# Possible Role of a Biorefinery´s Syngas Platform in a Biobased Economy – Assessment in IEA Bioenergy Task 42 “Biorefining”

G. Jungmeier[1], R. Van Ree[2], E. de Jong[3], H. Jørgensen[4], P. Walsh[4], M. Wellisch[4], H. Stichnothe[4], I. de Bari[4], M. Klembara[4], G. Garnier[4]

1. JOANNEUM RESEARCH, Elisabethstrasse 18, A-8010 Graz, Austria; gerfried.jungmeier@joanneum.at
2. Wageningen UR, Bio-based Products, Wageningen, The Netherlands
3. Avantium Chemicals BV, The Netherlands
4. National delegates of the 11 participating countries in IEA Bioenergy Task 42 “Biorefinery”

## Abstract

IEA Bioenergy Task 42 “Biorefining – Sustainable Processing of Biomass into a Spectrum of Marketable Bio-based Products and Bioenergy“ has formulated the following definition: “Biorefining is the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)”. “Energy-driven” biorefineries and “product-driven” biorefineries are distinguished. A classification system for biorefinery was developed to describe each biorefinery by the following four features: 1) platform e.g. syngas, 2) feedstock, 3) products and 4) processes, e.g. “A 3-platform (lignin, C6&C5 sugar, electricity&heat,) biorefinery using wood chips for bioethanol”. Based on the activities of the 12 participating countries (A, AUS, CA, DK, FR, G, I, IR, J, K, NL, US) the task identifies and assesses the current status and development potential of “energy-driven” biorefineries and “product-driven” biorefineries for a biobased economy. Synthesis gas (Syngas) is a mixture of mainly carbon monoxide and hydrogen. It is produced by gasification in the presence of oxygen, air or steam. After cleaning, the syngas can be used to produce power or can be converted into lower alcohols, fuel (e.g. Fischer-Tropsch diesel) and chemical products. Syngas can also be fermented to methanol, ethanol, ammonia and potentially other chemical building blocks. The most promising syngas derived chemicals are methanol, DME (dimethylether), bioethanol, hydrogen, carbon dioxide and Fischer-Tropsch diesel. The synthesis gas is a platform in different biorefinery concepts, of which the most promising biorefineries until 2025 with a syngas platform using wood and straw were identified in IEA Bioenergy Task 42. As a first step the 5 most interesting “energy-driven” biorefinery concepts until 2025 based on wood and straw to produce syngas and their value chains, including the integration and deployment options in industrial infrastructures, are analyzed. These concepts based on wood and straw produce the following transportation biofuels: FT-biofuels, biomethane, dimethyleter and hydrogen:

1. “4-platform (electricity&heat, hydrogen, biomethane, syngas) biorefinery using wood chips for biomethane (SNG), hydrogen and carbon dioxide“
2. “5-platform (C6 sugars, C5&C6 sugars, lignin, syngas, electricity&heat) biorefinery using starch crops and straw for bioethanol, FT-biofuels, feed, electricity and heat“
3. “2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification“
4. “3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification“
5. “4-platform (pulp, syngas, electricity&heat) biorefinery using wood chips for FT-biofuels, electricity, heat and pulp“

For these selected concepts “Biorefinery Fact Sheets” are made within the activities of IEA Bioenergy Task 42 “Biorefineries”. Based on the mass and energy balance of these biorefineries with a syngas platform in these “Biorefinery Fact Sheets” a sustainability assessment based on whole value chain including environmental, economic and social aspects is documented. Further information: http://www.iea-bioenergy.task42-biorefineries.com/

## 1. Introduction:

IEA Bioenergy Task 42 "Biorefineries – Sustainable Processing of Biomass into a Spectrum of Marketable Bio-based Products and Bioenergy" has formulated the following definition: "Biorefining is the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)". "Energy-driven" biorefineries and "product-driven" biorefineries are distinguished. A classification system for biorefinery was developed to describe each biorefinery by the following four features [1] (Figure 1, Figure 2): 1) platform e.g. syngas, 2) feedstock, 3) products and 4) processes, e.g. "A 3-platform (lignin, C6&C5 sugar, electricity&heat,) biorefinery using wood chips for bioethanol".

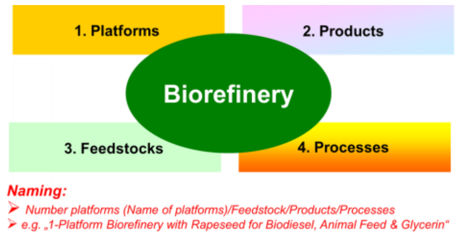


**Fig. 1: The 4 features to characterize a biorefinery system**

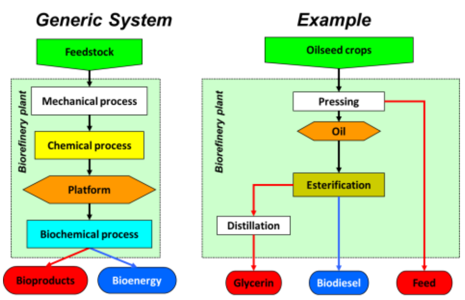


**Fig. 2: The generic system and an example for a biorefinery using the 4 features**

There are two different motivations recognized for the developing of biorefineries (Figure 3):

1) "Energy driven" biorefineries: production of large volumes of road transportation biofuels
2) "Product driven" biorefineries: production of bio-based materials and chemicals.

In "energy driven" biorefineries biomass is primarily used for the production of road transportation biofuels, power and heat). Process residues are sold or even further upgraded to value-added bio-based products to provide further economic and environmental benefits.

In "product driven" biorefineries biomass is typically fractionated into a portfolio of bio-based products with the focus being to derive the highest economic value from the biomass. A cascade approach is often used where the process residues are used for power and/or heat production.

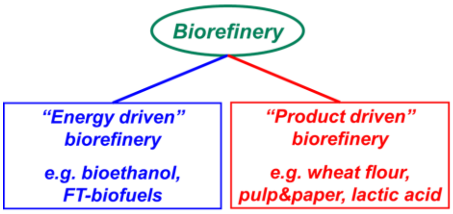


**Fig. 3: The two motivations for a biorefinery**

Based on the ongoing activities in the 12 countries (A, AUS, CA, DK, FR, G, I, IR, J, K, NL, US) participating in IEA Bioenergy Task 42 "Biorefineries", the task identifies and assesses the current status and development perspective of both "energy driven" biorefineries (incl. biofuels) and "product driven" biorefineries. These assessments are based on a "full value chain approach", covering raw material supply, conversion processes and final product applications in an integrated approach.

## 2. Approach:

The approach in this paper is to describe the most promising "energy driven" biorefineries already existing today or having the potential for implementation by 2025 using the synthesis gas as a platform [2].

Synthesis gas (Syngas) is a mixture of mainly carbon monoxide and hydrogen. It is produced by gasification in the presence of oxygen, air or steam. After cleaning, the syngas can be used to produce power or can be converted into lower alcohols, fuel (e.g. Fischer-Tropsch diesel) and chemical products. Syngas can also be fermented to methanol, ethanol, ammonia and potentially other chemical building blocks. The most promising syngas derived chemicals are methanol, DME (dimethylether), bioethanol, hydrogen, carbon dioxide and Fischer-Tropsch diesel.

The identification of the biorefinery concepts with syngas as a platform is done based on a selection procedure (described below) of the most promising road transportation biofuels, biomaterials and feedstocks with their possible combinations in biorefinery systems. Transportation biofuels for aviation and for ships are not covered here.

## 3. Selection of most interesting biorefineries with syngas platform

The selection was done in three steps:

1) selection of road transportation biofuels,
2) listing of co-produced bioproducts and
3) selection of possible feedstocks.

The main motivation of the selection procedure was to produce large volumes of road transportation biofuels at low costs in order to contribute substantially to the goal of increasing the share of renewable road transportation fuels e.g. in Europe 10% in 2020 according to the Directive on Renewable Energy (RED).

As a first step, a selection of the most interesting road transportation biofuels, biomaterials and feedstocks was carried out. The selection started with road transportation biofuels that are well suited to the current infrastructure for gasoline, diesel and natural gas for the existing vehicle fleet, e.g. utilizing the current infrastructure of pumps, pipelines and other existing equipment. Therefore the most interesting road transportation biofuels are considered to be “drop in” biofuels that can be easily mixed and used in internal combustion engines in different blends with the fossil road transportation fuels. This selection concluded with the following four road transportation biofuels:

1) biodiesel (FAME - fatty acid methyl ester),
2) bioethanol,
3) Fischer-Tropsch (FT)-biofuels and
4) biomethane from upgraded biogas and SNG (synthetic natural gas),

In total 14 energy driven biorefineris were selected, which are shown in Figure 4 of which 5 concepts use the syngas platform.

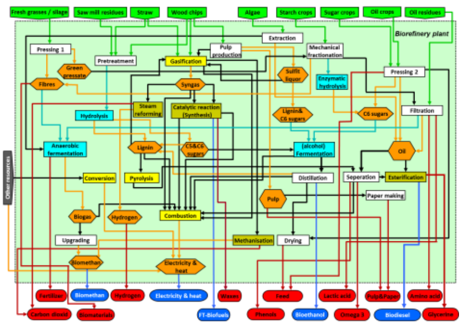

**Fig. 4: The 14 most interesting biorefineries until 2025 [2]**

The synthesis gas is a platform in different biorefinery concepts, of which the most promising biorefineries until 2025 with a syngas platform using wood and straw were identified in IEA Bioenergy Task 42. The 5 most interesting “energy-driven” biorefinery concepts until 2025 based on wood and straw to produce syngas and their value chains, including the integration and deployment options in industrial infrastructures, are analysed. These concepts based on wood and straw produce the following transportation biofuels:

- FT-biofuels,
- biomethane,
- dimethyleter and
- hydrogen.

The 5 most promising biorefinery concepts with syngas platform are presented in the following list using the classification nomenclature of IEA Bioenergy Task 42:

1. “4-platform (electricity&heat, hydrogen, biomethane, syngas) biorefinery using wood chips for biomethane (SNG), hydrogen and carbon dioxide“ (Figure 5)
2. “5-platform (C6 sugars, C5&C6 sugars, lignin, syngas, electricity&heat) biorefinery using starch crops and straw for bioethanol, FT-biofuels, feed, electricity and heat“ (Figure 6)
3. “3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification“ (Figure 7)
4. “2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification“ (Figure 8)
5. “4-platform (pulp, syngas, electricity&heat) biorefinery using

wood chips for FT-biofuels, electricity, heat and pulp“ (Figure 9)

The state of technology and their commercialization is quite different for these concepts. Here three different states of technologies are used in the further descriptions:

- Commercial scale energy driven biorefineries: these biorefineries are state of the art and are worldwide in commercial operation under current economic conditions
- Demonstration scale energy driven biorefineries: these biorefineries or their main processes are demonstrated on a technical scale at one or more locations worldwide, but they need further technical optimization and cannot be operated under current commercial conditions. It is expected that these biorefineries can be commercially operated in 2025.
- Conceptual energy driven biorefineries: these biorefineries are not demonstrated on technical scale so far, but it is expected that they will be further technically developed and demonstrated after further necessary R&D developments within the next years. It is expected that these biorefineries can be commercially operated in 2025.

The demonstration scale energy driven biorefinery “4-platform (electricity&heat, hydrogen, biomethane, syngas) biorefinery using wood chips for biomethane (SNG), hydrogen and carbon dioxide“ is shown in Figure 5. The wood chips are gasified with steam to produce a product gas which is upgraded to synthesis gas the steam gasification also includes a necessary gas treatment. Via methanation synthetic natural gas (SNG as biomethane) is produced. Via steam reforming the syngas is used to produce hydrogen, which can be used as a process media or chemical. Also Carbon dioxide is co-produced, which can be separated and used for various applications, e.g. food industry, industrial. Residues or gaseous side streams are used to produce electricity and heat in a CHP application. Depending on the further successful development beside the steam gasification of wood, which is suitable for smaller to medium sized gasifiers also the gasification with oxygen for large applications (e.g. entrained flow gasification) might become interesting. The necessary the oxygen must be produced via air separation or as a co-product from water electrolysis (e.g. with renewable electricity from excess wind power), which will offer further opportunities for integration in existing infrastructure to create additional synergies.

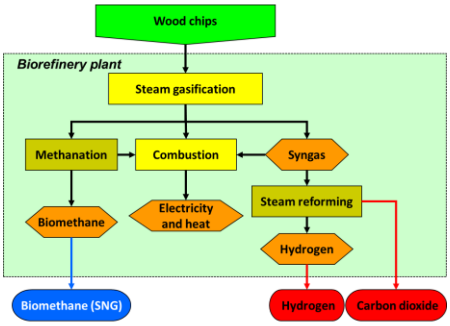


**Fig. 5: 4-platform (electricity&heat, hydrogen, biomethane, syngas) biorefinery using wood chips for biomethane (SNG), hydrogen and carbon dioxide“**

The conceptual energy driven biorefinery “5-platform (C6 sugars, C5&C6 sugars, lignin, syngas, electricity&heat) biorefinery using starch crops and straw for bioethanol, FT-biofuels, feed, electricity and heat“ is shown in Figure 6. The starch crops are transported to the biorefinery, where the starch is converted to C6 sugars in the enzymatic hydrolysis step. The straw is transported to the biorefinery, where the straw is pretreated for the hydrolysis to separate the sugars and the lignin. The C6 sugars from the starch crops and the C5&C6 sugars from the straw are fermented to bioethanol which is purified using distillation. The yeast to convert C5 sugars to bioethanol is not commercially available now. The fermentation solids, mainly proteins, are dried and pelleted for animal feed e.g. DDGS (Dried Distillers Grains with Solubles). In the fermentation $CO_2$ is produced, which can be separated and used for food industry (e.g. beverage industry) or as an industrial gas (e.g. pH control of waste water). The lignin is gasified, and the syngas out of the gasification is used to produce FT-biofuels. The residues are combusted to produce electricity and heat. After the necessary successful development of this biorefinery processes they might be well integrated into existing bioethanol production plants. The main advantage then is the possible common production of a substitute for gasoline and diesel in one biorefinery. With the syngas platform it is also possible to produce a further broad range of different chemicals. So with this type of biorefinery using starch crops and straw it will be possible to substitute the broad range of different petrochemical products from an oil refinery.

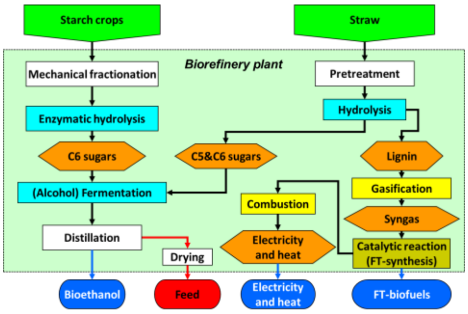


**Fig. 6: "5-platform (C6 sugars, C5&C6 sugars, lignin, syngas, electricity&heat) biorefinery using starch crops and straw for bioethanol, FT-biofuels, feed, electricity and heat"**

The demonstration scale energy driven biorefinery "3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification" is shown in Figure 7. In the fast pyrolysis the straw is used to produce pyrolysis oil and char in several decentralized locations close to the origin of the straw supply. The oil and the char are mixed together and are transported as slurry to one central gasification plant. In the gasification a syngas is produced by using oxygen as a gasification media. This syngas is then converted to FT-biofuels in the FT-synthesis and to methanol in the methanol synthesis. The main difference of the FT- and the methanol synthesis is on pressure, temperature, catalyst and the ratio between CO and H2 in the synthesis gas, e.g. FT-biofuel: 200 – 250 °C, 20 – 30 bar with Fe and/or Co as a catalyst. The methanol is mainly used as a chemical. Process residues are used to produce electricity and heat. After the successful development and demonstration of fast pyrolysis of straw in future further applications and uses for the pyrolysis oil might become interesting, e.g. the direct integration of pyrolysis oil in an existing oil refinery via upgrading to a renewable diesel fuel. In addition the char from pyrolysis can be used to produce other products for chemical industry to substitute fossil based products, e.g. activated char.

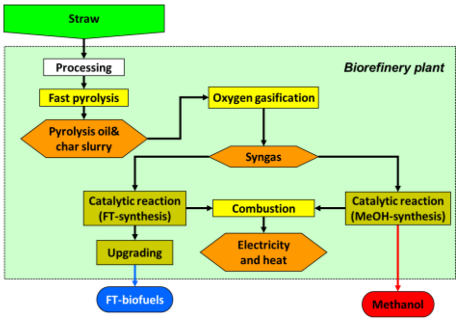


**Fig. 7: "3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification"**

The demonstration scale energy driven biorefinery "2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification" is shown in Figure 8 and the biorefinery "4-platform (pulp, syngas, electricity&heat) biorefinery using wood chips for FT-biofuels, electricity, heat and pulp" in Figure 9. Within the "2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification" the wood chips are gasified with steam to produce a product gas, which is used to produce raw FT-biofuels via a catalytic reaction (FT-synthesis). The final quality of the transportation FT biofuel is reached in the upgrading step, e.g. hydro processing. The process residues are combusted to produce electricity and heat. As a further product waxes are produced. In the "4-platform (pulp, syngas, electricity&heat) biorefinery using wood chips for FT-biofuels, electricity, heat and pulp" beside wood chips also black liquor form the pulp and paper industry is used to produce FT-biofuels, electricity and heat. This biorefinery could be integrated in an existing pulp and paper industry to realize technical and economic synergies. Depending on the further successful development beside the steam gasification of wood, which is suitable for smaller to medium sized gasifiers also the gasification with oxygen for large applications (e.g. entrained flow gasification) might become interesting. The large amount of syngas will then be an optimal starting point to produce additional synthetic products depending on the market demand for biomass based chemicals, e.g. methanol.

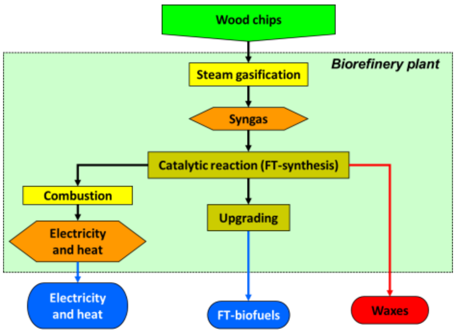


**Fig. 8: "2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification"**

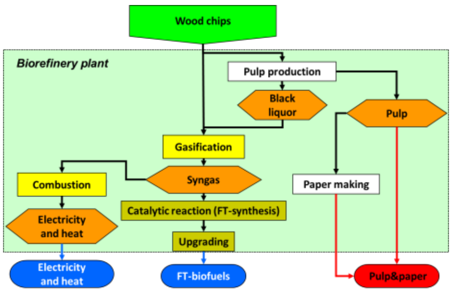


**Fig. 9: "4-platform (pulp, syngas, electricity&heat) biorefinery using wood chips for FT-biofuels, electricity, heat and pulp"**

## 4. Conclusion and Outlook

The role of a biorefinery´s syngas platform in a future biobased economy might be quite substantial. The currently driver for syngas platform biorefineries is the demand for large amounts of transportation biofuels. The key advantage of syngas is that it can be produced from various types of feedstocks and offers the possibility to produce a broad spectrum of different transportation biofuels and biobased chemicals.

In a next step for these selected concepts "Biorefinery Fact Sheets" are made within the activities of IEA Bioenergy Task 42 "Biorefineries". Based on the mass and energy balance of these biorefineries with a syngas platform in these "Biorefinery Fact Sheets" a sustainability assessment based on whole value chain including environmental, economic and social aspects is documented.

Based on this first selection of most promising biorefinery concepts to produce large volumes of road transportation biofuels by 2025 the Task 42 is assessing the sustainability of these biorefinery concepts by analyzing economic, environmental and social aspects in comparison to conventional processes and products.

In addition a so called "biorefinery complexity index" is under development for these biorefineries similar to the "Nelson`s complexity index" for oil refineries [3]. The "Nelson`s complexity index" was developed by Wilbur L. Nelson and was first mentioned in several articles of the Oil and Gas Journal in 1960-61.

Further information: http://www.iea-bioenergy.task42-biorefineries.com/

## 5. Acknowledgements

The Austrian participation in Tasks 42 of IEA Bioenergy is financed by the Federal Ministry for Transport, Innovation and Technology / Department for Energy and Environmental Technologies

## 6. References

[1] Cherubini F, Jungmeier G, Wellisch M, Willke T, Skiadas I, Van Ree R, de Jong E: Towards a common classification approach for Biorefinery Systems, Biofpr – Biofuels, Bioproducts and Biorefining, BBB 172, 2009

[2] Jungmeier G, Hingsamer M, van Ree R, Jorgenson H, Wellisch M, Stichnote H et al. Energy Driven Biorefineries - A Selection of the Most Promising Biorefinery Concepts to Produce Large Volumes of Road Transportation Biofuels by 2025, IEA Bioenergy Task 42 "Biorefining" Brochure, March 2013, *http://www.iea-bioenergy.task42-biorefineries.com/publications/reports/*

[3] Jungmeier G, Jørgensen H, Wellisch M, Willke T, Skiadas I, Van Ree R et al Do We Need a Biorefinery Complexity Index? – A Critical Review in IEA Bioenergy Task 42 "Biorefinery", CD, 20th European Biomass Conference, June 18 – 22, 2012 Milano, Italy