GasBio

Gasification for Biofuels

SINTEF

GasBio - Gasification for Biofuels

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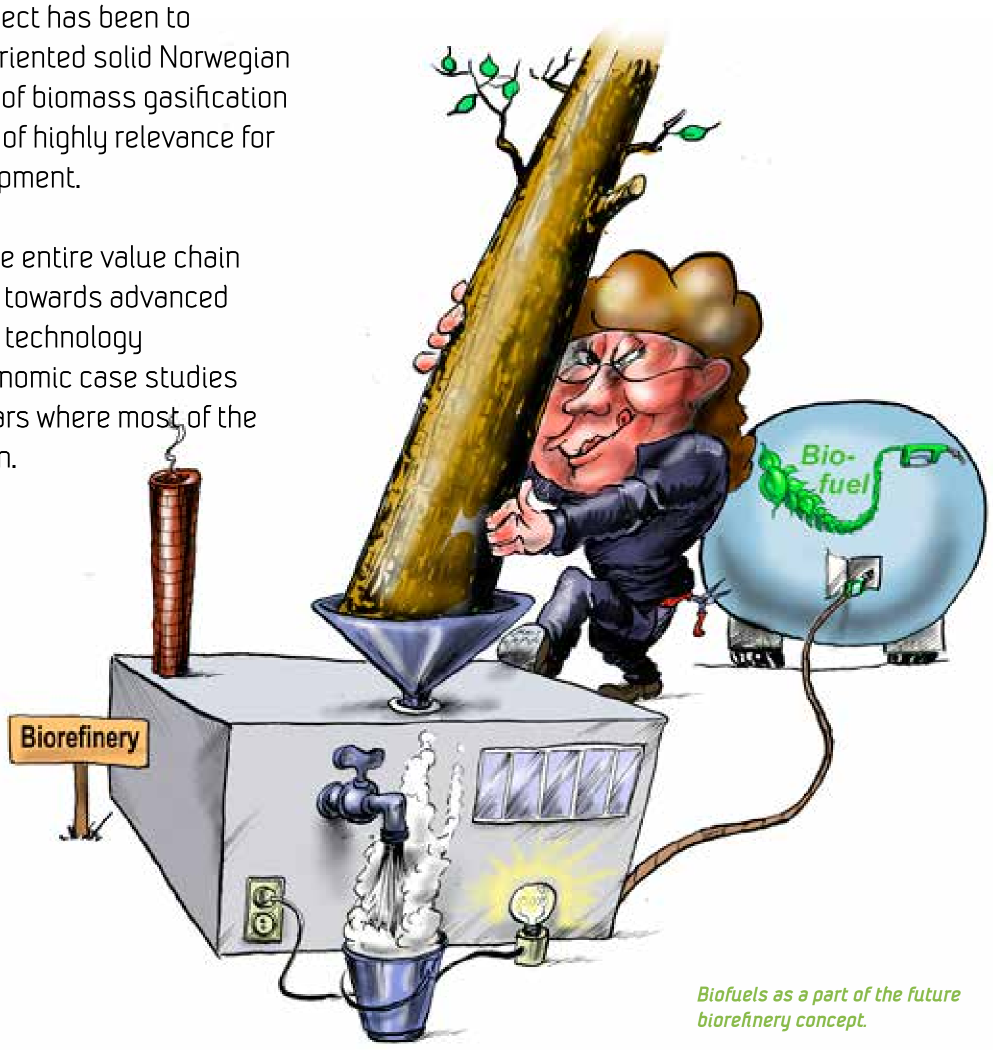
Background

This handbook has been prepared by SINTEF Energy Research with the purpose to provide both partners of the GasBio project and others with a simple and "easy to read" guide on the potential production of advanced biofuels in Norway and the remaining challenges.

The information in this handbook has mainly been obtained by studies performed throughout a 4-year project period in the competence building project entitled "GasBio – Gasification for Biofuels". The project has been financed by the Research Council of Norway and six industry partners: Avinor, Metso, Norske Skog, Statkraft, Statoil Petroleum ASA and Xynergo.

The main objective of the project has been to establish an internationally oriented solid Norwegian competence base in the area of biomass gasification for liquid biofuel applications of highly relevance for competitive industrial development.

The project has addressed the entire value chain of forestry biomass fractions towards advanced (2nd generation) biofuels, with technology development and techno-economic case studies as the two solid research pillars where most of the research has been focused on.



Biofuels as a part of the future biorefinery concept.

Why advanced biofuels?

Transportation, which is more than 90% powered by oil, is responsible for around a quarter of EU greenhouse gas emissions. Biofuels are one of the main measures to achieve sustainable transport in the future, particularly for the heavy and long-haul transport sectors (i.e. marine, aviation and long-haul road transportation), which in the near future have few or no other alternatives. Biofuels offer a replacement to today's fuels without the need of modifying engines or infrastructures as well as long range and fast refuel.

However, biofuels have received an unfortunate reputation due to the fact that those biofuels commercially available are mainly produced from agricultural land and food crops, thus leading to an either direct or indirect competition with food production and putting in doubt their sustainability. The aim is to move the society toward sustainable biofuels, which will power the future heavy transport. This is the case for the so-called advanced biofuels. These biofuels have lower carbon footprint and are derived from sustainable feedstock such as woody biomass, residues or algae that i) do not need agricultural land and thus do not compete with food and feed production and ii) require limited amounts of fresh water and fertilizers. However, advanced biofuels are costly as compared to conventional fossil-derived liquid fuels. The higher prices that make these fuels not competitive in today's market yet are a result of three main factors: high costs of the feedstock, immature technology and lack of incentives.

With research and innovation, it is believed that most of the barriers that are being faced at the moment can be overcome, enabling a greener transport that will certainly contribute to reach the ambitious national, European and global sustainability goals.

Biomass gasification in combination with Fischer-Tropsch (FT) is perceived as one of the most attractive processes for the production of advanced biofuels. It converts biomass to a high-density gas product that is further processed to liquid fuels. The most important advantages of this technological route are:

- Significant reduction of climate gas emissions
- Large feedstock flexibility
- Production of a large range of marketable products (eg. biodiesel, aviation biofuels, biochemicals)
- Possibility for coupling with other renewable energy sources such as integration of biomass gasification with wind or solar power

The high capital costs and the incomplete conversion of high energy containing intermediate products are the main remaining bottlenecks for the commercialization of this process, and hence it will be crucial to concentrate substantial research efforts on the minimization of the aforementioned challenges.

Industry interest

The GasBio project has been partly (20%) financed by industrial partners covering the whole value chain of forestry biomass fractions towards sustainable liquid biofuels, from feedstock suppliers to technology developers and end-users. Technology development and techno-economic studies have been the two solid research pillars where most of the efforts have been focused on, in order to meet the industrial challenges that the industry partners participating in the project are currently facing.

As for feedstock suppliers such as **Norske Skog**, GasBio has reviewed and identified relevant biomass species for gasification towards liquid biofuels and major characteristics affecting the process. Among those, it is worth mentioning the ash content and composition of the processed feedstock as well as the type of pretreatment used, whether thermal and/or mechanical.

In terms of technology development, significant efforts have been set in i) getting a better understanding of ash-related problems associated with the gasification process and ii) enhancing the process energy efficiency, being two of the main challenges **Metso** faces during daily operation in their gasification plants.

Similarly, the industry partners representing end-users have benefit from concrete research activities addressing their requirements. The techno-economic activity addressing mainly the optimization of the economics of liquid biofuels production with integrated heat and power production systems have been particularly relevant for Statoil, Statkraft and Avinor. **Statoil** has gained knowledge on the possibility of expanding their current fossil-derived fuels business with environmental friendly sources. As airport operator, the techno-economic results have enabled **Avinor** to i) evaluate the viability of producing liquid biofuels in Norway and ii) participate in the development of a strategy for the promotion, implementation and deployment of biojetfuel in the aviation sector in Norway. On the other hand, **Statkraft** has gained competence that i) can create added value to the current district heating business through the integration of heat production in a biofuels production plant and ii) open doors for new market opportunities through their possible engagement in biofuels production in the near future.

From a generic point of view, all industry partners have benefit from GasBio through yearly national and international industrial seminars, including site-visits at main European biofuels/biomass gasification plant facilities, that have resulted in fruitful discussions and establishment of network.

Biofuels for road transport.

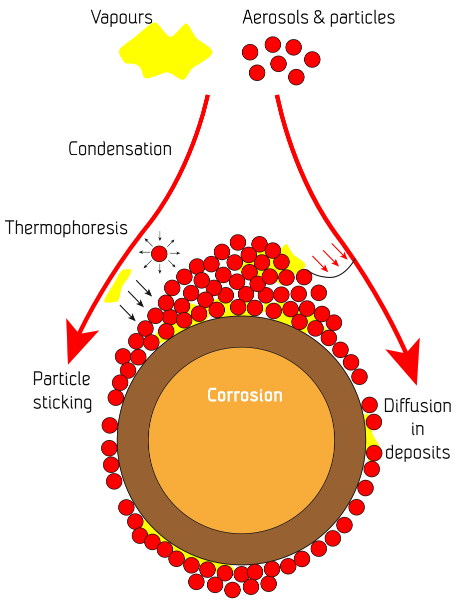
Ash-related challenges in gasification

Cl-induced high temperature corrosion, slagging, sintering, agglomeration and deposition are ash-related challenges that disturb operation and cause unplanned shutdowns as well as shorten the lifespan for exposed elements. These issues have been addressed through industrial case studies focusing on ash chemistry during biomass gasification using thermodynamic equilibrium modelling. This method is cheaper and faster than full-scale or laboratory tests, making it a good screening tool for preliminary investigations.

What is thermodynamic equilibrium modelling?

Thermodynamic modelling is based on Gibbs energy minimization techniques, which calculate the global minimum of the total Gibbs energy of a system at specified conditions, based on the thermodynamic data for all phases and compounds that are included in the calculations. The phase composition that results in the lowest Gibbs energy gives the final chemical equilibrium composition.

High temperature corrosion mechanisms during biomass gasification.



To evaluate high temperature Cl-induced corrosion severity for example, one can compute the total amount of alkali chlorides (as well as chlorine in the melt fraction) as they are the main vessel of chlorine to heat-exchange surfaces.

What are the limitations?

1. Equilibrium may not be attained in real systems due to kinetics constraints and/or low temperatures and residence times
2. No temperature or concentration gradient
3. Physical processes, like fly ash formation are not taken into account
4. Only elemental composition of the fuel is used as input
5. Results are dependent on the thermo dynamic databases quality

Despite these limitations, equilibrium calculations provide valuable and reliable information. Properly elaborated calculation methodologies and careful interpretation give useful information about the feasibility of chemical transformations and reactions. It is important to interpret the results in terms of overall stabilities and trends rather than quantitative values. They can also be of great support to understand underlying chemistry. Equilibrium calculations are an efficient tool to complement experimental studies.

Highlights

Many good insights and detailed chemical trends have been extracted from the GasBio case studies and the main findings can be summarised as such:

- Each combination of *fuel/thermal technology/operational parameters* produces significantly different ash chemistries that require specific investigations
- Even minor changes in operational parameters can impact ash chemistry significantly and hence have dramatic practical implications
- The previous point also indicates that local conditions in the boiler like hot / cold spots or zones of poor fuel/air mixing may be of great importance for plant operation

As a general rule of thumb, higher temperature combined with higher concentrations of both chlorine and alkali (Na, K) will lead to more corrosion. Low alkalis amounts (compared to Cl amount) will often promote HCl formation, a gas which is little corrosive compared to alkalis chlorides.

Gasification of raw biomasses and chars

Through the GasBio project we have studied the gasification of raw biomass materials and more importantly the gasification of incomplete converted carbon containing products such as soot, tars and char. The incomplete conversion of the aforementioned compounds has been identified as one of the remaining key challenges in the biomass gasification process in terms of operational problems and low energy efficiencies. In order to get a better understanding on the formation and conversion of these species, GasBio has conducted several multidisciplinary research studies. These have been based on a modelling-experimental integrated approach, including the two main gasification technologies currently available for biofuels production, namely fluidized bed (FB) and entrained flow (EF) gasification, and Norwegian forestry feedstock (mainly spruce).

Thermogravimetric studies have shown that the the physico-chemical properties of biomass particles such as the presence of inorganic elements in the biomass, as well as the reaction conditions and producing methods applied, do influence the gasification process significantly. A clear example that reflects this general statement is a comparative study between reactivity behaviors of spruce-derived char produced from either wood chips or forest residues which has shown that the latter has considerably higher reactivity. This means that forest residues are a promising raw feedstock for sustainable production of sustainable biofuels.

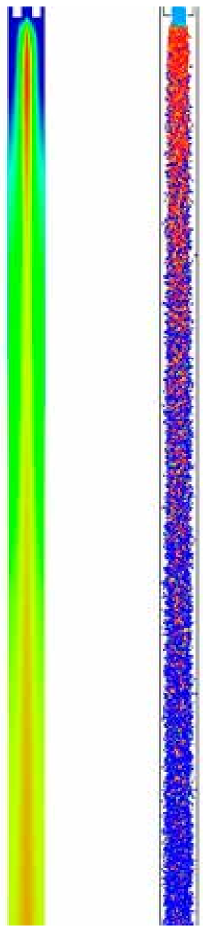
In order to compare the two main gasification technologies for conversion of Norwegian forestry-based biomass into biofuels, two comparative experimental campaigns have been conducted in collaboration with well-reputed international research teams with unique state-of-the-art installations.

The FB experimental work focused on the effect of pressure, catalytic effect (dolomite) and degree of torrefaction (as pre-treatment prior to gasification) on gas composition and tar/char formation. It can be concluded that higher degrees of torrefaction and presence of dolomite as catalyst had a significant positive effect by enhancing the total production of gas (volumes) and tar cracking (formation of lighter molecular weight distributions of tars). Higher pressures, on the other hand, affected negatively the gasification process as it resulted in increased tar yields. Based on this study thus, typical operating gasification conditions for biofuels production shall be carried out at atmospheric pressures, in presence of dolomite and using pretreated torrefied biomass.

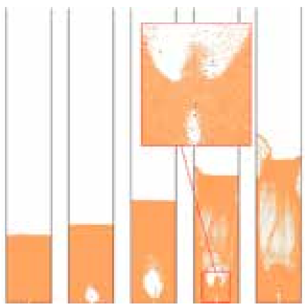
On the other hand, devolatilization of biomass and conversion of corresponding char were investigated in an EF gasifier at high temperature and high heating rate, of highly relevance at industrial scale. Temperature, heating rate, and torrefaction were found to have significant effects on physical and chemical properties of biomass and char, playing important roles in the rate of gasification of biomass. This work has not only provided a better understanding of gasification of biomass at industrial relevant conditions, but has also established a comprehensive experimental database for development of computational models.

Gasificaiton is a promising technology for biofuels production.

CFD modelling of biomass gasification



CFD simulation of beech wood gasification in an entrained flow reactor



Particle flow patterns in fluidized bed at the beginning of simulation

Computational fluid dynamics (CFD) simulations as a relatively cheap and non-intrusive technique have gained its popularity recently. It is a powerful tool to help engineers visualize the gasification process inside a reactor and evaluate different configurations of gasifiers in the design process. In the GasBio PhD-work, ANSYS Fluent and OpenFOAM were chosen as the CFD platforms to reflect the current state-of-the-art of multiphase reacting flow simulations. In addition, several sub-models such as turbulent dispersion of particles, collision of particles, and devolatilization of biomass have been developed and validated from experiments.

A series of CFD aided experiments have been carried out in a drop tube reactor to understand devolatilization of biomass and conversion of char, which are two of the most critical steps in the biomass gasification process. Particle residence time and particle thermal histories have been predicted through 3D ANSYS Fluent simulations of the drop tube reactor. The effect of torrefaction on gasification of biomass has been also studied.

For more detailed studies and understanding of the physical processes occuring during gasification, an Eulerian–Lagrangian CFD model based on OpenFOAM has been constructed to simulate gasification of biomass at high temperature conditions (1000–1400 °C) in an entrained-flow type of lab-scale reactor. Heat and mass transfer, pyrolysis, homogeneous and heterogeneous reactions, radiation, as well as the interactions between the continuous gas phase and discrete particles have been all considered in this model.

The results show that:

- an increase in the reactor temperature has a positive effect on the production of both H_2 and CO
- increasing the steam/carbon ratio increases the H_2 production but decreases the CO production
- increasing the excess air ratio decreases the production of both H_2 and CO

Gasification of biomass in a fluidized bed lab-scale reactor has been successfully simulated by CFD-Discrete Element Method (CFD-DEM) numerical model. As collision of particles is crucial in a fluidized bed reactor, this is taken into account in this model. A sensitivity analysis is performed to test the integrated model's response to variations of three different operating parameters; reactor temperature, steam/biomass ratio, and biomass injection position. The simulation results have been analyzed both qualitatively and quantitatively in terms of particle flow pattern, particle mixing and entrainment, bed pressure drop, product gas composition, and carbon conversion.

The CFD-tool developed has shown the ability to simulate the gasification of biomass in several types of lab-scale reactors. This is the first step in the development of a tool for studying issues related to scale-up of gasifiers.

Entrained flow gasification reactor

Parallel to all the gasification-related research activities in the GasBio project, SINTEF Energy Research has developed an advanced lab-scale entrained flow gasification reactor concept co-financed by GasBio, the FME CenBio, SINTEF Energy Research (own funding) and the recently granted national infrastructure project NorBioLab[1] (main funding). The reactor is expected to be commissioned during the fall of 2015.

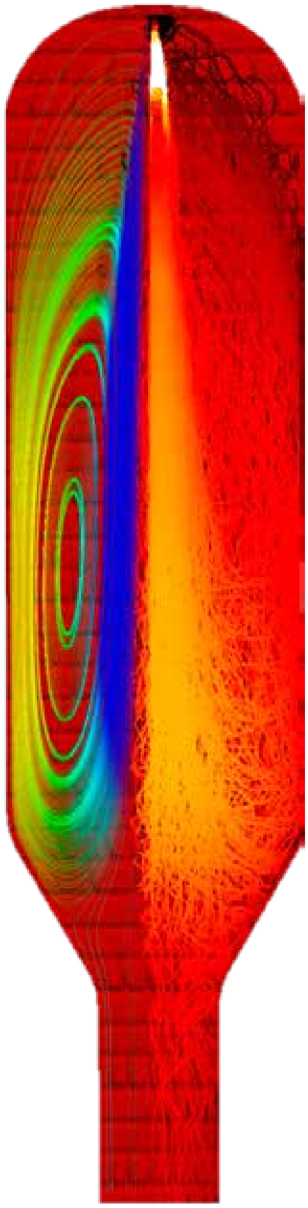
One of the benefits with entrained flow gasifiers is that they can operate with fuels containing varying and high ash contents. Fuels like reed canary grass, tops and branches, stumps and refuse derived fuels. The ash melts in the gasifier forming a solid slag once cooled. The slag may cause operational difficulties which can be addressed by adding fluxing materials, or by mixing different fuels to obtain suitable slag properties (in a way which is not possible in for example fluidized bed gasification). This approach enables the use of the previously mentioned, low grade, high ash-content fuels.

The main drawback with the entrained flow technology is that the fuel particle size needs to be small; typically less than 300 µm. This can be accomplished by using a liquid fuel (such as pyrolysis oil) and proper atomization, or by grinding a solid fuel to a suitable particle size.

Recognizing these challenges, the SINTEF Energy Research gasifier was designed to operate both as a conventional entrained flow gasifier and as a molten bed gasifier. The molten bed operation mode provides a unique opportunity to study entrained flow gasification with larger fuel particles than those conventionally used. The gasifier is designed to operate at up to 10 bar of pressure and 10 kW of thermal power and will contain all main equipment that is found in a full scale gasification plant. The decision to design the reactor as a miniature commercial gasifier instead of a pure characterization reactor was done to obtain a higher level of industrial relevance. The reactor will be used to study gasification of different fuels, using different process conditions together with advanced mathematical models in order to characterize the process and provide baseline data to economics models.

Who will benefit from this ?

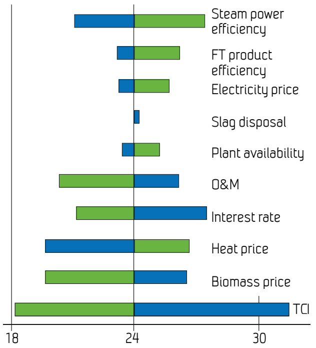
Chemicals or fuels produced via biomass gasification could contribute to the sustainable use and efficient consumption of Norway's renewable energy resources by creating value-added products increasing the use of biofuels in Norway. In addition, by having a gasification research facility available in Norway, knowledge can be directly transferred to the trade and industry sector thus strengthening and enabling new business development and innovation.



One step closer to deployment of biofuels production in Norway.

[1] Norwegian Biorefinery Laboratory (NorBioLab) was granted funding (2014 – 2021) from the Research Council of Norway to establish a national laboratory for biorefining. The laboratory will establish unique research infrastructures that will play a central role in research aiming at developing novel processes for sustainable conversion of Norwegian land and sea-based biomass into new, environmentally friendly biochemicals, biomaterials and bioenergy products. NorBioLab includes the research partners Paper and Fibre Research Institute (PFI), Norwegian University of Science and Technology (NTNU), SINTEF and the Norwegian University of Life Sciences (NMBU).

Let's get feasible biodiesel



Biocrude production cost

Future biodiesel production from woody biomass under Norwegian conditions has been studied through detailed techno-economic analysis and the results are highly promising.

The present evaluation has considered decentralized utilization of woody biomass for the production of higher-energy density crude (biocrude) with further upgrading of the biocrude to biodiesel at existing petrochemical facilities. This value-chain model minimizes the scale of the biomass conversion plants and, therefore, reduces the risks associated to large capital costs as well as the energy consumption and costs of feedstock procurement.

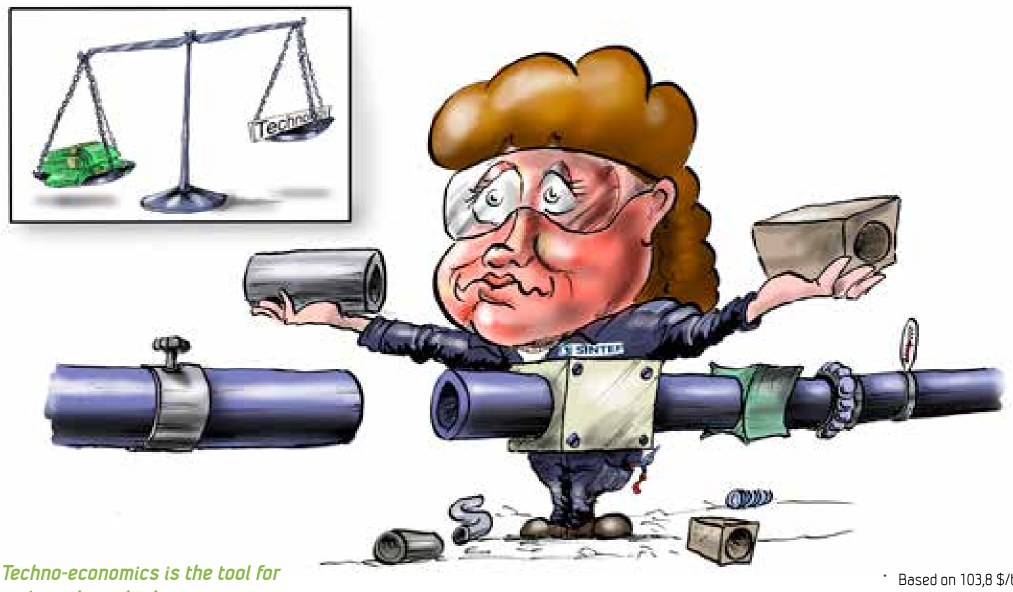
The main technology route proposed for the biomass to biocrude conversion includes two types of fuel preparation based on torrefaction and conventional drying, high temperature gasification with direct syngas cooling, CO_2-capture based on physical solvent (selexol) and Fischer Tropsch synthesis using cobalt-based catalysts. In addition, the integration and optimization of heat recovery for production of heat and electric power has been considered.

The study evaluates the influence of the key operational parameters, the fuel preparation options (drying/torrefaction) and the heat to electricity production ratio on the overall efficiencies and economic performance of the biocrude production for plant capacities in the range of 150 to 600 MW biomass input. This range has been considered to be relevant under Norwegian conditions as a trade-off between optimal utilization of the heat produced from the plant and reasonable biomass transport distances.

Highlights

The optimal economic performance of biocrude production in Norway are reached when combining the use of torrefaction for biomass pretreatment and utilization of 100% of the heat recovered for district heating. Under those conditions, biocrude production can reach profitability, based on 7% internal rate of investment and 70/30 debt to equity ratio, with biocrude market prices in the range of 1,75 and 2 times the current crude-oil market price* for plant capacities in the range of 150 and 600 MW biomass input.

Sensitivity analysis for the total biocrude production costs shows that the biomass price, total capital investment, the interest rate and the maintenance costs represent the most important factors influencing the economic viability.



Techno-economics is the tool for making the right decisions.

* Based on 103,8 $/barrel average crude-oil price in 2014 according to OPEC www.opec.org/opec_web/en/data_graphs/40.htm

Importance of networking

GasBio has become an excellent tool to establish new networks and strengthen the existing ones both at national and international level, and anchor our Norwegian biomass gasification activities among the most renowned players. This network strategy which has been an essential element in order to ensure proper dissemination of the main results and the knowledge built up throughout the project, has been applied at several levels:

International cooperation with world leading R&D players

- Catalonia Institute for Energy Research (IREC): fluidized bed biomass gasification experiments
- Sandia National Laboratories: entrained flow biomass gasification experiments
- Hungarian Academy of Science (HAS): modelling of gasification of biomass-derived chars
- Åbo Akademi University (ÅA): thermodynamic equilibrium modelling on ash-chemistry

Active role through several dissemination channels

- International strategic research arenas of great prestige such as
  - International Energy Agency (IEA) – Tasks 33 (Gasification) and 39 (Commercialization of liquid biofuels)
  - European Biofuels Technology Platform (EBTP)
  - European Energy Research Alliance (EERA) – Bioenergy
- National and international renowned conferences such as
  - SGC International Seminar on Gasification (Sweden)
  - ICAO aviation and sustainable alternative fuels (Canada)
  - Energy Sustainability Conference (USA)
  - International Conference on Applied Energy (South Africa, Taiwan)
  - European Biomass Conference and Exhibition (Germany)

- Media contributions in popular science TV programs, newspapers, newsletters, and magazines for those not familiar with the scientific field such as
  - Schrödingers katt (TV program)
  - Adresseavisen
  - Teknisk Ukeblad

Arrangement of study tours (two/year), one in Norway and one abroad, where the most relevant European gasification facilities have been visited. This initiative has been of great value to both researchers and industrial partners who have been able to get to know and exchange perspectives/points of view on gasification/biofuels production with European leaders in the field.

Partners

Sandia National Laboratories

Åbo Akademi University

IREC
Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

mta ttk

Future perspectives

The future of biomass gasification in Norway is bright. Key industry and government have identified its role as an enabling technology. Enabling in the sense that it promotes innovation and new business opportunities; it creates added value products in industry which is seeing a decline in sales for their conventional products (such as pulp and paper) and that biomass gasification has the potential to couple different sources of renewable energy and industry together.

We are seeing an increased interest from industry to mitigate their use of fossil fuel because green alternatives are starting to become competitive with their fossil counterpart. We are noticing an increased interest to integrate different types of industry to better utilize by-products and waste heat.

In the field of research, strong international initiatives are committed to mitigate and identify the technological and economical hurdles related to biomass gasification. SINTEF Energy Research is building new, flexible, industry relevant research infrastructure, and is making it available for the research and industry communities. Together with other thermochemical processes; such as fast pyrolysis for production of pyrolysis oil, carbonization, and torrefaction, biomass gasification stands strong and at the current pace, new installations are just around the corner. All these efforts will contribute to a sustainable utilization and efficient consumption of Norway's renewable energy resources, thus leading to a reduction of Norwegian and global emissions of climate gases.

Aviation biofuels is gaining tremendous interest nowadays. Biomass gasification coupled with Fischer-Tropsch conversion and refining is able to give a high quality, certified and advanced biojet fuel (Fischer-Tropsch Synthetic Paraffinic Kerosene: FT-SPK) which is relevant globally and especially in Norway due to very good sustainability. The commercial deployment will, however, be dependent on incentives as long as the oil prices are low.

Aviation will be a major market for advanced biofuels

Publications

Journal papers

J. Sandquist, R. S. Kempegowda, S. M. Paap, A. George, G del Alamo, M. Bugge, B. Matas Güell
Deployment of feasible routes to renewable jet-fuel, with an emphasis on the Norwegian landscape
To be submitted to Energy policy

T. Li, M. Geier, L. Wang, X. Ku, B. Matas Guell, T. Løvås, C. R. Shaddix
Modified two-competing rate kinetic model for rapid devolatilization of biomass: An experimental and CFD approach
To be submitted to Energy&Fuels

R. S. Kempegowda, G. del Alamo, B. Matas Güell
Co-processing of torrefied woodchips and low-grade wet biomass in dual entrained flow and hydrothermal gasification for biocrude production under Norwegian conditions: techno-economic analysis
Submitted to ASME Energy Resource Technology

R.S. Kempegowda. G. del Alamo, D. Berstad, M. Bugge, B.M Güell, K-Q. Tran
CHP-integrated Fischer-Tropsch biocrude production under Norwegian conditions: Techno-economic analysis
Submitted to Energy&Fuels

R.S. Kempegowda. G. del Alamo, B. Matas Güell, K-Q. Tran
Techno-economic analysis of biomass to Fischer-Tropsch diesel production with and without CCS under Norwegian conditions
Energy Procedia, 2014, in press

T. Li, M. Geier, L. Wang, X. Ku, B. Matas Güell, T. Løvås, C. R. Shaddix
Effect of torrefaction on physical properties and conversion behavior of high heating rate char of forest residue
Energy&Fuels, Under review, 2014

X. Ku, T. Li, T. Løvås
CFD-DEM simulation of biomass gasification with steam in a fluidized bed reactor
Chemical Engineering Science, In press 2014

X. Ku, T. Li, T. Løvås
Eulerian-Lagrangian simulation of biomass gasification behavior in a high-temperature entrained flow reactor
Energy&Fuels (2014), 28, pp 5184-5196

L. Wang, J. Sandquist, G. Varhegyi, B. Matas Güell
CO2 gasification of chars prepared from wood and forest residue. A kinetic study.
Energy&Fuels (2013), 27, pp 6098-6107

C. Berrueco, D. Montané, B. Matas Güell, G. del Alamo
Effect of temperature and dolomite on tar formation during gasification of torrefied biomass in a pressurized fluidized bed
Energy (2014), 66, pp. 849-859

C. Berrueco, J. Recari, B. Matas Güell, G. del Alamo
Pressurized gasification of torrefied woody biomass in a lab scale fluidized bed
Energy (2014), 70, pp 68-78

X. Ku, T. Li, T. Løvås.
Influence of drag force correlations on periodic fluidization behavior in Eulerian-Lagrangian simulation of a bubbling fluidized bed.
Chemical Engineering Science (2013), 95, pp 94-106

B. Matas Güell, J. Sandquist, L. Sørum.
Gasification of biomass to second generation biofuels: A review
Journal of Energy Resources Technology (2013), 135 (1)

J. Sandquist, B. Matas Güell
Overview of biofuels for aviation
Chemical Engineering Transactions (2012), 29, pp 1147-1152

T. Li, L. Zhao, X. Ku, H. Andersson, T. Løvås.
Numerical investigation of particles turbulent dispersion in channel flow
Thermal Science 2012, 16 (5), pp1510-1514

X. Ku, T. Li, T. Løvås.
Eulerian-Lagrangian simulation of a bubbling fluidized bed reactor: Assessment of drag force correlations.
Thermal Science 2012, 16 (5), pp1442-1445

Conference papers

R. S. Kempegowda,G. del Alamo, B. Matas Güell, Ø.Skreiberg, K-Q. Tran
Optimization of biocrude production through co-processing torrefied biomass with low-grade wet biomass in dual entrained flow gasification and steam hydrogasification
Proceedings of 22nd European Biomass Conference and Exhibition, 23-26 June 2014, Hamburg, Germany, pp. 596-603

R.S. Kempegowda, R. Khalil, Ø. Skreiberg
Techno-economics of dry and wet torrefaction process for improved bio-feedstocks for biorefinery applications
Proceedings of 22nd European Biomass Conference and Exhibition, 23-26 June 2014, Hamburg, Germany, pp. 969-979

R. S. Kempegowda, G. del Alamo, B. Matas Güell, K-Q. Tran
Techno-economic analysis of biomass to Fischer-Tropsch Diesel production with and without CCS under Norwegian conditions.
The 6th International Conference on Applied Energy, 30 May -2 June 2014, Taibei,Taiwan (ICAE 2014) -> Energy Procedia

X. Ku, T. Li, T. Løvås
CFD-DEM simulation of biomass gasification with steam in a fluidized bed reactor
Joint meeting of the British and Scandinavian-Nordic Sections of the Combustion Institute - The 7th Biennial Meeting for the Scandinavian-Nordic Section, 2014

T. Li, L. Wang, X. Ku, B. Matas Güell and T. Løvås
Effect of torrefaction on rapid devolatilization of biomass
Joint meeting of the British and Scandinavian-Nordic Sections of the Combustion Institute - The 7th Biennial Meeting for the Scandinavian-Nordic Section, 2014

R.S. Kempegowda, K-Q. Tran, Q.V. Bach, Ø. Skreiberg, M.Bugge.
Influence of wet and dry torrefaction process on biomass to liquid fuel production through Fischer-Tropsch under Norwegian conditions.
The 5th International Conference on Applied Energy, 1-4 July 2013, Pretoria, South Africa (ICAE2013)

R. Kempegowda, D. Berstad, M. Bugge, B. Matas Güell, K-Q. Tran.
System analysis of second generation biofuel production from high temperature gasification under Norwegian conditions.
Proceedings of 1st International Conference on Bioenergy, Environment and Sustainable Technologies, Tamilnadu, India. 27-30 January 2013

X. Ku, T. Li, T. Løvås.
Eulerian-Lagrangian simulation of wood gasification in a high-temperature entrained flow reactor
Proceedings of the 6th European Combustion Meeting, Lund, 26-28 June 2013

X. Ku, T. Li, T. Løvås.
Eulerian-Lagrangian simulation of a bubbling fluidized bed reactor: assessment of drag force correlations
4th International Symposium on Nonlinear Dynamics, Suzhou, China, 27-30 Oct 2012 -> Thermal Science

T. Li, L. Zhao, X. Ku, H. Andersson, T.Løvås.
Numerical investigation on turbulent dispersion of particles in channel flow
4th International Symposium on Nonlinear Dynamics, Suzhou, China, 27-30 October 2012 -> Thermal Science

J. Sandquist, B. Matas Güell
Biofuels in Aviation – an Overview
PRES 2012, Prague, Czech Republik, 27 Aug 2012
Chemical Engineering Transactions, ISBN 978-88-95608-20-4

B. Matas Güell, J. Sandquist, L. Sørum.
Gasification of biomass to second generation biofuels: a review
Proceedings of ASME ESFuelCell2011, Washington DC, 7-10 August 2011, pp. 1119-1129, ISBN 978-0-7918-5468-6

Conference presentations

T. Li, M. Geier, L. Wang, X. Ku, B. Matas Güell, T. Løvås, C. R. Shaddix
Effect of torrefaction on physical properties and conversion behavior of high heating rate char of forest residue
35th International Symposium on Combustion, San Francisco (CA), USA, 3 – 8 August 2014

X. Ku, T. Li, T. Løvås
Eulerian-Lagrangian simulation of biomass gasification in a high-temperature entrained flow reactor: Effects of biomass type and particle size
35th International Symposium on Combustion, San Francisco (CA), USA, 3 – 8 August 2014

J. Sandquist, B. Matas Güell
Aviation and biofuels
SFFE Lunch Lecture, 25 September 2013, Trondheim, Norway

J. Sandquist
Biomass gasification in Norway - Remaining challenges and emerging opportunities
3rd Annual Gasification 2013 Summit, London, 7 November 2013

R. Kempegowda, D. Berstad, R. Anantharaman, M. Bugge, B. Matas Güell, K-Q. Tran.
Integrated biomass gasification for production of second generation biofuels under Norwegian conditions.
International Process Integration Jubilee Conference, Gothenburg, Sweden, 18-20 March 2013

B. Matas Güell, K. Øyaas, G.L. Johansen.
Biofuels in Norway
Bioforum, Oslo, Norway, 1 February 2013

B. Matas Güell
Hydrothermal gasification of seaweed: a promising technology to biofuels production.
Seaweed to Biofuel Workshop arranged by SINTEF Fisheries and Aquaculture, Trondheim, Norway, 25 September 2012.

T. Li, X. Ku, T. Løvås.
CFD modelling of soot formation in high-temperature lignocellulosic biomass entrained flow gasifier.
34th International Symposium on Combustion, Warsaw, Poland. 29 July-3 August 2012

X. Ku, T. Li, T. Løvås.
Euler-Lagrangian simulation of biomass gasification in a high-temperature entrained flow reactor.
34th International Symposium on Combustion, Warsaw, Poland. 29 July-3 August 2012

J. Sandquist, B. Matas Güell, L. Sørum
Biofuels in aviation – an overview
International Nordic Bioenergy Conference, Jyväskylä, Finland, 5-9 September 2011

B. Matas Güell
Biodrivstoff fra termokjemiske prosesser
Teknologisk Møteplass, Oslo, Norway, 14 June 2012

J. Sandquist
Gassifisering og samarbeidet mellom SINTEF og industrien for utvikling av 2. generasjons biodrivstoff
Bioenergidagene, Oslo, Gardermoen, Norway, 8-9 November 2010

Media contributions

B. Matas Güell
Vedfyrte biler løste drivstoffproblemene under andre verdenskrig. Nå kan skogen igjen bli gull verdt. Denne gangen som drivstoff for fly
NRK1, Schrødingers katt, 2 October 2014 (national television in Norway)

J. Nilsen (J. Sandquist)
Bioflex 1 - Her kan de produsere 82 millioner liter bioethanol i året
Teknisk Ukeblad, 29 September 2014

J. Nilsen (J. Sandquist)
British Airways skal lage flydrivstoff av søppel
Teknisk Ukeblad, 04/25, 2014

J. Sandquist, G. Lohre Johansen
Norway - Recent progress in transport biofuels
IEA Task 39 Newsletter, Issue 34, 2013

Å. Dragland
Flydrivstoff fra norske skoger
Adresseavisen, Newspaper, 23 June, 2013

Å. Dragland
Flydrivstoff fra norske skoger
Gemini, Popular Science Magasine, 23 June, 2013

R. Ramsdal
Koker trær på 1500 grader for å lage flybiodrivstoff
Teknisk Ukeblad, Popular Science Magasine, 7 June 2013

B. Matas Güell/ A. Abelsen
Drivstoff fra skauen
Popular Science Magasine, Teknisk Ukeblad/ Forskningsrådet Status 2012 Renergi-Program, 1 November 2012

B. Matas Güell/ A. Abelsen
Derfor ble jeg energiforsker
Energiteknikk, October 2012

B. Matas Güell/ B. Sved
Utlendingene redder norsk teknologiforskning
Adresseavisen (Newspaper), February 2013

B. Matas Güell/M. Bugge/ A. Lundquist
Trær på tanken
Bioenergi, 1 November 2011

B. Matas Güell
Catalans a Noruega
COM Ràdio, December 2010

GasBio - Gasification for Biofuels

Industry partners: Avinor, Metso, Norske Skog, Statkraft, Statoil Petroleum ASA and Xynergo
Research partners: SINTEF and NTNU

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www.sintef.no/GasBio