Technical and Economical Evaluation of

Biomass-to-Liquid (BtL)
Power-to- Liquid (PtL)
Power & Biomass-to-Liquid (PBtL) Processes

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DLR – Research Group for Alternative Fuels

Open Workshop:
Energy System Integration of Bio-Based Fuels

Trondheim, NO
13th September 2018

DLR

Outline

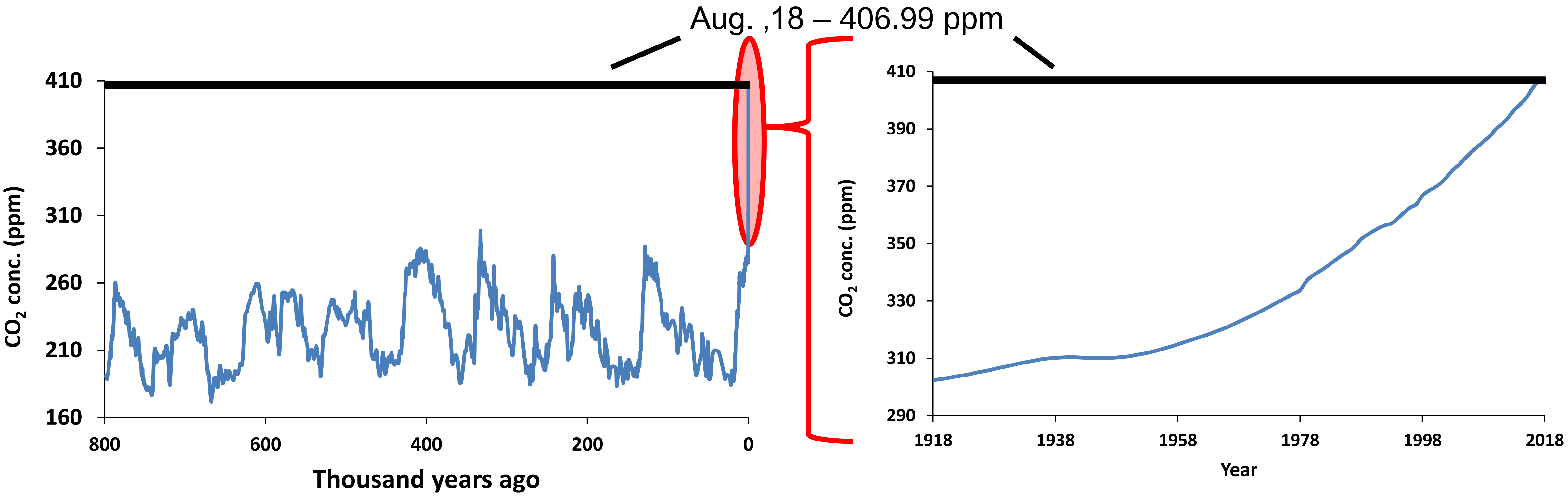
1. Brief introduction: DLR – German Aerospace Center

- 8.200 Employees (Feb. 2018)
- 40 institutes at 20 sites (+ offices in Brussels, Paris, Tokyo, Washington)
- Total budget 925 Mio.€ (2016)
- 6 research areas

Aeronautics | Space | Energy | Transport | Digitalization | Security

Research Group Alternative Fuels

1. Motivation for alternative fuels – Rising CO_2 levels



- 1 ppm CO_2 ≈ 8 Gt CO_2
- CO_2 absorbs thermal radiation - rising CO_2 levels → more heat is trapped in atmosphere

CO_2 – Data obtained from www.co2.earth

1. Demand for transportation & mobility is rising

- With rising prosperity comes rising demand in mobility and transportation
- Example: Increasing Air traffic

Time

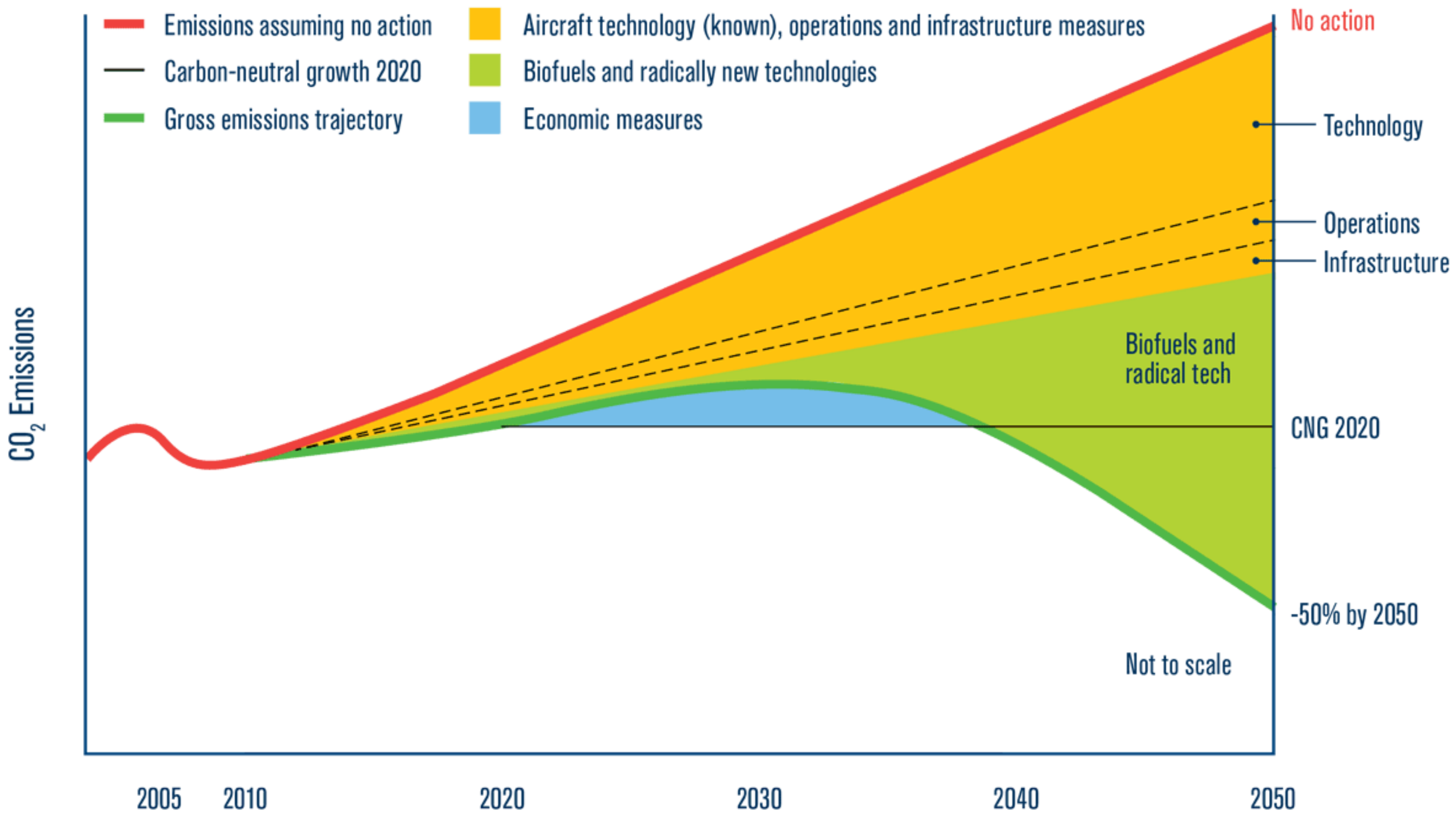
Year	Europe	North-America	China
2014	760 1210	1030 2880	510 370
2000	440 750	860 2720	77 60

Billion passenger km / per year

Passenger km / per year per person

Source: Thess et al., DGLR-Mitgliedermagazin „Luft- und Raumfahrt“ Ausgabe 2/2016, S.20 ff.

1. IATA Technology Roadmap - Reduction of CO_2 emissions in the air traffic sector



- Not every transport sector can be electrified (yet)

➢Renewable generated fuels are a solution to decarbonize transport sectors like air traffic

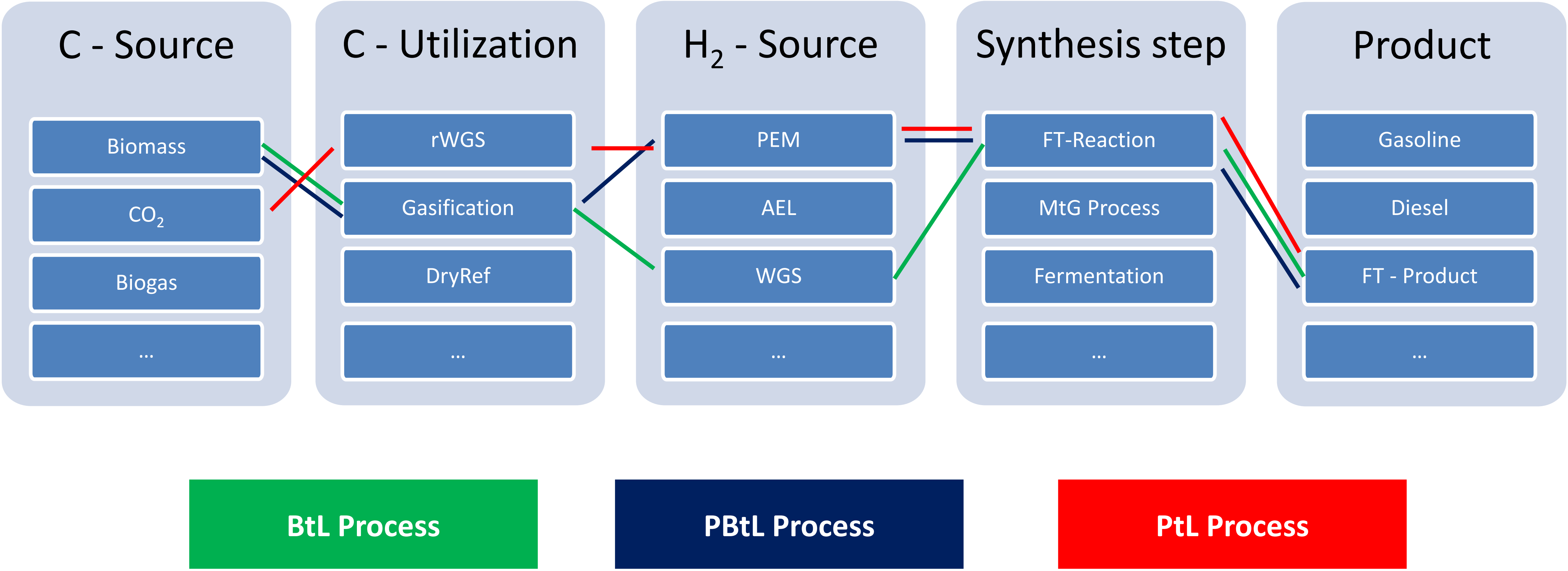
Source: iata.org

Outline

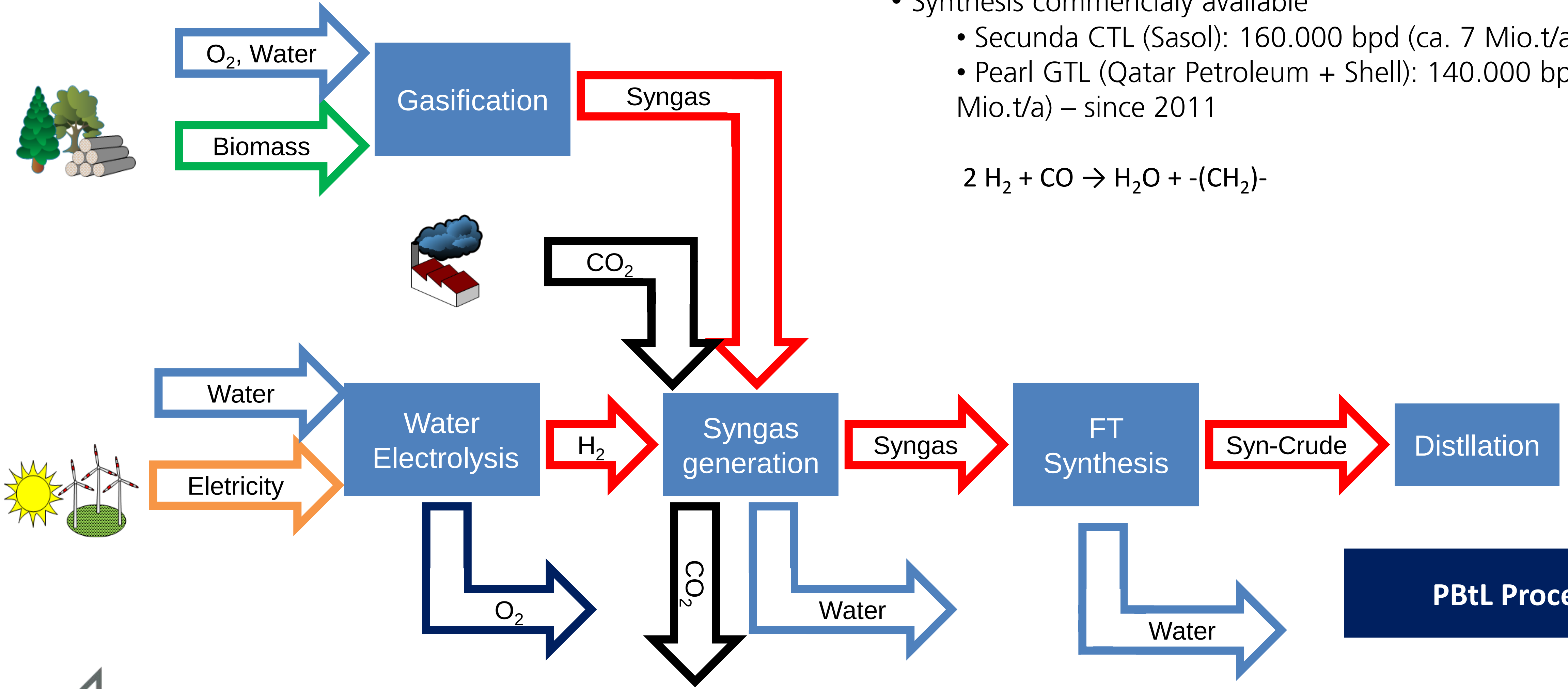
1. Introduction and Motivation
2. **Technical evaluation**
3. Economical evaluation
4. Results
5. Summary & Outlook

2. Technical evaluation - Production processes

- ASPEN Plus is used for the technical evaluation
- What are the options for alternative fuels



2. The BtL – PBtL – PtL Processes



- Synthesis commericialy available
  - Secunda CTL (Sasol): 160.000 bpd (ca. 7 Mio.t/a)
  - Pearl GTL (Qatar Petroleum + Shell): 140.000 bpd (ca. 6 Mio.t/a) – since 2011

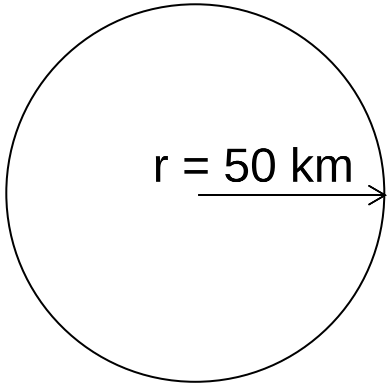
$$2\ H_2 + CO \rightarrow H_2O + \text{-}(CH_2)\text{-}$$

PBtL Process

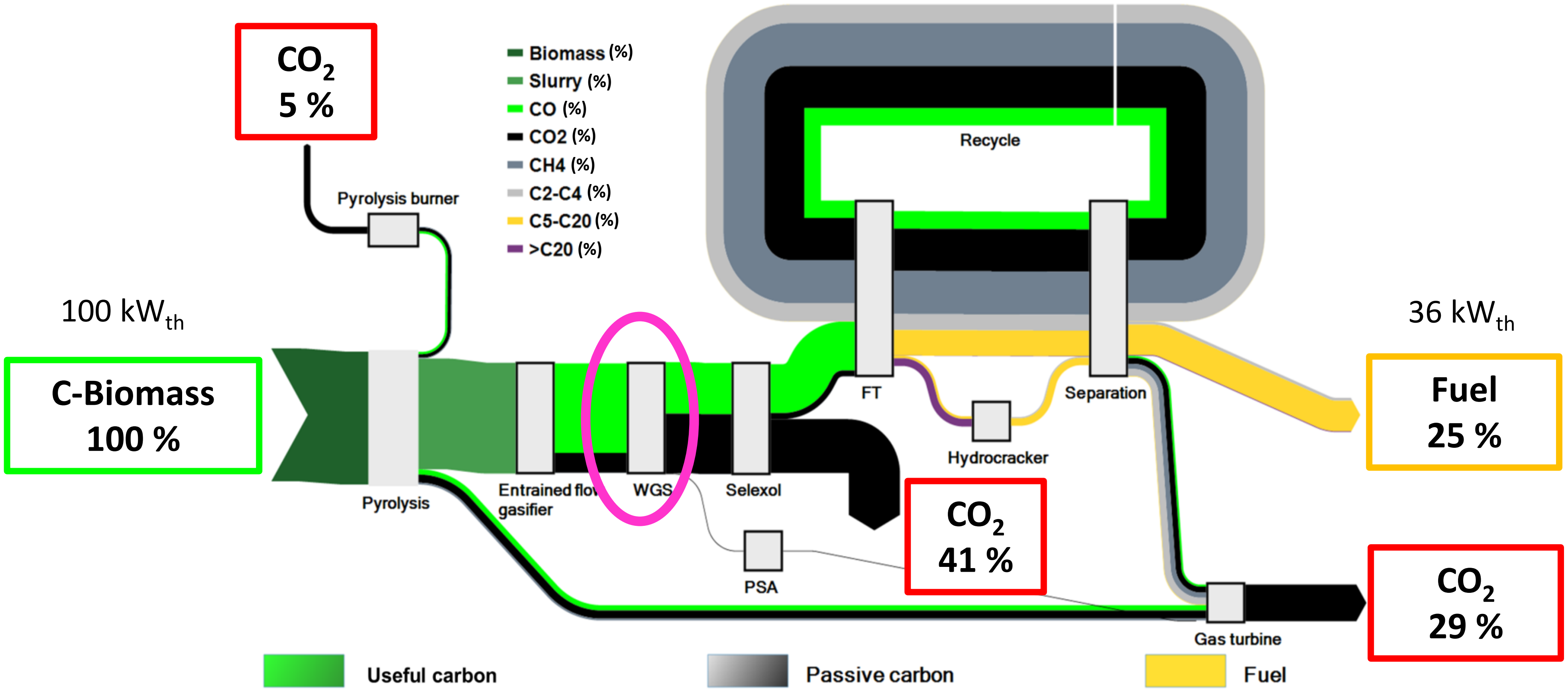
2. Process simulation – Key results for BtL Process

Stream [t/h]	BtL Process
Biomass	22

- H_2/CO ratio for FT-Synthesis ≈ 2
  $2\ H_2 + CO \rightarrow H_2O + \text{-}(CH_2)\text{-}$
- WGS reaction is H_2 source
  $H_2O + CO \rightleftharpoons H_2 + CO_2$



2. Carbon flow diagram – BtL Process



75 % of biomass carbon lost as CO_2

2. Process simulation – Key results for BtL Process

Stream [t/h]	BtL Process
Biomass	22
Liquid product	2.93
C - Conversion	25%

- H_2/CO ratio for FT-Synthesis ≈ 2
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➢ Deactivated carbon (CO_2) can‘t be reutilized
➢ Lack of H_2 leads to low C-conversion

➢ PBtL Process with additional H_2 source and rWGS Reactor

2. Process simulation – Key results

Stream [t/h]	BtL Process	PBtL Process
Biomass	22	22
H_2	-	3.57
Liquid Product	2.93	11.04
C - Conversion	25%	97.7%
XtL Effciency	36.3%	51.4%

Stream [t/h]	PtL – small	PtL - large
CO_2	9.05	34.20
H_2	1.48	5.77
Total	2.93	11.05
C - Conversion	98%	98%
XtL Effciency	50.6%	50.6%

$$\eta_{XtL} = \frac{\dot{m}_{Prod} \cdot LHV_{Prod}}{\dot{m}_{Biomass} \cdot LHV_{Biomass} + P_{El}}$$

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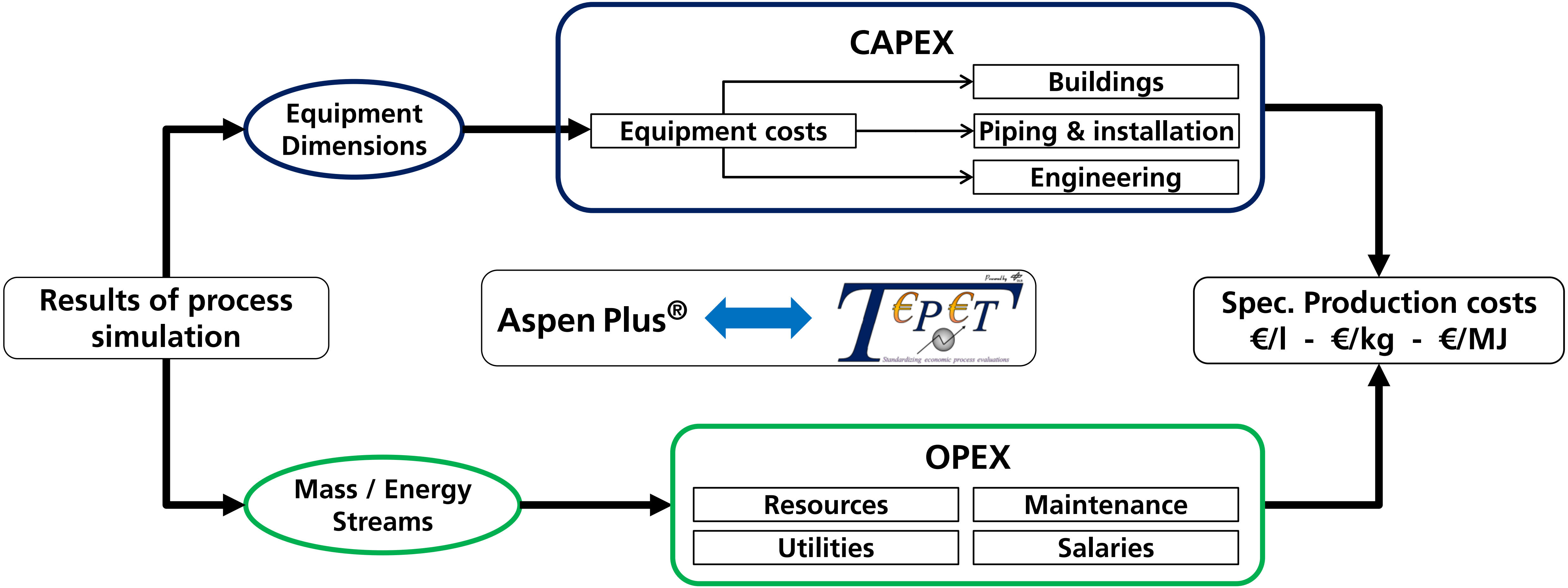
3. Economical evaluation

AACE Recommended Practice Class III + IV Accuracy of cost estimation $\pm 30\ \%$



TEPET
Techno economical process evaluation tool

3. Determination of costs

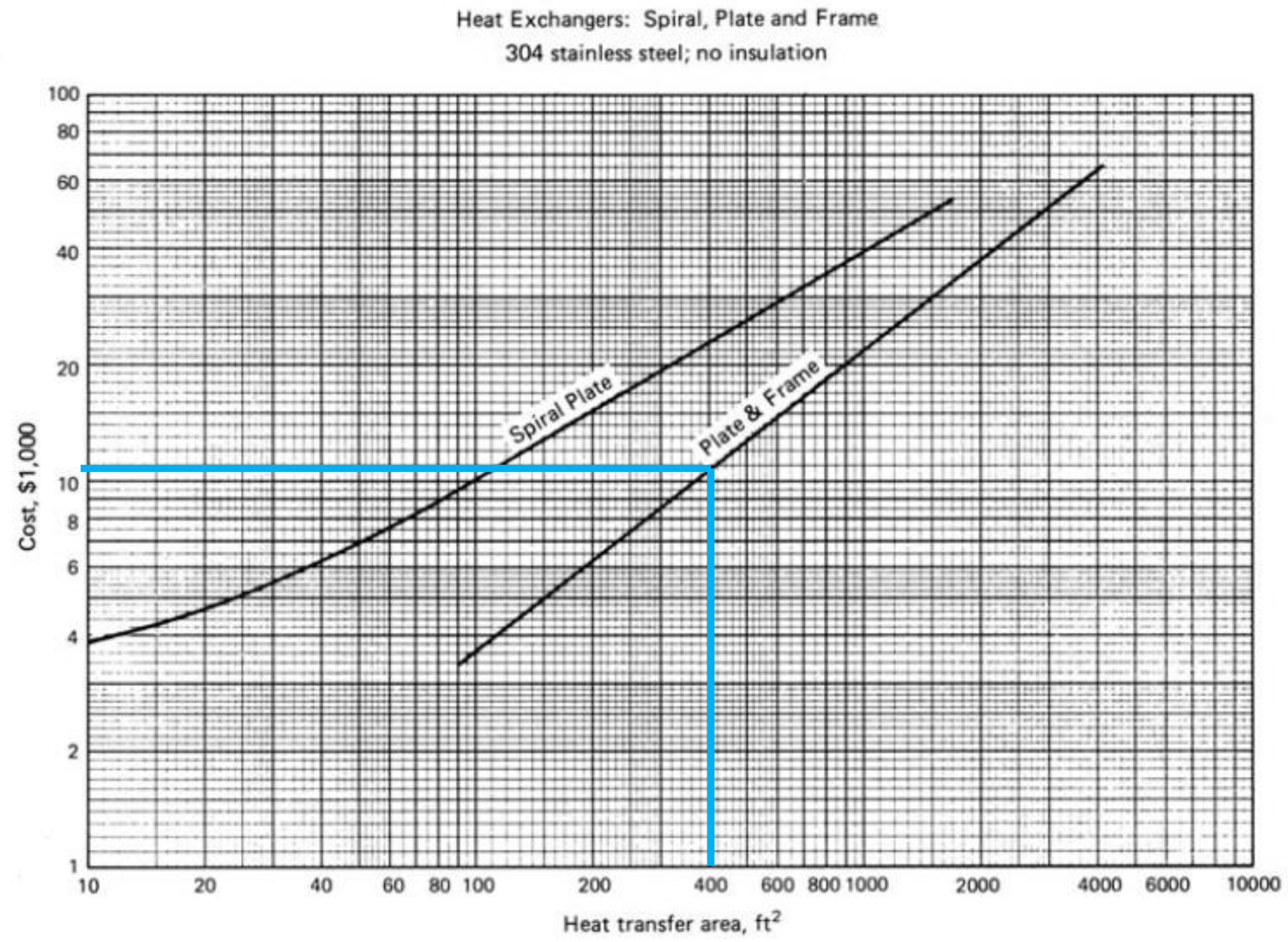
CAPEX

- Standard EQP (Heat exchanger,
- Special EQP has to be obtained f
- Remaining costs can be divided i
  - Installation, Buildings...

OPEX

- Available market prices for comm
- Remaining costs can be divided i
  - Maintenance, Salary,...

$$C_i = C_0 \cdot \left(\frac{S_i}{S_0}\right)^f \cdot \frac{Index_{Jahr_i}}{Index_{Jahr_0}}$$



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4. Scenarios the techno economical evaluation

Investment Costs			
PEM-Elektrolyseur (stack):	**720**	€/kW [1]	
PEM-Elektrolyseur (system):	**1.350**	€/kW	(TEPET, incl. cost factors)
Gasifier	**103.650**	€/(kg_{Slurry}/h) [2]	(Scale-factor: 0.7)
Fischer-Tropsch Reactor:	**17,44**	Mio.€/($kmol_{feed}$/s) [2]	(Scale-factor: 0.67)
Costs for Resources and by-products			
Electricity	**99,6**	€/MWh [3]	
Biomass	**80,1**	€/t [4]	
Oxygen (export):	**24,3**	€/t [5]	
Steam (export):	**19,8**	€/t [6]	

Further conditions

Reference year	2017	*Operating time of plant*	30 years
Annual full load hours	8.260 h/a	*Interest rate*	7%

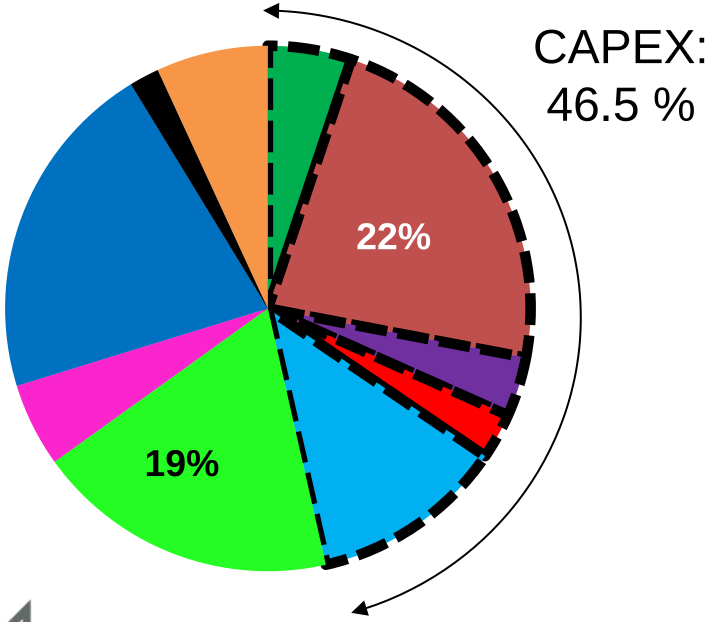
[1] G. Saur, Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study, Technical Report NREL, 2008
[2] I. Hannula and E. Kurkela, Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass, Espoo: VTT Technical Research Centre of Finland, 2013.
[3] Eurostat, Preise Elektrizität für Industrieabnehmer in Deutschland, 2017
[4] C.A.R.M.E.N. – Preisentwicklung bei Waldhackschnitzel (Energieholz-Index)
[5] NREL,“Appendix B: Carbon Dioxide Capture Technology Sheets - Oxygen Production,“ US Department of Energy, 2013
[6] Eigene Berechnung basierend auf dem Gaspreis der Eurostat Datenbank

4. Result: Cost comparison of BtL / PBtL / PtL - process

Elektrolysis | Pyrolysis | Gasifier | Selexol
Fischer-Tropsch | Rest (CAPEX) | Electricity | Biomass
Rest(Ressources/Utilities) | Maintenance | Salary | Rest (OPEX)

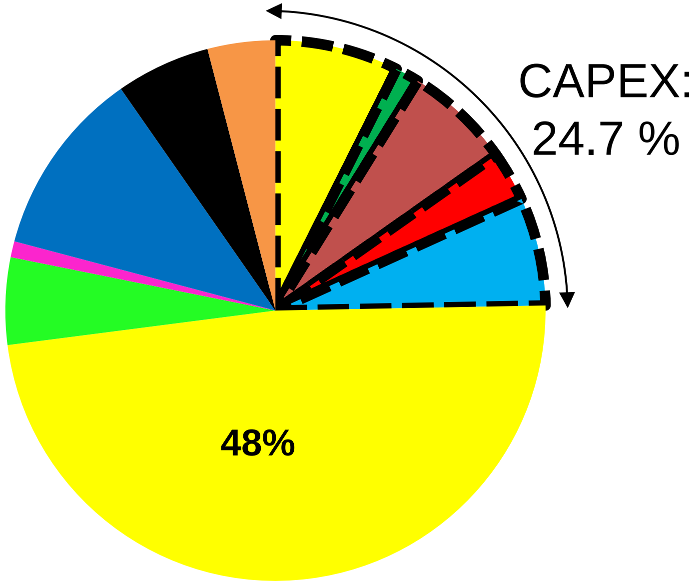
Biomass-to-Liquid (BtL)

FCI: ca. 411 Mio. €
Production costs: ca. **2.36 €/l**
Production capacity ca. **24.2 kt/a**



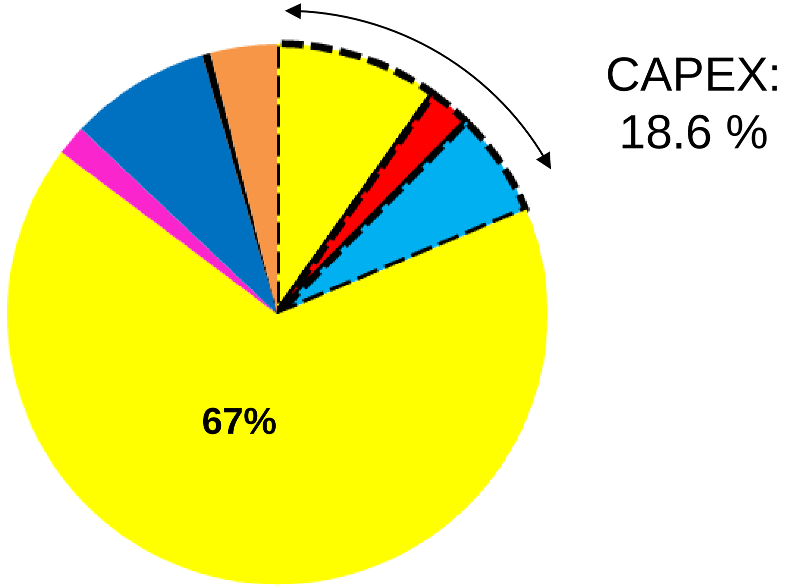
Power&Biomass-to-Liquid (PBtL)

FCI: ca. 781 Mio. €
Production costs ca. **2.23 €/l**
Production capacity ca. **91.2 kt/a**



Power-to-Liquid (PtL) - Large

FCI: ca. 696 Mio. €
Production costs: ca. **2.64 €/l**
Production capacity ca. **91.2 kt/a**

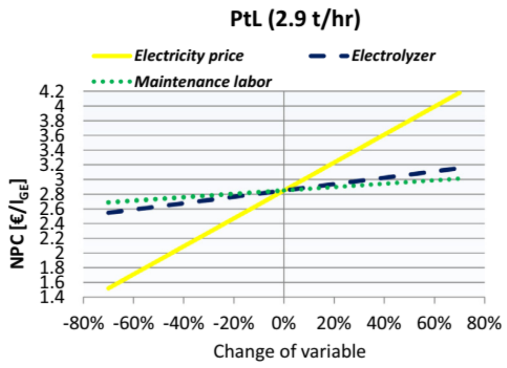


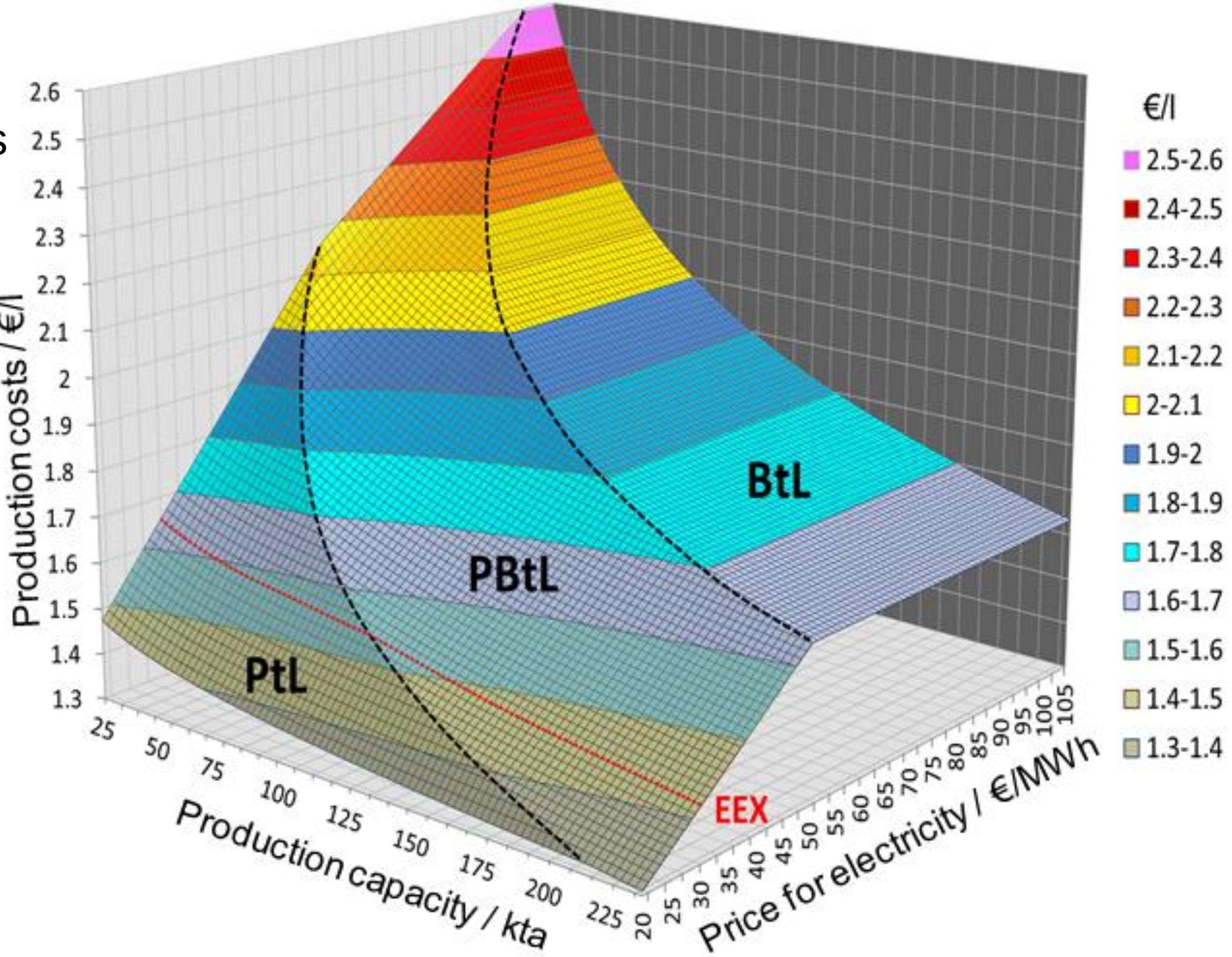
4. Sensitivity analysis

- TEPET is capable of performing sensitivity analyzes
- Specific production cost for different varying process parameters.

Example

- Influence of electricity price
- Influence of production capacity „economy of scale“





Outline

5. Summary

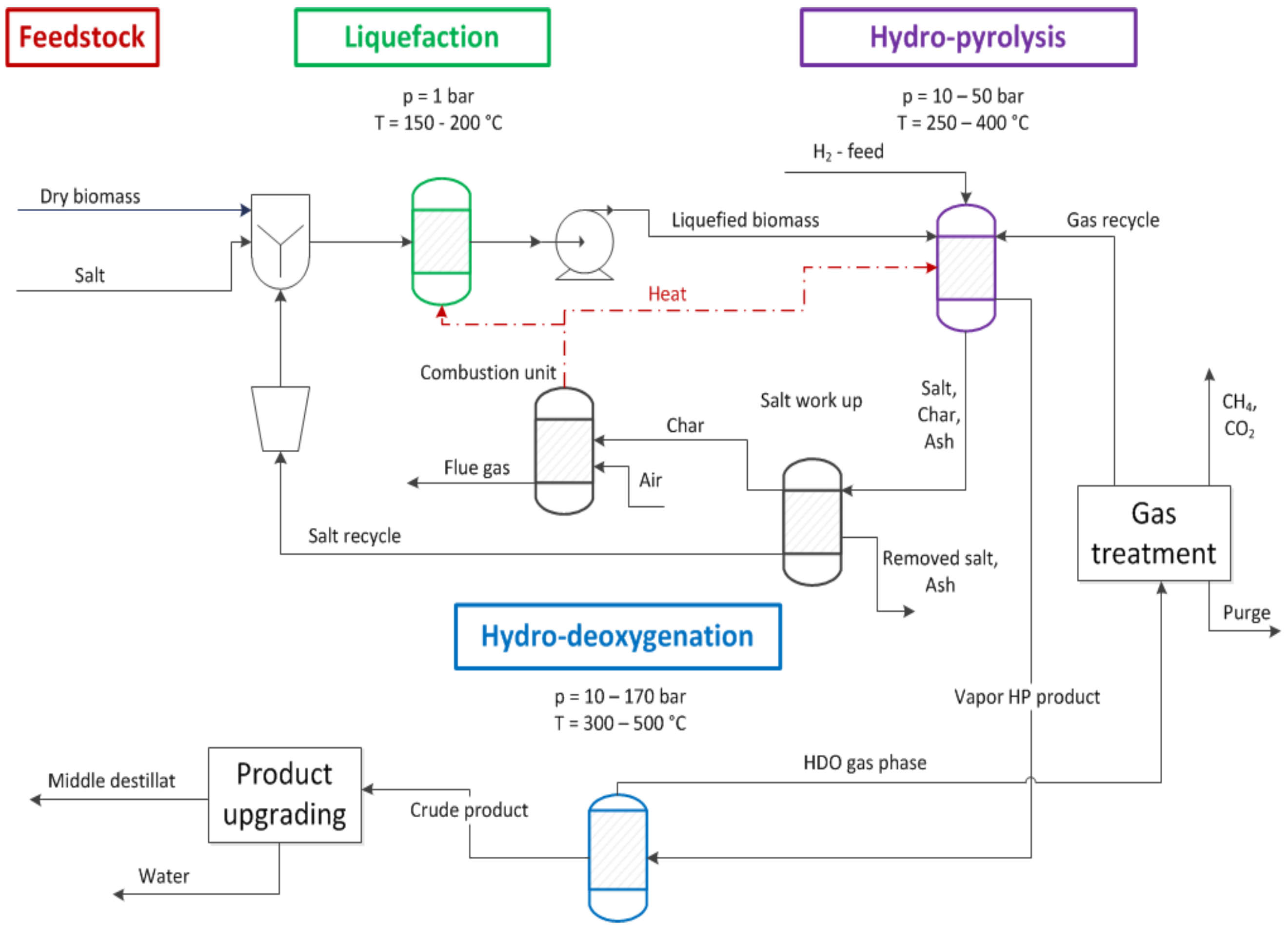
- Tool for the technical and economical evaluations are available
- Open and transparent cost estimation method
- Opportunities for development can be shown and outlined
    - Technological perspective: e.g.: Yield curves, efficiencies etc.
    - Economical perspektive: e.g.: Influence of electricity price, economy of scale etc.

➢ "Bottlenecks" and their influence can be identified and → e.g. carbon flow-diagram

1 - EU – ABC-Salt Project
www.abc-salt.eu – EU No. 764089

ABCSalt

- 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.%
- Diesel net production costs < 0.80 €/l



COMSYN
NEXT GENERATION
BIO-FUEL TECHNOLOGY

2 - EU – ComSyn Project

www.comsynproject.eu – EU No. 727476

- Compact Gasification and Synthesis process for Transport Fuels

DFB PILOT @ VTT

Hot gas filtration

VTT

GKN SINTER METALS

DFB Gasifier

VTT

Catalytic Reforming

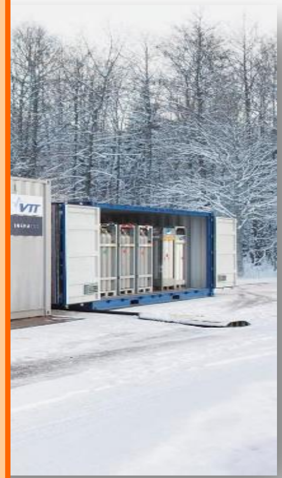
VTT

5 m³/h
Partial flow to s

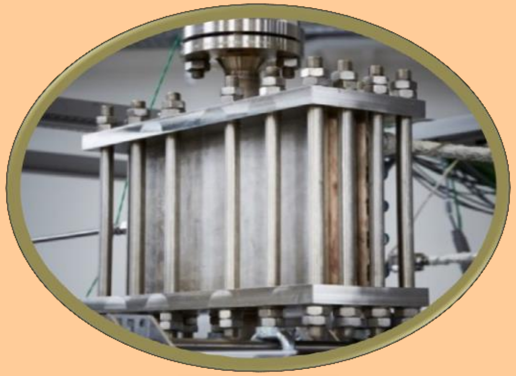
Gas cleaning

VTT

lant



Fischer-Tropsch Microreactor:



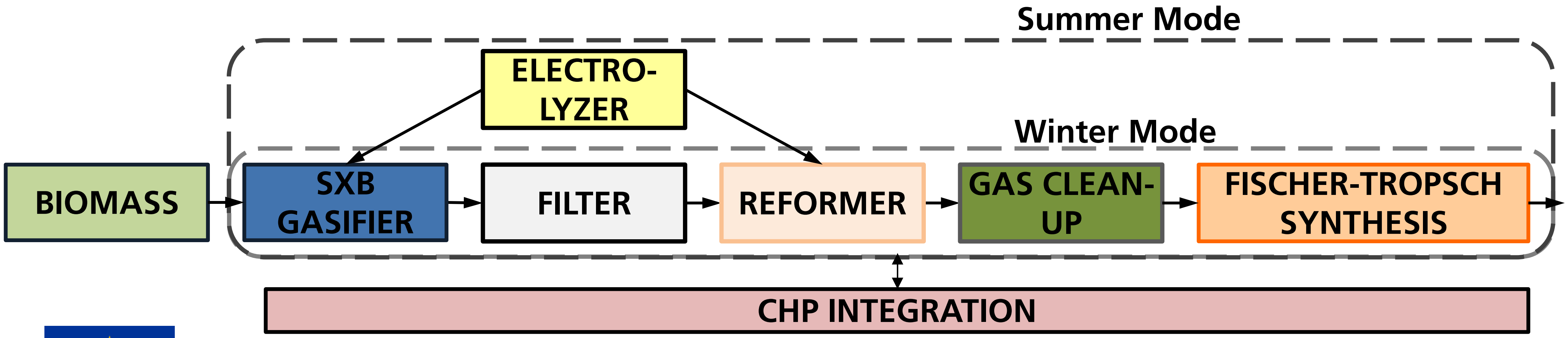
INERATEC

DFB gasification → **Filter** → **Reformer** → **Gas cleaning** → **Fischer-Tropsch Synthesis** → **Product Upgrading**

3 - EU – FlexCHx Project
www.flexchx.eu – EU No. 763919

- Flexible generation of heat, power and transport fuels

Catalytic Tar Reforming
- New and robust catalyst, developed by Johnson Matthey results in cheap operating expenditues with low investment costss
- CO content can be increased via CO_2 recycling



Thank you for your attention

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DLR

Energy system integration

➢What does the energy system of the future look like?

- Sector coupling → Breaking the boundaries of heat, electricity and fuel market
- Taking the influence of production process into account? Rising demand increases the price?
- Estimating the available amount of a given resource? e.g.: Biomass, CO_2, Electricity
    - Minimum energy required for gas purification
    - CO_2 with DAC: 1.08 GJ_e/t [1] → 0.3 MW / t_{CO2}/h

[1] APS Physics in 2011 Report about "Direct Air Capture of CO2 with Chemicals"