Pyrolysis

Methan Pyrolyse: Eine ökonomische Alternative zur Elektrolyse?



- Introduction
- Value Streams
- Hydrogen Demand Forecast Europe
- Renewable Energy Situation
- Carbon Footprint
- Carbon as Value Product

tde hydrogen and carbon technology Methane Pyrolysis Input and Output



tde hydrogen and carbon technology Ecosystym

Methane pyrolysis

Decomposition of methane at high temperatures in a reactor with liquid metal to hydrogen and solid carbon

Energy for process heat

20 to 25% of energy of electrolysis required

Processing Module* Hydrogen (H₂) Carbon (C) -Liquid metal • Methane (CH₄) -Natural gas (methane) Use of existing **Biogas** infrastructure

Negative emission balance

Solid carbon

- Agriculture
- Lightweight construction
- Food industry
- Industry (e.g. colors, tyres, batteries)

Hydrogen

- Chemical industry
- Ammonia and fertilizer
- Heavy transport
- Hydrogen storage

*Patents pending, with growing patent family around processing and C-quality)

tde hydrogen and carbon technology A sustainable path to scalable energy supply

- Supplying the heavy industry with CO₂ neutral and affordable hydrogen at industrial scale
- Utilize existing natural gas infrastructure
- Utilize carbon the building block of life as valuable secondary raw material

Cost to produce 1kg turquoise hydrogen in Europe

Comparison:

- Turquoise H₂ approx.
 44% cheaper to
 produce in 2025 and
 50% in 2030
- > 50% less renewable energy demand



tde energy pyrolysis: today and future outlook Pyrolysis is resilient toward gas price fluctuations

Currently, green hydrogen already outcompetes grey on costs



Hydrogen Demand Europe

European Market

currently 9.7 million tons hydrogen production

2030 est. 16.9 million tons

Distribution of main hydrogen production hubs in EU27 + UK. Green and blue dots represent chemical industries with hydrogen and ammonia production. Shaded polygons show EU coal regions in transition (CRiT). Background colors represent total demand in TWh per year i.e. the sum of electricity consumption and the potential demand for electrolysis only in hydrogen producing regions.



Hydrogen Demand Europe



Germany: 62 new funded projects onwards from 2021 ($\in 8Bn$):2GW H₂ via green electrolysis for 2030.



H, ERZEUGUNG

AquaVentus, Helgoland, RWE Renewables HGHH, Hamburg – Vattenfall/Shell/ Mitsubishi/Wärme Hamburg

- 3 Clean Hydrogen Coastline, NI –
- EWE/EWE Netz/swb 4 GET H2, Lingen – RWE Generation
- S GreenMotionSteel, Duisburg Air Liquide DE
- MAPEVA, NRW Neumann&Esser
- = 7 doing hydrogen, Rostock APEX Energy
- 8 doing hydrogen, MV, BB,SA ENERTRAG
- 9 Green Hydrogen Hub, Leuna Linde/Total
- 10 H2-SARA, Dresden Sunfire
- 11 LHyVE Erzeugung, Leipzig EDL
 12 LHyVE System, Leipzig LVV
 - 12 LHyVE System, Leipzig LVV
 13 Projektname noch nicht zur Veröffentlichung freigegeben
 - freigegeben
 Hydrohub Fenne, Völklingen Siemens
- Energy/STEAG
- 15 Hy4Chem, Ludwigshafen BASF
 16 ElYance, Erlangen Siemens Energy
- If GH@BD, DE/AUT Hydrogenious
- 18 HyTechHafen Rostock, Rostock Rostock PORT GmbH
- 19 Bosch Power Units, BW, BY Robert Bosch

MINFRASTRUKTUR

- 20 AquaVentus, Helgoland, GASCADE
- 21 HH-WIN Gasnetz Hamburg
- 22 Clean Hydrogen Coastline, NI EWE/EWE Netz/EWE Gasspeicher
- 23 Green Crane, Lingen Hydrogenious
- 24 Hyperlink Gasunie DE
 - 25 GET H2, Gronau RWE Gas Storage West
- 26 GET H2 Nowega
- 27 GET H2 Open Grid Europe
- 28 GET H2 Thyssengas
 29 doing hydrogen GASCADE
- 30 doing hydrogen GASCADE
- 30 doing hydrogen ONTRAS
 31 Green Octopus MD ONTRAS
- 32 Green Octopus MD, Bod Lauchstädt -
- VNG Gasspeicher
- 33 LHyVE Transport, Leipzig Ontras
- 34 mosaHyc Creos DE

- 35 Hyscale100, Kreis Dithmarschen Holcim Deutschland/Hynamics Deutschland/Ørsted Wind Power Germany/ Raffinerie Heide
- 36 H2H, Hamburg Arcelor Mittal
- 37 Clean Hydrogen Coastline, Bremen Arcelor Mittal
- 38 DRIBE2, Bremen, EH Arcelor Mittal
- 39 LGH2, Lingen BP
- 40 LGH2, Lingen Oersted
- 41 GET H2, Salzgitter Salzgitter Flachstahl
 42 e-Methanol Projekt, Stade DOW
- 42 e-Methanol Projekt, Stade DOW
 43 tKH2steel, Duisburg thyssenkrupp steel
- 44 Projektname noch nicht zur Veröffentlichung freigegeben
- 45 Projektname noch nicht zur Veröffentlichung freigegeben
- 46 doing hydrogen, BB ENERTRAG
- 47 doing Hydrogen, Rüdersdorf CEMEX
- 48 H2SYNGAS, Dillingen SHS/Saarstahl
- 49 BayH2, Neustadt Vattenfall Innovation/Bayernoil
- 50 RHYME Bavaria, Burghausen Wacker Chemie

NUTZUNG MOBILITÄT

- 51 SENECA, Berlin H2 MOBILITY DE
- 52 BMW Produkt, München Bayrische Motorenwerke
- 53 Brennstoffzellen Gigafactory, Region Kirchheim-Teck – cellcentric GmbH & Co KG
- 54 PEGASUS, Worth Daimler Truck
- 55 NextGen HD-Stack, Dettingen ElringKlinger
- 56 Clean Hydrogen Coastline, Nordwestdeutschland FAUN Umwelttechnik
- 57 NextGadila, Weinheim Freudenberg Performance Materials
- 58 WIPLIN, Hamburg Airbus Operations
- 59 H2Load, Hamburg Hamburger Hafen und Logistik
- 60 HyPA, Hamburg Hamburg Port Authority
 61 H2 HADAG HADAG Seetouristik und F\u00e4hrdienst
- 61 H2 HADAG HADAG Sectouristik ur
 62 H2SB Green Plug

Current Scenario using green electrolysis

- Volumes of green H₂ that could be produced from new-build renewable capacity only, will not be sufficient to ٠ meet central demand forecast
- By allowing all (!) forms of renewable and decarbonized electricity, the EU could produce enough hydrogen in both 2030 and 2050, avoiding imports and reliance on fossil fuel derived hydrogen.
- Pyrolysis will be advantageous and accelerate decarbonization driven by 50 to 80% less energy demand •

1.263

electricity

Transport will be reduced and capitalize on existing natural gas infrastructure

Volume analysis

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By allowing the use of all forms of RES and decarbonised electricity to produce hydrogen, the EU will be able to meet its demand



AUR 😂 RA

1,759

New-build RES &

SMR/ATR with CCS

Impact of 30% hydrogen production via pyrolysis

Pyrolysis can minimize this predicted deficit of 69TWh:

- It can save 48.6 million tons of CO₂ emissions.
- This enables the use of RES for other sectors other than hydrogen production such as heating, power generation etc.
- Pyrolysis can help in regions with low RES





TWh Pyrolysis TWh

tde hydrogen and carbon technology Cost of hydrogen imports to Europe

Cost of hydrogen imports are significant and may change the economics

Levelised cost of delivered hydrogen to Germany, 2030

€/kg H₂, real 2019



1) Preparation for transport includes conversion into ammonia, preparation for delivery includes conversion from ammonia to H2. 2) H2 production costs in Morocco, Australia & Chile were calculated based on a discounted wholesale price. 3) Transports costs assume new-build pipeline Source: Aurora Energy Research, IEA

Green house gases comparison "worst case scenario after Horwarth et al."



Note:

- tde energy process driven by green energy
- tde process demands lower temperature compared to other pyrolysis processes resulting in lower emission
- Howarth et al.

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Ude Hydrogen and carbon technology Value Product Carbon

- Soil Improver: Carbon Credits for addition of agricultural areas And improvement of fertilization?

- Construction: Substitution of cement?









ype of Carbon	Types of Applications	Expected Price for Carbon
Carbon Black	Tires, printing inks, high perfomance coating and plastics	\$0.4-2+/kg depending on product requirements
Graphite	Lithium-ion batteries; Graphite electrodes used in steel furnaces,	\$10+/kg
Carbon Fiber	3D printing, Aerospace, automobiles, sports and leisure, construction, wind turbines, carbonreinforced composite materials and textiles	\$25-113kg depending on product requirements
Carbon nanotubes	Polymers, plastics, electronics, lithium-ion batteries	\$0.10-600.00 per gram depending on application requirements
Needle coke	Graphite electrodes for electric arc steel furnaces	~\$1.5/kg
Graphene	Graphene used in flexible electronics, batteries, solar cells	~ \$50 -85\$ / kg

European Business Strategy

- Turquoise hydrogen fits very well in Europe:
 - Cost competitive
 - Less energy demand
 - Not cannibalizing on RES resources
 - Less dependency on hydrogen imports
 - Easy to implement into existing industrial and pipeline networks
 - Technical easier to handle compared to CCS and CCU
 - No water demand