Version 1.0, 2014-09-19

The Biorefinery Fact Sheet

Gerfried Jungmeier[1]

with contributions from: Rene van Ree[2], Henning Jørgensen[3], Ed de Jong[4], Heinz Stichnothe[5], Maria Wellisch[6] and the other IEA Task 42 members

[1]Contact: JOANNEUM RESEARCH Forschungsgesellschaft mbH
RESOURCES – Institute for Water, Energy and Sustainability
Elisabethstraße 18/II, 8010 Graz, Austria
+43 316 876 1313, gerfried.jungmeier@joanneum.at

[2]WUR, Wageningen, The Netherlands; [3]University of Copenhagen, Copenhagen, Denmark; [4]Avantium Chemicals BV, Amsterdam, The Netherlands; [5]vTI, Braunschweig, Germany; [6]Agriculture and Rural Development, Edmonton, Canada; all members of IEA Bioenergy Task 42 "Biorefining: Co-production of Fuels, Chemicals, Power and Materials from Biomass" (http://www.IEA-Bioenergy.Task42-Biorefineries.com).

Content

1. Introduction

As a first step the some selected biorefinery concepts until 2025 and their value chains, including the integration and deployment options in industrial infrastructures, are analysed. As the development status and the perspectives for implementation and development of these biorefineries are different the IEA task develops a “Biorefinery Fact Sheet” for the uniform description of the key facts of a Based on a technical description and the classification scheme the mass and energy balance is calculated for the most reasonable production capacity for each of the selected biorefineries. Then the three dimensions – economic, environmental and social - of sustainability are assessed for each biorefinery and documented in a compact form in the “Biorefinery Fact Sheet”. Based on these sheets an easy comparison of the different biorefinery systems is possible. The “Biorefinery Fact Sheet” assists various stakeholders in finding their position on biorefining in a future biobased economy. The “Biorefinery Fact Sheets” will be made for the 15 most interesting “energy driven biorefinery systems” identified by IEA Bioenergy Task 42.

1 The biorefinery Fact Sheet

The “Biorefinery Fact Sheets” consist of three parts (Figure 3):

1. Part A: Biorefinery plant
2. Part B: Value chain assessment and
3. Annex: Methodology of sustainability assessment and data

In Part A the key characteristics of the biorefinery plant are described by giving compact information on

- classification scheme,
- description of the biorefinery,
- mass and energy balance,
- share of costs and revenues.

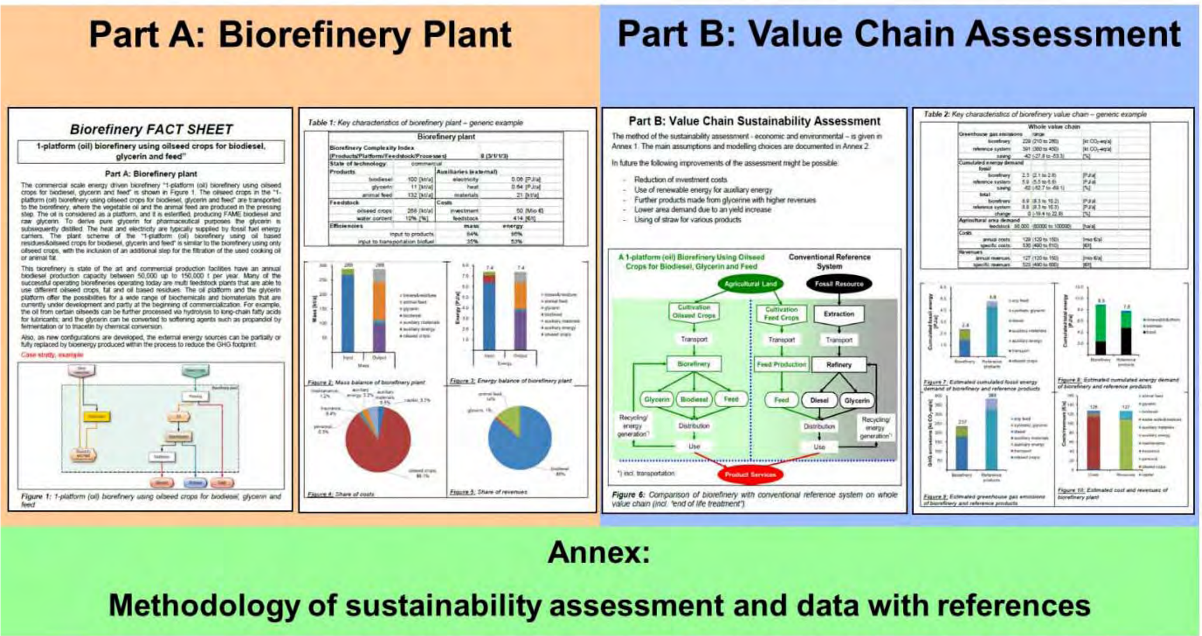


Figure 3: The three parts of the "Biorefinery Fact Sheet"

In Part B the sustainability assessment based on the whole value chain of the biorefinery plant is described by giving compact information on

- system boundaries,
- reference system,
- cumulated primary energy demand,
- greenhouse gas emissions and
- costs and revenues.

In Figure 7 to Figure 10 this compact information in Part B are shown for an example.

In the Annex of the "Biorefinery Fact Sheet" the main data for the sustainability assessment are documented.

One important aspect is the choice of the reference system to produce the same products as the biorefinery plant (Figure 11) and the basics of comparing a biorefinery to the reference system (Figure 12).

In a next step the "Biorefinery Fact Sheets" will be made for the 15 most interesting "energy driven biorefinery systems" identified by IEA Bioenergy Task 42. These biorefineries produce road transportation biofuels in huge amounts (biodiesel, bioethanol, biomethane and FT-diesel) from various feedstocks by coproducing high value products like food, feed, biochemicals and biomaterials.

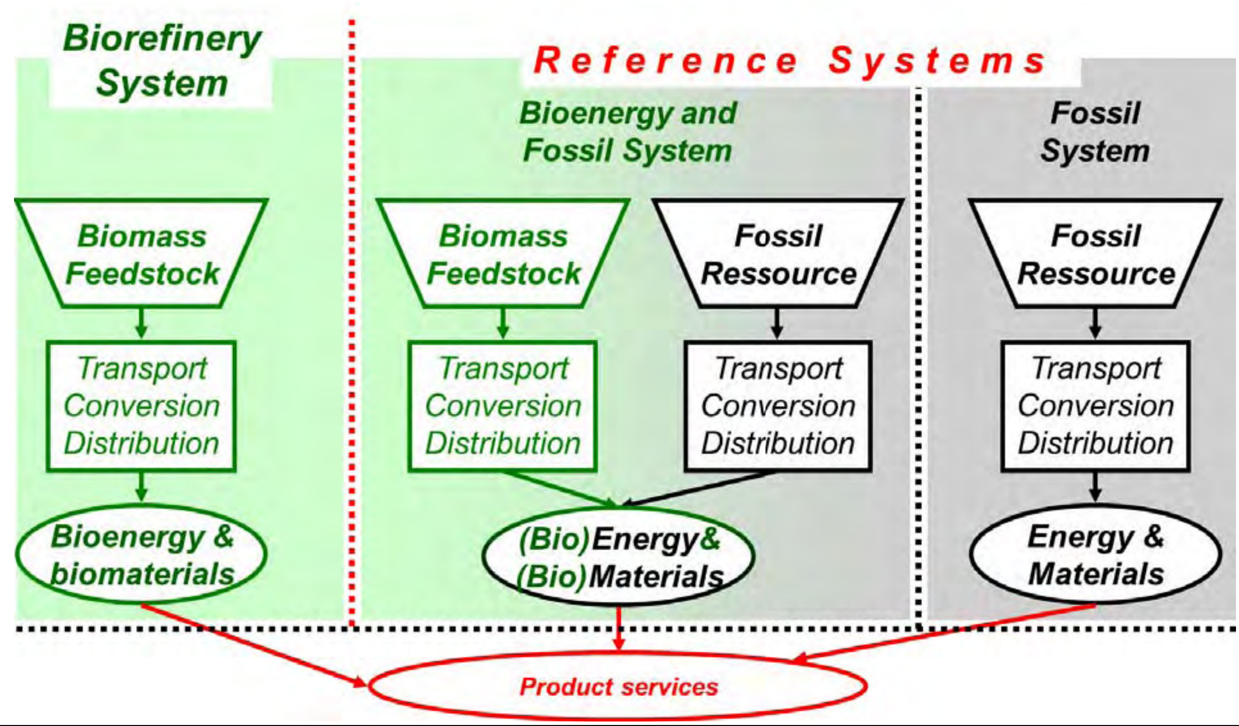


Figure 11: Choice and definition of the reference system for the sustainability assessment in the "Biorefinery Fact Sheet"

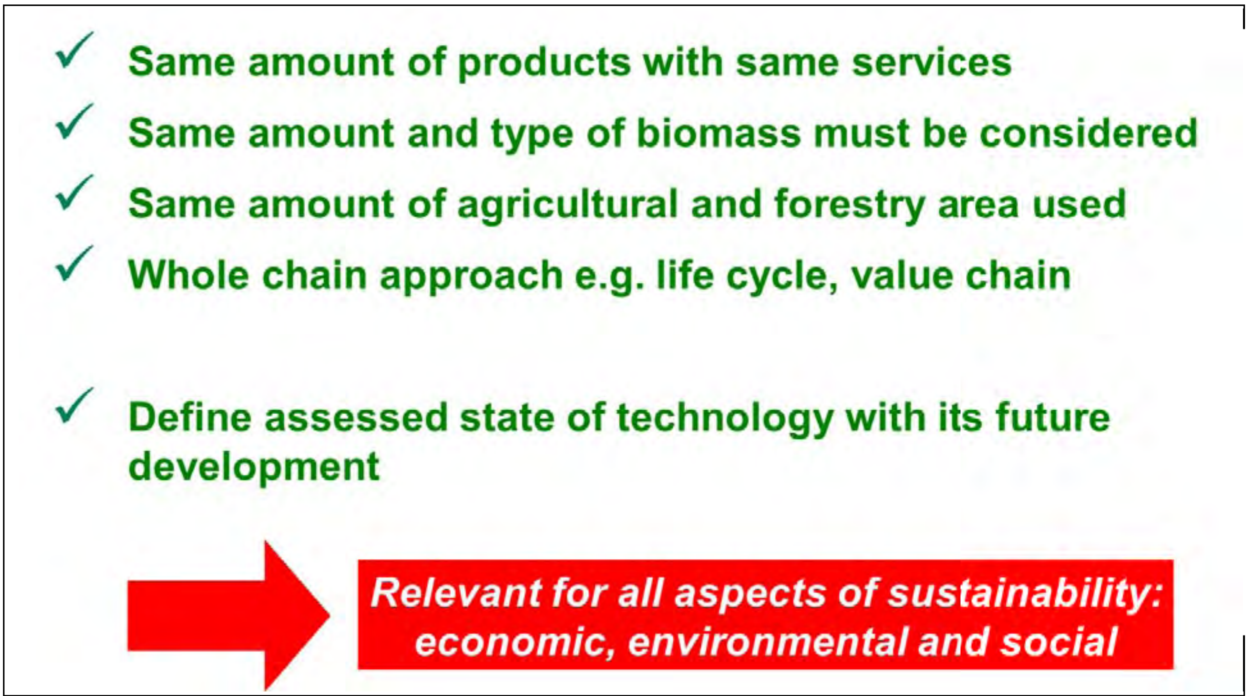


Figure 12: Basics for the consistent comparison of biorefineries to reference systems

2 Biorefinery Fact Sheets

2.1 4-platform (biogas, green juice, green fibres, electricity&heat) biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer, electricity

Biorefinery FACT SHEET

"4-platform (biogas, green juice, green fibres, electricity&heat) biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer, electricity"

Part A: Biorefinery plant

The "4-platform (biogas, green juice, green fibres, electricity&heat) biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer, electricity" is shown in in Figure 1. The grass is mechanically pressed and then separated in a liquid phase ("Green juice) and solid phase ("Fibres").The fibres are used as insulation material or are further pelletized to be used as an ingredient for bioplastic. The green juice is used to produce biogas in an anaerobic fermentation. Food residues are used as an additional feedstock for the biogas fermentation. The biogas is used in a CHP plant with an internal combustion engine to produce electricity and heat. The heat demand of the biorefinery is higher than the heat produced from biogas, so additionally natural gas is used to supply the heat. For electricity it is vice versa, so more electricity is produced than the electricity demand of the biorefinery is, so the excess electricity is sold to the grid. This type of biorefinery is already realised in several countries.

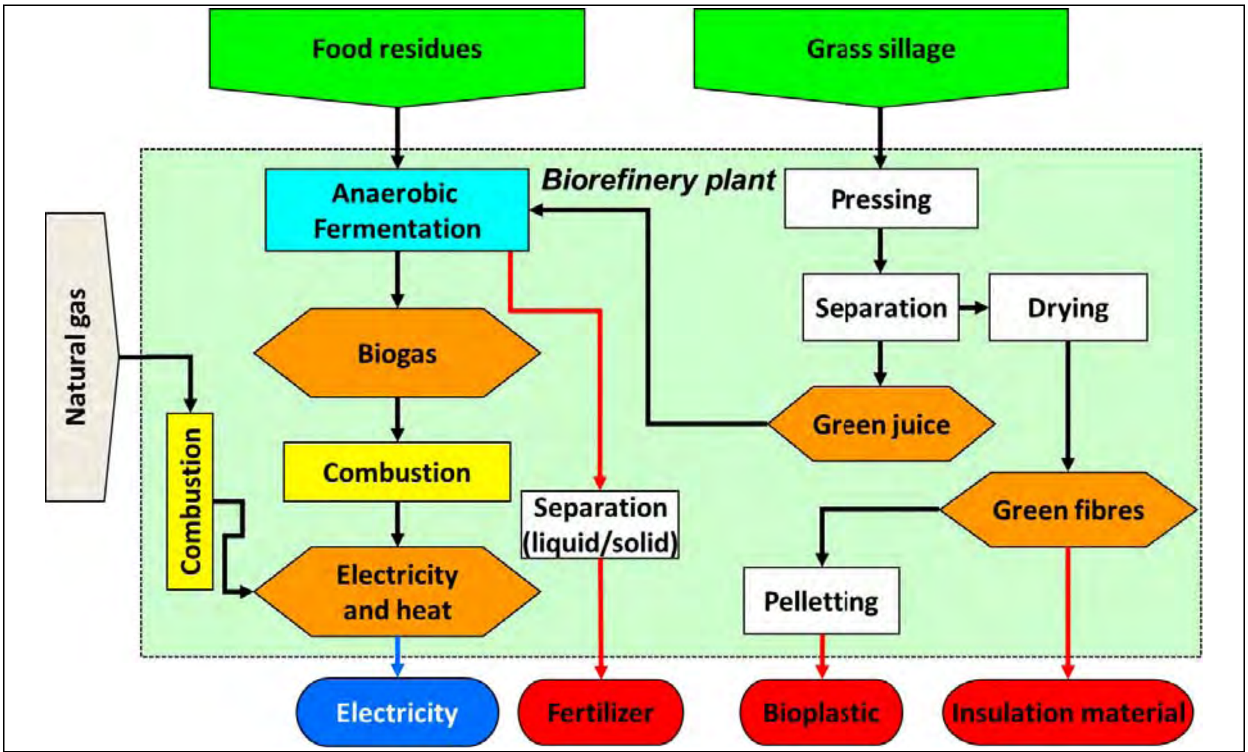


Figure 1: *4-platform (biogas, green juice, green fibres, electricity&heat) biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer and electricity*

Table 1: *Key characteristics of biorefinery plant*

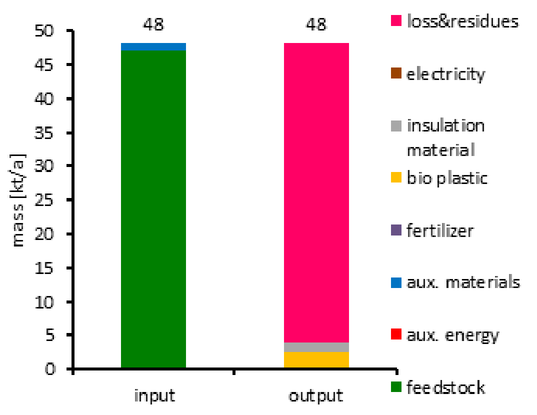
"4-platform (biogas, green juice, green fibres, electricity&heat) biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer, electricity"

State of technology:	commercial 2013	Biorefinery Complexity Index (Products/Platform/Feedstock/Processes)	28 (3/7/8/10)
Country:	EU 27		
Main data sources:	VDI 6310, JOANNEUM RESEARCH		

Products			**Auxiliaries (external)**		
fertilizer	0	[kt/a]	electricity	0	[PJ/a]
bio plastic	2.5	[kt/a]	heat	0.01	[PJ/a]
insulation material	1.4	[kt/a]	polypropylen (PP)	1.3	[kt/a]
electricity	0.02	[PJ/a]	urea	0.01	[kt/a]

Feedstock	**[kt/a]**	**water content [%]**	**Costs**		
grass sillage	7	65.0%	investment costs	17	[Mio €]
food residues	40	80.0%	feedstock costs	14	[€/t]
			number of employees	10	[#]

Efficiencies	**mass**	**energy**
input to products	8%	13%
input to transportation biofuel	0%	0%



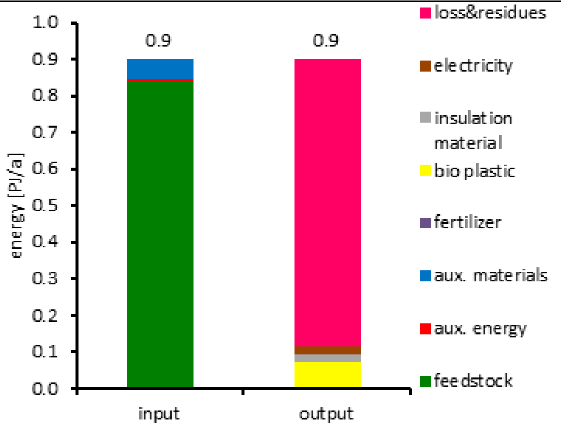
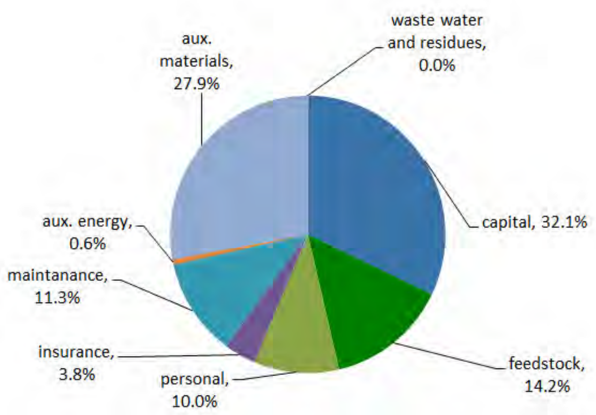


Figure 2: *Mass balance of biorefinery plant*

Figure 3: *Energy balance of biorefinery plant*



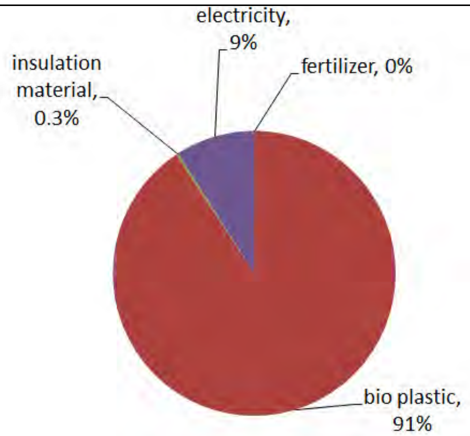


Figure 4: *Share of costs*

Figure 5: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

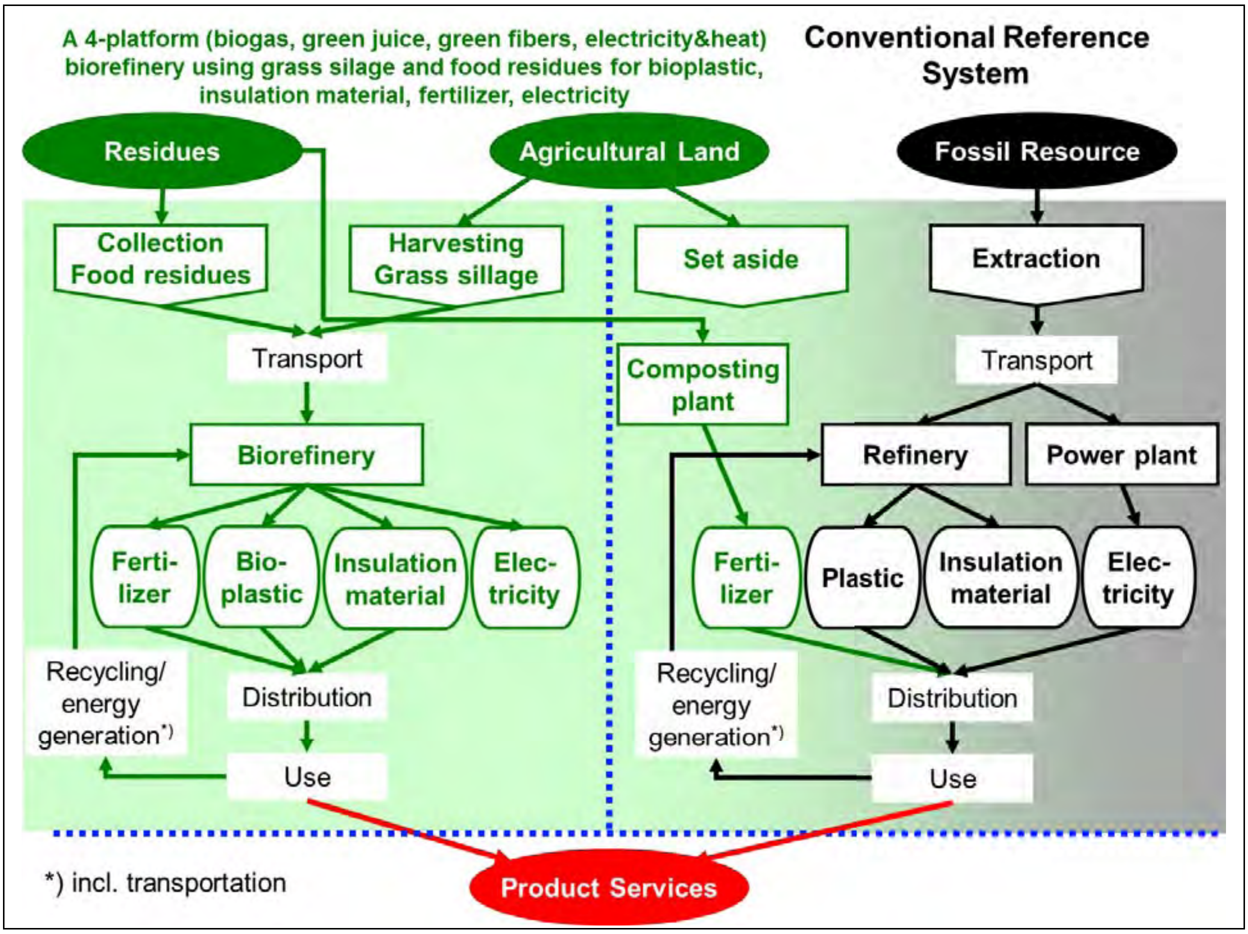


Figure 6: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 2: *Key characteristics of biorefinery value chain*

Whole value chain		range	
Greenhouse gas emissions			
biorefinery	5.5	(5.1 to 6.3)	[kt CO_2-eq/a]
reference system	21	(20 to 24)	[kt CO_2-eq/a]
saving	-74%	(-69% to -85%)	[%]
Cumulated energy demand			
fossil			
biorefinery	0.07	(0.07 to 0.08)	[PJ/a]
reference system	0.27	(0.25 to 0.31)	[PJ/a]
saving	-74%	(-69% to -85%)	[%]
total			
biorefinery	0.17	(0.16 to 0.2)	[PJ/a]
reference system	0.29	(0.27 to 0.34)	[PJ/a]
change	-42%	(-39% to -48%)	[%]
Agricultural area demand			
feedstock	700	(650 to 800)	[ha/a]
Costs			
annual costs	4.5	(4.2 to 5.2)	[Mio €/a]
specific costs	1,150	(1100 to 1300)	[€/t]
Revenues			
annual revenues	5.5	(5.1 to 6.3)	[Mio €/a]
specific revenues	1,410	(1300 to 1600)	[€/t]

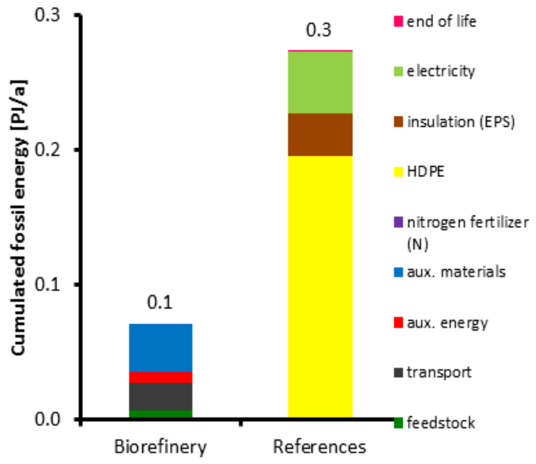


Figure 7: *Estimated cumulated fossil energy demand of biorefinery and reference products*

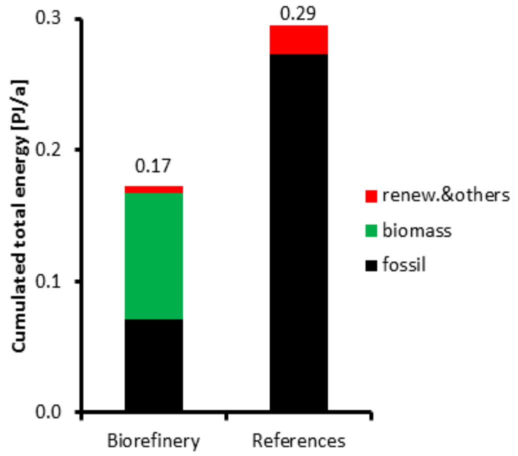


Figure 8: *Estimated cumulated energy demand of biorefinery and reference products*

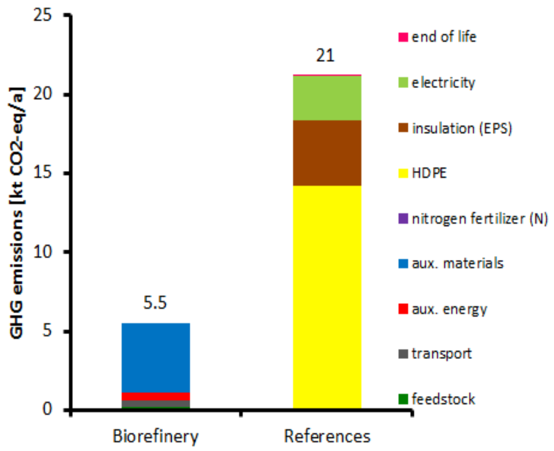


Figure 9: *Estimated greenhouse gas emissions of biorefinery and reference products*

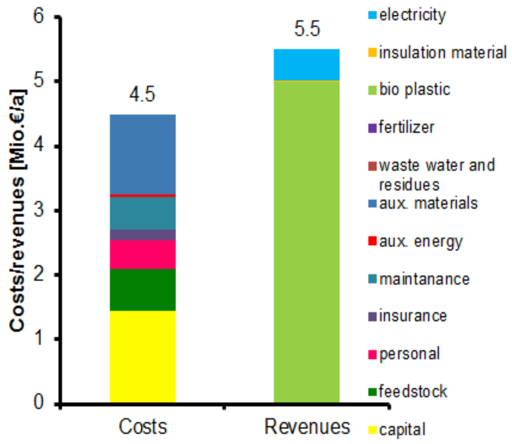


Figure 10*Estimated cost and revenues of biorefinery plant*

2.2 3-platform (black liquor, pulp, electricity&heat) biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat

Biorefinery FACT SHEET

"3-platform (black liquor, pulp, electricity&heat) biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat"

Part A: Biorefinery plant

The commercial scale "3-platform (black liquor, pulp, electricity&heat) biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat" is shown in Figure . The wood or wood chips are transported to the biorefinery, where the wood is mechanically debarked and chipped. Then the pulp is produced from the fibres and the rest of the wood and auxiliary chemicals end up in the black liquor. A share of the pulp is further processed to paper. Via a separation process the tall oil and the turpentine are produced and the rest of the black liquor is combusted to produce heat and electricity for the biorefinery and the surplus energy is sold. In the liquor combustion the chemicals are recovered and used again for pulp production.

This biorefinery is state of the art and commercial production facilities have an annual pulp production capacity between 200,000 up to 1,000,000 t per year. The black liquor platform contains a lot of other chemicals that are not recovered today due to economic and technical limitations. In future the broad variety of different chemical in the black liquor offers a great potential for future developments and new commercial products.

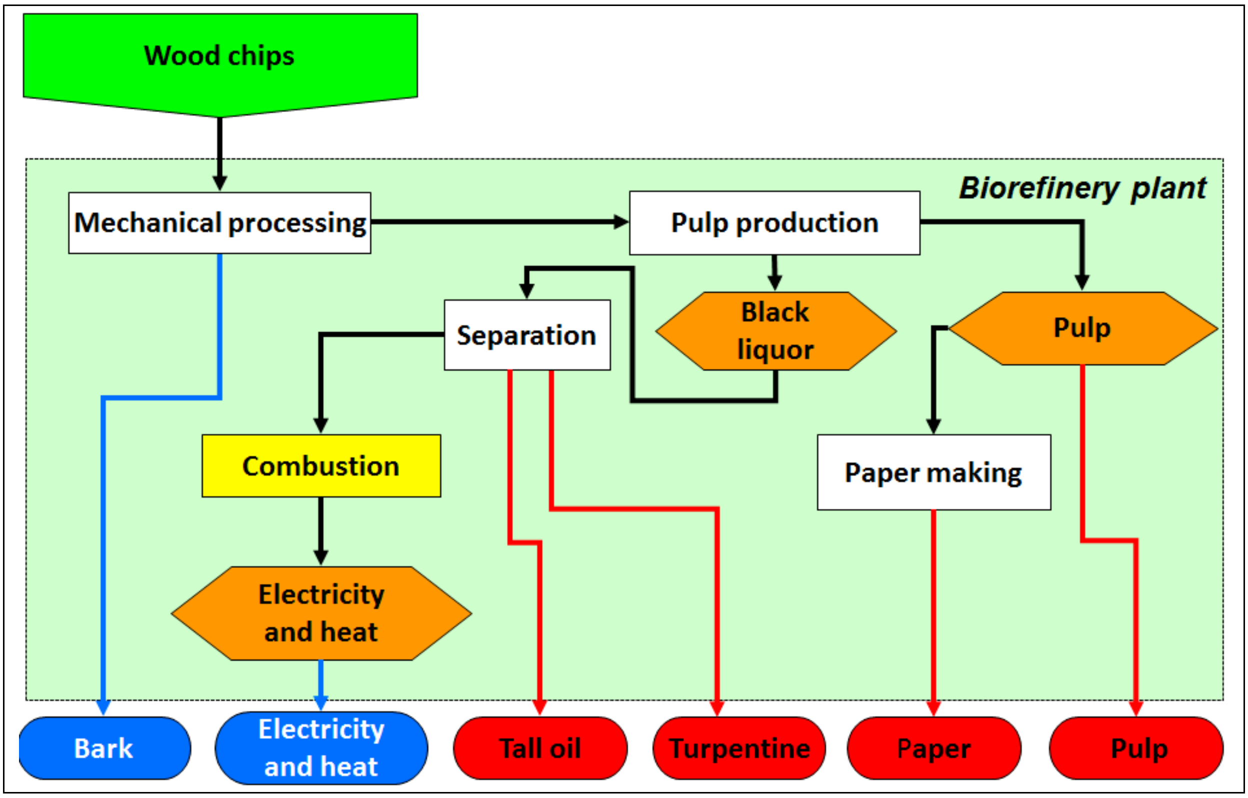


Figure 11: *3-platform (black liquor, pulp, electricity&heat) biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat*

Table 3: *Key characteristics of biorefinery plant*

"3-platform (black liquor, pulp, electricity&heat) biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat"							
State of technol	commercial 2013			Biorefinery Complexity Index (Products/Platform/Feedstock/ Processes)		15 (1/6/3/5)	
Country:	EU 27						
Main data sourc	JOANNEUM RESEARCH&Austropapier						
Products				**Auxiliaries (external)**			
pulp	400	[kt/a]		electricity	0.00	[PJ/a]	
paper	13	[kt/a]		heat	0.00	[PJ/a]	
bark (50%)	122	[kt/a]		energy carriers	1.29	[PJ/a]	
tall oil	6	[kt/a]		natriumchlorat	12.0	[kt/a]	
turpentine	0.2	[kt/a]		H2SO4 (97%)	9.0	[kt/a]	
electricity	0.4	[PJ/a]		O2	8.0	[kt/a]	
heat	0.25	[PJ/a]		NaOH (50%)	7.0	[kt/a]	
				burnt lime	5.0	[kt/a]	
Feedstock	**[kt/a]**	**water [%]**		**Costs**			
wood chips	1495	45.0%		investment costs	350	[Mio €]	
				feedstock costs	100	[€/t]	
				number of employees	400	[#]	
Efficiencies				**mass**		**energy**	
input to products				35%		32%	
input to transportation biofuel							

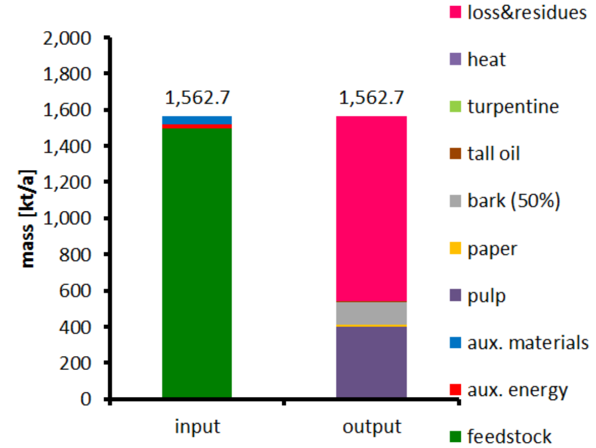


Figure 12: *Mass balance of biorefinery plant*

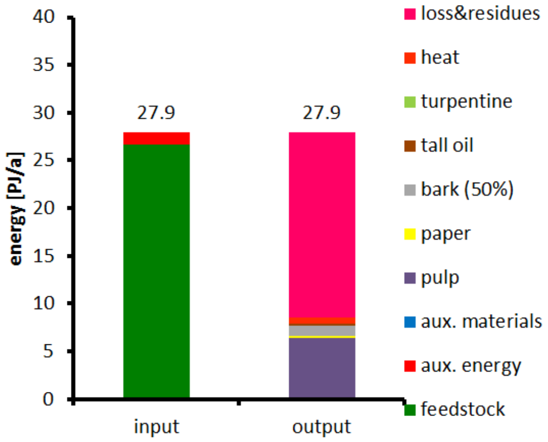


Figure 13: *Energy balance of biorefinery plant*

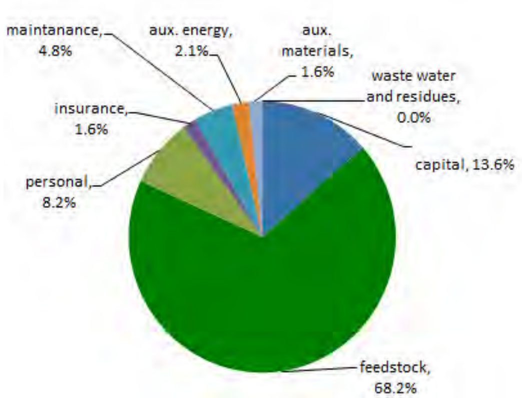


Figure 14: *Share of costs*

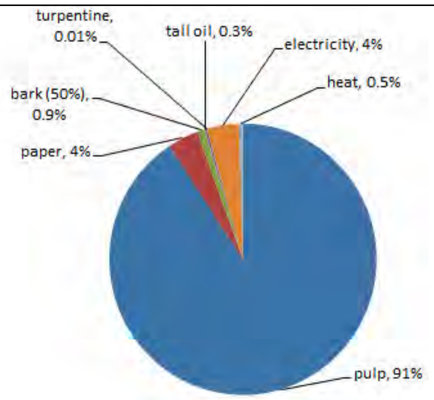


Figure 15: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

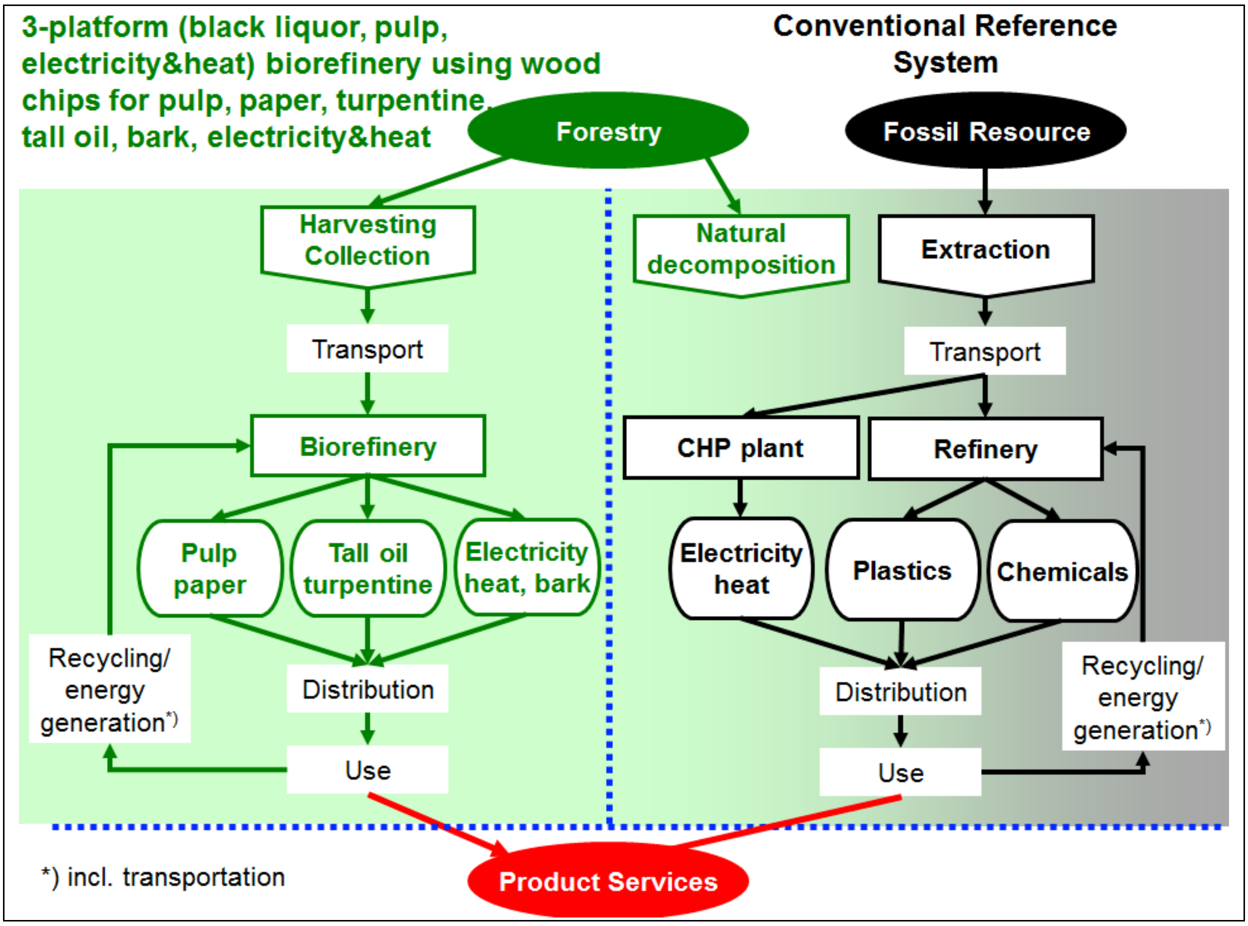
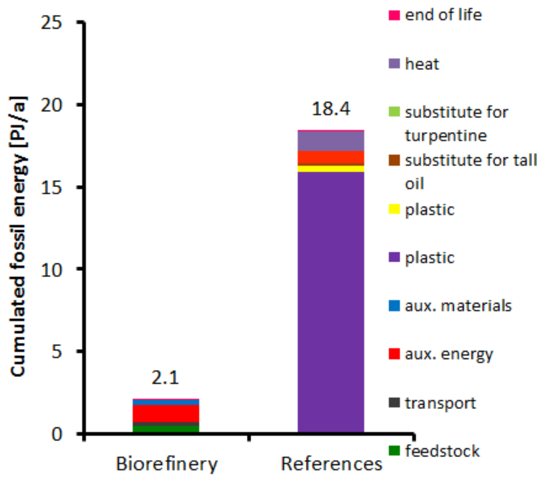


Figure 16: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 4: *Key characteristics of biorefinery value chain*

Whole value chain		range	
Greenhouse gas emissions			
	biorefinery	119 (110 to 140)	[kt CO_2-eq/a]
	reference system	1362 (1300 to 1600)	[kt CO_2-eq/a]
	saving	-91% (-85% to -105%)	[%]
Cumulated energy demand			
	fossil		
	biorefinery	2.1 (2 to 2.4)	[PJ/a]
	reference system	18.4 (17 to 21)	[PJ/a]
	saving	-89% (-82% to -102%)	[%]
	total		
	biorefinery	15.2 (14 to 17)	[PJ/a]
	reference system	20.0 (19 to 23)	[PJ/a]
	change	-24% (-22% to -27%)	[%]
Agricultural area demand			
	feedstock	0 (0 to 0)	[ha/a]
Costs			
	annual costs	219 (200 to 250)	[Mio €/a]
	specific costs	406 (380 to 470)	[€/t]
Revenues			
	annual revenues	220 (210 to 250)	[Mio €/a]
	specific revenues	408 (380 to 470)	[€/t]



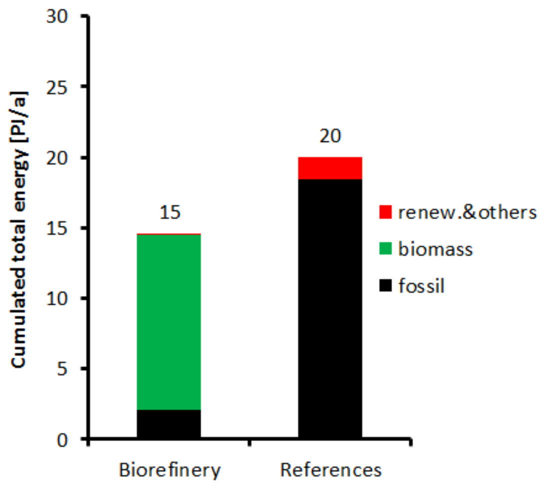
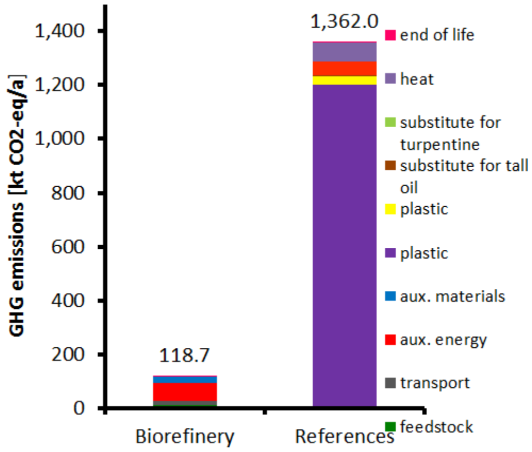


Figure 17: *Estimated cumulated fossil energy demand of biorefinery and reference products*

Figure 18: *Estimated cumulated energy demand of biorefinery and reference products*



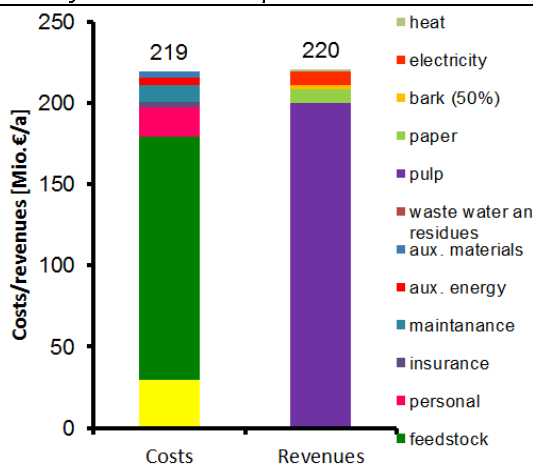


Figure 19: *Estimated greenhouse gas emissions of biorefinery and reference products*

Figure 201: *Estimated cost and revenues of biorefinery plant*

2.3 1-platform (C6 sugars) biorefinery using starch crops for bioethanol and feed

Biorefinery FACT SHEET

"1-platform (C6 sugars) biorefinery using starch crops for bioethanol and feed"

Part A: Biorefinery plant

The starch and/or crops in the "1-platform (C6 sugars) biorefinery using sugar&starch crops for bioethanol and feed" are transported to the biorefinery, where the starch is converted to C6 sugars in the enzymatic hydrolysis step.

The sugar crop e.g. from sugar beet is used to produce C6 sugars via mechanical pressing. The co-product, sugar beet pulp, is dried and used as animal feed. The C6 sugars are fermented to bioethanol which is purified using distillation. 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 heat and electricity are often supplied by fossil fuel energy This biorefinery is state of the art and commercial production facilities have an annual bioethanol production capacity between 100 up to 300 kt per year.

Many of the successful operating biorefineries in Europe are multi feedstock plants using different starch and sugar crops. In America most biorefineries use sugar cane or starch e.g. maize. The C6 sugars platform offers the possibilities to produce a wide range of biochemicals based on sugars. Such processes are currently under development or just starting to become commercialized. There will be a diversification of products from sugar and starch-derived C6 sugars (hexoses) towards other alcohols, chemicals and organic acids, as new biological and chemical processes to produce platform chemicals. A specific route currently under development, and likely to be commercialized in a medium term perspective is the fermentation of sugars to lipids. These lipids could be used by the oleochemical industry or to produce jet fuels, providing further integration potential between existing value chain. Also the sugar and starch based biorefinery offers interesting perspectives to integrate cereal straw (crop residues) into the supply chain, to produce C6 and C5 sugars. The use of dedicated lignocellulosic crops from agriculture is expected to increase when lignocellulosic conversion becomes more affordable.Also, as new configurations are developed, the external energy sources can be partially or fully replaced by bioenergy produced from within the process to reduce the GHG footprint.

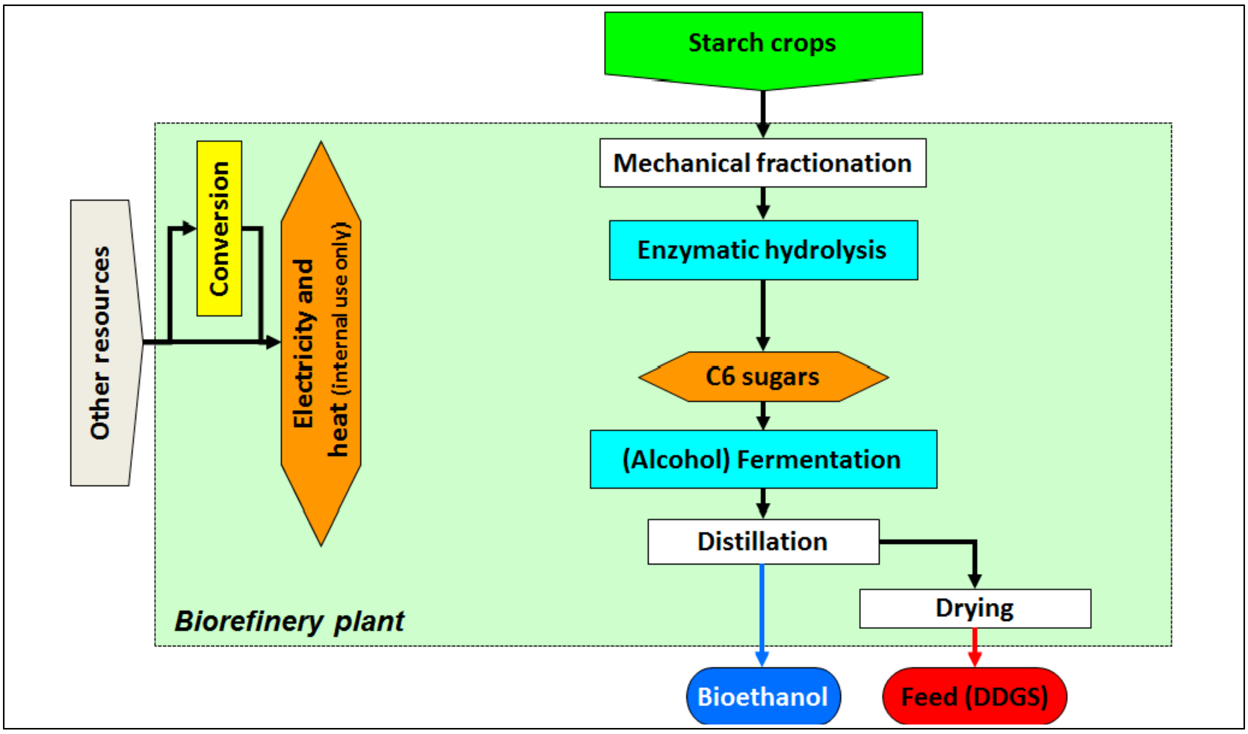


Figure 21: *1-platform (C6 sugars) biorefinery using starch crops for bioethanol and feed*

***Table 5:** Key characteristics of biorefinery plant*

“1-platform (C6 sugars) biorefinery using starch crops for bioethanol and feed“					
State of technology:	commercial 2013		Biorefinery Complexity Index (Products/Platform/Feedstock/Processes)		not calculated yet
Country:	EU 27				
Main data sources:	BIOGRACE, JOANNEUM RESEARCH				
Products			**Auxiliaries (external)**		
	bioethanol	150 [kt/a]		electricity	0.30 [PJ/a]
	DDGS	209 [kt/a]		heat	2.44 [PJ/a]
				others: various	5.0
Feedstock	**[kt/a]**	**water [%]**	**Costs**		
corn	496	15.0%		investment costs	120 [Mio €]
				feedstock costs	220 [€/t]
				number of employees	20 [#]
Efficiencies				**mass**	**energy**
		input to products		72%	61%
		input to transportation biofuel		30%	33%

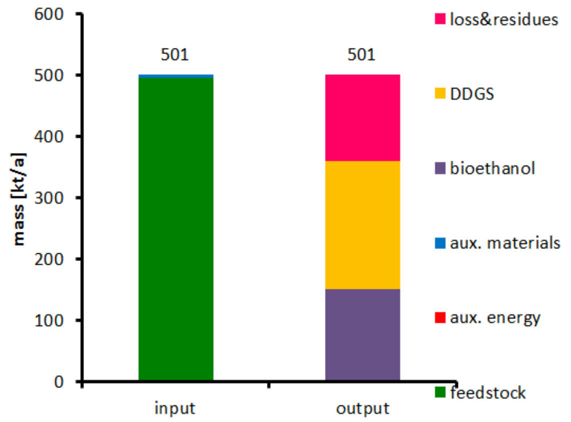


***Figure 22:** Mass balance of biorefinery plant*

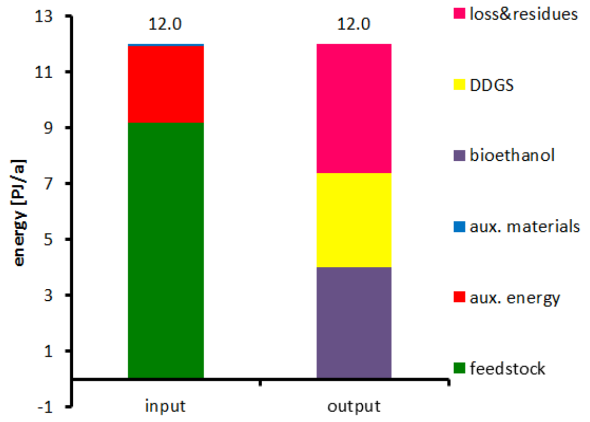


***Figure 23:** Energy balance of biorefinery plant*

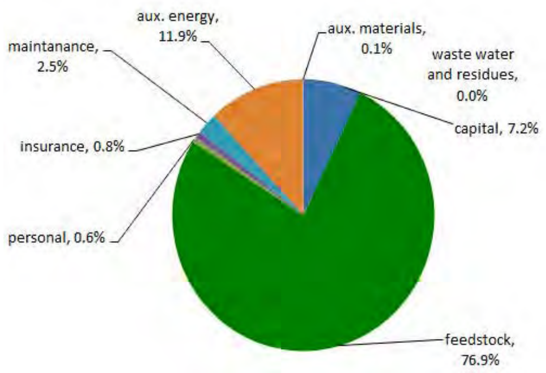


***Figure 24:** Share of costs*

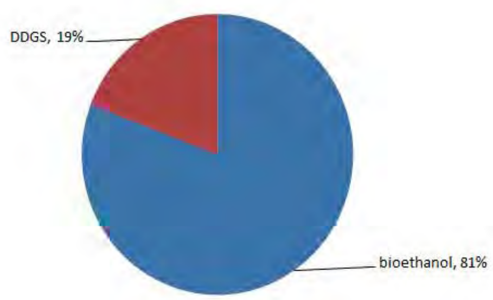


***Figure 25:** Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

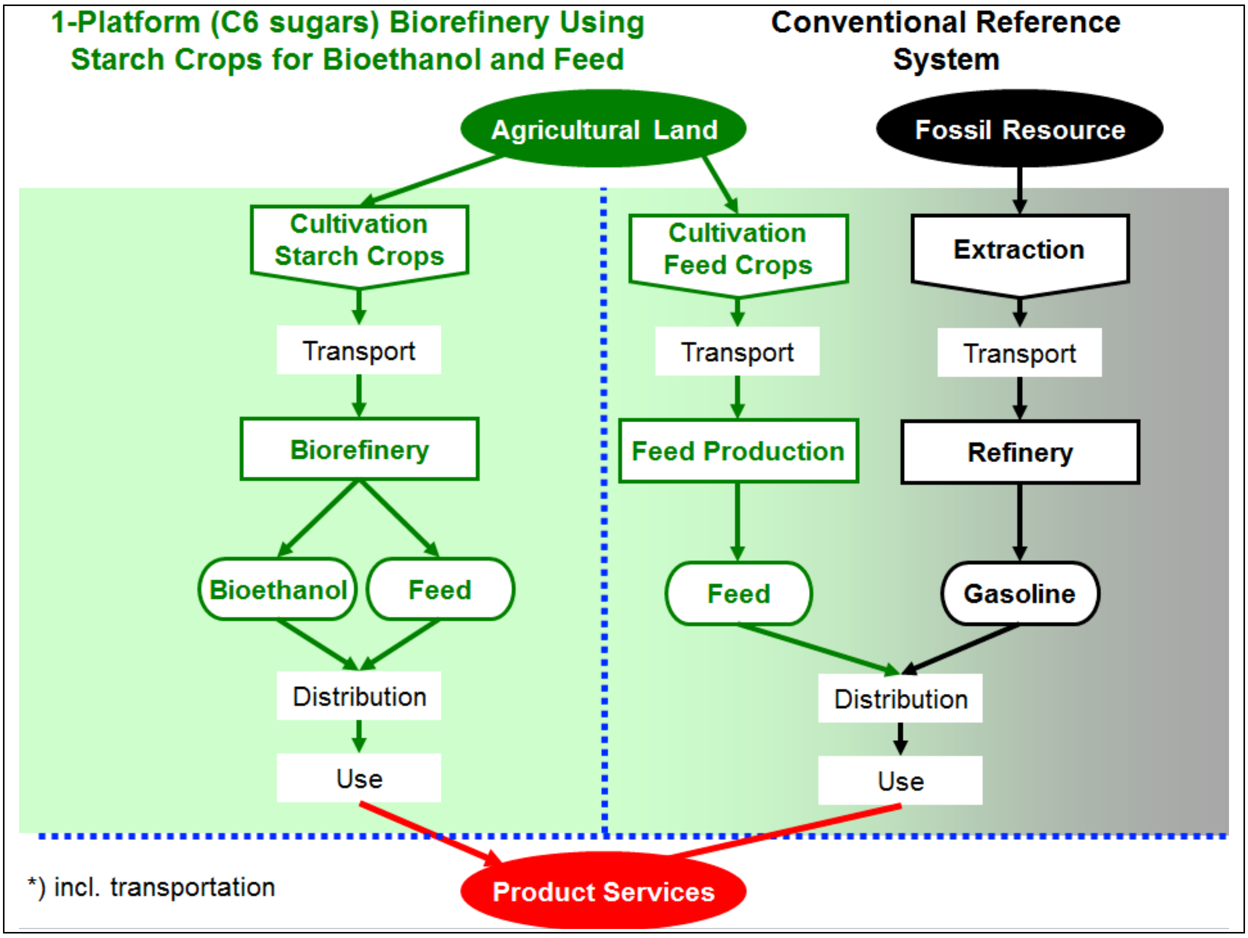


Figure26: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 6: *Key characteristics of biorefinery value chain*

Whole value chain			
Greenhouse gas emissions		**range**	
	biorefinery	360 (340 to 410)	[kt CO_2-eq/a]
	reference system	437 (410 to 500)	[kt CO_2-eq/a]
	saving	-17% (-16% to -20%)	[%]
Cumulated energy demand			
	fossil		
	biorefinery	4.6 (4,3 to 5,3)	[PJ/a]
	reference system	5.3 (5 to 6,1)	[PJ/a]
	saving	-13% (-12% to -15%)	[%]
	total		
	biorefinery	12.8 (12 to 15)	[PJ/a]
	reference system	9.6 (8,9 to 11)	[PJ/a]
	change	34% (31% to 39%)	[%]
Agricultural area demand			
	feedstock	128,000 (119000 to 147000)	[ha/a]
Costs			
	annual costs	142 (130 to 160)	[Mio €/a]
	specific costs	395 (370 to 450)	[€/t]
Revenues			
	annual revenues	141 (130 to 160)	[Mio €/a]
	specific revenues	394 (370 to 450)	[€/t]

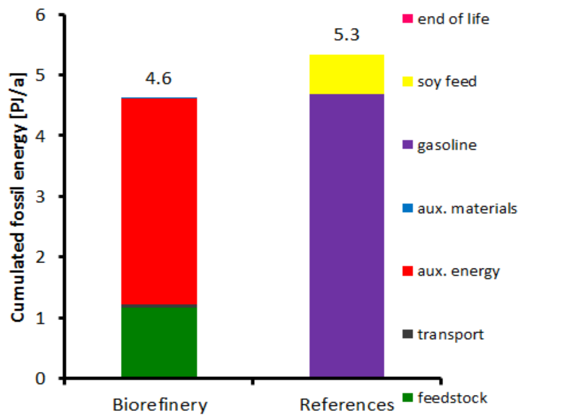


Figure 27: *Estimated cumulated fossil energy demand of biorefinery and reference products*

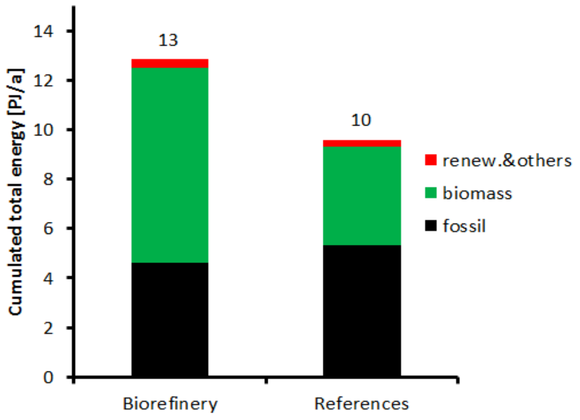


Figure 28: *Estimated cumulated energy demand of biorefinery and reference products*

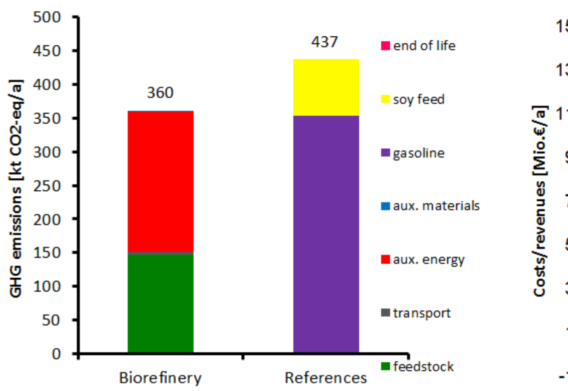


Figure 29: *Estimated greenhouse gas emissions of biorefinery and reference products*

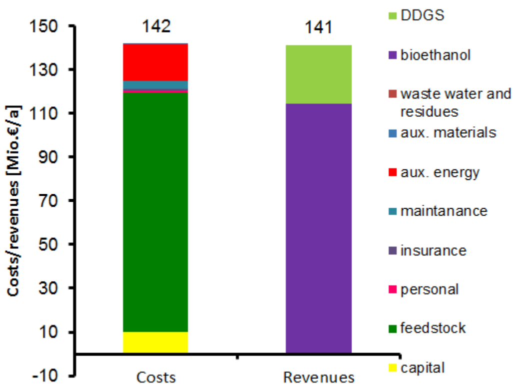


Figure 30*Estimated cost and revenues of biorefinery plant*

2.4 3-platform (C6&C5 sugar, electricity&heat, lignin) biorefinery using wood chips for bioethanol, electricity, heat and phenols

Biorefinery FACT SHEET

"3-platform (C6&C5 sugar, electricity&heat, lignin) biorefinery using wood chips for bioethanol, electricity, heat and phenols"

Part A: Biorefinery plant

The wood chips (without bark) are transported to the biorefinery, where the wood chips are pretreated for the hydrolysis to separate the sugars and the lignin. The C5&C6 sugars are fermented to bioethanol and the lignin is used to produce bio-oil via a pyrolysis step. The phenols from the bio-oil are separated and the residues are combusted to produce electricity and heat.

This biorefinery system is partly demonstrated, the production of bioethanol is demonstrated in Sweden and the pyrolysis of the lignin was tested on laboratory scale. So far the production of bioethanol from hard wood is easier to be developed than from soft wood. Recent R&D results show that the integration of a bioethanol production from wood in a pulp and paper production plant offers promising synergies like handling and logistic of wood, water and waste water treatment, electricity and steam infrastructure and personal. Realising these synergies would enable a commercial bioethanol production from wood by 2025.

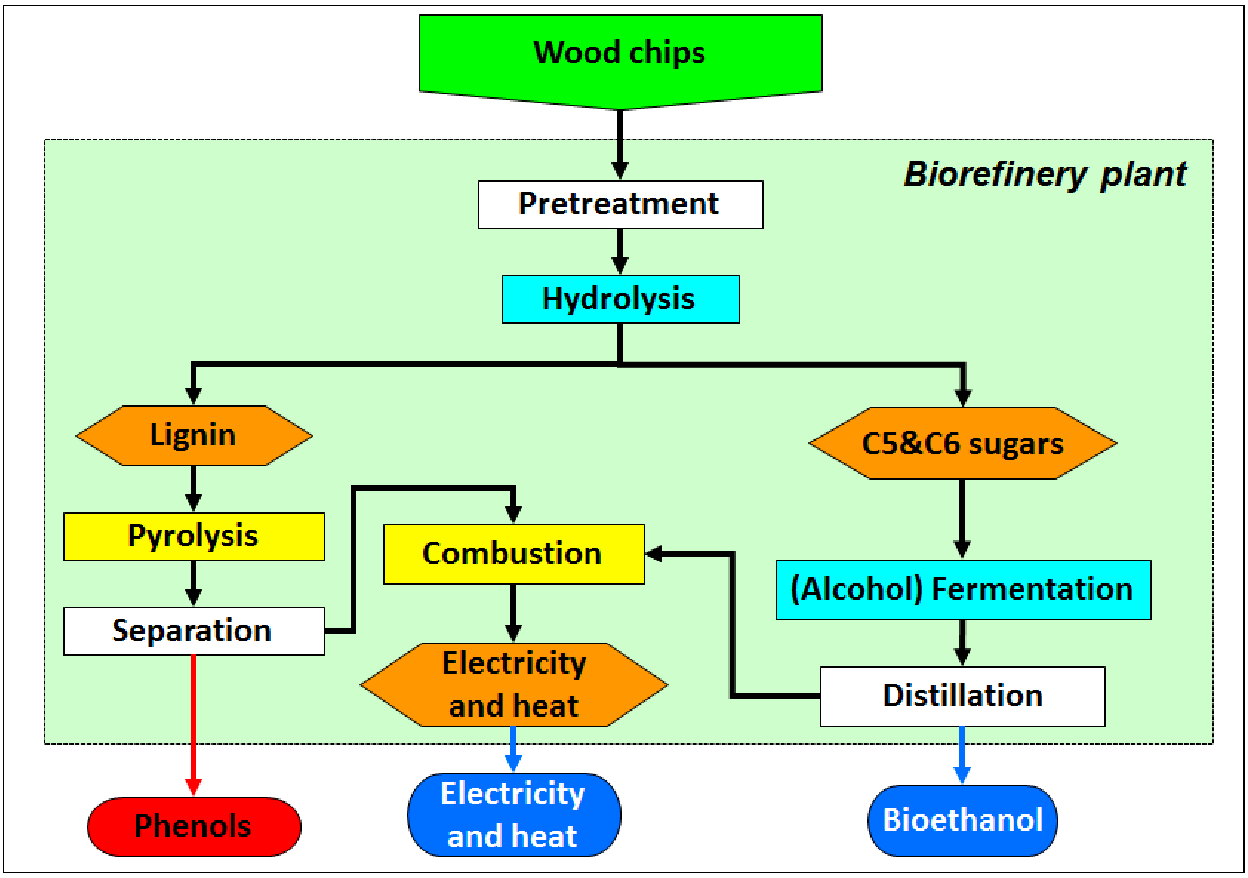


Figure 31: *3-platform (C6&C5 sugar, electricity&heat, lignin) biorefinery using wood chips for bioethanol, electricity, heat and phenols*

Table 7: *Key characteristics of biorefinery plant*

"3-platform (C6&C5 sugar, electricity&heat, lignin) biorefinery using wood chips for bioethanol, electricity, heat and phenols"

State of technology:	commercial 2013		Biorefinery Complexity Index		8
Country:	EU 27		(Products/Platform/Feedstock/Processes)		(3/1/1/3)
Main data sources:	BIOGRACE, JOANNEUM RESEARCH				
Products			**Auxiliaries (external)**		
bioethanol	150	[kt/a]	electricity	0.00	[PJ/a]
phenols	8	[kt/a]	heat	0.00	[PJ/a]
electricity	0.3	[PJ/a]			
			others: various	8.5	
Feedstock	**[kt/a]**	**water [%]**	**Costs**		
wood chips	850	45.0%	investment costs	250	[Mio €]
			feedstock costs	100	[€/t]
			number of employees	30	[#]
Efficiencies				**mass**	**energy**
		input to products		18%	30%
		input to transportation biofuel		17%	26%

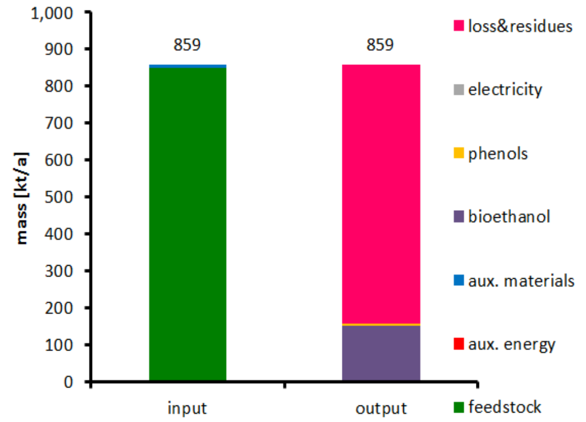


Figure 32: *Mass balance of biorefinery plant*

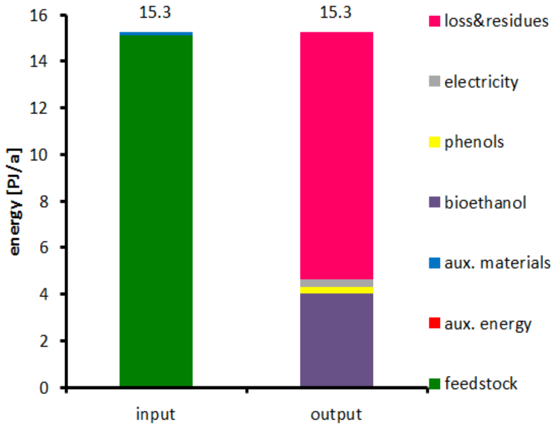


Figure 33: *Energy balance of biorefinery plant*

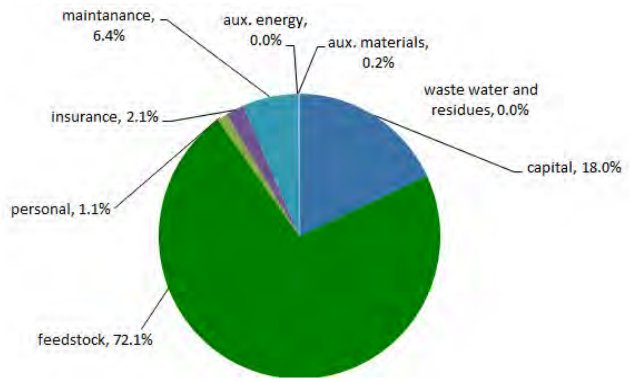


Figure 34: *Share of costs*

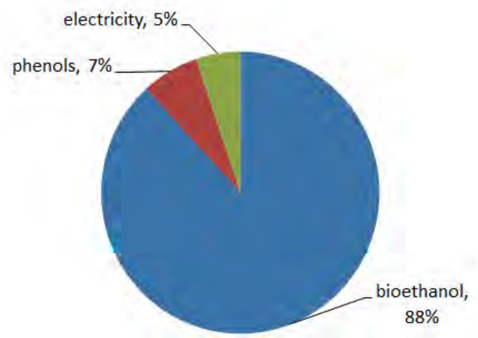


Figure 35: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

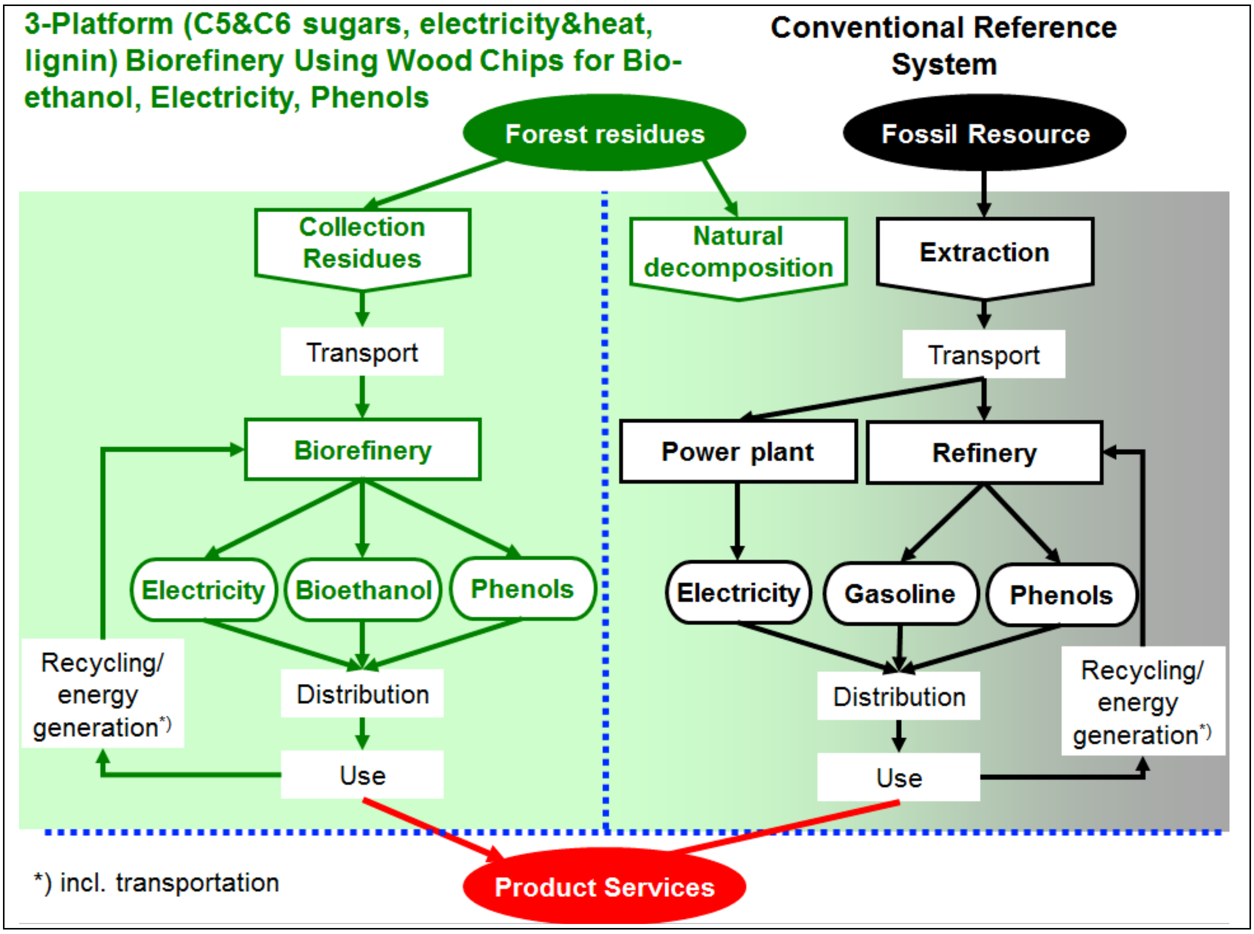


Figure 36: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 8: *Key characteristics of biorefinery value chain*

Whole value chain			
Greenhouse gas emissions	**range**		
biorefinery	32	(30 to 37)	[kt CO_2-eq/a]
reference system	403	(370 to 460)	[kt CO_2-eq/a]
saving	-92%	(-86% to -106%)	[%]
Cumulated energy demand			
fossil			
biorefinery	0.4	(0,37 to 0,45)	[PJ/a]
reference system	5.6	(5,2 to 6,4)	[PJ/a]
saving	-93%	(-86% to -107%)	[%]
total			
biorefinery	8.8	(8,2 to 10,1)	[PJ/a]
reference system	5.9	(5,5 to 6,8)	[PJ/a]
change	50%	(46% to 57%)	[%]
Agricultural area demand			
feedstock	0	(0 to 0)	[ha/a]
Costs			
annual costs	118	(110 to 140)	[Mio €/a]
specific costs	748	(700 to 860)	[€/t]
Revenues			
annual revenues	130	(120 to 150)	[Mio €/a]
specific revenues	822	(760 to 950)	[€/t]

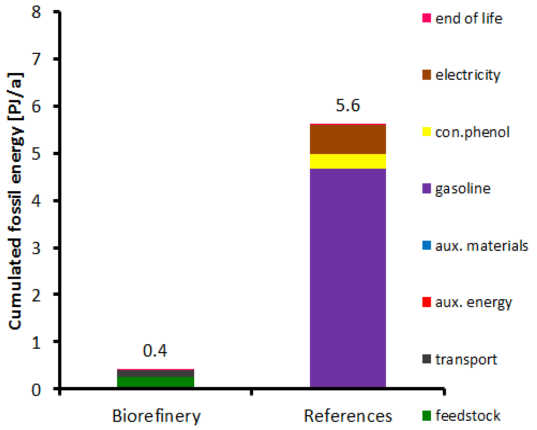


Figure 37: *Estimated cumulated fossil energy demand of biorefinery and reference products*

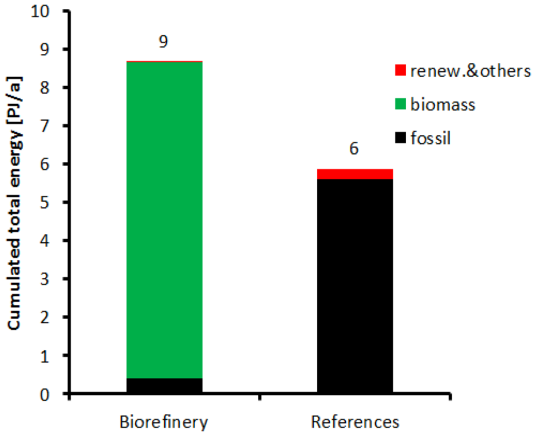


Figure 38: *Estimated cumulated energy demand of biorefinery and reference products*

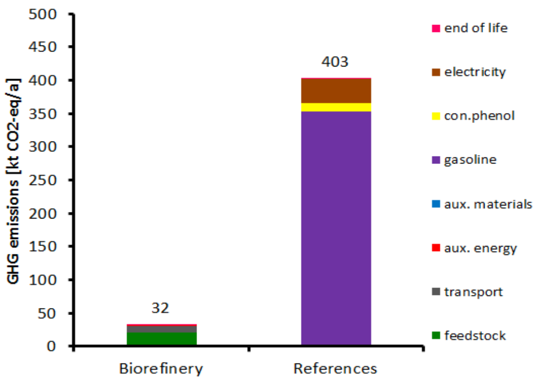


Figure 39: *Estimated greenhouse gas emissions of biorefinery and reference products*

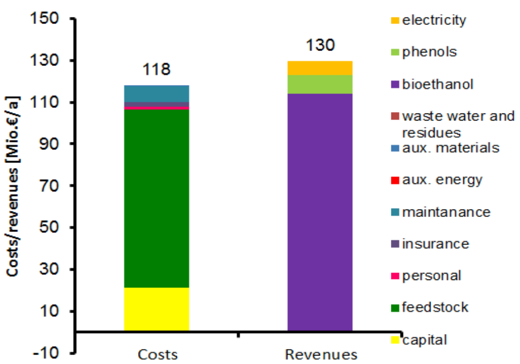


Figure 40 *Estimated cost and revenues of biorefinery plant*

2.5 1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerine and feed

Biorefinery FACT SHEET

"1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerine and feed"

Part A: Biorefinery plant

The commercial scale energy driven "1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerin and feed" is shown in Figure . The oilseed crops in the "1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerin and feed" are transported to the biorefinery, where the vegetable oil and the animal feed are produced in the pressing step. The oil is considered as a platform, and it is esterified, producing FAME biodiesel and raw glycerin. To derive pure glycerin for pharmaceutical purposes the glycerin is subsequently distilled. The heat and electricity are typically supplied by fossil fuel energy carriers.

This biorefinery is state of the art and commercial production facilities have an annual biodiesel production capacity between 50,000 up to 150,000 t per year. Many of the successful operating biorefineries operating today are multi feedstock plants that are able to use different oilseed crops, fat and oil based residues. The oil platform and the glycerin platform offer the possibilities for a wide range of biochemicals and biomaterials that are currently under development and partly at the beginning of commercialization. For example, the oil from certain oilseeds can be further processed via hydrolysis to long-chain fatty acids for lubricants; and the glycerin can be converted to softening agents such as propandiol by fermentation or to triacetin by chemical conversion.

Also, as new configurations are developed, the external energy sources can be partially or fully replaced by bioenergy produced within the process to reduce the GHG footprint.

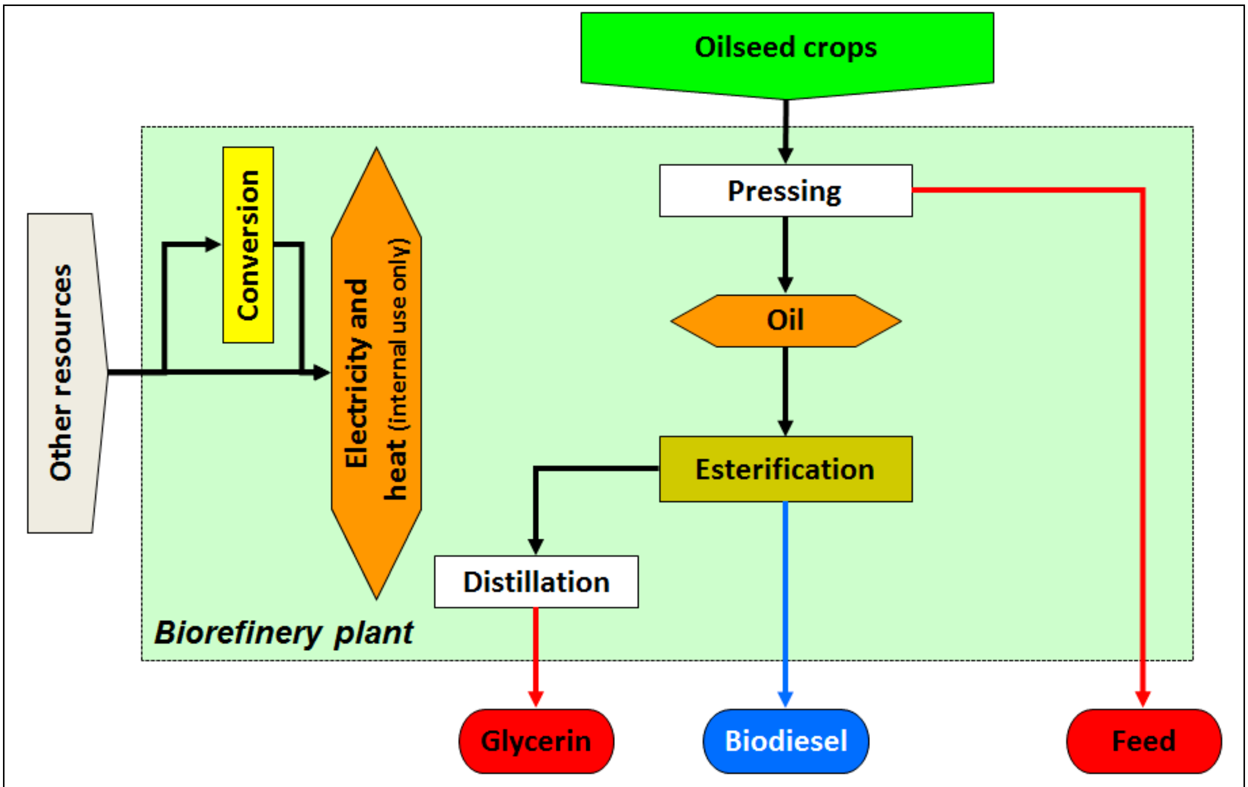


Figure 41: *1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerine and feed*

Table 9: *Key characteristics of biorefinery plant*

"1-platform (oil) biorefinery using oilseed crops for biodiesel, glycerine and feed"					
State of technology:	commercial 2013		Biorefinery Complexity Index		8
Country:	EU 27		(Products/Platform/Feedstock/Processes)		(3/1/1/3)
Main data sources:	BIOGRACE, JOANNEUM RESEARCH				
Products			**Auxiliaries (external)**		
	biodiesel	100 [kt/a]		electricity	0.06 [PJ/a]
	glycerin	11 [kt/a]		heat	0.64 [PJ/a]
	rape seed cake	132 [kt/a]		methanol	15.3 [kt/a]
				hydrochloric acid (HCl)	2.8 [kt/a]
				sodium hydroxide (NaOH)	0.9 [kt/a]
				fuller's earth	0.9 [kt/a]
				n-Hexane	0.4 [kt/a]
				sodium carbonate (Na2CO3)	0.4 [kt/a]
				others	0.2 [kt/a]
Feedstock	**[kt/a]**	**water [%]**	**Costs**		
rape seed	268	10.0%		investment costs	50 [Mio €]
waste cooking oil	108	10.0%		feedstock costs	539 [€/t]
				number of employees	10 [#]
Efficiencies			**mass**	**energy**	
		input to products	61%	53%	
		input to transportation biofuel	35%	46%	

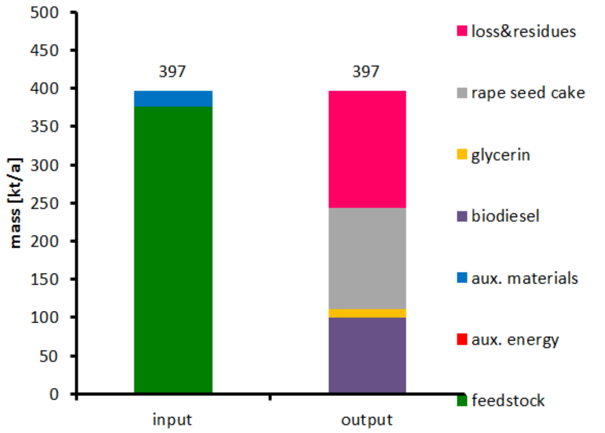


Figure 42: *Mass balance of biorefinery plant*

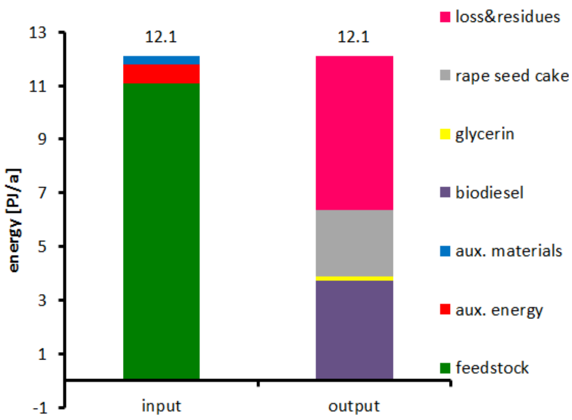


Figure 43: *Energy balance of biorefinery plant*

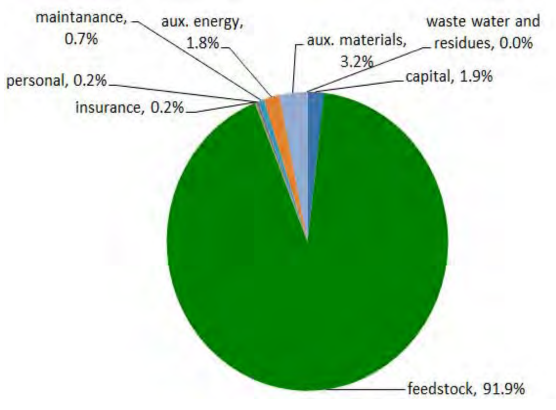


Figure 44: *Share of costs*

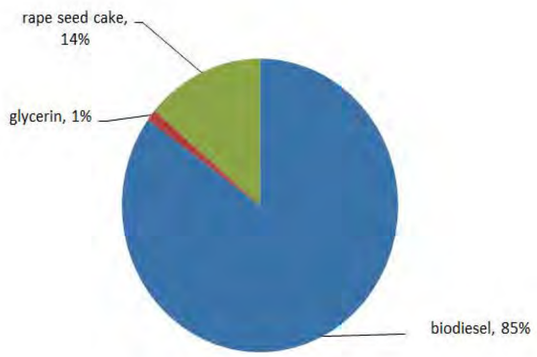


Figure 45: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

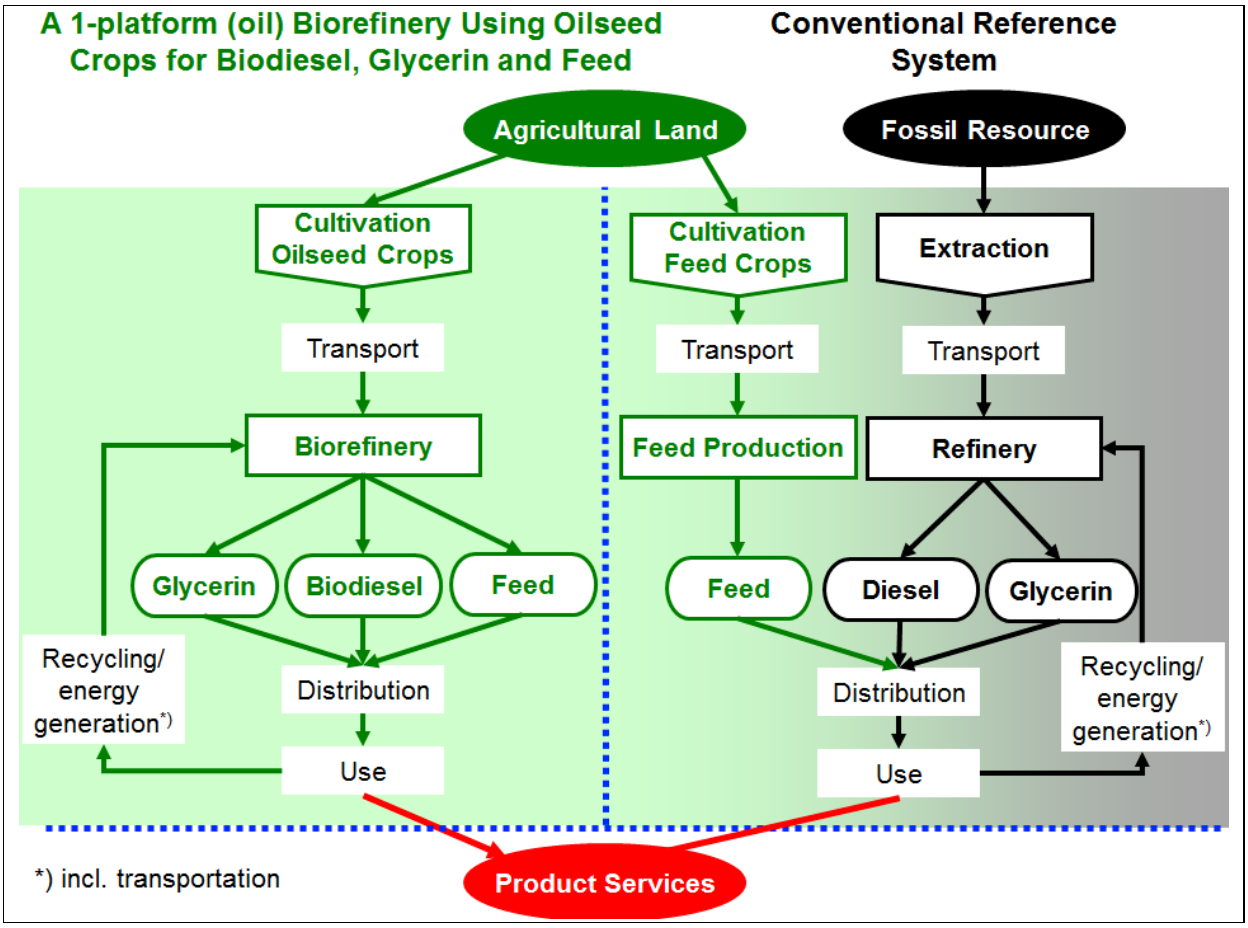


Figure 46: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 10: *Key characteristics of biorefinery value chain*

Whole value chain		range	
Greenhouse gas emissions			
biorefinery	234	(220 to 270)	[kt CO_2-eq/a]
reference system	398	(370 to 460)	[kt CO_2-eq/a]
saving	-41%	(-38% to -47%)	[%]
Cumulated energy demand			
fossil			
biorefinery	2.4	(2,3 to 2,8)	[PJ/a]
reference system	6.1	(5,7 to 7)	[PJ/a]
saving	-60%	(-56% to -69%)	[%]
total			
biorefinery	12.6	(12 to 14)	[PJ/a]
reference system	9.1	(8,4 to 10,4)	[PJ/a]
change	38%	(36% to 44%)	[%]
Agricultural area demand			
feedstock	86,000	(80000 to 99000)	[ha/a]
Costs			
annual costs	221	(210 to 250)	[Mio €/a]
specific costs	908	(840 to 1040)	[€/t]
Revenues			
annual revenues	124	(120 to 140)	[Mio €/a]
specific revenues	512	(480 to 590)	[€/t]

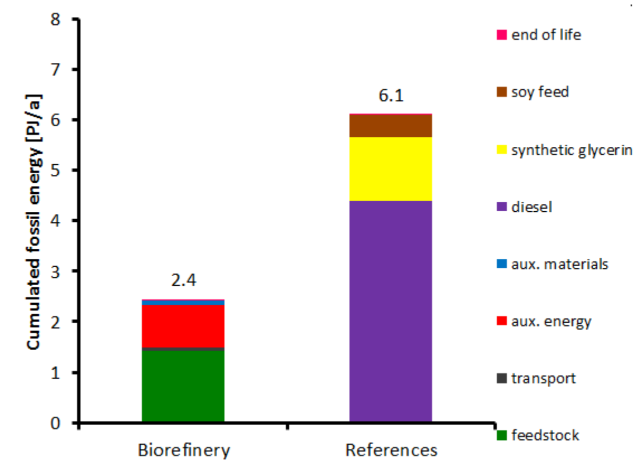


Figure 472: *Estimated cumulated fossil energy demand of biorefinery and reference products*

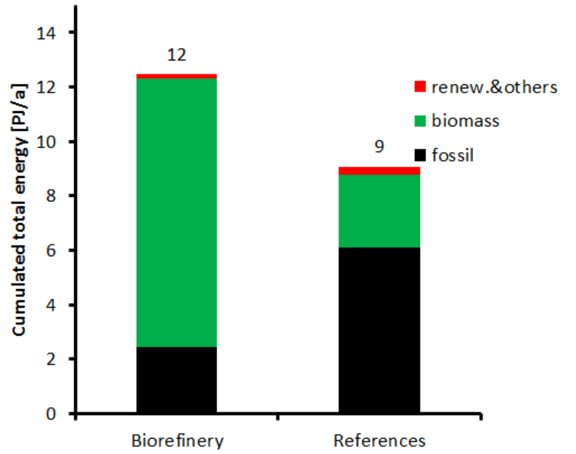


Figure 483: *Estimated cumulated energy demand of biorefinery and reference products*

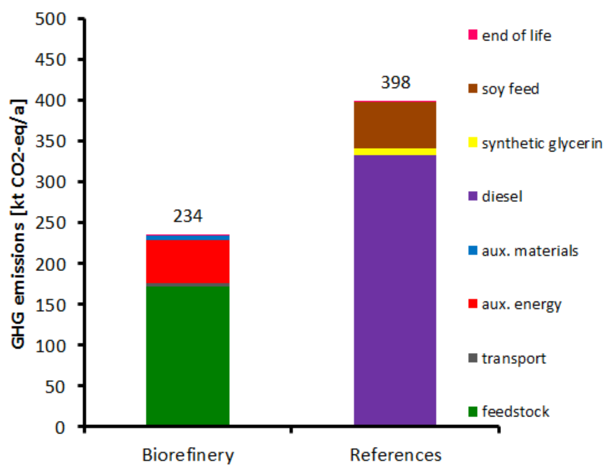


Figure 49: *Estimated greenhouse gas emissions of biorefinery and reference products*

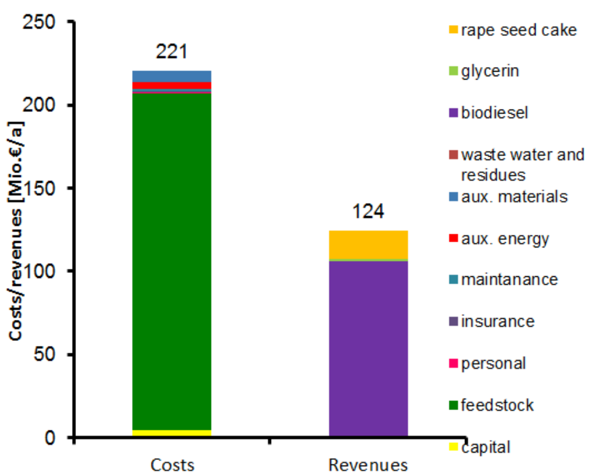


Figure 504: *Estimated cost and revenues of biorefinery plant*

2.6 1-platform (oil) biorefinery using oil based residues for biodiesel, glycerine, bio oil and fertilizer

Biorefinery FACT SHEET

"1-platform (oil) biorefinery using oil based residues for biodiesel, glycerine, bio oil and fertilizer"

Part A: Biorefinery plant

The commercial scale energy driven "1-platform (oil) biorefinery using oil based residues crops for biodiesel, glycerin, bio oil and fertilizer" is shown in Figure 51. The oil based residues are collected from food industry and households and restaurants to the biorefinery, where the feedstock is filtered in a first step. The oil is considered as a platform, and it is esterified, producing FAME biodiesel and raw glycerin. To derive pure glycerin for pharmaceutical purposes the glycerin is subsequently distilled. A part of the oil cannot be converted to biodiesel so it is used as bio oil as energy carrier similar to heating oil. The heat and electricity are typically supplied by fossil fuel energy carriers.

This biorefinery is state of the art and commercial production facilities have an annual biodiesel production capacity between 20,000 up to 100,000 t per year. Many of the successful operating biorefineries operating today are multi feedstock plants that are able to use different oilseed crops, fat and oil based residues. The oil platform and the glycerin platform offer the possibilities for a wide range of biochemicals and biomaterials that are currently under development and partly at the beginning of commercialization. For example, the oil from certain oilseeds can be further processed via hydrolysis to long-chain fatty acids for lubricants; and the glycerin can be converted to softening agents such as propandiol by fermentation or to triacetin by chemical conversion.

Also, as new configurations are developed, the external energy sources can be partially or fully replaced by bioenergy produced within the process to reduce the GHG footprint.

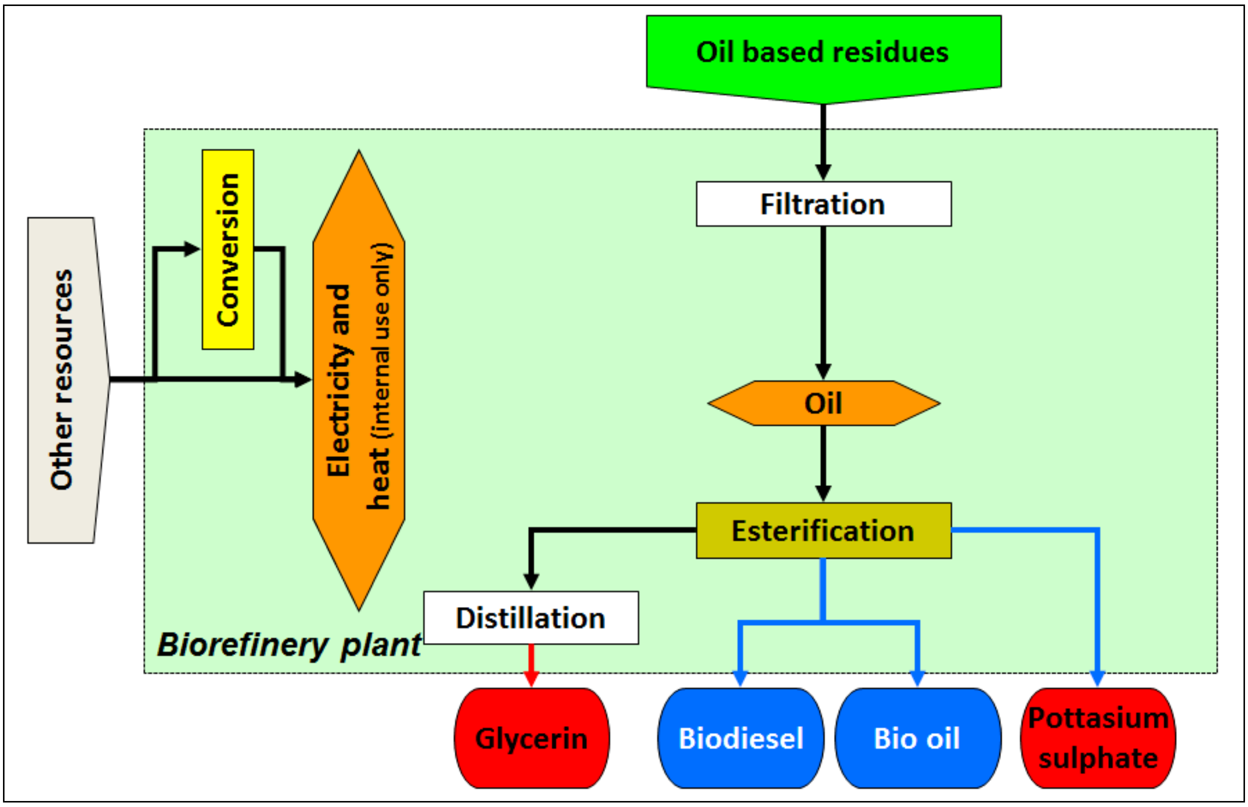


***Figure 51:** 1-platform (oil) biorefinery using oil based residues for biodiesel, glycerine, bio oil and fertilizer*

Table 11: *Key characteristics of biorefinery plant*

“1-platform (oil) biorefinery using oil based residues for biodiesel, glycerine, bio oil and fertilizer“					
State of technology:	commercial 2013		Biorefinery Complexity Index (Products/Platform/Feedstock/Processes)	8 (3/1/1/3)	
Country:	EU 27				
Main data sources:	BIOGRACE, JOANNEUM RESEARCH				
Products			**Auxiliaries (external)**		
biodiesel	100 [kt/a]		electricity	0.03 [PJ/a]	
glycerin	10 [kt/a]		heat	0.56 [PJ/a]	
bio oil	3 [kt/a]		methanol	15.8 [kt/a]	
potassium sulphate (K2SO4)	4 [kt/a]		phosphoric acid (H3PO4)	2.0 [kt/a]	
			potassium hydroxide (KOH)	1.9 [kt/a]	
			fuller's earth	0.9 [kt/a]	
Feedstock	**[kt/a]**	**water [%]**	**Costs**		
waste cooking oil	112	10.0%	investment costs	35 [Mio €]	
			feedstock costs	850 [€/t]	
			number of employees	10 [#]	
Efficiencies			**mass**	**energy**	
input to products			88%	78%	
input to transportation biofuel			75%	74%	

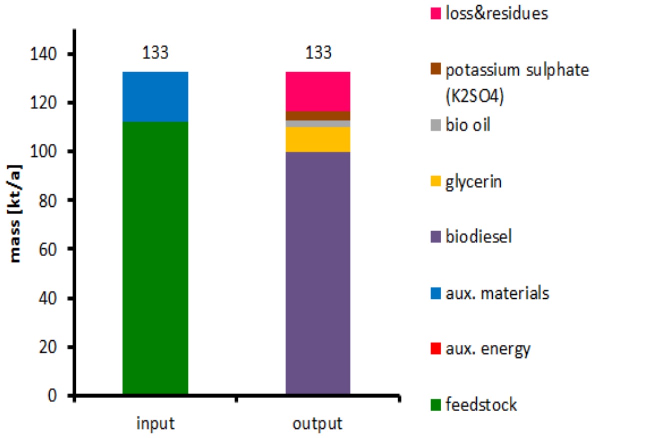


Figure 52: *Mass balance of biorefinery plant*

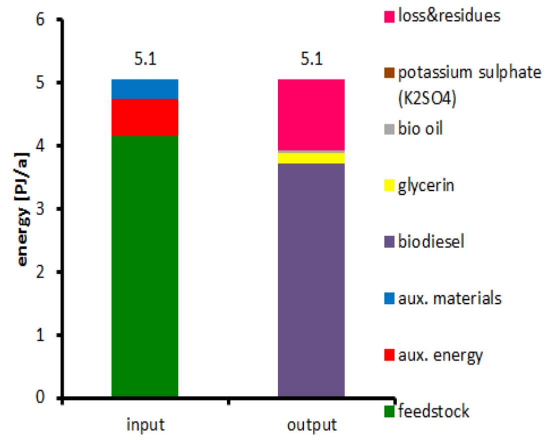


Figure 53: *Energy balance of biorefinery plant*

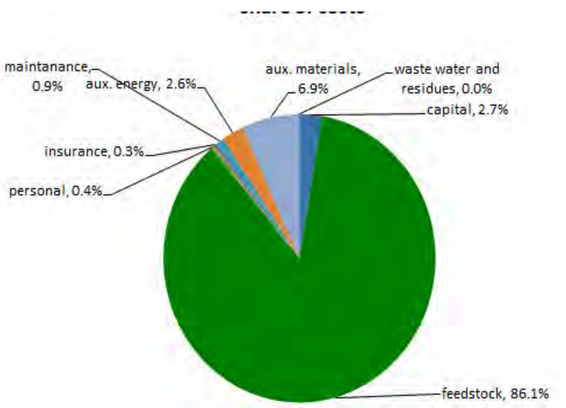


Figure 54: *Share of costs*

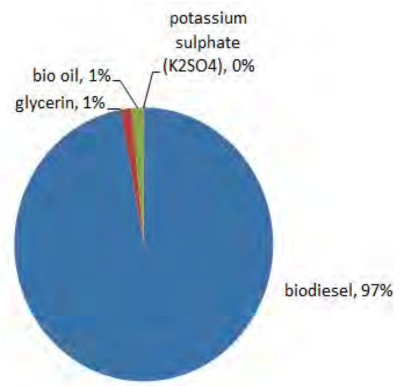


Figure 55: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

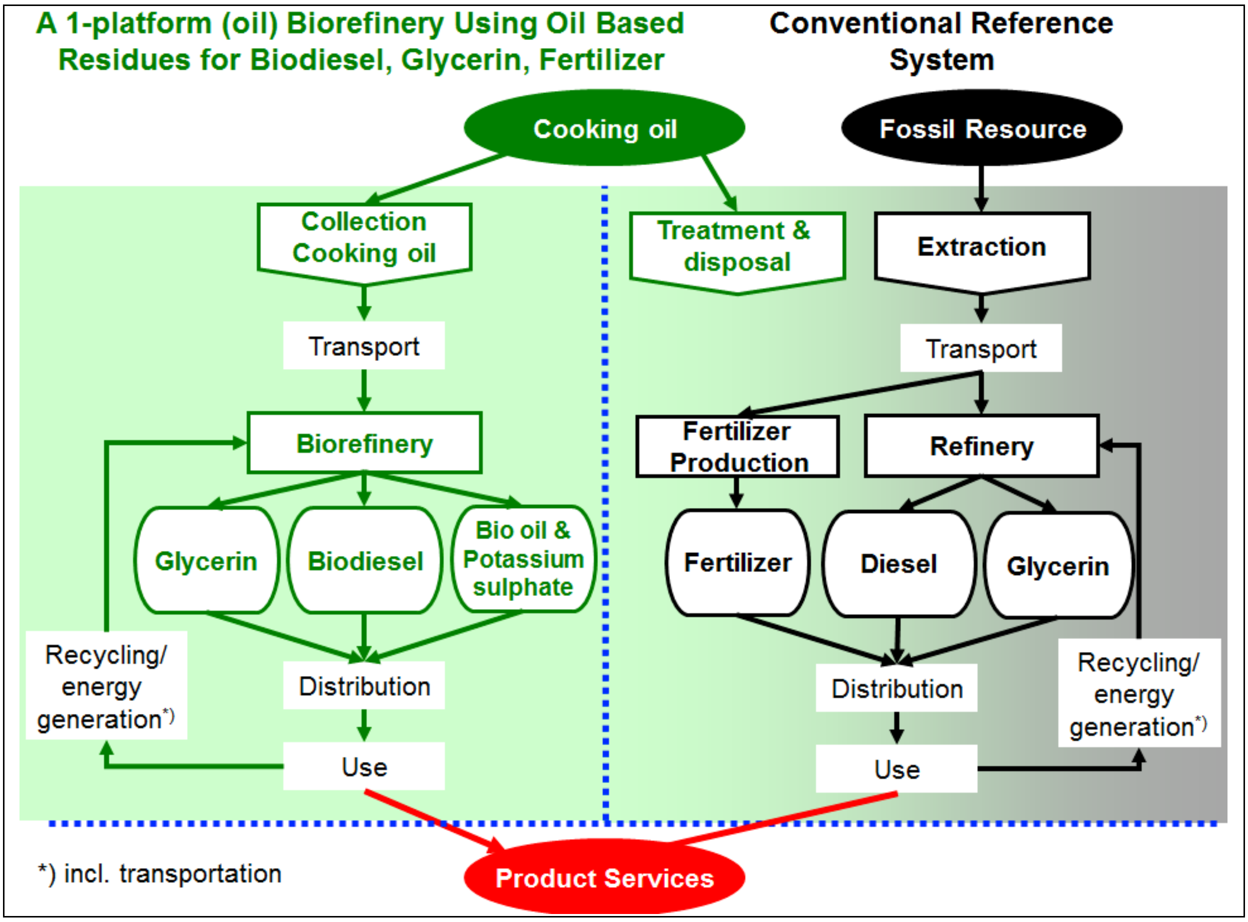


Figure 56: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 13: *Key characteristics of biorefinery value chain*

Whole value chain			
Greenhouse gas emissions		**range**	
biorefinery	43	(40 to 50)	[kt CO_2-eq/a]
reference system	350	(330 to 400)	[kt CO_2-eq/a]
saving	-88%	(-81% to -101%)	[%]
Cumulated energy demand			
fossil			
biorefinery	0.8	(0,74 to 0,91)	[PJ/a]
reference system	5.7	(5,3 to 6,6)	[PJ/a]
saving	-86%	(-80% to -99%)	[%]
total			
biorefinery	4.6	(4,3 to 5,3)	[PJ/a]
reference system	6.0	(5,6 to 6,9)	[PJ/a]
change	-24%	(-22% to -27%)	[%]
Agricultural area demand			
feedstock	0	(0 to 0)	[ha/a]
Costs			
annual costs	111	(100 to 130)	[Mio €/a]
specific costs	950	(880 to 1090)	[€/t]
Revenues			
annual revenues	109	(100 to 130)	[Mio €/a]
specific revenues	935	(870 to 1080)	[€/t]

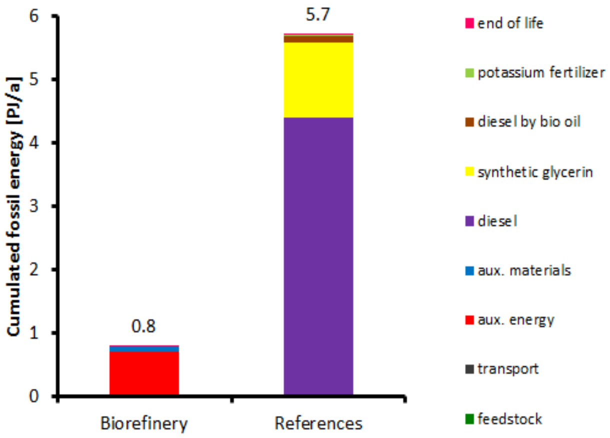


Figure 57: *Estimated cumulated fossil energy demand of biorefinery and reference products*

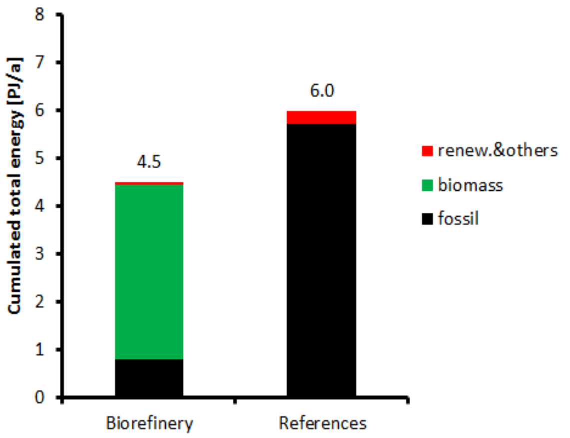


Figure 58: *Estimated cumulated energy demand of biorefinery and reference products*

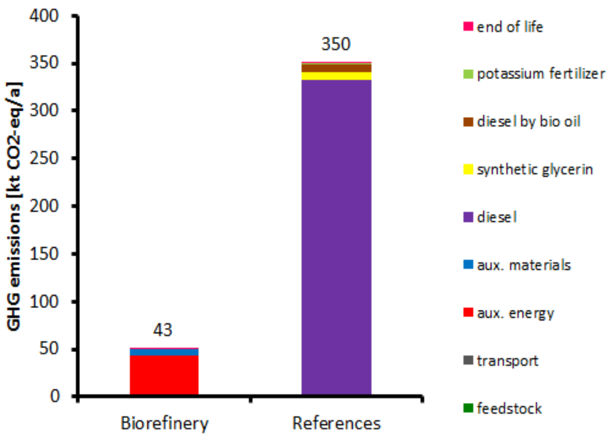


Figure 59: *Estimated greenhouse gas emissions of biorefinery and reference products*

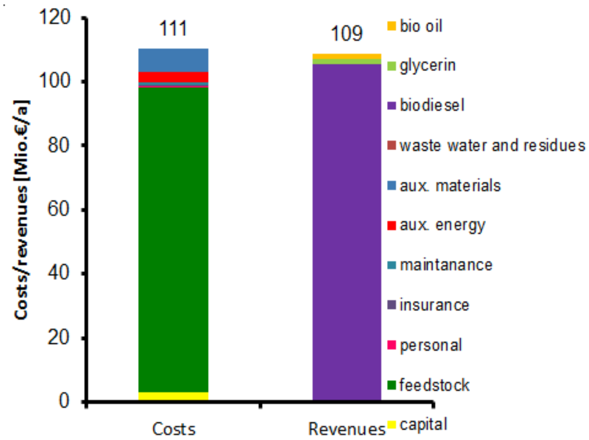


Figure 60*Estimated cost and revenues of biorefinery plant*

2.7 2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification

Biorefinery FACT SHEET

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

Part A: Biorefinery plant

The demonstration scale energy driven "2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification" is shown in Figure 61.

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. hydroprocessing. The process residues are combusted to produce electricity and heat. As a further product waxes are produced.

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.

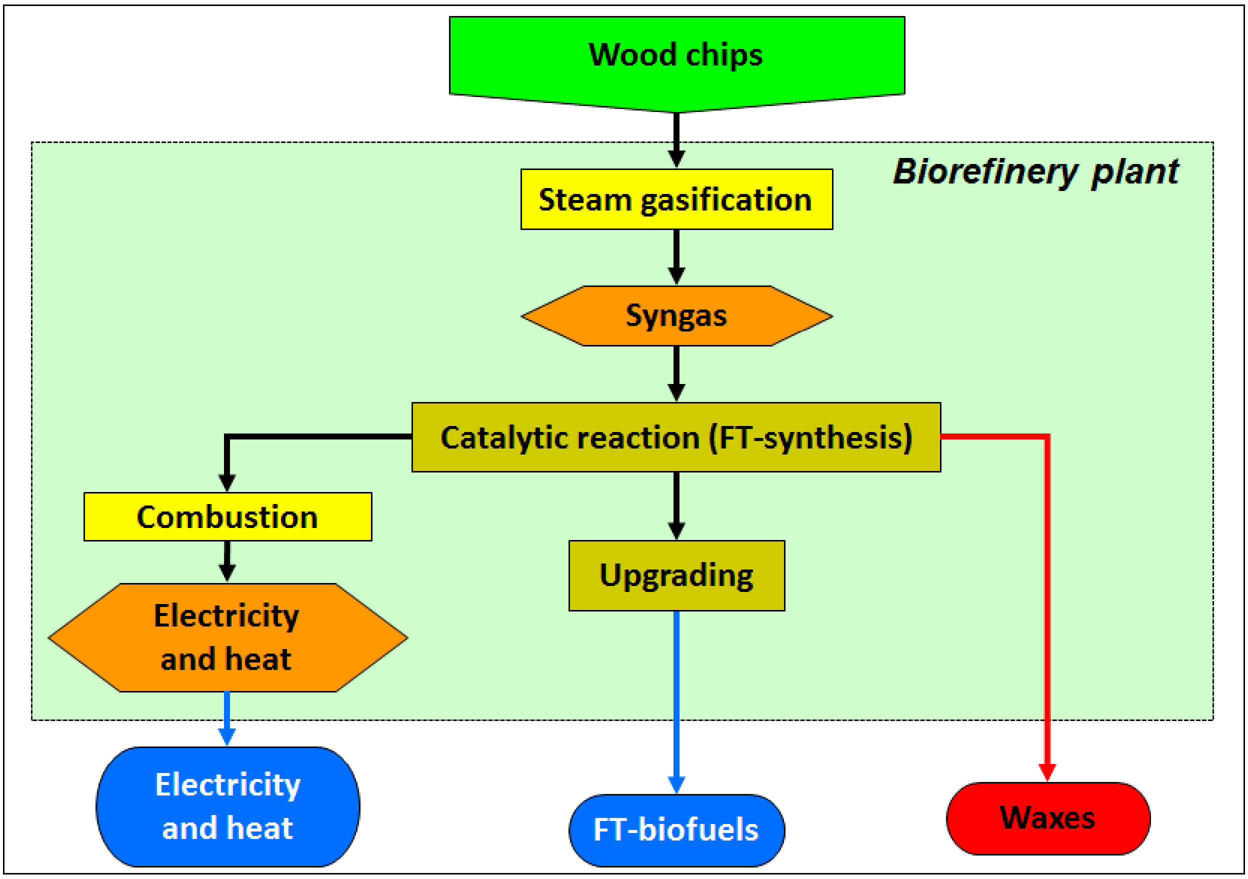


Figure 61: *2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification*

Table 13: *Key characteristics of biorefinery plant*

"2-platform (electricity&heat, syngas) biorefinery using wood chips for FT-biofuels, electricity, heat and waxes with steam gasification"						
State of technology:	commercial 2013		Biorefinery Complexity Index		14.5	
Country:	EU 27		(Products/Platform/Feedstock/Processes)		(4.5/3/2/5)	
Main data sources:	BIOGRACE, JOANNEUM RESEARCH					
Products			**Auxiliaries (external)**			
	FT-diesel	105 [kt/a]		electricity	0.00 [PJ/a]	
	FT-gasoline	70 [kt/a]		heat	0.00 [PJ/a]	
	waxes	10 [kt/a]				
	heat	0.3 [PJ/a]		others: various	29.2	
Feedstock	**[kt/a]**	**water [%]**	**Costs**			
wood chips	1459	45.0%		investment costs	500 [Mio €]	
				feedstock costs	100 [€/t]	
				number of employees	35 [#]	
Efficiencies				**mass**	**energy**	
input to products				12%	30%	
input to transportation biofuel				7%	17%	

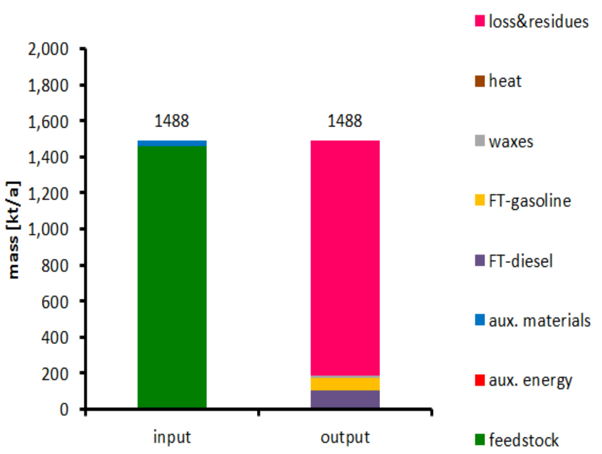


Figure 62: *Mass balance of biorefinery plant*

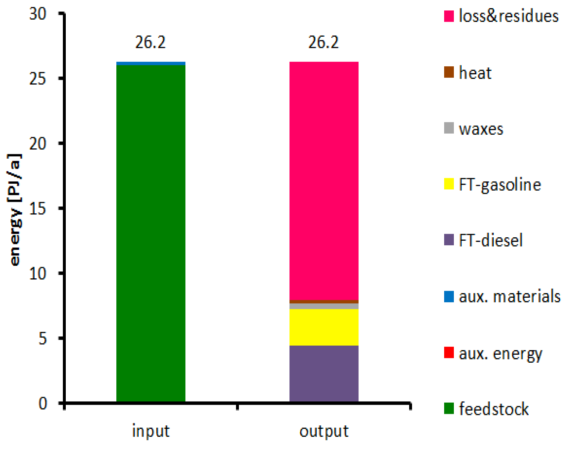


Figure 63: *Energy balance of biorefinery plant*

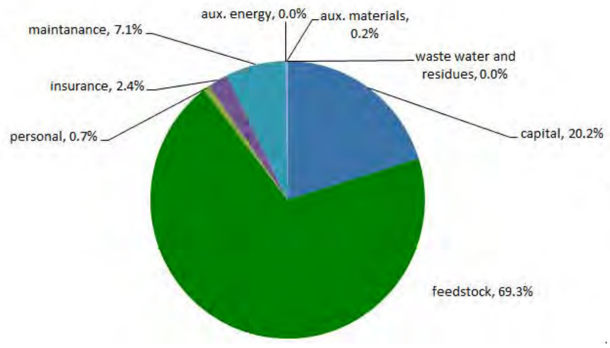


Figure 64: *Share of costs*

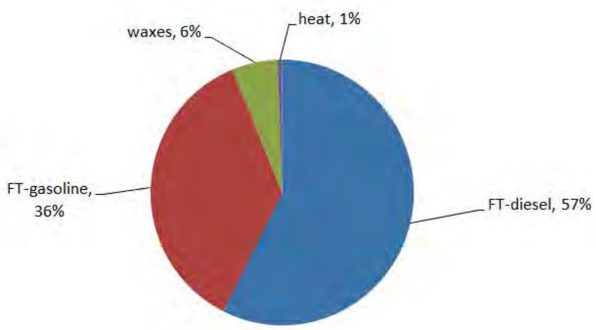


Figure 65: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

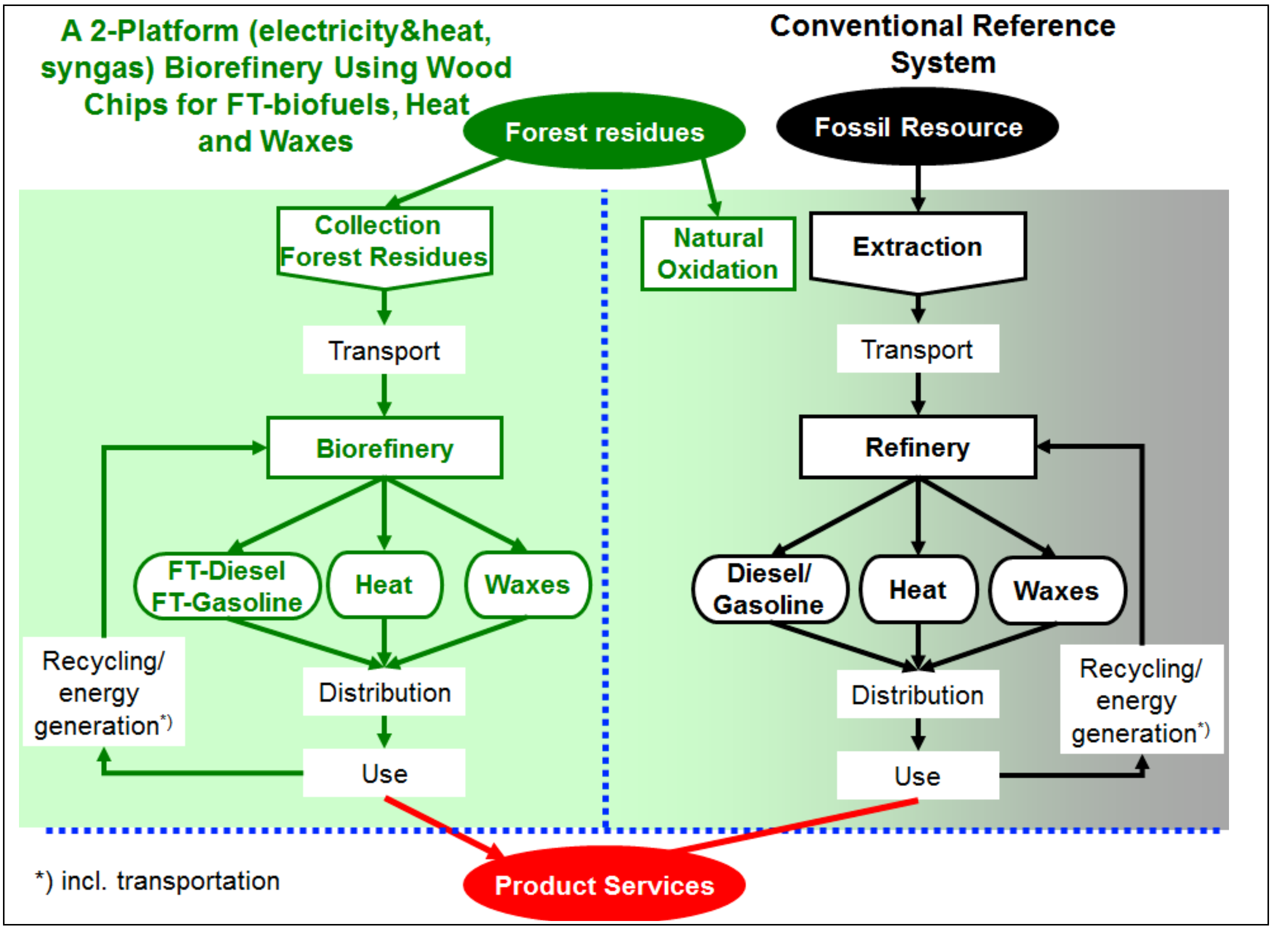


Figure 66: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. “end of life management”)*

Table 14: *Key characteristics of biorefinery value chain*

Whole value chain		
Greenhouse gas emissions	**range**	
biorefinery	59 (55 to 68)	[kt CO_2-eq/a]
reference system	674 (630 to 770)	[kt CO_2-eq/a]
saving	-91% (-85% to -105%)	[%]
Cumulated energy demand		
fossil		
biorefinery	0.7 (0,63 to 0,78)	[PJ/a]
reference system	8.7 (8,1 to 10)	[PJ/a]
saving	-92% (-86% to -106%)	[%]
total		
biorefinery	15.1 (14 to 17)	[PJ/a]
reference system	9.2 (8,5 to 10,5)	[PJ/a]
change	65% (61% to 75%)	[%]
Agricultural area demand		
feedstock	0 (0 to 0)	[ha/a]
Costs		
annual costs	210 (200 to 240)	[Mio €/a]
specific costs	1,137 (1100 to 1300)	[€/t]
Revenues		
annual revenues	218 (200 to 250)	[Mio €/a]
specific revenues	1,180 (1100 to 1400)	[€/t]

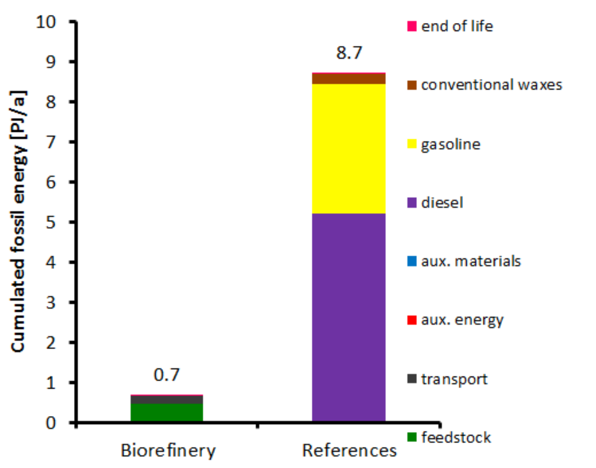


Figure 67: Estimated cumulated fossil energy demand of biorefinery and reference products

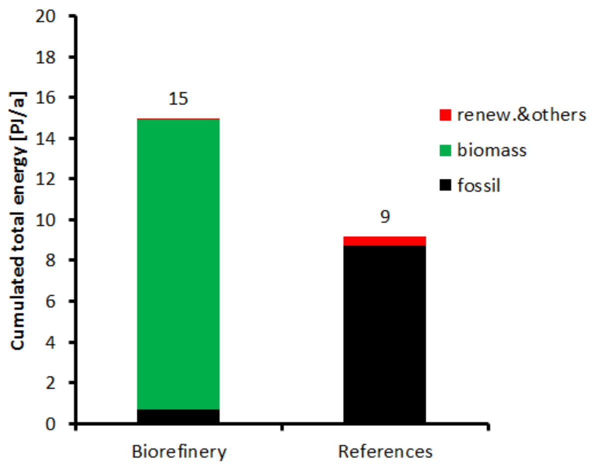


Figure 68: Estimated cumulated energy demand of biorefinery and reference products

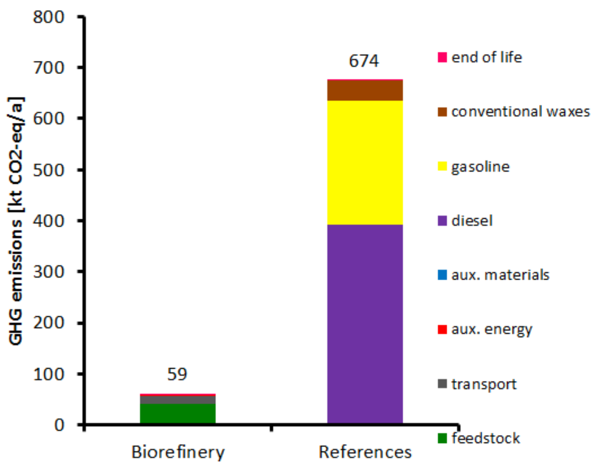


Figure 69: *Estimated greenhouse gas emissions of biorefinery and reference products*

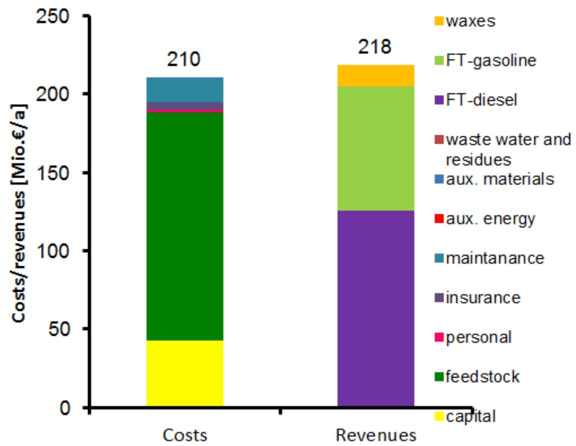


Figure 70*Estimated cost and revenues of biorefinery plant*

2.8 3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification

Biorefinery FACT SHEET

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

Part A: Biorefinery plant

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 a 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 H_2 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.

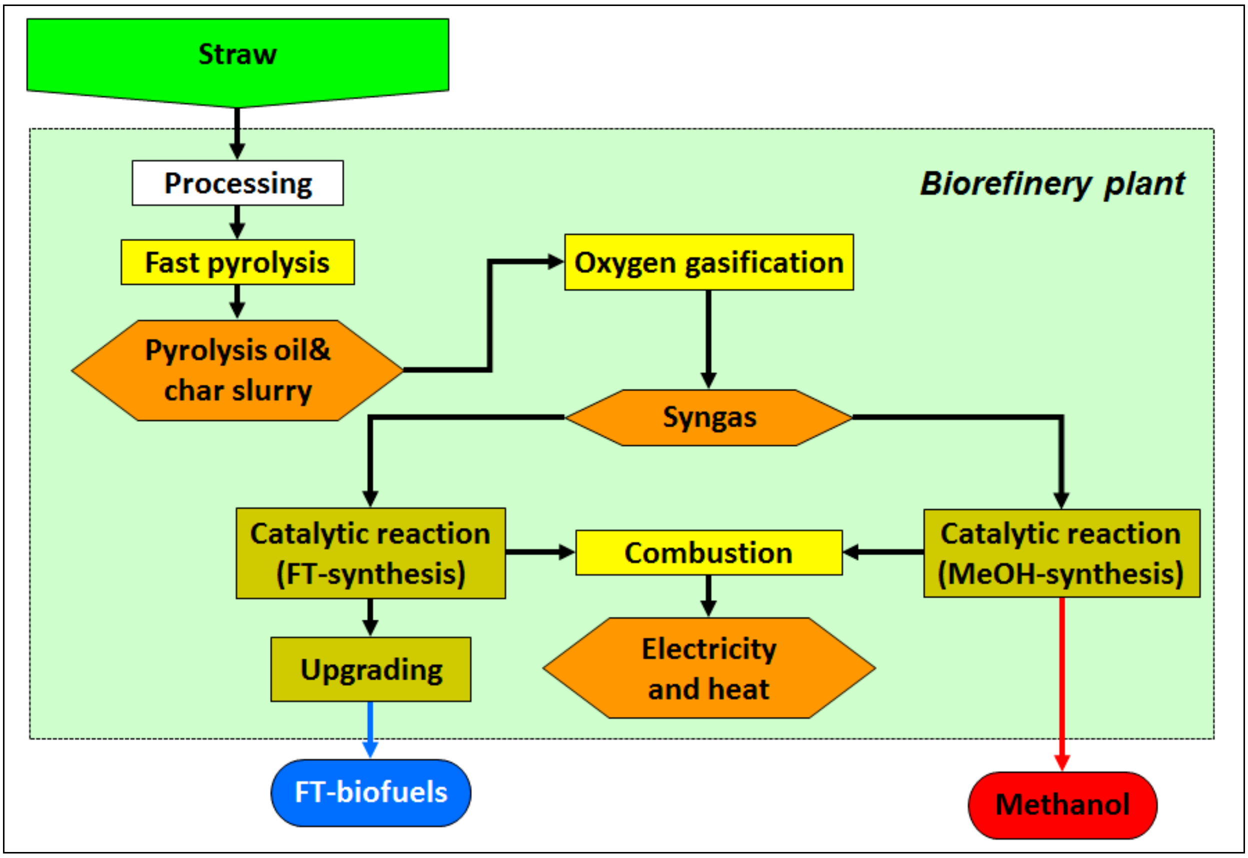


Figure 71: *3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification*

Table 45: *Key characteristics of biorefinery plant*

"3-platform (pyrolysis oil, syngas, electricity&heat) biorefinery using straw for FT-biofuels and methanol with oxygen gasification"						
State of technology:	commercial 2013		Biorefinery Complexity Index (Products/Platform/Feedstock/Processes)		not calculated yet	
Country:	EU 27					
Main data sources:	BIOGRACE, JOANNEUM RESEARCH					
Products			**Auxiliaries (external)**			
FT-diesel	120 [kt/a]		electricity	0.36 [PJ/a]		
methanol	30 [kt/a]		heat	0.00 [PJ/a]		
			others: various	20.7		
Feedstock	**[kt/a]**	**water [%]**	**Costs**			
straw	518	15.0%	investment costs	255 [Mio €]		
			feedstock costs	64 [€/t]		
			number of employees	30 [#]		
Efficiencies			**mass**	**energy**		
input to products			28%	60%		
input to transportation biofuel			22%	54%		

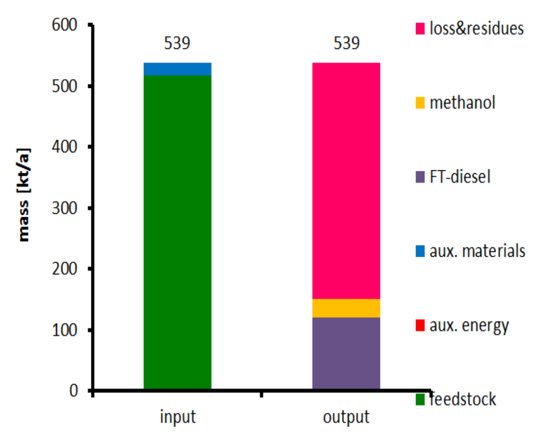


Figure 72: *Mass balance of biorefinery plant*

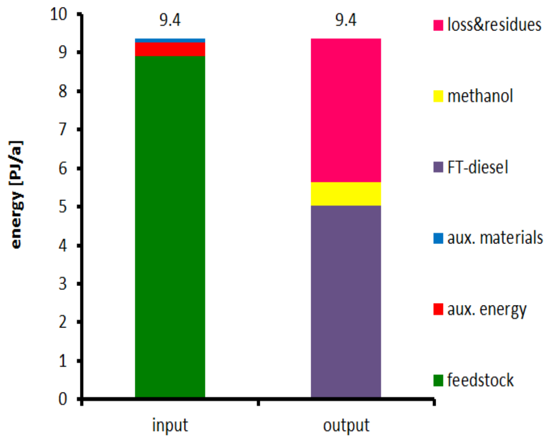


Figure 73: *Energy balance of biorefinery plant*

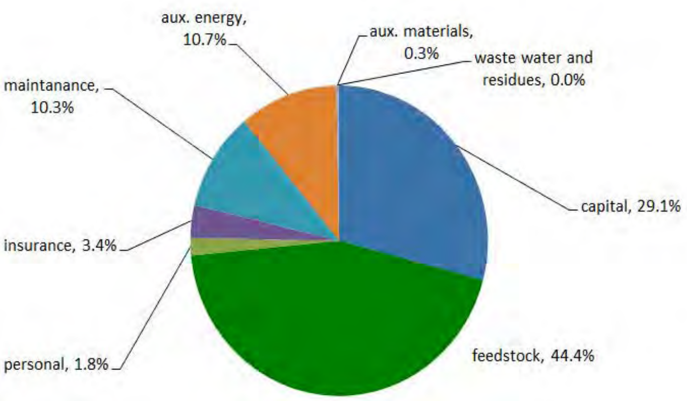


Figure 74: *Share of costs*

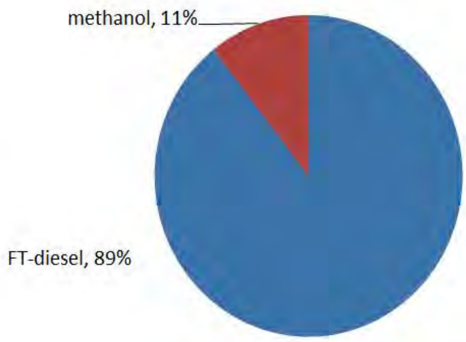


Figure 75: *Share of revenues*

Part B: Value Chain Sustainability Assessment

The method of the sustainability assessment - economic and environmental – is given in Annex 1. The main assumptions and modelling choices are documented in Annex 2.

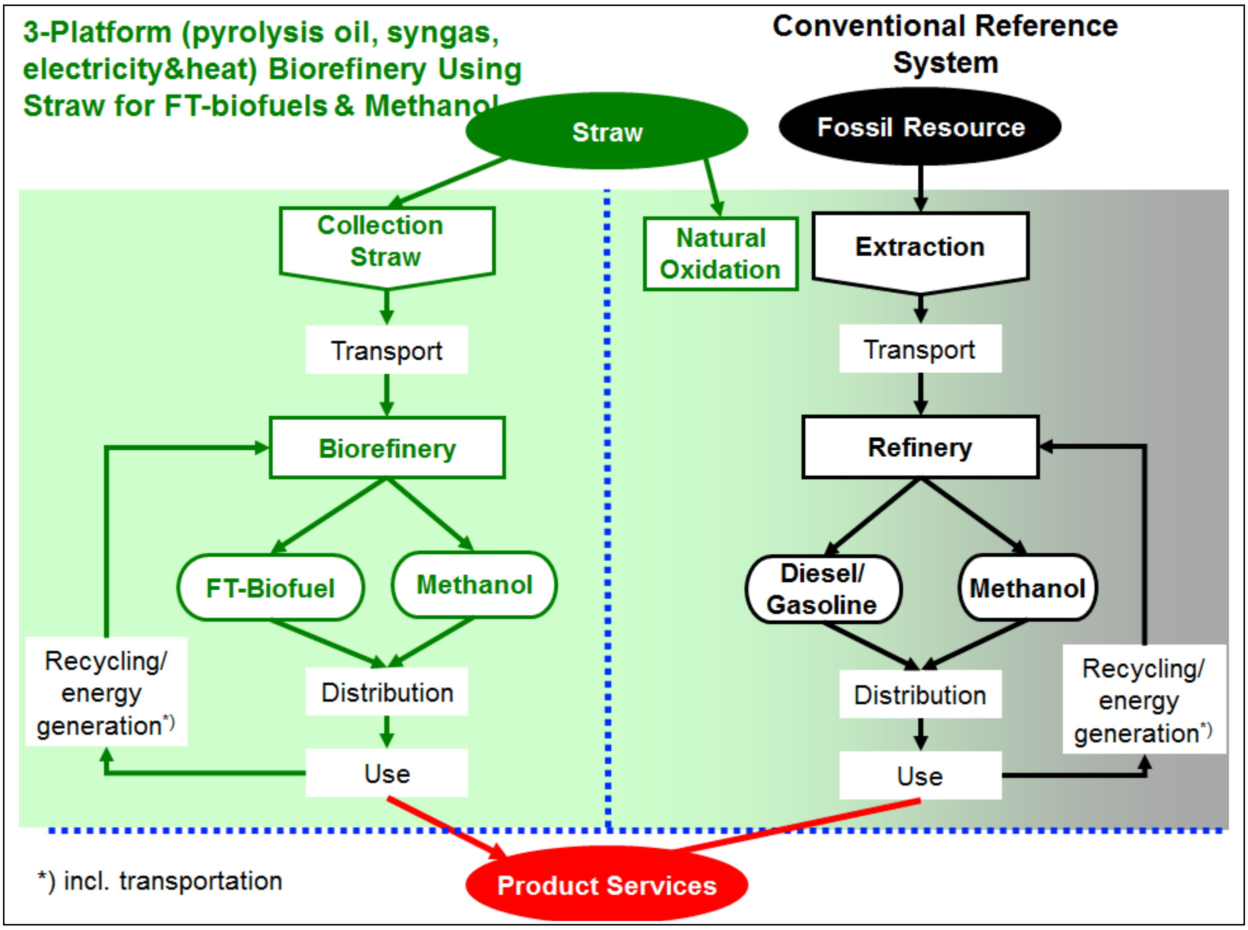


Figure 76: *Comparison of the biorefinery with the conventional reference system on whole value chain (incl. "end of life management")*

Table 16: *Key characteristics of biorefinery value chain*

Whole value chain		range	
Greenhouse gas emissions			
biorefinery	42	(39 to 48)	[kt CO_2-eq/a]
reference system	449	(420 to 520)	[kt CO_2-eq/a]
saving	-91%	(-84% to -104%)	[%]
Cumulated energy demand			
fossil			
biorefinery	1.0	(0,9 to 1,2)	[PJ/a]
reference system	5.9	(5,5 to 6,8)	[PJ/a]
saving	-83%	(-77% to -95%)	[%]
total			
biorefinery	8.7	(8,1 to 10)	[PJ/a]
reference system	6.2	(5,8 to 7,2)	[PJ/a]
change	40%	(37% to 46%)	[%]
Agricultural area demand			
feedstock	207,000	(193000 to 238000)	[ha/a]
Costs			
annual costs	74	(69 to 86)	[Mio €/a]
specific costs	496	(460 to 570)	[€/t]
Revenues			
annual revenues	160	(150 to 180)	[Mio €/a]
specific revenues	1,068	(1000 to 1200)	[€/t]

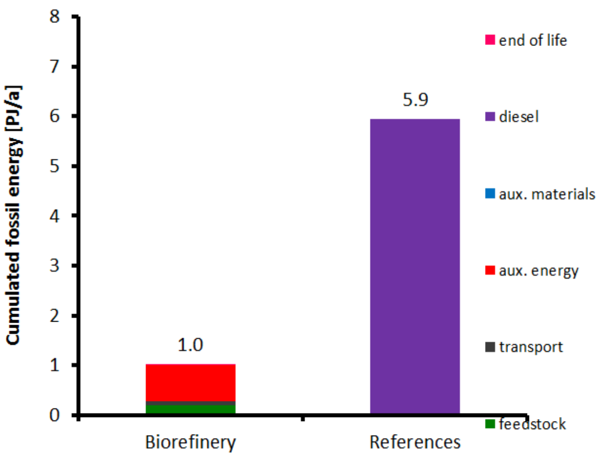


Figure 77: *Estimated cumulated fossil energy demand of biorefinery and reference products*

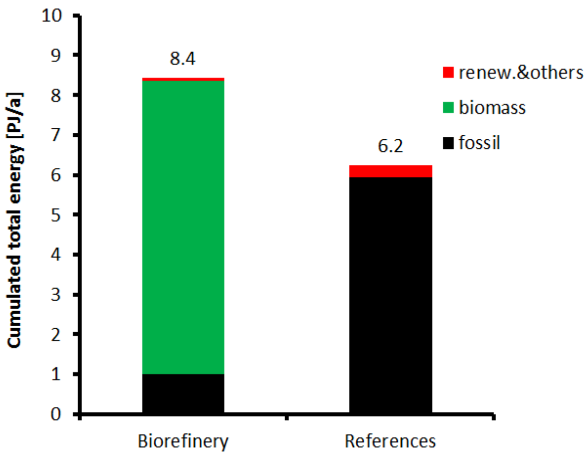


Figure 78: *Estimated cumulated energy demand of biorefinery and reference products*

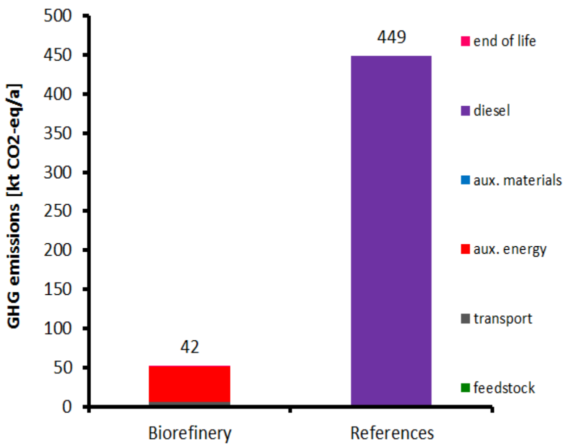


Figure 79: *Estimated greenhouse gas emissions of biorefinery and reference products*

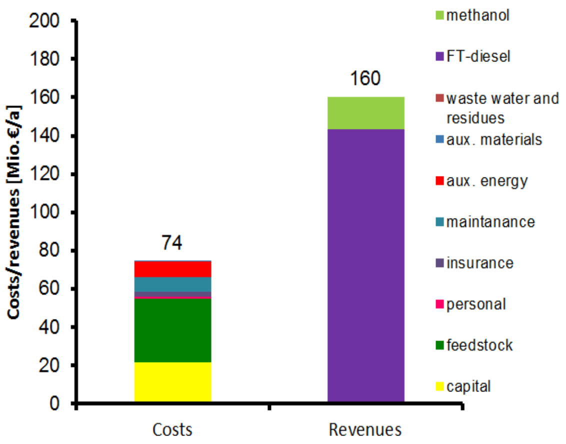


Figure 80*Estimated cost and revenues of biorefinery plant*

Annex: Main assumptions and modelling choices

Table 5: *Main Assumptions*

BASIC ASSUMPTIONS		value	optimal	poor	description
uncertainty range	[%]	0%	-7%	15%	
fossil energy consumption general	[GJ/kg CO_2-eq]	0.01			assumption
fossil energy consumption cultivation	[GJ/kg CO_2-eq]	0.008			assumption
renwabel energy share	[%]	5%			
other energy share	[%]	2%			
life time	[a]	20			
calculated interest rate	[%]	7%			
personal costs	[€/(Person*a)]	45,000			
insurance	[% of investment]	1%			
maintenance costs	[% of investment]	3%			
waste water treatment	[€/m³]	0.00			
transport distance "end of life" biochemicals	[km]	200			
gasoline price at filling station	[€/l]	1.5			
taxes	[%]	40%			
gasoline costs without tax	[€/l]	*0.9*			
	[€/GJ]	*28.4*			
share GHG emissions and energy demand for auxiliary materials to cultivation	[%]	1%			
share auxiliary materials costs to cultivation costs	[%]	1%			
CH_4+N_2O	[g/MJ]	0.2			GHG emissions from the combustions of biogene residues for the energy production (CHP, el and heat) for internal consumptionhis own need

Table 2: *Feedstock*

FEEDSTOCK	yield	water content	heating value		co-product	GHG emissions	primary energy consumption				price (incl. transport)	data source
	[t/(ha*a) or t/a]	[%]	[MJ/kgDM]	[MJ/kg]	[-]	[g CO_2-eq/kg]	[MJ_{foss}/kg]	[MJ_{biom}/kg]	[MJ_{renew}/kg]	[MJ_{other}/kg]	[€/t]	[-]
rape seed	3.11	10%	26.4	23.5	straw	668.3	5.3	23.5	0.26	0.11	414	BioGrace, assumptions
corn	3.88	15%	18.5	15.4	straw	296.5	2.3	15.4	0.12	0.05	220	BioGrace, assumptions
straw	2.50	15%	17.2	14.3	crops	26.3	0.4	14.3	0.02	0.01	63.75	BioGrace, assumptions
waste cooking oil		10%	37.1	33.1	none	0.1	0.1	33.1	0.01	0.00	850	BioGrace, assumptions
wood chips		45%	17.8	8.7	round wood	39.2	0.3	8.7	0.02	0.01	100	BioGrace, assumptions
grass sillage	10.00	65%	17.8	4.6	none	25.0	0.4	4.6	0.02	0.01	45.5	assumption, price 130 - 150 €/tDM
food residues	0.00	80%	17.8	1.6	none	0.1	0.1	1.6	0.01	0.00	8	assumption, price 6 - 45 €/t

Table 3: *Products*

PRODUCTS	heating value	water content	CO_2-emission from combustion	revenue	collecting rate	data source
	[MJ/kg]	[%]	[g CO_2/kg]	[€/t]	[%]	[-]
biodiesel	37.20		2,902	*1057*		BioGrace, assumptions
bioethanol	26.81		2,091	*762*		BioGrace, assumptions
FT-diesel	42.00		3,276	*1193*		assumptions
FT-gasoline	40.00		3,120	*1136*		assumptions
bio oil	21.80		1,700	635		BioGrace, assumptions
rape seed cake	18.65		1,455	130		BioGrace, assumptions
glycerin	16.00		1,248	150	50%	BioGrace, assumptions
rape seed oil	36.00		2,808			BioGrace, assumptions
cooking oil	33.15		2,585			BioGrace, assumptions
DDGS	16.00		1,248	130		BioGrace, assumptions
waxes	43.00		3,354	*1222*	*50%*	assumptions
methanol	19.90		1,552	*565*	*50%*	BioGrace, assumptions
potassium sulphate (K2SO4)	0.00		0	*0*		BioGrace, assumptions
phenols	40.50		3,159	*1151*	*50%*	assumptions
pellets	19.78		1,543	*562*		assumptions
pulp	16.07		1,253	500	0%	assumptions
paper	14.40		1,123	650	0%	assumptions
bark (50%)	8.50		663	17	50%	assumptions
tall oil	37.90		2,956	95	50%	assumptions
turpentine	44.00		3,432	88	50%	assumptions
CO2	0.00		0	20		assumptions
fertilizer	0.00	10%	0	0		
bio plastic	28.80	0%	2,246	2000		
insulation material	15.00	0%	1,170	10		

Table 3: *Auxiliary Energy*

AUXILIARY ENERGY		GHG	primary energy consumption				price	data source
		[g CO_2-eq/MJ]	[MJ_{fossil}/MJ]	[MJ_{biom}/MJ]	[MJ_{renew}/MJ]	[MJ_{others}/MJ]	[€/GJ]	[-]
aux. electricity	natural gas plant	125.2	2.1		0.103	0.041	22.2	BioGrace, assumptions
	light oil plant	169.8	2.3		0.01	0.002	22.2	GEMIS 4.5
	wood chips plant	16.6	0.1	3.1	0.001	0.001	22.2	GEMIS 4.5
aux. heat	natural gas boiler	69.5	1.1		0.1	0.02	4.17	BioGrace, assumptions
	light oil boiler	99.6	1.3		0.004	0.001	4.17	GEMIS 4.5
	wood chips boiler	6.8	0.1	1.2	0.001	0.0005	4.17	GEMIS 4.5

Table 4: *Heat and Electricity*

Heat&Electricity	revenue		data source
	[€/GJ]	[€/MWh]	[-]
heat	4.17	15	assumption
electricity	22.2	80	assumption

Table 5: *Energy Carriers*

ENERGY CARRIERS	heating value	density	GHG	primary energy consumption			price	data source
	[MJ/kg]	[kg/l o kg/Nm3]	[g CO_2-eq/kg]	[MJ_{fossil}/kg]	[MJ_{renew}/kg]	[MJ_{others}/kg]	[€/t]	[-]
natural gas	36.0		2,448	40.6	2.03	0.81	3.5	BioGrace, assumptions
heating oil	42.5		3,721	51.0	2.55	1.02	3.2	BioGrace, assumptions

Table 6: *Auxiliary Materials*

AUXILIARY MATERIALS	heating value [MJ/kg]	spec. GHG emissions [g CO_2-eq/kg]	primary energy consumption [MJ_{fossil}/kg]	[MJ_{renew}/kg]	[MJ_{other}/kg]	price [€/t]	data source / comment [-]
n-Hexane	45.11	3,632.5	14.45			2000	BioGrace, assumptions
fuller's earth		199.8	2.54			75	BioGrace, assumptions
phosphoric acid (H3PO4)		3,038	28.37	0.041	0.333	800	GEMIS 4.5
potassium hydroxide (KOH)		0.00				200	BioGrace, assumptions
hydrochloric acid (HCl)		753.2	15.43			100	BioGrace, assumptions
sodium carbonate (Na2CO3)		1,203	13.79			150	BioGrace, assumptions
sodium hydroxide (NaOH)		471	10.22			400	BioGrace, assumptions
methanol	19.90	*5.03*	*1.08*			350	BioGrace, assumptions
water						2	BioGrace, assumptions
burnt lime		1,031	4.60			50	GEMIS 4.5
NaOH (50%)		*235.7*	*5.11*			200	BioGrace, assumptions
H2SO4 (97%)		208.8	3.90			50	BioGrace, assumptions
O2		370.0	5.44			100	GEMIS 4.5
natriumchlorat		987.0	14.10			50	BioGrace, assumptions
polypropylen (PP)	45.36	3,500.0	28.23	2.0	0.8	1000	GEMIS 4.9
urea	9.36	1,550.0	12.24	0.044	0.029	300	GEMIS 4.9

Table 7: *Transport*

TRANSPORT	spec GHG emissions [g CO_2-eq/(t*km)]	primary energy consumption [MJ_{fossil}/(t*km)]	[MJ_{renew}/(t*km)]	[MJ_{other}/(t*km)]	data source / comment [-]
middle truck	190.8	8.75	0.02	0.13	GEMIS 4.5
big truck	116.6	1.49	0.00	0.02	GEMIS 4.5
standard truck	81.3	0.93	0.05	0.02	BioGrace, assumptions

Table 8: *References product systems*

REFERENCES (mat.)	heating value [MJ/kg]	[MJ/l]	spec GHG emissions [g CO_2-eq/kg]	CO_2-emission from [g CO_2/kg]	primary energy consumption [MJ_{fossil}/kg]	[MJ_{biom}/kg]	[MJ_{renew}/kg]	[MJ_{other}/kg]	collecting rate [%]	data source / comment [-]
gasoline	42.7	31.7	3,740	3,330	49.5		2.48	0.05		BioGrace, assumptions
diesel	43.1	35.3	3,776	3,362	50.0		2.50	0.05		BioGrace, assumptions
synthetic glycerin			922	0	125.0		4.50	0.20	50%	BioGrace,
soy feed	23.76		497	1,853	3.93	23.76	0.20	0.08		
potassium fertilizer			579	0	9.68		0.48	0.19		
con.phenol	32.40		1,968	2,527	66.6		0.178	0.07	50%	9 kWh/kg
potassium fertilizer (K)			81.8	0	1.32		0.013	0.0096		
plastic	28.80		5,012	2,246	80.6		4.03	1.61	50%	assumption
substitute for tall oil			1,000	0	20.0		1.00	0.40	50%	
substitute for turpentine			1,000	0	20.0		1.00	0.40	50%	
diesel by bio oil	43.1		3,776	3,362	50.0		2.50	0.05		BioGrace, assumptions
conventional waxes	43.0		3,776	3,354	50.0		2.50	0.05	50%	assumption
nitrogen fertilizer (N)			5,917	0	49.0		2.45	0.98		BioGrace, assumptions
insulation (EPS)			3,670	0	27.9		1.3000	0.5000	30%	GEMIS 4.9
polypropylen (PP)	45.36		3,500	3,538	28.2		2.00	0.80		GEMIS 4.10
HDPE	28.80		6,300	2,246	101.4		5.07	2.03	50%	BIOWERT Vortrag VDI

Table 9: *References energy systems*

REFERENCES (en.)	spec GHG	primary energy demand			data source / comment
	[g CO_2-eq/MJ]	[MJ_{fossil}/MJ]	[$MJ_{renew.}$/MJ]	[MJ_{other}/MJ]	[-]
light oil plant	170	2.3	0.01	0.00	BioGrace,
natural gas plant	125	2.1	0.10	0.04	BioGrace, assumptions
light oil boiler	100	1.3	0.00	0.00	BioGrace, assumptions
natural gas boiler	70	1.1	0.06	0.02	BioGrace, assumptions