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Alternative fuels from Biomass and Power (PBtL) – A case study on process options, technical potentials, fuel costs and ecological performance

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German Aerospace Center (DLR)
5th World Bioenergy Congress
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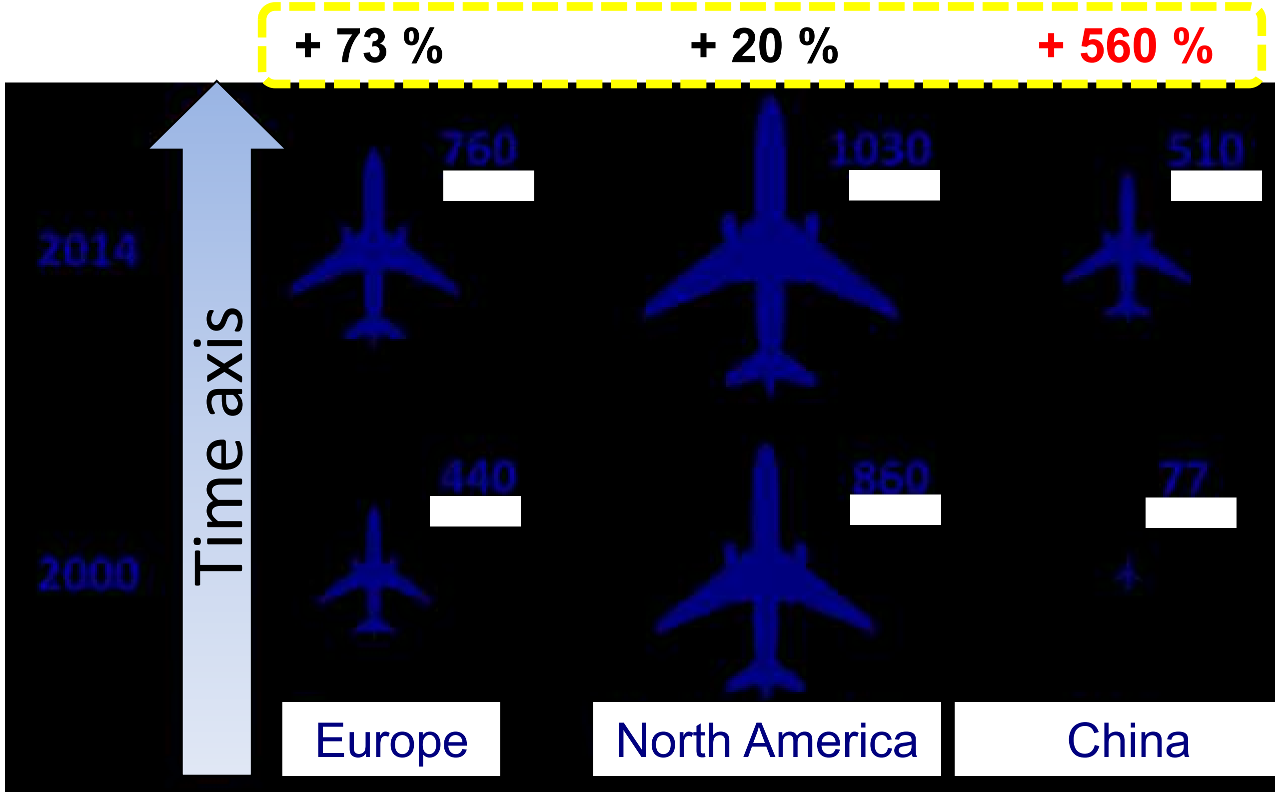
Growth sector aviation

Aviation mileage within three world regions



(in billion passenger kilometers /a)

Source: Thess et al., DGLR-Mitgliedermagazin „Luft- und Raumfahrt“ edition 2/2016, p.20 et seq.

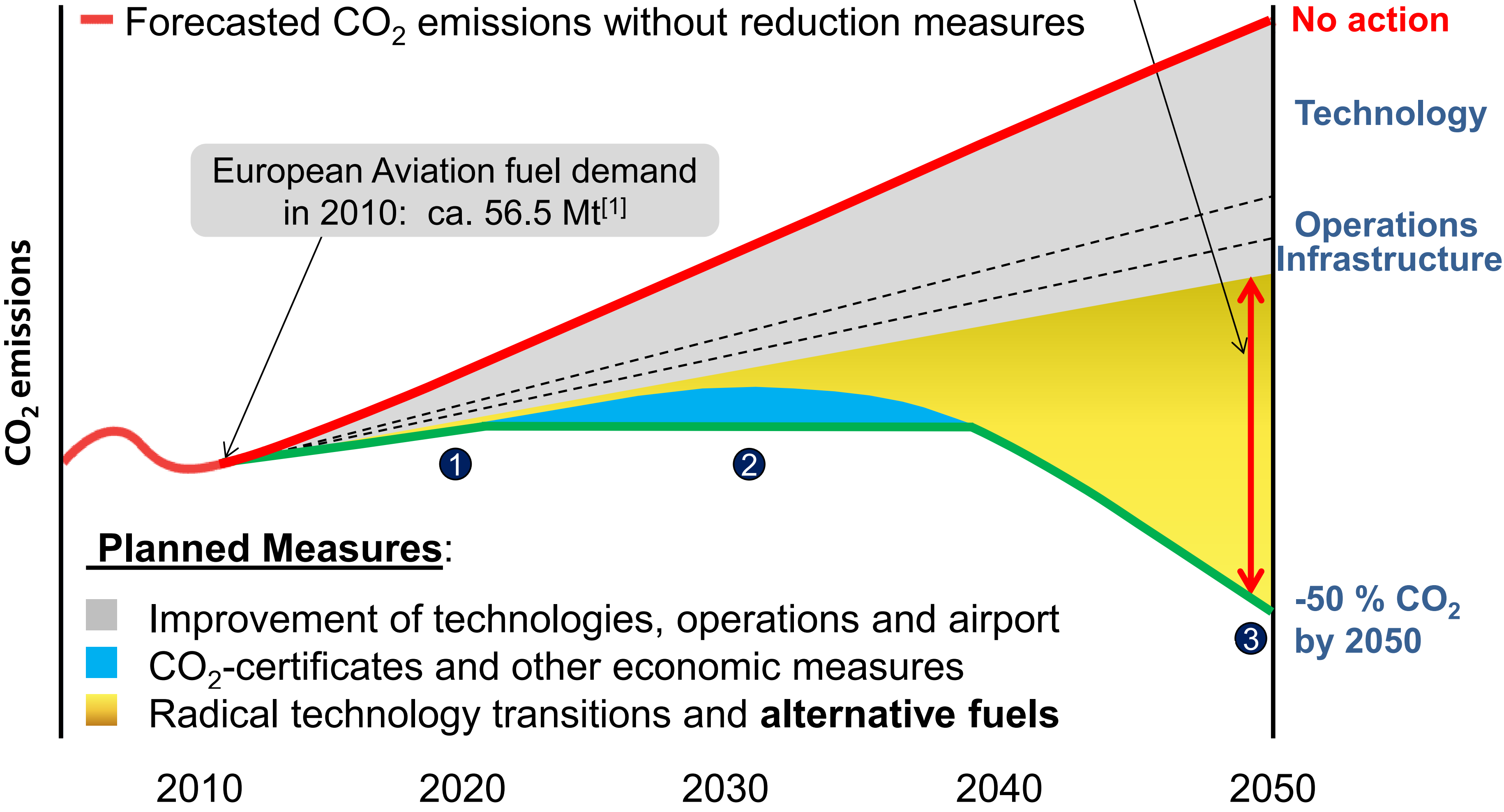
IATA Technology Roadmap

4. Edition, June 2013

(optimistic) assumption until 2050: biofuels are 100% CO_2-„neutral“
demand of ≈ 56 - 60 Mt kerosene equivalent

Main goals:

1. Improvement of fuel efficiency about 1,5 %p.a. until 2020
2. Carbon-neutral growth from 2020
3. Potential CO_2 emissions reductions by 2050



Certified sustainable 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
Triglicerides from Biomass (e.g. algae, jatropha, soya, palm, animals fats and used cooking oil)	Hydroprocessed esters and fatty acids (HEFA)	Synthetic paraffinic kerosene
Sugar from Biomass (sugar crops, cereals starch)	Direct Sugars to Hydrocarbons (DSHC)	Synthetic iso-paraffins / Farnesane
Bioethanol (-propanol, -butanol)	dehydration+oligomerization+hydration (Alcohol-to-Jet, AtJ)	AD-SPK

- AtJ in Europe (EU28)? – For example wheat
  - Wheat area$_{2014}$[2]: **26.7 Mio.ha** ➔ Ethanol yield: **2.2 t/ha**[3] (range -30 % European yield average[])
    Conversion to fuel[4]: **0.56 $t_{kerosene}/t_{ethanol}$**
    Kerosene wheat based: **23.0** to **32.9 Mt/a** (≈ 40.1 – 58.2 % of the aviation demand)

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] Eurostat „Crop statistics“ 2014
[3] Specialist agency renewable raw materials e. V., „Introduction of fuel ethanol”, 2016
[4] NREL, „Review of Biojet Fuel Conversion Technologies”, Golden, 2016

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- DSHC in Europe (EU28)? – For example sugar beets

  - Sugar beet area$_{2014}$[2]: **1.6 Mio.ha** ➔ sugar beet yield: **131 Mt**[2] ➔ sugar content$_{average}$ ≈ **18 %**[3]
    Conversion to fuel[4]: **0.168 $t_{kerosene}/t_{sugar}$**
    Kerosene sugar based: **3.96 Mt/a** (≈ 7.0 % of the Aviation demand)

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] Eurostat „Crop statistics“ 2014
[3] Specialist agency renewable raw materials e. V., „Introduction of fuel ethanol”, 2016
[4] NREL, „Review of Biojet Fuel Conversion Technologies”, Golden, 2016

Fuels for a sustanable aviation sector

Synthetic jet fuels (ASTM D7566 – 14c)[1]

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- HEFA in Europe (EU28)? – For example rape oil
  - Rapeseed area$_{2014}$[2]: **12.9 Mio.ha** ➔ rape yield: **24.1 Mio.t** ➔ oil content$_{average}$ ≈ **42 %**[3]
    Conversion to fuel[4]: **0.49 $t_{kerosene}/t_{rape\ oil}$**
    Kerosene sugar based: **7.3 Mio.t/a** (≈ 12.9 % of the Aviation demand)

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] Eurostat „Crop statistics“ 2014
[3] UFOP “Rapeseed the Power Plant“ 2017
[4] DBFZ, „Abschlussbericht Projekt BurnFAIR”, 2014

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Fuels for a sustanable aviation sector

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Fischer-Tropsch synthesis

- Large scale, commercial technology
- Based on synthesis gas, which can be produced from almost any carbon and hydrogen source
- Fully synthetic kerosene achievable[2]

[1] ASTM International, „ASTM D7566 - 14C: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons“, 2015
[2] UK Ministry of Defense, „DEF STAN 91-91: Turbine Fuel, Kerosene Type, Jet A-1,“ UK Defense Standardization, 2011

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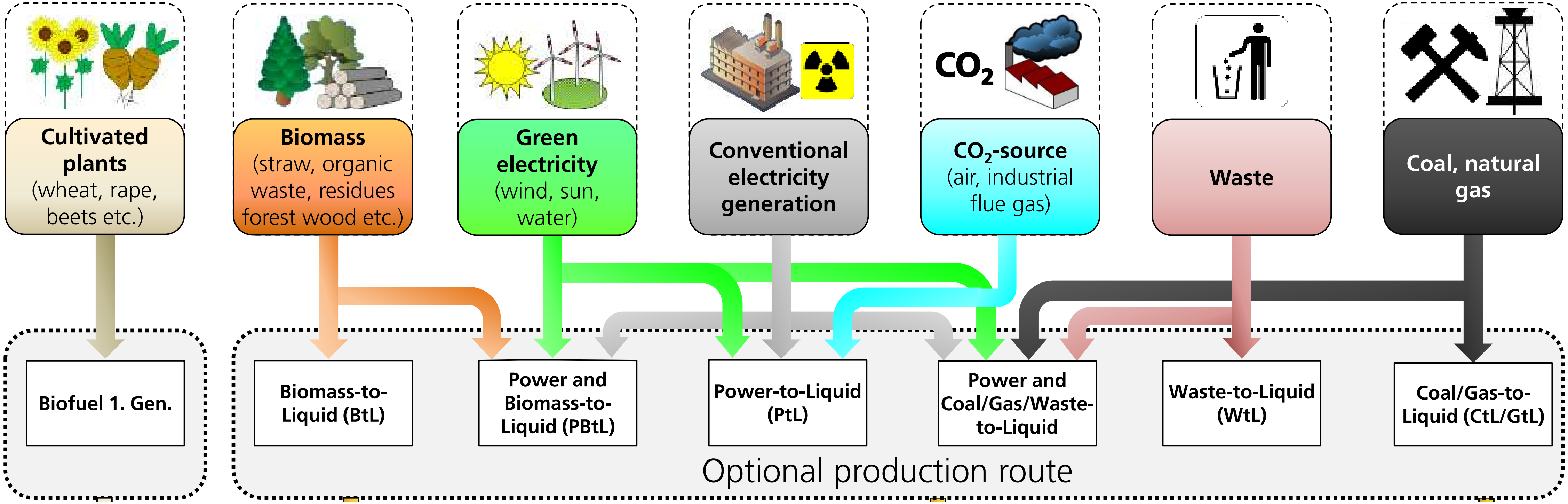
Production routes of alternative Kerosene



The supply of large quantities of alternative kerosene within low GHG emissions is possible by coupling the sectors electricity generation and fuel markets *(without biomass imports)*.

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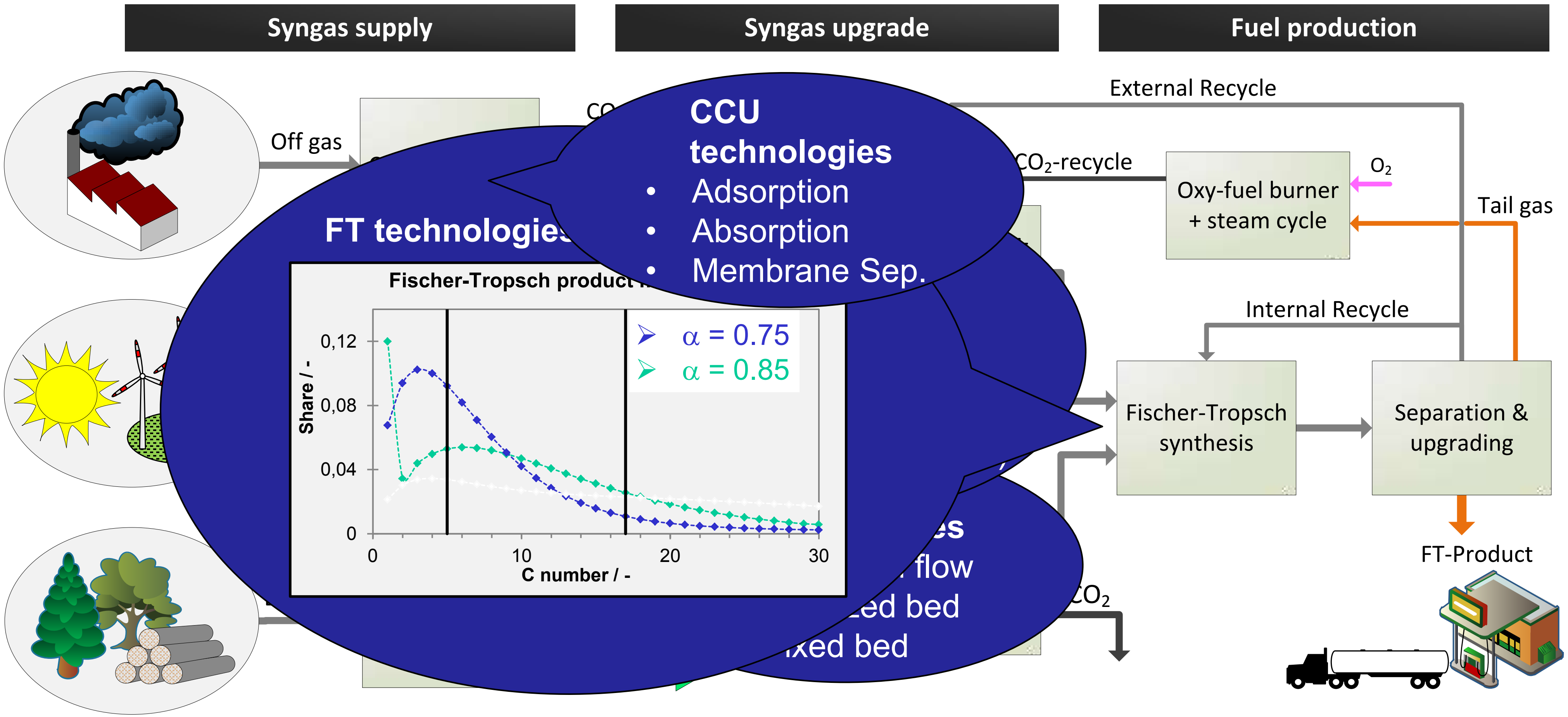
Multiple Options for Power-to-Liquid combined with biomass processing



See: F. G. Albrecht, D. H. König, N. Baucks und R. U. Dietrich, „A standardized methodology for the techno-

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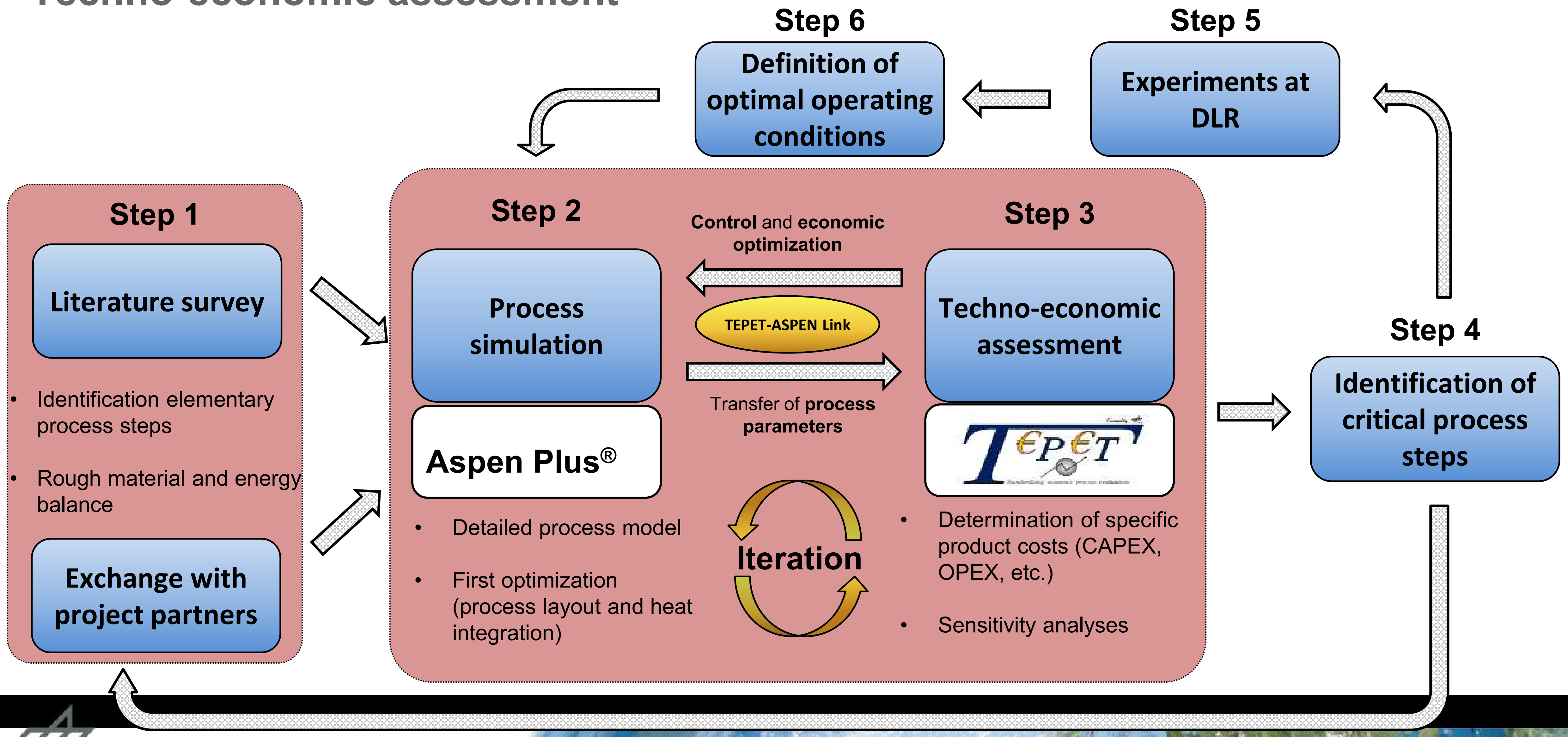
Techno-economic assessment



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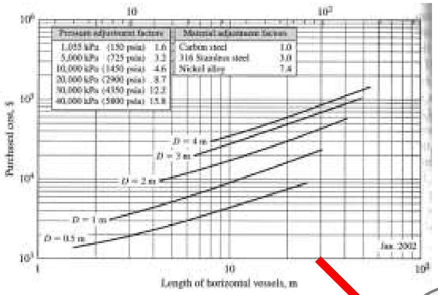
Process simulation + Techno-economic assessment

Meets AACE class 3-4
Accuracy: **+/- 30 %**



Process simulation results

Plant and unit sizes

material and energy balance

Aspen Plus®

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TEPET

Capital costs

- Equipment costs
- Piping & installation
- Factory buildings
- Engineering services …

Operational costs

- Raw materials
- Operating materials
- Maintenance
- Wages …

Production costs
€/l , €/kg , €/MJ

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Fuel production cost evaluation

Plant size: **100 MW_{th}**

Investitionskosten:

PEM-Elektrolyszer:	**640** €/kW [1]	(installed capacity)
Entrained flow gasification:	**103.650** €/(kg_{Slurry}/h) [2]	(scale-factor 0.7)

Raw material prices:

Power:	**105** €/MWh [3]	(industrial consumer)
Biomass (35% moisture):	**97.4** €/t [4]	

General economic assumptions:

Reference year:	2014	*System operation:*	30 a
Operating hours:	8,260 h/year	*Capital interest:*	7 %

[1] G. Saur, Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study, Technical Report NREL, 2008
[2] P. Kerdoncuff, Modellierung und Bewertung von Prozessketten zur Herstellung von Biokraftstoffen der zweiten Generation, Dissertation, KIT, Karlsruhe, 2008
[redacted]

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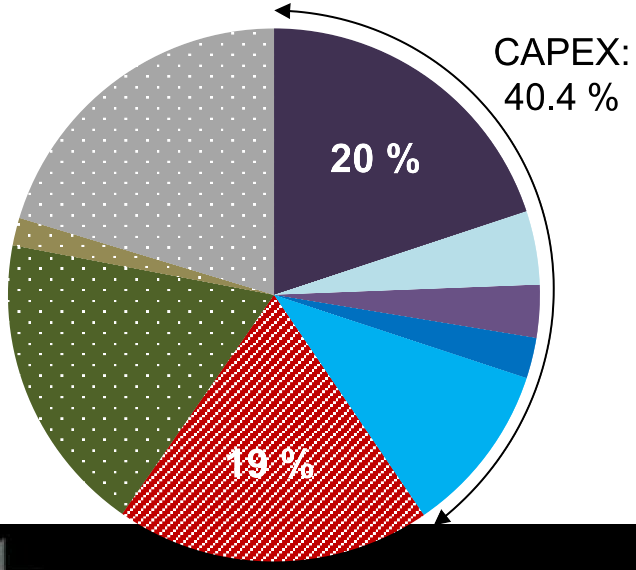
Comparison of Costs BTL / PBTL / PTL

Plant size: 100 MW_{th}

- Electrolyzer
- Entrained flow gasification
- Pyrolyse
- Fischer-Tropsch
- Selexol
- Remaining (CAPEX)
- Power[3]
- Biomass[4]
- Remaining (Utilities)
- Maintenance
- Labor costs
- Remaining (OPEX)

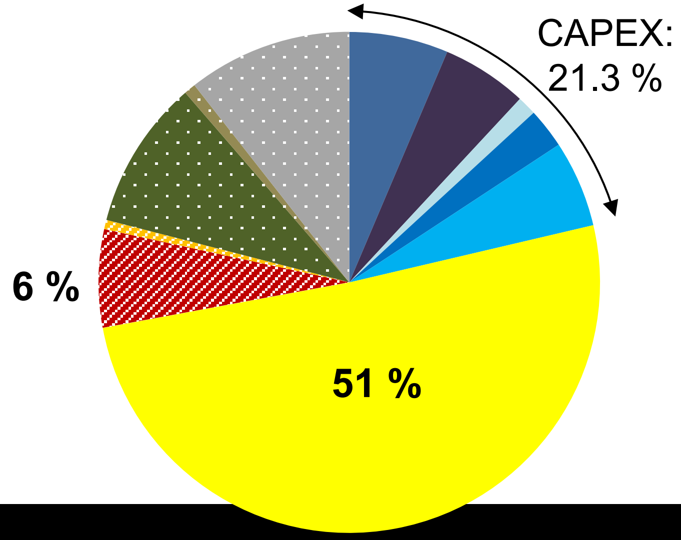
Biomass-to-Liquid (BTL)

Investment: ca. 395.2 mio. €
Fuel production: 24.17 Mt
Fuel costs: ca. **2.34 €/l**



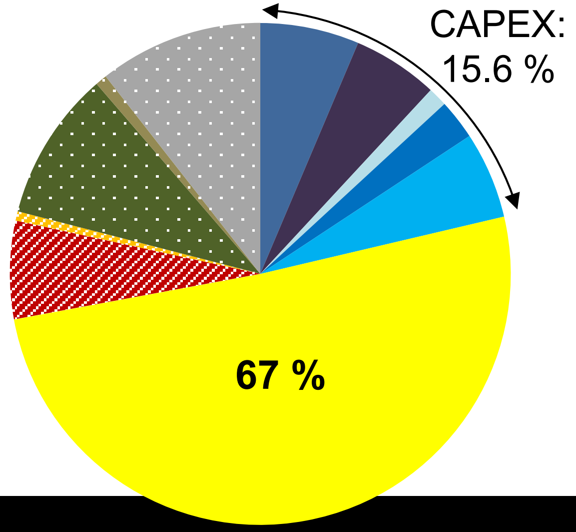
Power&Biomass-to-Liquid (PBTL)

Investment: ca. 751 mio. €
Fuel production: 91.27 Mt
Fuel costs : ca. **2.24 €/l**



Power-to-Liquid (PTL)

Investment: ca. 672.5 mio. €
Fuel production: 91.27 Mt
Fuel costs : ca. **2.74 €/l**



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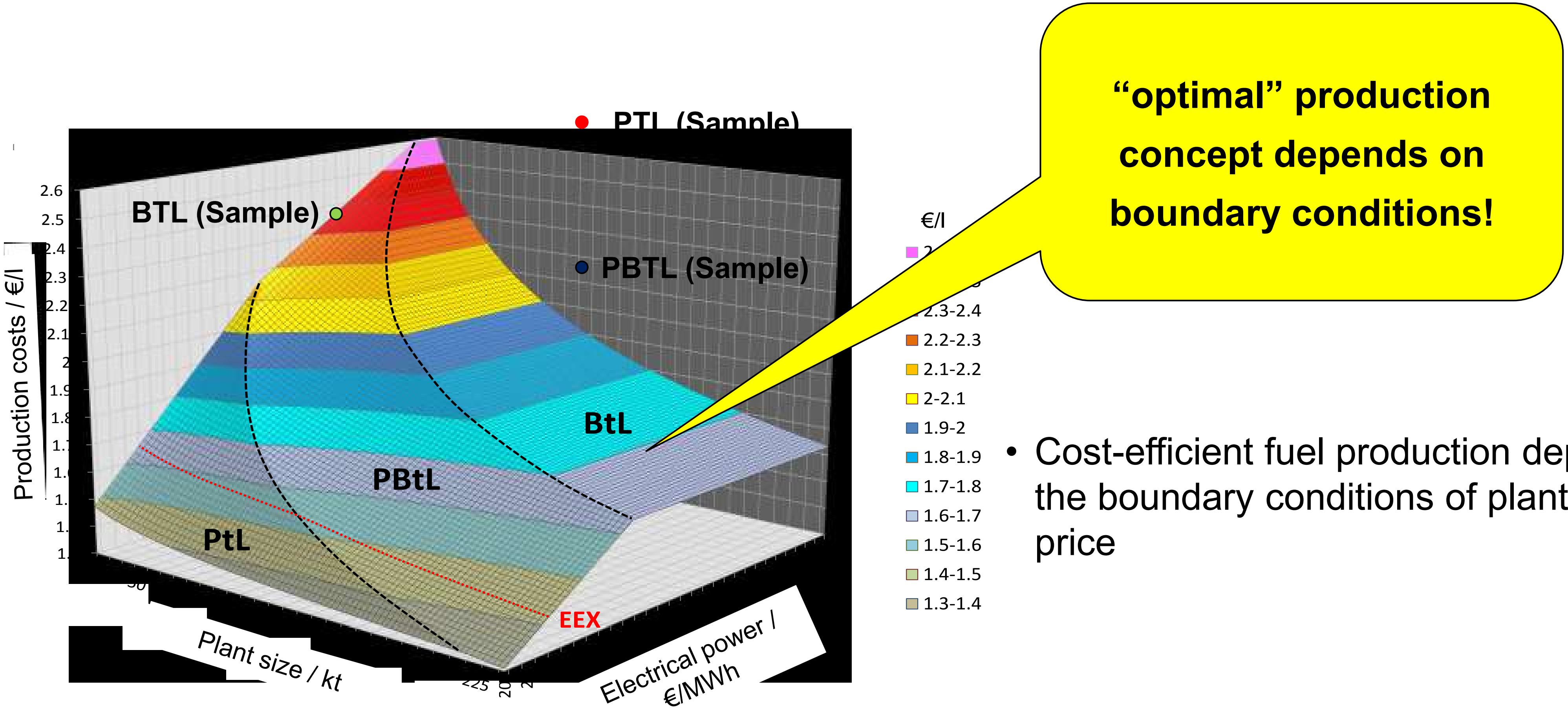
Techno-economic assessment



- Cost-efficient fuel production depends mainly on the boundary conditions of plant size and power price

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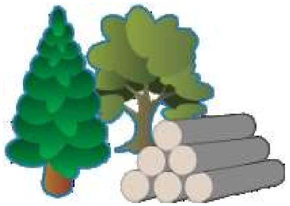
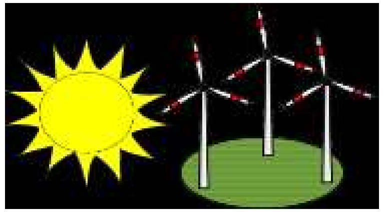
CO_2-Footprint of alternative fuels? ➔ Look at the feedstocksfirst

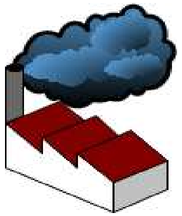
Biomass



Power



Carbon dioxide



Oxygen

O_2

Functional unit	$[kg_{CO2eq}/t]^a$	$[kg_{CO2eq}/MWh]^b$	$[kg_{CO2eq}/t]^c$	$[kg_{CO2eq}/t]$
Low boundary	13.6	10	5	100
Average	134.3	272.5	77.5	250
High boundary	255	535	150	400

[a] Based on own calculations taking into account biomass type (forest residues, straw etc.) and transport distances. CO_2-emissions during cultivation and harvesting are accounted for.
[b] Low boundary value for pure wind electricity taken from[1]. High value corresponds to the actual CO_2-footprint of the German electricity sector [2].
[c] Based on own calculations. The carbon footprint represents emissions arising from sequestration of CO_2 from flue gas. Flue gas from cement industry and coal fired power plants were investigated. The probably fossil nature of the flue gas was not taken into account. Low/high value: energy demand of CO2-sequestration is covered with wind energy/German electricity mix.
[d] Taken from ProBas databank [1]. Low/high value due to different electricity sources.

[1] Umweltbundesamt, "Prozessorientierte Basisdaten für Umweltmanagementsysteme," http://www.probas.umweltbundesamt.de/php/index.php.
[2] Umweltbundesamt, "Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990 – 2016," Dessau-Roßlau,2017.

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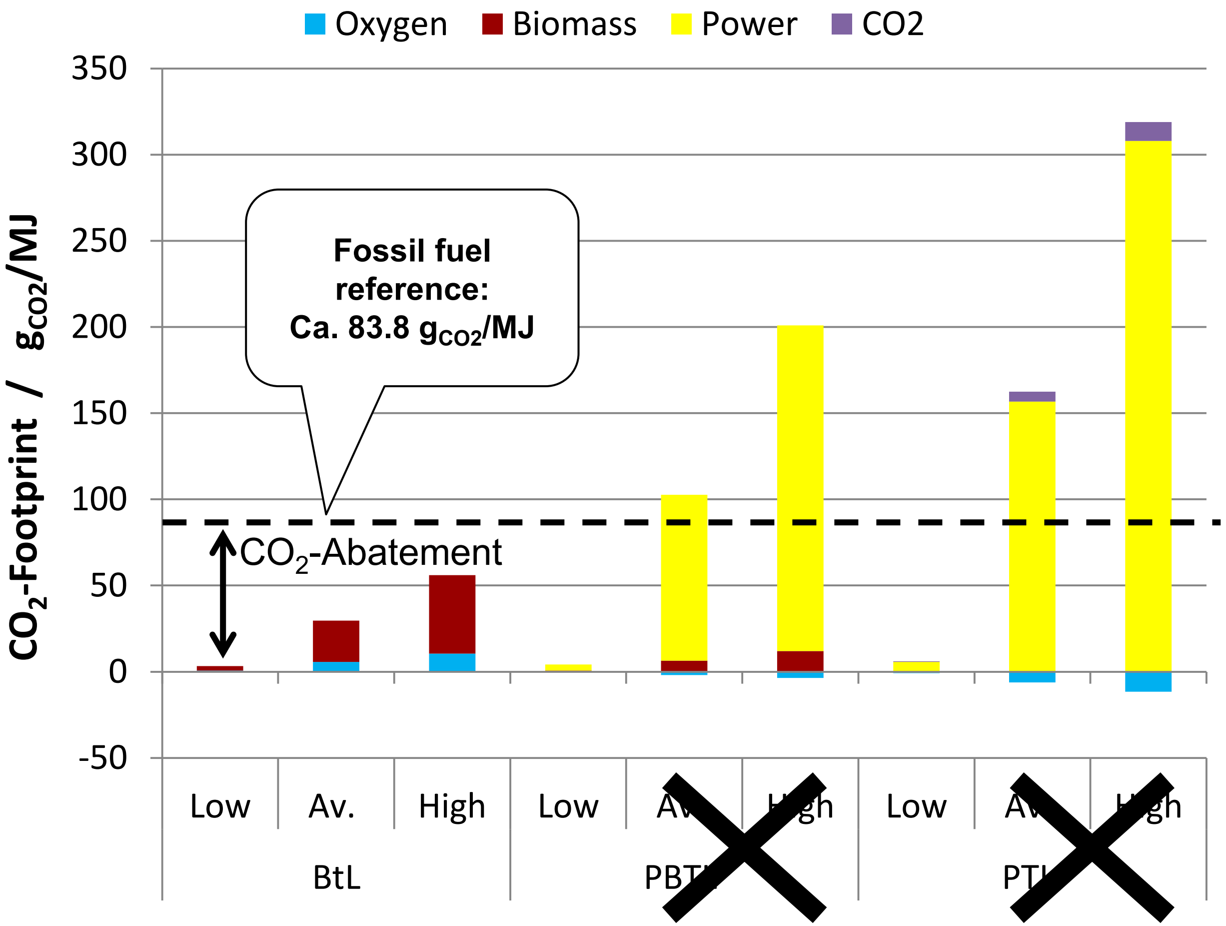
CO_2-Footprint of alternative fuels



CO2-Abatement costs:

Case1 (realistic):

Price of fossil kerosene: ca. 0.5 €/l
Power price: 105 €/MWh
Biomass price: 100 €/t

Case2 (optimistic):

Price of fossil kerosene: ca. 1 €/l
Power price: 30 €/MWh
Biomass price: 60 €/t

CO_2-Abatement costs € / t_{CO_2}					
Case	BtL-Low	BtL-Av.	BtL-High	PBtL-Low	PtL-Low
1	662	985	2756	631	827
2	406	605	1183	134	155

Current Price of CO_2-European Emission Allowances:
ca 5 €/t

Power-based fuel concepts only viable when using renewable power!

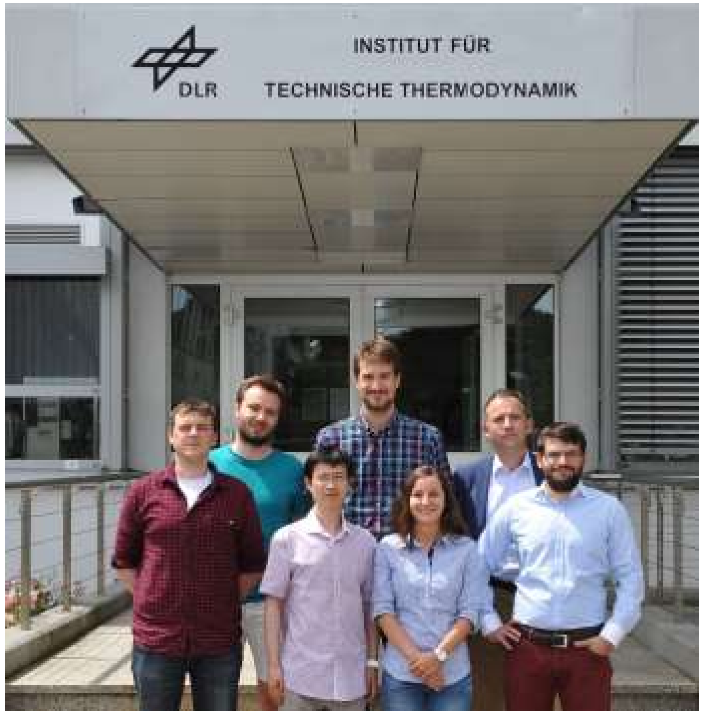
DLR

Summary

- 1st gen. biofuel ➔ important step towards decarbonization of transport
  ➔ far too little for future demand
- European renewable electricity potential ➔ Able to increase the biofuel production significantly (PTL, PBTL)
- PBTL: co-utilization of power and biomass ➔ enhanced carbon-efficiency, larger plant size, lower costs
- German Aerospace Center (DLR): standardized methodology for the evaluation of alterative jet fuels with respect to technical, economic and ecological key performance parameters
  (CAPEX, OPEX, net production costs, CO_2-Abatement costs)

Outlook

- Technical demonstration of PBtL concepts (search for cooperation partners)



THANK YOU FOR YOUR ATTENTION!

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