Chair of Energy Systems
TUM School of Engineering and Design
Technical University of Munich

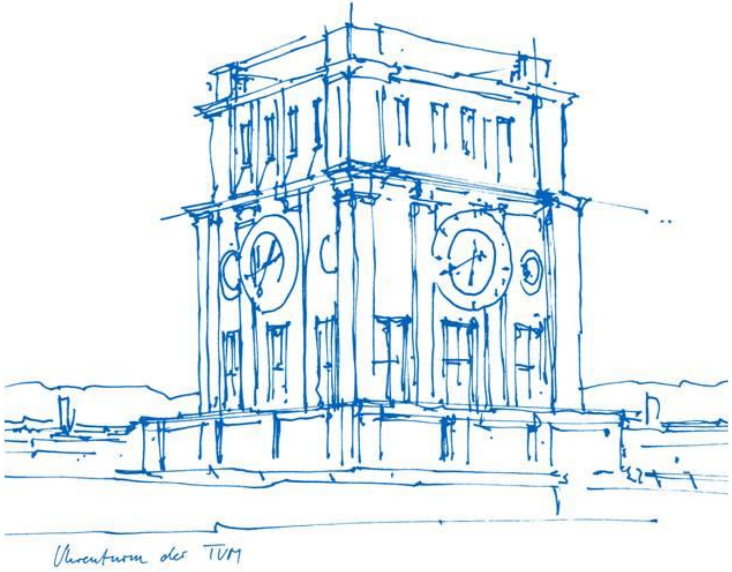
Maximizing carbon efficiency through electrolysis for an advanced biomass-to-liquid process producing sustainable aviation fuels

Marcel Dossow, Sebastian Fendt, Harmut Spliethoff

Technical University of Munich
TUM School of Engineering and Design
Chair of Energy Systems

19th International Conference on Renewable Mobility
Fuels of the Future 2022

Munich, 27th January 2022

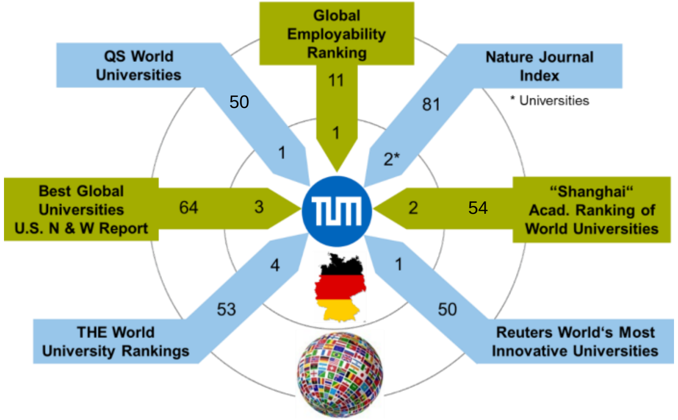


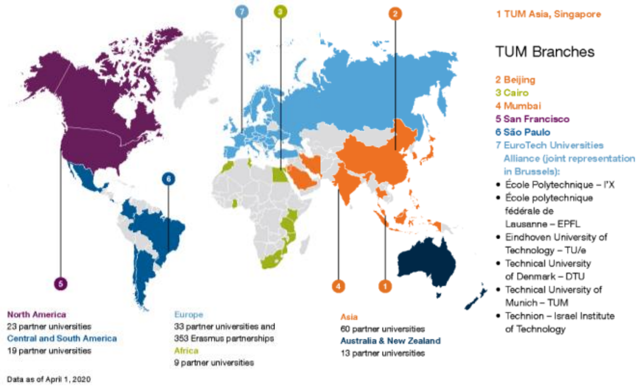
Technical University of Munich

Overview

TUM in numbers

- 11 TUM schools and Departments
- 6 Integrative Research Centers
- 7 Corporate Research Centers
- 11,269 staff members, 48 000 students & 612 professors
- 183 degree programs
- 17 Nobel prizes





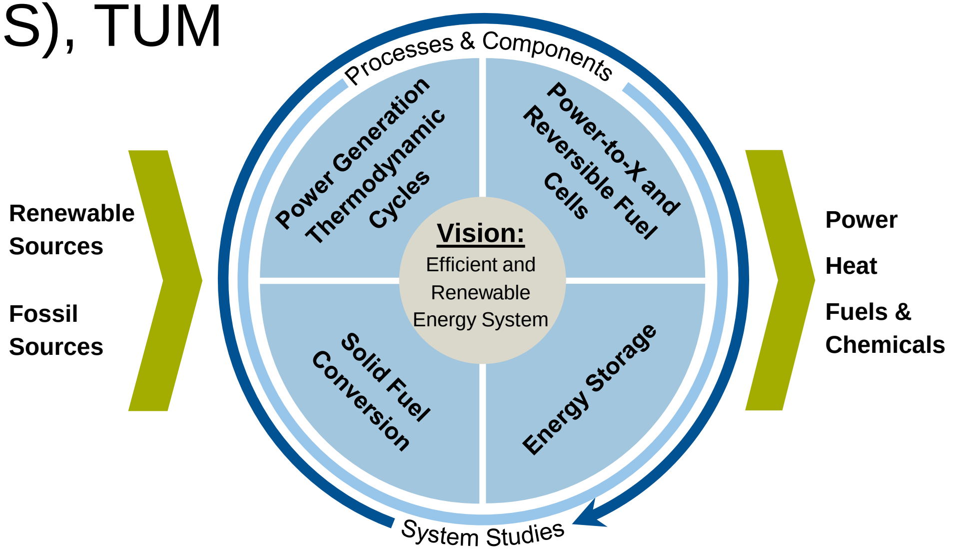
→ https://www.tum.de/

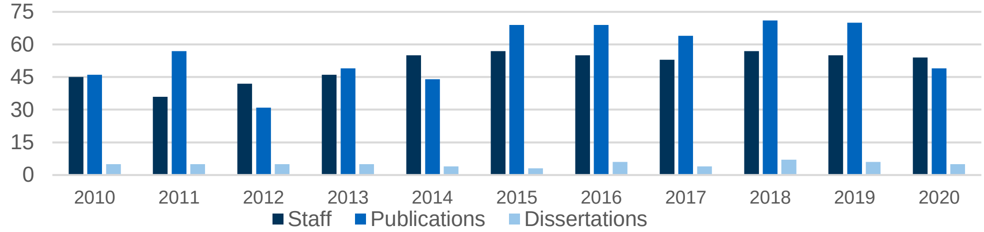
Chair of Energy Systems (CES), TUM

Chair of Energy Systems
Prof. Dr.-Ing. H. Spliethoff

<u>Staff</u>: (01.06.2021)
- 60 Employees
- 35 PhD students
- 5 Postdocs

<u>Supervisors:</u>
- Gleis, Stephan, Dr.-Ing.
- Wieland, Christoph, Dr.-Ing.
- Kerscher, Florian, M.Sc.
- Fendt, Sebastian, Dr.-Ing.
- Herrmann, Stefan, Dr.-Ing.





TUM.Hydrogen & Power-to-X

Research on Hydrogen and Power-to-X

From basic, laboratory research and pilot scale application to integration in the energy system

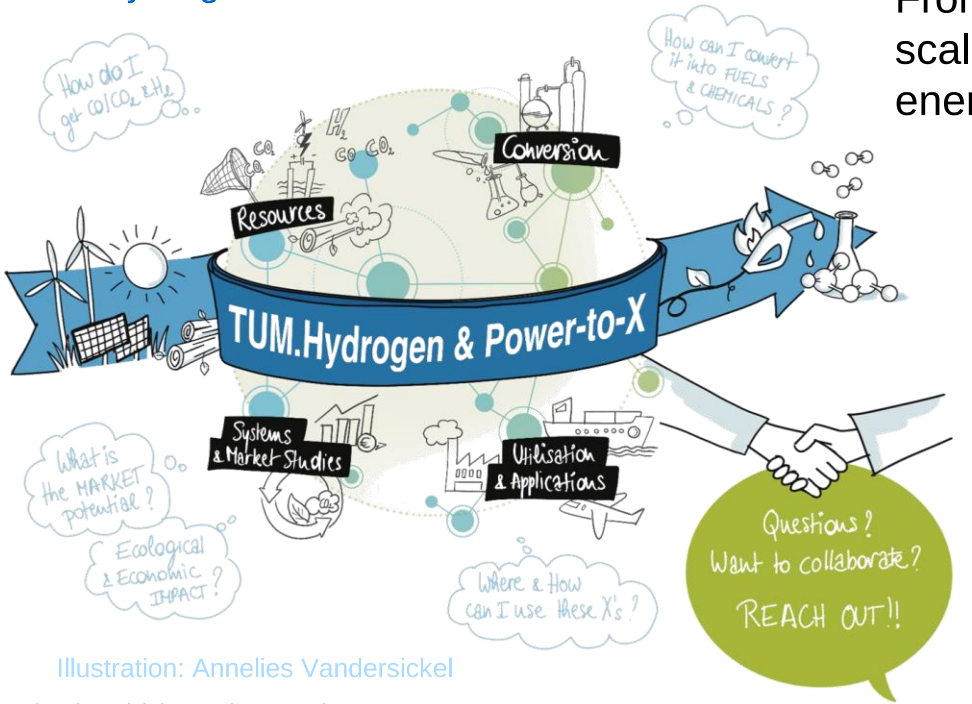


Illustration: Annelies Vandersickel

WASSERSTOFF BÜNDNIS BAYERN

Contact

TUM.Hydrogen & Power-to-X
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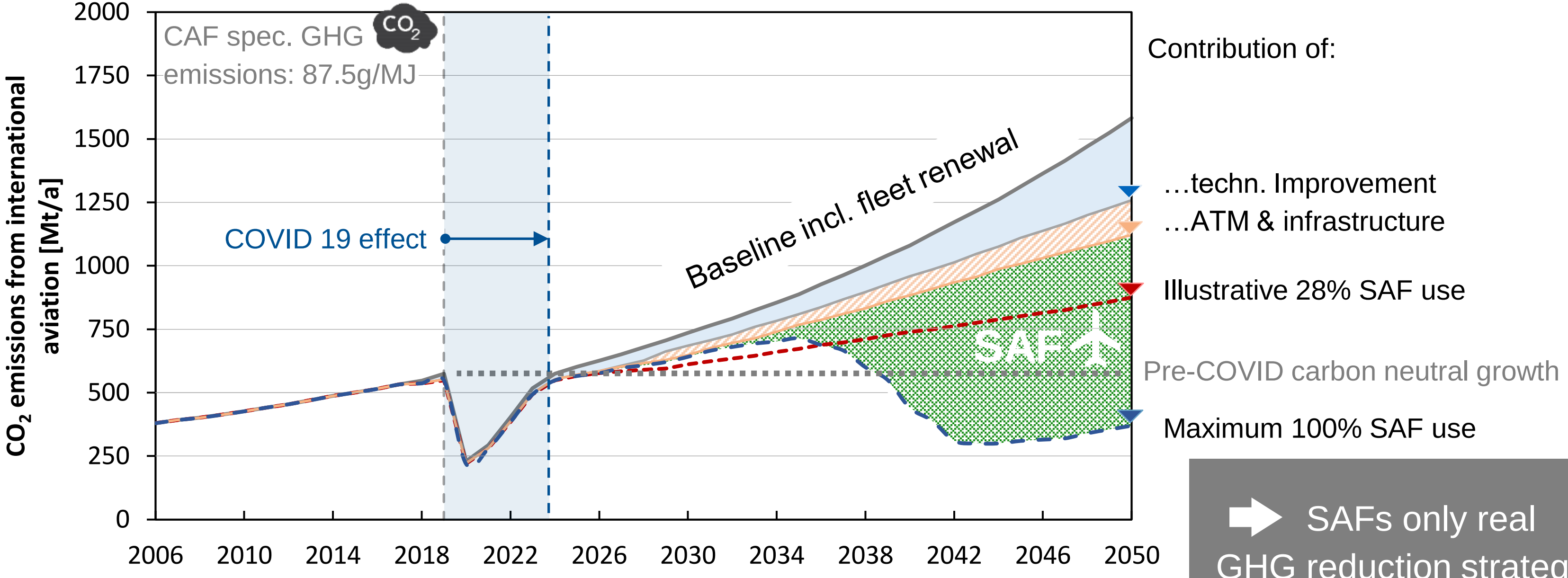
Motivation for sustainable aviation fuels

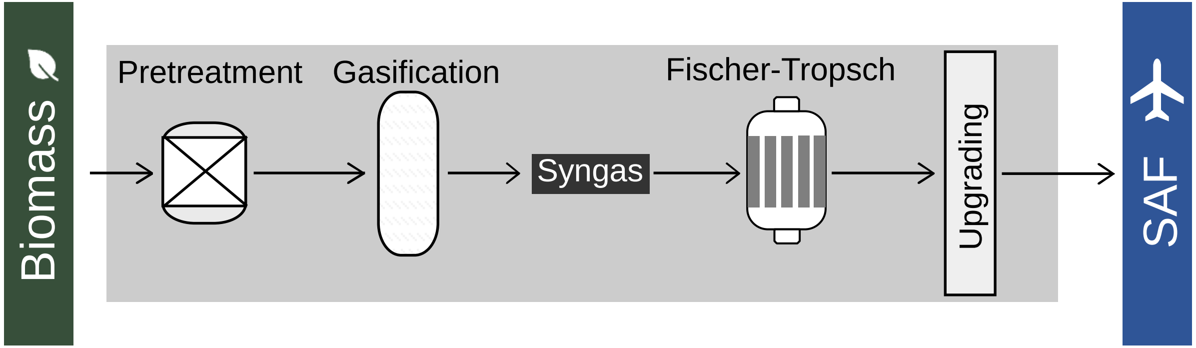
Forecast on GHG emissions from international aviation



➡ SAFs only real GHG reduction strategy

FT pathway and BtL modeling

Conversion of lignocellulosic biomass through gasification and Fischer-Tropsch synthesis

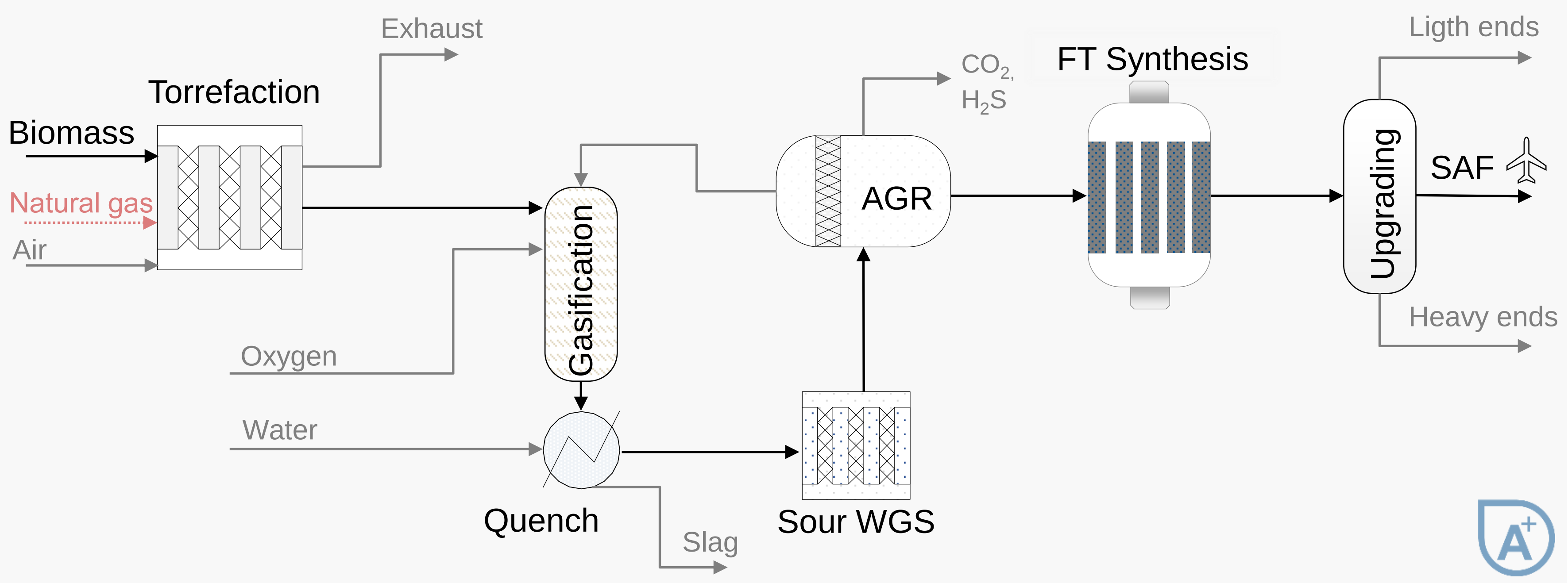


Production potential?
GHG emission reduction?

➡ Detailed thermo-dynamic modelling of FT process route

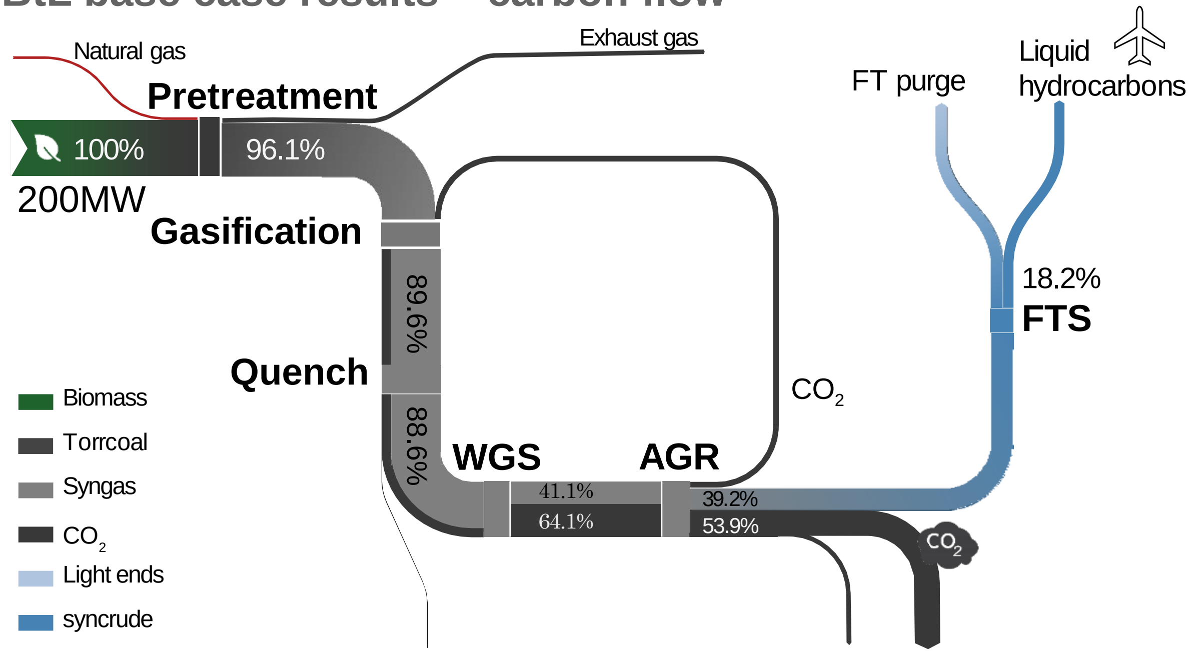
FT pathway and BtL modeling

Aspen Plus BtL base case simulation

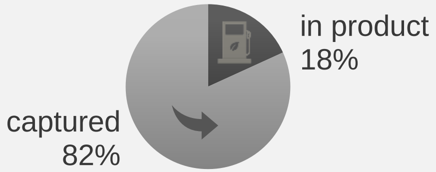


BtL simulation results

BtL base case results – carbon flow



Carbon efficiency



Product yield: 0.11t/BDT

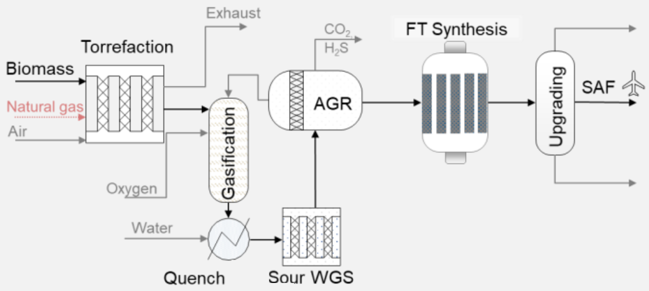
Energy efficiency 18.5%

GHG emissions 48.71g/MJ

BtL simulation results

Aspen plus BtL simulation cases

Base case



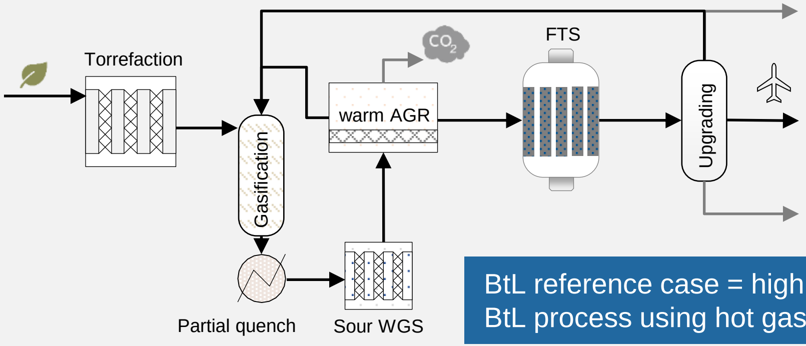
Carbon efficiency

Product yield: 0.24t/BDT

Energy efficiency 45.4%

GHG emissions 20.78g/MJ

Reference case

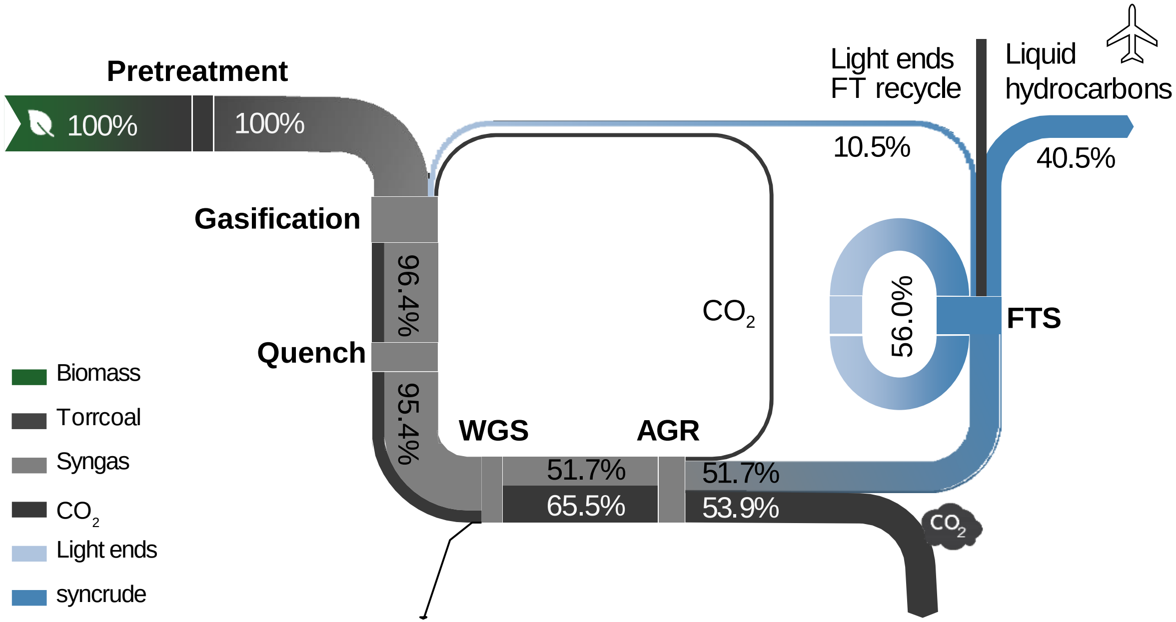


BtL reference case = highly integrated BtL process using hot gas cleaning

- Exhaust heat for torrefaction, recycle to gasification, direct FT recycle
- Hot gas filtration after gasification
- Warm AGR (ZnO, PSA)

BtL simulation results

BtL reference case results – carbon flow



Carbon efficiency

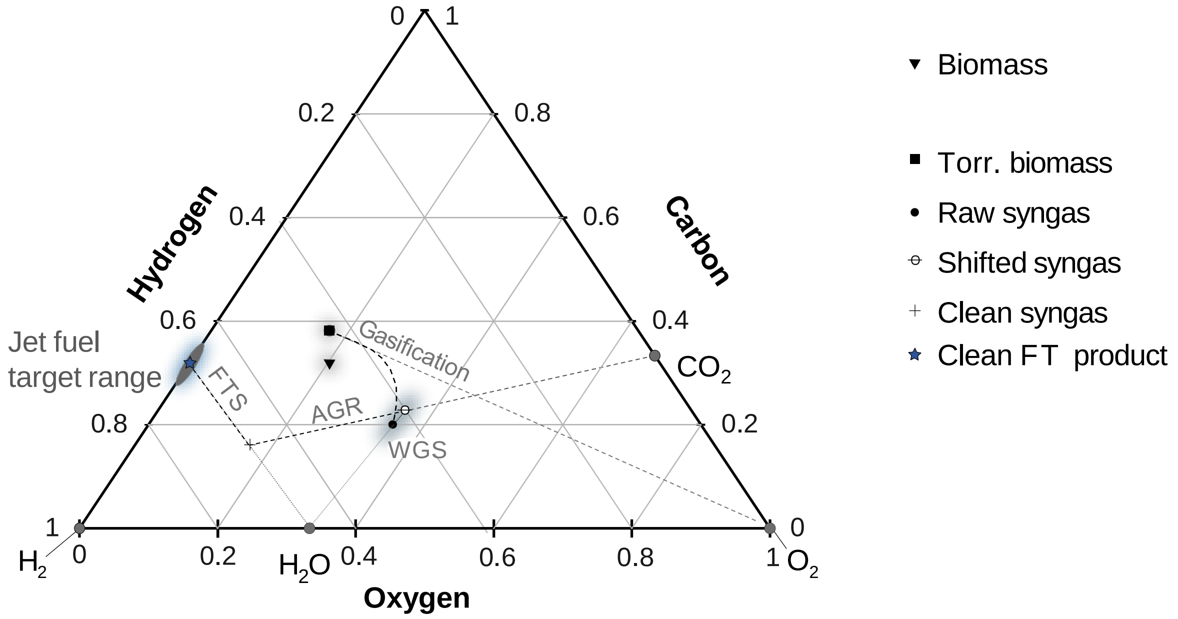
Product yield: 0.24t/BDT

Energy efficiency 45.4%

GHG emissions 20.78g/MJ

BtL simulation results

Limited carbon conversion efficiency



low hydrogen to carbon ratio in the initial biomass

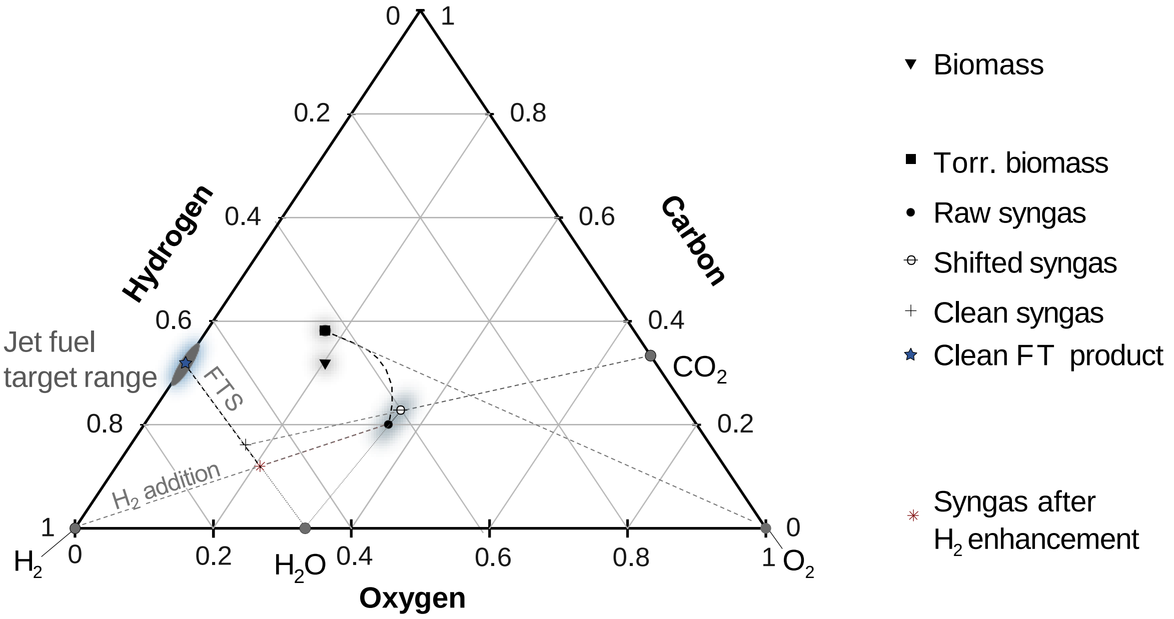
CO_2

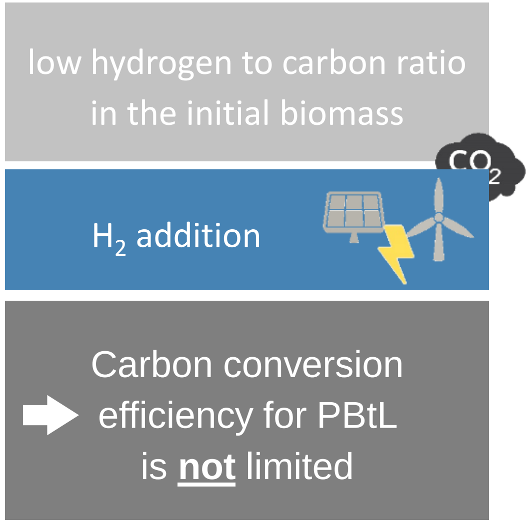
➡ CO_2 removal inevitable

➡ Carbon conversion efficiency for BtL processes is limited

BtL simulation results

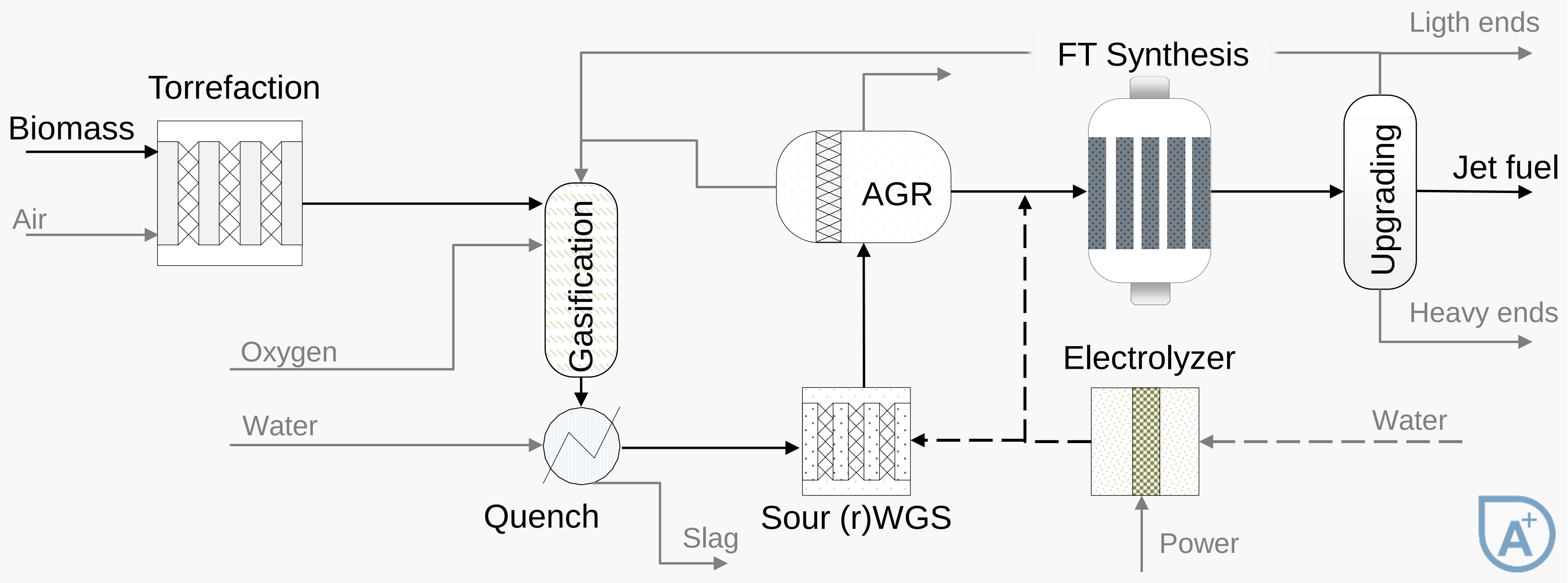
A power-and-biomass-to-liquid (PBtL) approach





Hydrogen enhancement - PBtL approach

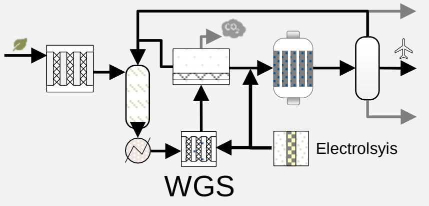
Aspen Plus PBtL simulation

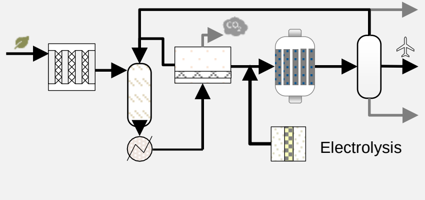


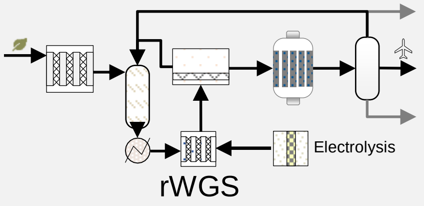
Hydrogen enhancement - PBtL approach

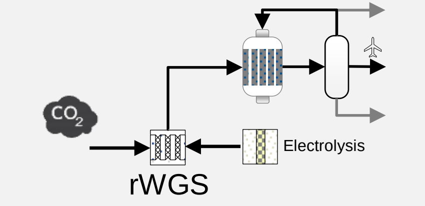
Aspen Plus PBtL simulation cases

PBtL case 1	PBtL case 2	PBtL case 3	PtL reference case
PEM/SO electrolysis	PEM/SO electrolysis	PEM/SO electrolysis	PEM electrolysis
WGS to produced oxygen for gasification	No WGS reduced process complexity	Max. reverse WGS Max. carbon conversion	CO_2 point source Full reverse WGS







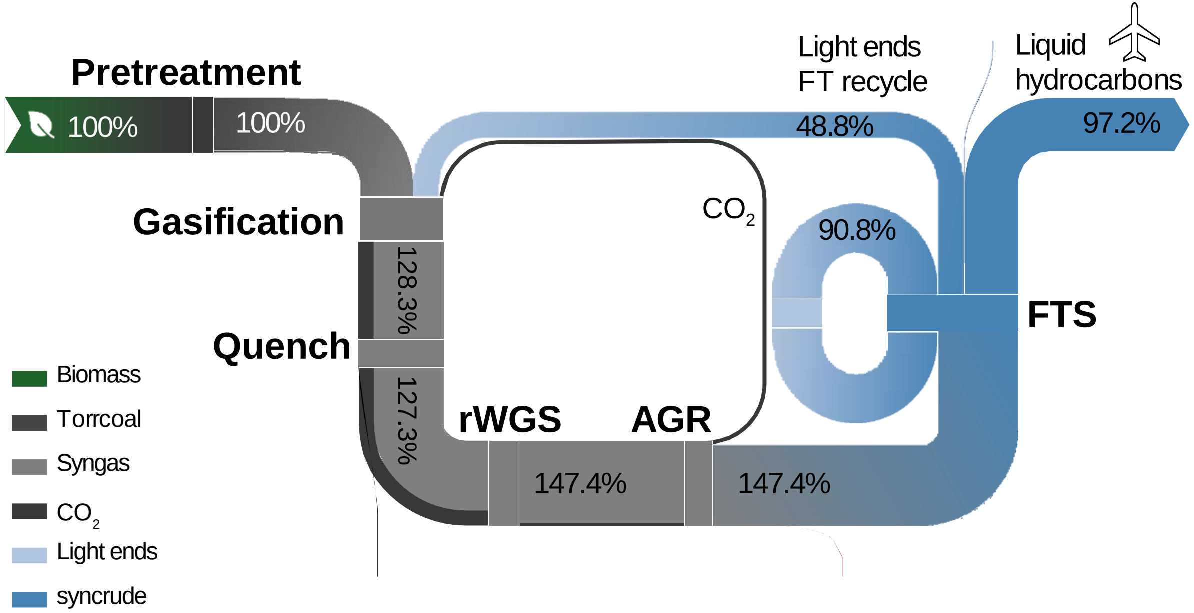


Electrolyzer size

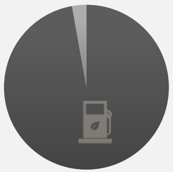
H_2 requirement

Hydrogen enhancement - PBtL approach

Aspen Plus PBtL case 3 results – carbon flow



Carbon efficiency



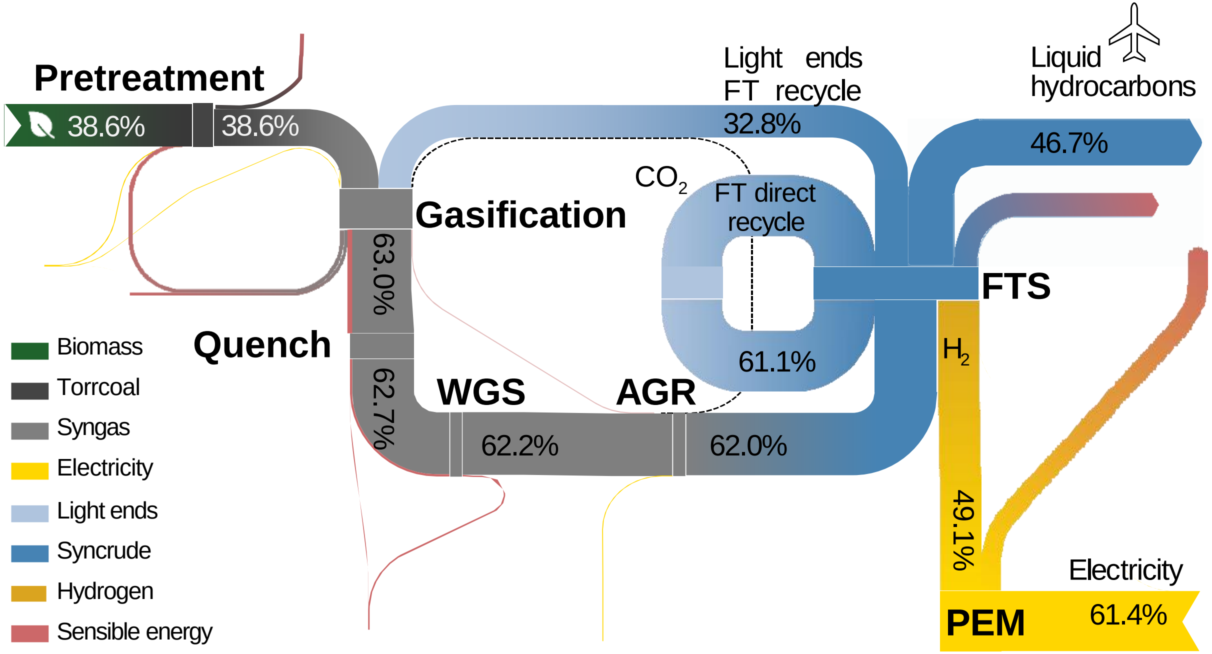
Product yield: 0.57t/BDT

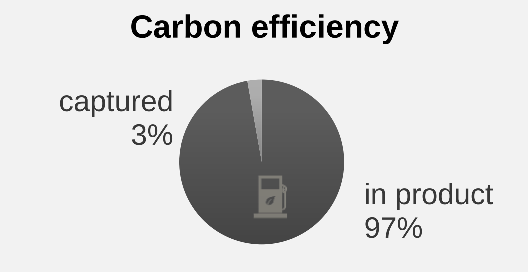
Energy efficiency 45.8%

GHG emissions 150.9g/MJ

Hydrogen enhancement - PBtL approach

Aspen Plus PBtL case 3 results – energy flow





Product yield: 0.57t/BDT

Energy efficiency 45.8%

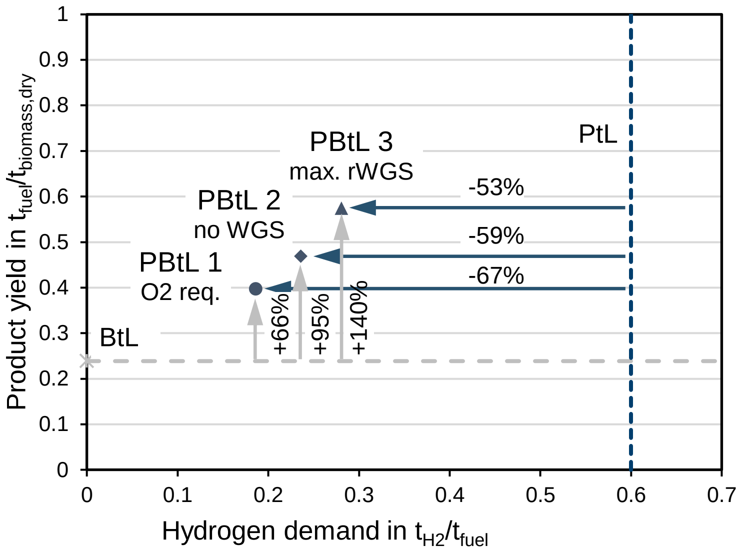
GHG emissions 150.9g/MJ

Electrolyzer size 320MW

H_2 required 0.28t/t$_{product}$

Hydrogen enhancement - PBtL approach

Aspen Plus PBtL results comparison



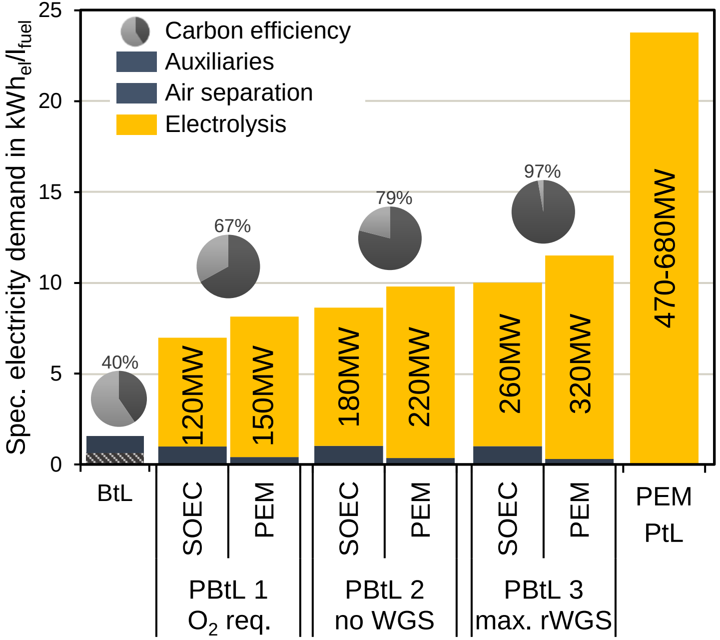
Amount of produced fuel more than doubled compared to BtL cases

Amount of required hydrogen reduced by more than 50%

H_2 required for PBtL
0.19-0.28t/$t_{product}$

Hydrogen enhancement - PBtL approach

Aspen Plus PBtL results comparison



Amount of produced fuel more than doubled compared to BtL cases

➔ **Carbon conversion efficiency**
67-97%

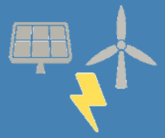
Amount of required hydrogen reduced by more than 50%

H_2 required for PBtL
0.19-0.28t/t$_{product}$

Total electricity required
7.0-11.5kWh/l$_{product}$

SOEC reduces electrolyzer size by about 20%

Electrolysis requirement reduced by ~50% compared to PtL



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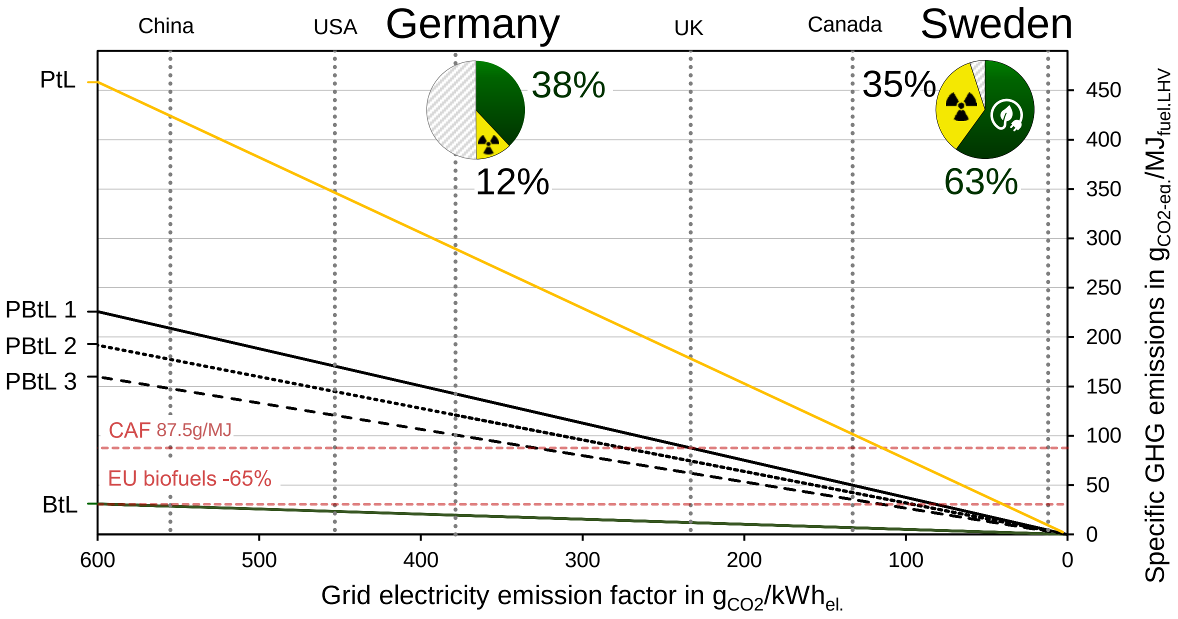


→ 65% GHG emission reduction requires low emissions from electricity

Conclusion

Syngas-to-fuel (FT) pathway for SAF production

- Detailed process modeling shows huge potential of novel BtL and PtL combination.
- Novel process offers high potential to defossilize transportation, i.e. aviation.

BtL pathway

- Carbon conversion efficiency limited to 40%
- GHG emission reduction up to 76%

PBtL pathway

- Carbon conversion efficiency increased to 97%
- Required electrolyzer sizes are about 60%–160% of the biomass input: >120MW for 200MW PBtL plant
- Low emission factor needed for GHG reduction
- Use of electrolysis O_2 within the process and smaller electrolyser sizes offer advantage over PtL process routes

Dossow M, Dieterich V, Hanel A, Spliethoff H, Fend S:
Improving carbon efficiency for an advanced Biomass-to-Liquid process using hydrogen and oxygen from electrolysis,
Renewable and Sustainable Energy Reviews, 2021 (152) https://doi.org/10.1016/j.rser.2021.111670.

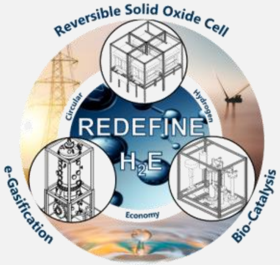
Outlook – Future Work

Currently: Techno-Economic Assessment

- Process option selection
- SAF production and selling price
- CO_2 mitigation price

Next Steps:

- Dynamics of hydrogen production/availability/storage
- FutureLab H_2E REDEFINE
  - Electrically assisted gasification as alternative to H_2 addition from electrolysis
  - Integration SOEC (Co-electrolysis) as alternative to H_2 addition from electrolysis
- Scenarios and possible locations for PBtL plant



Thank you for your attention

any questions?

Marcel Dossow, S. Fendt, H. Spliethoff

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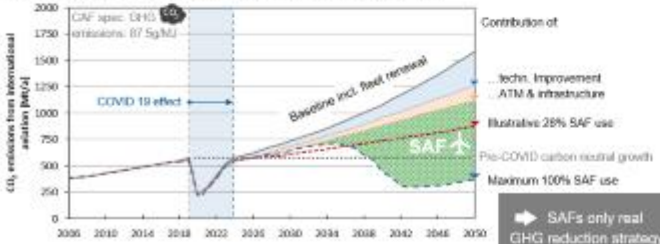

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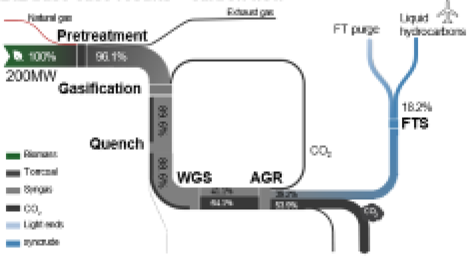


Carbon efficiency

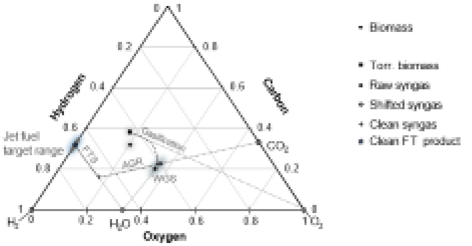
in product 18%

captured 82%

Product yield: 0.11t/BDT
Energy efficiency 18.5%
GHG emissions 48.71g/MJ

BtL simulation results

Limited carbon conversion efficiency



- Biomass
- Torr. biomass
- Raw syngas
- Shifted syngas
- Clean syngas
- Clean FT product

low hydrogen to carbon ratio in the initial biomass

➡ CO_2 removal inevitable

➡ Carbon conversion efficiency for BtL processes is limited

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