Opportunities and Challenges for Power-to-Liquid Technologies towards Sustainable Aviation

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Agenda

1. Motivation for Alternative Fuels
- Need for GHG emission reduction
- Actual GHG emissions in Europe
- Biofuels options in European transport
- Options to reduce GHG emissions

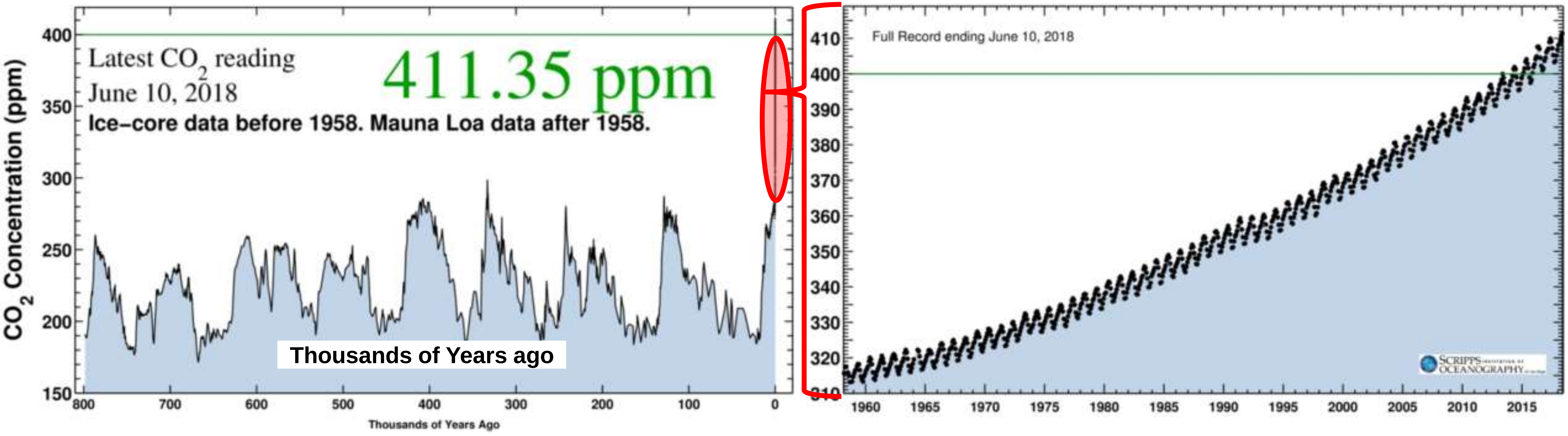
2. Alternative Fuels Options
- Raw materials and available energy sources
- Fuel potential in Europe

3. Process Evaluation of Renewable Kerosene
- Introduction to DLR methodology
- Example: PtL – Jet fuel by Fischer-Tropsch

4. Summary and Outlook

1. Climate Change – Driver for Renewable Fuels?

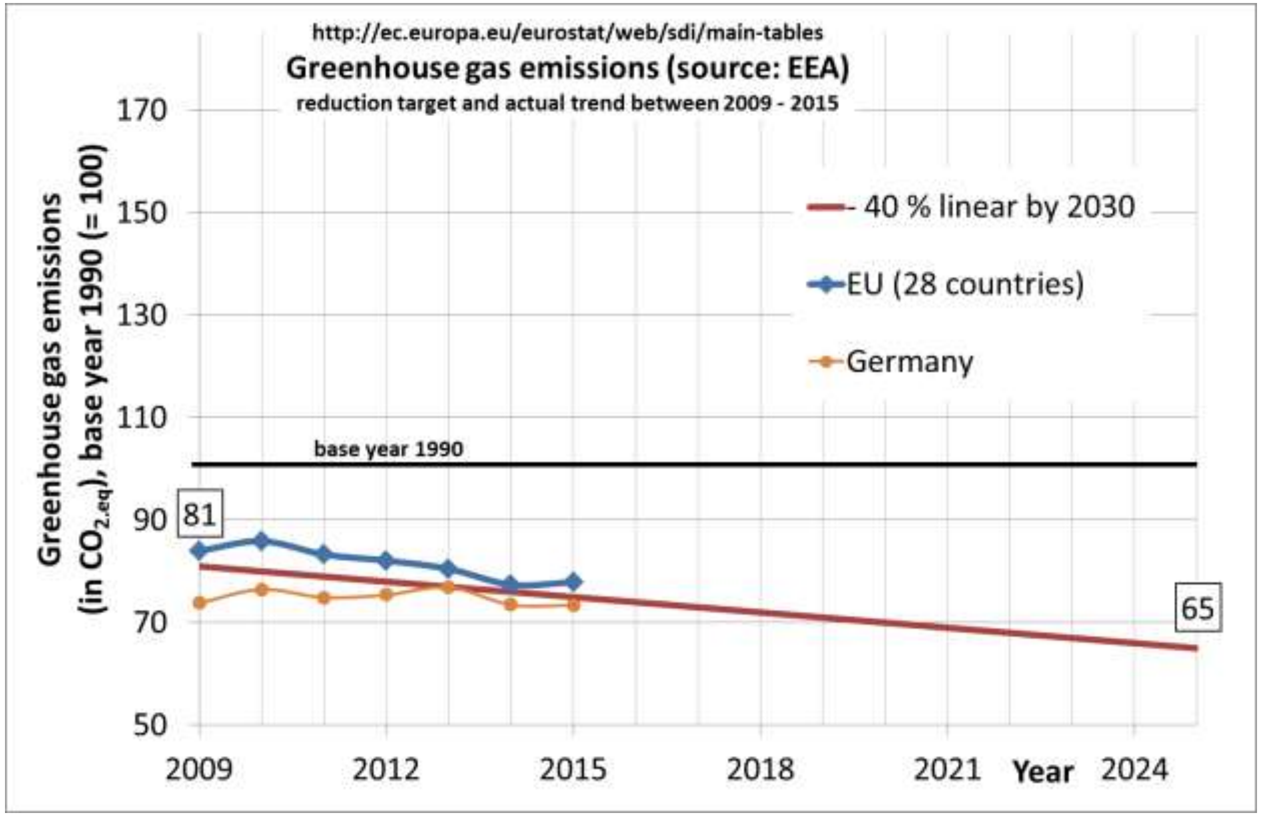
- Historic natural fluctuation between 180 and 280 ppm CO_2 concentration
- undeniable break-out since 1960's
- No visible impact of renewables introduction since 2000's

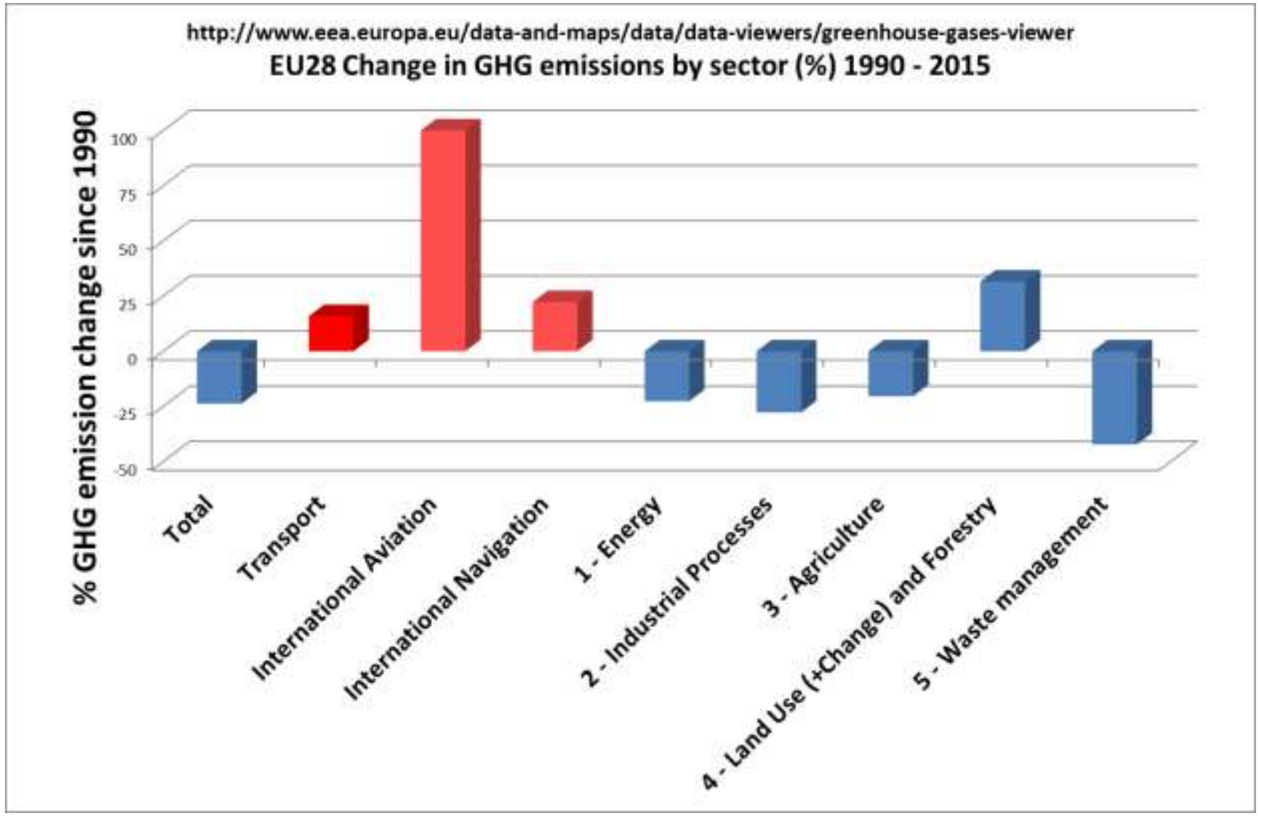


Source: https://www.co2.earth/daily-co2

1. GHG emission trend in Europe

- European GHG reduction behind target (slow reduction in Germany)
- Transport GHG emissions grow considerable





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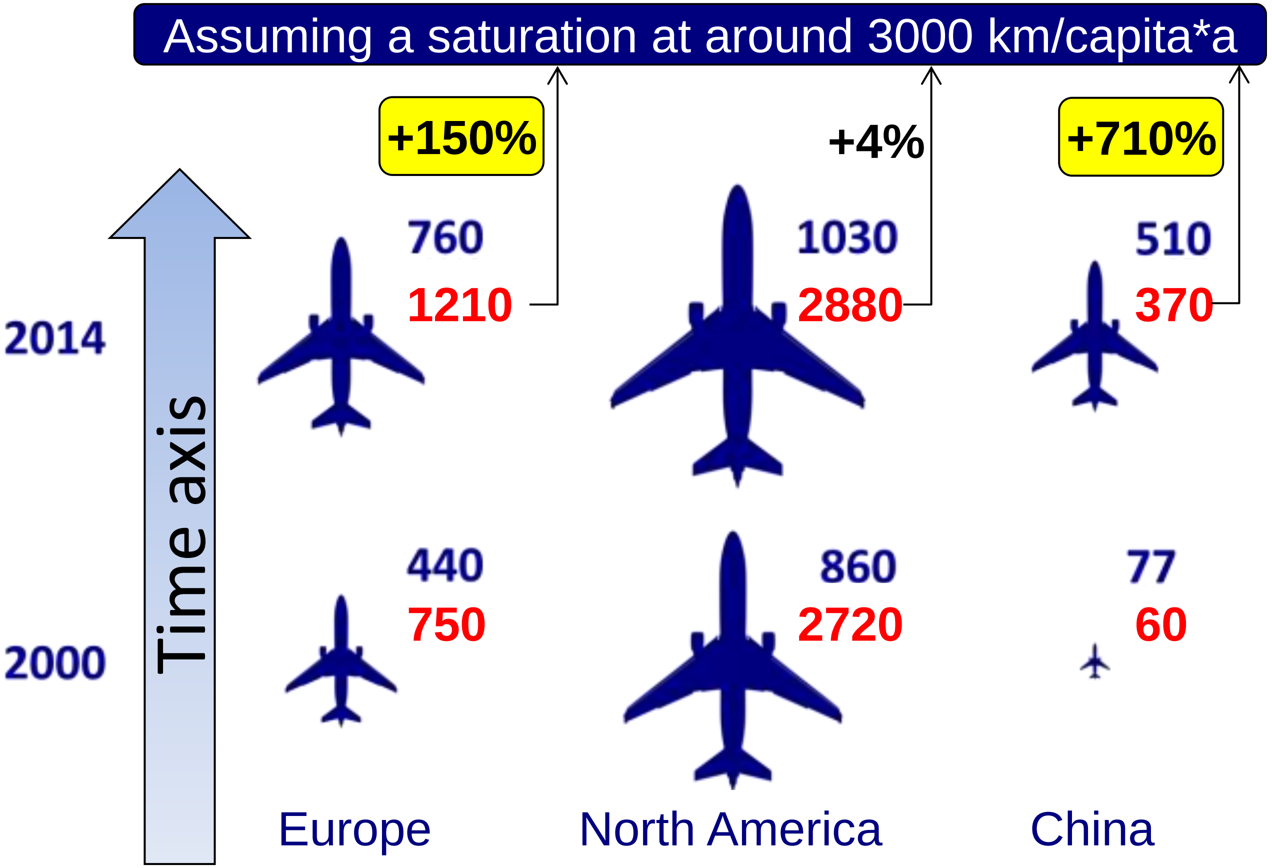
1. Growth in Aviation Sector



(in billion passenger kilometers /a)

(specific passenger kilometers per capita/a)

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

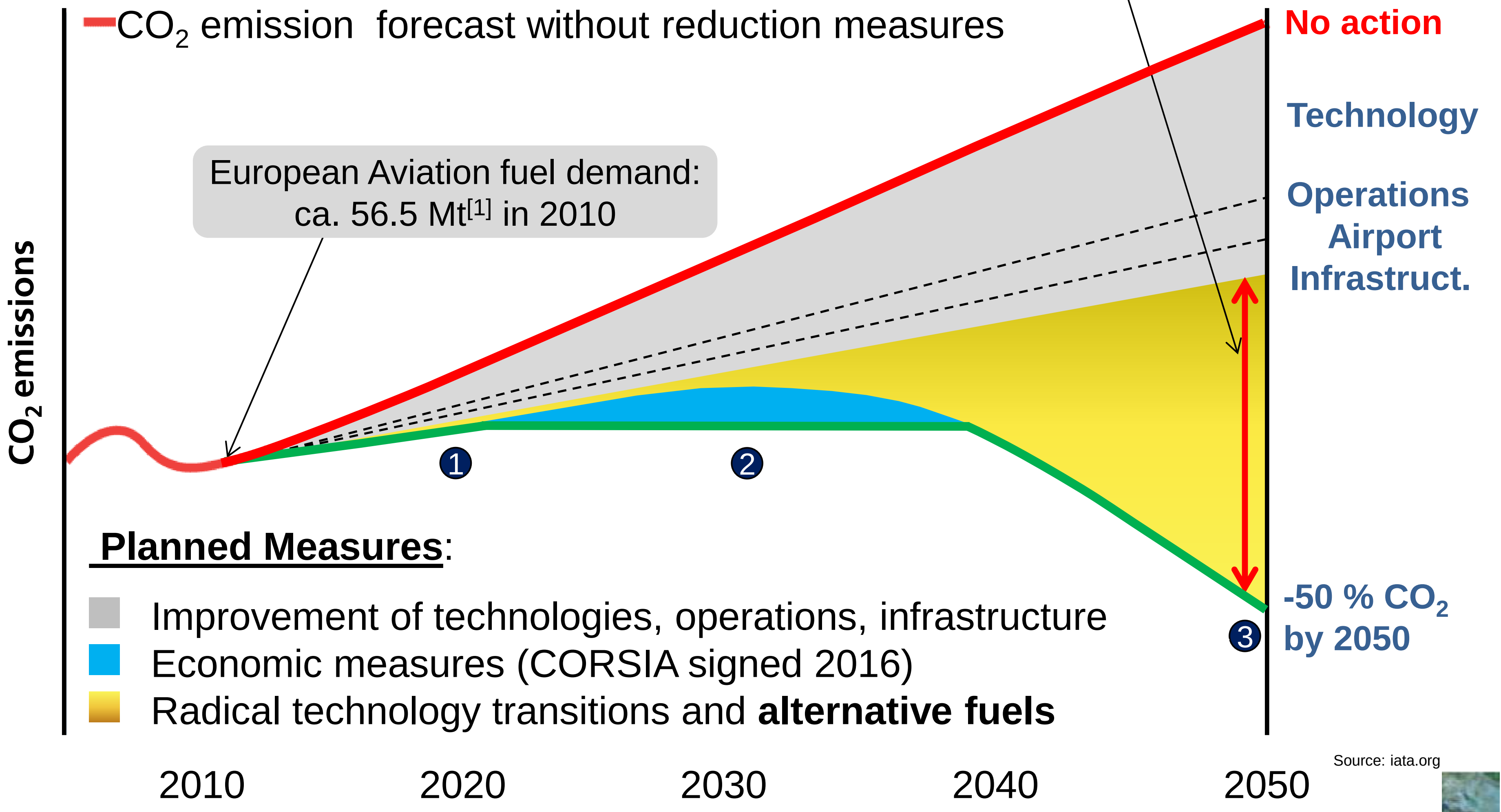
1. IATA Technology Roadmap

4. Edition, June 2013

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

Aviation Self-commitments:

1. Improvement of fuel efficiency ≈ 1,5 % p.a. until 2020
2. Carbon-neutral growth from 2020
3. CO_2 emission reductions of 50 % by 2050 (comp. to 2010)



Source: iata.org

[1] FuelsEurope “Statistical Report“ 2010

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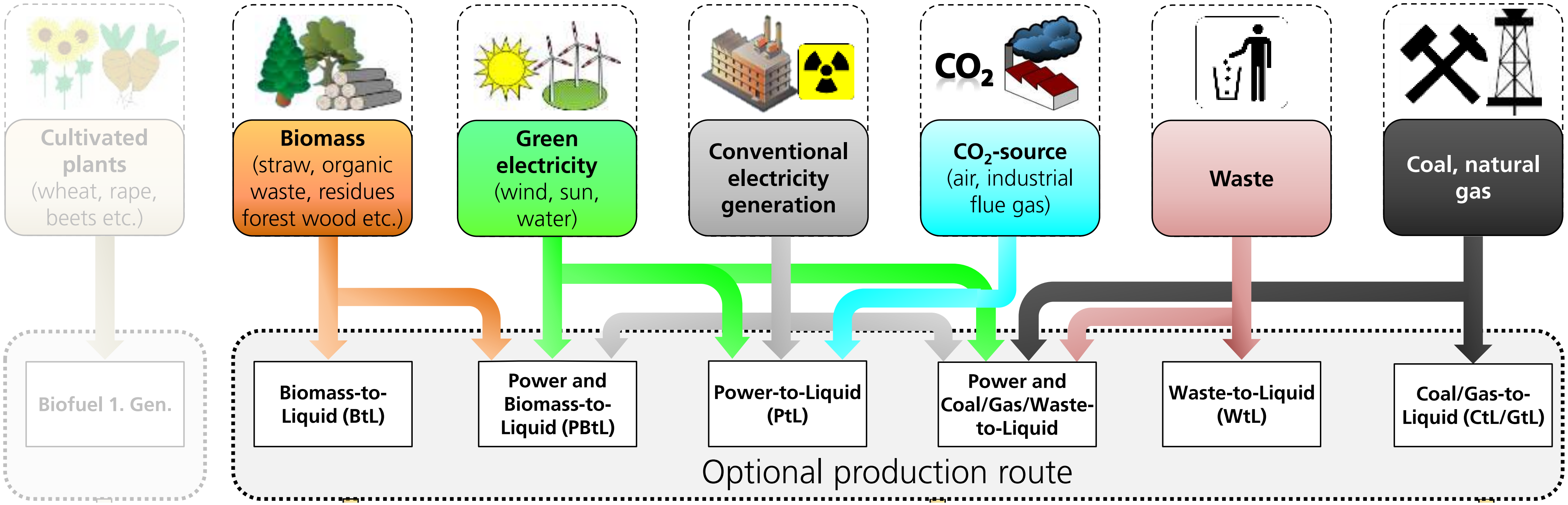
2. Sources & Routes for Alternative FT-Kerosene

- Too large CO_2 footprint
- Low usable raw material potential
- RED II restriction?



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).*

2. Renewable Energy Potential for Europe

Potential for Europe? – e.g. jet fuel from wind power

- Current jet fuel consumption: ≈ 56 Mt/a[1]
- Power demand for exclusively power based kerosene in Europe: ≈ 1,410 TWh (η_{xtL} ca. 50 %)
- European wind power potential[2]: 12,200 – 30,400 TWh ≈ **8.6 - 22 times of power based kerosene demand**!

[1] Eurostat database, 2015
[2] European Environment Agency, “Europe's onshore and offshore wind energy potential,” 2009.

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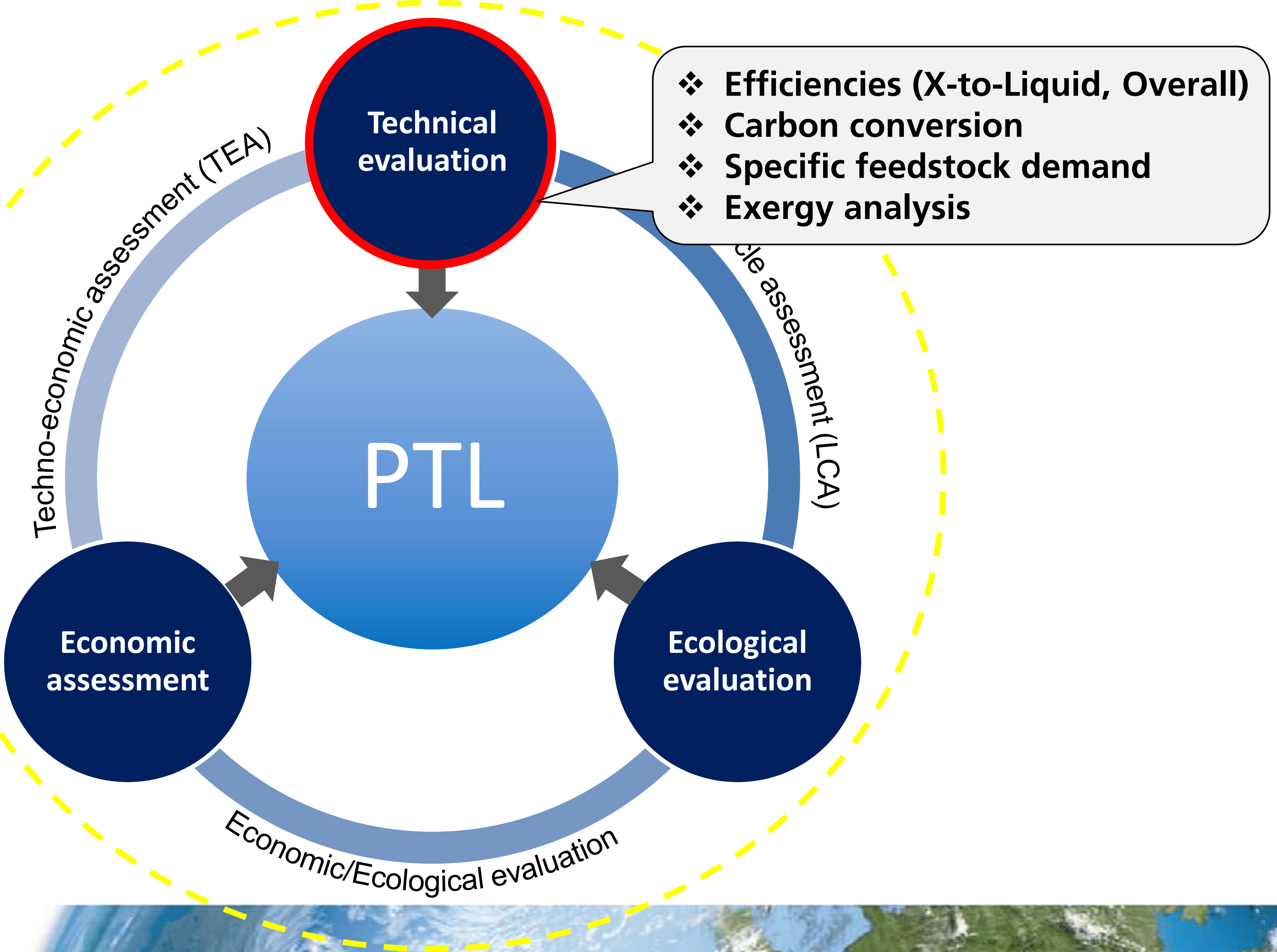
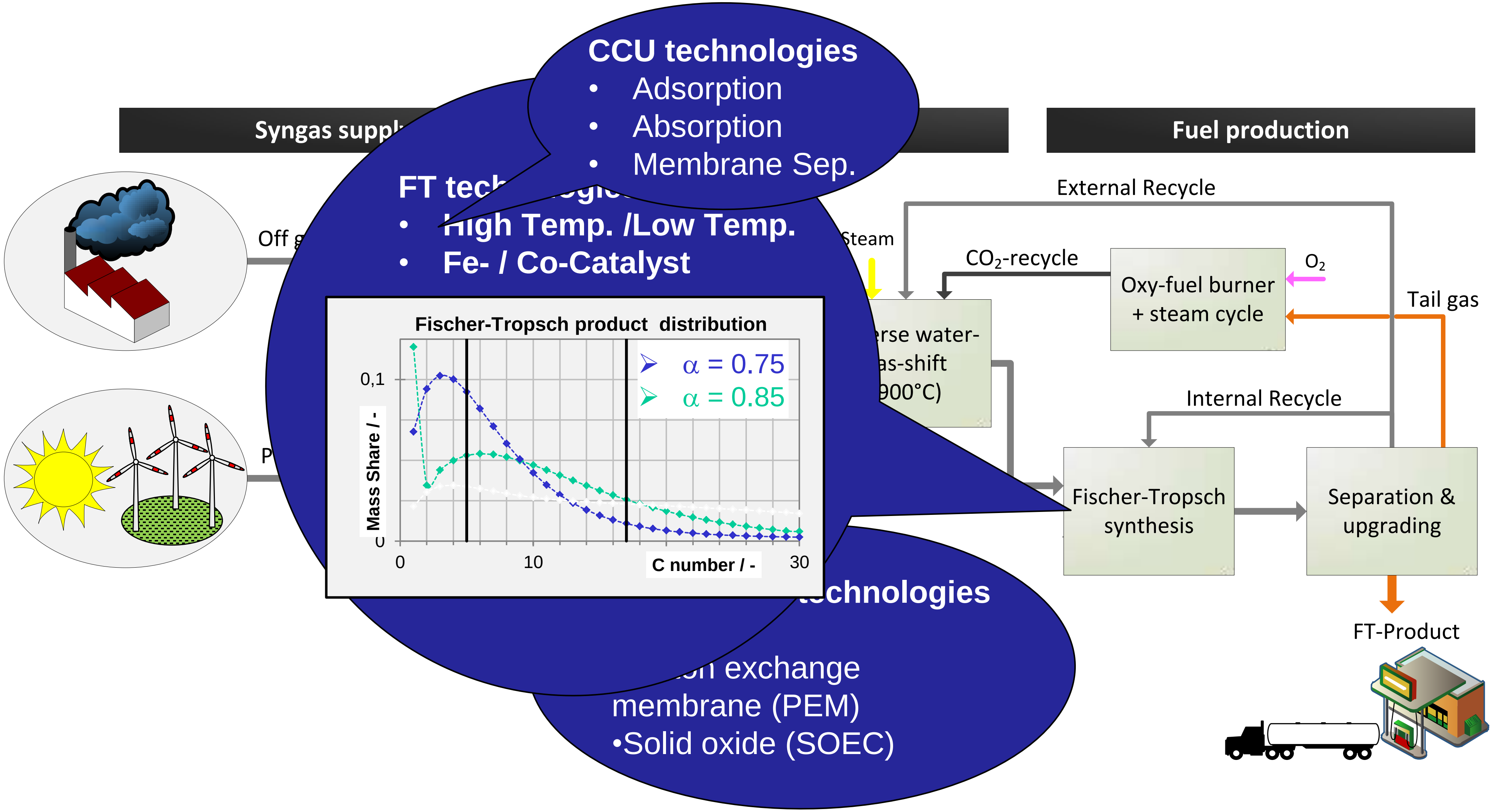
3. Process Evaluation @ DLR

DLR-evaluation and optimization tool

TEPET
Standardizing economic process evaluations



3. Multiple Options for Power-to-Liquid



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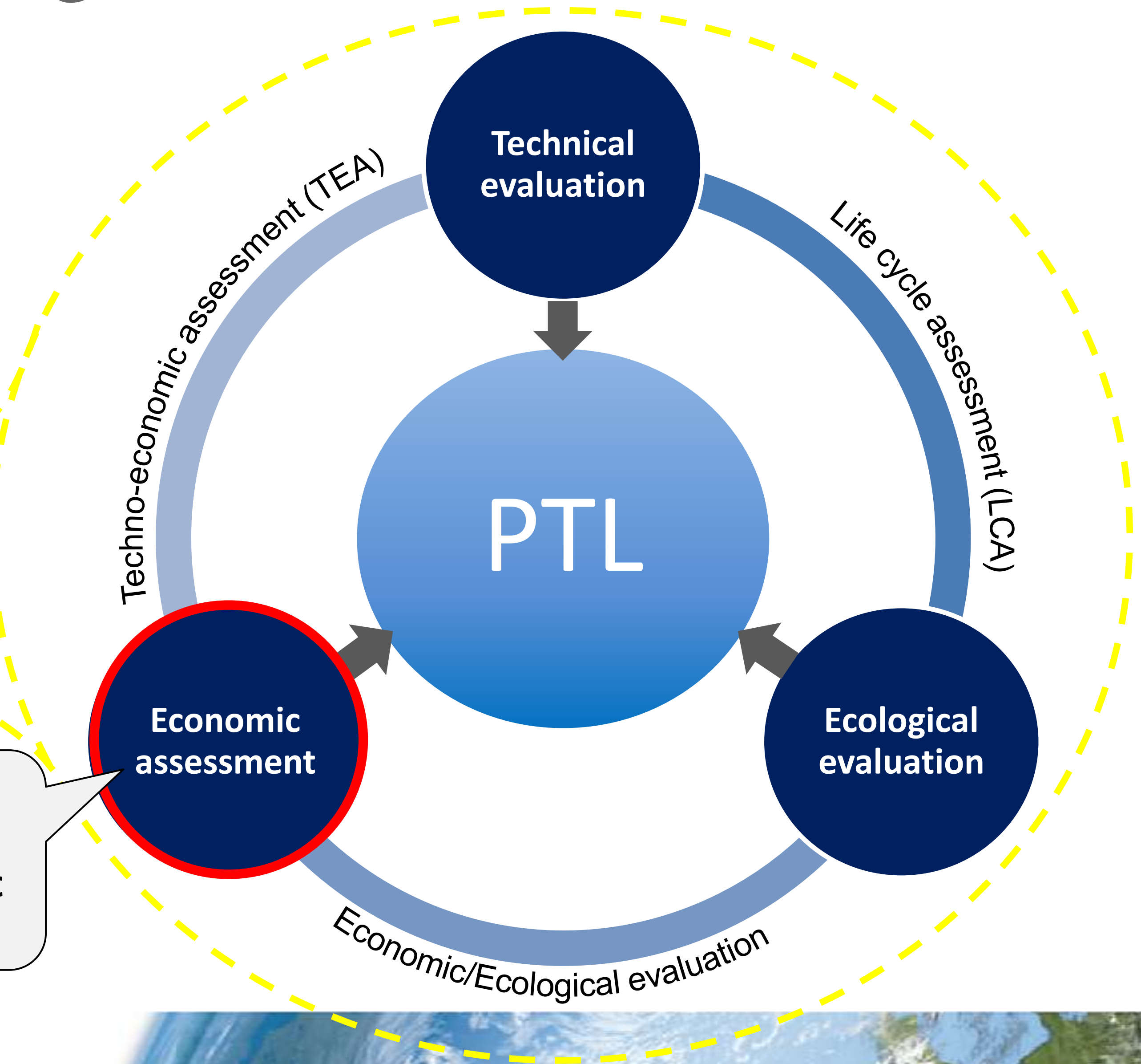
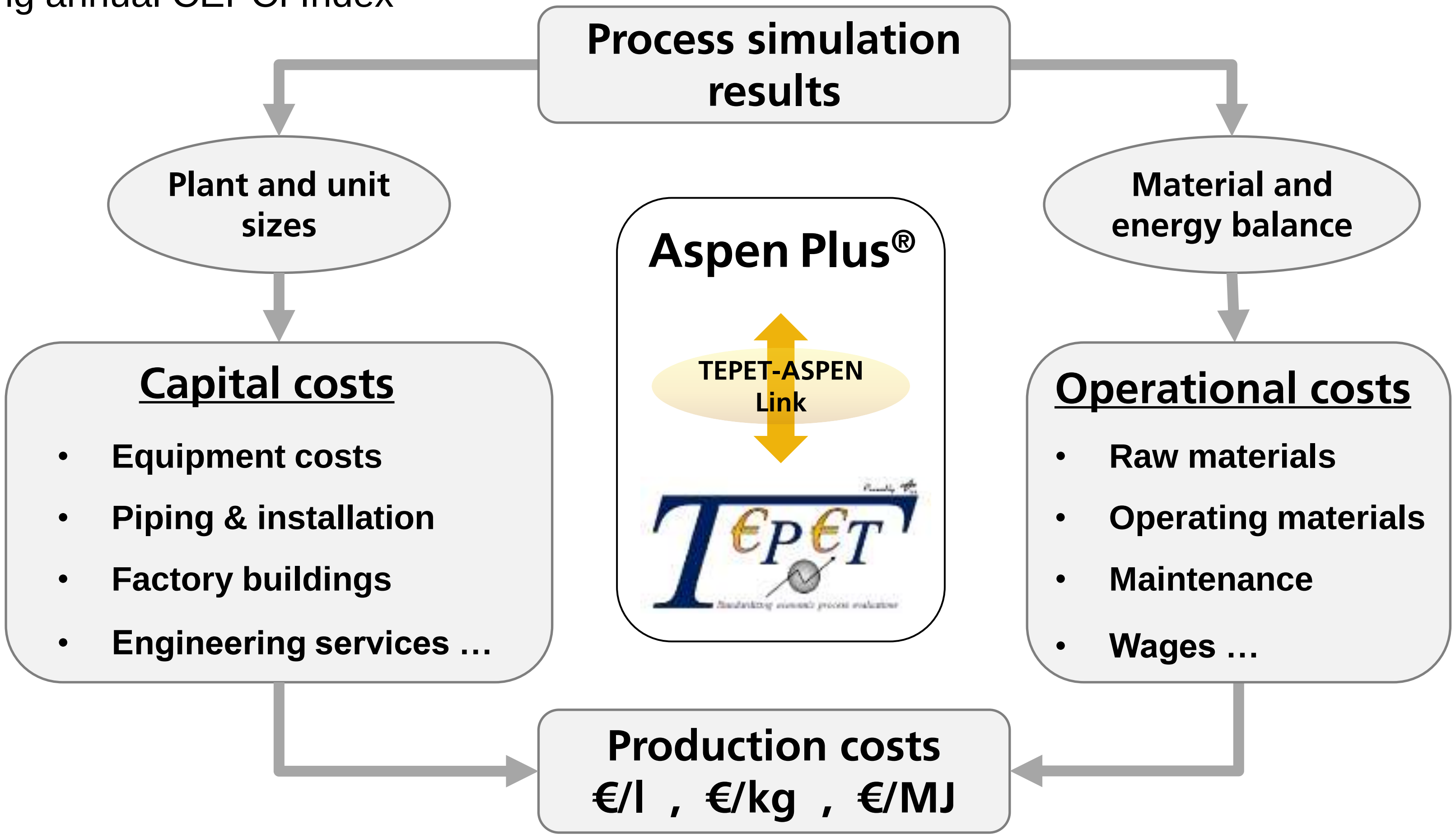
TEPET
Standardizing economic process evaluations

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



3. Techno-Economic Assessment (TEA) Methodology

- Adapted from **best-practice chem. eng. methodology**
- Meets AACE class 3-4, accuracy: **+/- 30 %**
- **Year specific** using annual CEPCI Index



3. TEA: Base Case definition

PtL Plant capacity:

- ❖ Power Input: 293 MW_e
- ❖ **Fuel Production: 100 kt/a**

Investment costs:

PEM-Electrolyzer (stack):	**720**	€/kW [1]
PEM-Electrolyzer (system):	**1,350**	€/kW factors according to [2]
Fischer-Tropsch reactor:	**17.44**	Mio.€/($kmol_{feed}$/s) [3]

Raw materials and utility costs

German Grid Power:	**83.7**	€/MWh [4]
Oxygen (export):	**23.7**	€/t [5]
Steam (export):	**14.7**	€/t [6]

General economic assumptions:

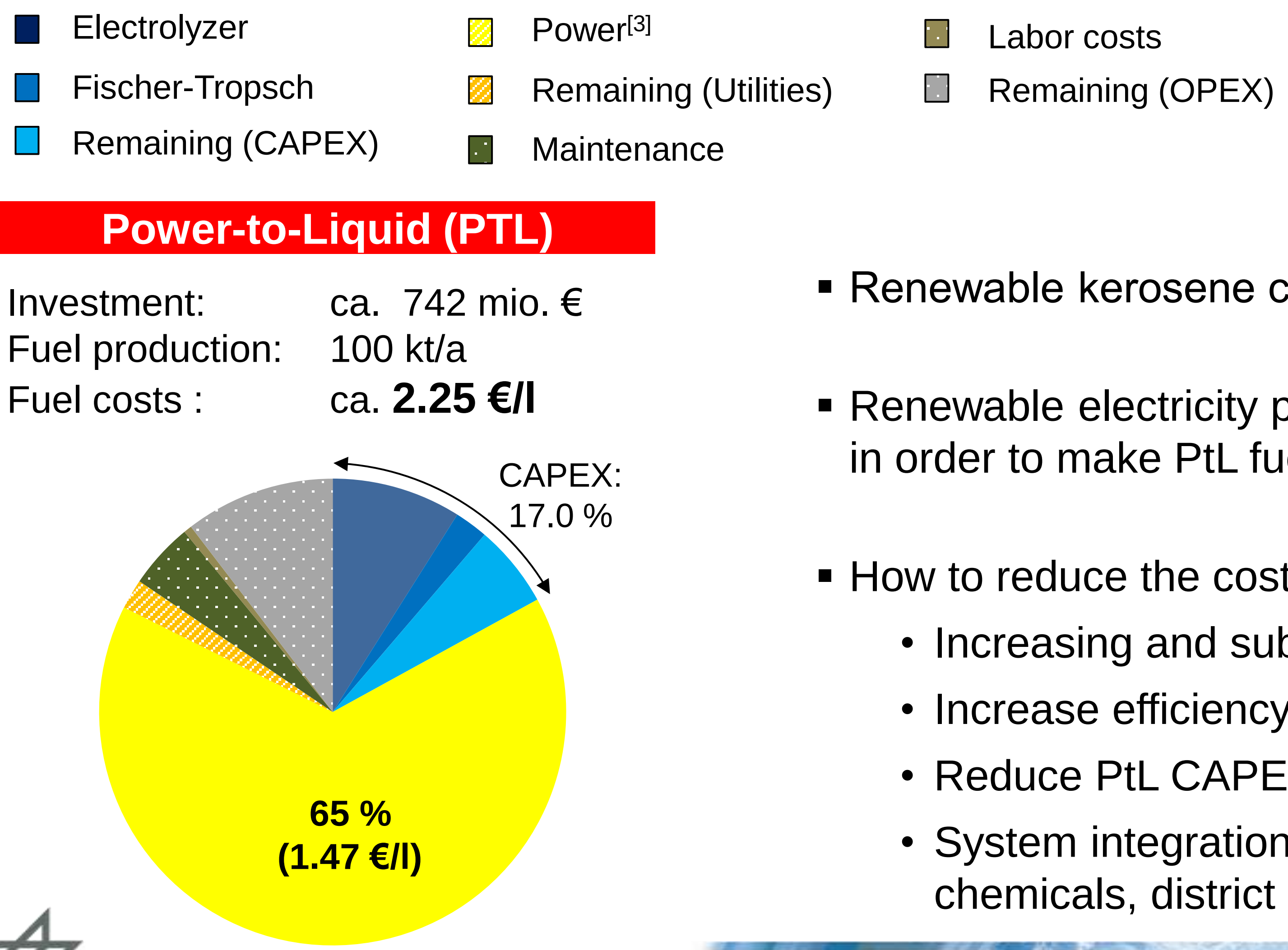
Year:	2016	*Plant lifetime:*	30 years
Full load hours:	8,260 h/a	*Interest rate:*	5%

[1] G. Saur, Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study, Technical Report NREL, 2008
[2] Peters M, Timmerhaus K, West R. Plant design and economics for chemical engineers, New York, 2004
[3] 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
[4] Eurostat, Preise Elektrizität für Industrieabnehmer in Deutschland, 2016
[5] NREL,“Appendix B: Carbon Dioxide Capture Technology Sheets - Oxygen Production,“ US Department of Energy, 2013
[6] Own calculations based on natural gas price from Eurostat database

3. Base Case Results of TEA

Power-to-Liquid (PTL)

Investment: ca. 742 mio. €
Fuel production: 100 kt/a
Fuel costs : ca. **2.25 €/l**



- Renewable kerosene can‘t compete against fossil kerosene
- Renewable electricity price has to decrease tremendously in order to make PtL fuels competitive
- How to reduce the costs for renewable kerosene?
  - Increasing and subsidizing renewable power production
  - Increase efficiency (e.g. electrolyzer)
  - Reduce PtL CAPEX (e.g. electrolyzer, FT synthesis)
  - System integration (Sector coupling and multiple products: Fuel, chemicals, district heat, steam, oxygen, power-storage, etc.)

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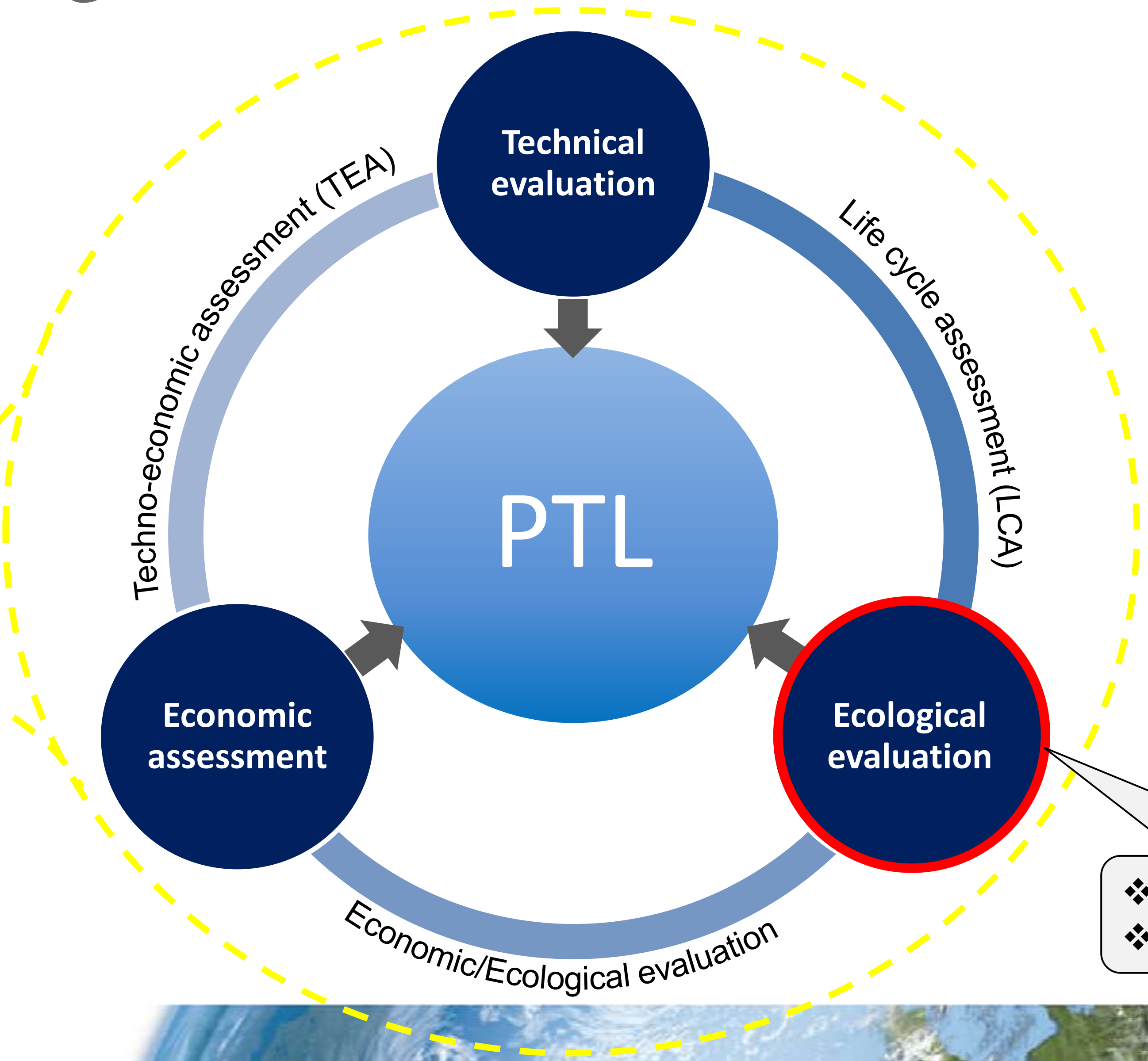
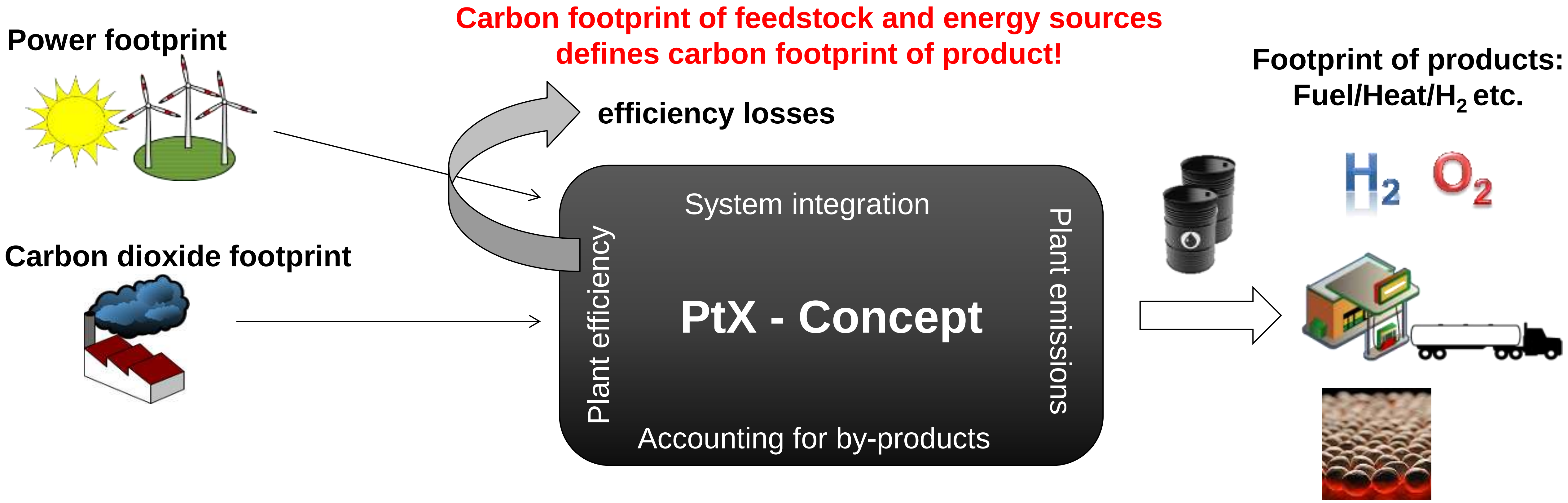
DLR-evaluation and optimization tool

TEPET – Standardizing economic process evaluations



- CO_2-footprint
- CO_2-abatement costs

3. CO_2-Footprint Calculation - Methodology



$$CO_2\ Abatement\ Costs\left[\frac{€}{t_{CO_2}}\right] = \frac{Difference\ in\ Fuel/Heat/H_2\ Costs}{CO_2\ Emission\ Reduction}$$

3. CO_2-Footprint calculation - Bounderies



	Power	Carbon dioxide	Oxygen
Functional unit	**[kg_{CO2eq}/MWh][a]**	**[kg_{CO2eq}/t][b]**	**[kg_{CO2eq}/t] [c]**
Low boundary	10	5	100
Average	272.5	77.5	250
High boundary	535	150	400

[a] 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].
[b] 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.
[c] 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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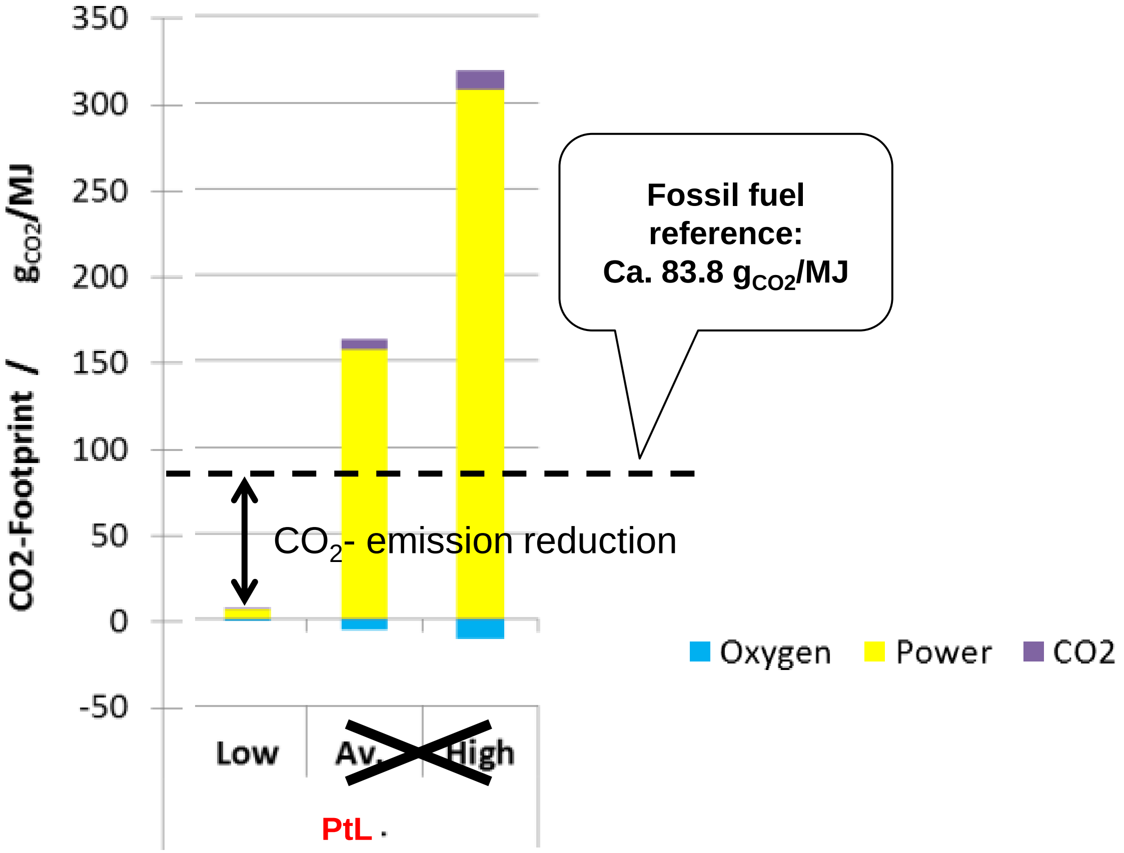
3. CO_2-Footprint - Results

$$CO_2\ Abatement\ Costs\ \left[\frac{€}{t_{CO_2}}\right] = \frac{Difference\ in\ Fuel/Heat/H_2\ Costs}{CO_2\ Emission\ Reduction}$$



PtL-concepts only viable using CO_2-neutral power!

CO_2-Abatement costs:

Case 1 – Status quo:
Price of fossil kerosene: ca. 0.5 €/l
Power price: 83.7 €/MWh

Case 2 – Pressure on fossil energy:
Price of fossil kerosene: ca. 1.0 €/l
Power price: 30 €/MWh

CO_2-Abatement costs	€ / t_{CO_2}
Case	PtL-Low
1	827
2	155

Current CO_2 price of EU Emissions Trading System:
ca. 5-15 €/$t_{CO2.eq}$

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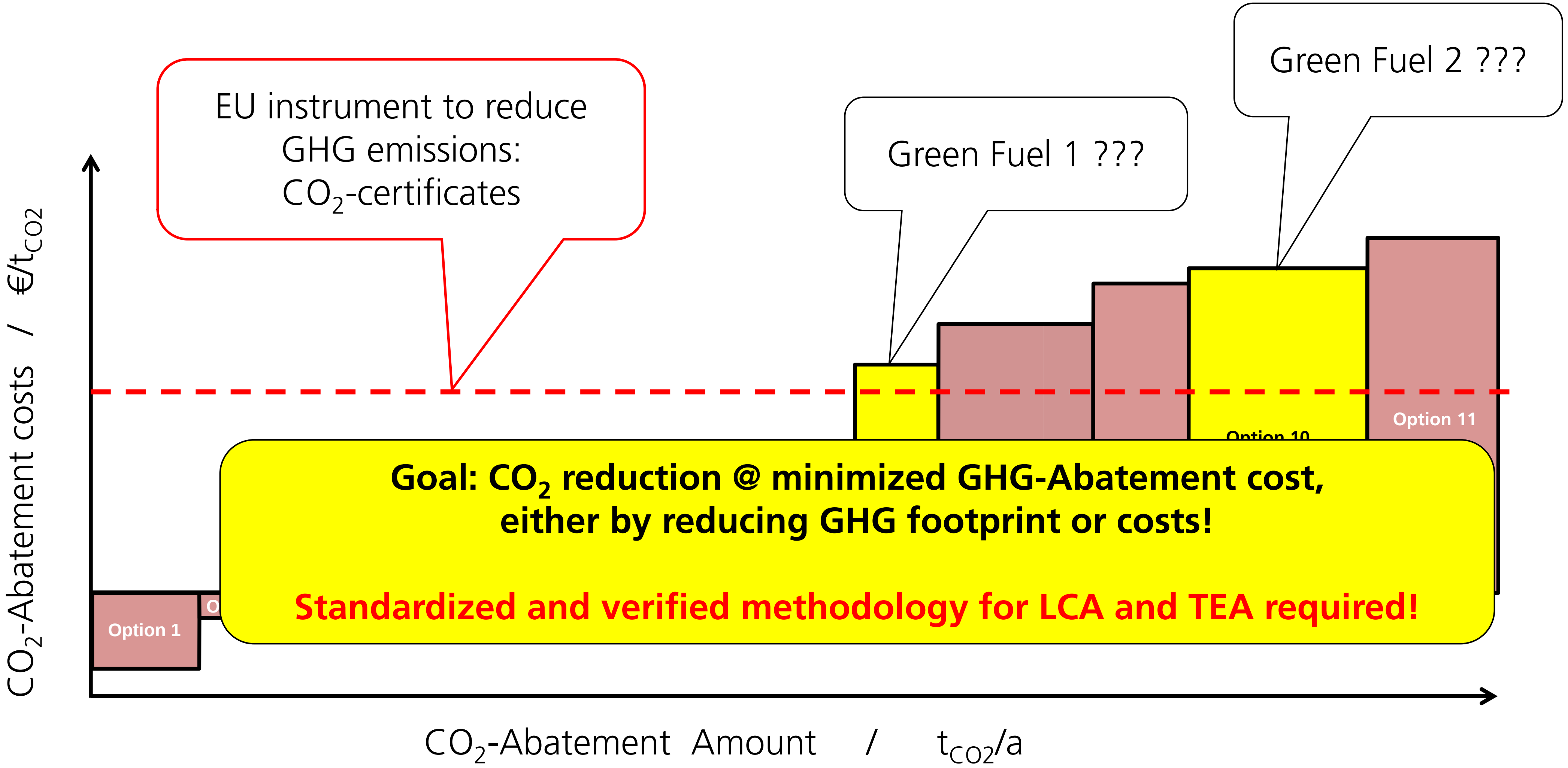
3. Long-term Target: Merit-Order of Carbon Mitigation Technologies



Goal: CO_2 reduction @ minimized GHG-Abatement cost, either by reducing GHG footprint or costs!

Standardized and verified methodology for LCA and TEA required!

4. Summary & Outlook

- European GHG emission reduction by 1 % p.a. required – only 5 EU28 countries on track
- Renewable kerosene will be long-term required for aviation
- Transparent and standardized methodology for cost estimation and GHG-footprint calculation available @ DLR
- European green fuels have large potential to contribute to GHG emission reduction
- **Research, development, demo and market introduction of sustainable aviation fuels need to speed up - R&D&D alone will never achieve (energy price) competitiveness**

THANK YOU FOR YOUR ATTENTION!

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