IEA Bioenergy
Technology Collaboration Programme

Task 42 Biorefining in a Circular Economy

Technical, Economic and Environmental Assessment (TEE) of biorefinery concepts

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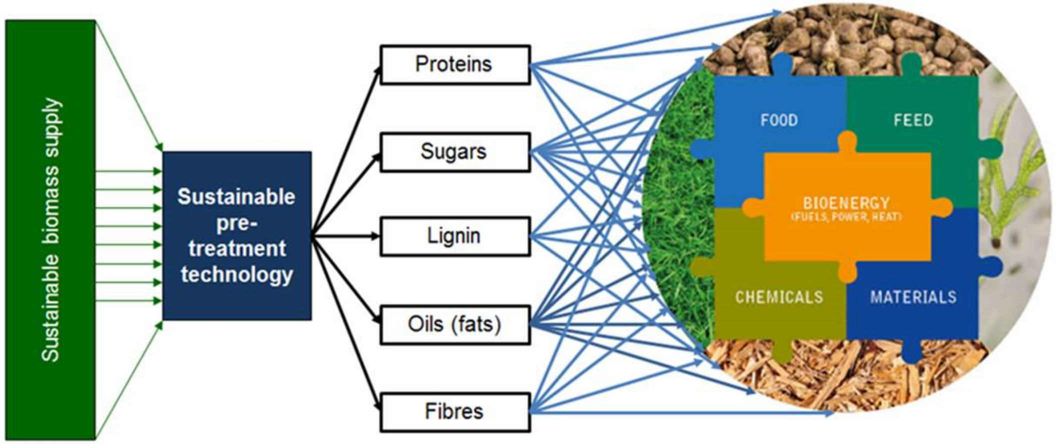
(Wageningen Food & Biobased Research & Leader Task 42)

IETS Workshop Future Scenarios and Strategic Decision-Making for Industry Transformation: Powered by System Engineering, Zoom, 6 May 2021

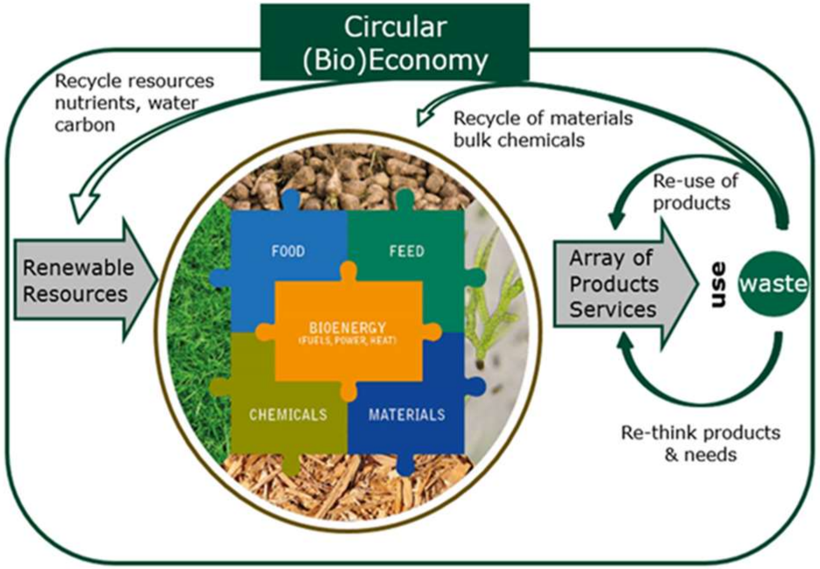
Task 42 Biorefining in a Circular Economy - Introduction

- Biorefining = sustainable processing of biomass into a portfolio of marketable biobased products (food and feed ingredients, chemicals, materials, minerals, CO_2) and bioenergy (fuels, power, heat)
- Task 42 started in 2007 and now operates during its 5th Triennium 2019-2021
- Member countries are:
  Austria, Australia, Denmark,
  Germany, Ireland, Italy,
  The Netherlands & Sweden



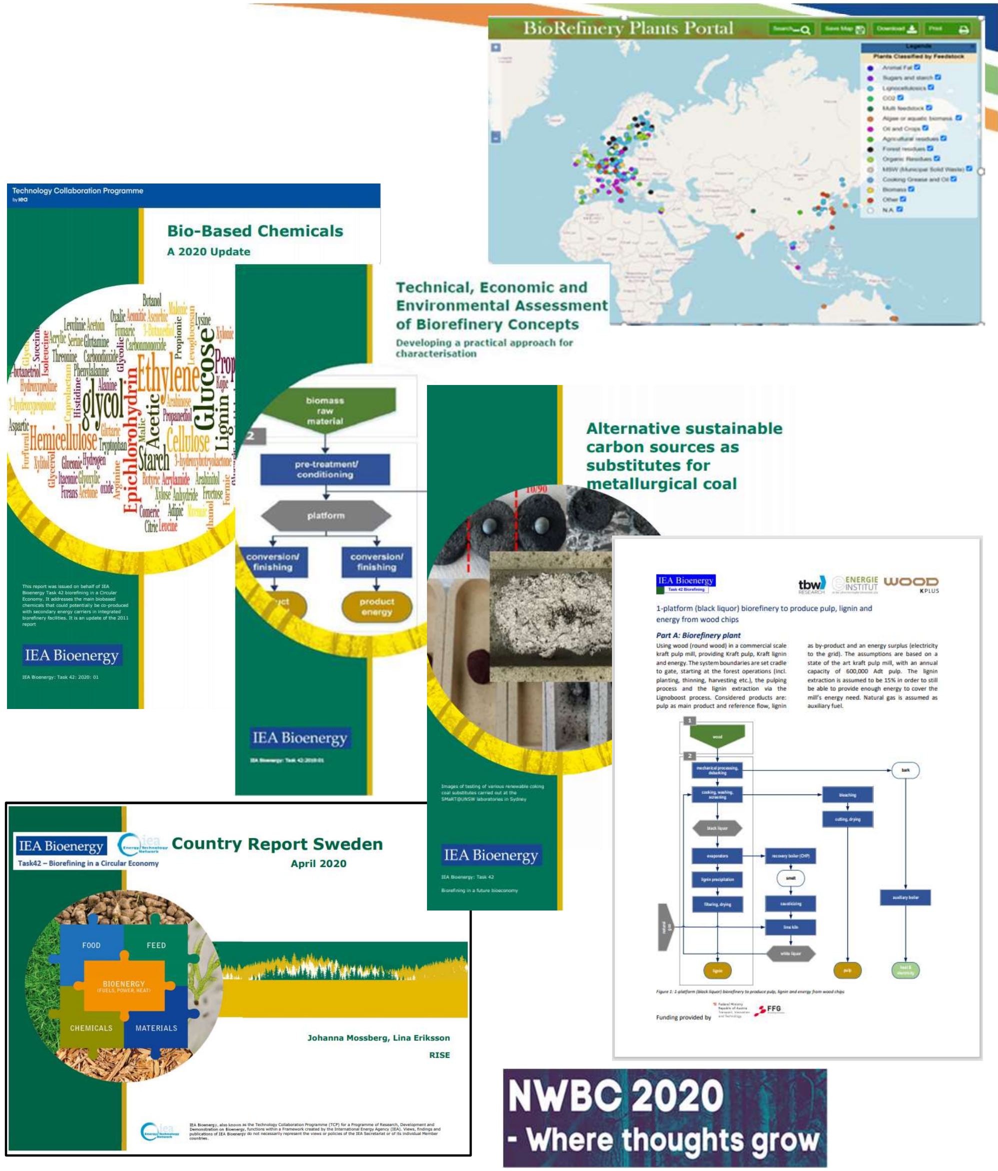
Task 42 Biorefining in a Circular Economy - Objectives

- Facilitate commercialization and market deployment of biorefinery systems and technologies (environmentally sound, socially acceptable, and cost-competitive)
- Support and advise policy and industrial decision makers
- Provide an international platform for collaboration and information exchange between industry, SMEs, GOs, NGOs, RTOs and universities
- Focus on biorefinery research, development, demonstration and policy analysis
- Development of networks, dissemination of information, and provision of science-based technology analysis
- Address gaps and barriers to deployment



Results Task 42 in 2019-2021

- Reports:
  - Bio-Based Chemicals: A 2020 Update
  - Technical, Economic and Environmental Assessment of Biorefinery Concepts
  - Alternative sustainable carbon sources as substitutes for metallurgical coal
  - Sustainable lignin valorization (draft)
- Factsheets of Biorefinery Concepts
- Biorefinery plants portal & database
- Case study market diffusion barriers & incentives
- Country reports
- Website
- Lectures at conferences (e.g. Nordic Wood Biorefinery Conference 2020)



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Bio-Based Chemicals

A 2020 Update

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Technical, Economic and Environmental Assessment of Biorefinery Concepts

Developing a practical approach for characterisation

IEA Bioenergy

Alternative sustainable carbon sources as substitutes for metallurgical coal

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IEA Bioenergy Task 42 Biorefining

1-platform (black liquor) biorefinery to produce pulp, lignin and energy from wood chips

Part A: Biorefinery plant

Using wood (round wood) in a commercial scale kraft pulp mill, providing Kraft pulp, Kraft lignin and energy. The system boundaries are set cradle to gate, starting at the forest operations (incl. planting, thinning, harvesting etc.), the pulping process and the lignin extraction via the Lignoboost process. Considered products are: pulp as main product and reference flow, lignin as by-product and an energy surplus (electricity to the grid). The assumptions are based on a state of the art kraft pulp mill, with an annual capacity of 600,000 Adt pulp. The lignin extraction is assumed to be 15% in order to still be able to provide enough energy to cover the mill's energy need. Natural gas is assumed as auxiliary fuel.

Figure 1: 1-platform (black liquor) biorefinery to produce pulp, lignin and energy from wood chips

Funding provided by

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Task42 – Biorefining in a Circular Economy

Country Report Sweden

April 2020

Johanna Mossberg, Lina Eriksson

RISE

NWBC 2020

- Where thoughts grow

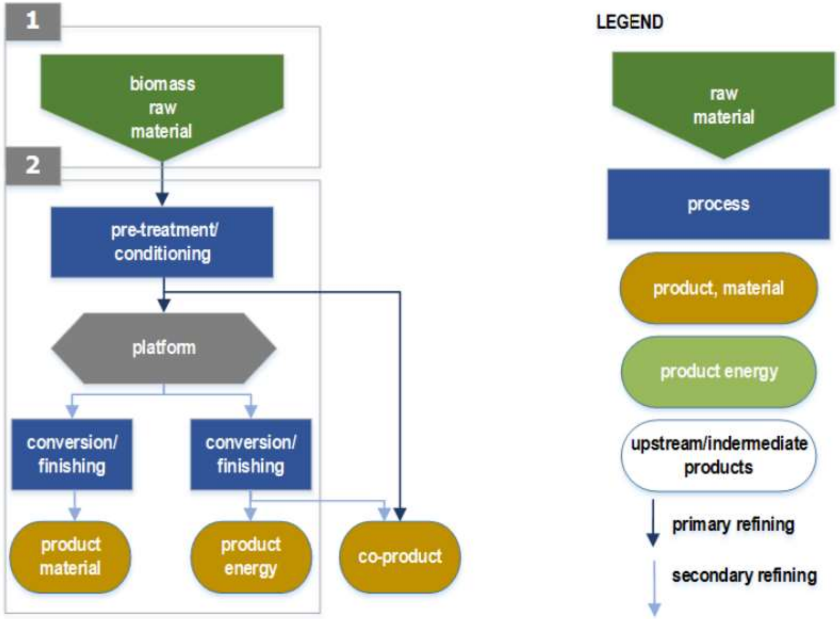
www.ieabioenergy.com
http://task42.ieabioenergy.com

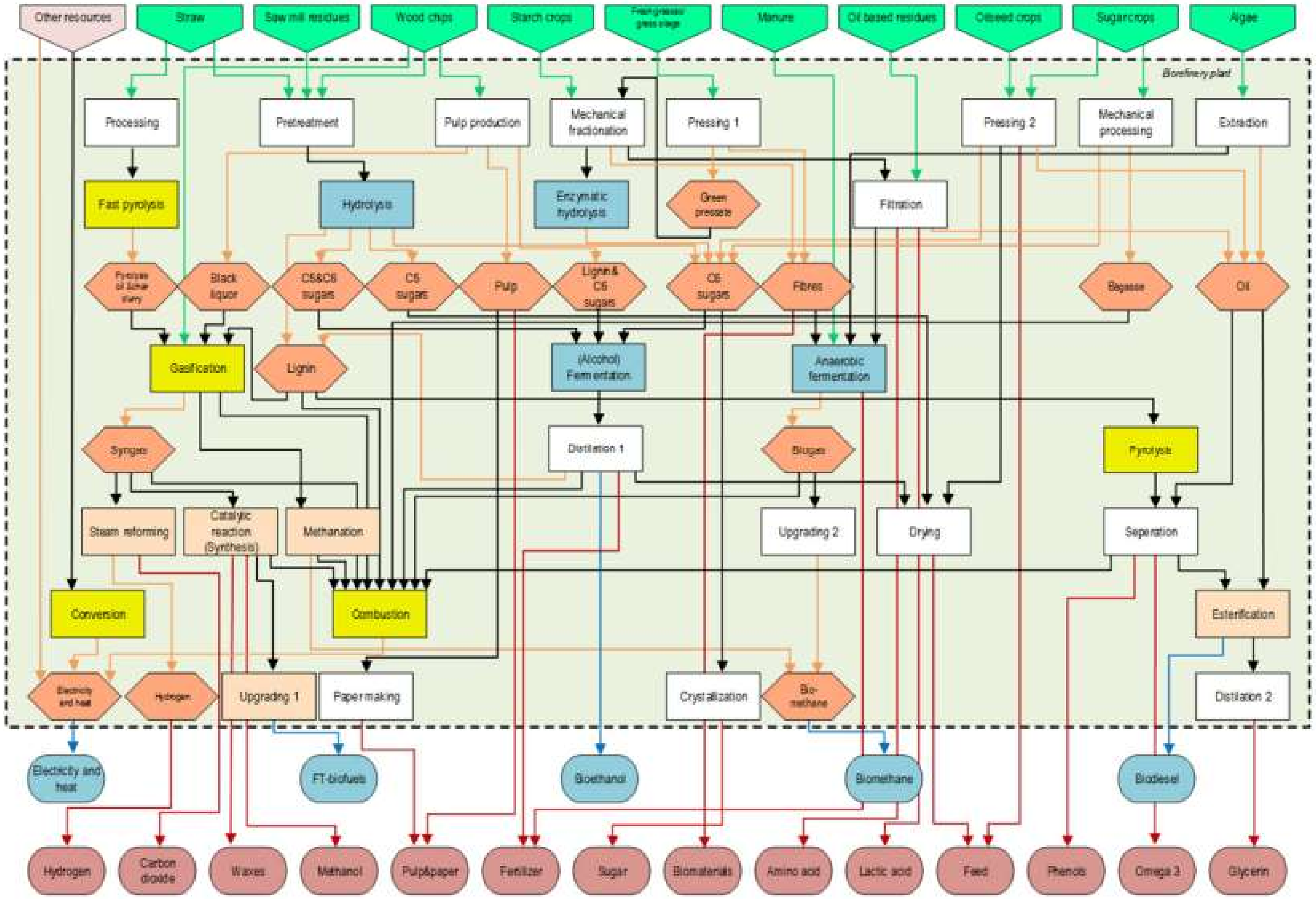
Objectives of Task 42 TEE-Assessment methodology

- Underpin the sustainability claim of integrated biorefineries through Technical, Economic and Environmental (TEE) Assessments
  - quantitative environmental and economic assessment approach
  - with generic initial biorefinery models for iterative refinement
  - encourage stakeholders to participate in the assessment of biorefinery technologies
- Provide an open access approach

Task 42 biorefinery classification system

Motivation: establishment of a common ‘language’





Source: based on Cherubini, F.et al., 2009 & IEA Task 42

Recent update of classification system

FEEDSTOCK

Primary biomass
- Aquatic biomass
- Lignocellulosic from croplands and grasslands
- Lignocellulosic wood/forestry
- Oil crops
- Starch crops
- Sugar crops
- *Other

Secondary biomass
- Microbial biomass
- Residues from agriculture
- Residues from aquatic biomass
- Residues from forestry
- Residues from nature and landscape management
- Residues from recycled bio-based products
- *Other

CONVERSION PROCESS

Biochemical
- Aerobic conversion
- Anaerobic digestion
- Enzymatic process
- Fermentation
- Insect-based bioconversion
- *Other

Chemical
- Catalytic
- Esterification
- Hydrogenation
- Hydrolysis
- Methanation
- Chemical Pulping
- Steam reforming
- Water electrolysis
- Water gas shift
- *Other

Mechanical and thermomechanical
- Blending
- Extraction
- Mechanical & thermomechanical disruption & fractionation
- Mechanical pulping
- Separation processes
- *Other

Thermochemical
- Combustion
- Gasification
- Hydrothermal liquefaction
- Pyrolysis
- Supercritical conversion
- Torrefaction & Carbonization
- *Other

PLATFORM

- Biochar
- Bio-coal
- Bio-crude
- Biogas
- Bio-oils
- Bio-hydrogen
- Bio-naphtha
- C5/C6 sugars
- Carbon dioxide
- Lignin
- Oils
- Organic fibers
- Organic juice
- Protein
- Pyrolytic liquid
- Starch
- Syngas
- *Other

PRODUCT

Chemicals
- Additives
- Agrochemicals
- Building blocks
- Catalysts & Enzymes
- Colorants
- Cosmeceuticals
- Flavours & Fragrances
- Lubricants
- Nutraceuticals
- Paints & Coatings
- Pharmaceuticals
- Solvents
- Surfactants
- *Other

Materials
- Composites
- **Fibers
- Organic Fertilizers
- Polymers
- Resins
- *Other

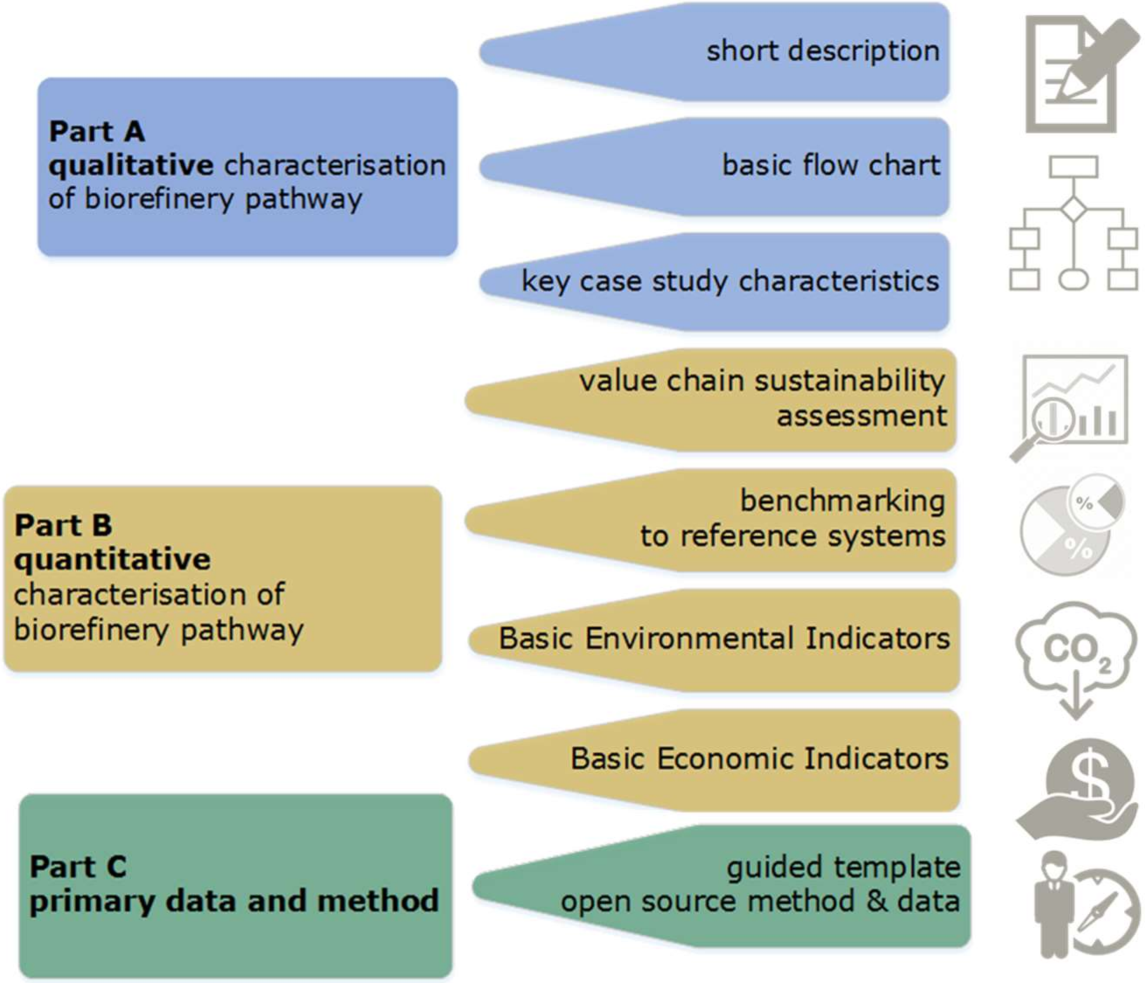
Food

Animal Feed

Energy
- Cooling agents
- Fuels
- Heat
- Power
- *Other

Source: EU Biorefinery Outlook to 2030 project, 2021

Methodology of TEE-Assessment



Part A
qualitative characterisation of biorefinery pathway

- short description
- basic flow chart
- key case study characteristics

Part B
quantitative characterisation of biorefinery pathway

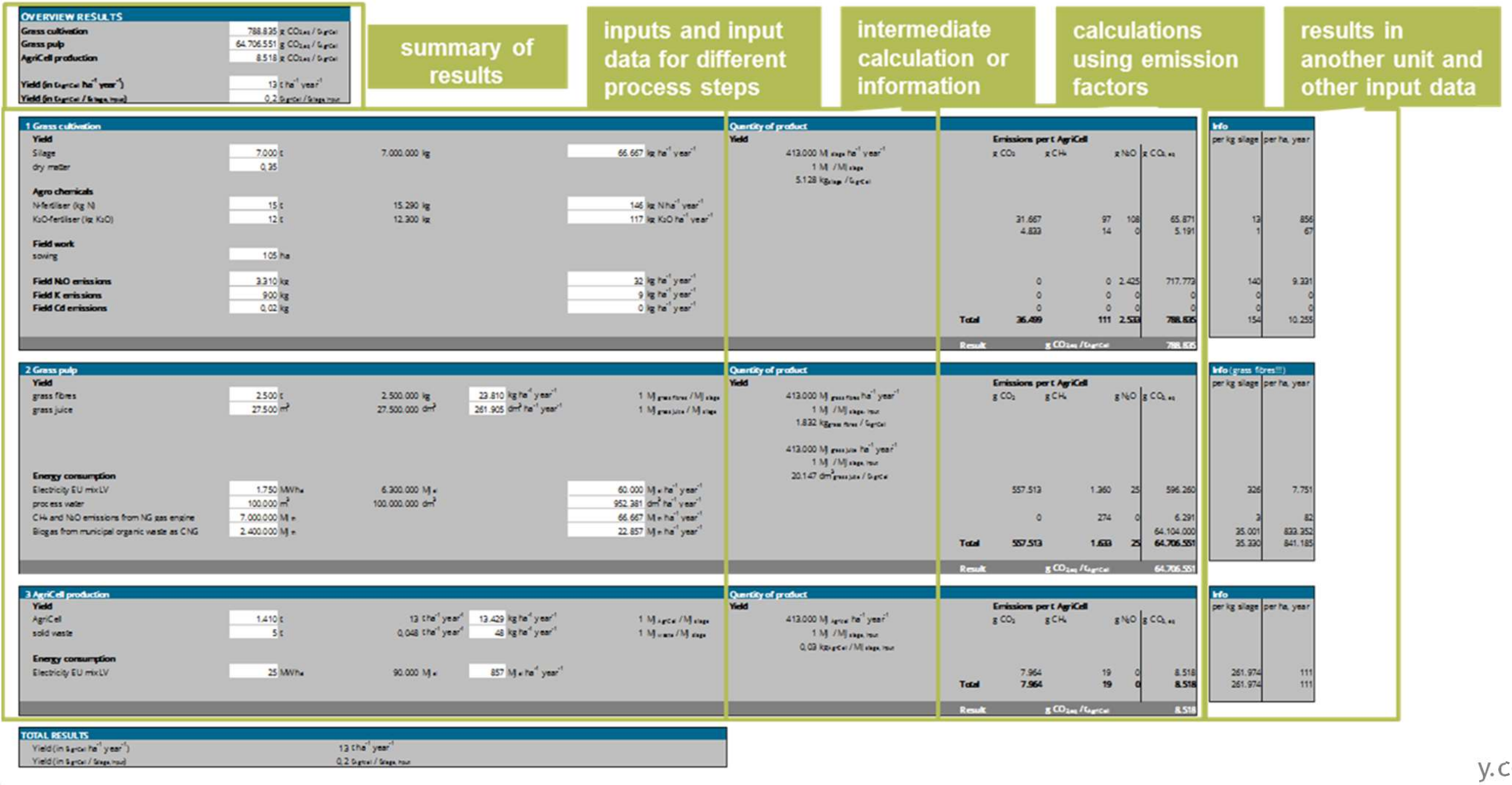
- value chain sustainability assessment
- benchmarking to reference systems
- Basic Environmental Indicators
- Basic Economic Indicators

Part C
primary data and method

- guided template open source method & data

Basic Economic/Environmental evaluation

transparent primary data mining



summary of results

inputs and input data for different process steps

intermediate calculation or information

calculations using emission factors

results in another unit and other input data

OVERVIEW RESULTS

Grass cultivation	788.835	$g\ CO_{2eq} / t_{AgriCell}$
Grass pulp	64.706.551	$g\ CO_{2eq} / t_{AgriCell}$
AgriCell production	8.518	$g\ CO_{2eq} / t_{AgriCell}$
Yield (in $t_{AgriCell}\ ha^{-1}\ year^{-1}$)	13	$t\ ha^{-1}\ year^{-1}$
Yield (in $t_{AgriCell} / t_{Silage,input}$)	0,2	$t_{AgriCell} / t_{Silage,input}$

1 Grass cultivation

				g CO_2	g CH_4	g N_2O	g $CO_{2,eq}$	per kg silage	per ha, year
Yield									
Silage	7.000 t	7.000.000 kg	66.667 kg $ha^{-1}\ year^{-1}$						
dry matter	0,35								
Agro chemicals									
N-fertiliser (kg N)	15 t	15.290 kg	146 kg N $ha^{-1}\ year^{-1}$	31.667	97	108	65.871	13	856
K_2O-fertiliser (kg K_2O)	12 t	12.300 kg	117 kg K_2O $ha^{-1}\ year^{-1}$	4.833	14	0	5.191	1	67
Field work									
sowing	105 ha								
Field N_2O emissions	3.310 kg		32 kg $ha^{-1}\ year^{-1}$	0	0	2.425	717.773	140	9.331
Field K emissions	900 kg		9 kg $ha^{-1}\ year^{-1}$	0	0	0	0	0	0
Field Cd emissions	0,02 kg		0 kg $ha^{-1}\ year^{-1}$	0	0	0	0	0	0
Total				**36.499**	**111**	**2.533**	**788.835**	154	10.255
Result				$g\ CO_{2eq} / t_{AgriCell}$			**788.835**		

Quantity of product

Yield

413.000 $MJ_{silage}\ ha^{-1}\ year^{-1}$

1 MJ / MJ_{silage}

5.128 $kg_{silage} / t_{AgriCell}$

Emissions per t AgriCell

Info

2 Grass pulp

					g CO_2	g CH_4	g N_2O	g $CO_{2,eq}$	per kg silage	per ha, year
Yield										
grass fibres	2.500 t	2.500.000 kg	23.810 kg $ha^{-1}\ year^{-1}$	1 $MJ_{grass\ fibres} / MJ_{silage}$						
grass juice	27.500 m^3	27.500.000 dm^3	261.905 $dm^3\ ha^{-1}\ year^{-1}$	1 $MJ_{grass\ juice} / MJ_{silage}$						
Energy consumption										
Electricity EU mix LV	1.750 MWh_{el}	6.300.000 MJ_{el}	60.000 $MJ_{el}\ ha^{-1}\ year^{-1}$		557.513	1.360	25	596.260	326	7.751
process water	100.000 m^3	100.000.000 dm^3	952.381 $dm^3\ ha^{-1}\ year^{-1}$							
CH4 and N2O emissions from NG gas engine	7.000.000 MJ_{th}		66.667 $MJ_{th}\ ha^{-1}\ year^{-1}$		0	274	0	6.291	3	82
Biogas from municipal organic waste as CNG	2.400.000 MJ_{th}		22.857 $MJ_{th}\ ha^{-1}\ year^{-1}$					64.104.000	35.001	833.352
Total					**557.513**	**1.633**	**25**	**64.706.551**	35.330	841.185
Result					$g\ CO_{2eq} / t_{AgriCell}$			**64.706.551**		

Quantity of product

Yield

413.000 $MJ_{grass\ fibres}\ ha^{-1}\ year^{-1}$

1 MJ / $MJ_{silage,input}$

1.832 $kg_{grass\ fibres} / t_{AgriCell}$

413.000 $MJ_{grass\ juice}\ ha^{-1}\ year^{-1}$

1 MJ / $MJ_{silage,input}$

20.147 $dm^3_{grass\ juice} / t_{AgriCell}$

Emissions per t AgriCell

Info (grass fibres!!!)

3 AgriCell production

					g CO_2	g CH_4	g N_2O	g $CO_{2,eq}$	per kg silage	per ha, year
Yield										
AgriCell	1.410 t	13 $t\ ha^{-1}\ year^{-1}$	13.429 kg $ha^{-1}\ year^{-1}$	1 $MJ_{AgriCell} / MJ_{silage}$						
solid waste	5 t	0,048 $t\ ha^{-1}\ year^{-1}$	48 kg $ha^{-1}\ year^{-1}$	1 MJ_{waste} / MJ_{silage}						
Energy consumption										
Electricity EU mix LV	25 MWh_{el}	90.000 MJ_{el}	857 $MJ_{el}\ ha^{-1}\ year^{-1}$		7.964	19	0	8.518	261.974	111
Total					**7.964**	**19**	**0**	**8.518**	261.974	111
Result					$g\ CO_{2eq} / t_{AgriCell}$			**8.518**		

Quantity of product

Yield

413.000 $MJ_{AgriCell}\ ha^{-1}\ year^{-1}$

1 MJ / $MJ_{silage,input}$

0,03 $kg_{AgriCell} / MJ_{silage,input}$

Emissions per t AgriCell

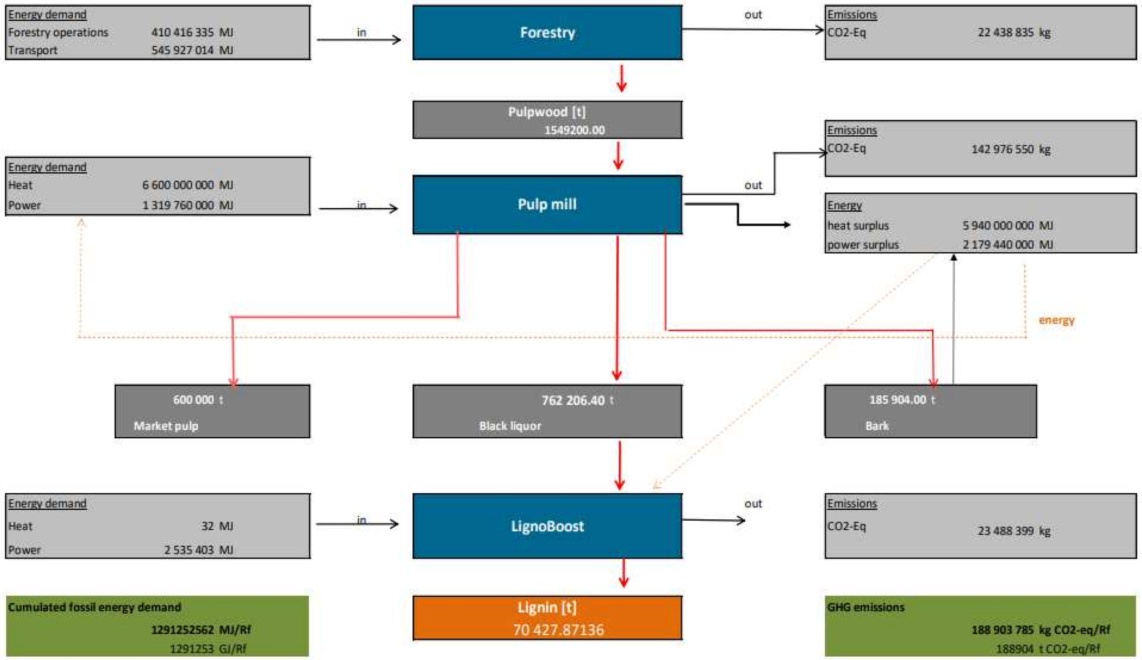
Info

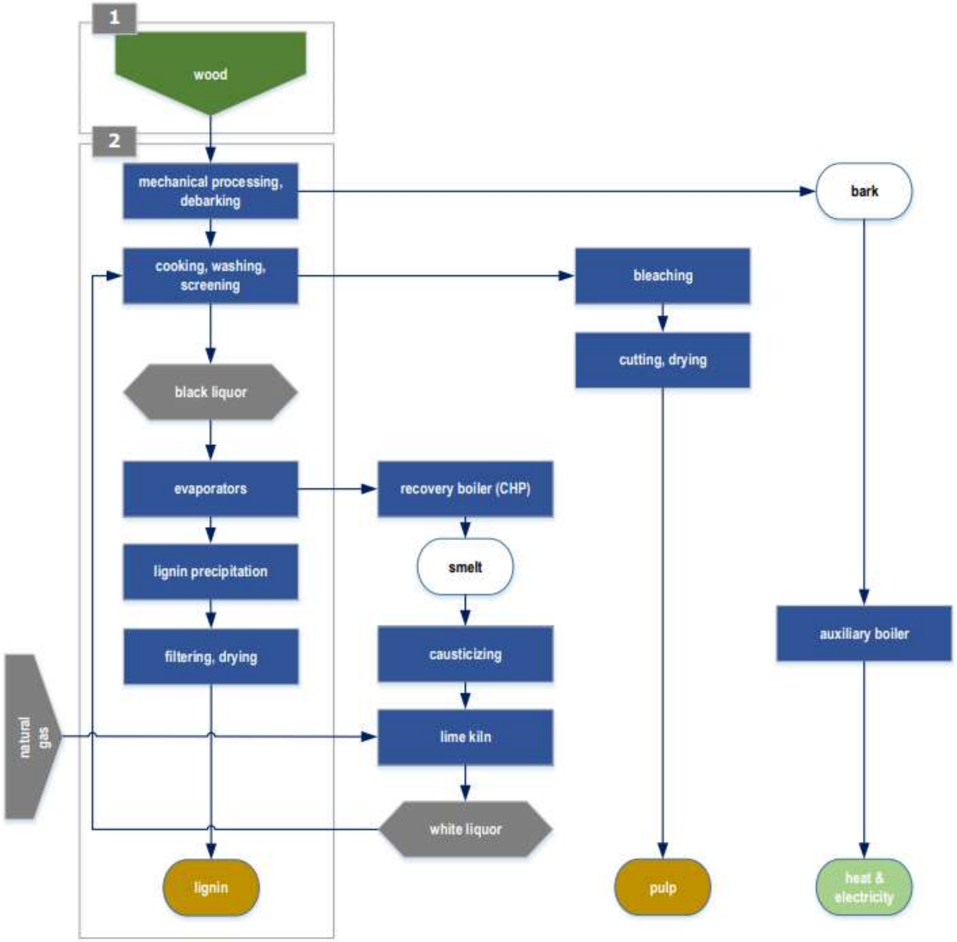
TOTAL RESULTS

Yield (in $t_{AgriCell}\ ha^{-1}\ year^{-1}$)	13 $t\ ha^{-1}\ year^{-1}$
Yield (in $t_{AgriCell} / t_{Silage,input}$)	0,2 $t_{AgriCell} / t_{Silage,input}$

Results communication - Example Case 4

Part A biorefinery key characteristics





Case 4 = 1-platform (black liquor) biorefinery to produce pulp, lignin and energy from wood chips (details in Task 42 report)

Results communication

Part A biorefinery key characteristics

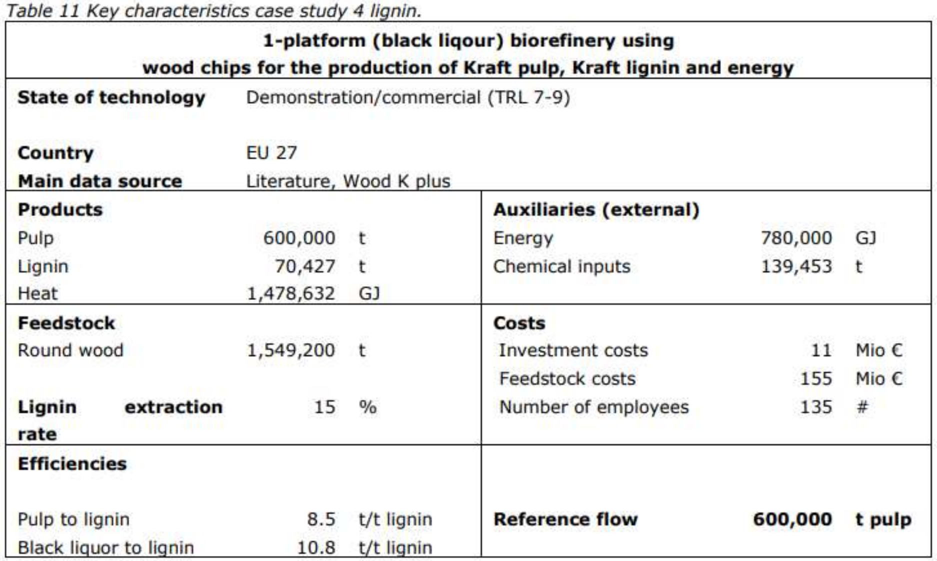
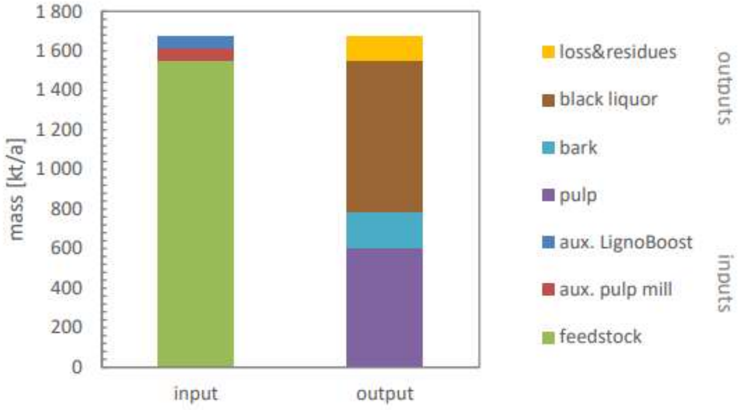
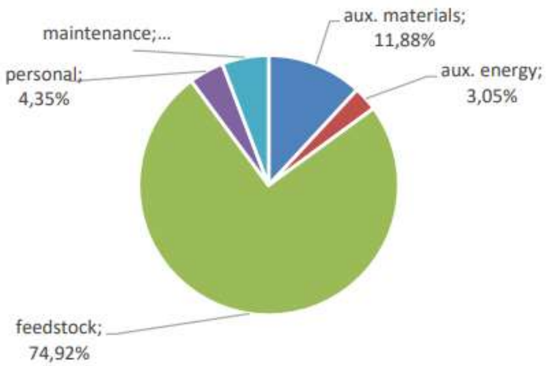
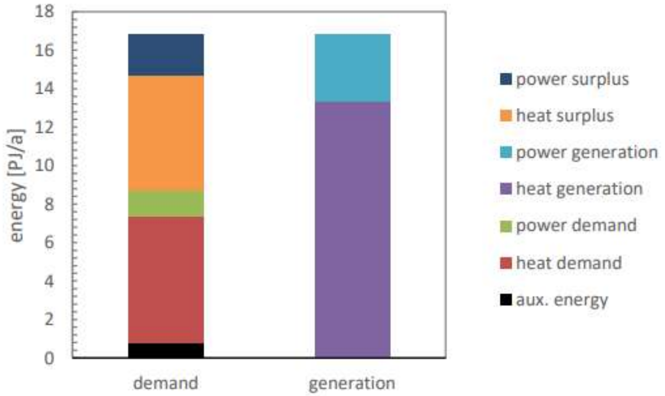


Table 11 Key characteristics case study 4 lignin.

1-platform (black liqour) biorefinery using wood chips for the production of Kraft pulp, Kraft lignin and energy					
State of technology	Demonstration/commercial (TRL 7-9)				
Country	EU 27				
Main data source	Literature, Wood K plus				
Products			**Auxiliaries (external)**		
Pulp	600,000	t	Energy	780,000	GJ
Lignin	70,427	t	Chemical inputs	139,453	t
Heat	1,478,632	GJ			
Feedstock			**Costs**		
Round wood	1,549,200	t	Investment costs	11	Mio €
			Feedstock costs	155	Mio €
Lignin extraction rate	15	%	Number of employees	135	#
Efficiencies					
Pulp to lignin	8.5	t/t lignin	**Reference flow**	**600,000**	**t pulp**
Black liquor to lignin	10.8	t/t lignin			

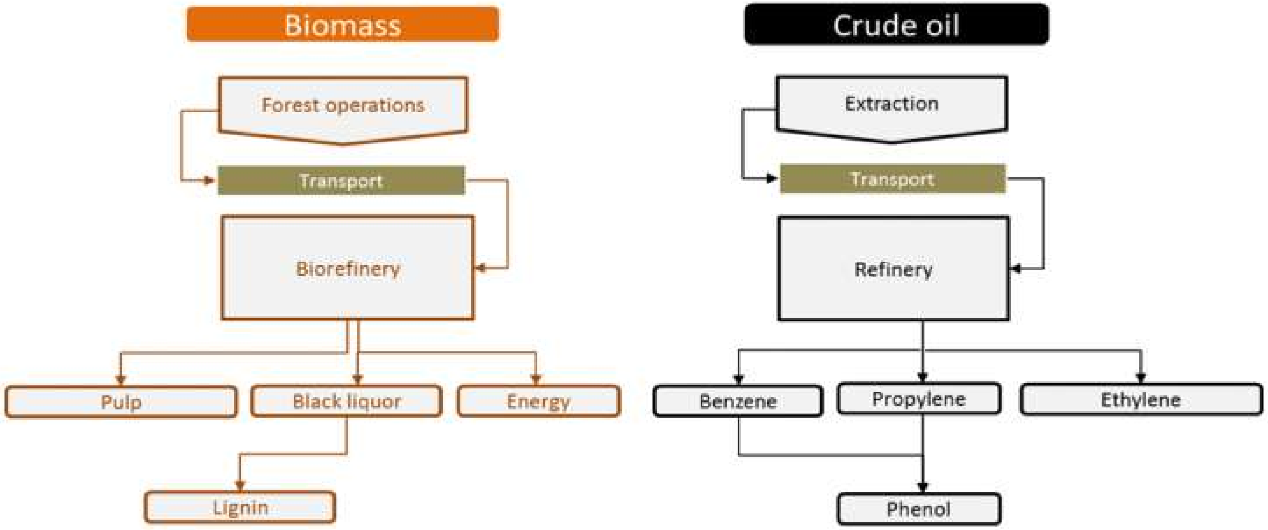






Results Communication

Part B Value Chain Sustainability Assessment



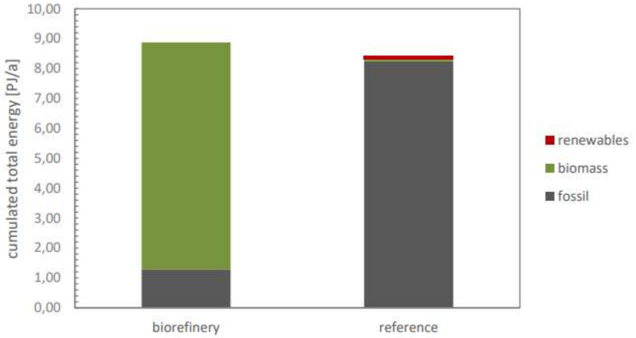


Figure 37 Cumulated energy demand of biorefinery compared to reference plant case study 4.

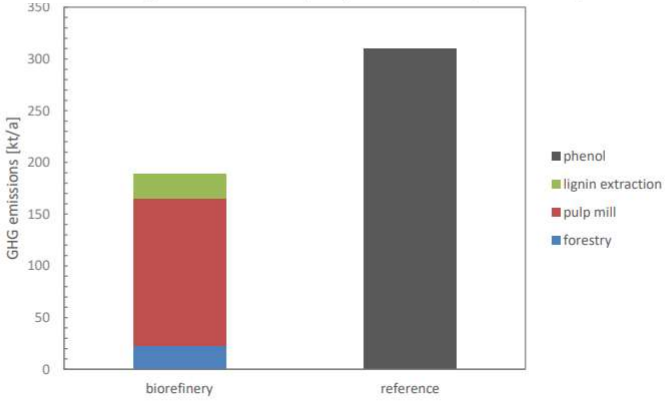


Figure 38 Greenhouse gas emissions of biorefinery compared to reference plant case study 4.

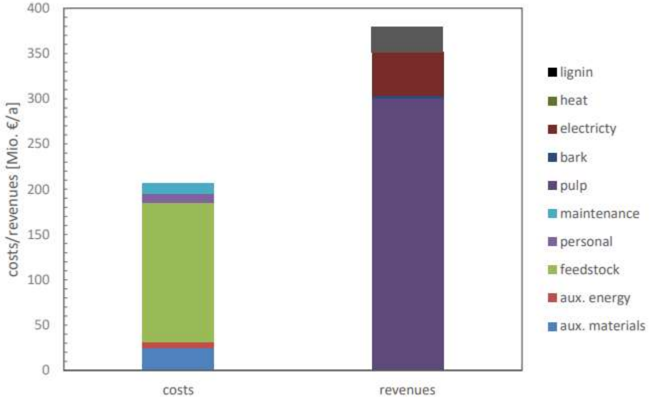


Figure 39 Costs and revenues - case study 4.

Factsheets produced in former Triennia

- 4-platform biorefinery using grass silage and food residues for bio plastic, insulation material, fertilizer, electricity
- 3-platform biorefinery using wood chips for pulp, paper, turpentine, tall oil, bark, electricity and heat
- 1-platform biorefinery using starch crops for bioethanol and feed
- 3-platform biorefinery using wood chips for bioethanol, electricity, heat and phenols
- 1-platform biorefinery using oilseed crops for biodiesel, glycerine and feed
- 1-platform biorefinery using oil based residues for biodiesel, glycerine, bio oil & fertilizer
- 2-platform biorefinery using wood chips for FT-biofuels, electricity, heat and waxes
- 3-platform biorefinery using straw for FT-biofuels and methanol
- 2-platform biorefinery using wood chips for FT-diesel, FT-gasoline, heat and waxes
- 3-platform biorefinery using straw for FT-diesel and methanol
- 3-platform biorefinery using wood for renewable gasoline/diesel, biochar and pyrolysis oil

Recently published Biorefinery assessments and Fact Sheets

- 3-platform biorefinery (pulp, lignin, energy) using woodchips for pulp, lignin and energy; (LignoBoost process)
- 2-platform biorefinery (C5 & C6 sugar, lignin) using corn straw for the production of bioethanol and electricity & heat
- 2-platform biorefinery (C5 & C6 sugar, biogas) using sugar beet or cane for the biopolymer PHB and electricity & heat
- 2-platform biorefinery (C5 & C6 sugar, biogas) using maize for the production of biopolymer PLA and electricity & heat

- ... and more to come!

More information TEE methodology & factsheets

- Task 42 report ‘Technical, Economic and Environmental Assessment of Biorefinery Concepts’: https://task42.ieabioenergy.com/publications/tee-2019/
- IEA Bioenergy Annual report 2020 ‘Technical, ecological and economic assessment of biorefinery cases’ (page 7-22): https://www.ieabioenergy.com/blog/publications/new-publication-iea-bioenergy-annual-report-2020/
- Factsheets: https://task42.ieabioenergy.com/document-category/factsheets/

Thank you for your attention

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Johannes Lindorfer, Karin Fazeni &
Daniel Rosenfeld (Energy Institute at the
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Franziska Hesser & Miriam Lettner
(Wood K plus)

Michael Mandl (tbw research)

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TEE Assessment of further biorefinery pathways - options

- Biorefinery concept for integrated production of green diesel, naptha and ethanol from **microalgae** biomass (literature based)
- Combined industrial processes for the conversion of **forestry residuals and in-process emissions** into valuable bio-petrochemical materials and fuels (literature based)
- 2-3 case studies on **gasification** with Task 33
- 2-3 case studies on **biogas** with Task 37
- 1-2 case studies via the questionnaire outreach
- Additional case studies from selected biobased products (and/or other Tasks)
- Additional back-up from on H2020 projects
  - CO_2-based product **ethylene oxide** (current H2020 project) CO₂EXIDE
  - **2nd generation jet fuel** (current H2020 project) REWOFUEL

Report biobased building blocks

- Within the bio-based economy as a whole and within the operation of a specific biorefinery there are significant opportunities for the development of bio-based building blocks (chemicals and polymers) and materials (fibre products, starch derivatives, etc.)
- In many cases this happens in conjunction with the production of bioenergy or biofuels
- It is estimated that the production of bio-based products, in addition to biofuels, could generate US$ 10 billion of revenue for the global chemical industry
- However, current market conditions, uncertainty about trade agreements, future carbon pricing as well as a non-holistic and polarized bioeconomy debate have hampered the deployment as well as the role-out of biobased initiatives
- IEA Task42 can contribute to the debate by showing that biorefineries can contribute to a broader valorization of biomass into a spectrum of high-value biobased products like biochemicals


Technology Collaboration Programme

Bio-Based Chemicals

A 2020 Update

IEA Bioenergy

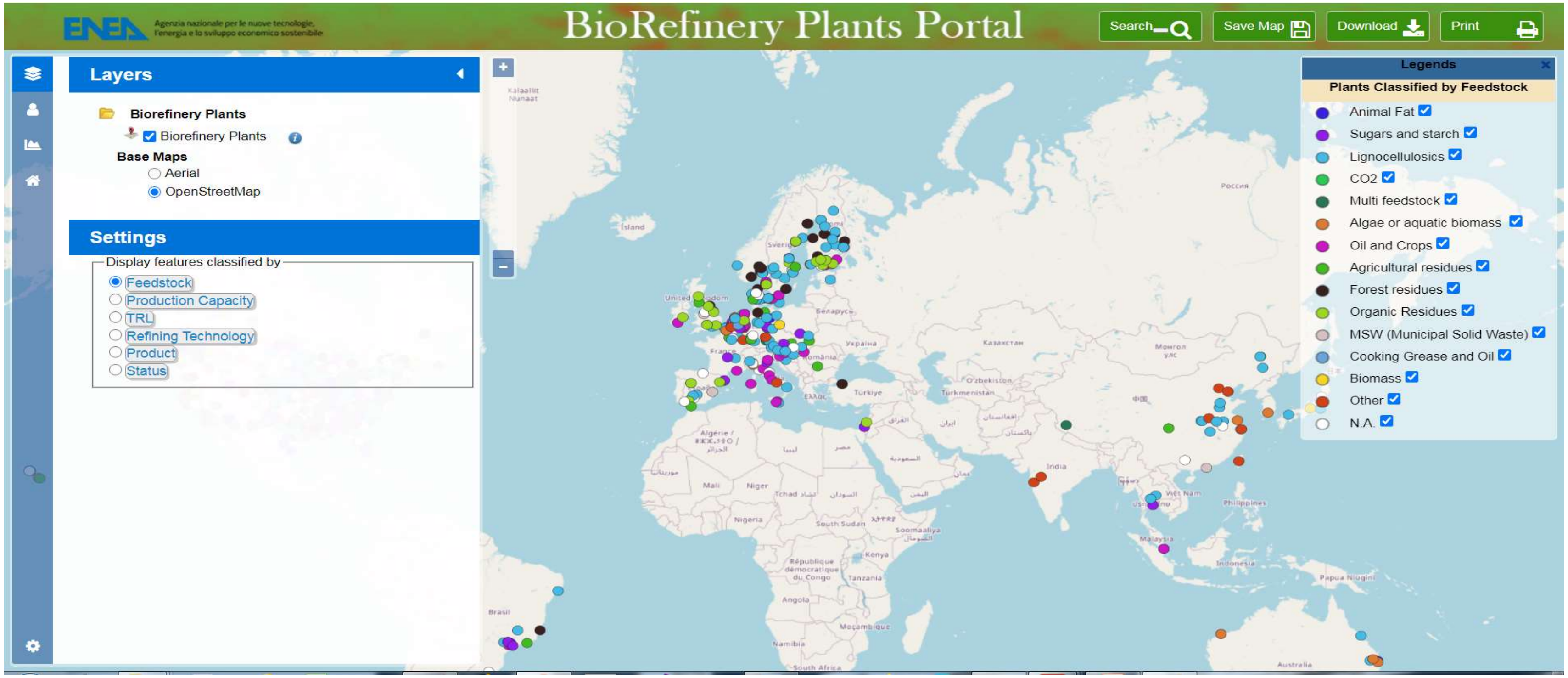
Report lignin as replacement of metallurgical coal

- Each year over 1 billion tonnes of metallurgical coal (coking coal) is utilized to produce most of the 1.7 billion tonnes of steel produced worldwide
- Renewable alternatives need to be developed so that current fossil derived coking coal can be substituted by renewables at reasonable cost
- Lignin has potential to reduce non-renewable coke consumption
- Calculations suggest that if 10% of the world's gasoline demand were replaced with ethanol produced from lignocellulosic sources approximately 20% of fossil coke consumption could be replaced by renewable lignin

Alternative sustainable carbon sources as substitutes for metallurgical coal

IEA Bioenergy

WebGis Biorefineries



Biorefinery Plants
☑ Biorefinery Plants

Base Maps
○ Aerial
● OpenStreetMap

Display features classified by
● Feedstock
○ Production Capacity
○ TRL
○ Refining Technology
○ Product
○ Status

Plants Classified by Feedstock
● Animal Fat ☑
● Sugars and starch ☑
● Lignocellulosics ☑
● CO2 ☑
● Multi feedstock ☑
● Algae or aquatic biomass ☑
● Oil and Crops ☑
● Agricultural residues ☑
● Forest residues ☑
● Organic Residues ☑
● MSW (Municipal Solid Waste) ☑
● Cooking Grease and Oil ☑
● Biomass ☑
● Other ☑
○ N.A. ☑

Possibility to change the plants displayed on the map selecting the desired attributes on the legend

Possibility to display features for:
- Feedstock
- Production capacity
- TRL
- Type of refining technology
- Product (mail product)
- Status

IEA Report on Sustainable lignin valorization

Chapters:

1) lignin chemistry, for each lignin source, analytical methods to know the lignin structure and composition are described; a summary table with everyone lignin is proposed and analyzed.
2) most important international projects on lignin are listed and described; an assessment of potential industrial outputs is also carried out
3) an inventory of the lignin derived products is presented. In particular, polymeric materials (foams, resins, etc.), chemicals, fuels, aromatic compounds, acids are considered in the third chapter, describing for each one the main industrial production process from lignin
4) several process flowsheets for the lignin valorization are proposed and studied through mathematical modeling and/or process simulation methodologies

Cooperation with LignoCOST network

- Activity regarding the **modeling of the biorefinery processes** for the transformation of **different sources of lignin to target products**
- Assessment of the economical parameters (i.e. payback selling price of the target products, maximum lignin cost…) to make convenient the utilization of low quality/high quantity lignin (e.g., Kraft lignin) to produce high-added value compounds