FUELING TOMORROW
EXPLORING THE FUTURE OF TRANSPORTATION AND INDUSTRIAL FUELS

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ORGANIZZATO DA

BFWE
BOLOGNAFIERE WATER&ENERGY

Bologna: un hub di ricerca per lo sviluppo dell'idrogeno - 9 ottobre 2024

STORM:NG

Reattori elettrificati per Idrogeno da cracking del metano

Patricia Benito

Dipartimento Chimica Industriale «Toso Montanari»

BolognaFiere 9-11 ottobre

STORM:NG

STructured unconventional reactors for CO_2-fRee Methane catalytic crackING

HORIZON-CL5-2021-D2-01-09: Methane cracking to usable hydrogen and carbon

HORIZON-WIDERA-2022-ACCESS-07 (2nd cut-off)

Starting date: 1st September **2022**

Project duration: 36 months

Budget: 3 125 714.75 Euro

305 833.00 Euro for UK partner

STORMING CONSORTIUM

DTU Danmarks Tekniske Universitet

Alma Mater Studiorum Università di Bologna

Universidad Zaragoza

CSIC

Finden

vito

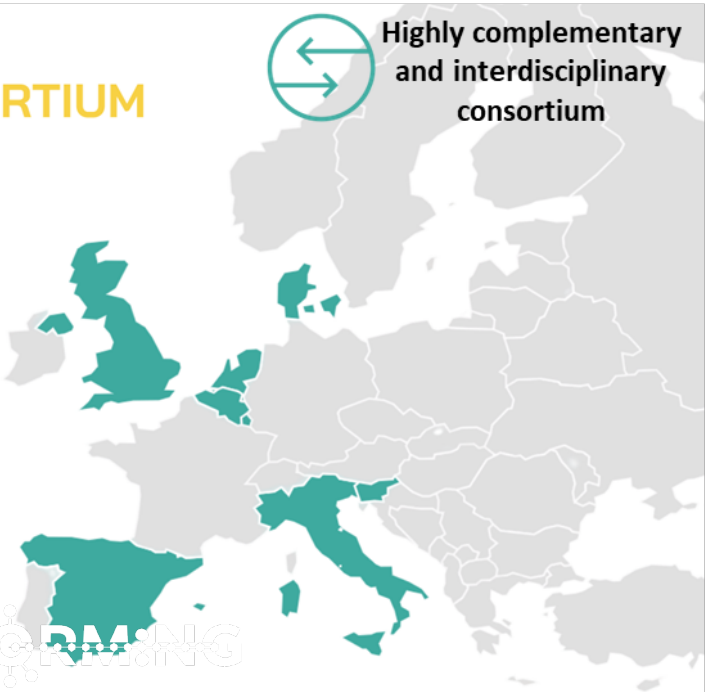
Cleancarb

HYGEAR

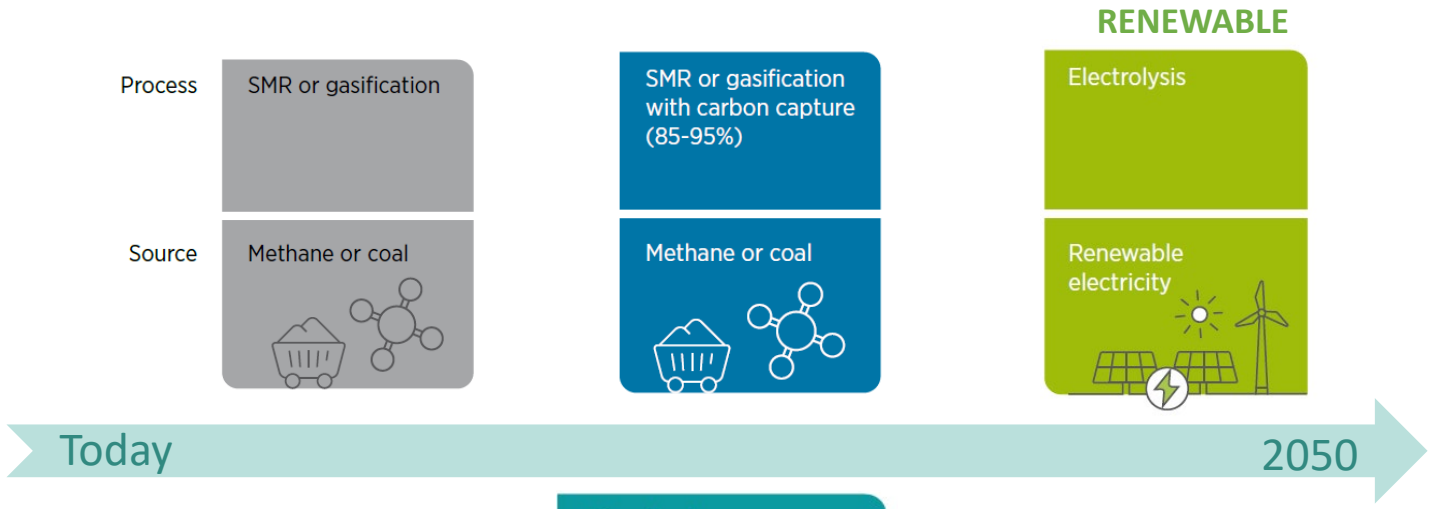
Energy Efficiency in Industrial Processes

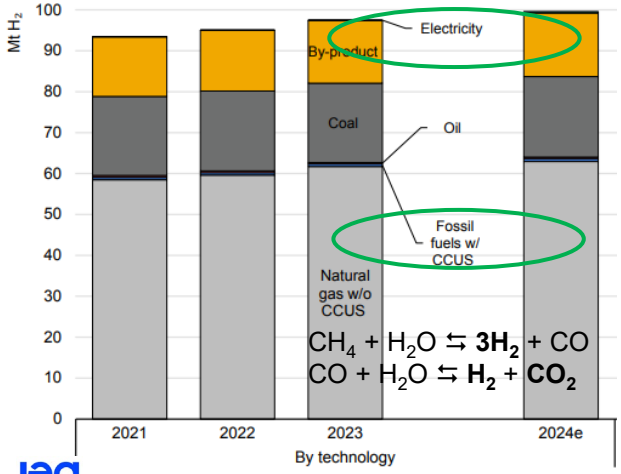
National Institute of Chemistry

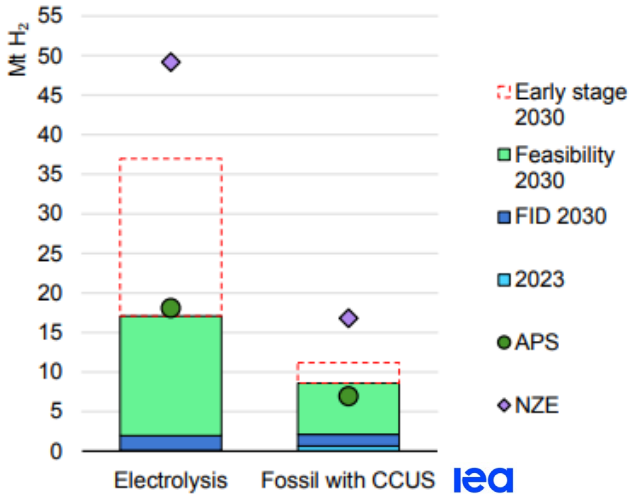
Universidad de Sevilla



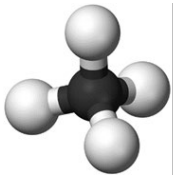
Decarbonization of H_2 production

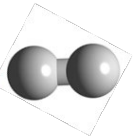






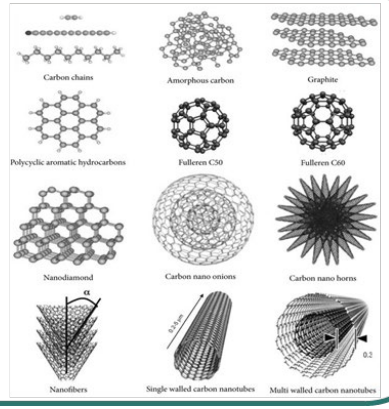
Bio(methane) decomposition

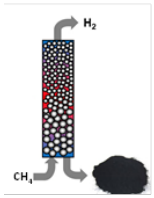


⇆ 2  + Carbon

One step

Carbon black

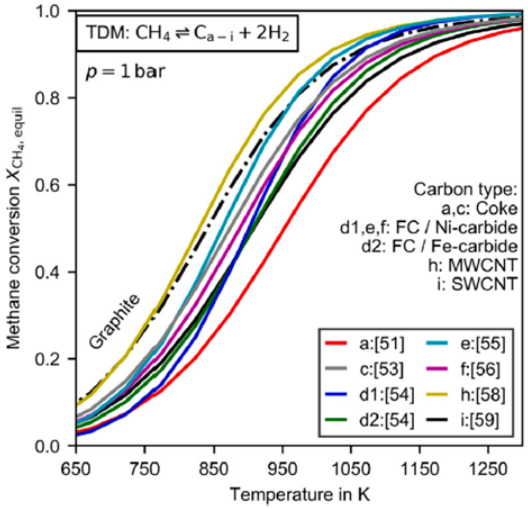




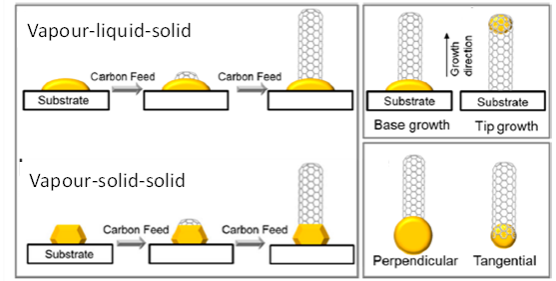
	Reactor type	Temp	Regeneration	Type Carbon	Energy	Development Status
BASF[a]	Moving bed carbon granules	1000°C-1400°C	Carbon recycling	Black carbon	Renew. electr. Electrodes	Pilot plant
Monolith[b]	Plasma reactor	Ca. 2000°C		Carbon black	Renew.energy	Commercial
C-Zero[c]	Liquid bubble column reactor	900-1000°C		Carbon black		Pilot plant
Hazer[d]	Fluidised Bed	900°C	No	graphite	Renew. Electr.	Commercial
Hycamite[e]	Fixed bed Fluidized bed	500-800 ºC	n.a.	Several allotropes	H_2, renew. electricity	Test facility

Catalytic Methane decomposition

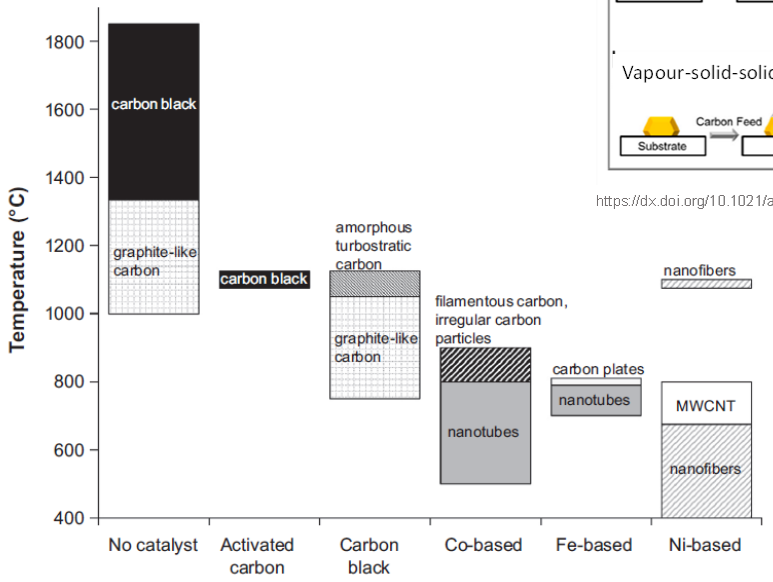
$$CH_{4(g)} \leftrightarrows C_{(s)} + 2H_{2(g)} \qquad \Delta H^0_{298K} = 74.5\ kJ/mol$$



- Type of carbon depends on reaction conditions and catalyst



https://dx.doi.org/10.1021/acs.chemrev.9b00835



Challenges:

- **Carbon has a twofold deactivation** effect:
  - Deactivation catalytic sites
  - Clogging of the reactor
- **Heat transfer**

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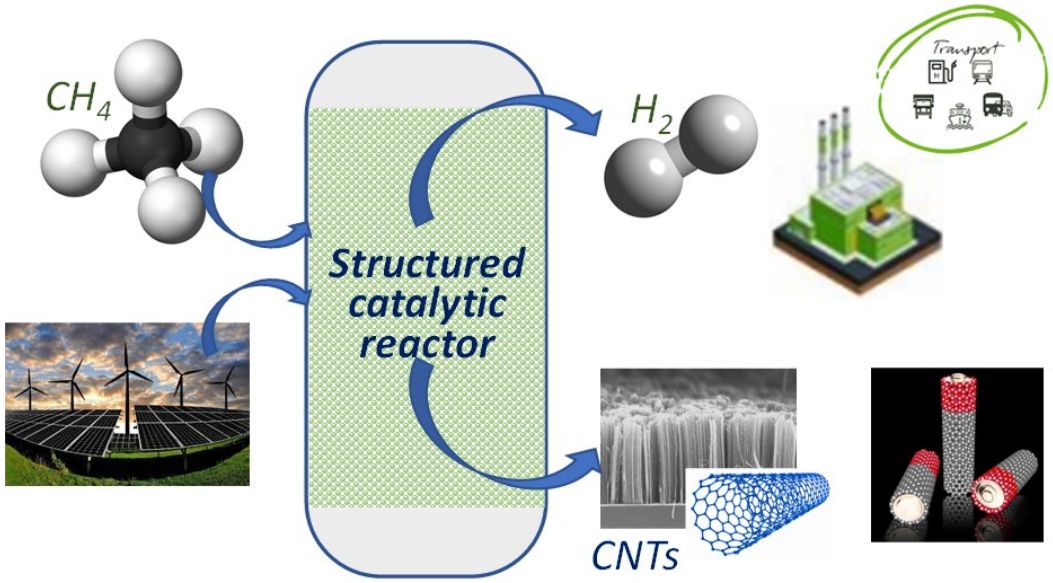

To develop breakthrough **structured catalytic reactors** powered by **renewable electricity** to simultaneously produce CO_2-free or CO_2-negative H_2 and **high-quality carbon nanotubes, CNTs,** in a **continuous technology** that could be deployed in a sustainable manner.

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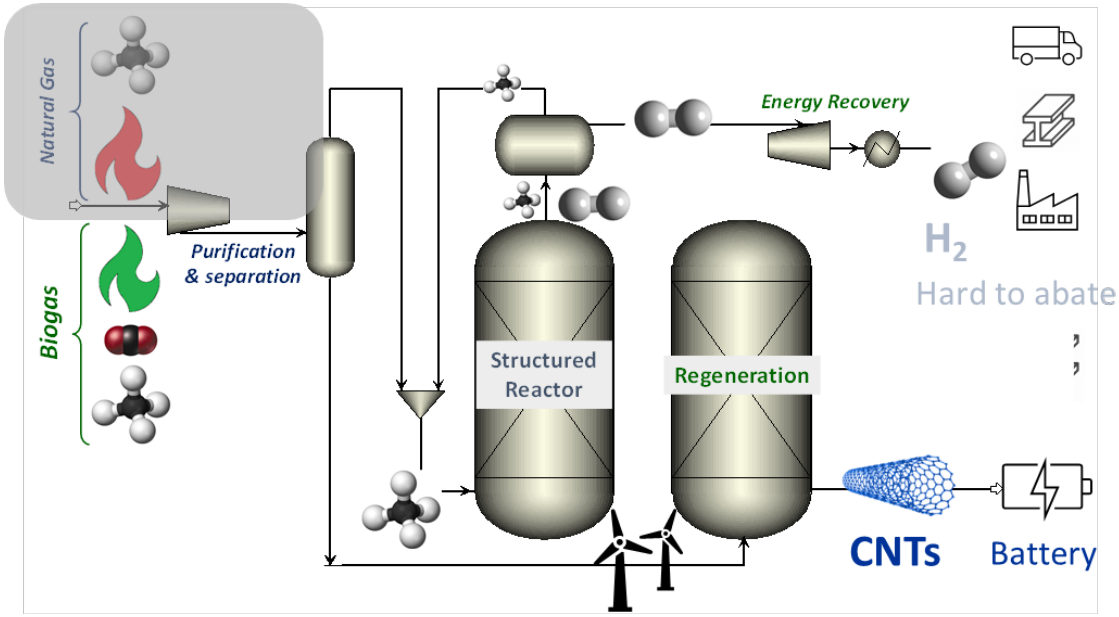
Production of **captive H_2** (on-site production) and the **capture of C** from the CH_4 as **CNTs,** an economic credit that reduces the delivered net cost of H_2.



Early-stage breakthrough **catalytic technologies powered by renewable energy** to

↘ overcome CH_4 catalytic cracking challenges

↘ match with the final H_2 application and the supply of renewable energy

↘ be easily and quickly scalable to produce H_2 at similar prices to those of grey H_2

Catalysts and catalytic reactors operating in a **continuous mode** with maximized efficiency.

Parallel reactors: cyclic mode (switching feedstock feed and regeneration agent stream between the reactors)

All the **value chain**: feedsctock and product purification

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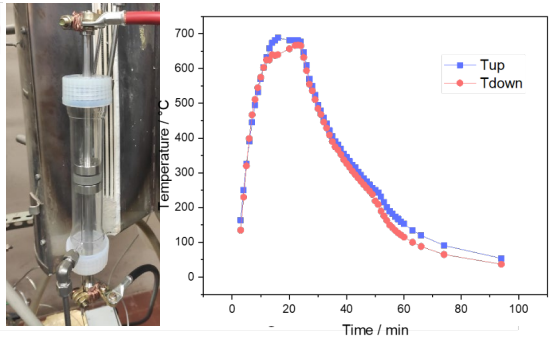
Heat transfer: Electrified reactors

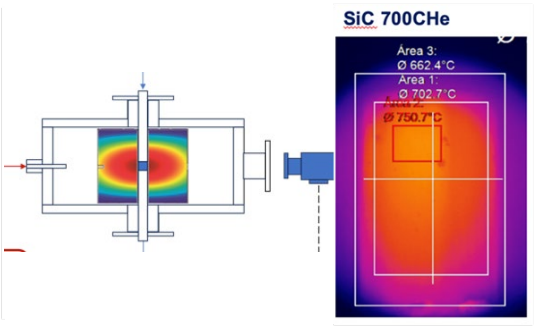
Three complementary **structured** catalytic **reactors** powered by **renewable energy**

Joule heated fixed bed



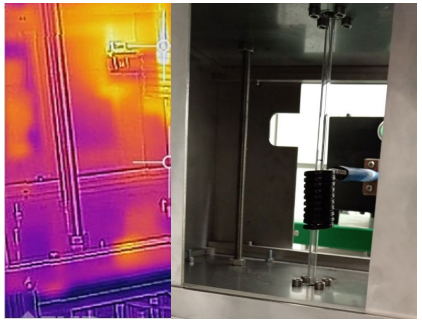
↘ Heat generated by passing a current through a **resistive** material.
↘ Avoid wall effect and few to no thermal gradients.

Microwave heated fluidized bed



↘ Selective **dielectric** heating of catalytic materials.
↘ Gas-solid temperature control

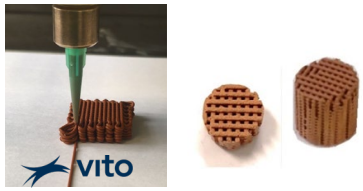
Induction heated fluidized bed

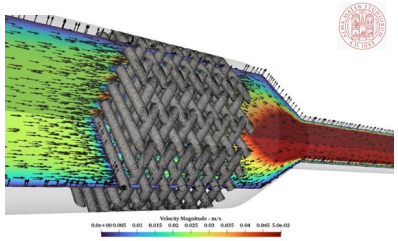


↘ Selective heating of **electrically conductive** and **ferromagnetic** materials.
↘ Fast heating, enhance heat transfer.

Direct heating of the catalyst → Decrease of temperature gradients and heat losses → Increasing heating efficiency
Quick start-up time

Structured catalysts/materials





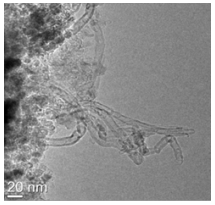
Devices with **advanced design**, **easy production**, and **high adaptation**

Combination of **geometry** and **composition** to better **control:**

- Heating:
  - Resistance for Joule Heating
  - Dielectric properties to absorb MWs
  - Ferromagnetic materials for Induction Heating
- Pressure drop
- Heat and mass transfer
- Mechanical stability
- Activity

Complex process dynamics

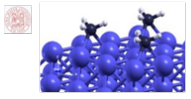
Smart rational design

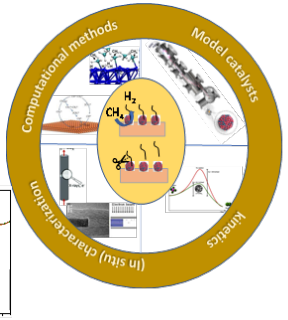


Fe-based catalysts selective for controlled **CNTs growth**

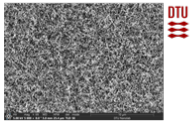
↘ non-toxic & easily available

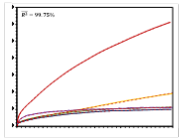
↘ more active and stable at high temperature than Ni





Chemical scissor protocols (waste-free) **to harvest** CNTs and **regenerate** the catalyst





Impacts STORMING technology

Switching to **renewable energy**

Improved energy efficiency (60 % efficiency, > 95 % considering CNTs) **& Selectivity** (100% H_2)

Directly heat the catalyst

Accurate thermal control

Operate at < 800°C no side-products

Process intensification

Operating under **transient conditions** (quick start-up and shut-down) determined by supply (feedstock, renewable energy)/demand requirements.

Avoid GHG emissions (CO_2 and NO_x)

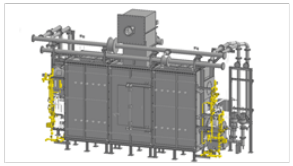
10 % decrease cost than SMR + CCS

Heavy-transport

↘ Fuel cell

Hard to abate industry

High temperature heat
Combustion

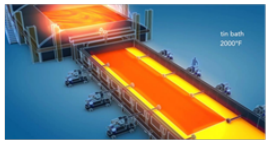


Steel manufacturing
Brightening (DRI)

Chemical companies

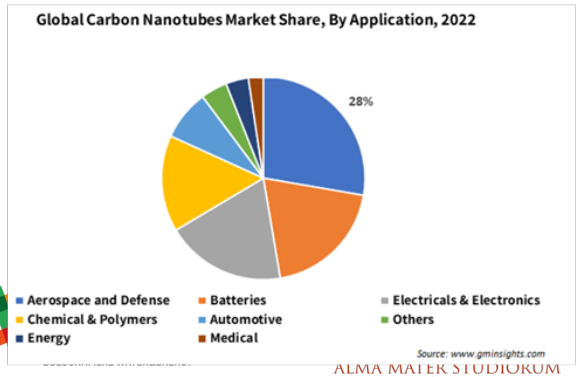
$N_2 + H_2 \leftrightarrows NH_3$

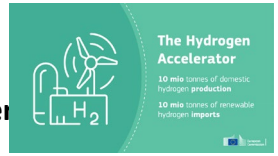
Float glass
Tin bath



(MW)CNTS for **batteries** to replace graphite (CRM)

MWCNTs prize in current market (from 0.4 to 285 US$ /g)





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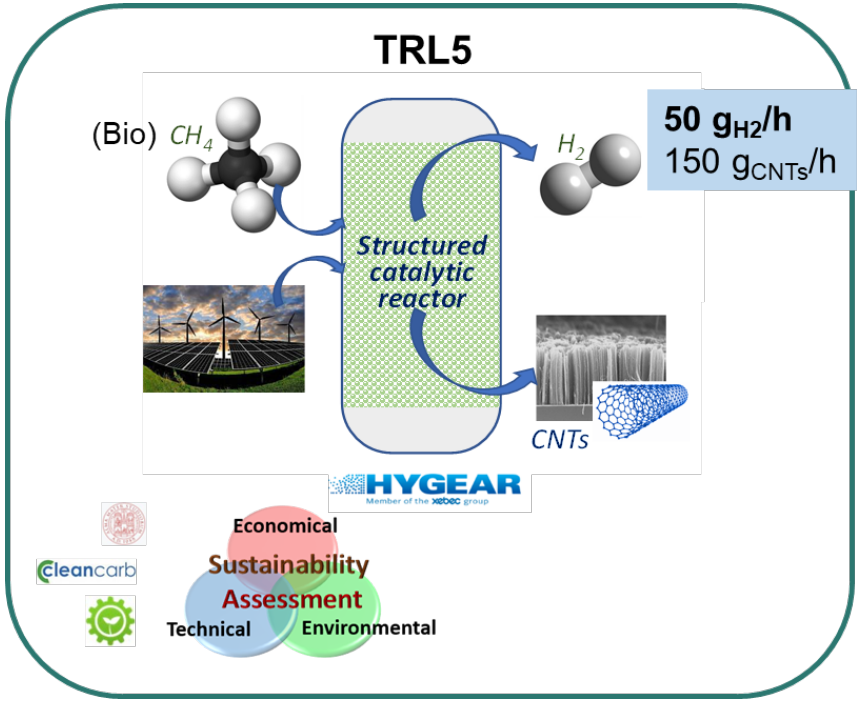
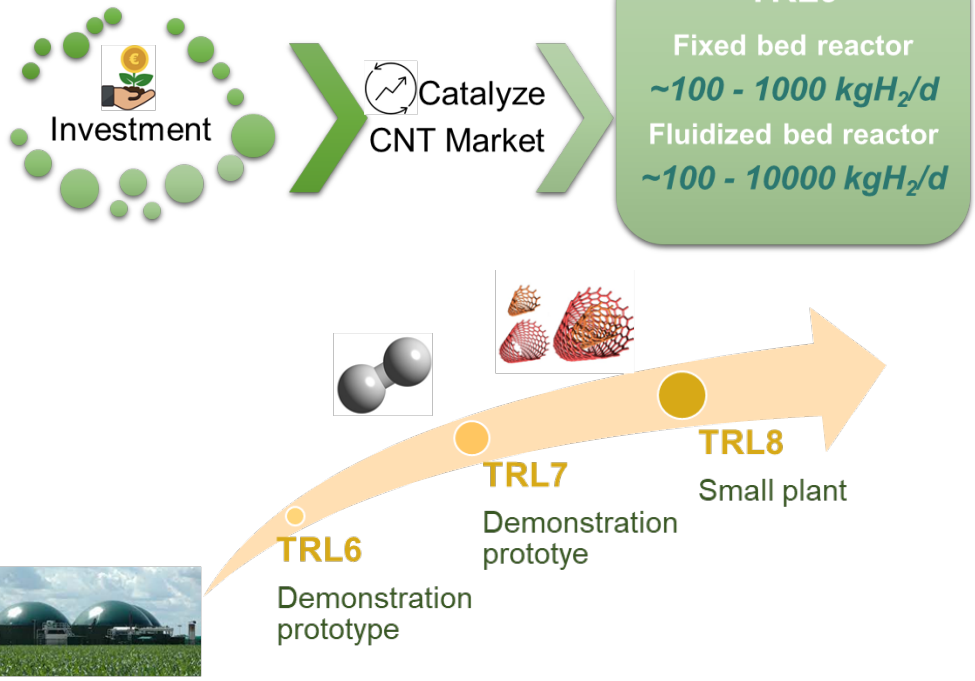
Pathway to TRL9





Validation of the most promising catalytic technology

Storming-project.eu

@StormingEU

Storming EU Project

PROUD EXHIBITOR

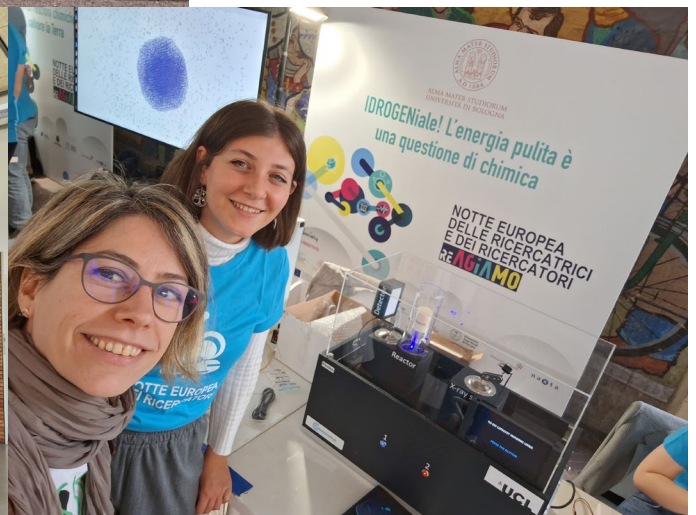
STORMING

BOOTH K20 | BRUSSELS EXPO

#EUH2Week

European Hydrogen Week

18 - 22 November 2024
Brussels, Belgium



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