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Direct decarbonization of natural gas: A key technology into the energy transition

Alberto Abánades

Decarbonization of our economy: a need

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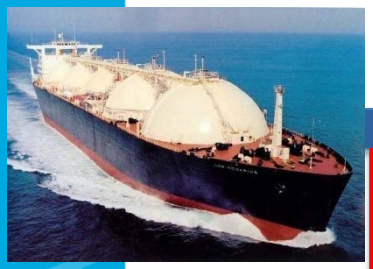
- The decarbonisation of our economy system is a must to avoid dramatic consequences for our Society.
- The transition must be as fast as reasonably achievable: avoiding social, economic and environmental problems, and
- A fast transition is only possible considering all the available technologies and resources.
- There is no a unique solutions, but a combination of approaches and tools to achieve the target of CO_2 emissions reduction and/or elimination.
- Hydrogen is called to play an important role as energy vector, and an important component of natural gas.

New path for processing fossil resources



CO_2 Emissions into the environment

CO_2 Capture

- Pre-combustion
- Post-combustion
- Oxy-fuel process

Storage

Usage

$CH_{4(g)} \rightarrow C_{(s)} + 2H_{2(g)}$

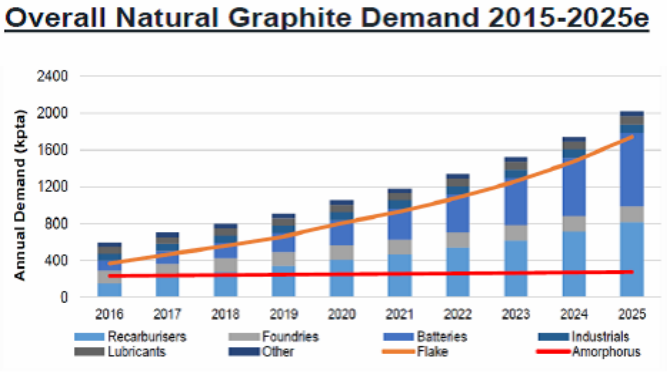
Solid Carbon is the only by-product

Heat & Electricity

Market needs

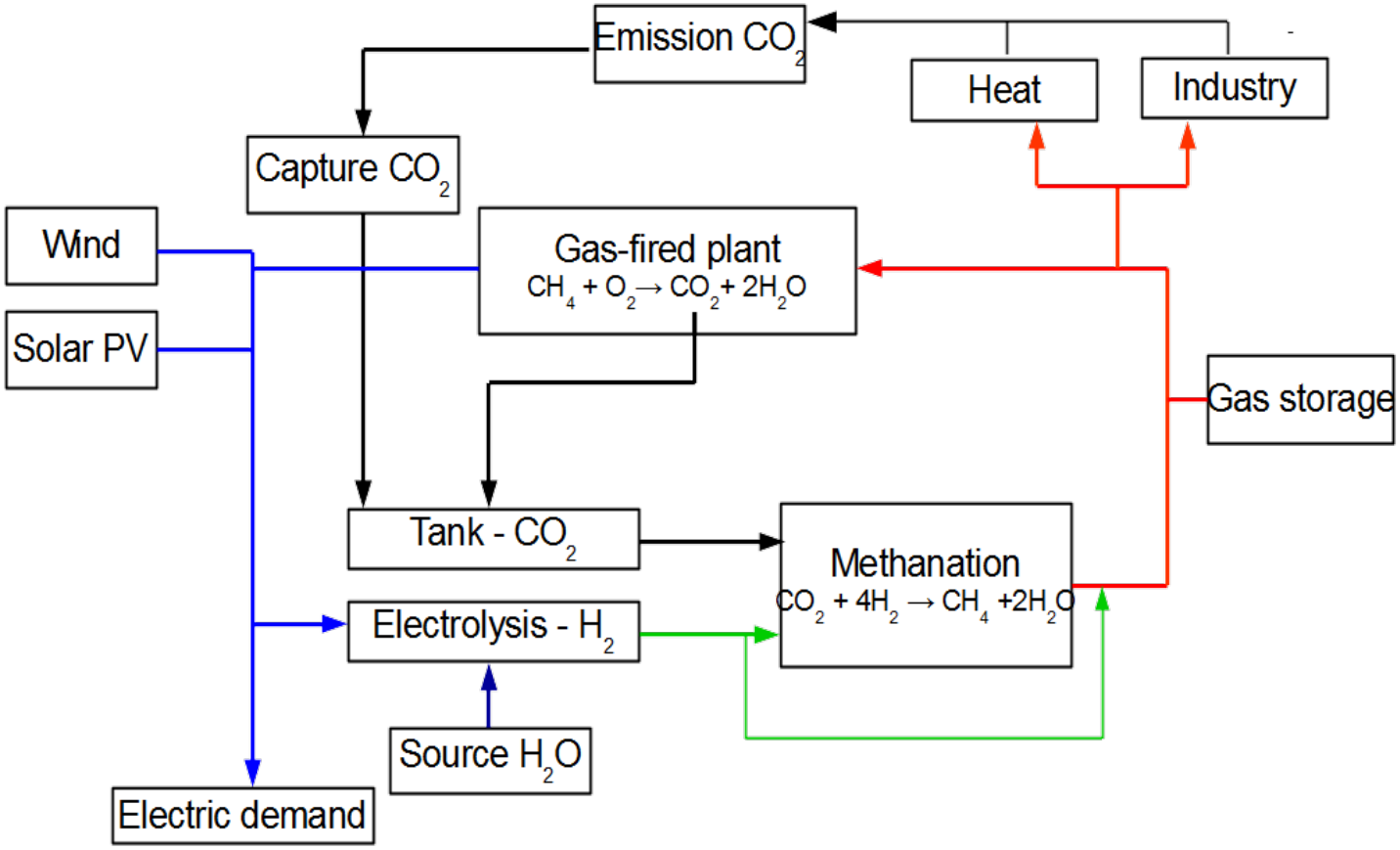
- **Low-Carbon technologies for the use of fossil resources are a must in view of international greenhouse control agreements.**
- **Hydrogen** is a very important feedstock in:
  - many chemical processes, as ammonia production, refineries, clean fuel production and energy storage.
  - new technological processes as iron ore reduction for the steel industry.

- **Graphitic and metallurgic carbon** is a critical raw materials in the EU.
  - China: 70% world production
  - **Europe production of natural graphite powders is less than 1%**.(EU Demand: 10%)
  - Required by traditional industries, as steel manufacturing, and high tech, as Li-ion batteries

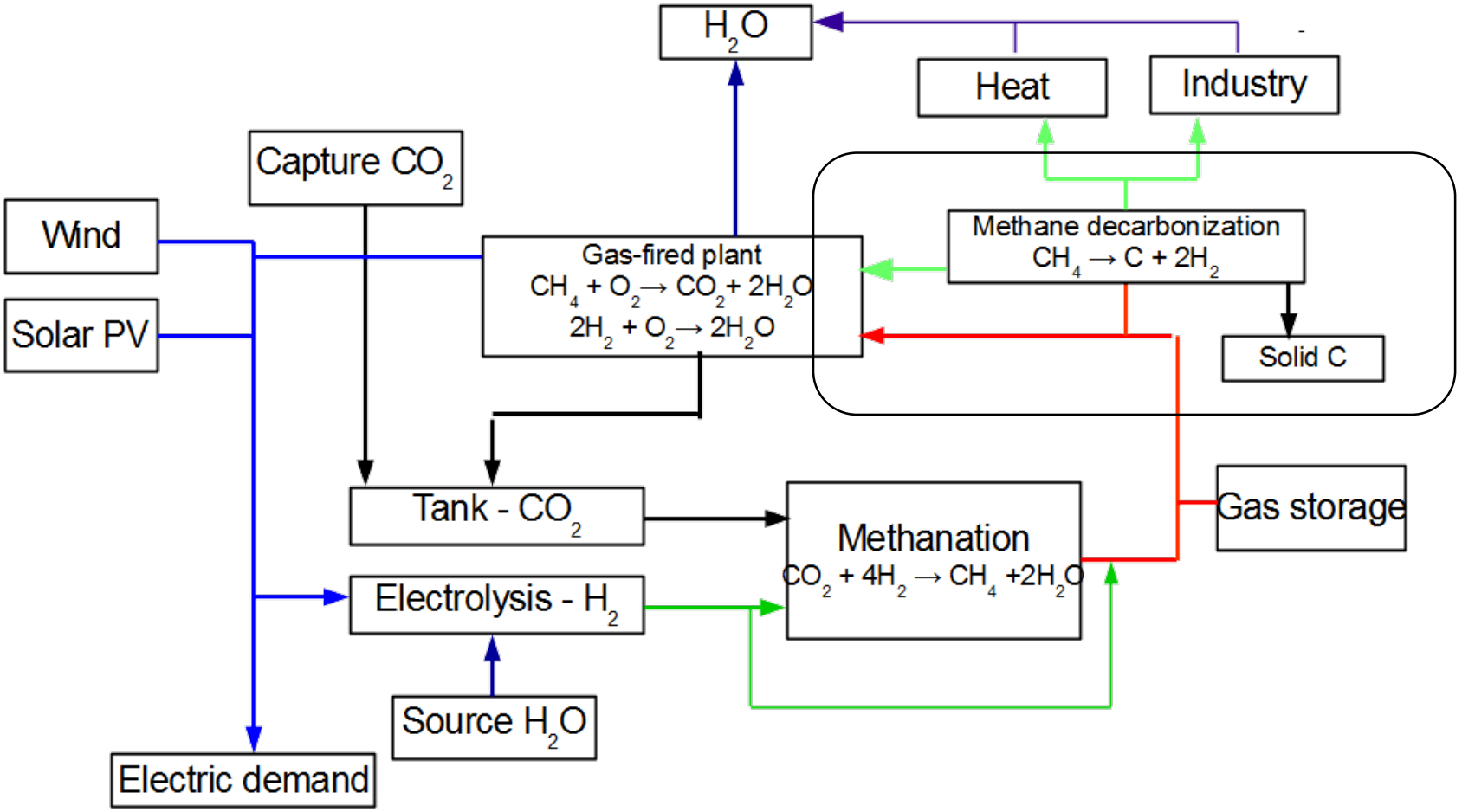


Cheap and environmentally friendly graphitic carbon and hydrogen from natural gas may be of paramount importance for the **competitiveness of natural gas companies.**

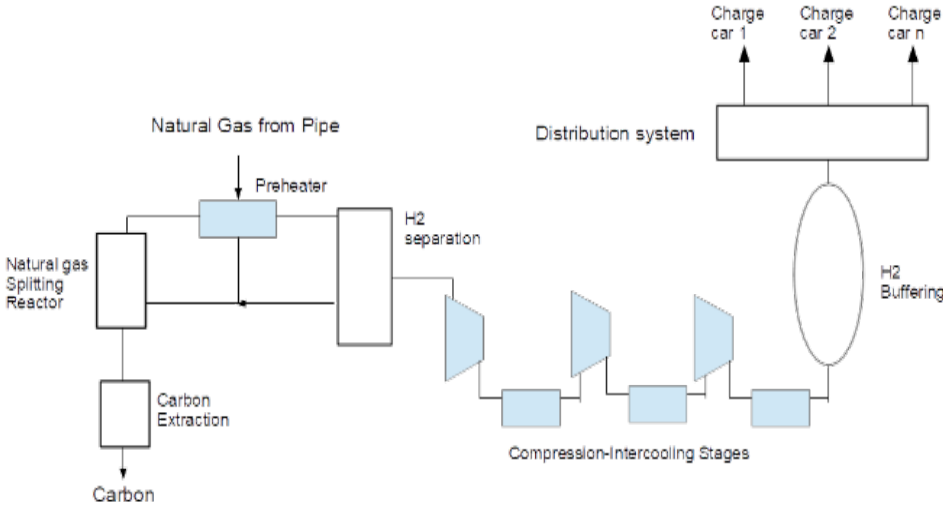
Power-to-Gas concept



MD downstream Power-to-Gas



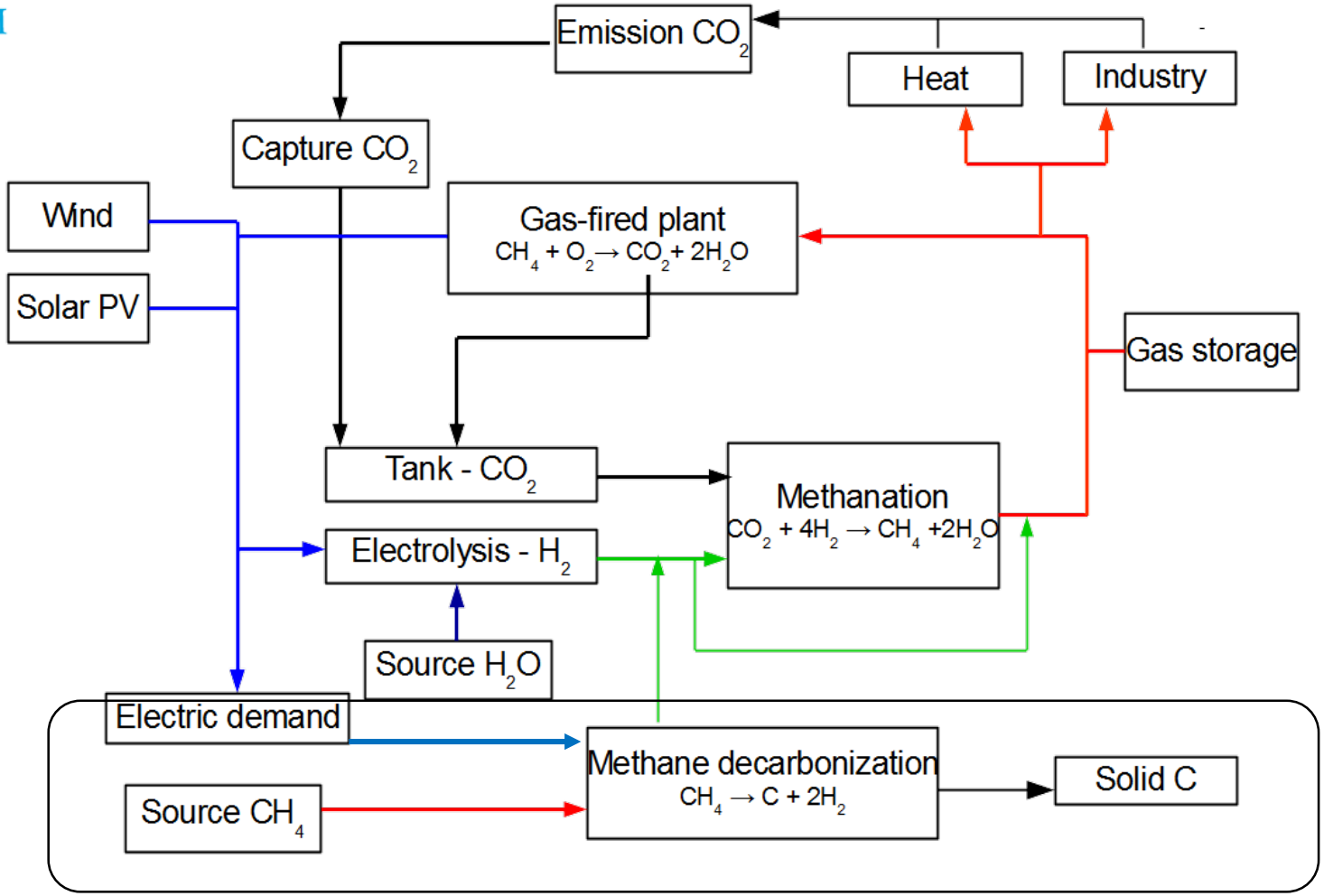
Hydrogen station analysis



- A hydrogen station
  - Delivering **150 kg/h of hydrogen**
  - Working at full capacity 16 h/day.
  - Total amount of **carbon produced is 572 kg/h**.
- The **CAPEX** of the installation according to our analysis is evaluated as **1.1 €/W**, what imply a total cost for our station of 5.5 M€, including
  - Decarbonization reactor and process equipment, including separation by membranes.
  - Hydrogen compression/buffering equipment.
- We evaluated the operational costs (**OPEX**) of the facility, being of the order of **4.1 €/kgH**, including
  - Manpower and substitution of spare parts during operation.
  - The energy for the compression stage corresponds to approximately 30% of the total cost.
  - Such analysis has been done for **European cost of natural gas (11 €/GJ** as upper limit including taxes 2nd Sem. 2016(Eurostat 2018)). This cost is higher to that of the natural gas in international markets as it is applied to a medium consumer.
- The total **levelised cost of hydrogen** for a typical 20 year lifetime is **5-6 €/kgH_2**

Abánades A (2018) Natural Gas Decarbonization as Tool for Greenhouse Gases Emission Control. Front. Energy Res. 6:47.

MD upstream Power-to-Gas



Plasma-arc technologies

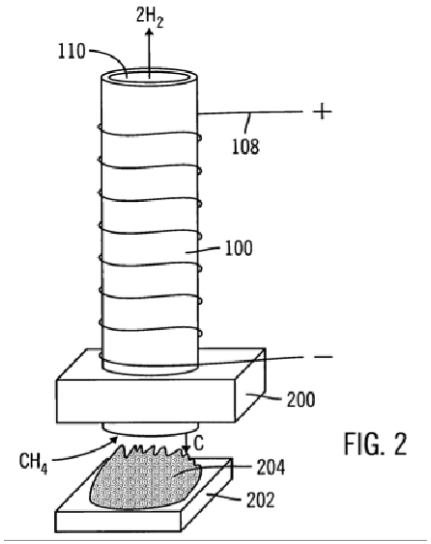
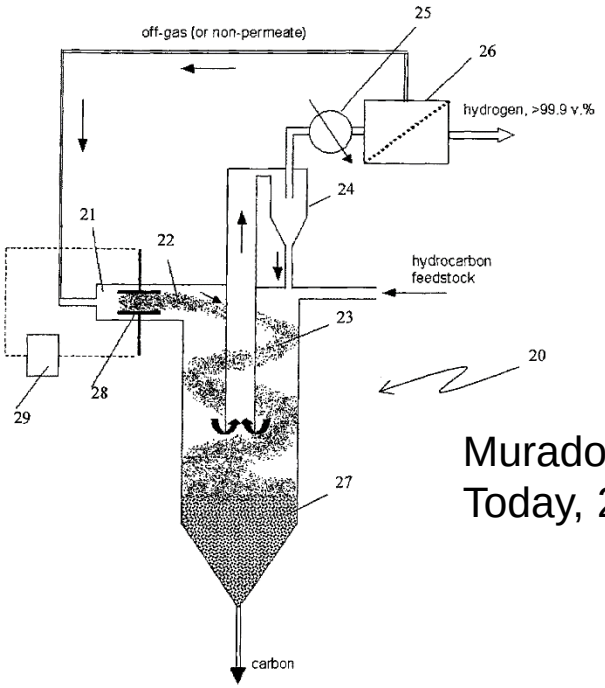


FIG. 2

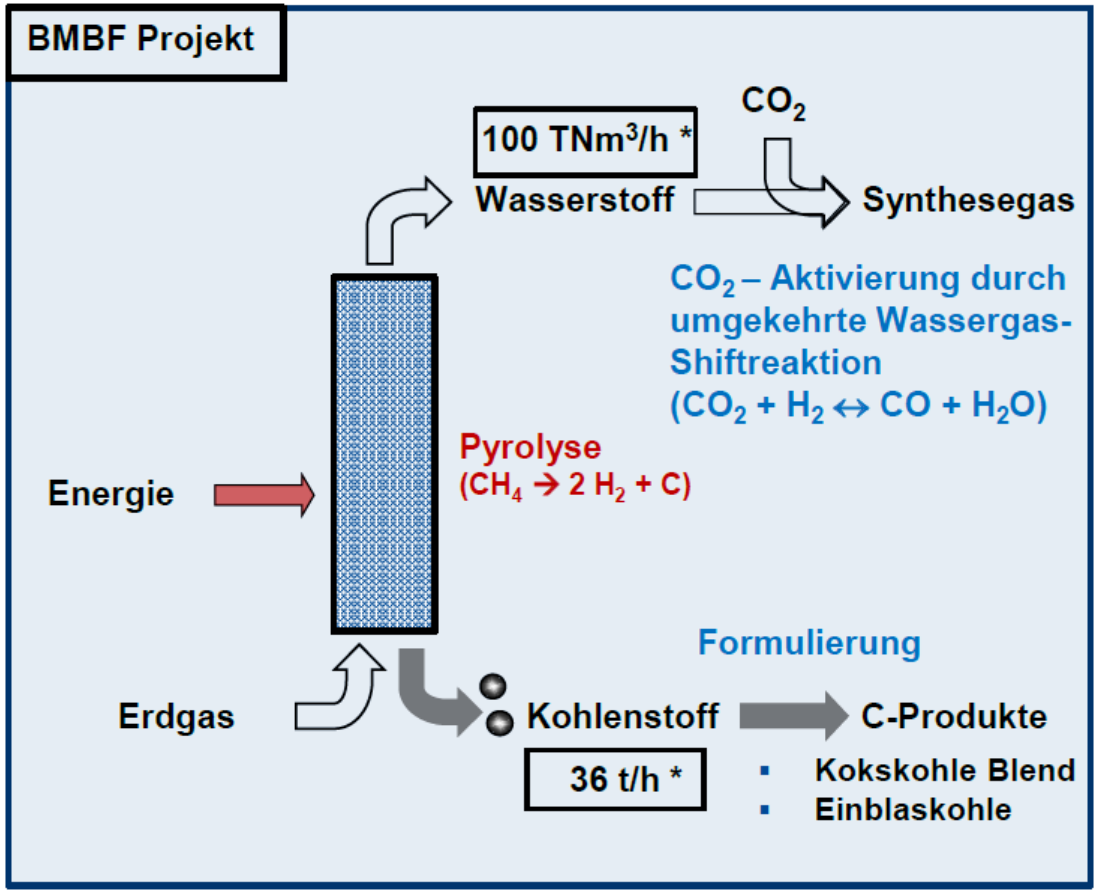


Muradov, et al. Catalysis Today, 2006, 116, 281 – 288

US20060130400 by Bockris (2006)

- Industrial innitiatives:
  - Hvaerner black C and H2 process/SINTEF (closed)
  - GasPlas (Microwaves)
- Electricity dependant, high temperatures.

Industrial initiatives



Chemische Industrie

- Basischemikalien
- Kraftstoffe

BASF
The Chemical Company

Stahlindustrie

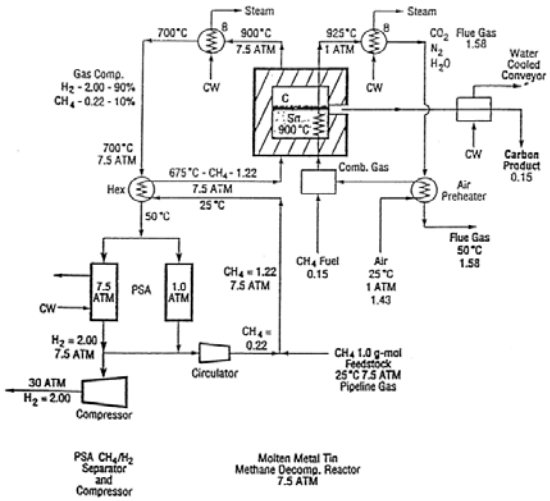
Hochofen

Kokerei

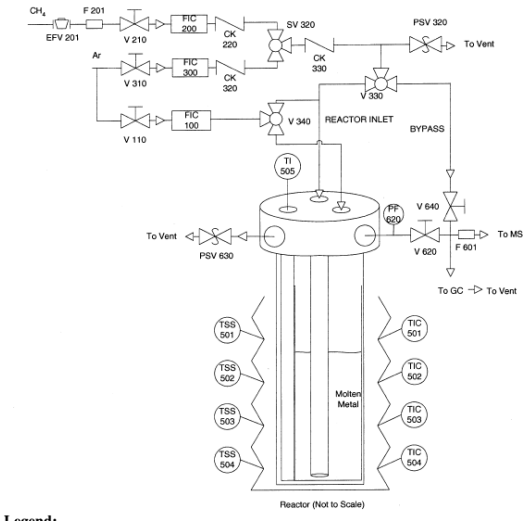
300.000 t/a *

Industrial initiatives

Liquid metal tech. as alternative



Steinberg M. 1999. IJHE 24(8):771-777

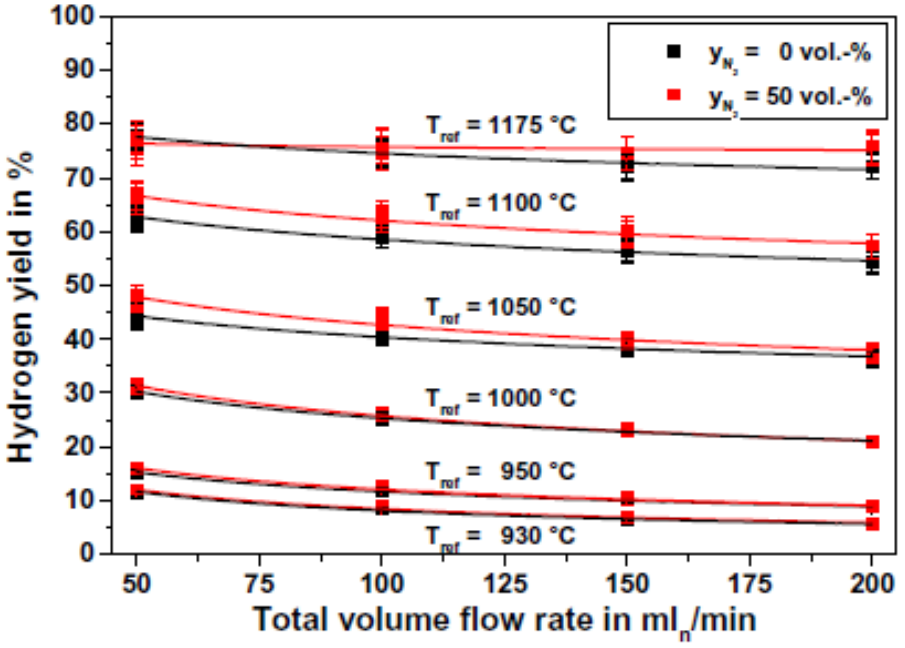


Serban M (2007) Energy & Fuels 17: 705-713

- Carbon separation by differential density.
- Large thermal diffusivity: temperature homogenization during scalability
- Enables high temperature operation for direct cracking.

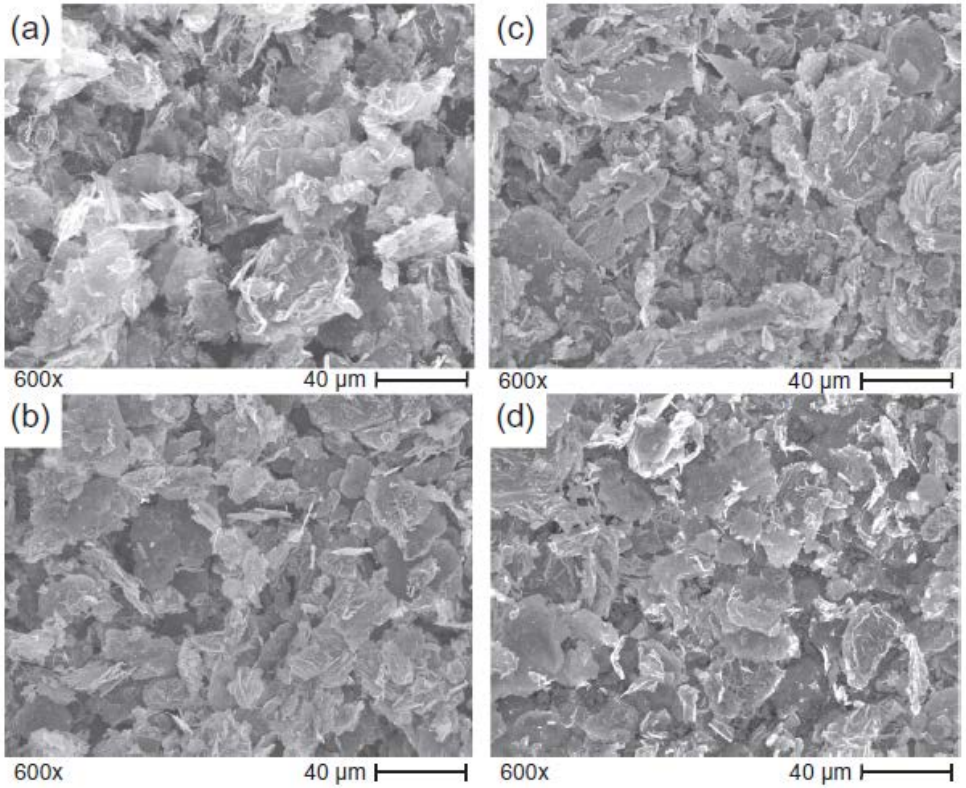
Status of development

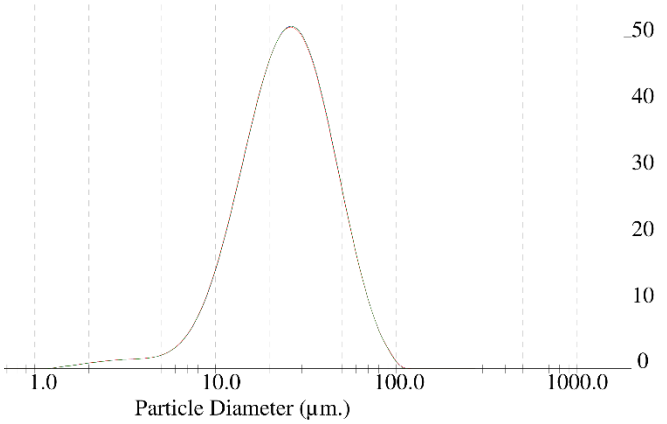
- **Our concept is on TRL 4**: We have successfully operated a **proof-of-concept.**
- We have obtained a **reasonable methane conversion (up to 80%)** during a **considerable period of time (10 days)** at an industrially achievable temperature (1175 ºC) in a **one-step reactor, easy to operate and scalable from medium to high capacity demands**.



Chemical Engineering Journal 299 (2016) 192–200

Graphitic carbon production

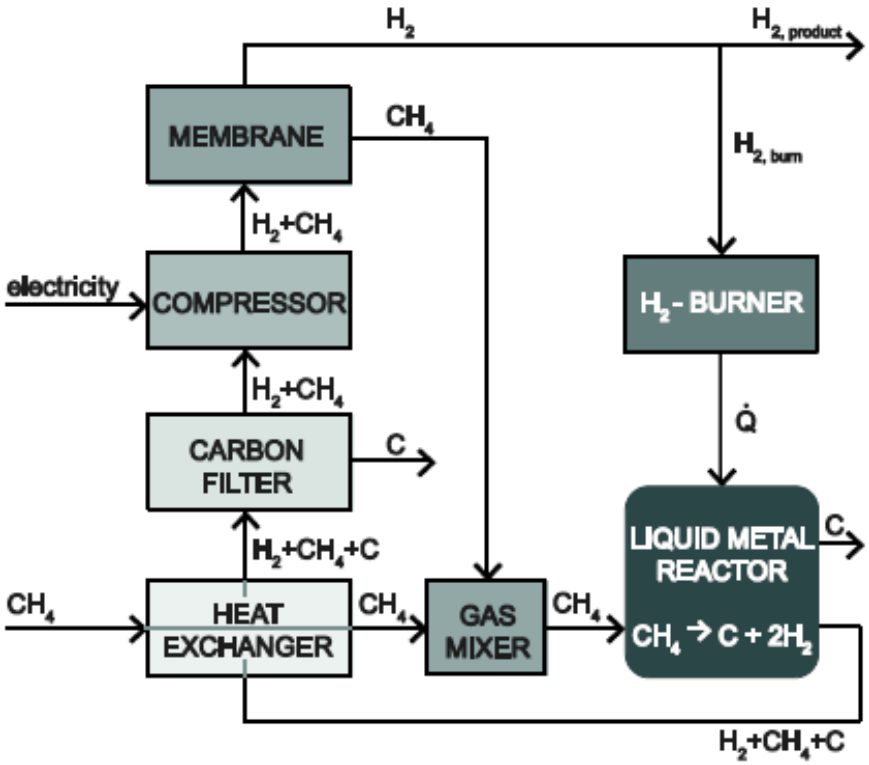




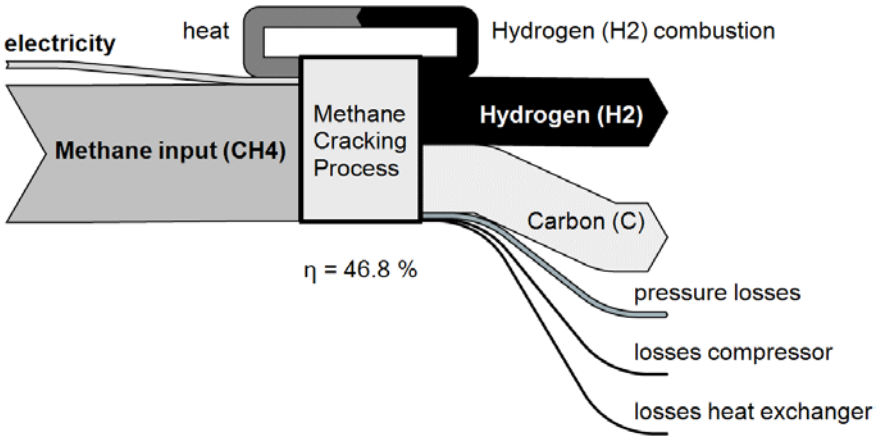
Courtesy: Nalonchem

- Low density graphitic carbon

Basic process description (DECARGAS)



Thermodynamic limit efficiency: 60.3%
Estimated efficiency at industrial scale: 46.8 % (ineffiencies+separation)



International Journal of Hydrogen Energy 41 (2016) 23204-23212

Viable production of H_2 & C for the circular economy

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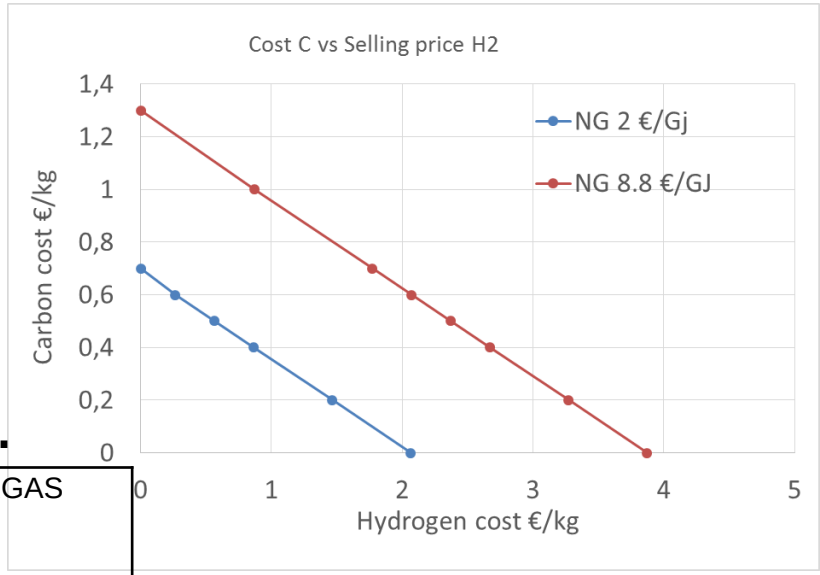
- **Production cost of the two products are very competitive.** At NG price of 9€/GJ, average in EU):
  - graphitic carbon @ 0,6 €/kg
  - hydrogen @ 2 €/kg
- **Specific process CO2 taxes are avoided.**



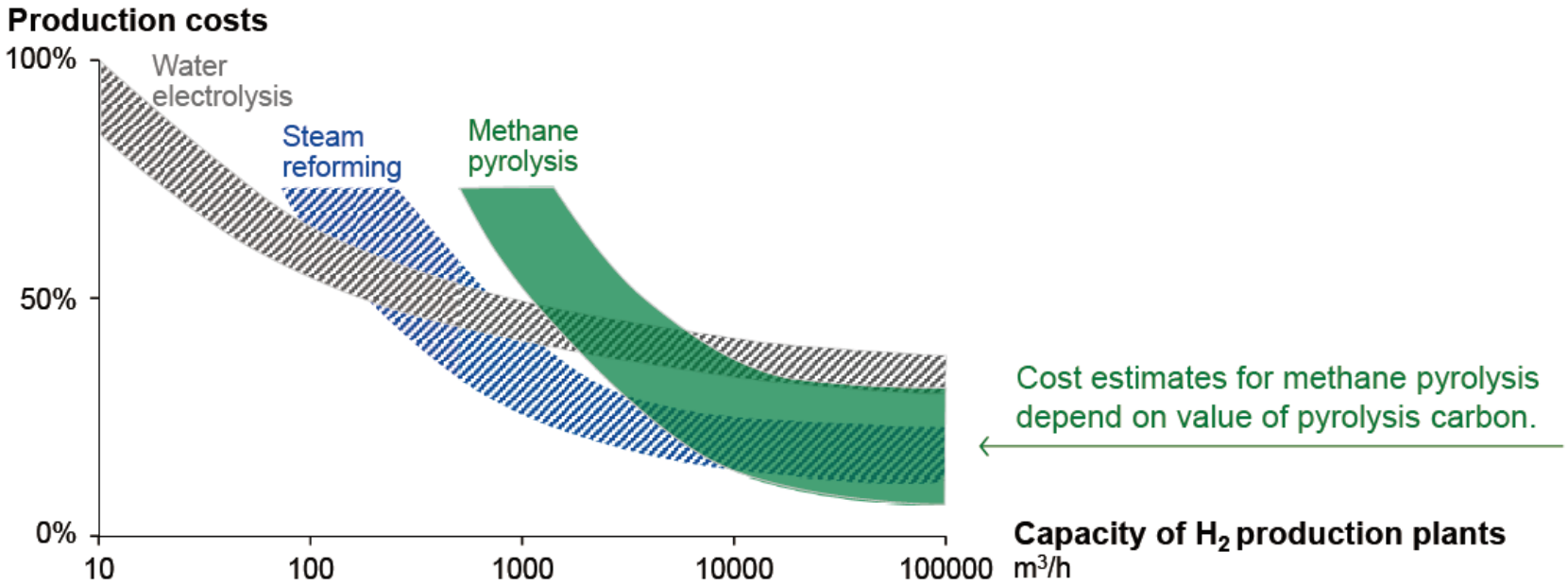
	Price (€/kg)	CO2 tax=50 €/ton (€/kg)	DECARGAS (€/kg) Two-product worth	DECARGAS (€/kg) One-product worth
Metallurgical coke	0.12-0.32	0,14	0.6	0.7-1.3
Black carbon	0.5-2			
Graphitic carbon	1.5	0,7		
H2 Steam Reforming	2.21	0.27	2	2-3.8
H2 Coal gasification	3.06	0.55		
H2 Biomass	3.53			
H2 electrolysis	6.17			

[1] Cost Summary for hydrogen: https://www.ika.rwth-aachen.de/r2h/index.php/Hydrogen_Pathway:_Cost_Analysis.html
Carbon'Majors: Accounting'for'carbon'and'methane'emissions'1854;2010 Methods'&'Results'Report

Cost

BASF Research Press Conference 2019

Is methane pyrolysis cost competitive?

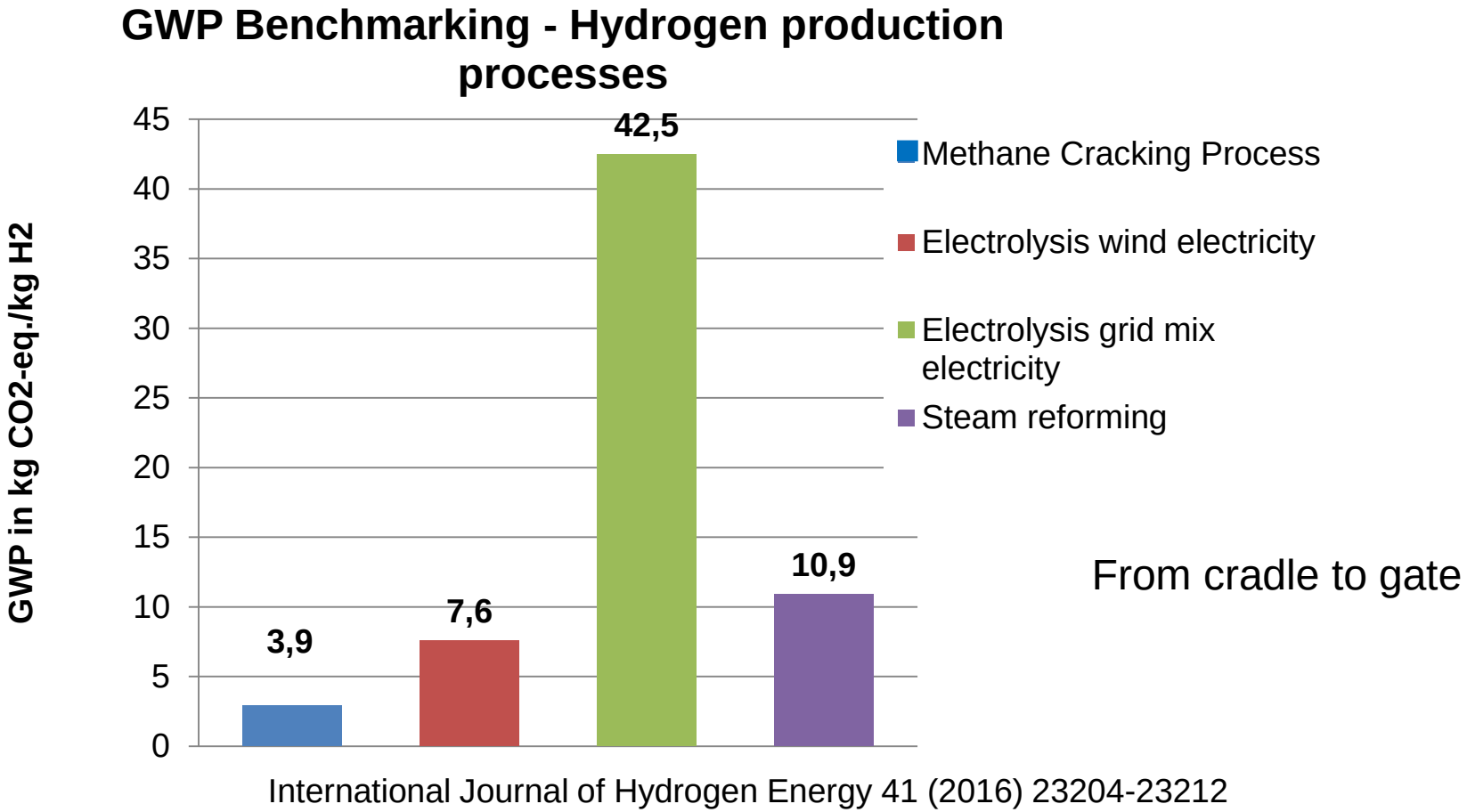


Cost estimates for methane pyrolysis depend on value of pyrolysis carbon.

Carbon sales price or cost for storage is critical

BASF
We create chemistry

Life Cycle Analysis



From cradle to gate

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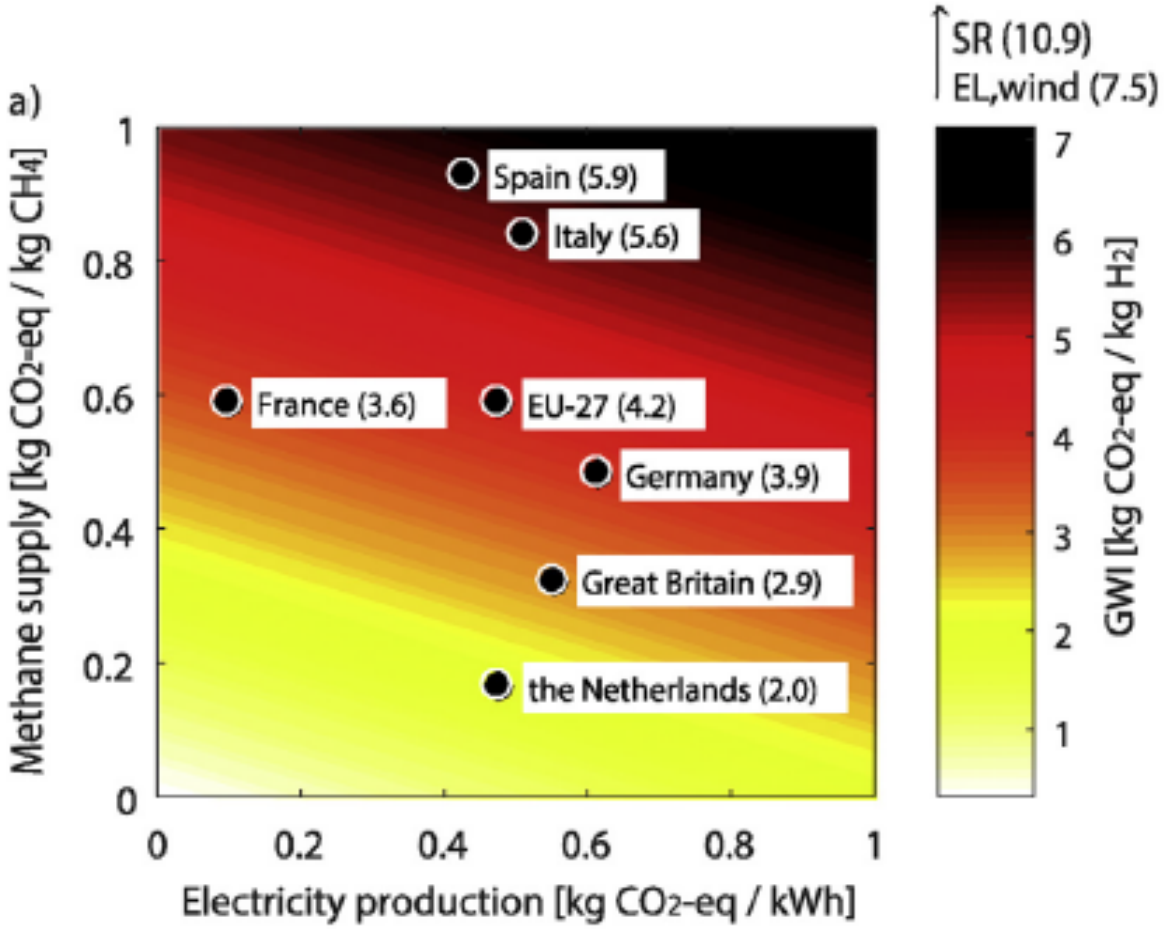
Life Cycle Analysis



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Life Cycle Assessment (others)

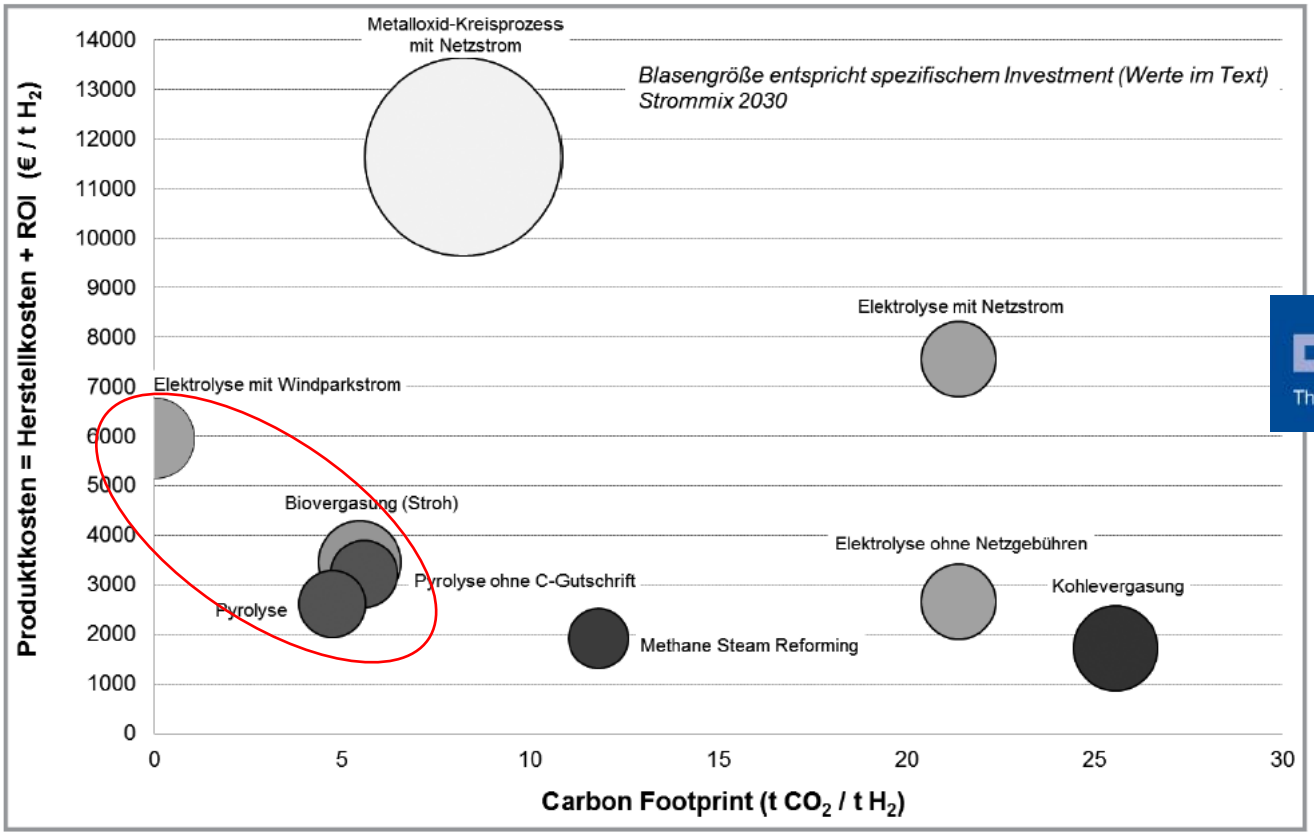

Abbildung 7. Ökonologie (Produktkosten und Carbon Footprint) von Technologien für die Wasserstoffherstellung auf Basis von Annahmen für den Standort Deutschland.

Chem. Ing. Tech. 2015, 87, No. 4, 1–11

Other existing solutions

- Some solution to develop natural gas decomposition has been proposed based on the utilization of plasma-arc technologies and catalysts.

Other concepts	DECARGAS advantages
HYPRO Universal Oil Products - fluidized bed reactor-Ni-Fe-Co catalyst	No use of catalyst. One continuous reactor. Easy operation.
Boxer Industry – plasma arc	Safety problems, massive electricity consumption
BASF – fluidized bed reactor + plasma arc carbon particle section	No previous plasma arc section needed. Easy operation. Homogeneous heating.
SINTEF Kvaerner CB&H process – plasma arc methane decomposition.	No electricity required. No safety problems expected due to plasma arc production..
GasPlas – heating gas by microwaves	No electricity required. Easy scale-up to high capacity.
CMAT energy solution – liquid Sn reactor, in combination with molten salts	No use of catalysts and lower complexibility (only one liquid media)
Hazer group Ltd – Iron catalyst fluidized bed reactor	No use of catalyst. No catalyst regeneration.

Conclusions

- The transition to a low-CO2 society must be as fast as reasonably achievable: avoiding social, economic and environmental problems, and is only possible considering all the available technologies and resources.
- Innovation and technological development may convert natural gas in part of the solution to control GHG emisions in the short-medium term.
- Natural gas decarbonisation is a technology under development that can open the possibility to reduce drastically CO2 emissions in the energy sector and in many other industrial processes.
- Natural gas decarbonisation is easily introduced in the circular economy by the complete transformation of hydrocarbons into valuable products as
  - Graphitic carbon: Required by traditional industries, as steel manufacturing, and high tech, as Li-ion batteries, or graphene.
  - Hydrogen: chemical processes, as ammonia production, refineries, iron ore reduction, clean fuel production and energy storage.

- December 2018: Award of the German Gas Industry in R&D
- 2nd Price BIC EIT Raw Materials
- 2nd Price Innovatech UPM 2T Challenge 2017
- Cover New Scientist (October 2016)

Thanks for your attention!!!