P2X for future sustainable aviation – Demand and opportunities

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DLR – Research Group for Techno-economic assessments

Lappeenranta, FIN
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Agenda

1. **Motivation and demand**
2. **Opportunities**
3. **Techno-economic assessment**
4. **Technical challenges & research**
5. **Outlook**

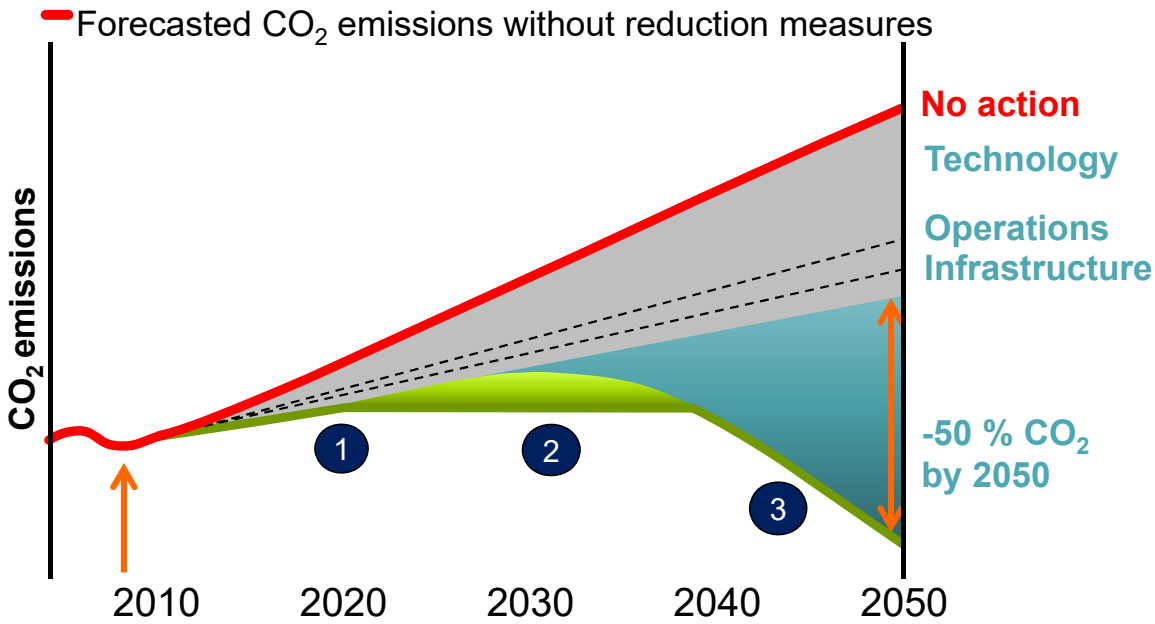
1. Motivation for renewable Aviation: IATA Technology Roadmap [1]

Main goals:

1. Improvement of fuel efficiency about 1.5% p.a. until 2020
2. Carbon-neutral growth from 2020
3. 50% CO_2 emissions reductions by 2050 relative to 2005 levels

- European aviation kerosene demand in 2010: ca. 56.5 Mt[3]

➢ Assumption: Demand for renewable kerosene demand in 2050 equals total demand of 2010



Planned Measures:

- Improvement of technologies, operations and airport infrastructure
- CO_2-certificates and other economic measures (CORSIA[2] 2016)
- Radical technology transitions and **alternative fuels**

[1] iata.org, IATA Technology Roadmap 4. Edition, June 2013
[2] ICAO-Resolution A39-3: Carbon Offsetting and Reduction Scheme for International Aviation
[3] FuelsEurope "Statistical Report" 2010

2. Opportunities: Certified alternative jet fuels (ASTM D7566 – 14c [1])

Feedstock	Synthesis technology	Fuel
Coal, natural gas, biomass, CO_2 & H_2	Fischer-Tropsch (FT) synthesis	Synthetic paraffinic kerosene (SPK)
Lipids from Biomass (e.g. algae, soya, jatropha)	Hydroprocessed esters and fatty acids (HEFA)	Synthetic paraffinic kerosene
Sugar from Biomass	Direct Sugars to Hydrocarbons (DSHC)	Synthetic iso-paraffins / Farnesane
Bioethanol (-propanol, -butanol)	dehydration+oligomerization+hydration (Alcohol-to-Jet, AtJ)	ATJ-SPK

European **crop based** kerosene? – feedstock options: rapeseed & soya / sugar beet / wheat

- All European rapeseed & soya to HEFA: 14.7 Mt/a (≈ 26 % of aviation demand) [2]
- All European sugar beet to DSHC: 3.4 Mt/a (≈ 6 % of demand) [2]
- All European wheat to AtJ: 31.9 Mt/a (≈ 56 % of demand) [2]

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] Dietrich et al., “Challenges & opportunities for sustainable aviation”, 13th Concawe Symposium - Low Carbon Pathways and Refining Technologies, March 2019, Antwerp

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European **BtL** Fischer-Tropsch kerosene? – feedstock forestry and municipal waste:

Forest residues, municipal waste potential [2]: **≈ 8 EJ_{LHV}/a**

Conversion to fuel [3]: **0.363 $P_{LHV, SynCrude}/P_{LHV,Biomass}$**

European kerosene production based on BtL: **34.2 Mt/a (61 %** of demand)

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] Pablo Ruiz, „The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries”, Table 38-43, 2015
[3] Albrecht, “A standardized methodology for the techno-economic evaluation of alternaitve fuels – a case study”, 2016

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Wind power increase of 34 GW/a required for aviation until 2050 !!!
(2018 European wind power capacity installation: 11.7 GW [3])

European **PtL** Fischer-Tropsch kerosene? – feedstock renewable electricity:

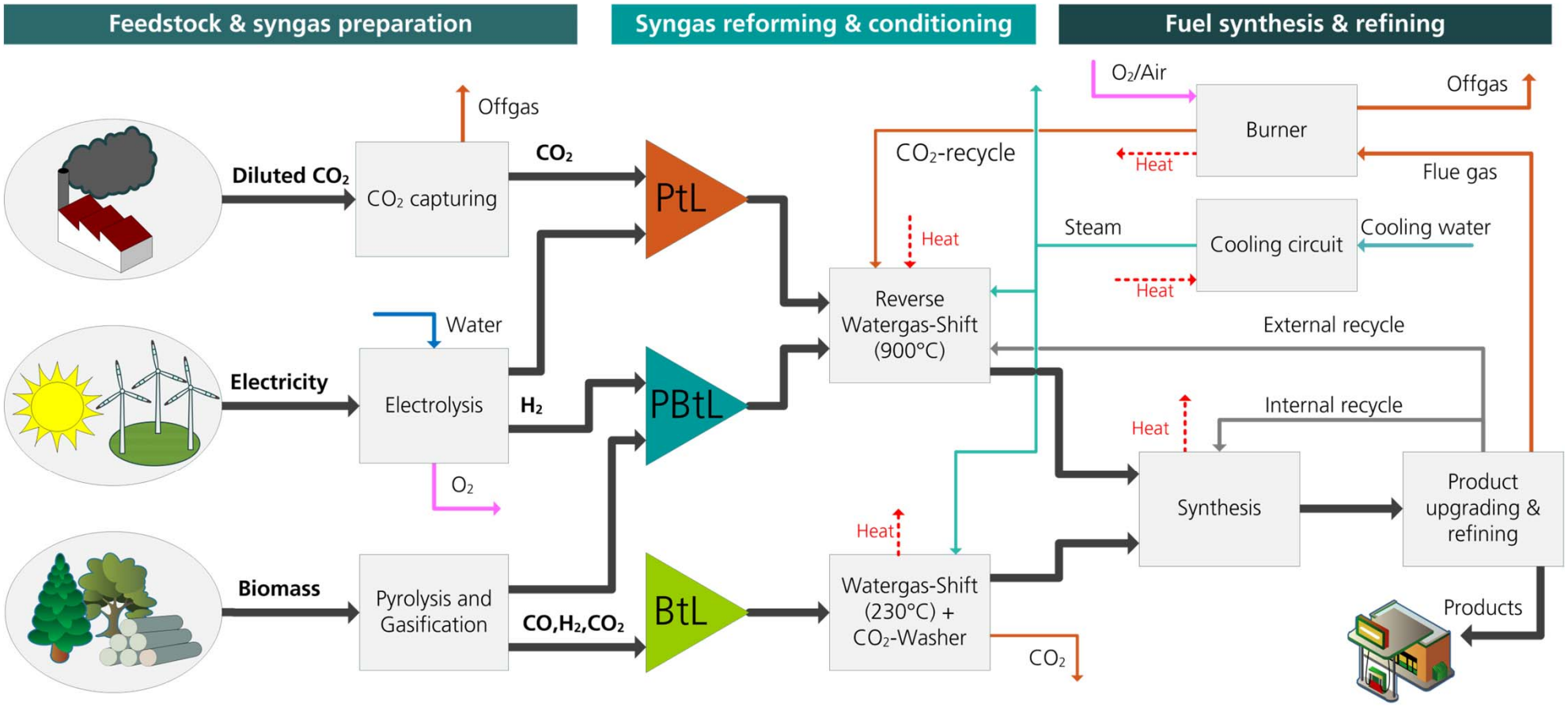
European wind power potential [2]: **44 – 109 EJ_e/a** (2018: 1.3 EJ_e/a [3])

Conversion to fuel [4]: **0.506 $P_{LHV, SynCrude}/P_e$**

European kerosene production based on PtL: **56.5 Mt/a** (**10 - 20% of wind potential**)

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] European Environment Agency, “Europe's onshore and offshore wind energy potential,” 2009
[3] Komusanac et al, “Wind energy in Europe in 2018”, 2019
[4] Albrecht, “A standardized methodology for the techno-economic evaluation of alternative fuels – a case study”, 2016

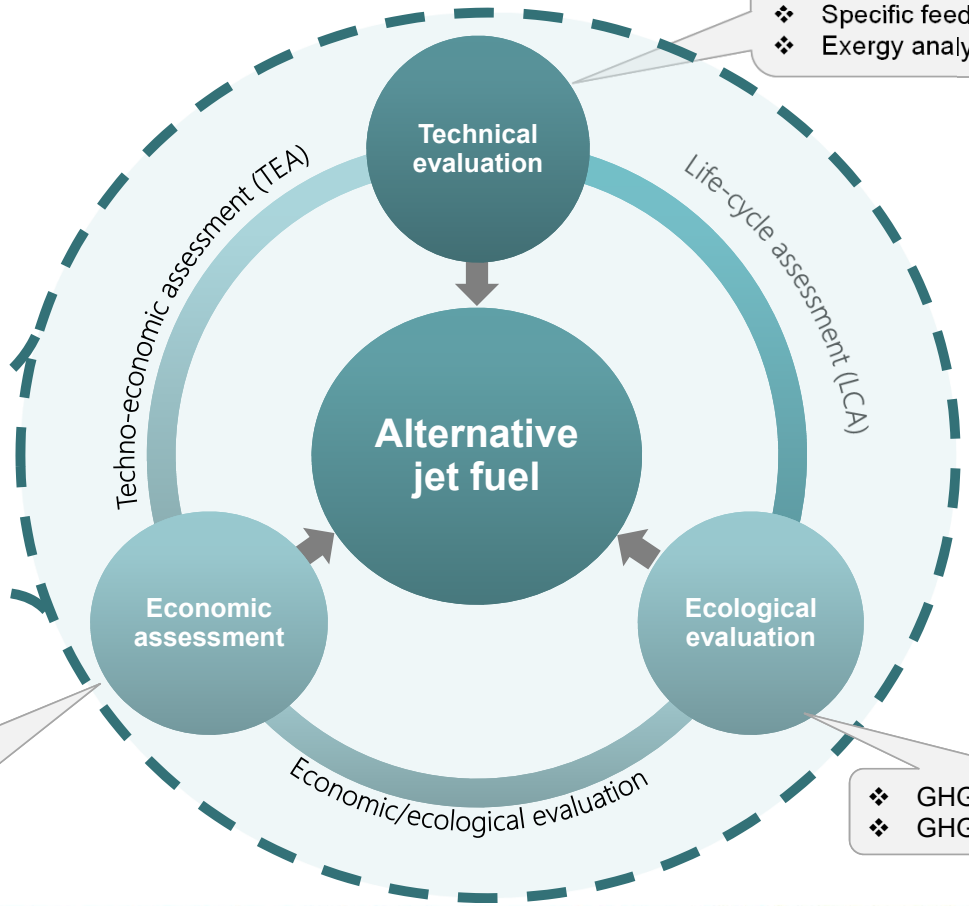
2. Overview: Fischer-Tropsch Kerosene Concepts [1]



[1] F. G. Albrecht, D. H. König, N. Baucks und R. U. Dietrich, „A standardized methodology for the techno-economic evaluation of alternative fuels," Fuel, Bd. 194, pp. 511-526, 2017.

3. Techno-economic and ecological assessment (TEEA)

DLR's Techno economic process evaluation tool

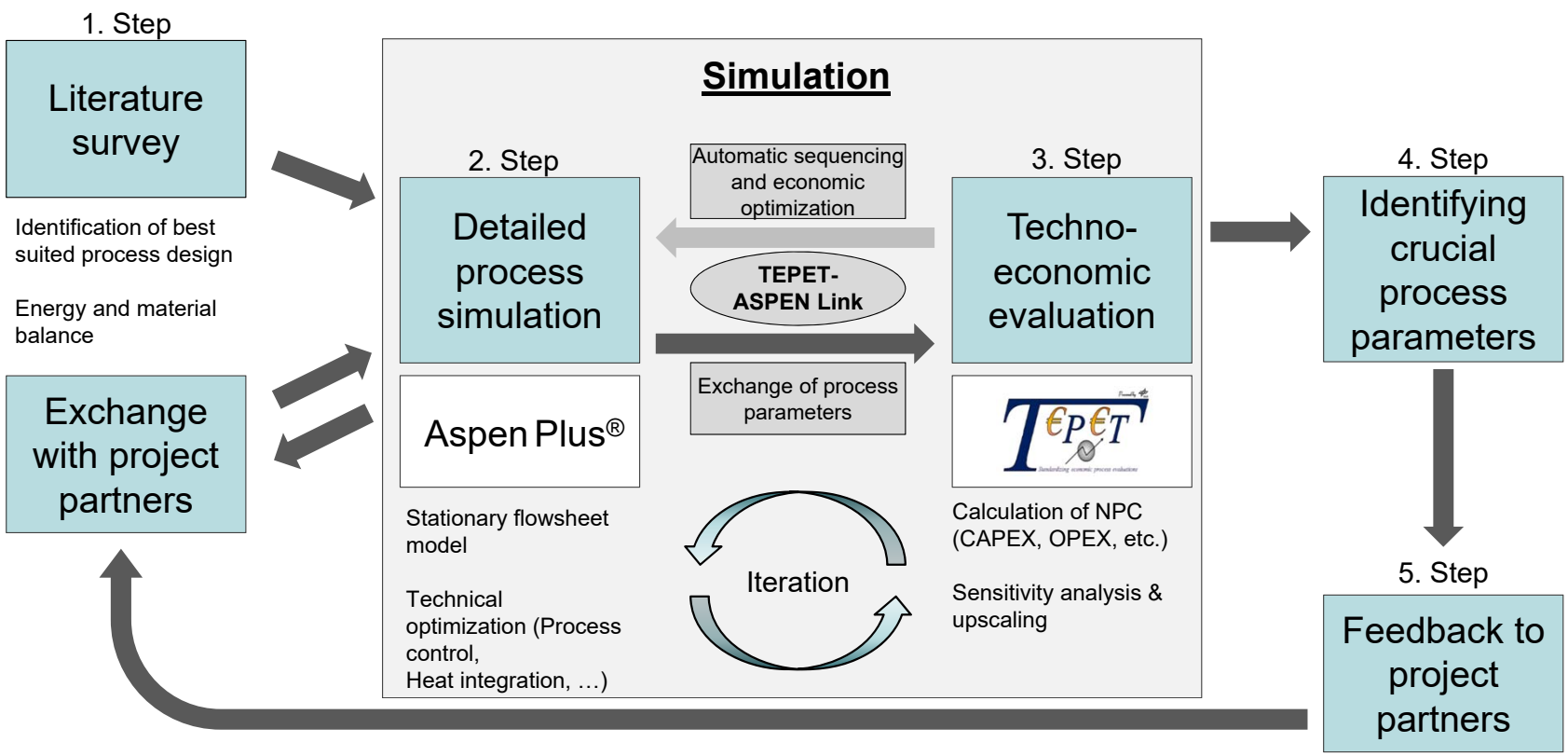


- Efficiencies (X-to-Liquid, Overall)
- Carbon conversion
- Specific feedstock demand
- Exergy analysis

- CAPEX, OPEX, NPC
- Sensitivity analysis
- Identification of most economic feasible process design

- GHG-footprint
- GHG-abatement costs

3. TEEA approach @ DLR



3. TE(E)A of PtL, PBtL & BtL

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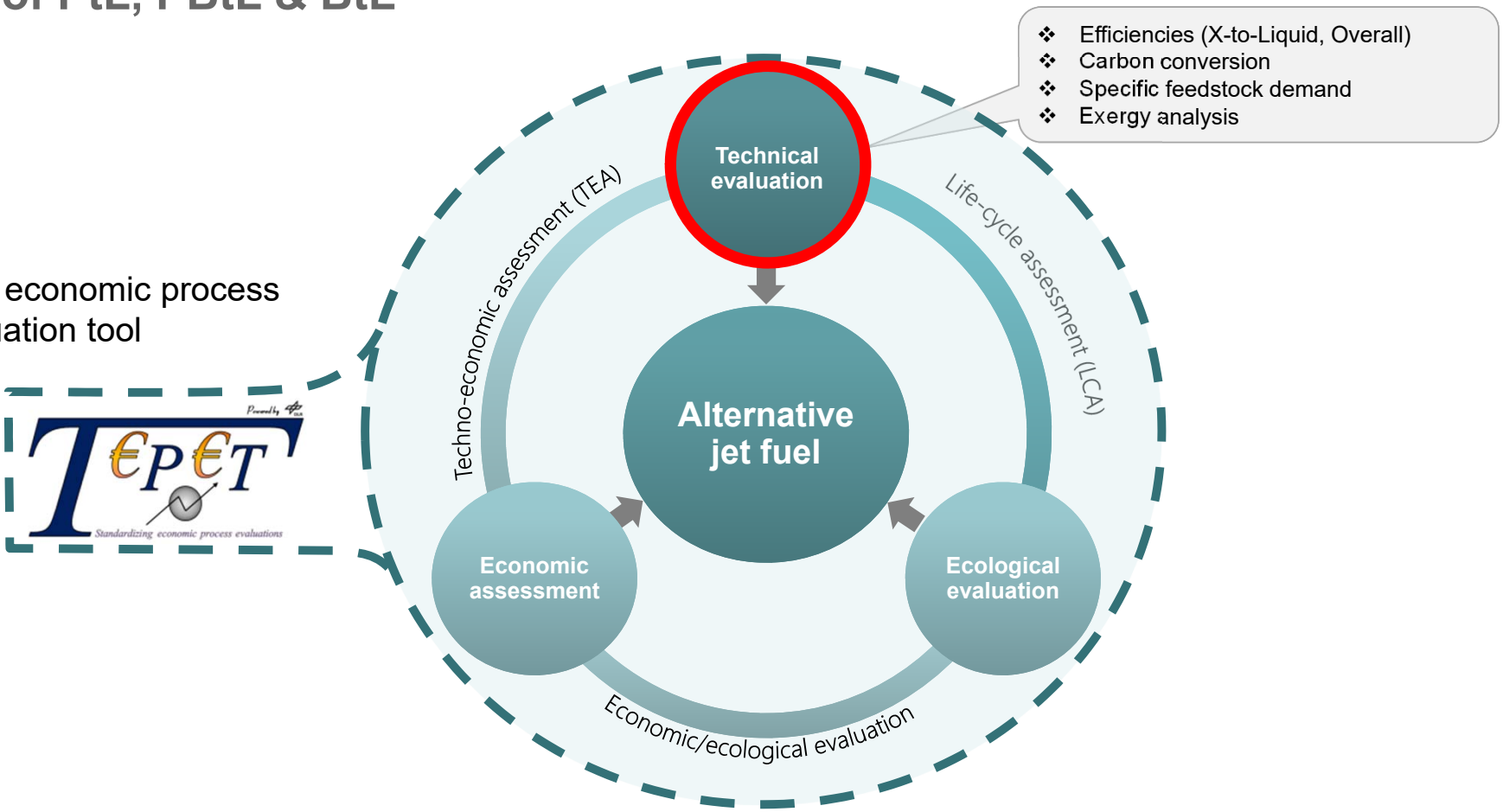

3. Technical evaluation of renewable jet fuel options [1]

Comparison	Biomass-to-Liquid	Power/Biomass-to-Liquid	Power-to-Liquid
X-to-Liquid efficiency, η_{XtL}	36.3 %	51.4 %	50.6 %
Energy efficiency, η_e	82.6 %	65.0 %	66.8 %
Carbon conversion, η_c	24.9 %	97.7 %	98 %

Feedstock Supply for 100 kt/a SynCrude Production (LHV ca. 1,200 TWh_{th}/a)			
Biomass [kt/a | TWh_{th}/a]	748 | 3341	199 | 889	
CO_2 [kt/a]			310
Elec. Power [MW_e| TWh_e/a]	51 | 423	180 | 1489	293 | 2419

[1] Albrecht, “A standardized methodology for the techno-economic evaluation of alternative fuels – a case study”, 2016

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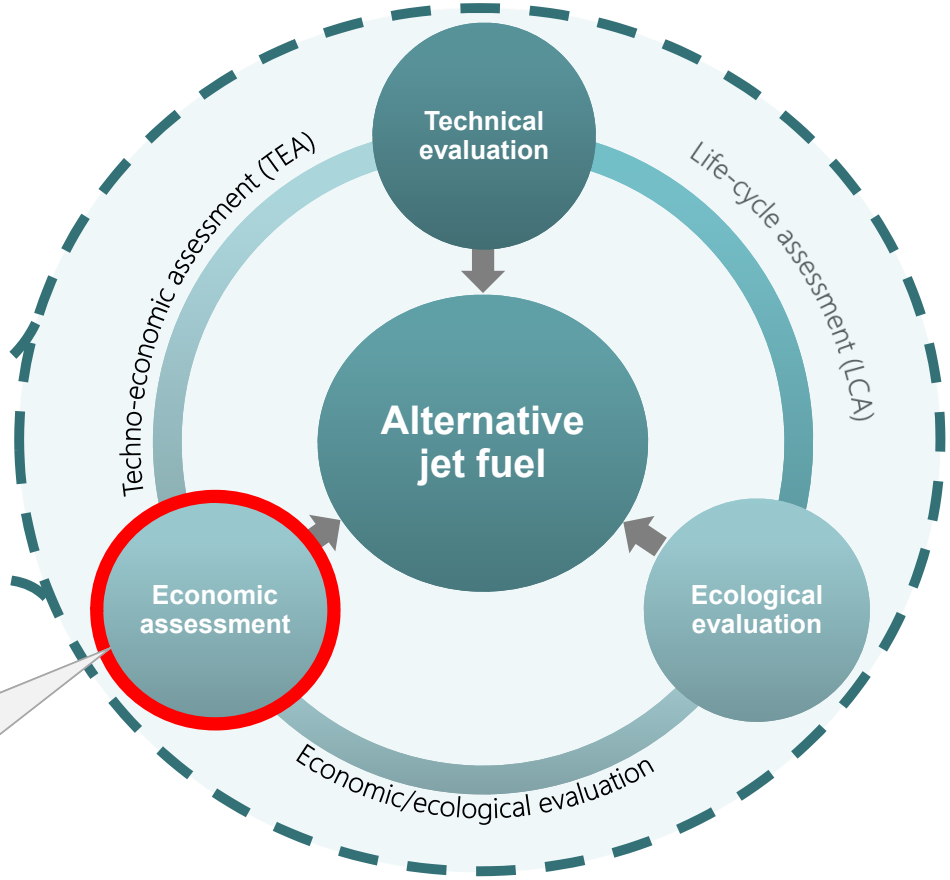
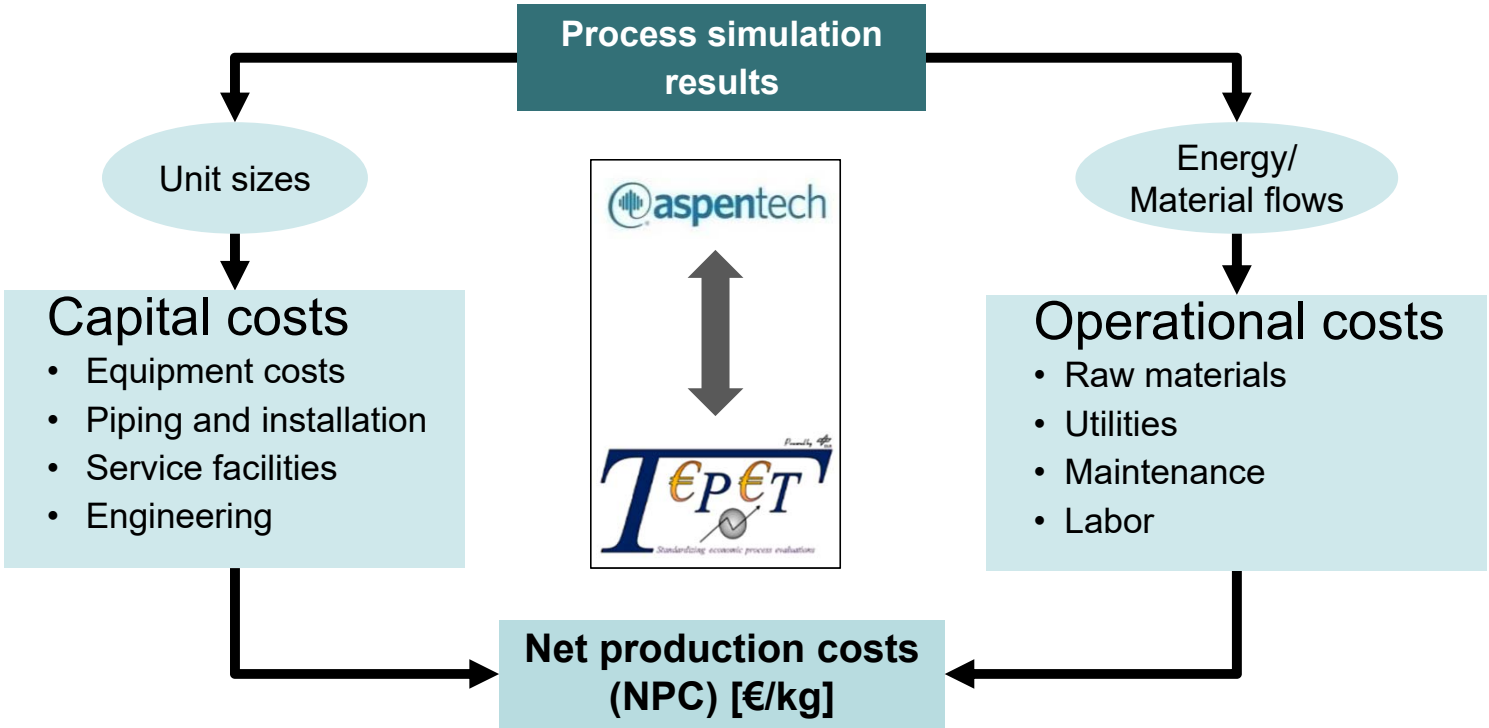


- CAPEX, OPEX, NPC
- Sensitivity analysis
- Identification of most economic feasible process design

3. TEA tool TEPET @ DLR

- Method adapted from best-practice chem. eng. methodology
- Meets AACE class 3-4, Accuracy: **+/- 30 % (basic engineering)**



3. Example: TEA of sustainable jet fuel production

Plant capacity: 550 $kt_{SynCrude}$/a

Investment costs:			
PEM-Electrolyzer (stack):	**850**	€/kW [1]	(scale factor: 1)
PEM-Electrolyzer (system):	**1,370**	€/kW	(TEPET, incl. supplementary factors)
Fischer-Tropsch reactor:	**17.44**	Mio.€/($kmol_{feed}$/s) [2]	(scale factor: 0.67)
Raw materials and utility costs			
Electricity (German grid):	**99.6**	€/MWh [3]	
Biomass:	**80.1**	€/t [4]	⇨(**198** €/t for 550 kt/a plant)
District heating	**27.0**	€/MWh [5,7]	Byproduct
Steam (export):	**19.8**	€/t [6]	Byproduct

General economic assumptions:

Year:	2017	*Plant lifetime:*	30 years
Full load hours:	8,260 h/a	*Interest rate:*	5 %

[1] G. Saur, Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study, Technical Report NREL, 2008
[2] I. Hannula and E. Kurkela, Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass, VTT, Finland, 2013.
[3] Eurostat, Preise Elektrizität für Industrieabnehmer in Deutschland, 2016
[4] C.A.R.M.E.N. – Preisentwicklung bei Waldhackschnitzel (Energieholz-Index), 2017
[5] Energieeffizienzverband für Wärme, Kälte und KWK e.V., Heizkostenvergleich nach VDI 2067-Musterrechnung, 2014
[6] Own calculations based on natural gas price from Eurostat database 2017
[7] http://www.rogersrawmaterials.com/home.asp (accessed 02/2018)

3. Example: TEA of sustainable fuel production – Base year: 2017

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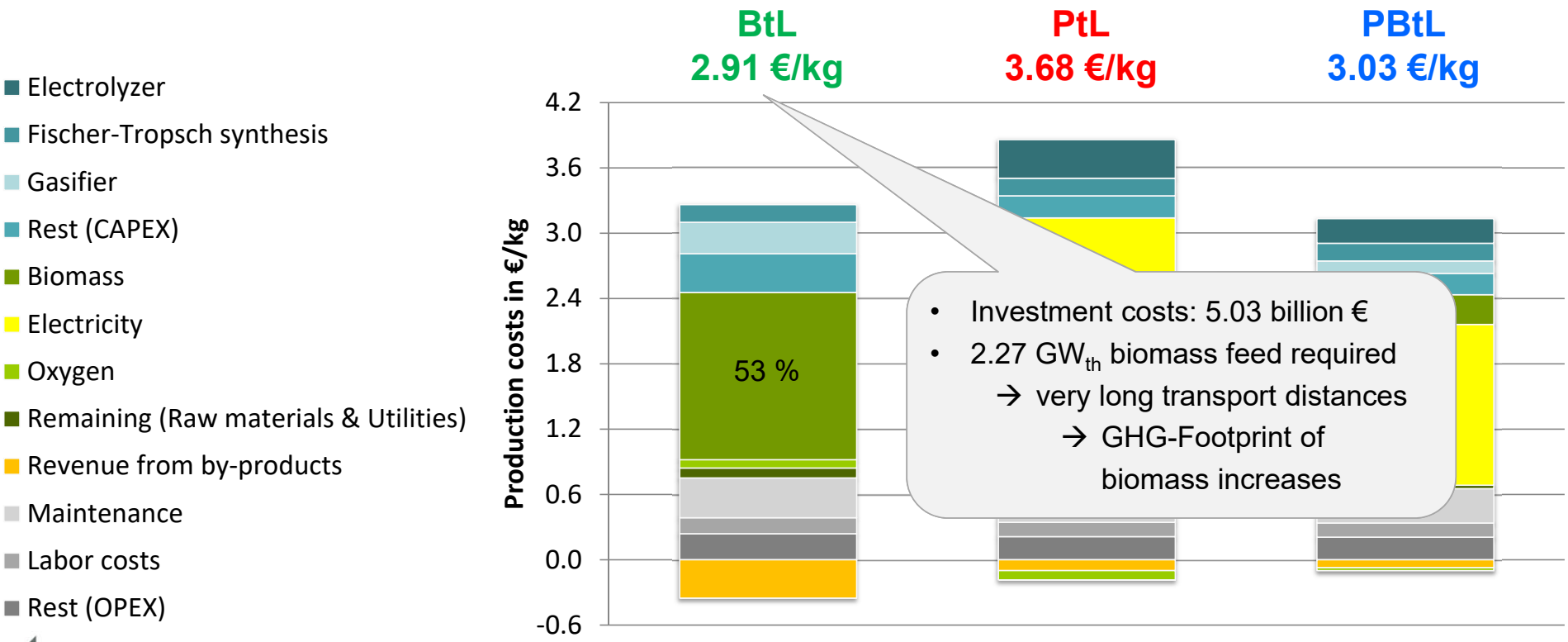

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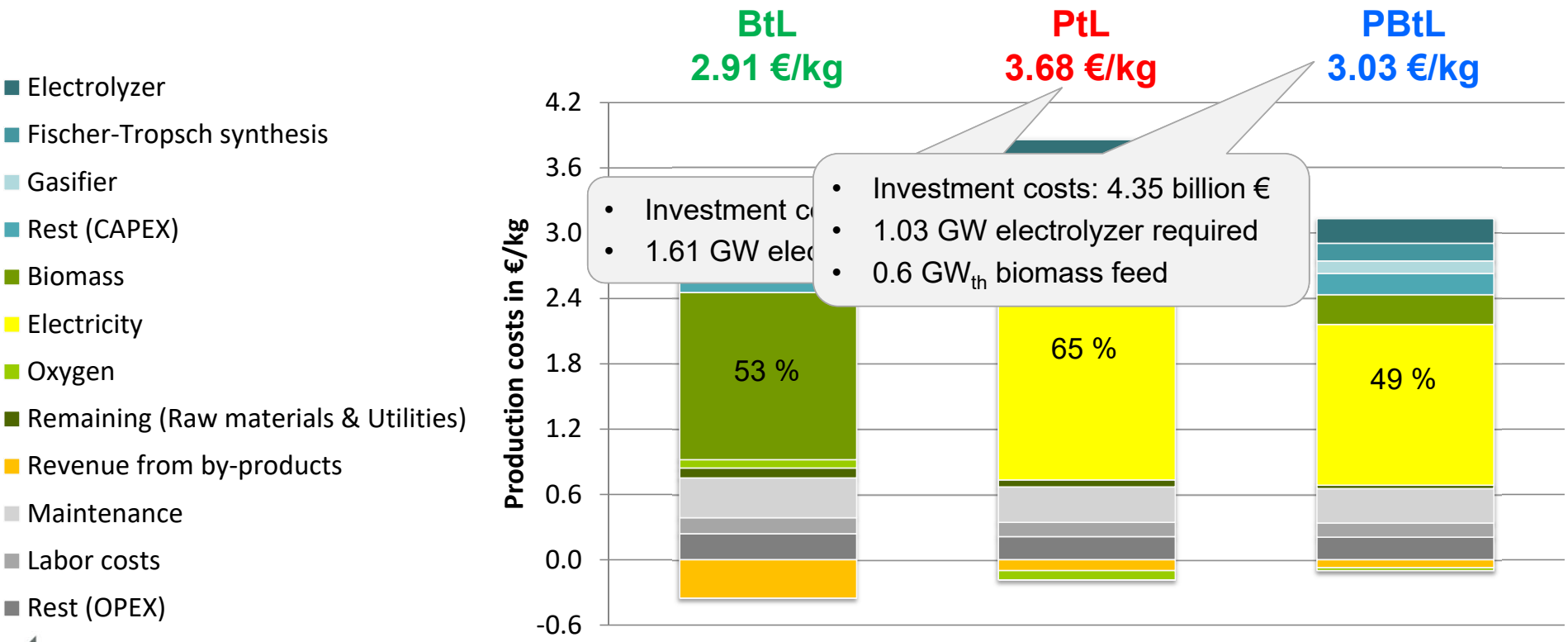
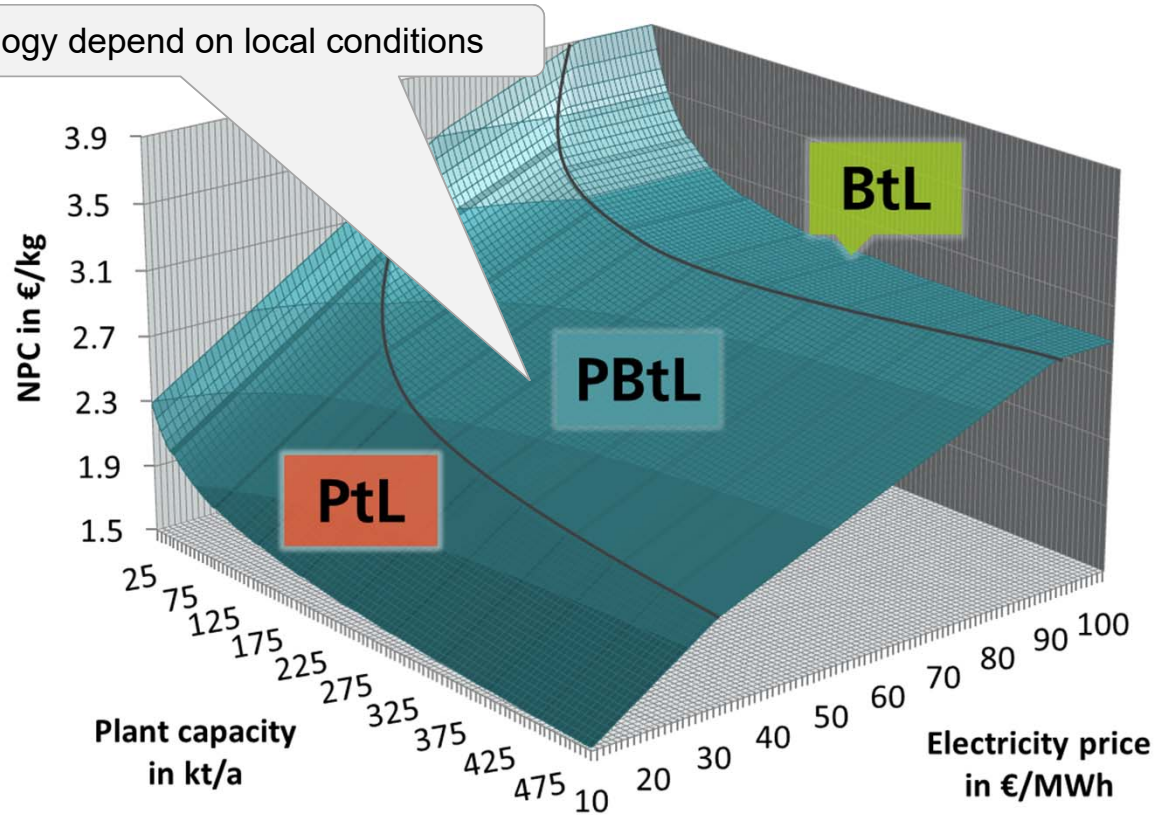


3. Example: Cost sensitivity of sustainable jet fuel production – Base year: 2017

Plant construction / operation in Germany

Preferred technology depend on local conditions



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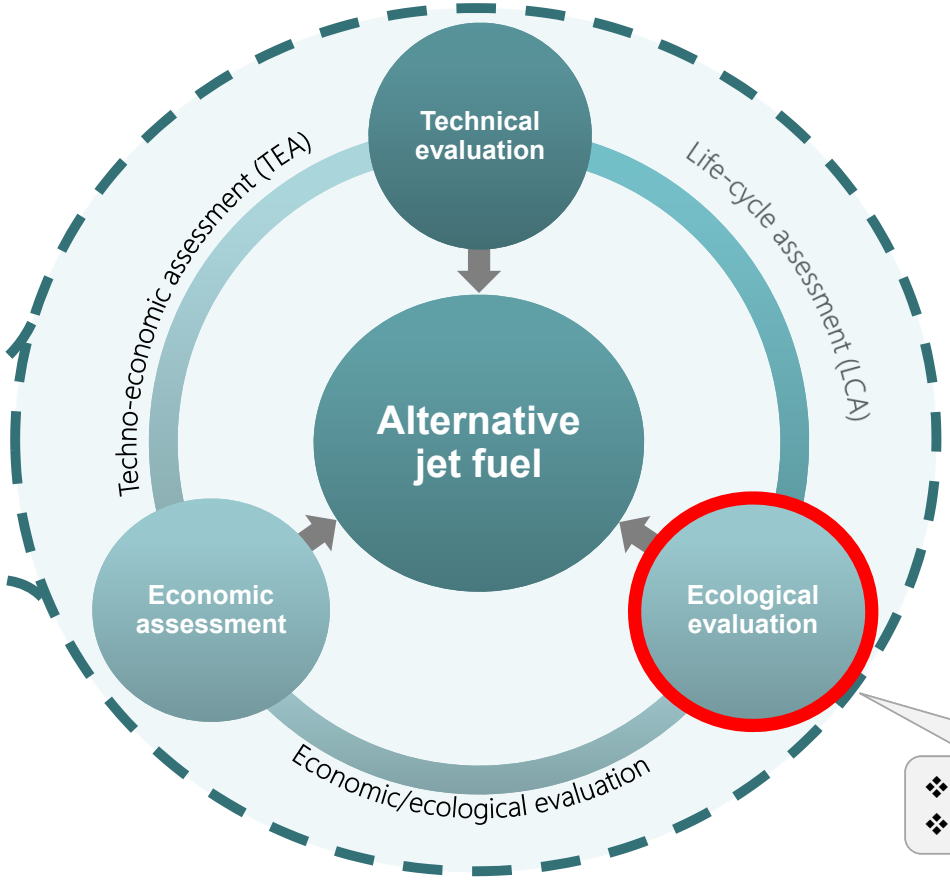
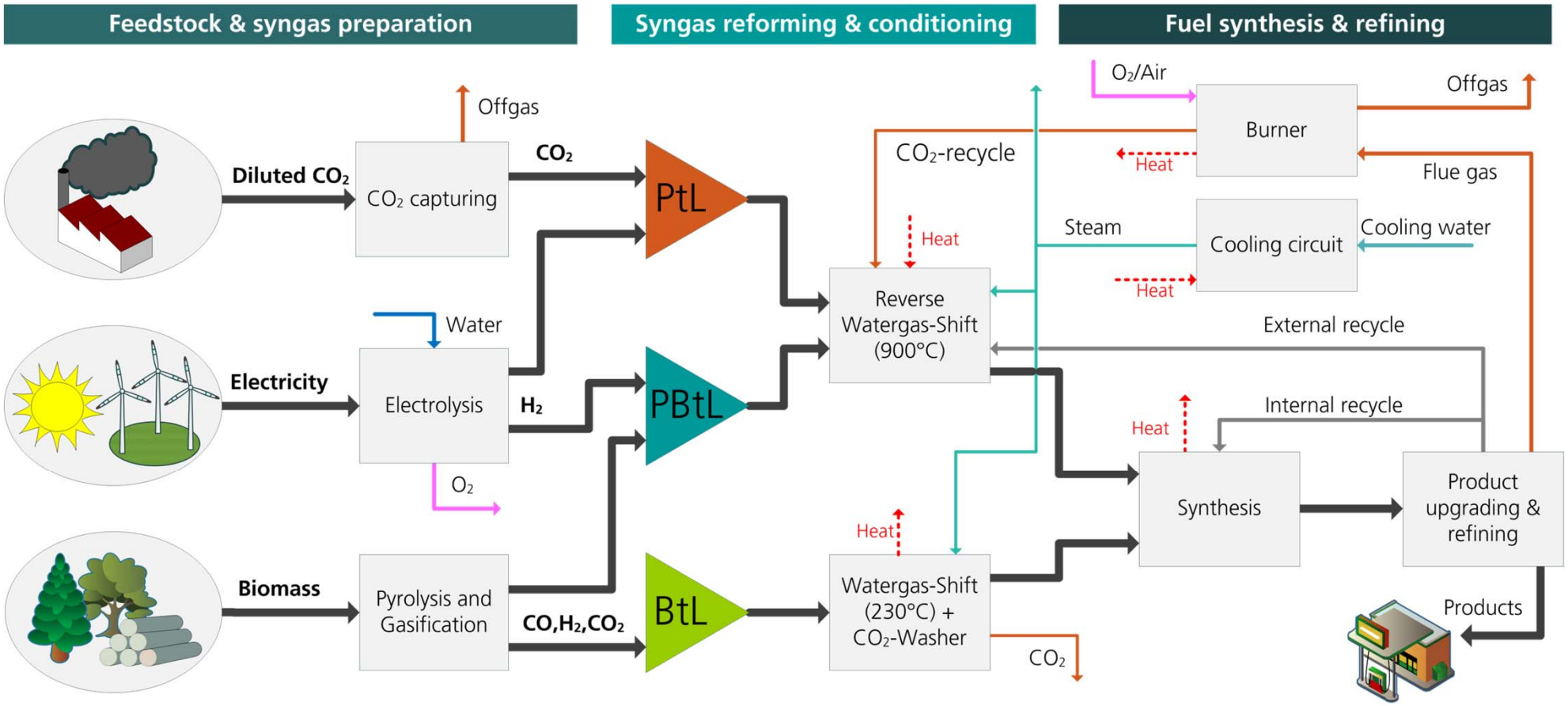


- GHG-footprint
- GHG-abatement costs

4. Technical Challenges for renewable jetfuel mass production



4. Technical Challenges and research for renewable jetfuel mass production

- Pyrolysis and Gasification
- Electrolysis ⇨ scale up and cost
- New Fischer-Tropsch for decentralized approach?
- Validation of entire process change, technology maturity
- Flexible response to supply and demand
- Accompanying research

ABCSalt
This project has received funding from the European Union's H2020 Research and Innovation Programme Under Grant Agreement Number 764089

Deutsches Zentrum für Luft- und Raumfahrt

INERATEC

COMSYN
COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727476

FLEXCHX
FlexCHX project has received funding from the European Union's Horizon 2020 research and innovation Programme under Grant Agreement No 763919.

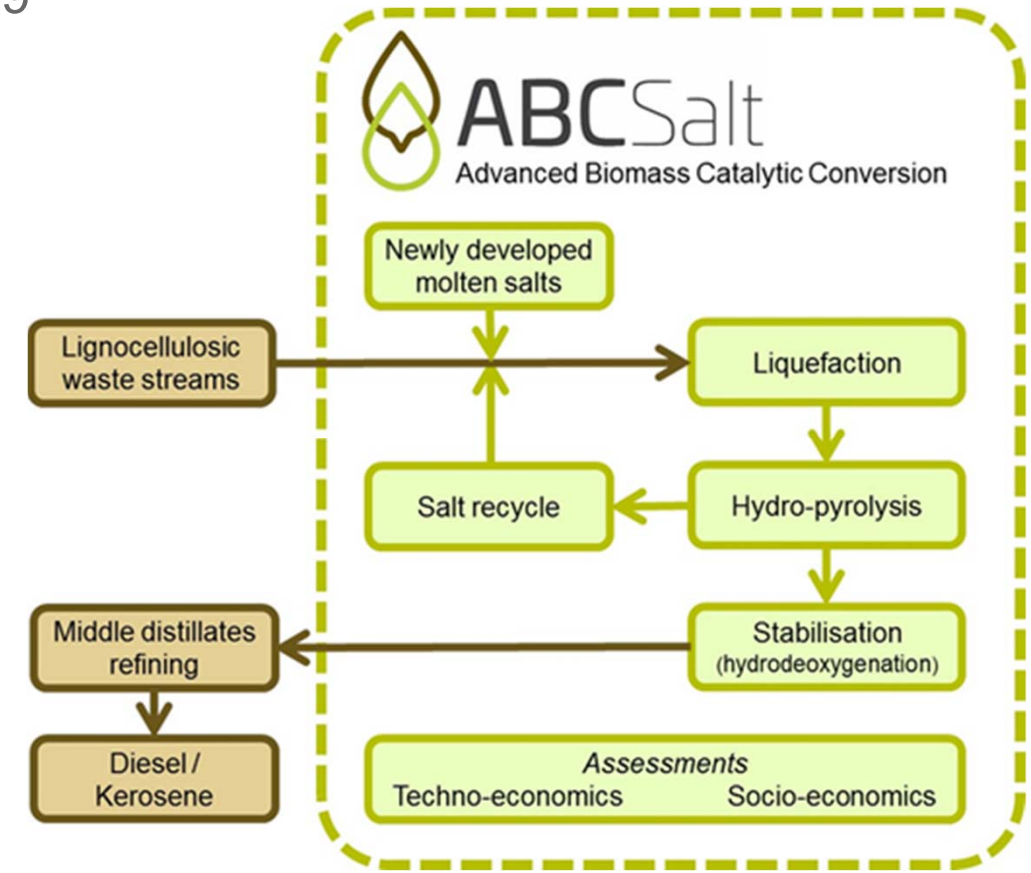
BEniVer
Begleitforschung Energiewende im Verkehr

ABC-Salt project has received funding from the European Union's Horizon 2020 research and innovation Programme under Grant Agreement No 764089.

4. EU project: ABC-Salt – EU No. 764089

Molten salts

- Liquefaction of biomass in a molten salt environment with subsequent middle distillate production by the process steps:
  - Biomass liquefaction
  - Hydro-pyrolysis
  - Hydro-deoxygenation
- Process development from TRL 2 up to 4
- Prototype manufacture with a biomass feed of 100 g/h and a hydrocarbon yield of 35 wt.%
- Target: Diesel net production costs < 0.80 €/l
- www.abc-salt.eu



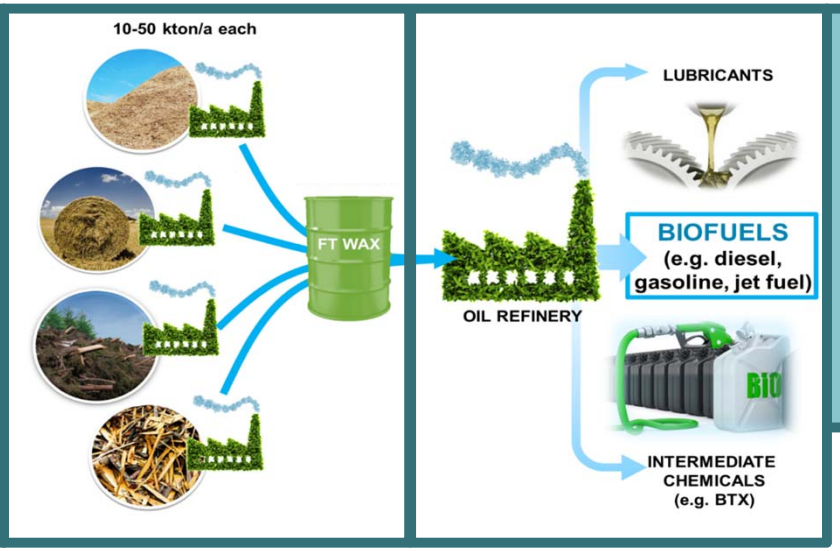
COMSYN

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727476

4. EU project: COMSYN – EU No. 727476
Decentralized Approach www.comsynproject.eu

- New decentralized BTL production concept

PRIMARY CONVERSION
Decentralized FT wax production at **small-to-medium scale** units at biomass sites (50-150 MW_{th} input) + locally utilized excess heat for η_{total} > 80 %



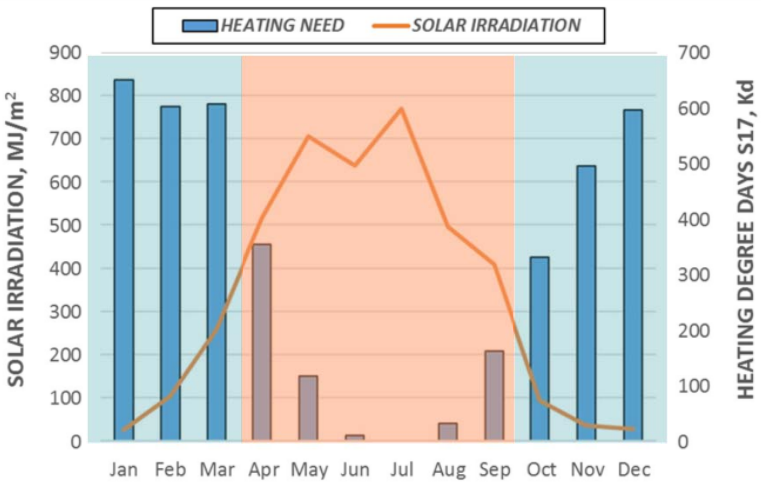
PRODUCT UPGRADING
Centralized FT product refining to high quality drop-in liquid fuels at existing oil refineries

[1] Special thanks to the contribution of: P. Simell, J. Kihlman, S. Tuomi, E. Kurkela, C. Frilund, V. Kivelä (VTT), T. Böltken, M. Selinsek (INERATEC), H. Balzer (GKN), J. Hajek (UniCRE), V. Tota (Wood), V. Hankalin (ÅF Consult)

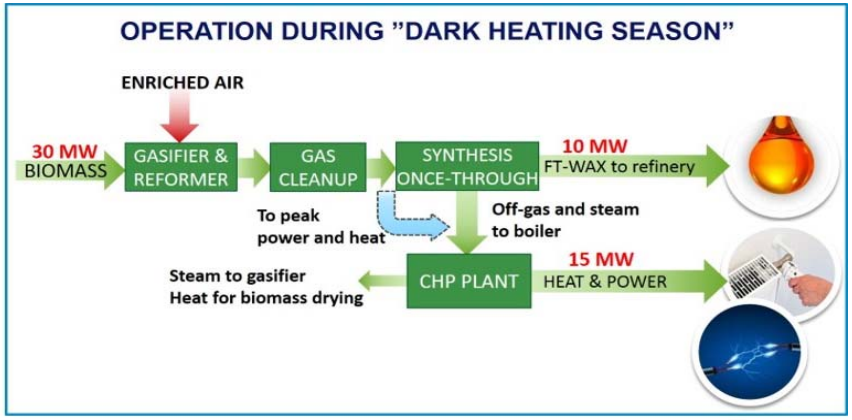
FlexCHX project has received funding from the European Union's Horizon 2020 research and innovation Programme under Grant Agreement No 763919.

4. EU project: FlexCHX – EU No. 727476

Flexible response to supply and demand



High heat demand & Low renewable electricity availability



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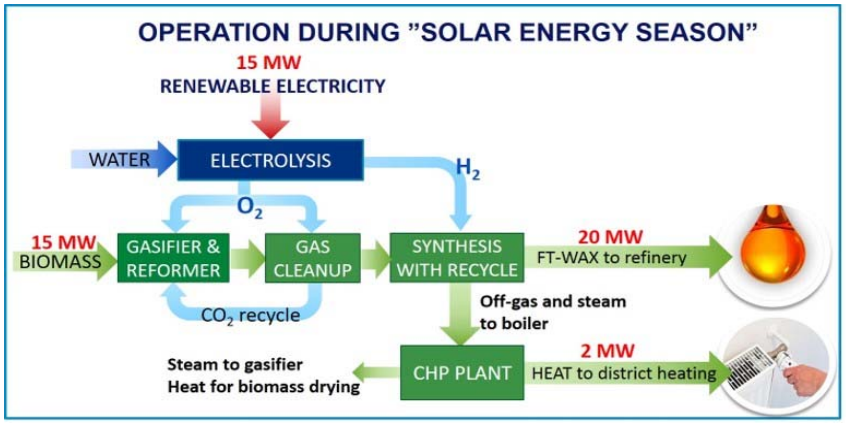

BEniVer
Begleitforschung Energiewende im Verkehr

4. BEniVer

Accompanying research for energy transition in the transport sector

- Focus on renewable fuels for internal combustion engines
- ≈ 15 Projects with different concepts, fuel production routes, fields of use…
- Holistic evaluation of every concept (energy system, TEEA, integration into existing markets, acceptance…)
  - ➢Comparable TEA of different fuel production roots
  - ➢**Further kerosene production routes are considered (e.g. Methanol to Jet)**

Further information

- www.energieforschung.de
- Moritz.raab@dlr.de

5. Outlook

- Renewable aviation fuels development requires strong research commitment and immediate scale up efforts
- European GHG abatement will change global fossil energy market ➔ leading countries, other stakeholders?
- Upcoming CO_2 regulation will need techno economic guidance ➔ GHG abatement costs
- Technology demonstration not sufficient for future renewable aviation
  ➔ market introduction requires political measures
- DLR supports every promising technology towards renewable aviation ➔ HORIZON 2020 calls available

Thank you for your attention!

Moritz Raab
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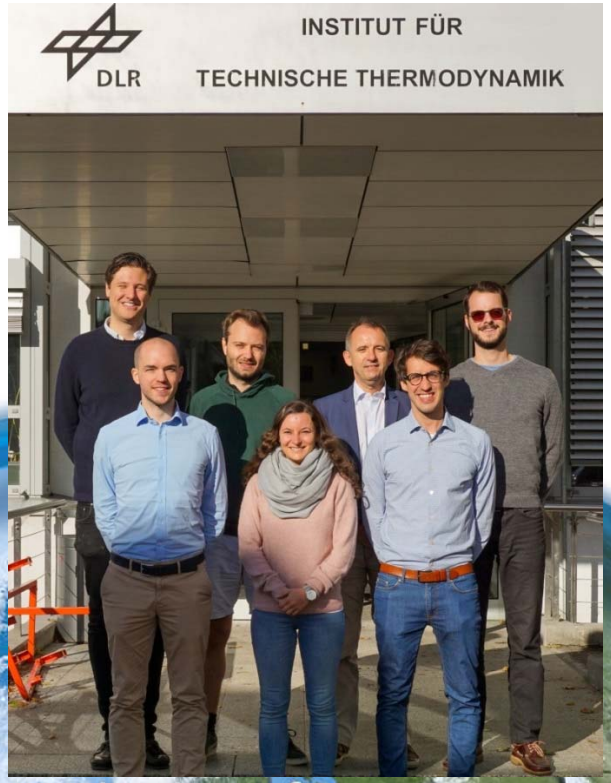
German Aerospace Center /
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Institute of Engineering Thermodynamics



Knowledge for Tomorrow

COMSYN

COMSYN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727476

Decentralized Approach: EU project COMSYN

Project tasks and responsibilities

DFB Gasifier

- Finalized: 2015
- Biomass feed: c
- Gasifier tempera
- Oxidizer temper
- Bed material: D

DFB GASIFIE

UNIT

ding

sing of FT-waxes or
treatment
ydroisomerisation unit)

UniCRE

Product Upgrading

Open Questions / Development Tasks

Within COMSYN:

- Technical Validation
- Fuel Flexibility
- Techno-economic assessments
- Ecological impact
- Business cases for different European regions

Beyond COMSYN:

- No. of European sites for decentralized fuels production
- Logistic to interconnect multiple decentralized sites
- Mass manufacturing of decentralized fuel plants

Validation of decentralized sustainable fuel production for large scale defossilization of aviation!

DLR

EU project FlexCHX

Project tasks and responsibilities

Fischer-Tropsch reactor

- Experimental evaluation of the flexible lab-scale FT synthesis for different operation points
- Demonstration plant combining mobile synthesis unit (MOBSU) with the SXB gasifier
- Comparison of different off-gas recycles

INERATEC

Process highlights:

- Large range of possible feedstock
- Tar removal in the gasifier
- No gas cooling for the filter required
- Flexible electrolyzer with oxygen storage
- Autothermal reforming
- Cost-efficient gas clean-up
- FT By-pass for high heat demand

o-economic & ecologic analysis