Electrification of gasification-based Biomass-to-X processes

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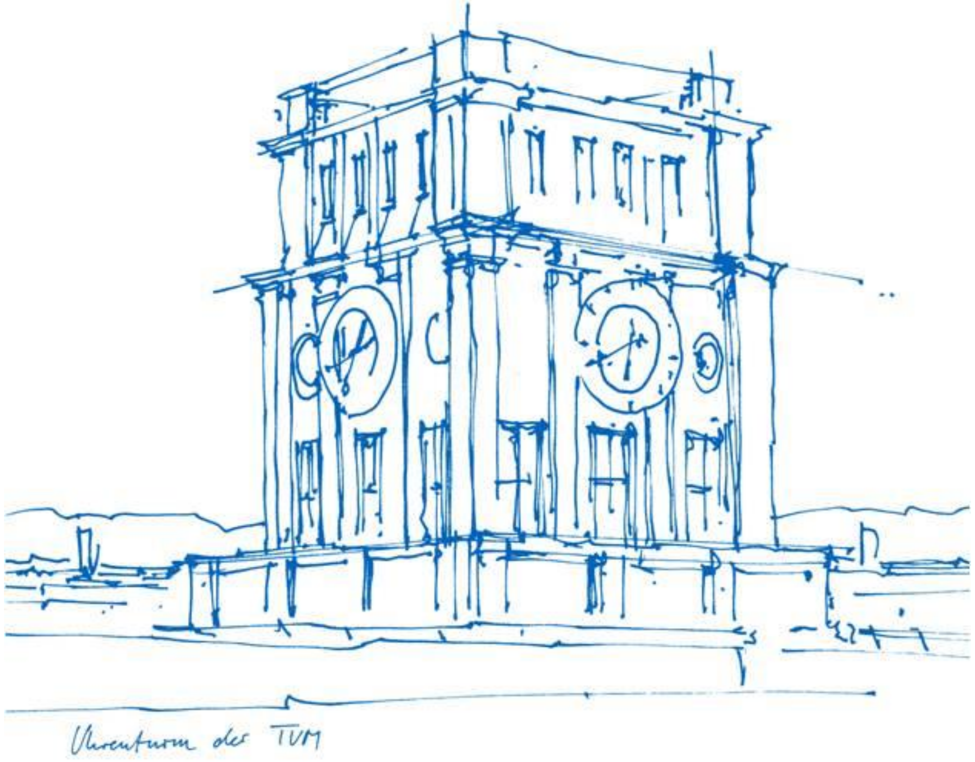
TUM School of Engineering and Design

Chair of Energy Systems

TUM.Hydrogen and PtX

Karlsruhe, 2024/06/12

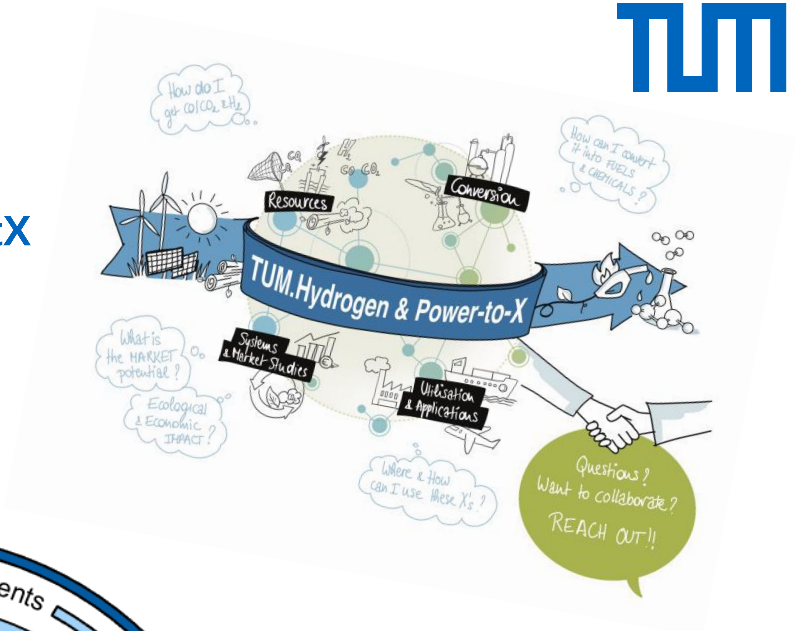
IEA Task 33 Workshop



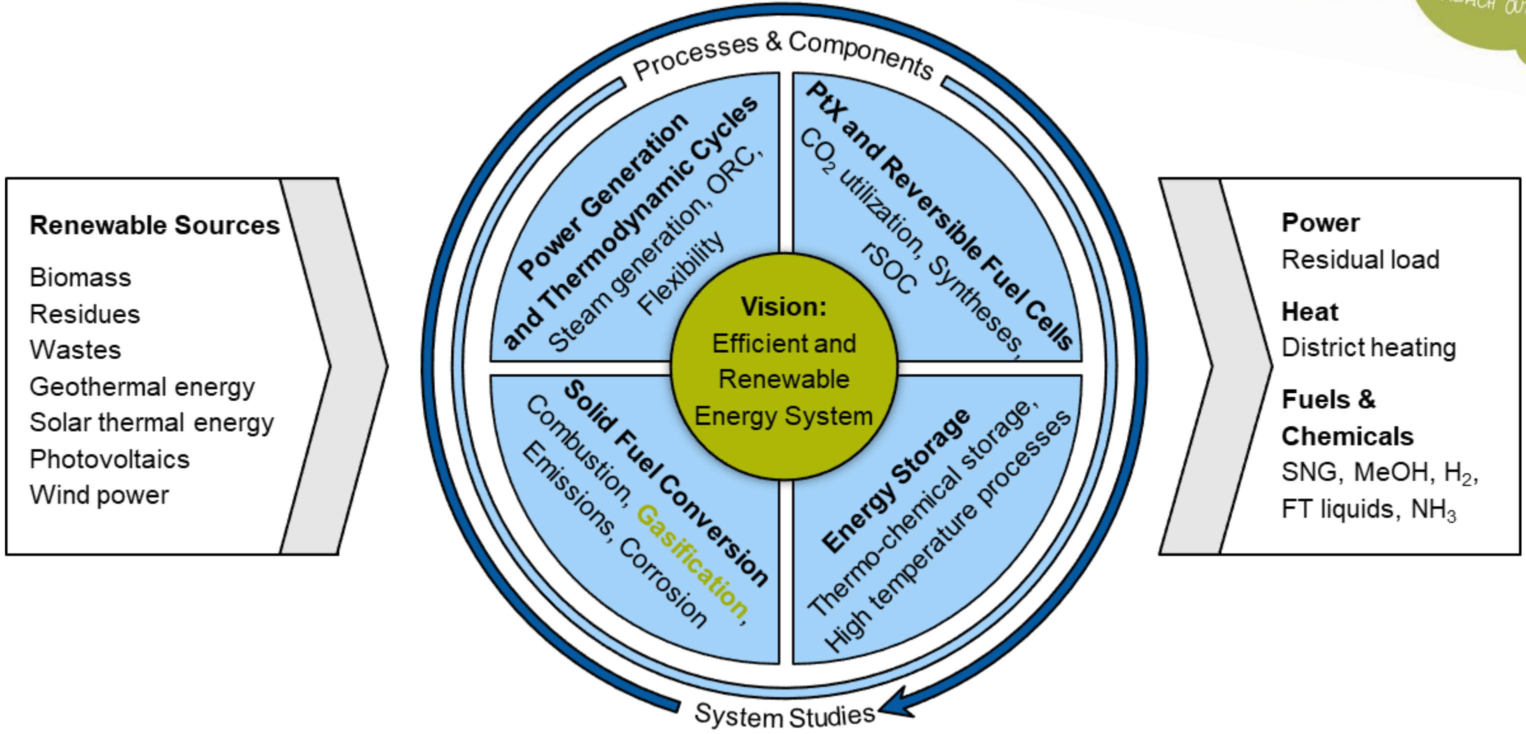
Intro: Chair of Energy Systems (CES)

Research and Technology Areas

TUM.Hydrogen and PtX



- Chair: Prof. Dr.-Ing. Hartmut Spliethoff
- Located at the Campus Garching, north of Munich (6.000 employees, 12.000+ students)
- Part of the TUM School of Engineering and Design
- CES-Staff: ~ 70 employees (~ 40 PhD students, 5 Postdocs)
  → https://www.epe.ed.tum.de/en/es

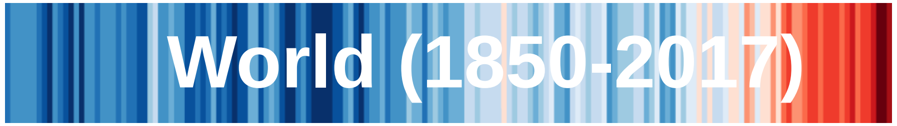


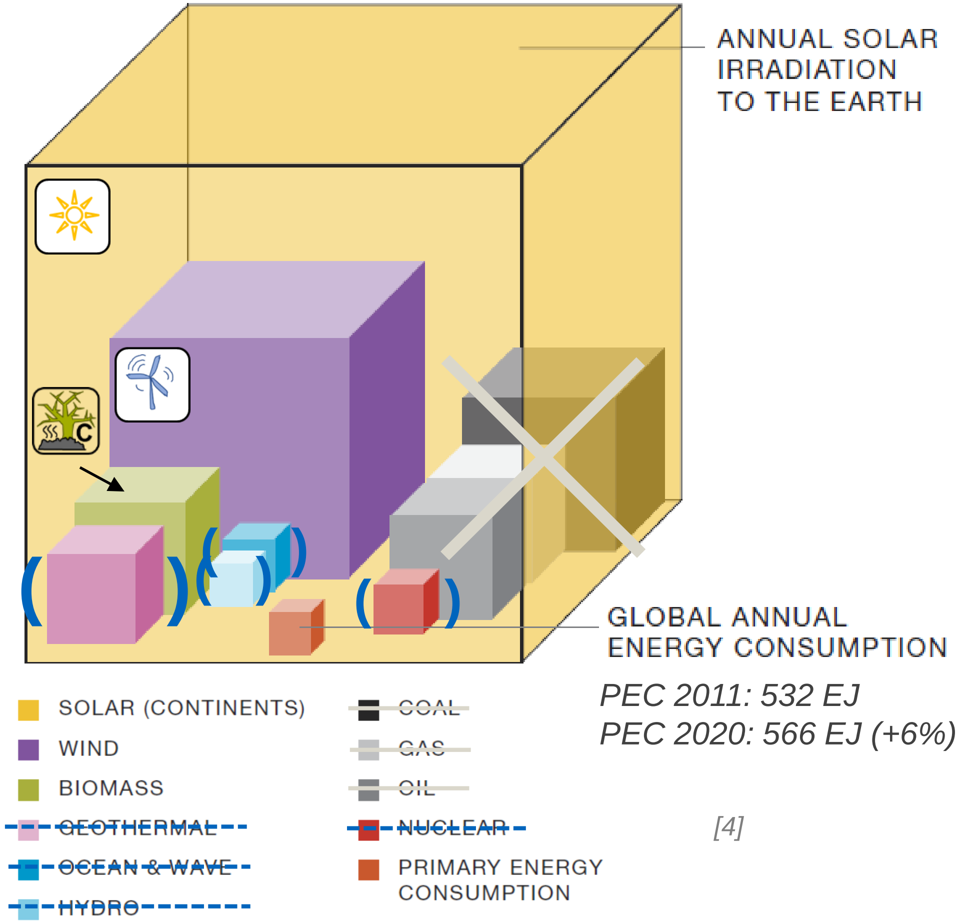
Content

Content

Motivation and context - transition towards RE

Where will our (primary) energy come from in the future – potentials!





PEC 2011: 532 EJ
PEC 2020: 566 EJ (+6%)

[4]

- **Coal, Gas and Oil**: need to be substituted in the future!
- **Nuclear:** not discussed as a potential future energy source here!
- **Geothermal**: very interesting, but mainly for heat sector, limited regional potential (Germany), not discussed in detail here!
- **Ocean and Wave**: limited potential for Germany!
- **Hydro**: limited potential in Germany!

→ **Main primary energy sources for Germany in the future:**

Solar, … **Wind and …** **Biomass/Waste**

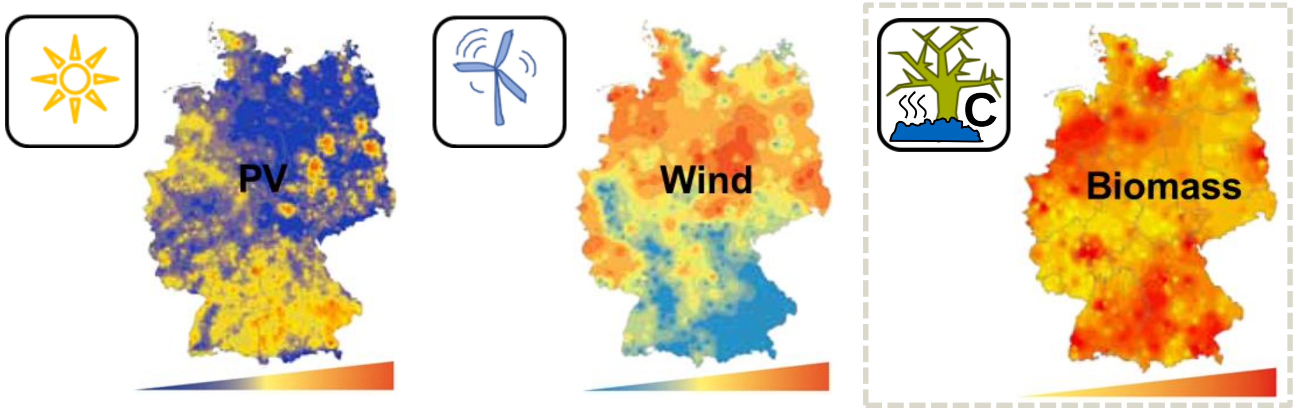
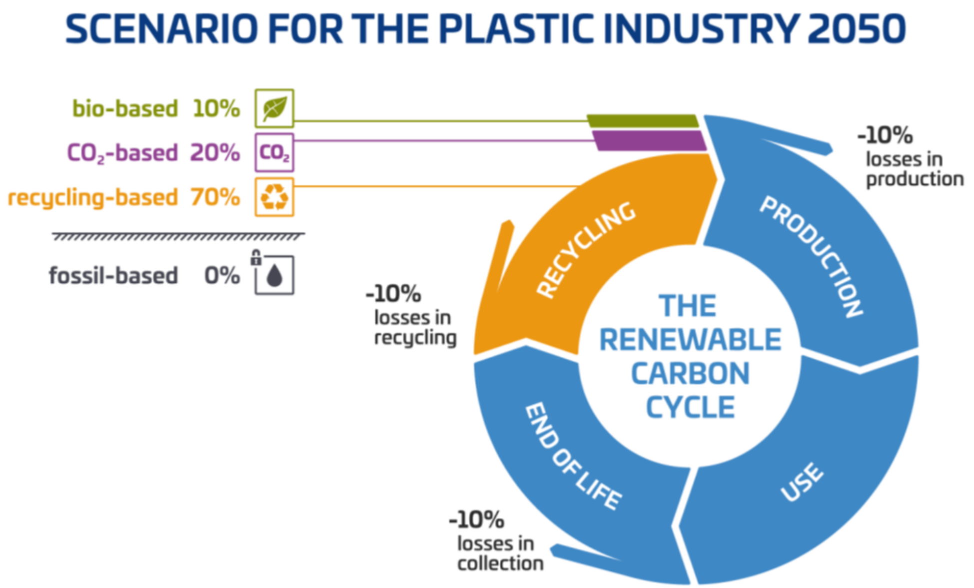


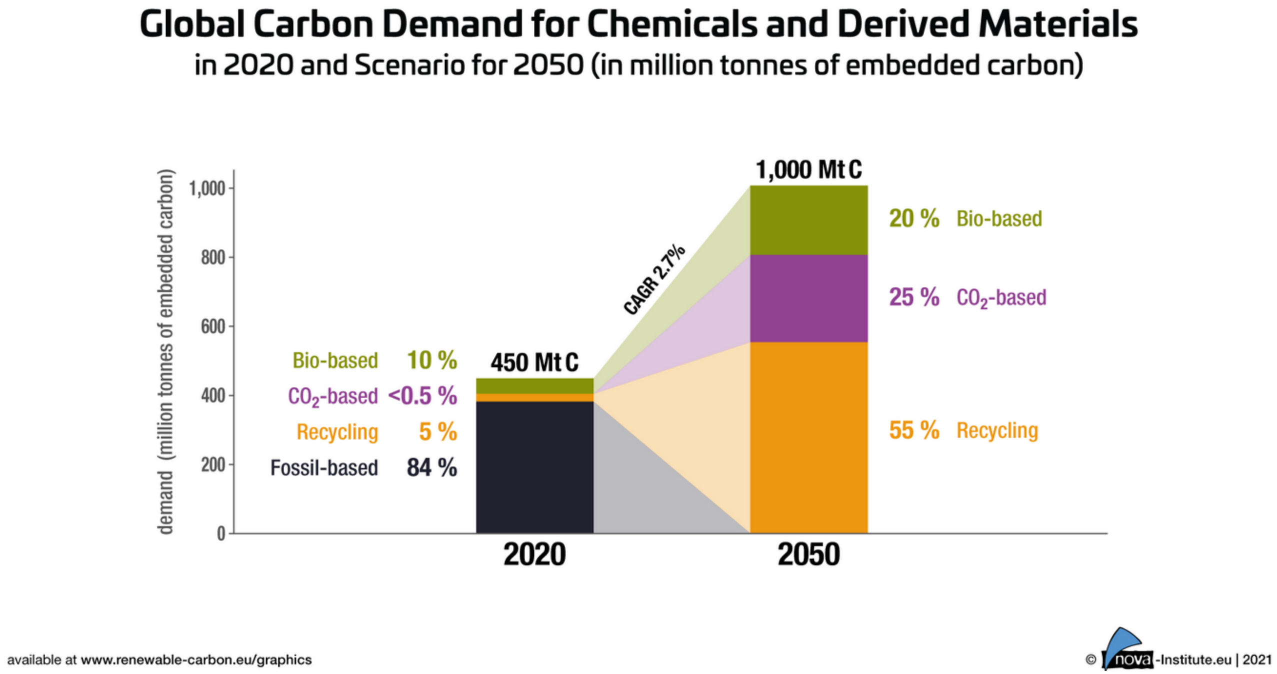
Fig: Distribution of the average el. power fed into the grid [5]

Motivation and context - carbon recycling / circular economy

Why is carbon recovery crucial?

- ➢ Decarbonization vs. defossilization
- ➢ Transition from a linear to a circular economy





- Recycling of carbon from unavoidable wastes crucial
- Biomass (and CC) most important **sustainable carbon** sources
- **Gasification** of waste streams as key technology in a future circular economy → **Carbon recovery** from difficult feedstock

[6], [7]

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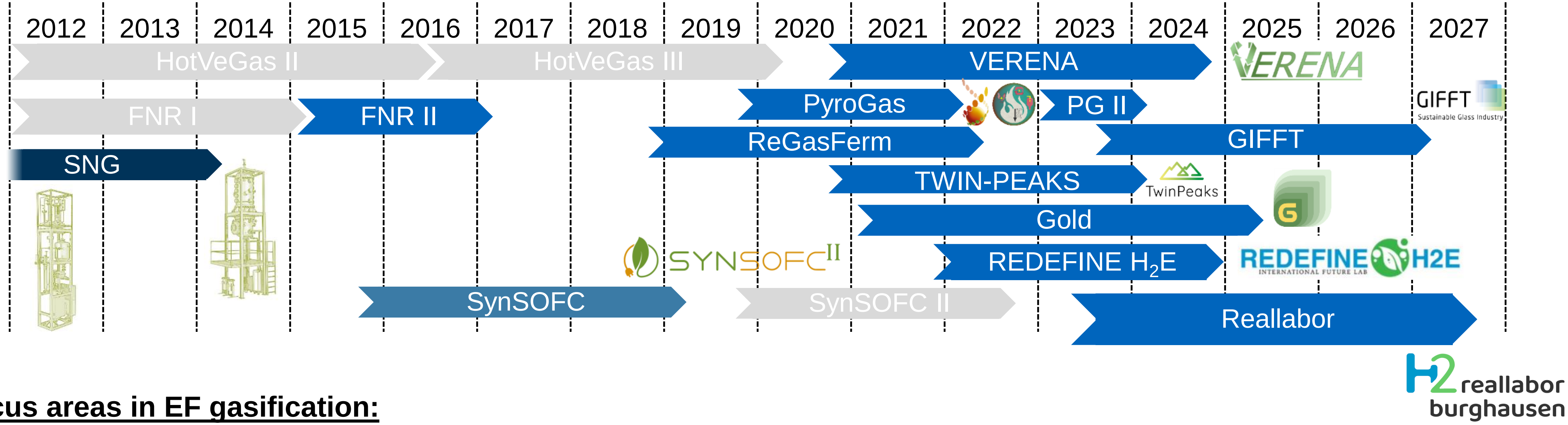
Overview of gasification research projects over the last years

Chronological overview of relevant gasification projects



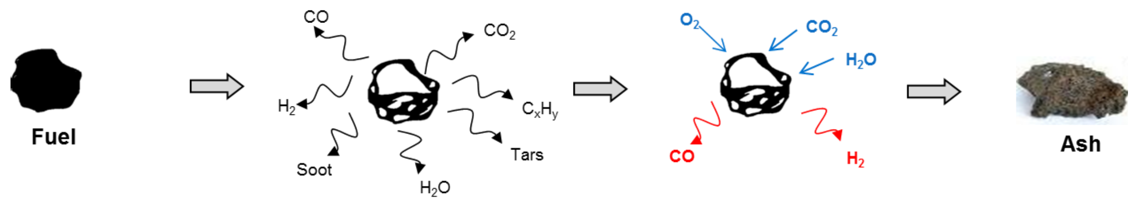
Focus areas in EF gasification:

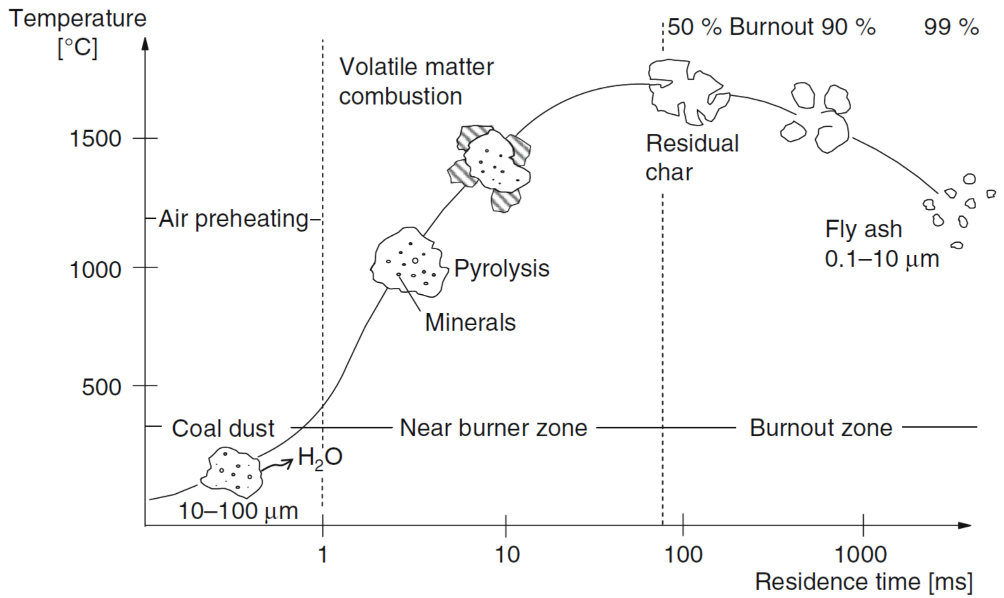
- Use of **low-grade/waste feedstock** e.g. phytoremediation or sewage sludge utilization (GOLD, VERENA and PyroGas)
- **Coupling of biological and thermochemical processes** to make use of synergies (ReGasFerm and GOLD)
- **Power integration** e.g. via plasma integration for either product enhancement and/or increase of yield and/or enabling very difficult feedstock to be used (Reallabor, GIFFT and REDEFINE) and/or hydrogen (VERENA)

Gasification research approach at TUM/CES

From basic understanding to applied research

Entrained flow gasification (EFG)





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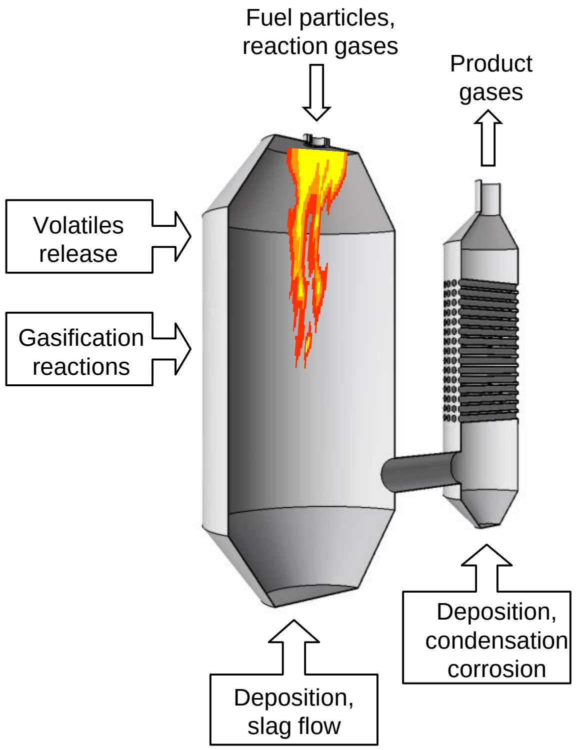
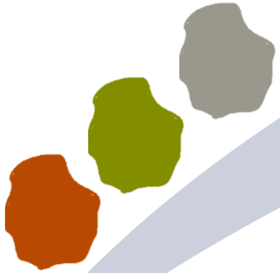


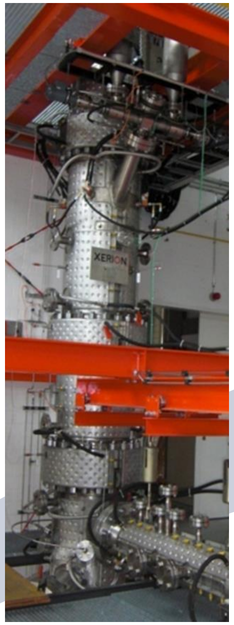
Combination of modeling and experimental investigation

EF gasification research needs both modeling and experimental investigations

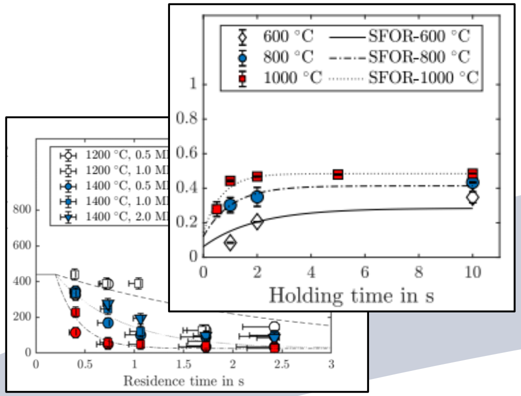
Model validation



Biomass and residues

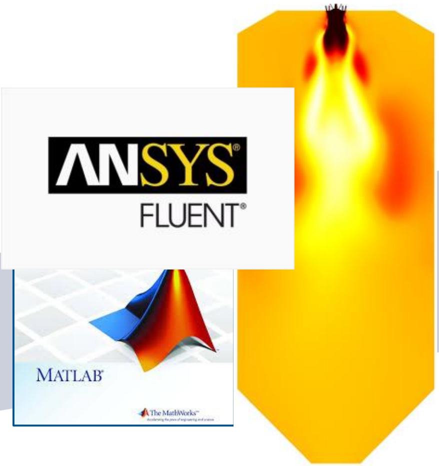


Experiments

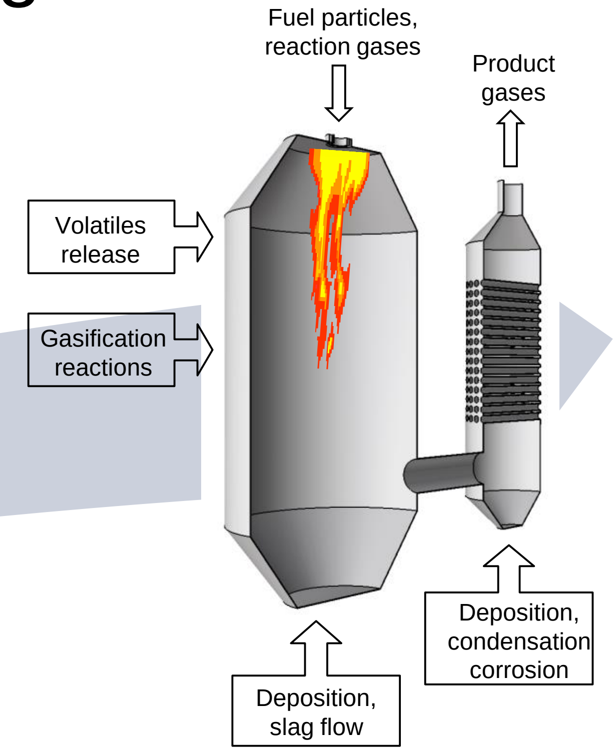


$$r_{obs} = \frac{\eta \cdot S \cdot k_{0,1} \exp\left(-\frac{E_{A,1}}{RT}\right) p_{VM}}{1 + k_{0,a} \exp\left(-\frac{E_{A,a}}{RT}\right) p_{VM} + k_{0,b} \exp\left(-\frac{E_{A,b}}{RT}\right) p_{PG}}$$

Models



Simulations

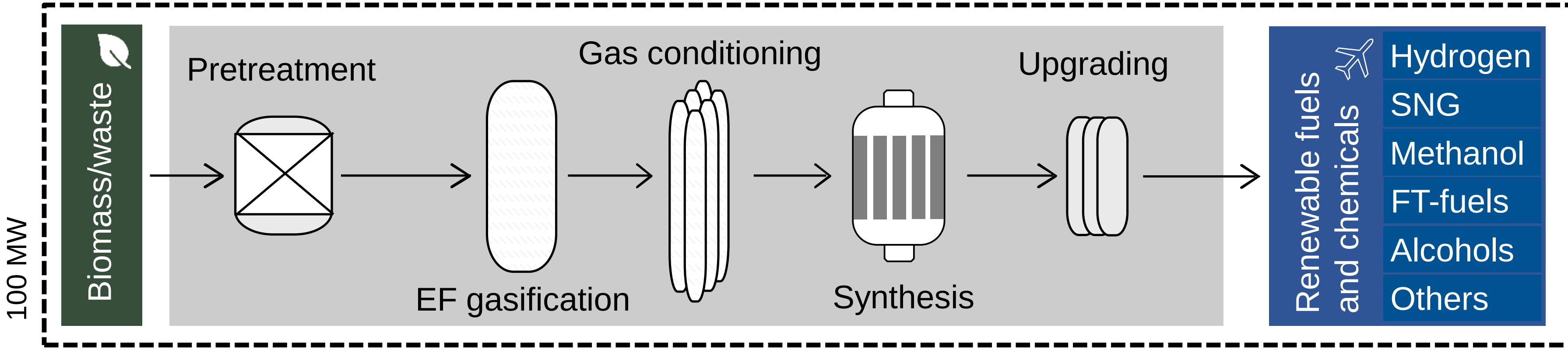


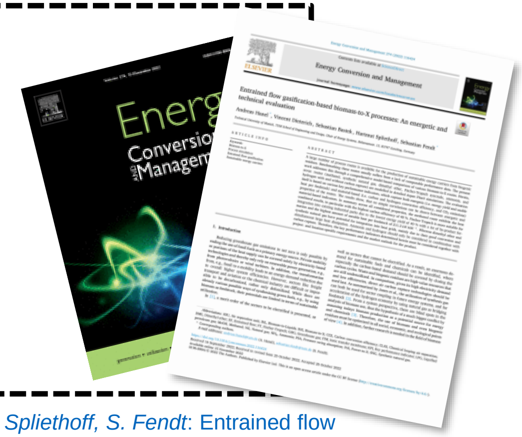
Design optimization

Sensitivity analysis

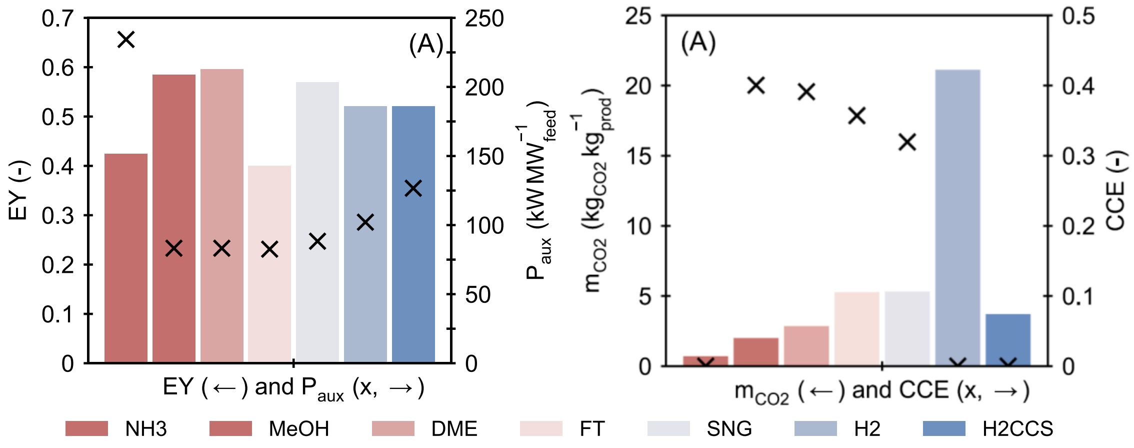
Overview of EF-based Biomass/Waste-to-X process options

Renewable fuels and chemicals from biomass via entrained flow gasification (EFG)





A. Hanel, V. Dieterich, S. Bastek, H. Spliethoff, S. Fendt: Entrained flow gasification-based biomass-to-X processes: An energetic and technical evaluation



Comparison of the energy efficiency and energy yield (A) and CO_2 emissions and carbon conversion efficiency for BtX routes

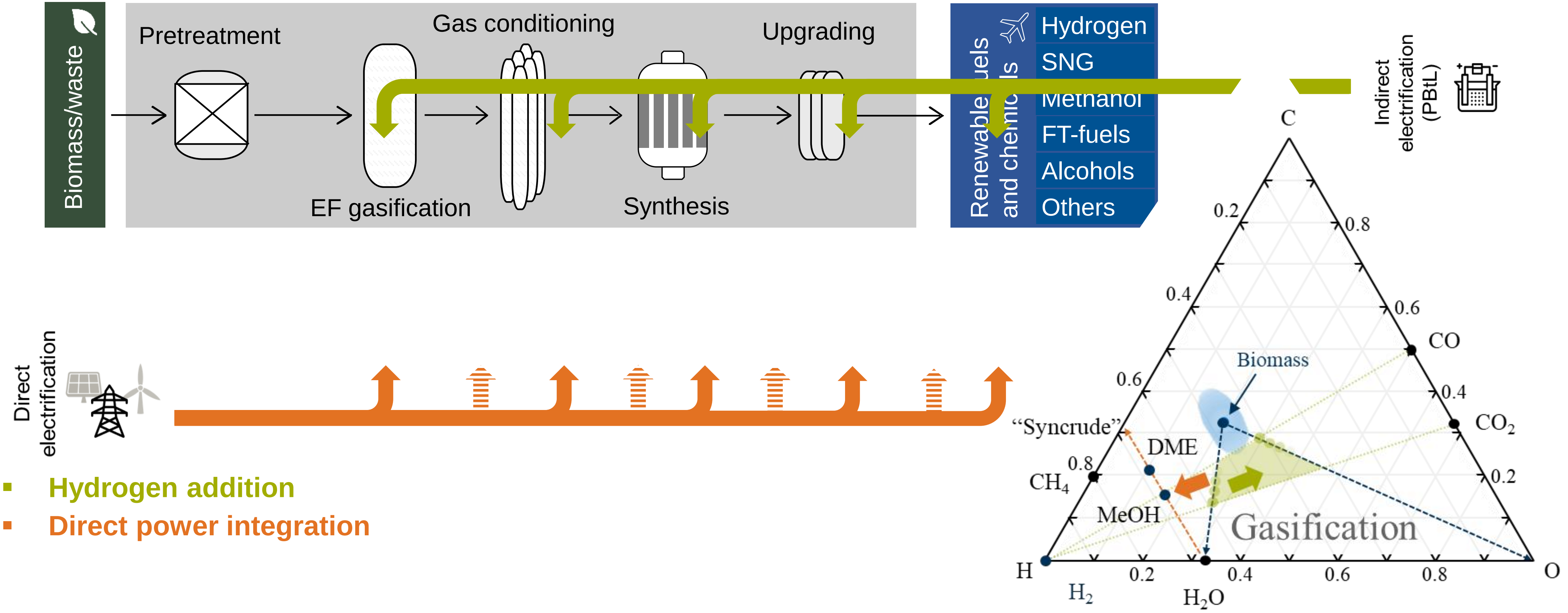
<u>Energetic and technical evaluation reveals:</u>

- Overall, no single, “optimal” BtX route exists
- Considering the value of biogenic carbon in future energy systems, BtX routes that do not utilize the carbon (NH_3, H2CCS) only represent a solution in the short and medium term as a carbon negative technology

[8], [9]

Enhanced BtX processes

Electrification and integration of hydrogen in BtX processes



- **Hydrogen addition**
- **Direct power integration**

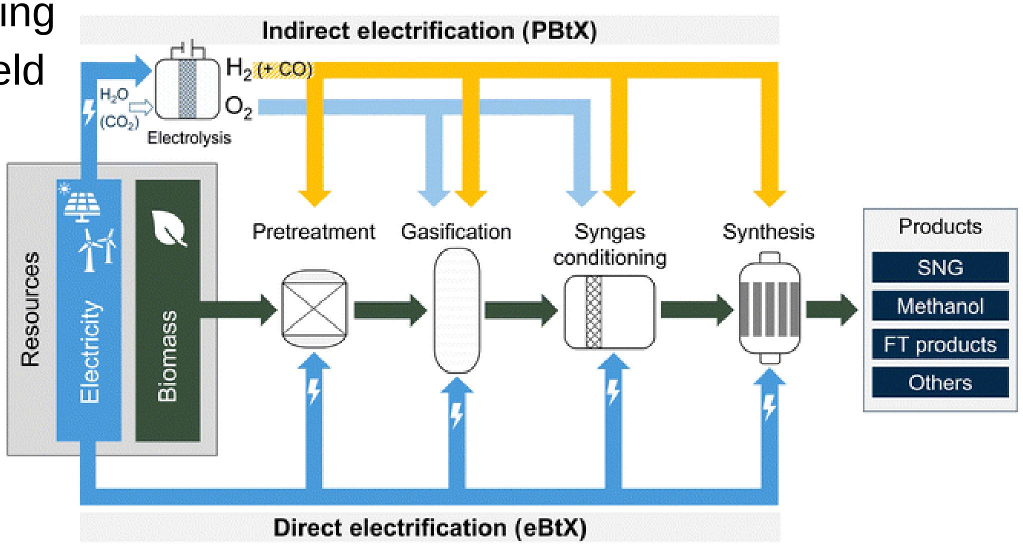
Content

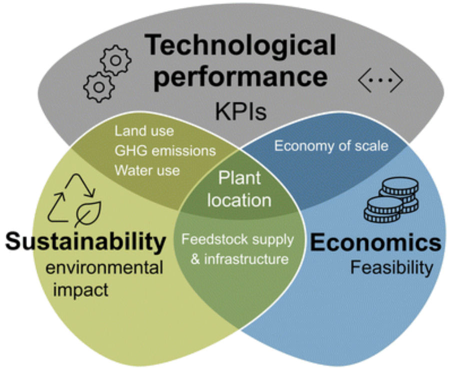
Review Paper

Electrification of gasification-based biomass-to-X processes – a critical review and in-depth assessment

M. Dossow, D. Klueh, K. Umeki, M. Gaderer, H. Spliethoff, S. Fendt

- Electrification of Biomass-to-X (BtX) processes as a technological option to enhance chemical and fuel production from biomass to **overcome carbon limitation in BtX**
- Electrification options classified into indirect electrification (addition of H2 from water electrolysis, Power-and-Biomass-to-X, **PBtX**), and direct electrification (**eBtX**)
- H_2 addition in PBtX is state-of-the art showing increased carbon efficiency and product yield
- Studies on direct electrification (eBtX) are limited in the literature due to low technological maturity

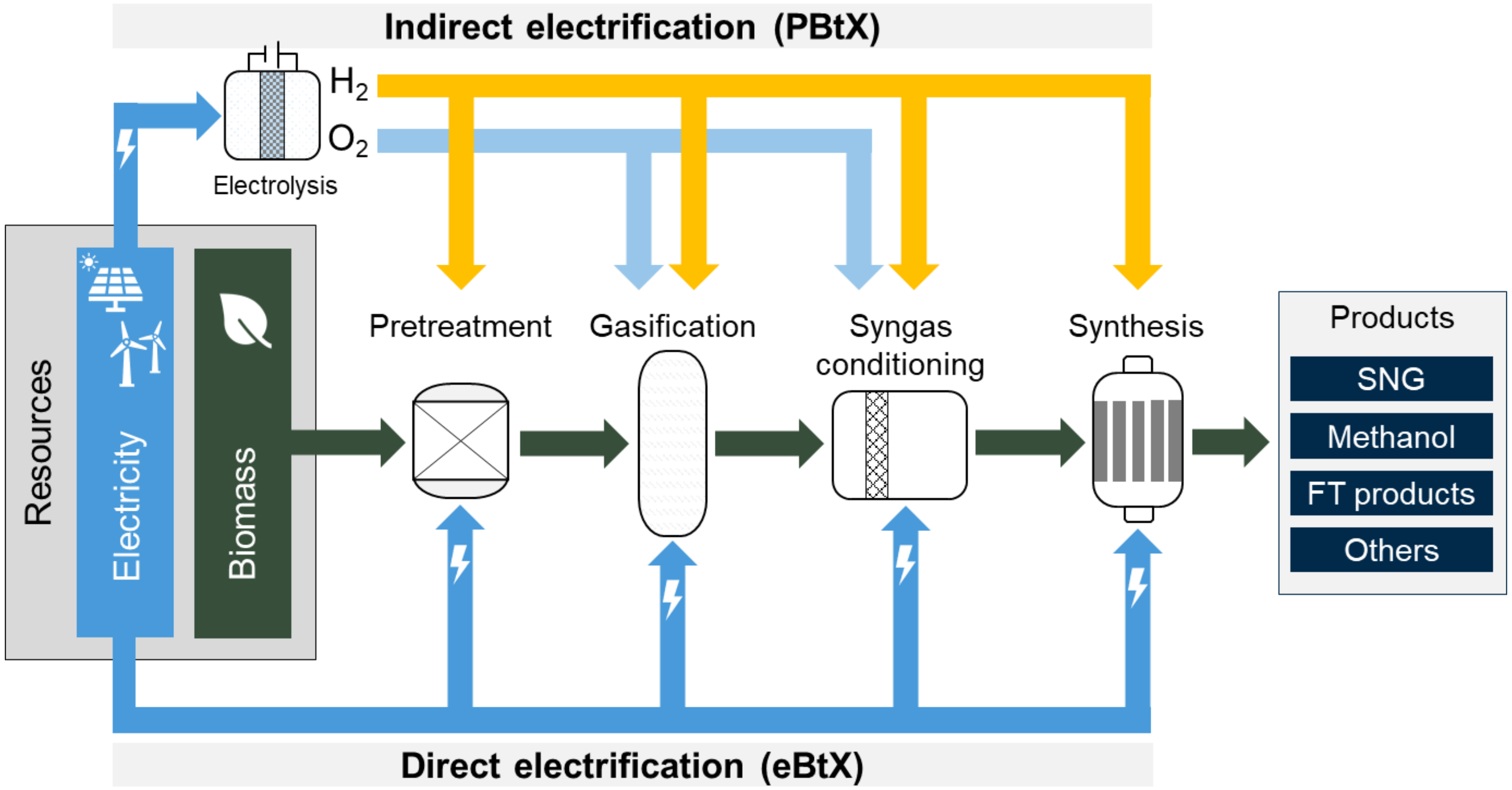




Energy and Environmental Science, 2023, 17(3), pp. 925–973
https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

Overview of options and wording



Indirect electrification (PBtX)

- H_2 and O_2 from electrolysis (water electrolysis or co-electrolysis)
- rWGS for CO_2-to-CO conversion
- BtX and PtX (power-to-X) hybrid

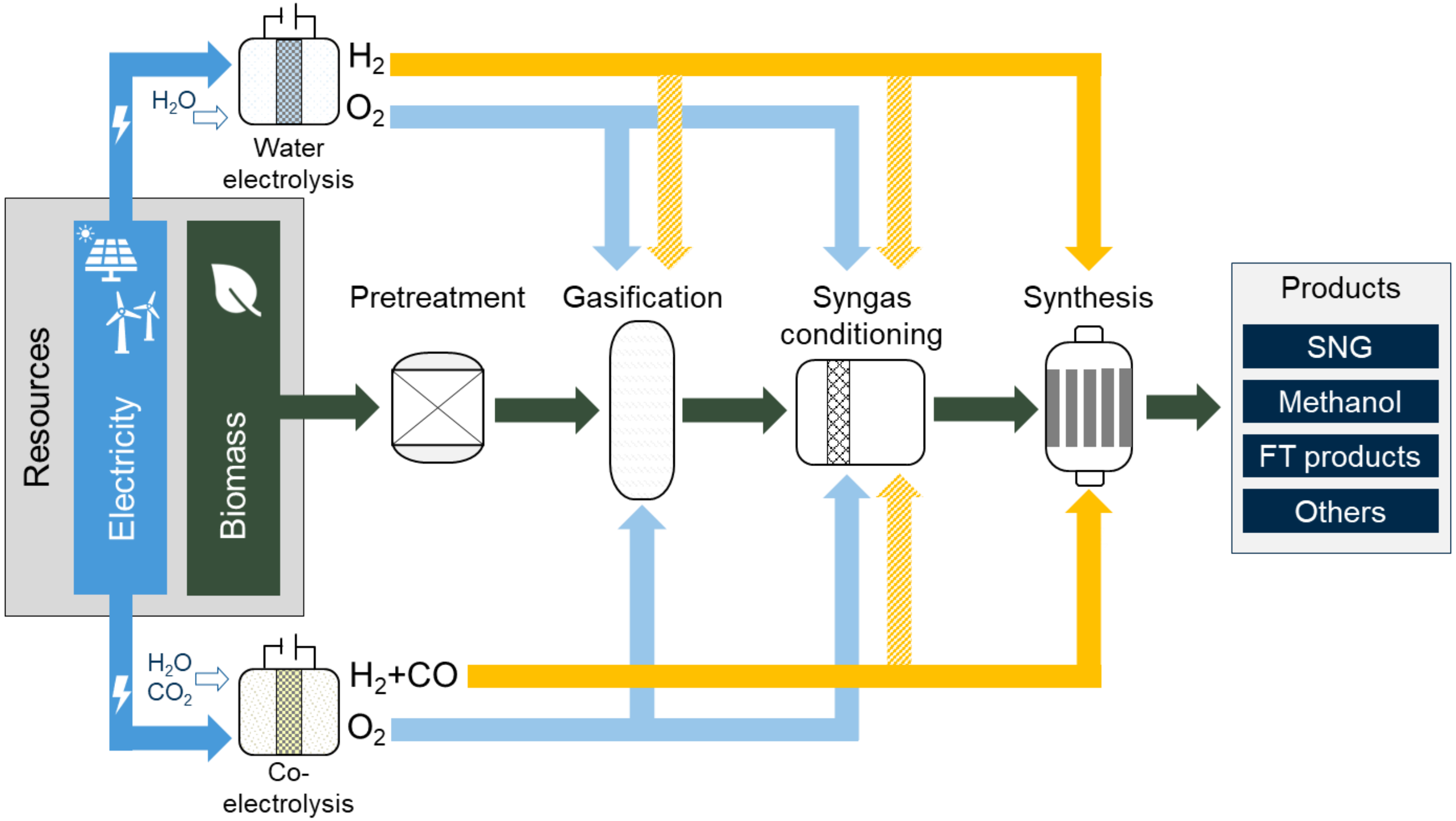
Direct electrification (eBtX)

- Electricity-driven heat supply or co-electrolysis
- Reduction of CO_2 formation
- Improved reaction kinetics or energy efficiency

M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

Indirect electrification - PBtX (Power- and Biomass-to-X)

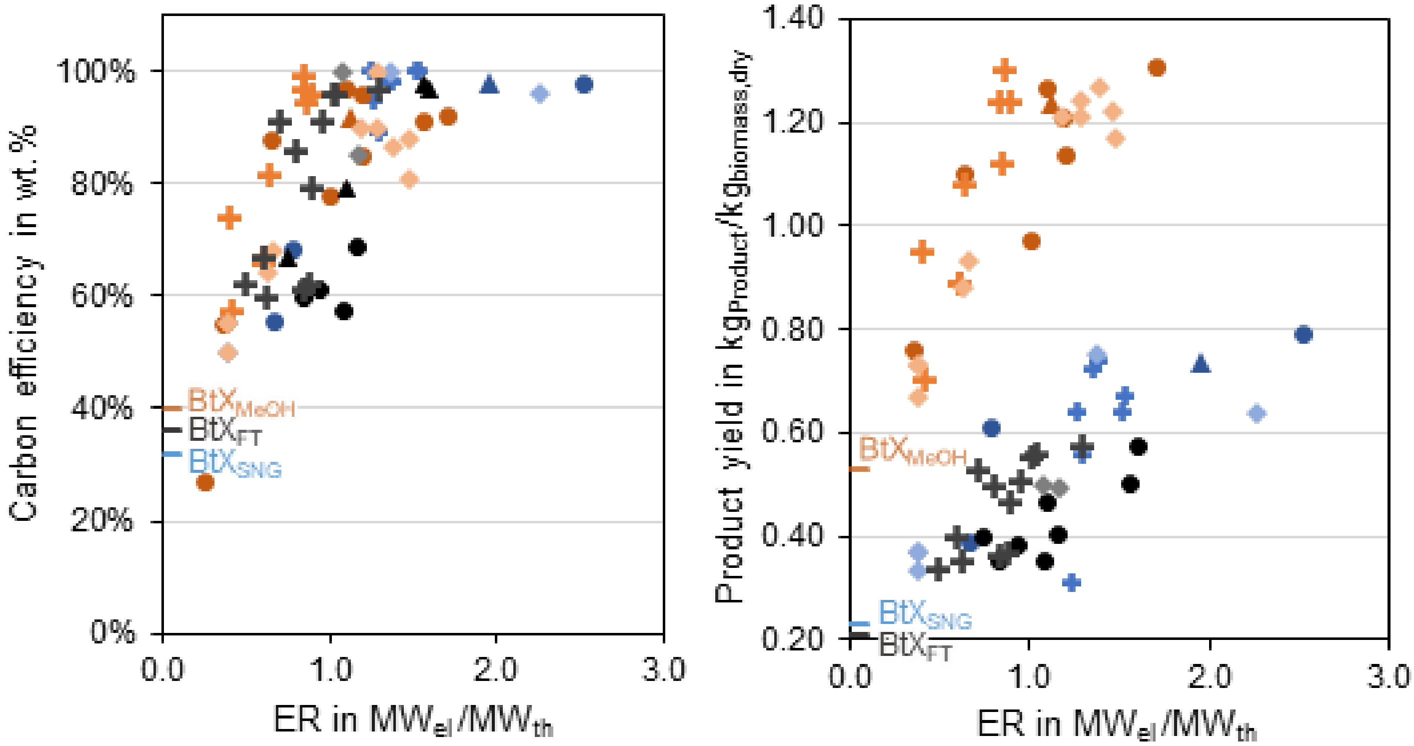


- Utilization of H_2 and O_2 from electrolysis (water electrolysis or co-electrolysis)
- rWGS for CO_2-to-CO conversion

M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

Indirect electrification - PBtX (Power- and Biomass-to-X)



Increased carbon efficiency

- Percentage of carbon atoms converted from biomass to final product
- 30-40% for conventional BtX
- Meta-analysis shows potential of close to 100% at 50-50 energy input from electricity and biomass

Increased product yield

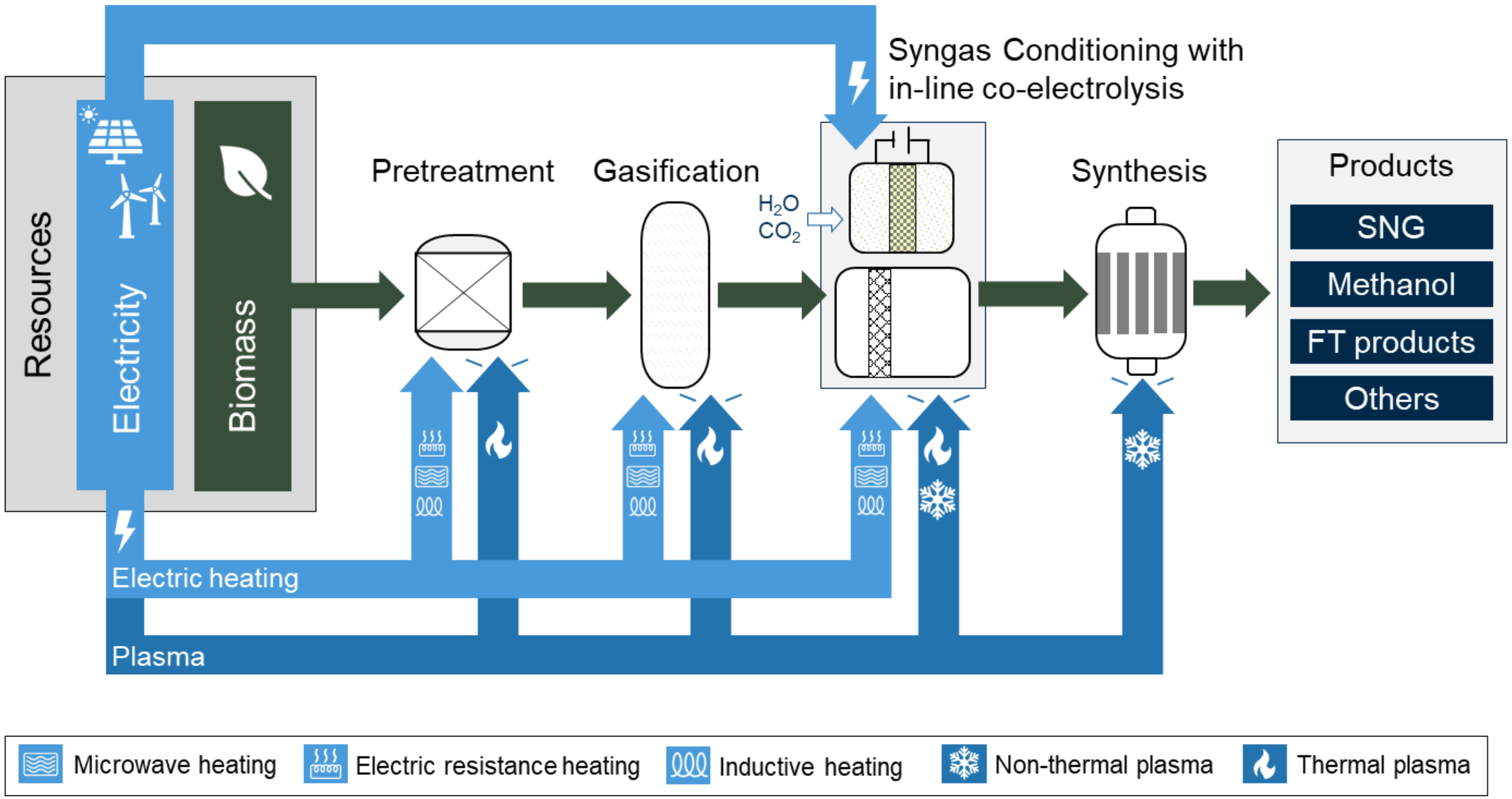
- Limited by carbon efficiency in conventional BtX
- 2x to 4x higher yields with electrification

→ **Synergies in electrification: PBtX advantageous over PtX and BtX**

M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

Direct electrification - eBtX



Direct electrification (eBtX)

- Electricity-driven heat supply or co-electrolysis
- Reduction of CO2 formation

Improved reaction kinetics or energy efficiency

eBtX potentially advantageous compared to PBtX

M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

Direct electrification – eBtX → Options for e-Gasification

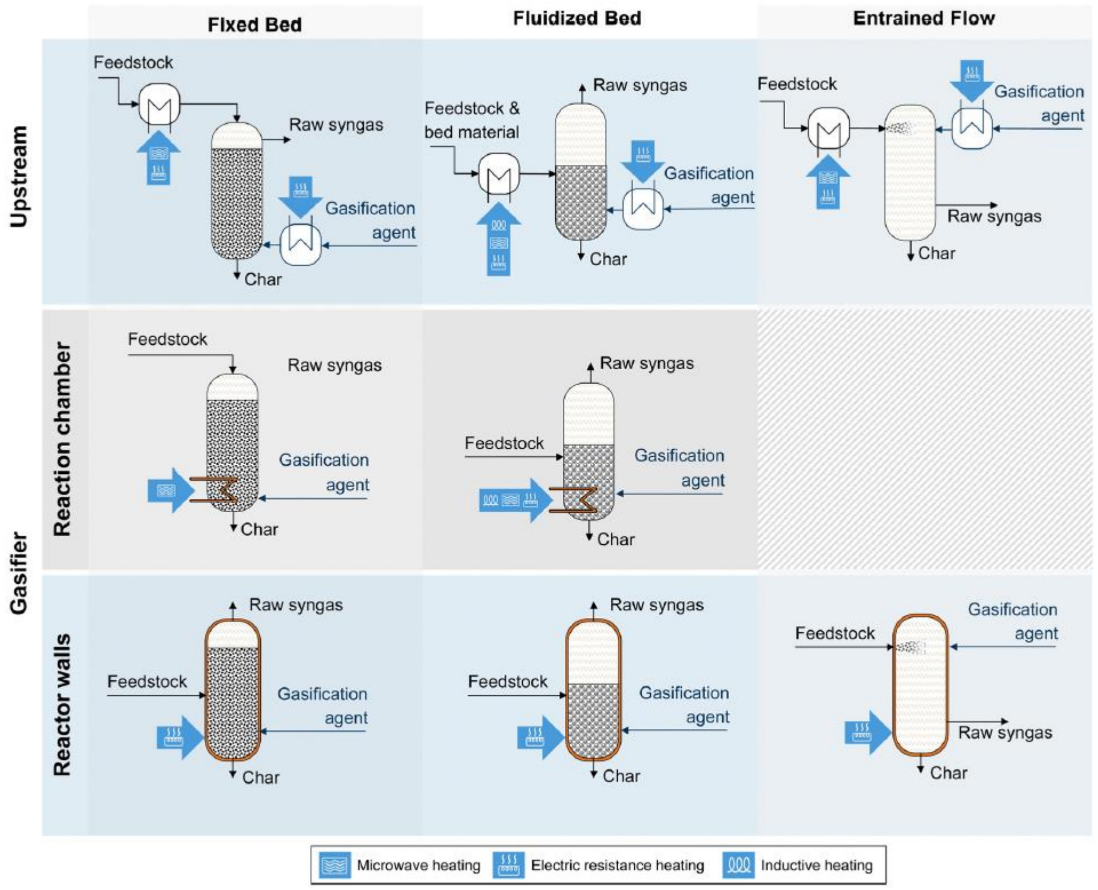
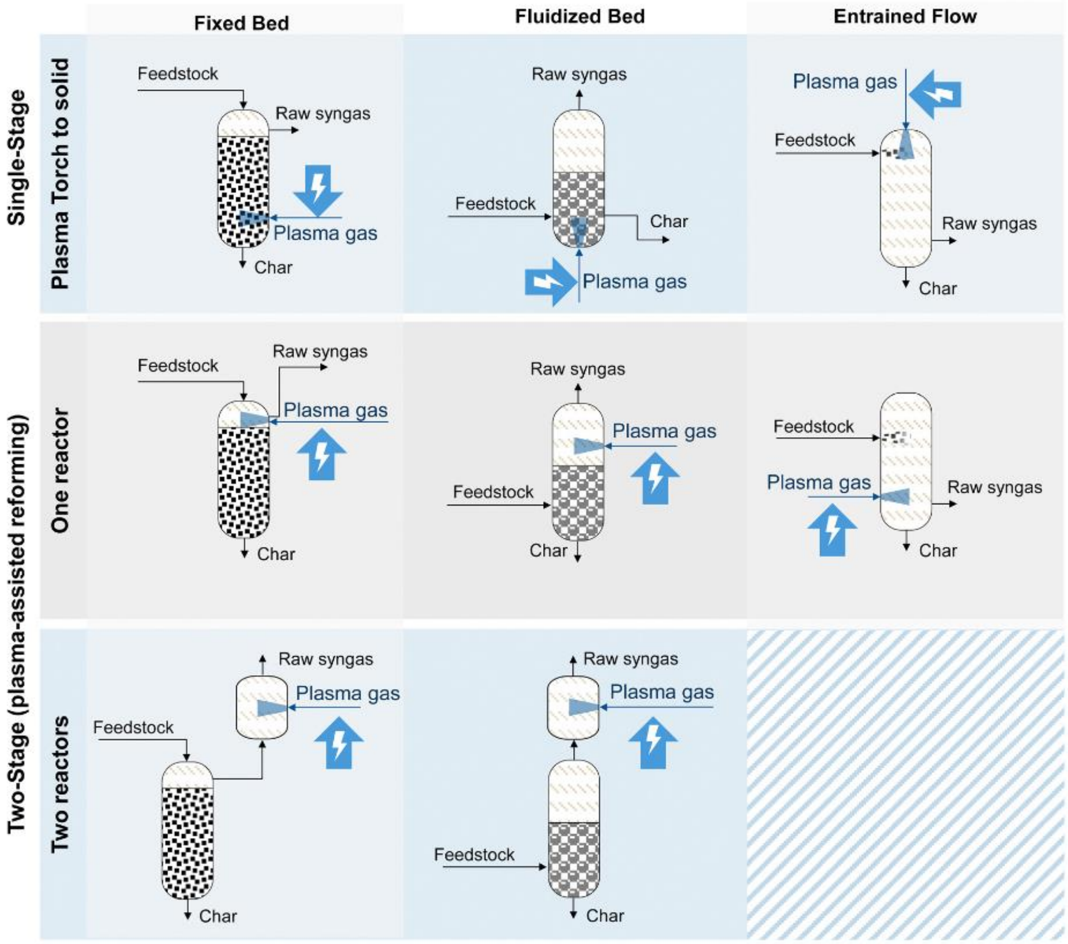


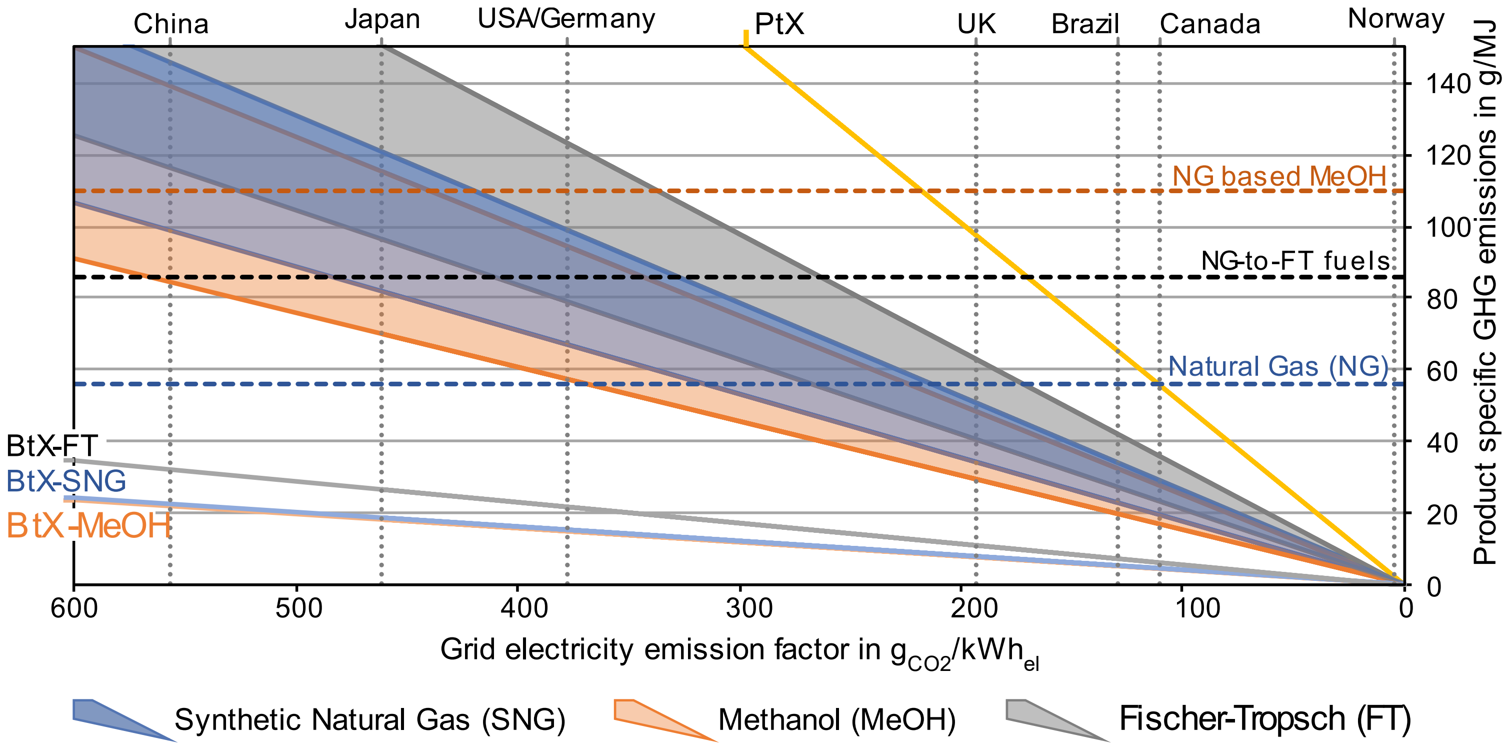
Fig. 8 Simplified schematics of different options and technologies to electrically heat gasification depending on gasifier reactor type and point of electrical heating. For fixed bed gasification a downdraft gasifier setup is shown exemplarily. Carrier gas, and auxiliaries are not included for simplicity.



M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

Electrification of gasification-based BtX processes

GHG emissions



Product-specific GHG emissions for P-/eBtX processes for 90% carbon efficiency depending on grid electricity factor compared to Biomass-to-X (BtX), Power-to-X (PtX) and fossil alternatives.

→ Electricity needs to have a very small carbon footprint.

→ Electrification of BtX in general increases the situation / lowers the emissions compared to PtX!

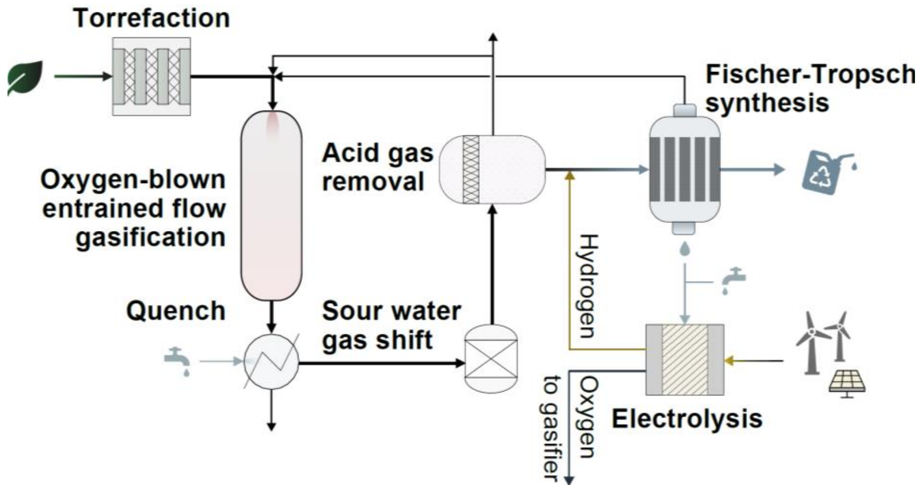
M. Dossow et al. (2023) https://doi.org/10.1039/D3EE02876C

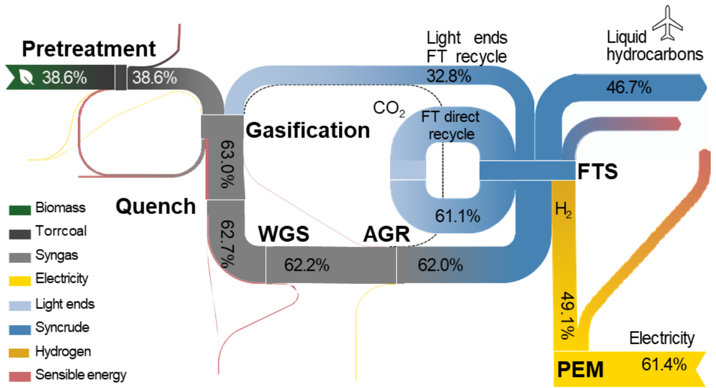
Specific PBtL Study for advanced SAF production

Improving carbon efficiency for an advanced BtL process using H_2 & O_2 from electrolysis

M. Dossow, V. Dieterich, A. Hanel, S. Fendt, H. Spliethoff

- Detailed process modeling shows huge potential of BtL and PtL combination.
- Fuel yield is more than doubled at 97% carbon efficiency adding H_2 to BtL process.
- Required electrolyzer sizes are about 60%–160% of the biomass input.
- Use of electrolysis O_2 within the process offers advantage over PtL process routes.
- Novel process offers high potential to defossilize transportation, e.g., aviation.

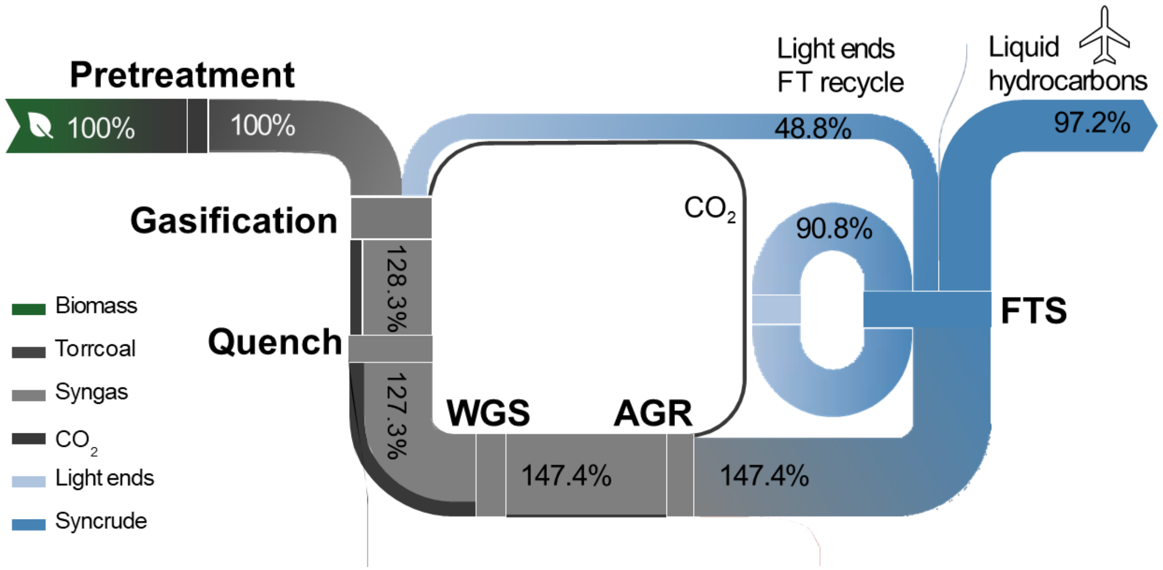


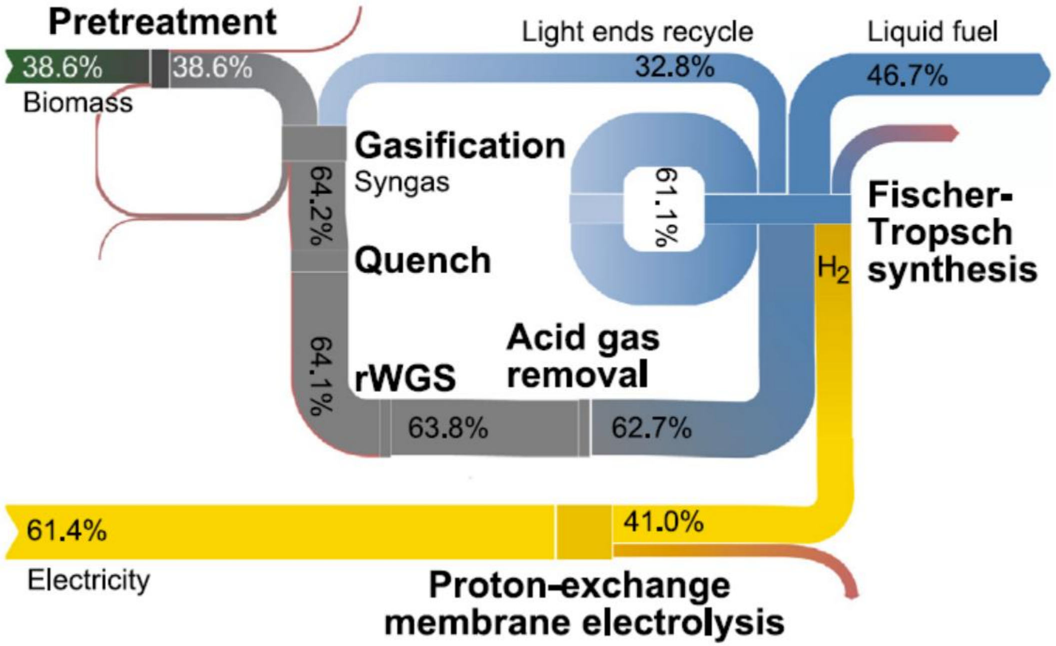


Renewable and Sustainable Energy Reviews
Volume 152, December 2021, 111670
https://doi.org/10.1016/j.rser.2021.111670

Combining a BtL process with PtL - PBtL

Results: Carbon and energy flow - Sankey diagrams



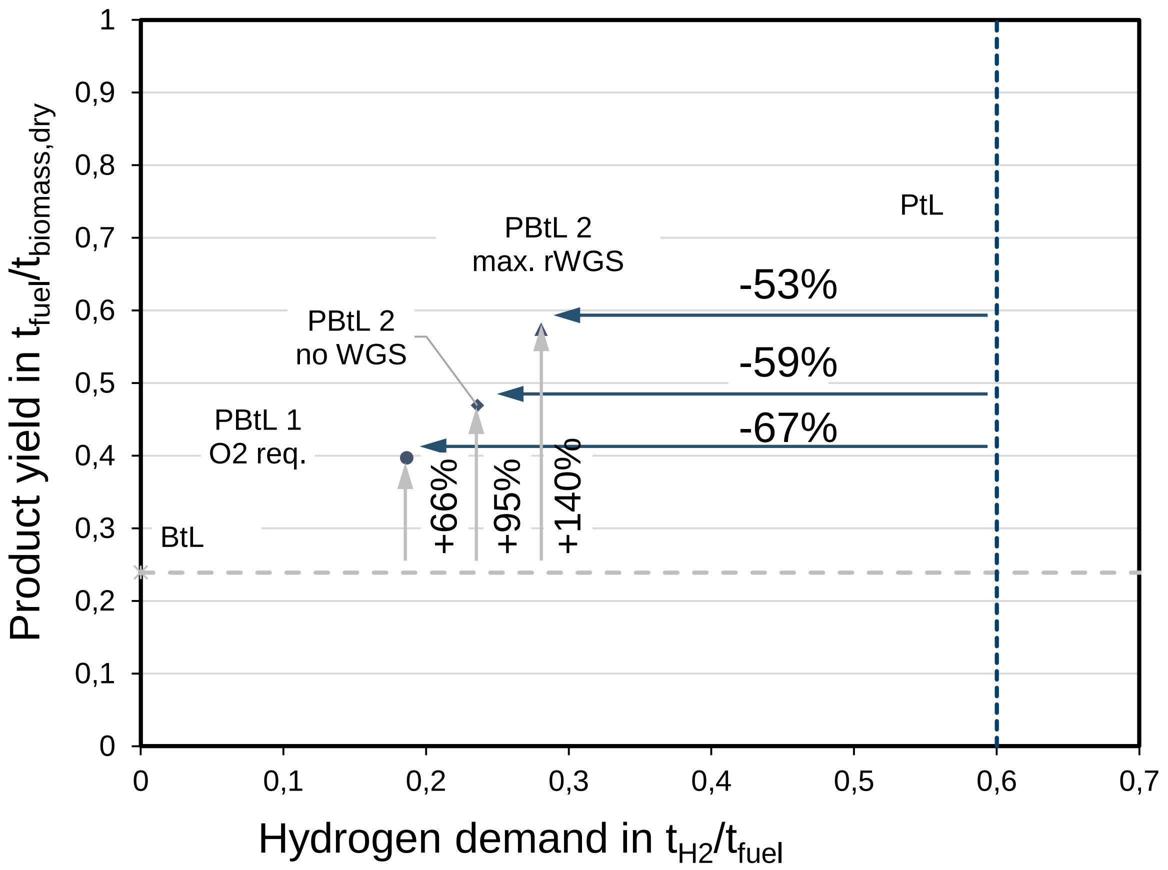


- Share of carbon recovered in the product can be enhanced from about 40% to up to 97%
- Electricity for the water electrolysis needs to come from renewables, otherwise the carbon footprint might very well be worse than fossil alternatives
- Use of electrolysis O_2 within the process offers advantage over PtL process routes.

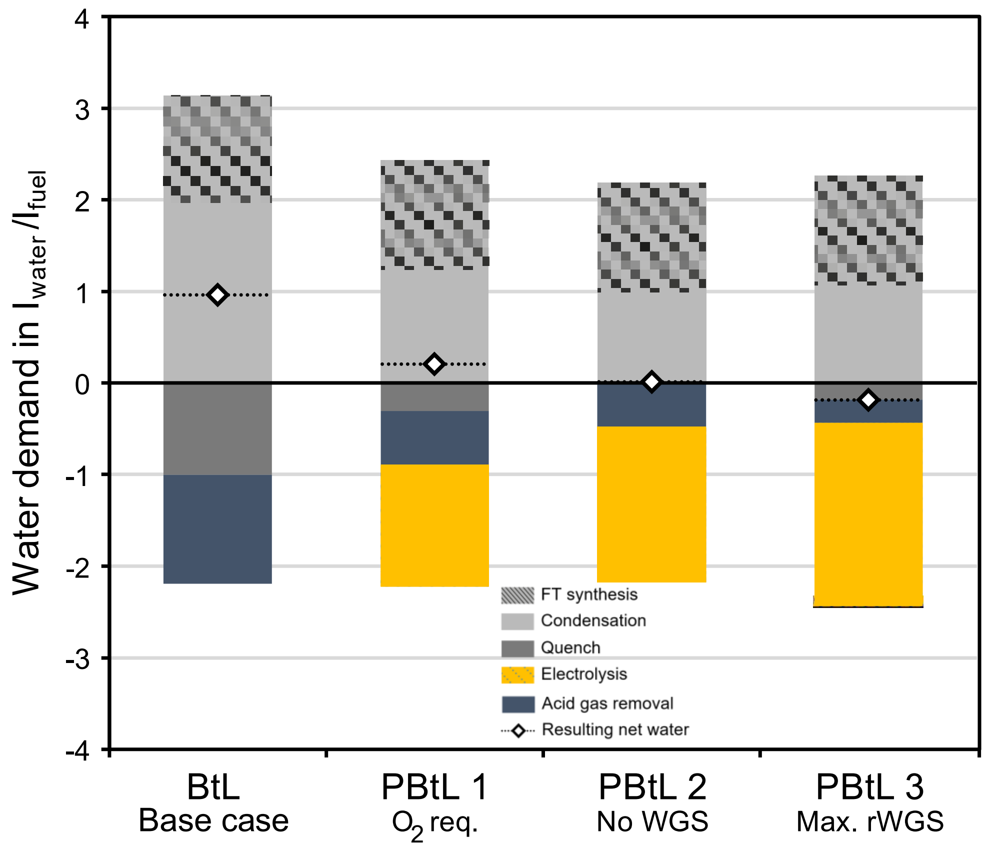
Improving carbon efficiency for an advanced BtSAF process

Most important results/findings

+140% in product yield

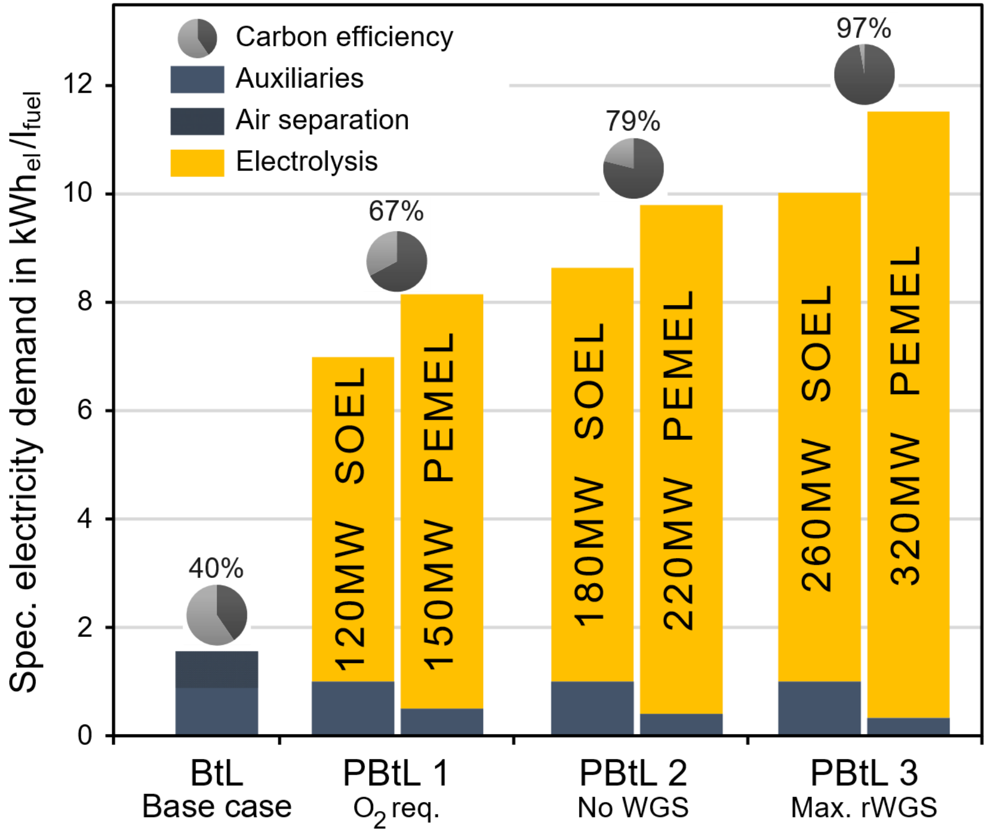


Process can be net water neutral!



Improving carbon efficiency for an advanced BtSAF process

Most important results/findings



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

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

SOEL reduced size by about 20%

H_2 required for PtL
0.6 t/t$_{product}$

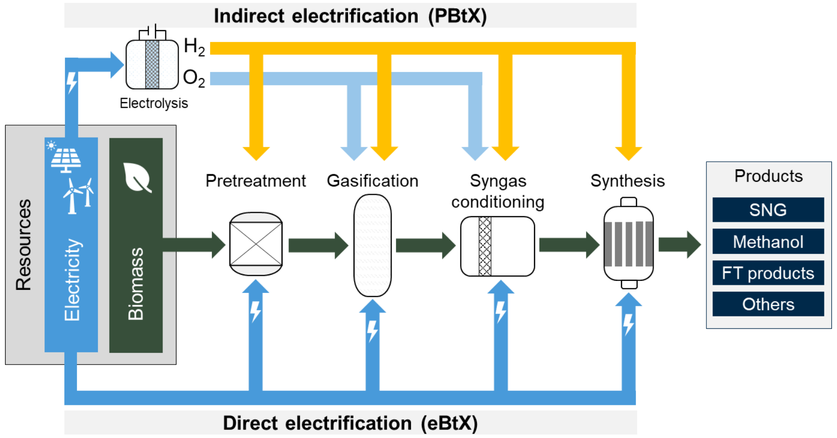
Total specific electricity required for PtL
<24 kWh/l$_{product}$

Content

Conclusion

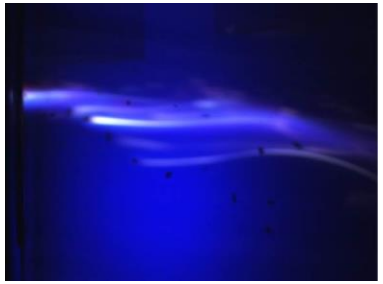
And outlook

- **Renewable electricity (wind and solar) will become the largest energy vector on the way towards a net-zero emission energy system**
- **Carbon will be a valuable resource** we need to be very careful about. We need to make the most out of any sustainable/renewable carbon source!
- **Holistic view on sustainability** will increase additional concerns and challenges we need to face today, e.g. **water balance**, social acceptance and other aspects



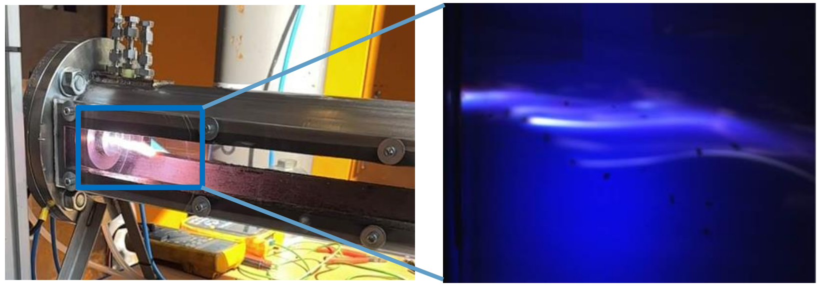
→ **Electrification of chemical processes, especially BtX**

✓ **Special focus on: Plasma-assisted gasification** as a very promising option with a lot of potential but also many challenges to be solved by fundamental and applied research!

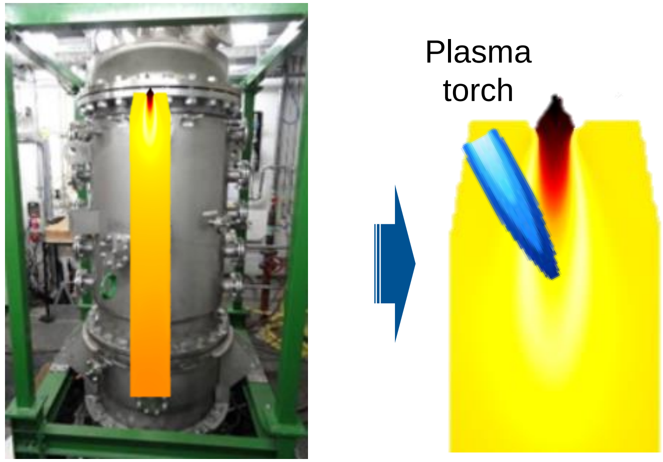


Current plasma gasification research: Experiments and simulations

Experiments



- **Plasma – particle interaction**



- **Plasma gasification process**
- **Plasma torch design**

Reactor design, sensitivity analysis

?

- **Fundamental understanding of the Process**
- **Industrial scale-up**

Model parameter
Validation data

Simulations

Process simulations
- Setting reasonable operating parameter
- Basic dimensioning

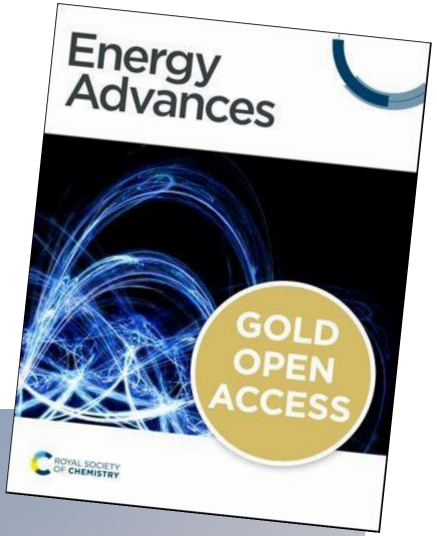
CFD simulations
- Fuel particle conversion behavior
- Reactor design
- Optimization of operating conditions
- Plasma-torch design

Goal:
Plasma gasification model containing all important phenomena occurring under industrial scale conditions for scale-up applications

Invitation

Munich Hydrogen Symposium 21.10.-23.10.2024

	Monday, October 21st	Tuesday, October 22nd	Wednesday, October 23rd	Thursday, October 23rd
09:00 – 10:30		**Keynote 3: Circular Economy** **Session T. 1A** Topic: Circular Economy	**Session W. 2A** Topic: System Studies **Session W. 2B** Topic: H2 Utilization in Biotechnology	**Technical Tours:** • ChemDelta Burghausen • TUM Campus Garching
10:30 – 11:00	**Coffee break**			
11:00 – 12:30	**Opening Session** **Keynote 1: System Studies** **Keynote 2: H_2 Utilization**	**Session T. 2A** Topic: Power-to-X	**Keynote 4: H2 Production** **Session W. 1A** Topic: System Studies **Session W. 2B** Topic: Reactor Concepts	
12:30 – 13:30	**Lunch break**			
13:30 – 15:00	**Panel Discussion** **Politics: *tba*** **Industry: *Dr Peter von Zumbusch (Wacker)*** **Research: *tba*** **Representative: *tba***	**Session T. 3A** Topic: H2-Production	**Session W. 3A** Topic: Entrained Flow Gasification	
15:00 – 15:30	**Coffee break**			
15:30 – 17:00	**Session M. 1A** Topic: System Studies	**Poster Session** **Conference Dinner**	**Session W. 4A** Topic: Plasma Utilization **Closing Session & Award**	



- Abract submission still open!
- Focus session(s) on gasifcation and power integration
- Chemical industry participation
- Special Issue paper publication

Thanks for the attention!!!

Looking forward to the discussion!

Thanks to my group at the Chair of Energy Systems

.. and thanks for the funding:

Federal Ministry of Education and Research

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