6th Nuremberg Workshop on Methanation and 2nd generation Fuels, June 1st, 2023

Project overview
EU project CarbonNeutralLNG

Truly Carbon Neutral electricity enhanced Synthesis of Liquefied Natural Gas (LNG) from biomass

Funded by the European Union
HORIZON EUROPE grant agreement N° 101084066

GreenLNG
Our process
Challenges
Impacts
Conclusion

1. Why do we need GreenLNG?

- GreenLNG for the mobility sector
- Backing up the European power sector

2. The projects technical concept

- Power-t-X and e-fuels
- Electricity enhanced Biomass-to-LNG process

3. The technologies key challenge

- LNG logistics and methane emissions
- Roadmap to market

4. The projects expected impacts

- Project plan
- Main impacts

1. Why do we need GreenLNG?

- GreenLNG for the mobility sector
- Backing up the European power sector

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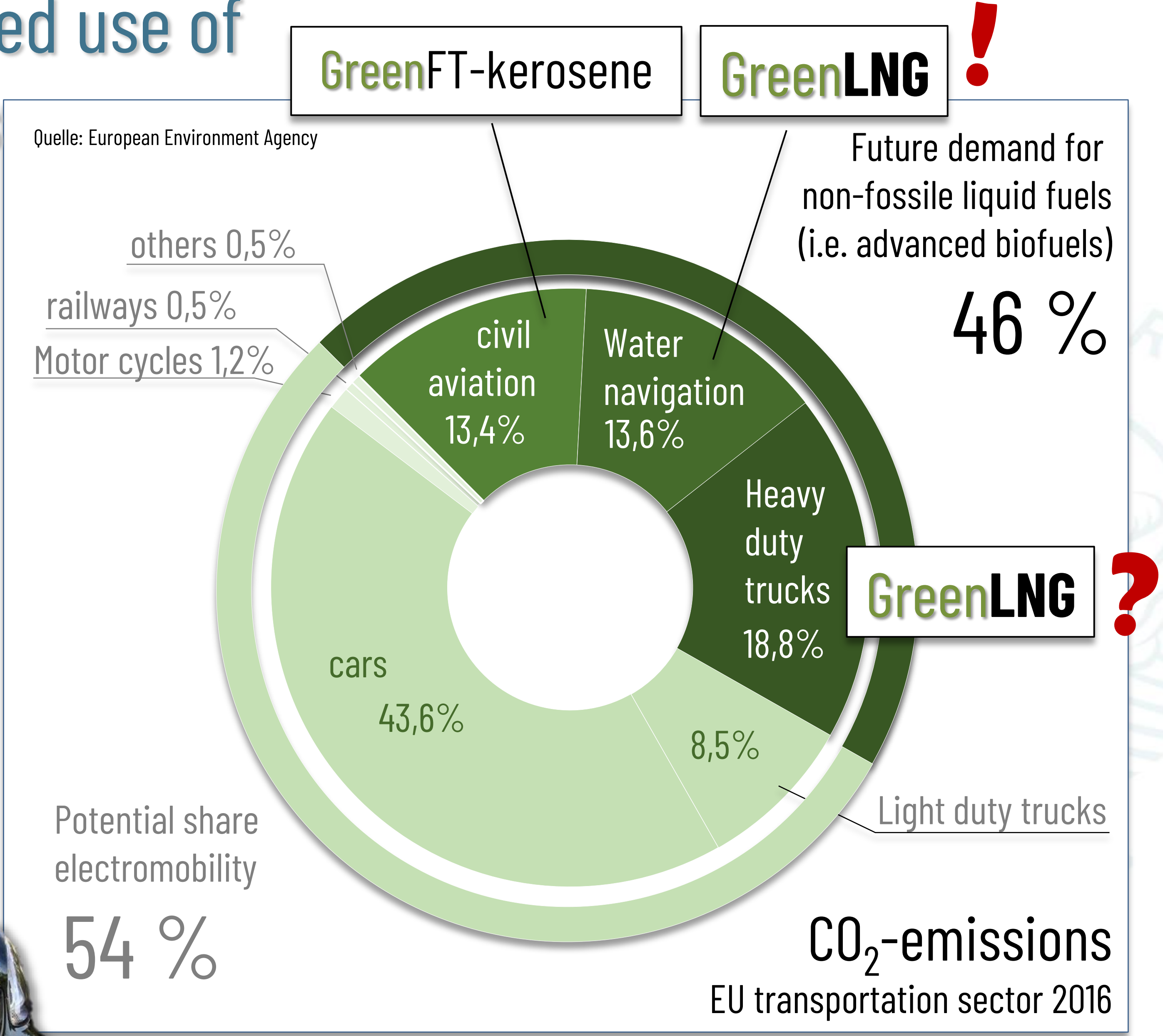
Reasons for the continued use of liquid and gaseous fuels

Status Quo

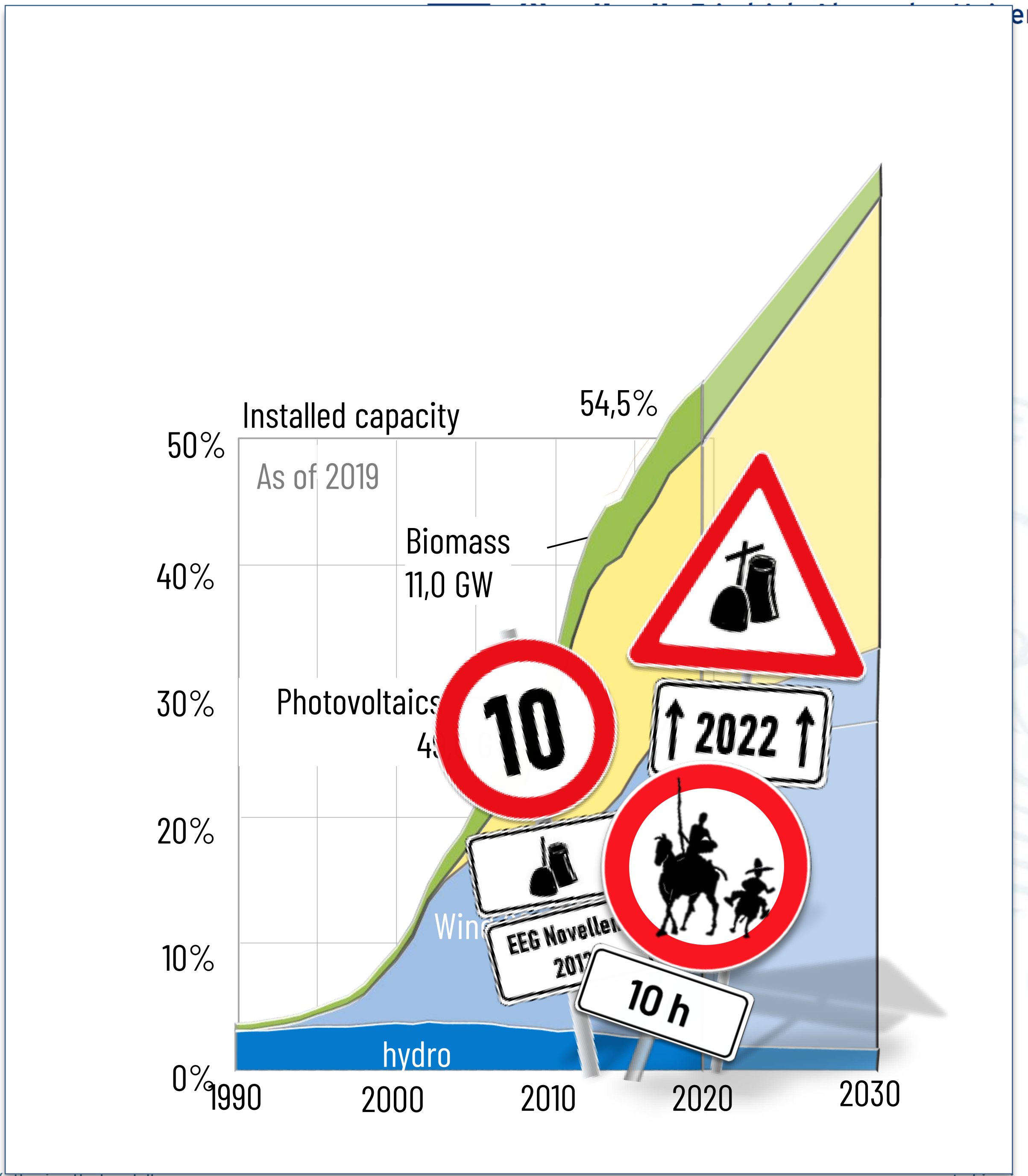
- Energy density of batteries is still limited
- The worldwide conversion of the existing infrastructure will take decades

- GreenLNG is certainly the most adequate option for the marine sector



The situation on the German electricity market

- Conventional power plants are outdated, gas-fired power plants were unprofitable and were not built
- The EEG 2000 was unexpectedly successful at first and was massively slowed down with the EEG 2012



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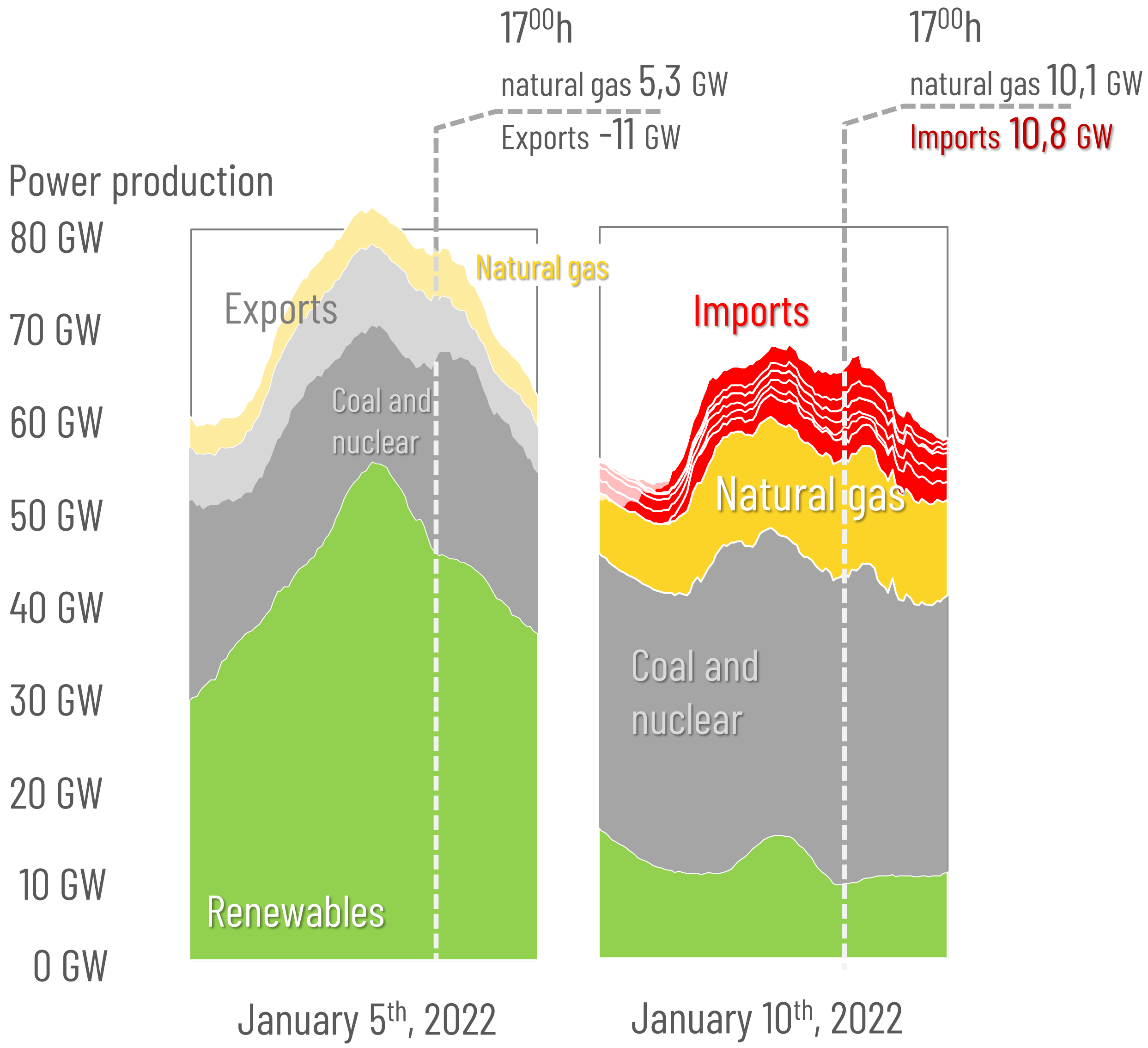

Quelle: www.smard.de

Status Quo

- Germany usually produces more electricity than needed, but unfortunately not always…

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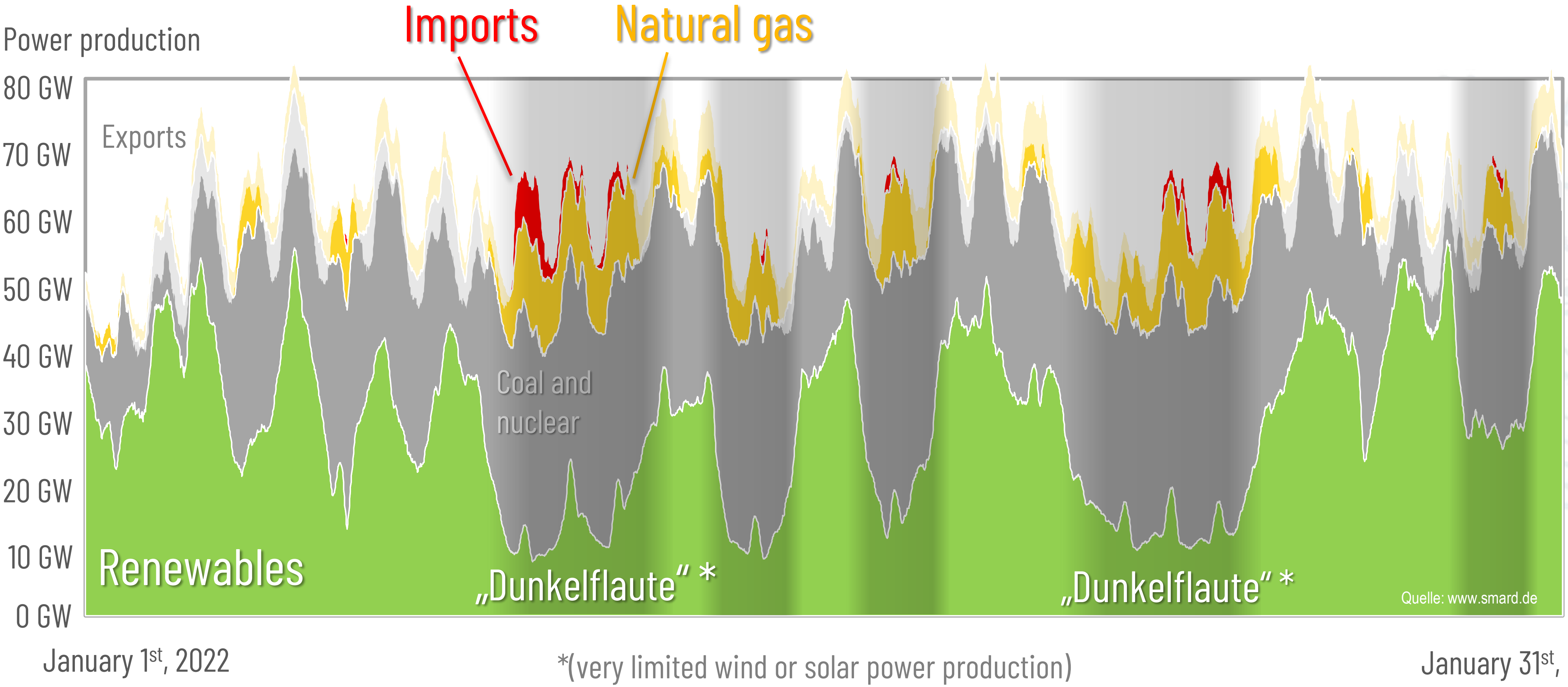
Power supply in winter 2021/2022

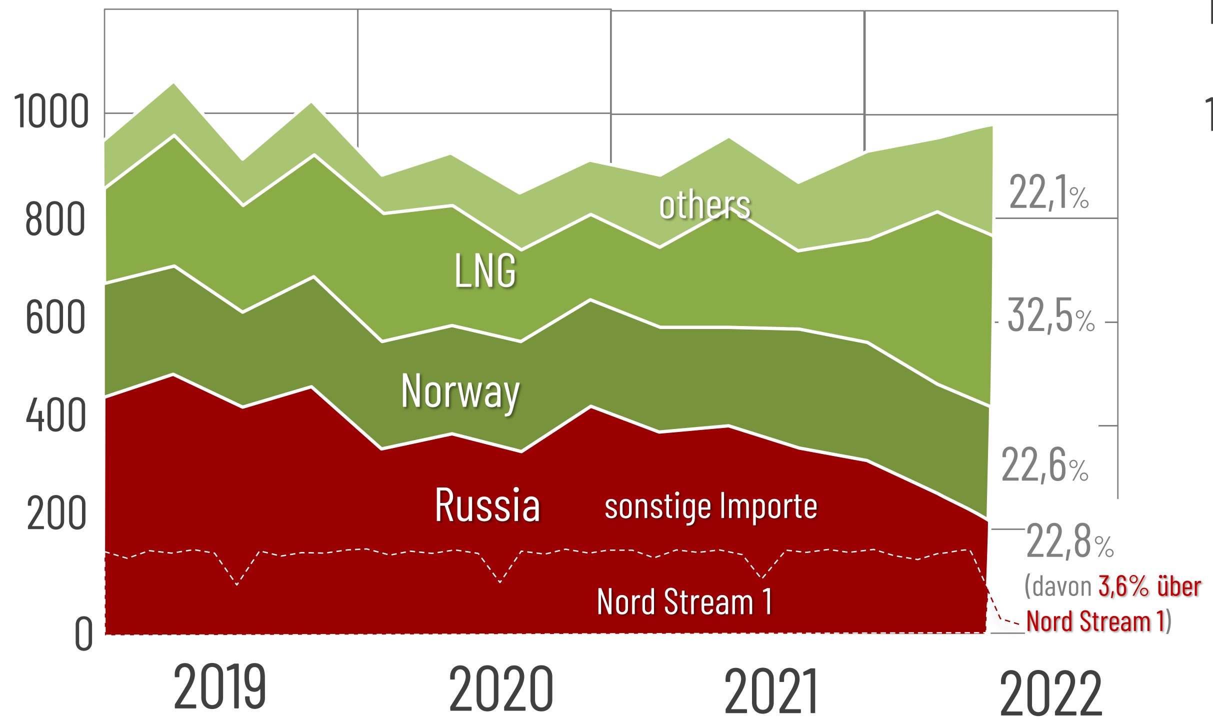
- In the period from December 2021 to March 2022, there were a total of 16 "Dunkelflauten" *
- Up to 10.8 GW had to be imported

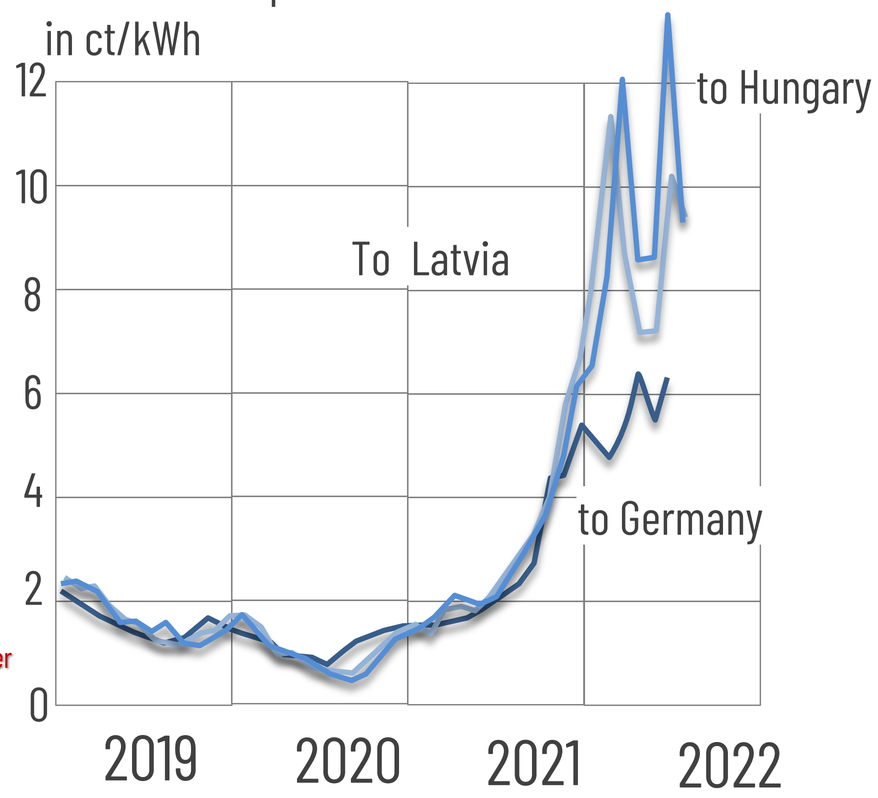


*(very limited wind or solar power production)

Europe's natural gas supply

- Until 2021 Russia supplied about 50% of European gas consumption
- About 22% was imported as Liquefied Natural Gas (LNG)
- Starting 2021, imports from Russia reduced gravely
- At the same time, border crossing prices multiplied ...





Quelle: Quarterly report On European gas markets
DG Energy, Volume 15 (issue 2, covering second quarter of 2022)

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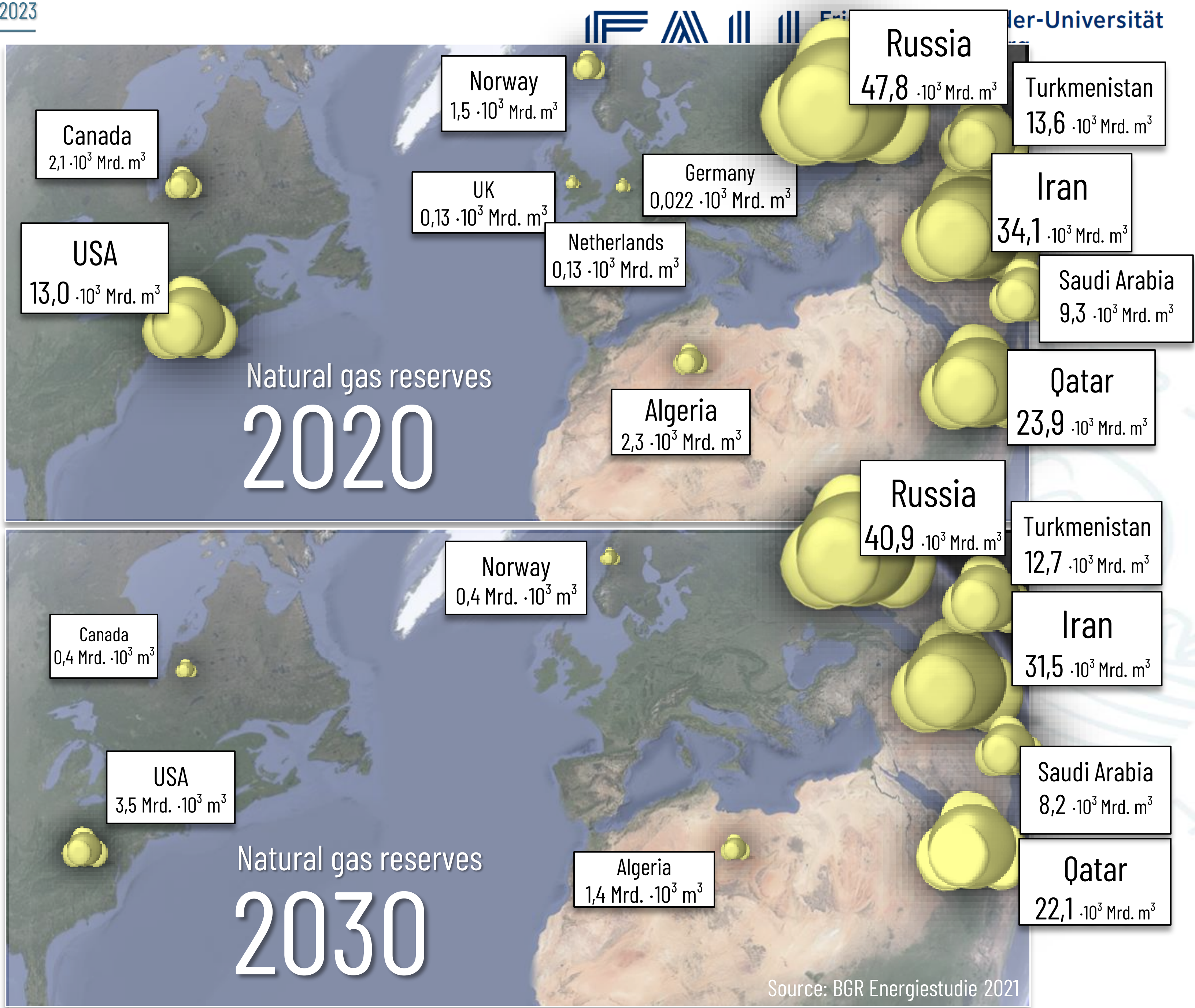
Long-term prospects fossil LNG markets

- USA provides currently almost half of the European LNG imports
- sufficient reserves for LNG deliveries to the EU exist only in Russia and the Middle East
- The **reserves-to-production** ratio in the USA is currently **about 13 years only** …



Conclusions

1. GreenLNG is not only the most advantageous option for shipping, but also essential to secure the energy transition in the electricity market.

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2. The projects technical concept

- Power-t-X and e-fuels
- Electricity enhanced Biomass-to-LNG process

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Methanation: Synthesis of Substitute Natural Gas (SNG)

GreenLNG
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- In 1902 Paul Sabatier first observed the methanation of syngas over a Nickel-catalyst

syngas*) — *) From coal gasification

„methanation“

$$CO + 3H_2 \xrightarrow{\Delta H = -206 kJ/mol} CH_4 + H_2O$$

„Sabatier-Reaction“

$$CO_2 + 4H_2 \xrightarrow{\Delta H = -165 kJ/mol} CH_4 + 2H_2O$$

- First large scale commercial developments started in the 1970s ...
- Natural gas exploitation put coal-to-SNG on hold

Paul Sabatier (1854-1941)
Nobel-prize in Chemistry 1912

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Methanation: Synthesis of Substitute Natural Gas (SNG)

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- 1902 Paul Sabatier first observed methanation of syngas over a Nickel-catalyst
- Production of Natural Gas Substitutes (SNG) and ethylene from coal experienced revival in particular in China and Korea…

Posco SNG-plant, Gwangyang, South Korea
www.Linde.com

Dakota Gas Great Plains Synfuel plant

SNG-plant, CPI Xinjiang Energy Co. Ltd, Yili City Xingjiang, China, 8 x 500 MW Siemens SFG-500 coal-gasifier, commissioning 2014

NCPP I coal to polypropylene project, Shenhua Ningxia Coal Industry, 5 x 500MW Siemens SFG-500 coal-gasifier, commissioning 2011

SNG production from biomass

GoBiGas Plant in Gothenborg, Sweden:

- Thermal power: 32 MW_{th} + 3 MW_{el} + 0.5 MW RME
- SNG Capacity 20 MW_{SNG}
- Useful heat 11 MW_{th}
- Commissioning 13.11.2013
- shut down in April 2018

GoBiGas-Plant Göteborg, as of December 2012

Lessons learned

- State-of-the-art processes are much too complex for decentralized, smaller scale (biomass) plants
- New gas upgrading concepts (i.e. hot gas cleaning) are needed

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Today's trend: Power-to-X for mobility /e-Fuels

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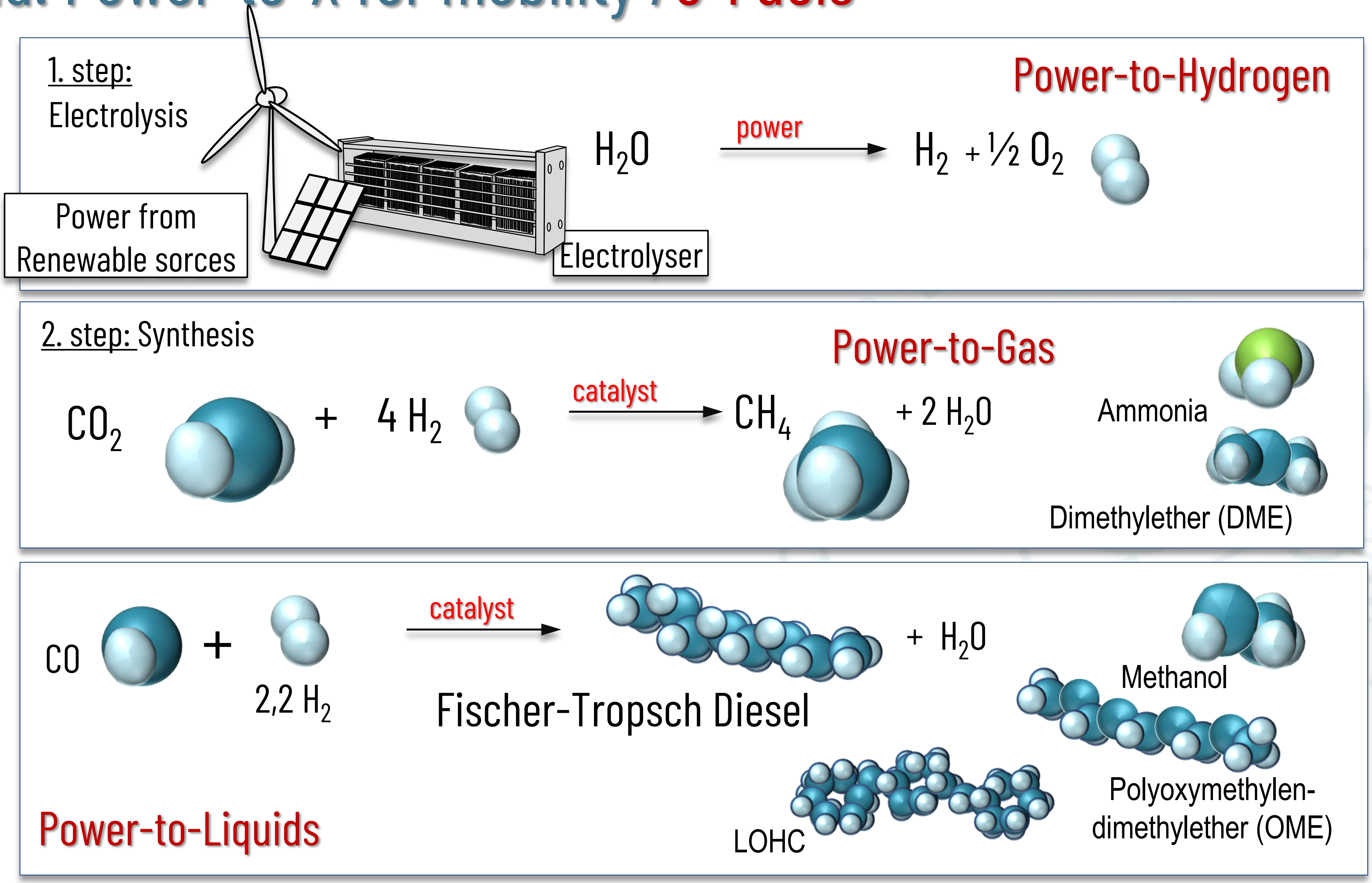
- Power-to-X and e-Fuels are commonly hydrocarbons C_xH_yO



Something that is often forgotten:

- Power-to-X and e-Fuels are commonly hydrocarbons C_xH_yO

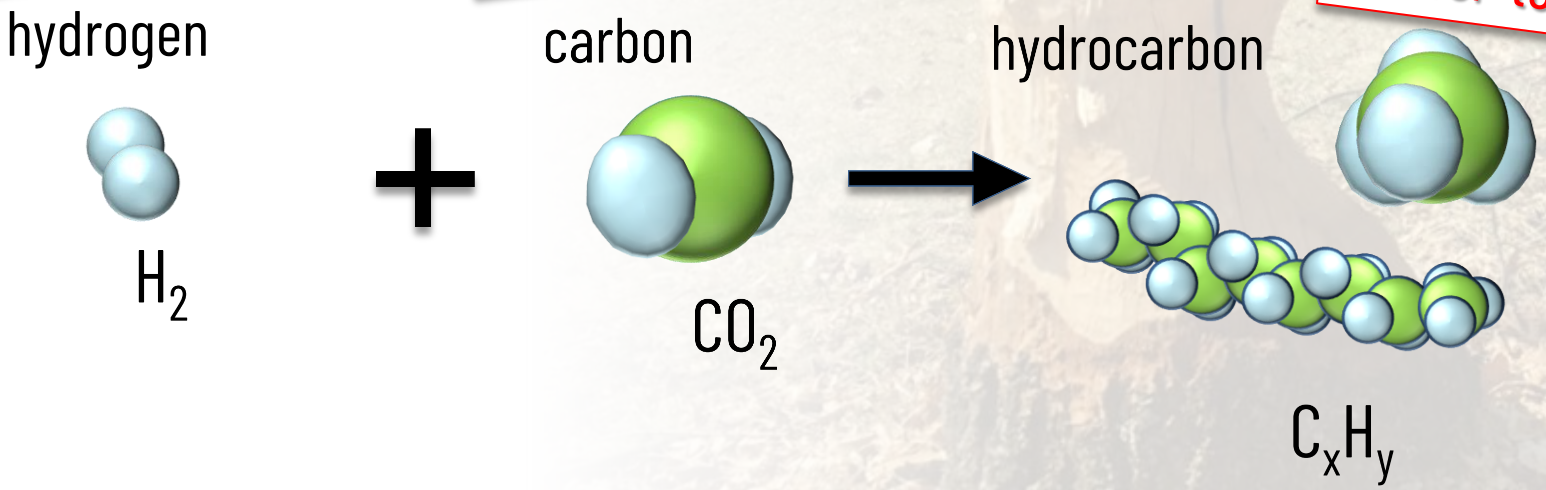
- Synthetic hydrocarbons need hydrogen <u>and</u> carbon

From renewable electricity!

From biomass!

„e-fuels"

„Power-to-X"



E-fuels are always also Biofuels... *)

*) If they are supposed to be carbon neutral

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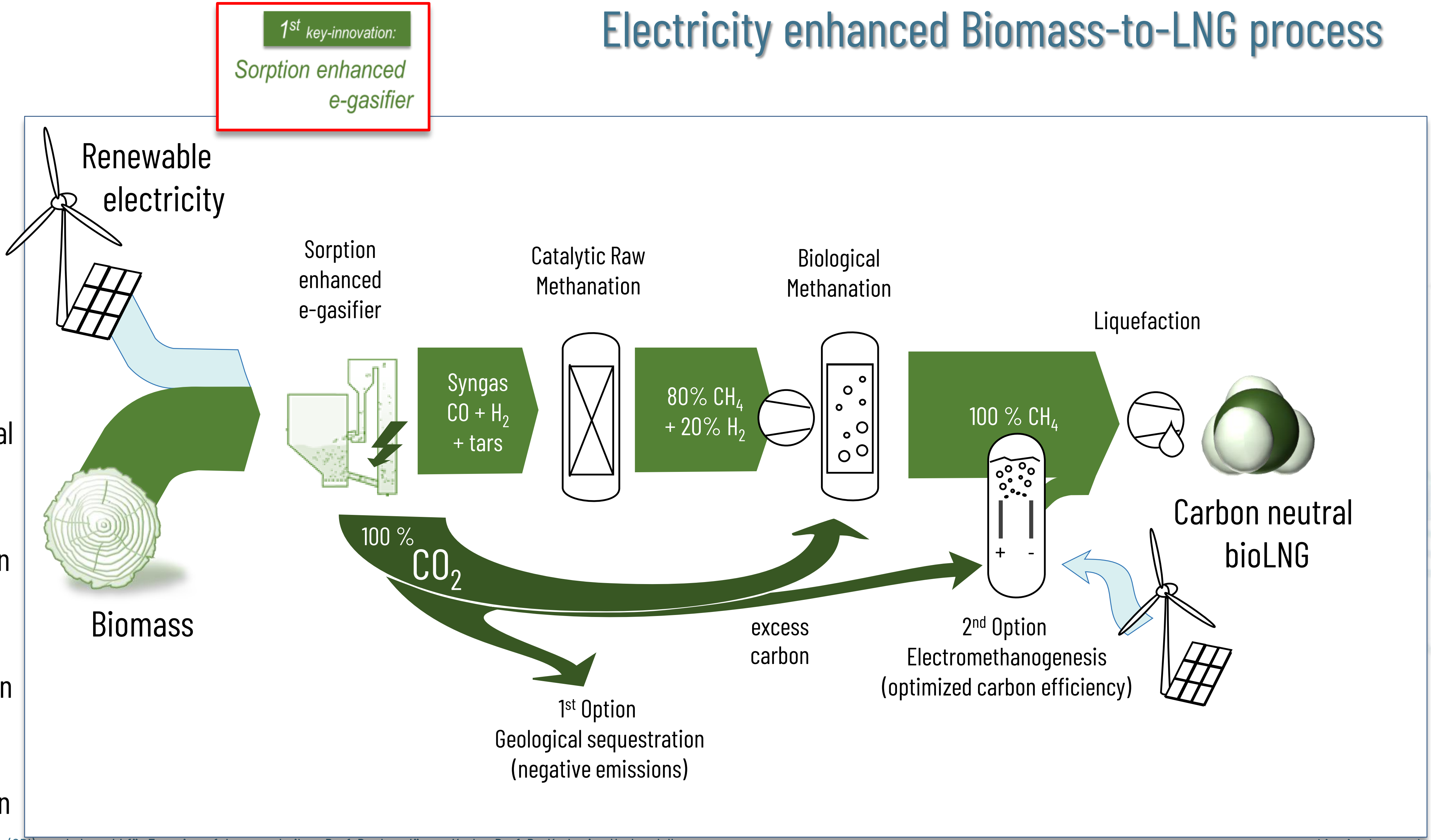
Electricity enhanced Biomass-to-LNG process

- the process avoids the drawbacks of catalytic and biological methanation
- Process accepts incomplete conversion after catalytic methanation
- Biological methanation is not exposed to CO and tars from the gasification



(Steam-) Gasification of Biomass – state-of-the art

Dual-fluidized Bed -Gasifier Güssing

- CHP-plant 2 MW_{el}, 4,5 MW_{th}, commissioning 2001
- most successful steam gasification technology worldwide!
- Finally five plants were in operation in Europe

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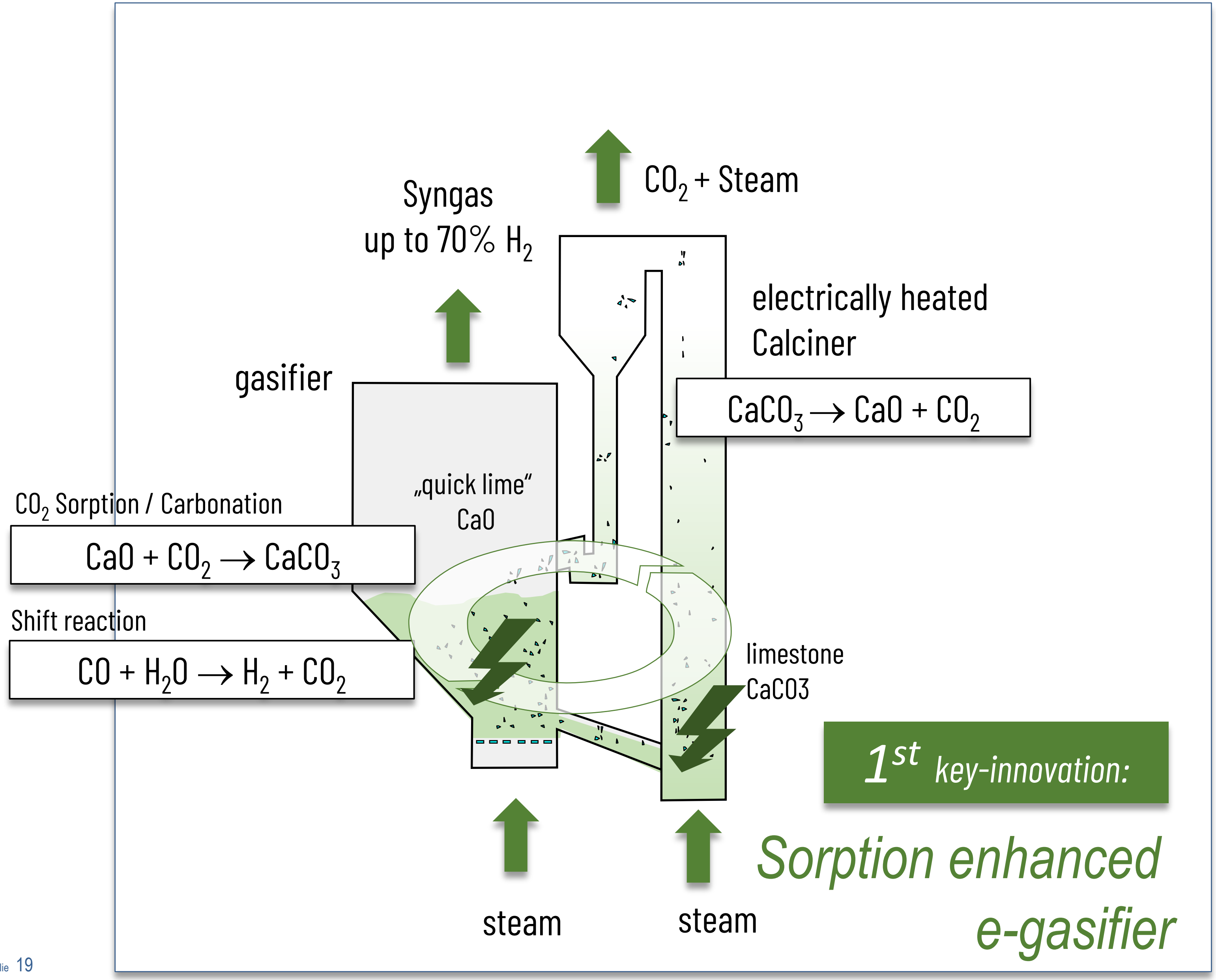
Principle Dual Fluidized bed gasifier



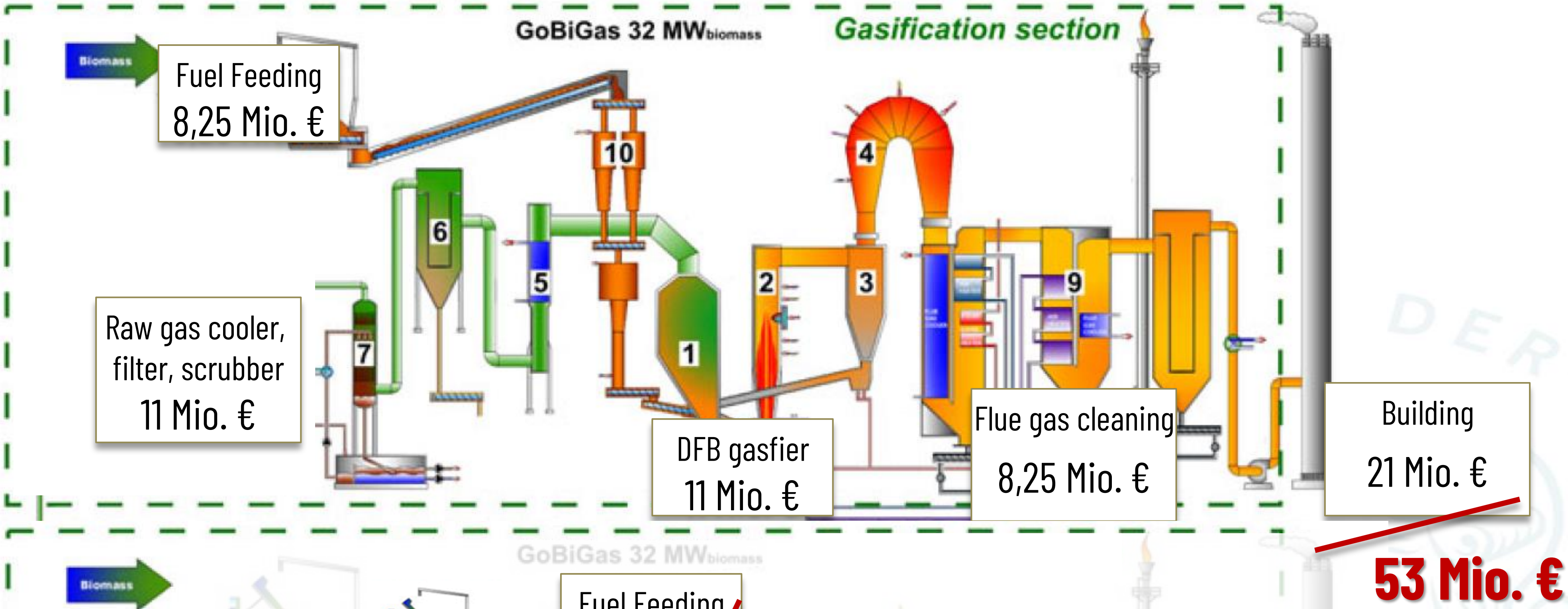
- Endothermal gasifications require Reactors require extremely high heat fluxes at highest temperatures
- Hot sand particles transfer heat from Combustion into gasifier

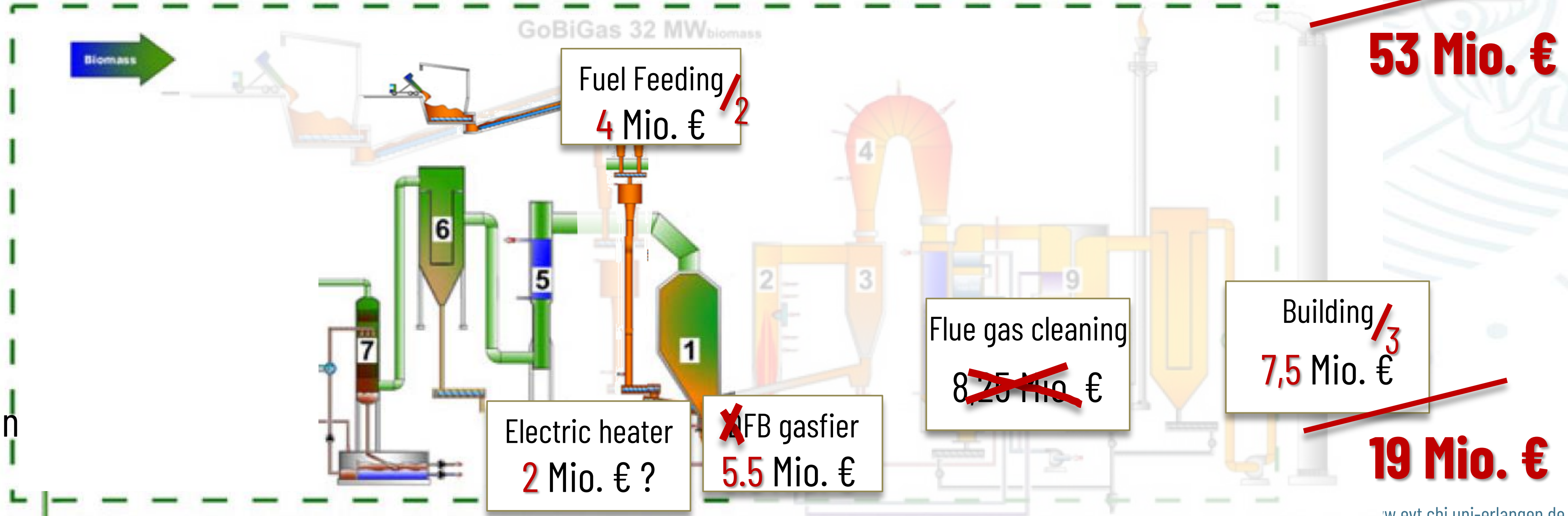
New concept

- Electrical heating replaces combustion
- Carbonate Looping separates CO_2

Advantages of eliminating the combustion chamber

- No combustion chamber (no flue gas losses, flue gas cleaning, no emission monitoring…)
- Fuel handling cut in half (56% biomass + 18% electricity instead of 100% biomass)
- Reduced area consumption





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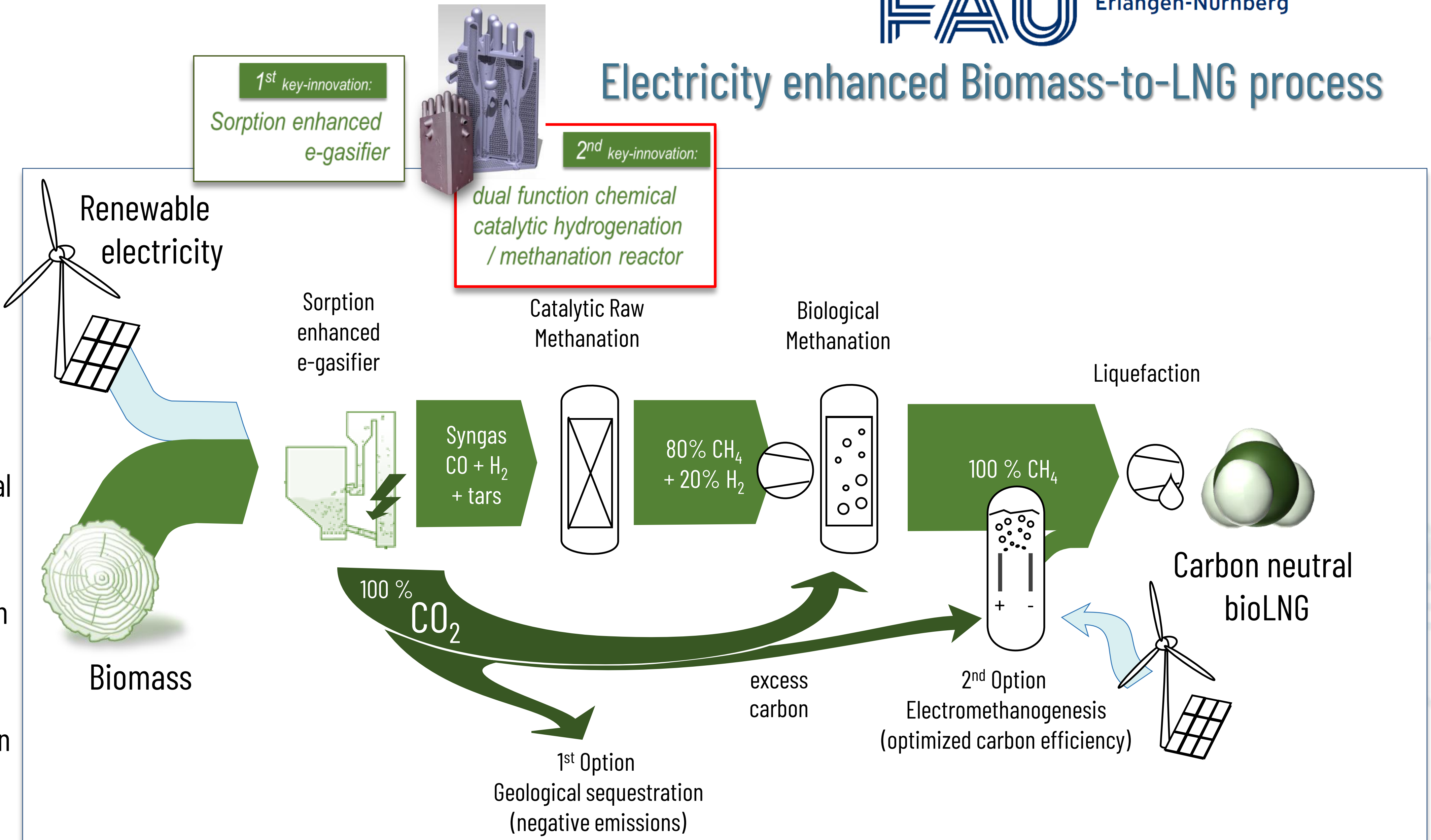

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Research Questions: Catalytic Methanation

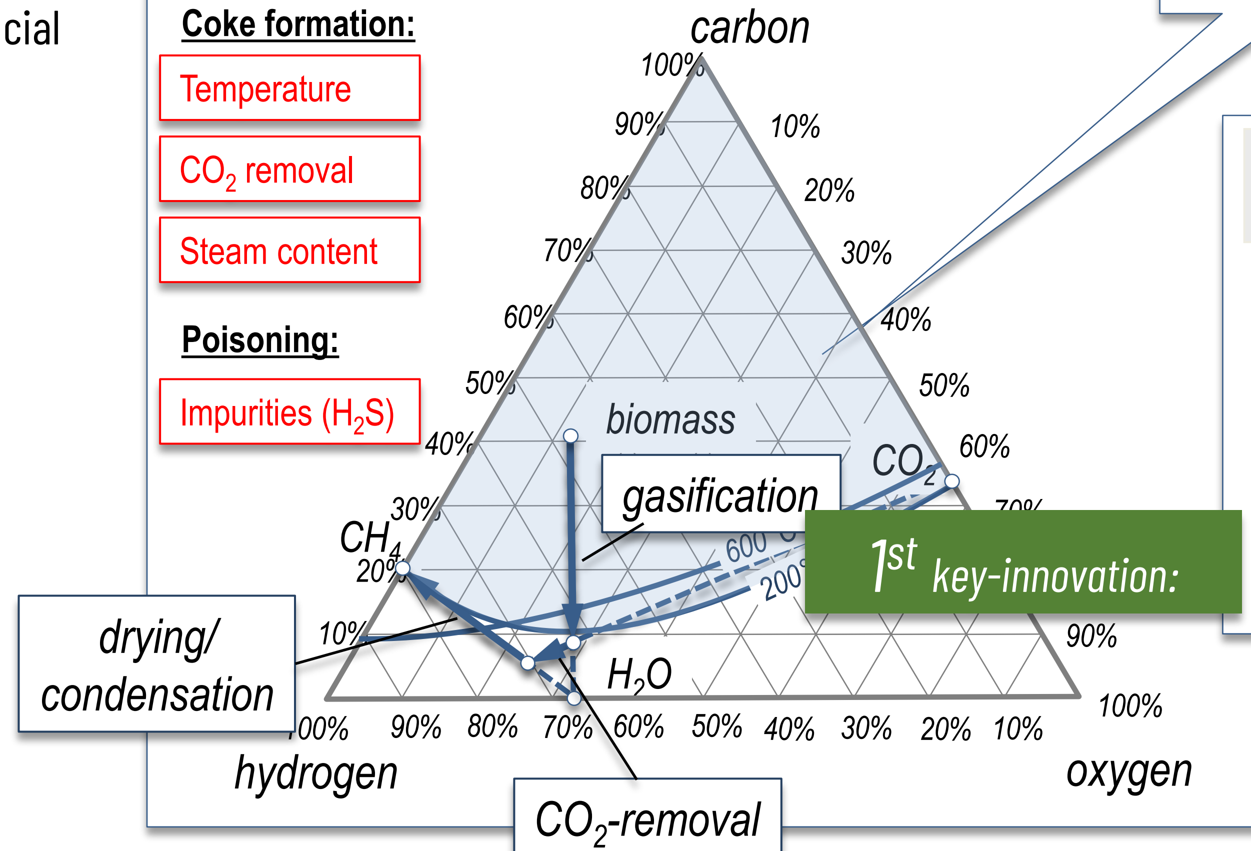
- Synthesis has to avoid degradation of the **catalyst**
- Design of the process chain is most crucial

Coke formation:

- Temperature
- CO_2 removal
- Steam content

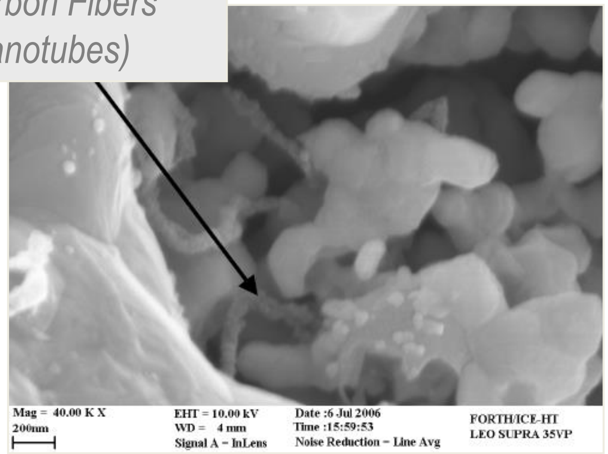
Poisoning:

- Impurities (H_2S)



Catalyst before … … and after methanation experiments

Carbon Fibers (Nanotubes)



1st key-innovation:

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Research Questions: Catalytic Methanation

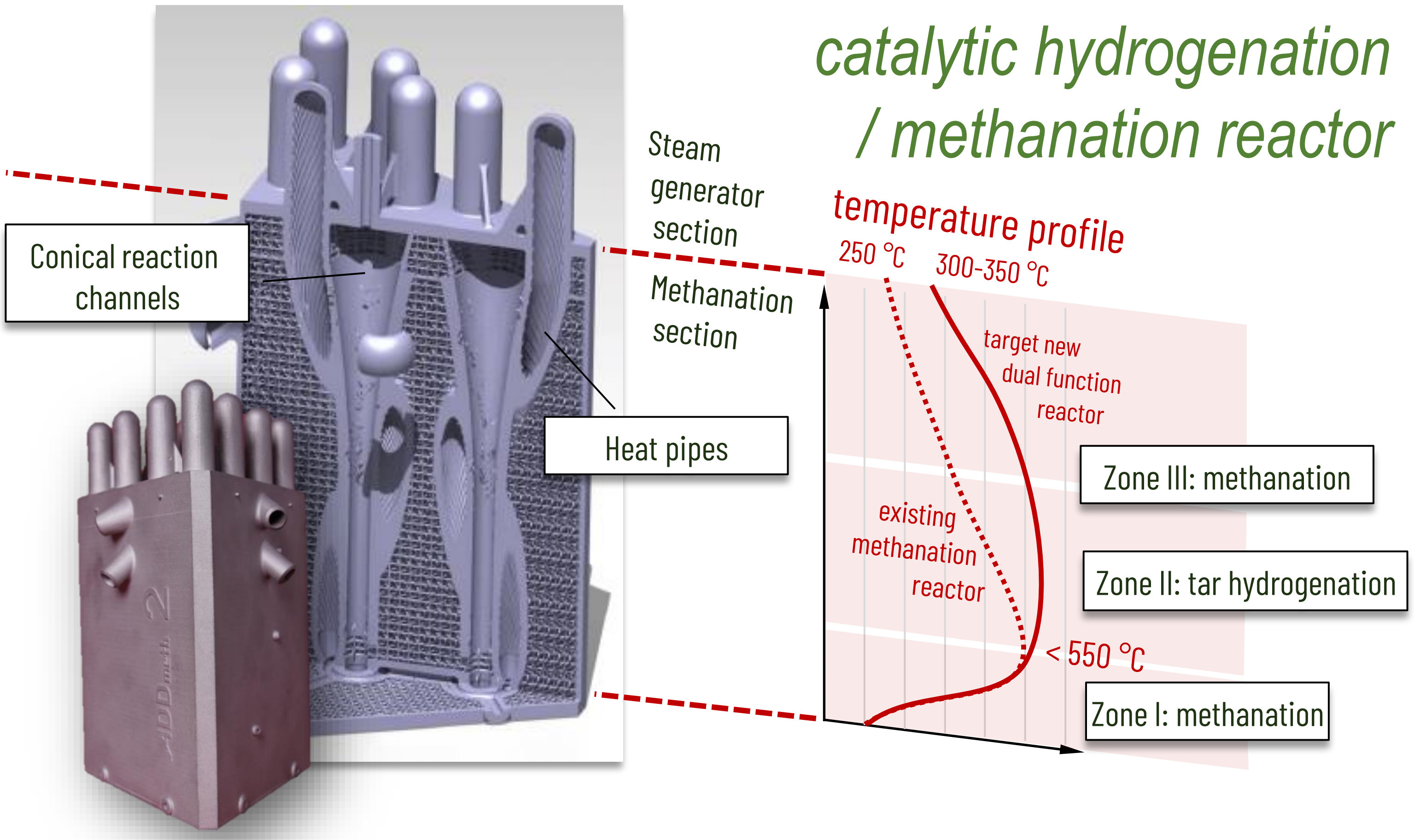
- Synthesis has to avoid degradation of the catalyst
- Design of the process chain is most crucial

New concept

- Additively manufacturing enables optimized geometries (based on CFD simulation)

2nd key-innovation:

dual function chemical catalytic hydrogenation / methanation reactor



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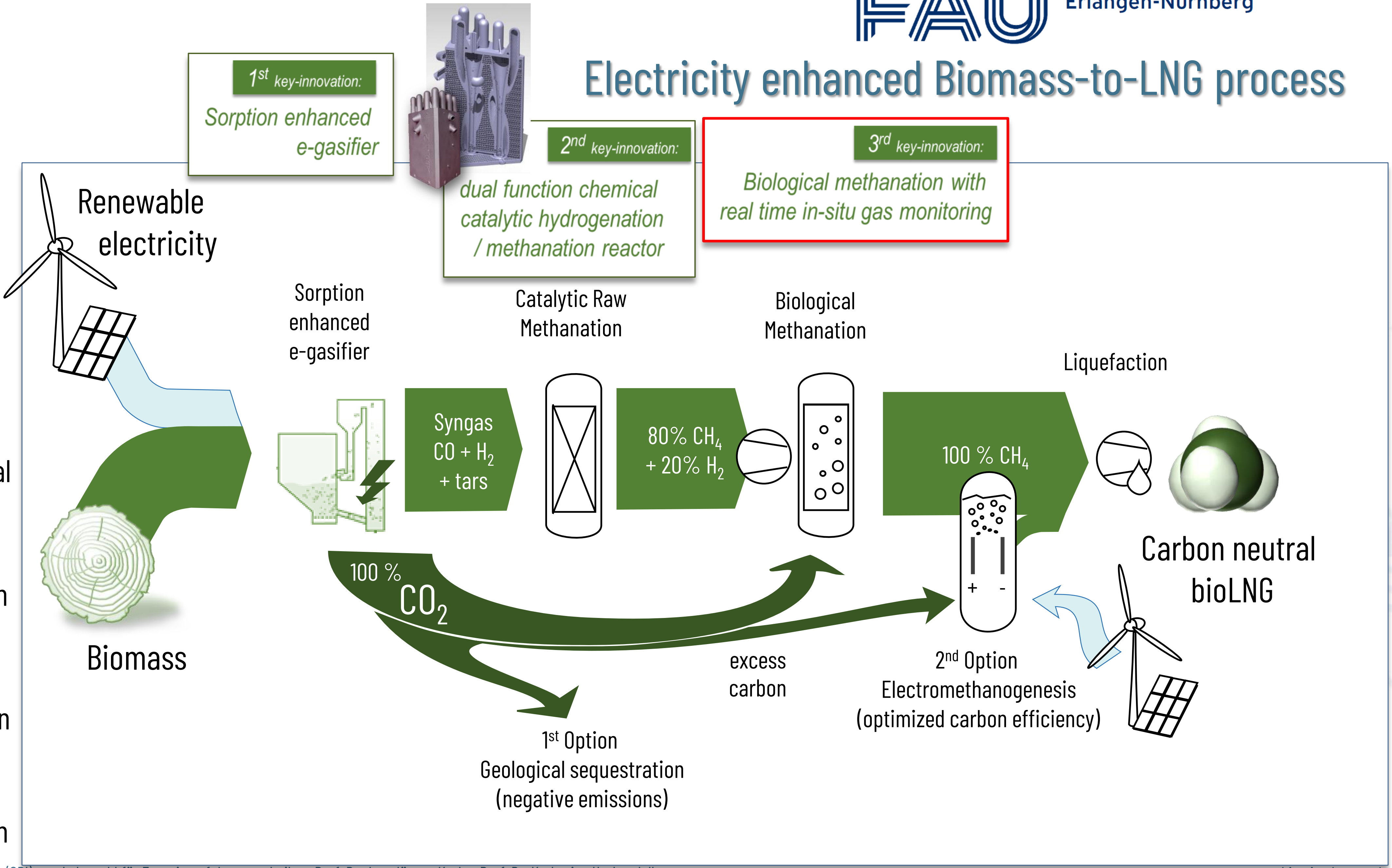
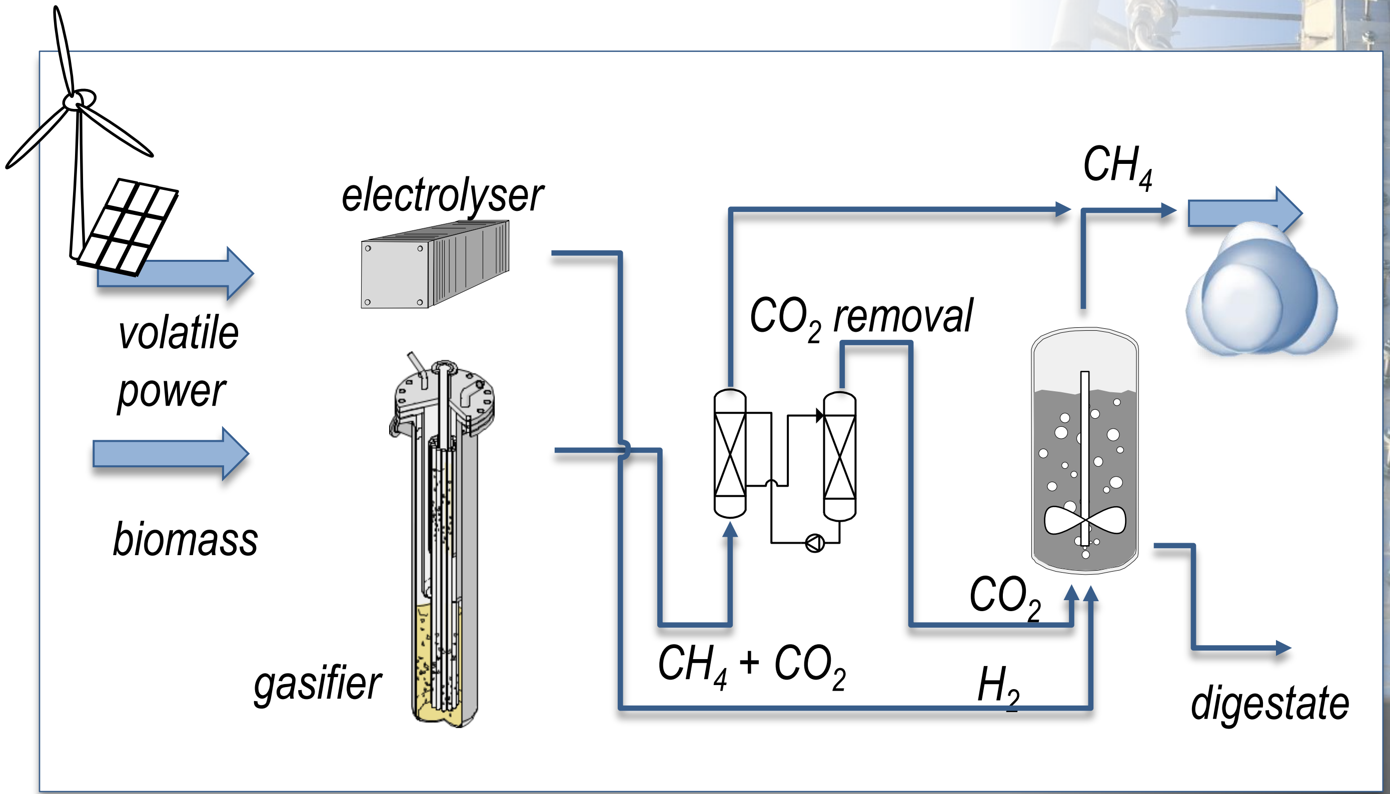


Research Questions:
Biological methanation

- Microbiological methanation of (green) syngas from biomass needs Adaptation of archae microorganisms to CO and tar loaded syngas



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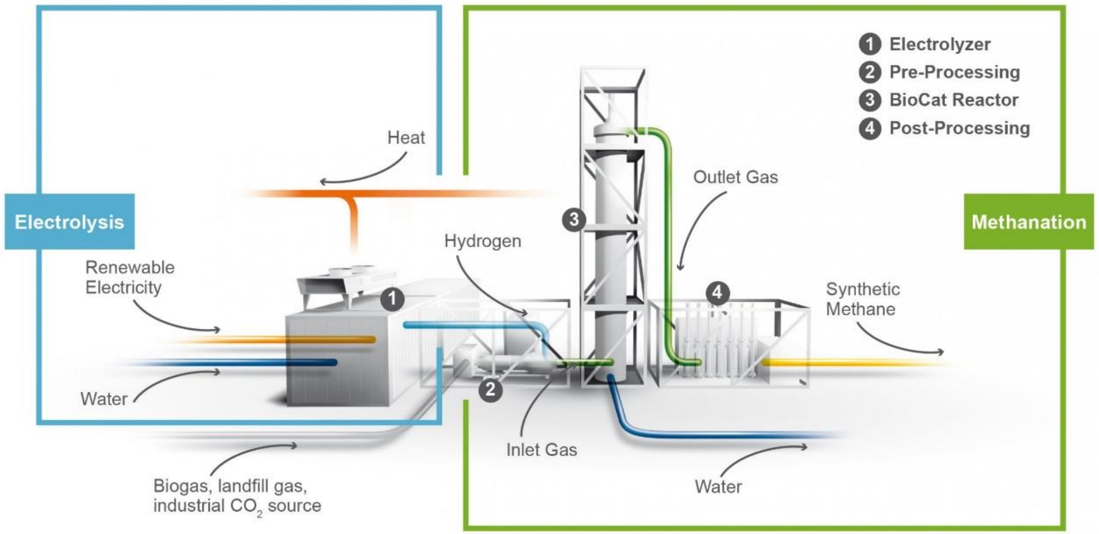
Electrochaea's BioCat Methanation System



https://www.electrochaea.com/press-resources/

New concept

- In situ gas monitoring for advanced process control in the fermenter

Electrochaea

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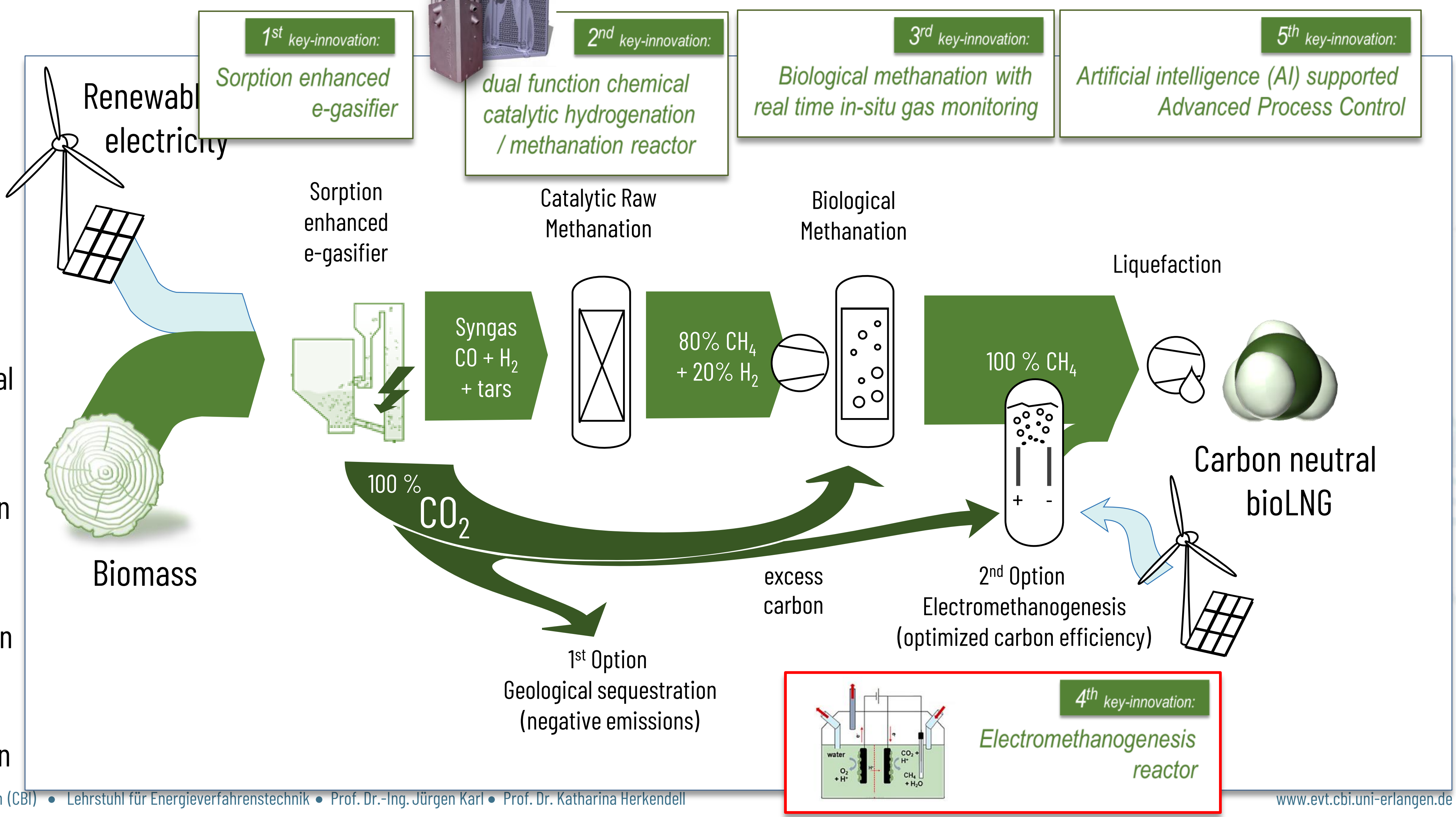

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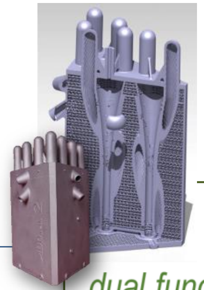
Electricity enhanced Biomass-to-LNG process

- GreenLNG
- **Our process**
- Challenges
- Impacts
- Conclusion



1st key-innovation: *Sorption enhanced e-gasifier*

2nd key-innovation: *dual function chemical catalytic hydrogenation / methanation reactor*

3rd key-innovation: *Biological methanation with real time in-situ gas monitoring*

4th key-innovation: *Electromethanogenesis reactor*

5th key-innovation: *Artificial intelligence (AI) supported Advanced Process Control*

Key Innovation	TRL 1 – TRL 4	Reference	Reference TRL	Reference technology
1	Sorption enhanced e-gasifier	Reference technology	TRL 7	Adsorption Enhanced Reforming (AER) process
2	dual function catalytic hydrogenation/ methanation reactor	Reference technology: Additively manufactured methanation reactor	TRL 5	
3	Biological methanation with real time in- situ gas monitoring	Reference technology	TRL 7- 8	steady-state Biological Methanation
4	Electromethanogenesis reactor	(no reference technology)		
5	Artificial intelligence (AI) supported Advanced Process control	Reference technology	TRL 9	Process control with Conventional PLC systems

TRL 1 | TRL 2 | TRL 3 | TRL 4 | TRL 5 | TRL 6 | TRL 7 | TRL 8 | TRL 9

Conclusions

1. GreenLNG is not only the most advantageous option for shipping, but also essential to secure the energy transition in the electricity market.
2. Sustainable e-fuels always requires carbon from the atmosphere, and for now atmospheric carbon is most easily available from biomass.

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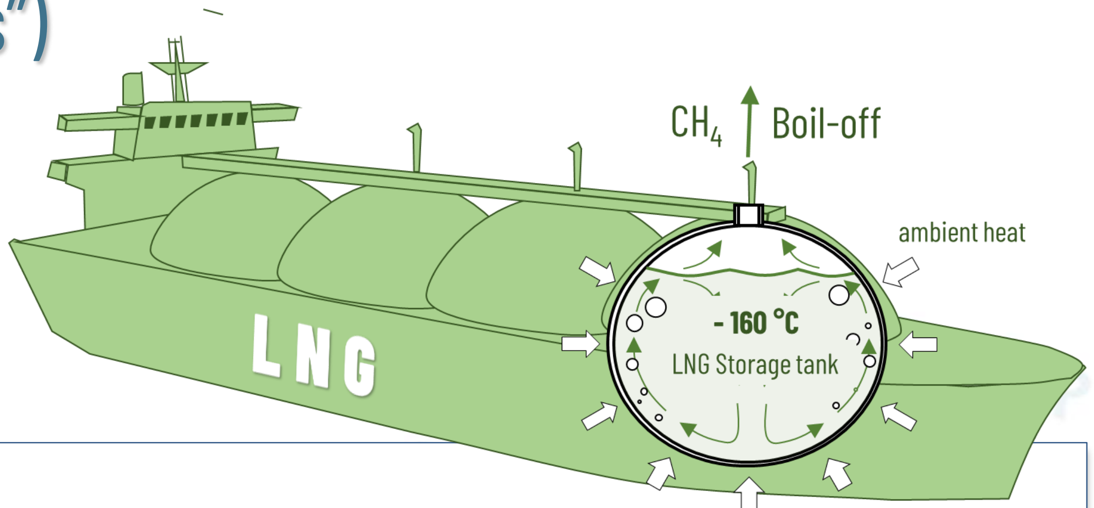
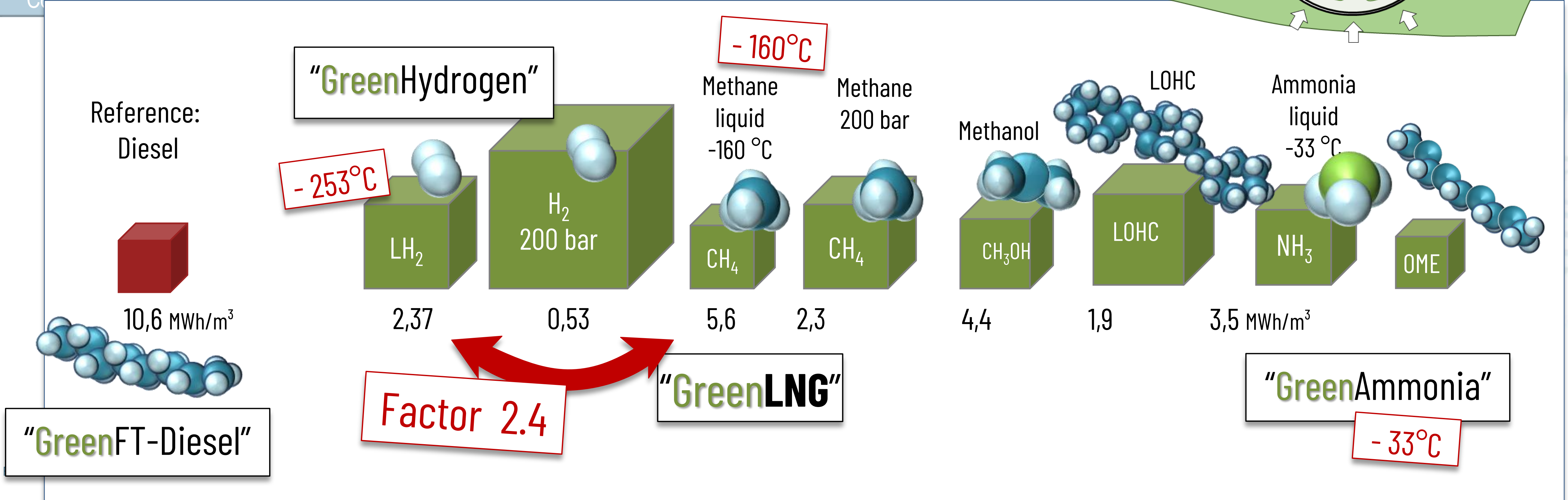
3. The technology's key challenge

- LNG logistics and methane emissions
- Roadmap to market

Energy density of e-fuels ("hydrogen carriers")

- Storage density and transport costs determine the cost of the hydrogen carrier
- Long-distance transport in atmospheric tanks requires deep temperatures and results in losses for liquefaction and during storage and transport





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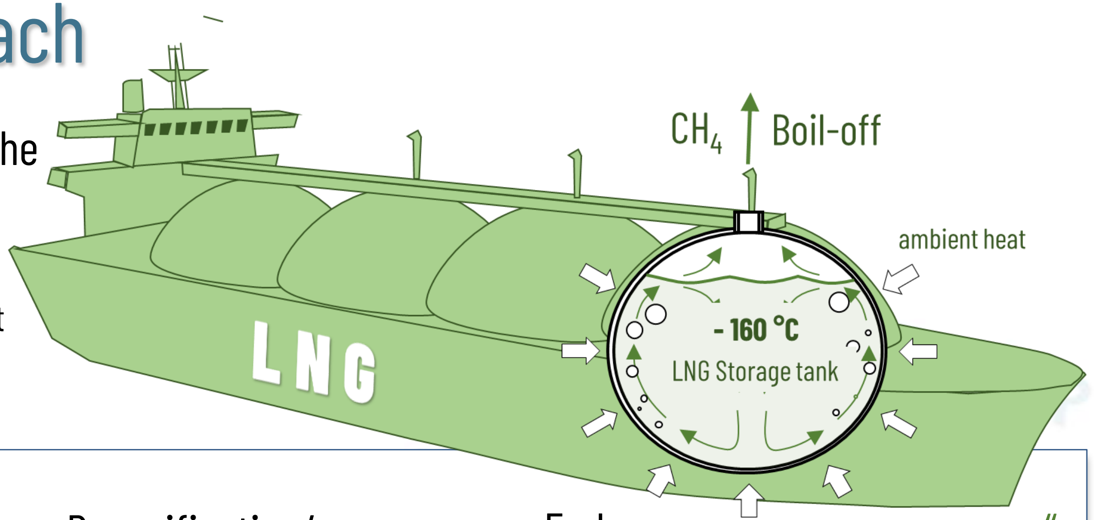
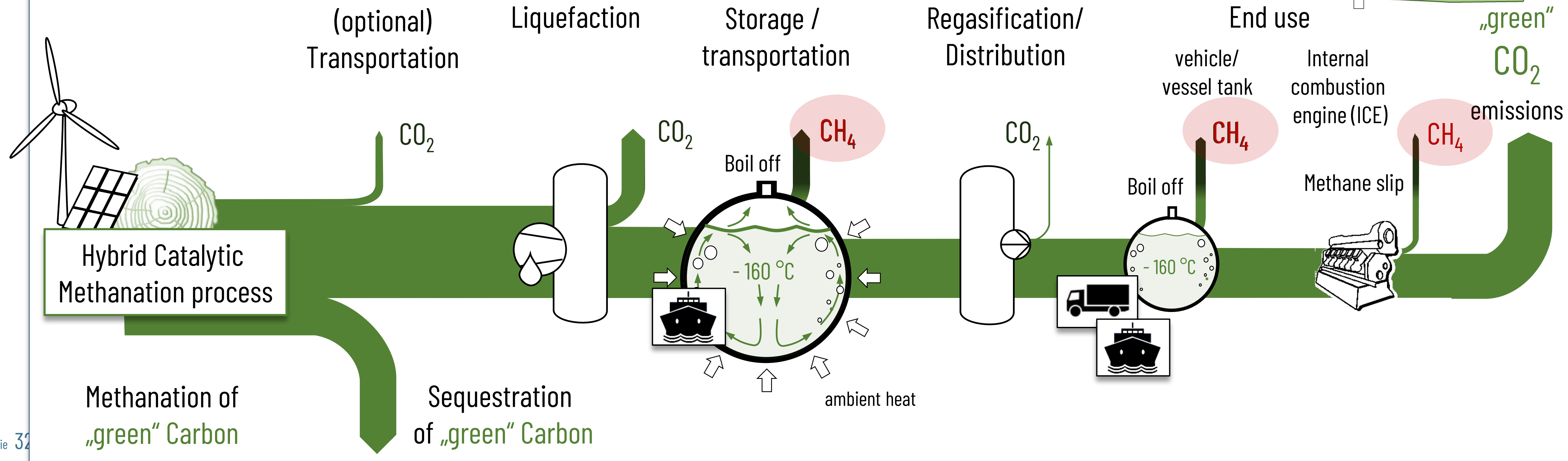
Key challenge: Zero Emission approach

Work Package 4

- fugitive methane emissions are particularly harmful due to the high global warming potential (GWP_{20} = 82.5, GWP_{100} = 29.5)*)
- Monitoring includes remote sensing of fugitive emissions, biomass potentials and Life Cycle Assessments (LCA)

*) IPCC Sixth Assessment Report





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The other Challenge: Roadmap to market

GreenLNG
Our process
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- Renewable energy must be "harvested" where electricity is cheap and available over many hours

Business cases depend on

- Policies and legal framework
- consumer acceptance and expectations
- Costs and logistics concepts

Work Package 5

Conclusions

1. GreenLNG is not only the most advantageous option for shipping, but also essential to secure the energy transition in the electricity market.

2. Sustainable e-fuels always need carbon from the atmosphere, and for the time being this atmospheric carbon will only be available from biomass.

3. A precondition for market introduction is the minimization of methane losses during storage and transport.

Carbon Neutral LNG

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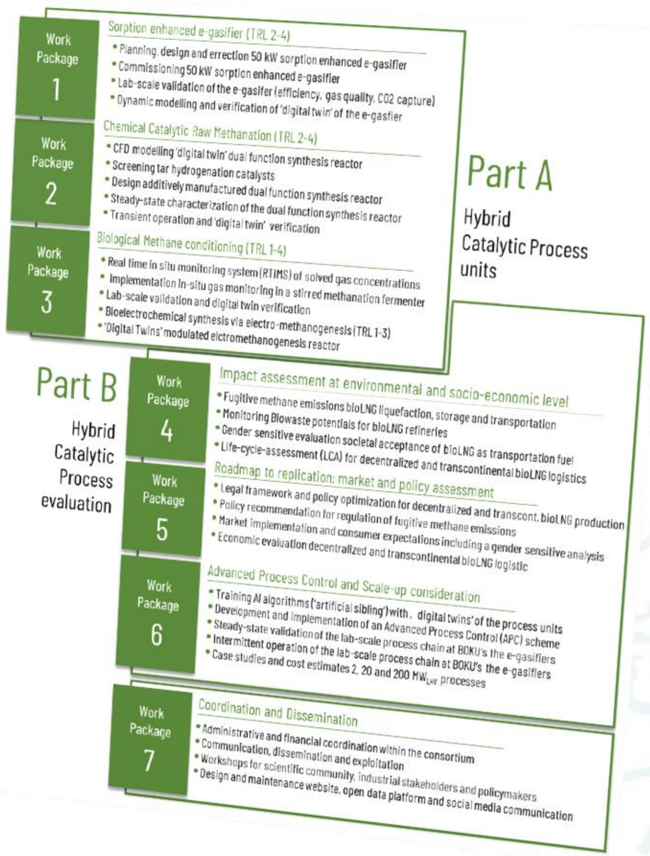
4. The projects expected impacts

- Project plan
- Main impacts



The project plan

Part A

Hybrid Catalytic Process units

Work Package 1

Sorption enhanced e-gasifier (TRL 2-4)

- Planning, design and errection 50 kW sorption enhanced e-gasifier
- Commissioning 50 kW sorption enhanced e-gasifier
- Lab-scale validation of the e-gasifer (efficiency, gas quality, CO2 capture)
- Dynamic modelling and verification of 'digital twin' of the e-gasfier

Work Package 2

Chemical Catalytic Raw Methanation (TRL 2-4)

- CFD modelling 'digital twin' dual function synthesis reactor
- Screening tar hydrogenation catalysts
- Design additively manufactured dual function synthesis reactor
- Steady-state characterization of the dual function synthesis reactor
- Transient operation and 'digital twin' verification

Work Package 3

Biological Methane conditioning (TRL 1-4)

- Real time in situ monitoring system (RTIMS) of solved gas concentrations
- Implementation in-situ gas monitoring in a stirred methanation fermenter
- Lab-scale validation and digital twin verification
- Bioelectrochemical synthesis via electro-methanogenesis (TRL 1-3)
- 'Digital Twins' modulated elctromethanogenesis reactor

Part B

Hybrid Catalytic Process evaluation

Work Package 4

Impact assessment at environmental and socio-economic level

- Fugitive methane emissions bioLNG liquefaction, storage and transportation
- Monitoring Biowaste potentials for bioLNG refineries
- Gender sensitive evaluation societal acceptance of bioLNG as transportation fuel
- Life-cycle-assessment (LCA) for decentralized and transcontinental bioLNG logistics

Work Package 5

Roadmap to replication: market and policy assessment

- Legal framework and policy optimization for decentralized and transcont. bioLNG production
- Policy recommendation for regulation of fugitive methane emissions
- Market implementation and consumer expectations including a gender sensitive analysis
- Economic evaluation decentralized and transcontinental bioLNG logistic

Work Package 6

Advanced Process Control and Scale-up consideration

- Training AI algorithms ('artificial sibling') with, digital twins' of the process units
- Development and implementation of an Advanced Process Control (APC) scheme
- Steady-state validation of the lab-scale process chain at BOKU's the e-gasifiers
- Intermittent operation of the lab-scale process chain at BOKU's the e-gasifiers
- Case studies and cost estimates 2, 20 and 200 MW_{LHV} processes

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The project main impacts

The project will contribute …

- … to establish a global renewable gas sector and intra-European and intercontinental supply chains for renewable energy
- … to make Europe's LNG supply independent from fossil natural gas from Russia and the Middle East
- … to ensure a most effective and sustainable use of scarce "green" carbon and biomass in order to provide truly carbon neutral fuels

Conclusions

1. GreenLNG is not only the most advantageous option for shipping, but also essential to secure the energy transition in the electricity market.

2. Sustainable e-fuels always need carbon from the atmosphere, and for the time being this atmospheric carbon will only be available from biomass.

3. A precondition for market introduction is the minimization of methane losses during storage and transport.

and

4. Renewable gases and CO_2-neutral fuels are the most important challenges of the energy transition

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