
- Long term commitment

Proposal from Parliament in State budget 2016

- 25% discount in landing fees for flights on 25% biofuel in 2016 and 2017.
- From 1 JAN 2018: mandatory drop in requirement (amount not yet disclosed)

Other policy measures for biofuels

- No domestic CO₂-tax (= NOK 1,08 pr litre)
- EU ETS waived
- Could newly introduced EUR 9 air passenger duty be waived?
- Several green technology programs in place (reducing CAPEX)
- Reasonable framework conditions for industry in Norway, but could be improved

Aviation fuel from worlds forest

Martin Rügsegger, ETECA

World aviation fuel production is about 258 458 Mt (=2,5 million GWh/8000h is about 312 GW), which means lots of biomass (about 50% of worlds forest) will be needed to replace fossil aviation fuel by renewables.

BP Rotterdam refinery since 1967

19.000.000 tpy 57 600 tpd → 26 GW Power output

Jamnagar India worlds biggest refinery since 2010

66 000 000 tpy 200 000 tpd (330 days) 8 250 t/h

→ 100 GW Power output

For world fossil jet fuel production 3x Jamnagar needed



Figure 22: Jamnagar photos

Why go into aviation fuel market with renewable kerosene, if:

- Aviation fuel is currently one of the hardest markets
- Highest security and quality standards needed
- Kerosene is worldwide a tax-free fuel
- No CO₂ tax nor CO₂ compensation or mitigation strategy world wide exists for aviation fuel
- For any kind of production plants today consider bigger to be better (small are closed down due economics)
- REN fuel production today in operation 20 MW

Conclusions and recommendation

- REN Aviation fuel is green Airline Marketing with very little impact
- Even negative rebound effect for more fossil flights will appear
- Why not go with REN fuel to surface road traffic first
 - Profit from CO₂ taxes for mitigating and compensation
 - Get a better price
 - Get faster increase of REN fuel production
 - Even so it will be hard enough
 - Extend and grow new forest today on waste land to get the biomass for tomorrow's REN aviation fuel

Conclusions

Worldwide, flights produced 770 million tonnes of CO₂ in 2015, aviation was responsible for 12% of CO₂ emissions from all transport sources. A third of the operating costs of airlines is spent on fuel: 33%, which is up from 13% in 2001. The proportion is likely to rise further as fuel prices go up. So this alone is a major incentive for the whole industry to focus on fuel efficiency (source: www.atag.org).

Alternative fuels, particularly sustainable biofuels, have been identified as excellent candidates for helping achieve the industry and climate targets. Biofuels derived from biomass such as algae, jatropha and camelina have been shown to reduce the carbon footprint of aviation fuel by up to 80% over their full lifecycle. If commercial aviation were to get 6% of its fuel supply from biofuel by 2020, this would reduce its overall carbon footprint by 5%.

In 1945, it took 130 weeks for a person earning the average Australian wage to earn enough for the lowest Sydney to London return airfare. In 2009, it took just 1.7 weeks. Travelling by plane is no exclusive issue any more; thousands of people worldwide take advantage of charter flights daily without thinking about the environmental impacts.

It is clear that it will not be possible to cover 100% of aviation fuels only by renewables in the near future. However, partial usage of biofuels will be able to reduce the CO₂ footprint of aviation.

Research and development projects in Europe and the United States are advancing technology for economic production of biofuels and several demonstration projects and partnerships coming on-line are helping push production of aviation biofuels through biomass gasification towards commercialization.