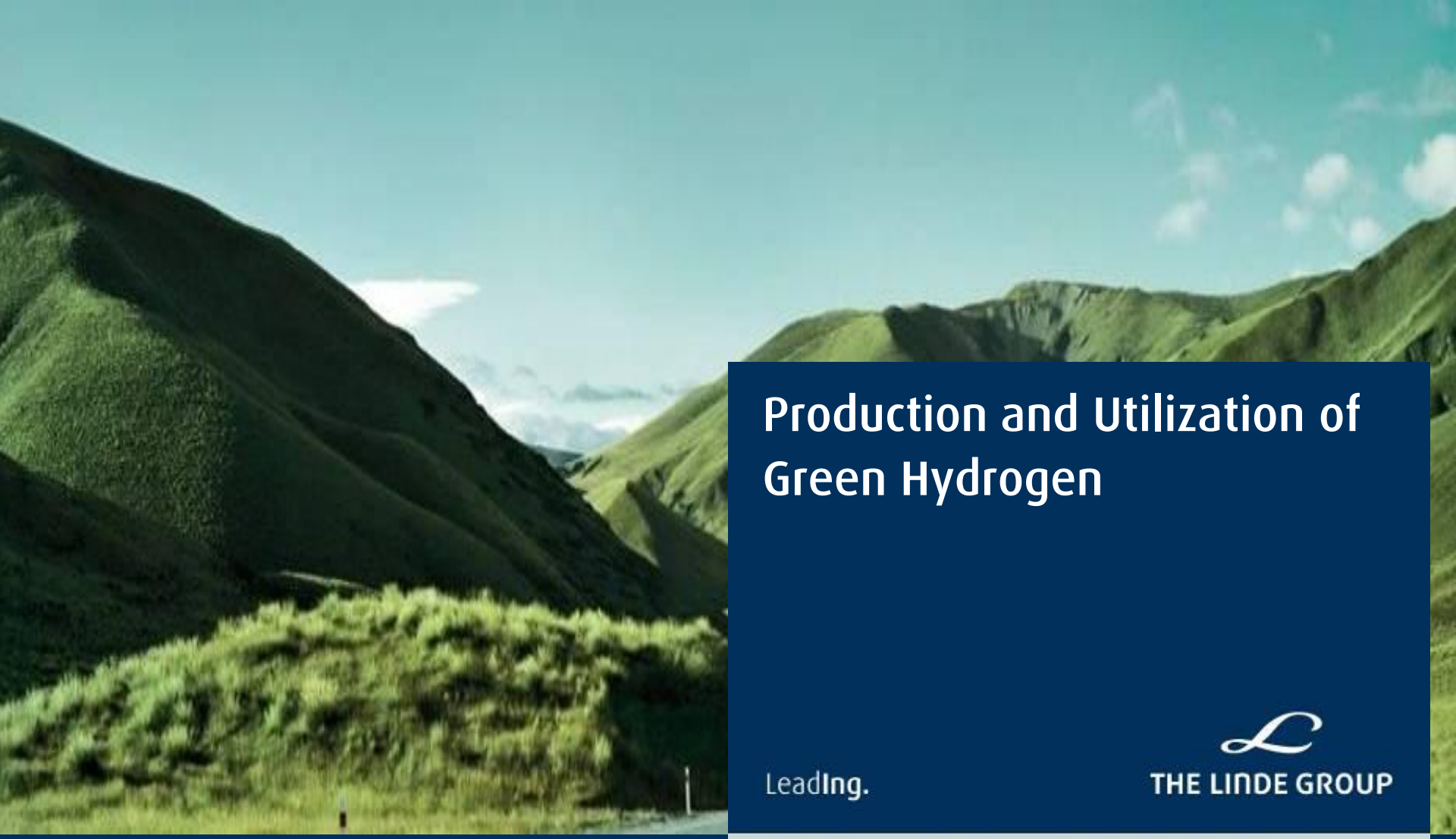

Production and Utilization of Green Hydrogen

LeadIng.

THE LINDE GROUP

Mathias Mostertz

GAFOE Meeting, April 27, 2013

Agenda

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1. **The Linde Group – General Overview**
   - Clean Energy Technology Biomass Program
2. **Utilization of Green Hydrogen**
   - Existing markets and applications
   - New and emerging markets and applications
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   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification
4. **Conclusion**

The Linde Group

Structured in two main divisions

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(€ 15.3 billion revenue in 2012)

Linde Gas

Linde Engineering

(Headquarter Munich, Germany)

Clean Energy Technology Biomass Program
Overview of different pathways

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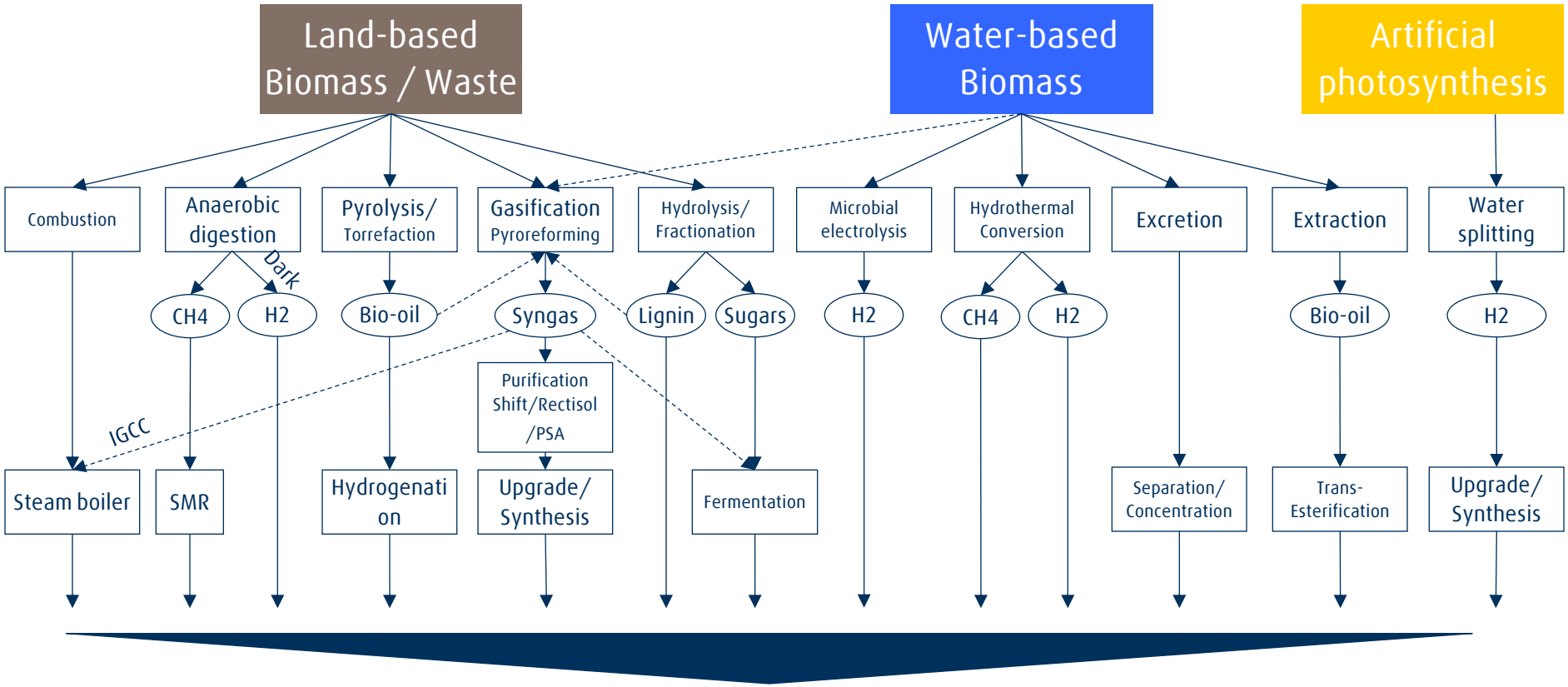

Energy:
- Electricity / Power
- Heat

Platform chemicals
- Alcohols
- Syngas (Acetic acid, MeOH)
- Phenols
- Bio-ethylene
- Olefins

Drop-in fuels:
- Gasoline
- Diesel
- Jet

Other fuels:
- Hydrogen
- CH4 (SNG)
- Ethanol
- Butanol

Clean Energy Technology Biomass Program
Industrial Gas opportunities

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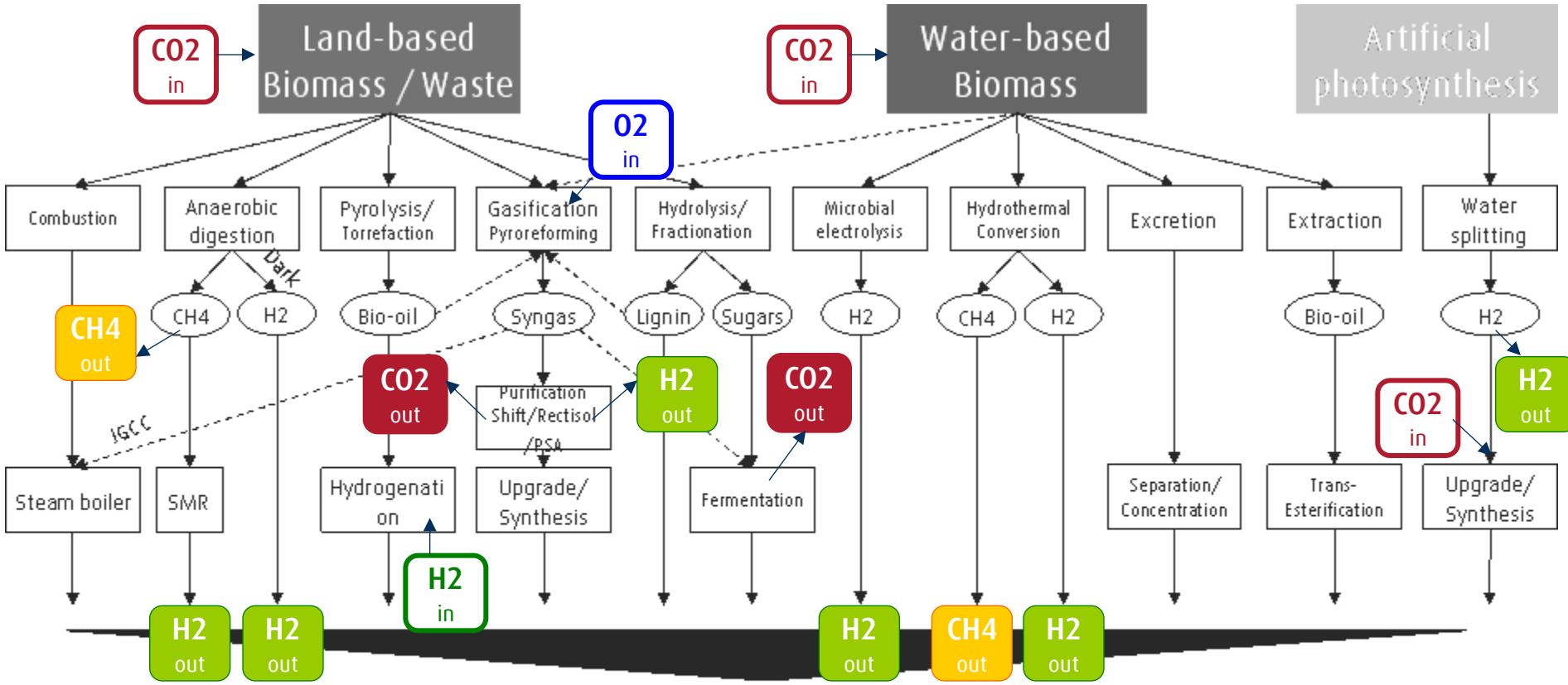

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Hydrogen Market

Existing markets and applications

Ca. 500 Mrd. Nm3/yr worldwide
~ 1500 TWh/yr or
~ 300 Mill. Fuel cell vehicles

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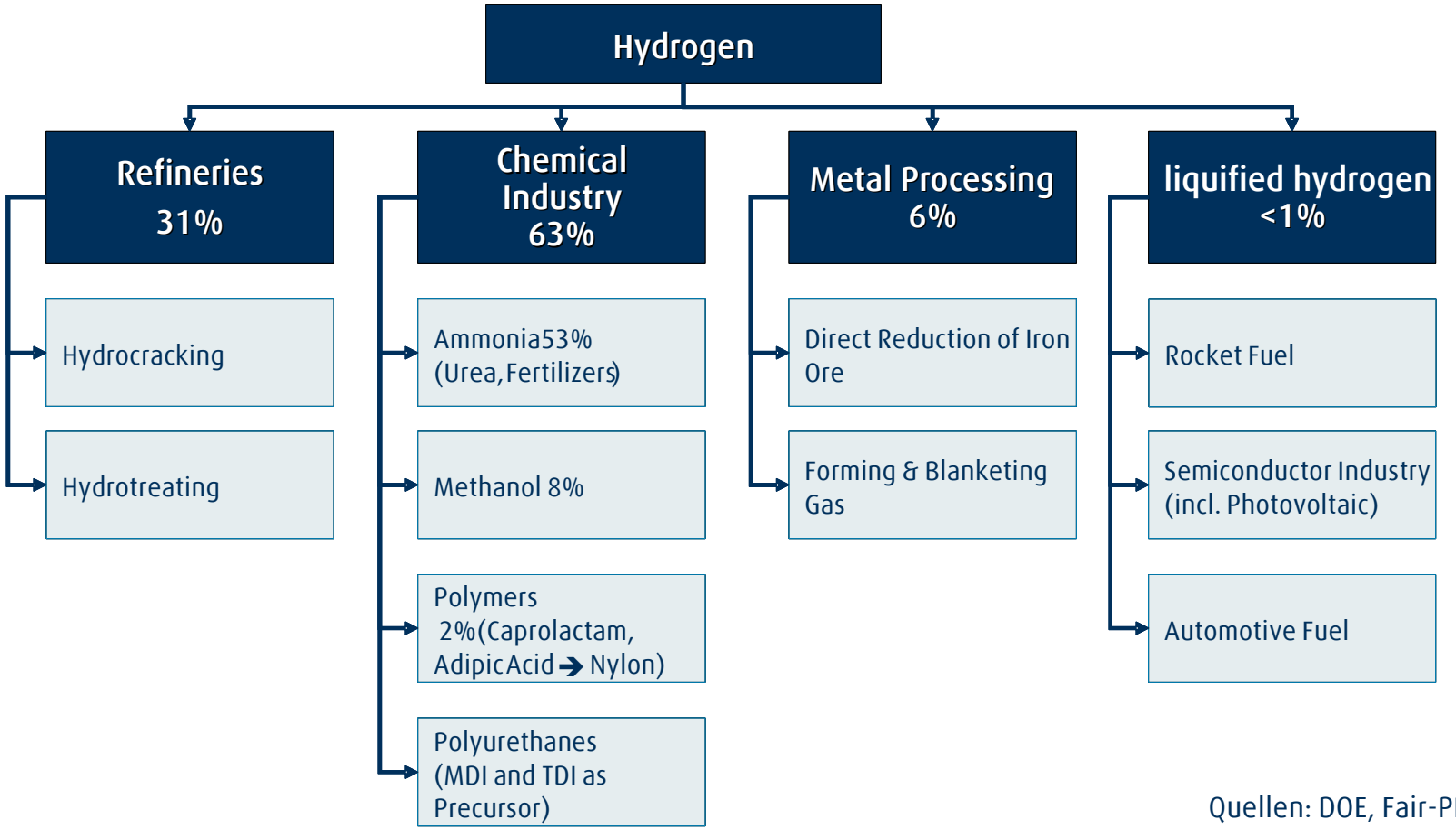

Quellen: DOE, Fair-PR

- Further applications (<1000 Nm^3/h): glas production, food (hydrogenation of fats), cooling of electric generators
- Only appr. 5% of produced H_2 is transported

Hydrogen Market

New and emerging markets and applications – Mobility

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Conditioning (Rectisol, PSA, liquefaction etc.)

Logistic

Front End: H_2-filling station

Automotive appl. Combustion engine fuel cell

thermochemical H_2 generation

electrochemical H_2 generation

fossile feedstock

renewable feedstock

wind, hydro or solar power

Why Hydrogen as fuel?
New and emerging markets and applications

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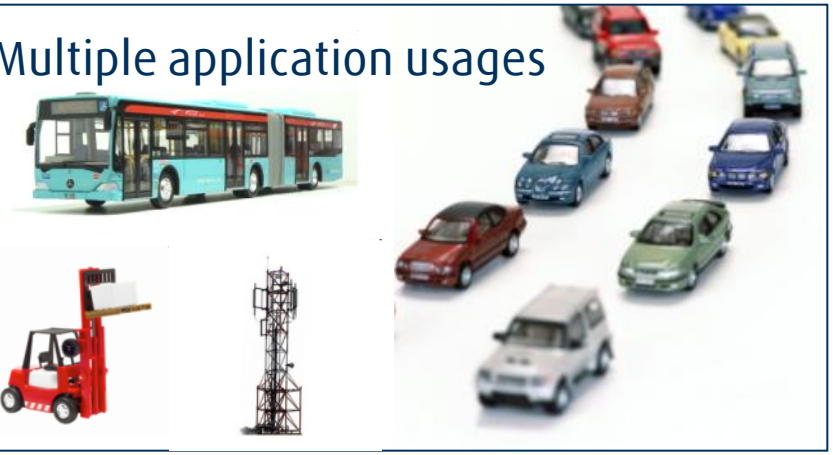
Hydrogen offers...

CO2 reduction potentials

Diversification of primary energy sources

Zero emissions at the tailpipe

Multiple application usages



..just like batteries

* Especially compared to electricity based transportation

Application areas for Hydrogen as fuel and Linde's fuelling experience

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Today's focus

Linde's experience

Passenger Cars

- > 50 stations delivered
- > 80.000 fuellings

Public Transport

- > 10 stations delivered
- > 20.000 fuellings

Material Handling

- > 10 stations delivered
- > 300.000 fuellings

Backup Power

- > 10 units delivered

Linde's experience

Maritime / ships

- 2 stations delivered
- ferry and submarines

Aviation

- Supply of pilot projects
- Market studies

H2 Based CHP private homes

- Market studies

Portable Applications

- Market studies

Linde covers the whole value added chain

Hydrogen mobility applications

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Production

Decentralization

Conventional
(e.g. SMR)

Green
(e.g., BtH*)

Supply/Storage

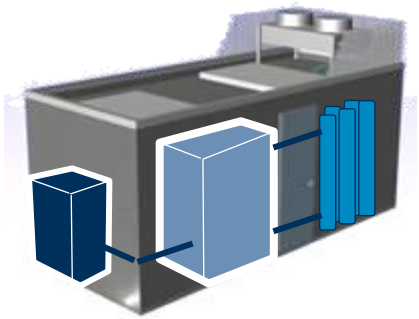
CGH_2 storage

LH_2 storage

Onsite SMR

Onsite Electrolysis

Compression/Transfer



Ionic compressor

Cryo pump

Dispenser

350 bar

700 bar

* Biomass to Hydrogen

Hydrogen Market
New and emerging markets and applications – Mobility

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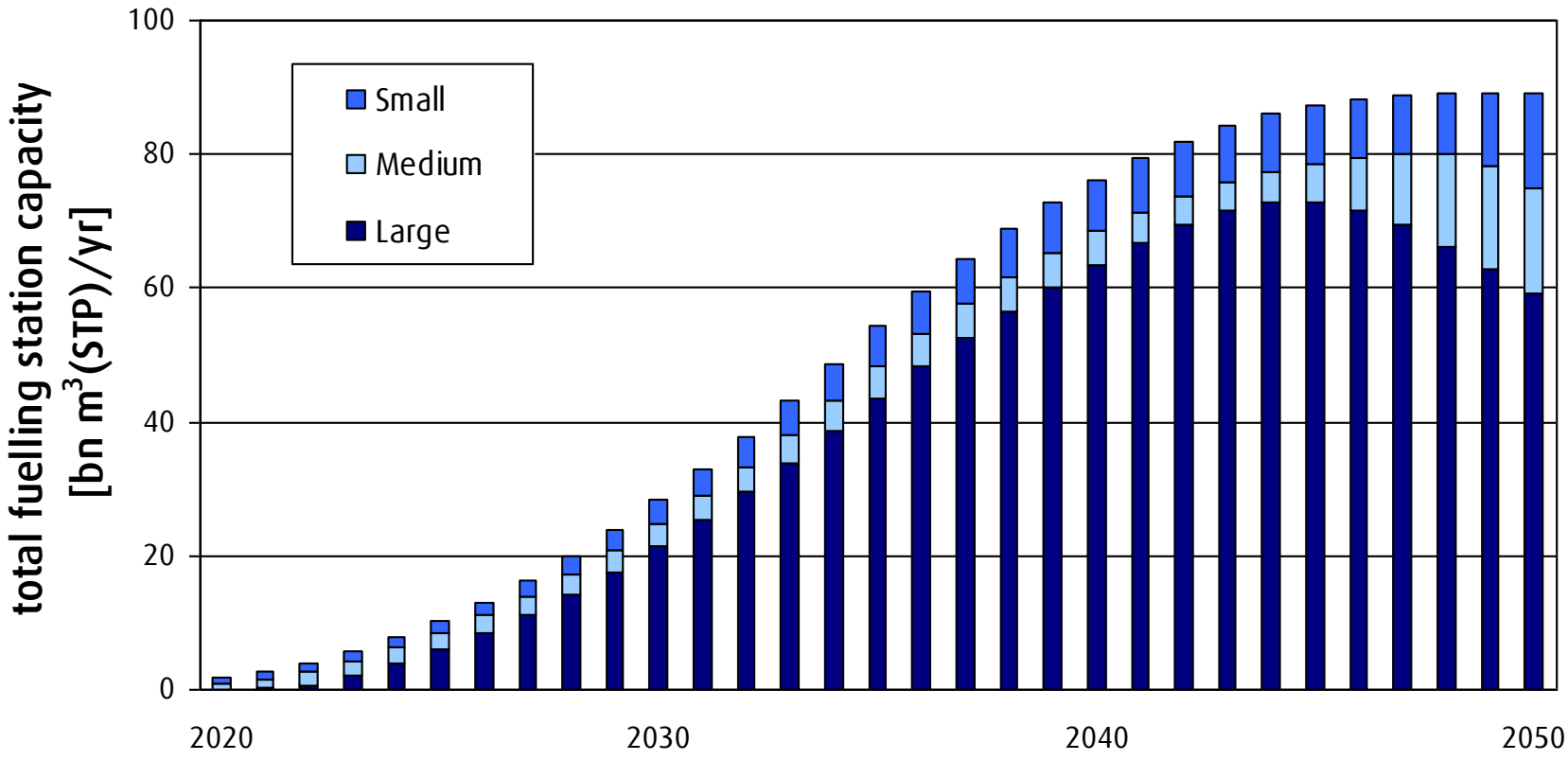
25% FCEV penetration in 2050 (hydrogen retail network covers 75% of EU29, giving local access to 97% of all cars)



Note Small stations have maximum capacity of 400 kg H_2/day, medium have 1 tonne H_2 /day and large have 2.5 tonnes H_2 /day

SOURCE: EU coalition study

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Production of Green Hydrogen

Glycerine Pyroreforming – Linde pilot plant in Leuna (1)

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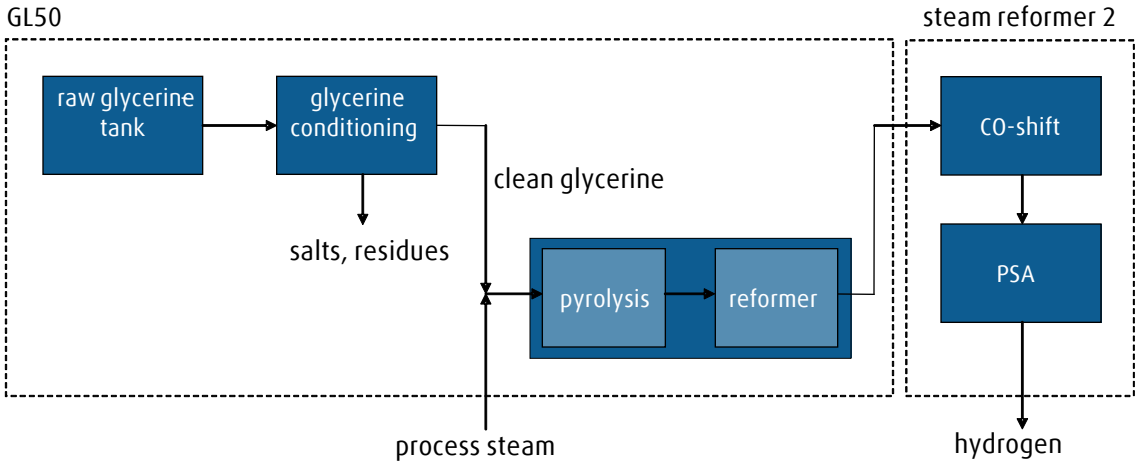

Worldwide first plant for green hydrogen production from Glycerine (By-product of biodiesel production)

Start of operation: 2011

Capacity: 50 Nm³/h

NIP-funding

Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

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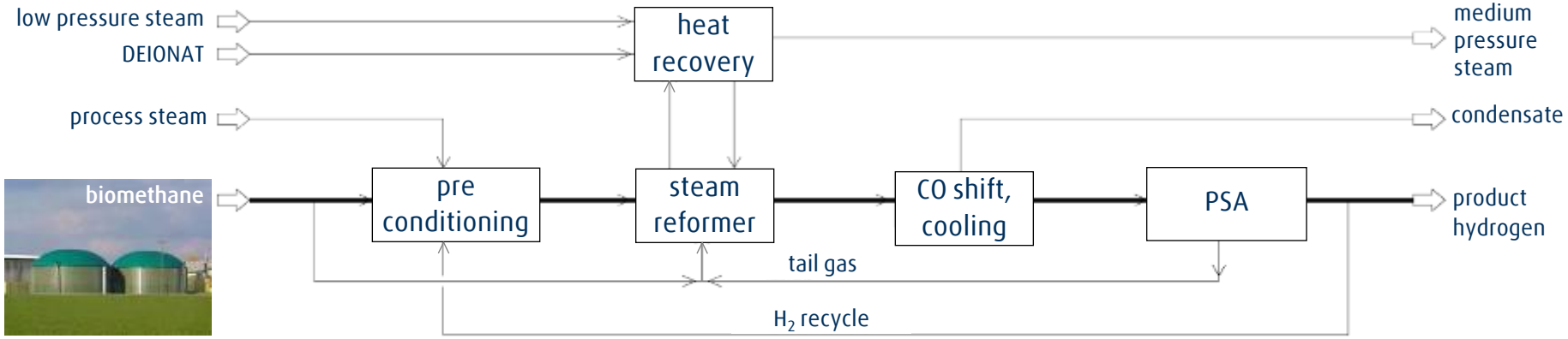
Biomethane reforming – Linde steam methane reformer in Leuna



- Total biomethane feeding into NG grid, Germany, 2010*: 30,650 $m^3(CH_4, STP)/h$ (0.27 % of NG consumption Germany)
  → it corresponds roughly to the NG consumption of both Leuna-SMR's

Steamreformer I (35.000 Nm^3/h hydrogen capacity)

Steamreformer II (35.000 Nm^3/h hydrogen capacity)

* Biogas monitoring report 2011, Federal Network Agency Germany

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Production of Green Hydrogen
Gasification of solid cellulosic Biomass

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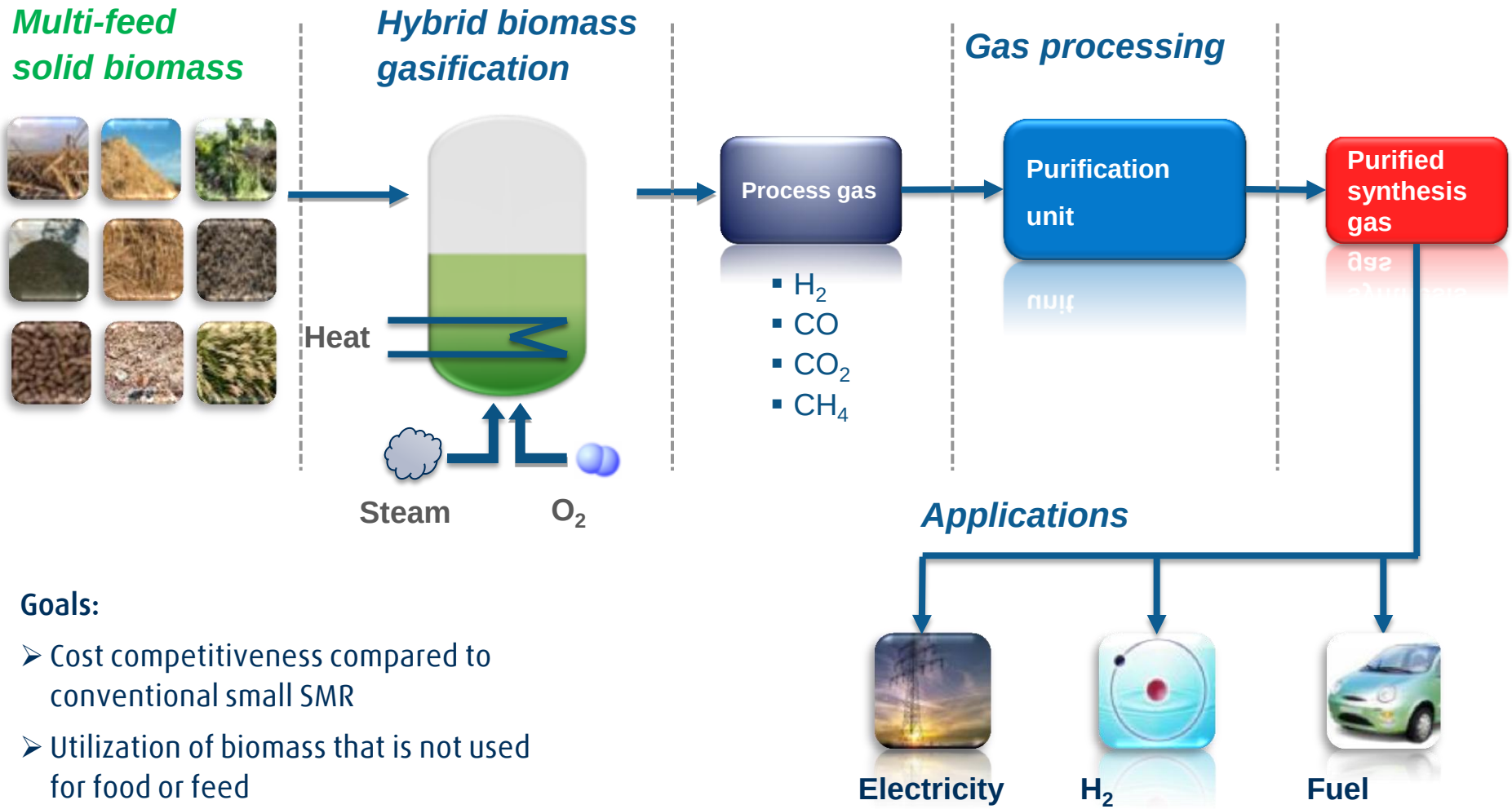

Goals:

- Cost competitiveness compared to conventional small SMR
- Utilization of biomass that is not used for food or feed
- Versatile, decentralized technology

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Conclusions

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- High amounts of conventional H_2 are already used in industry today
- Substitution by green hydrogen helps for reduction of emissions
- Today the chances/added value for companies consists in strengthening of its green image/perception and saving of CO_2-certificates
- A harmonization of the costs can be achieved by
  - further development of the technologies
  - price increase of fossil fuels
  - favorable political conditions and regulations
- Linde is active on:
  - → worldwide first glycerine plant, biomass gasification, biomethane reforming, hydrogen by electrolysis
  - → demonstration projects for various H_2 energy platform technologies

Thank you very much for your attention!