H2 SITE

Membrane reactors for H2 generation

Decentralized ammonia applications for HRS: from technology to business

Let's focus in ammonia

We need to align supply & tech roadmaps

We need hydrogen

Hard to transport

Different Energy carriers

Ammonia is a good option

Import hubs & Decentralized

Topics to consider

Overall ammonia logistics

Current technology status

Transformation / Reconversion stages

HRS: A business case

Production & Consumption patterns

The real deal: Ammogen project

Handling ammonia on site

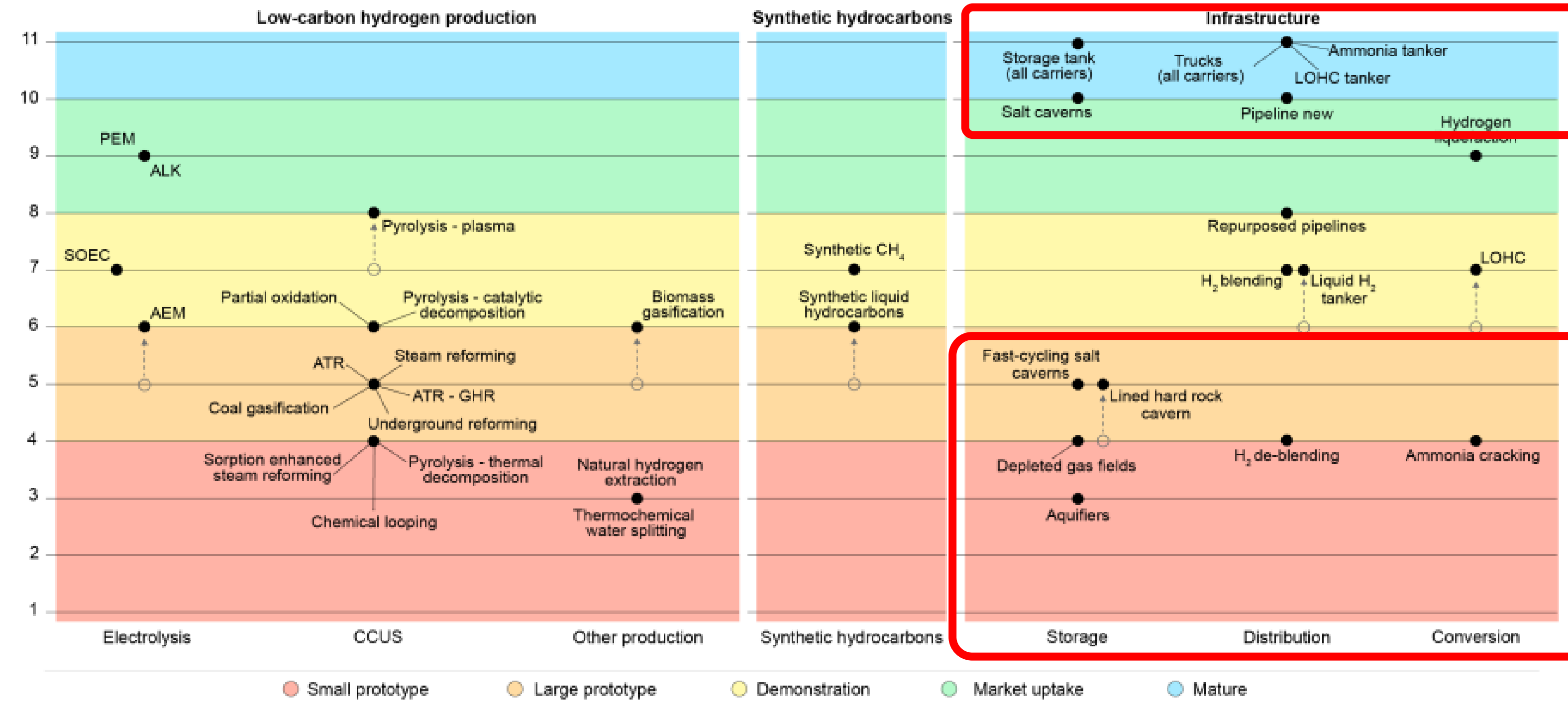
Roadmap

Current technology status

TRL low for hubs but optimal for distributed

Technology development is advancing across the hydrogen value chain, though several key technologies, particularly in end-uses, are far from being commercial

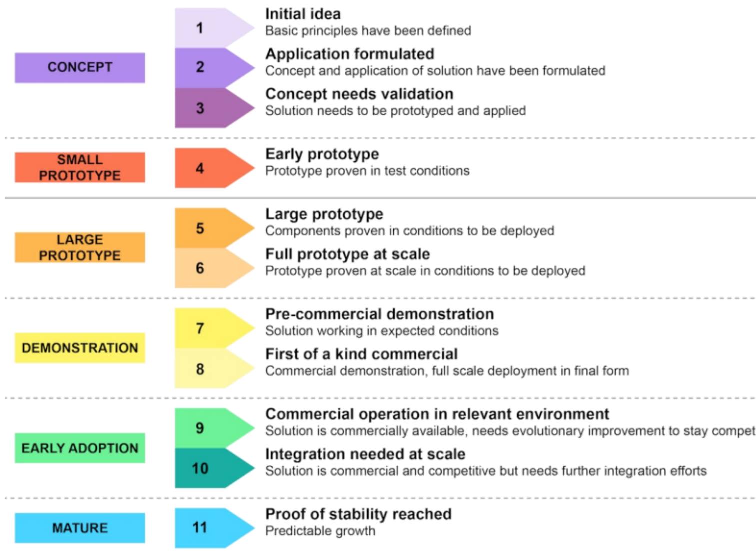
Technology readiness levels of production of low-emission hydrogen and synthetic fuels, and infrastructure



Creating demand

Room to scale up

Tecnological opportunity



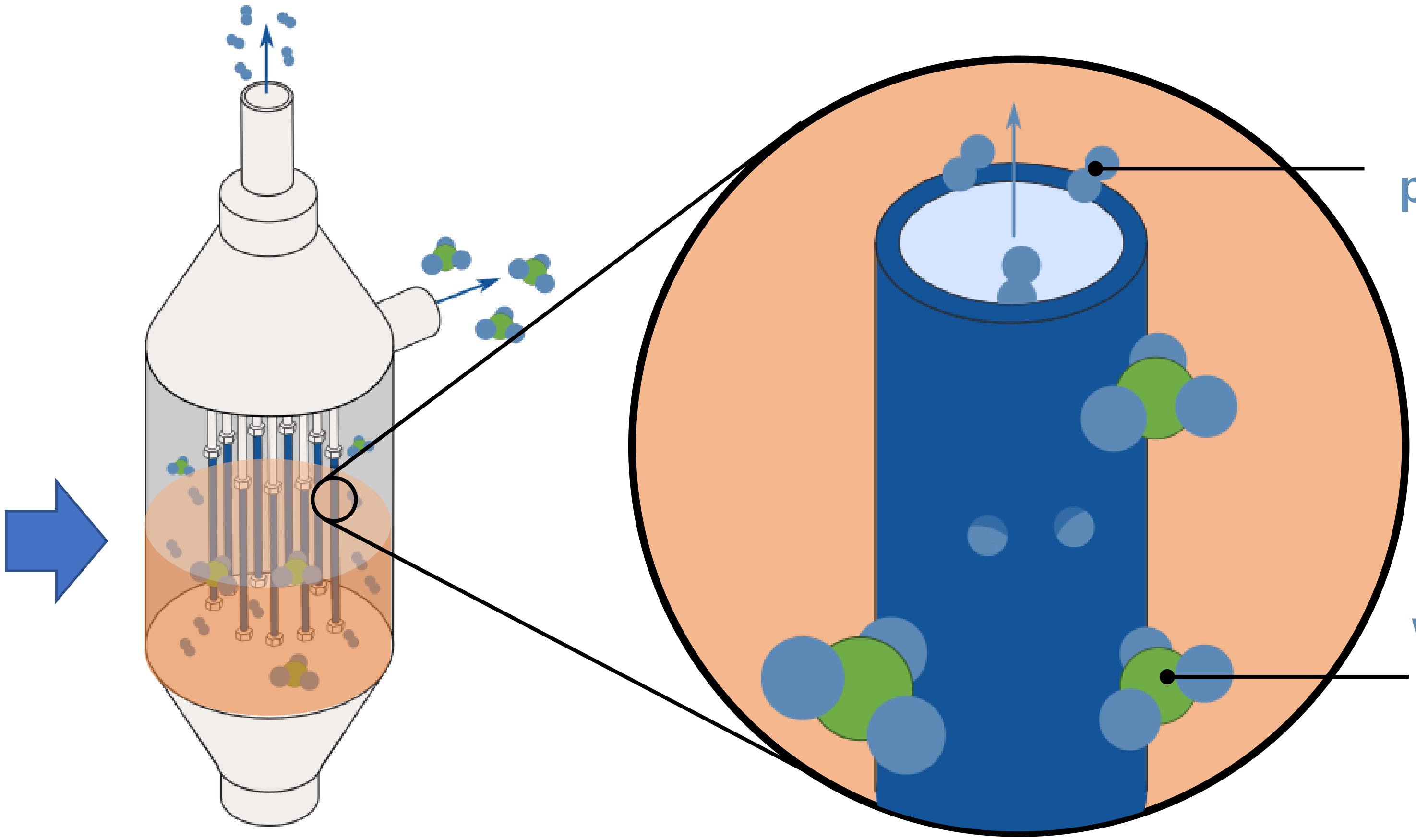
Notes: AEM = anion exchange membrane; ALK = alkaline; ATR = autothermal reformer; CCUS = carbon capture, utilisation and storage; CH_4 = methane; GHR = gas-heated reformer; HT = high temperature; LOHC = liquid organic hydrogen carrier; LT = low temperature; NH_3 = ammonia; PEM = proton exchange membrane; SOEC = solid oxide electrolyser cell. Biomass refers to both biomass and waste. Arrows show changes in technology readiness level as a consequence of progress in the last year. For technologies in the CCUS category, the technology readiness level refers to the overall concept of coupling production technologies with CCUS and high CO_2 capture rates. Pipelines refer to onshore transmission pipelines. Storage in depleted gas fields and aquifers refers to pure hydrogen and not to blends. LOHC refers to hydrogenation and dehydrogenation of liquid organic hydrogen carriers. Ammonia cracking refers to low temperature ammonia cracking. Technology readiness level classification based on Clean Energy Innovation (2020).

Source: ETP Clean Energy Technology Guide, IEA (2022).

Reconversion to H_2 is key

70% of the cost is related to feedstock

Palladium Alloy Membranes



We separate pure hydrogen

✓ 99.97% H_2

We transform molecules

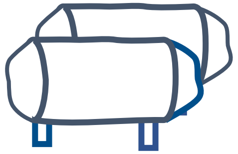
✓ $2NH_3 \rightarrow N_2 + 3H_2$

<u>Reaction & Separation in one step</u>

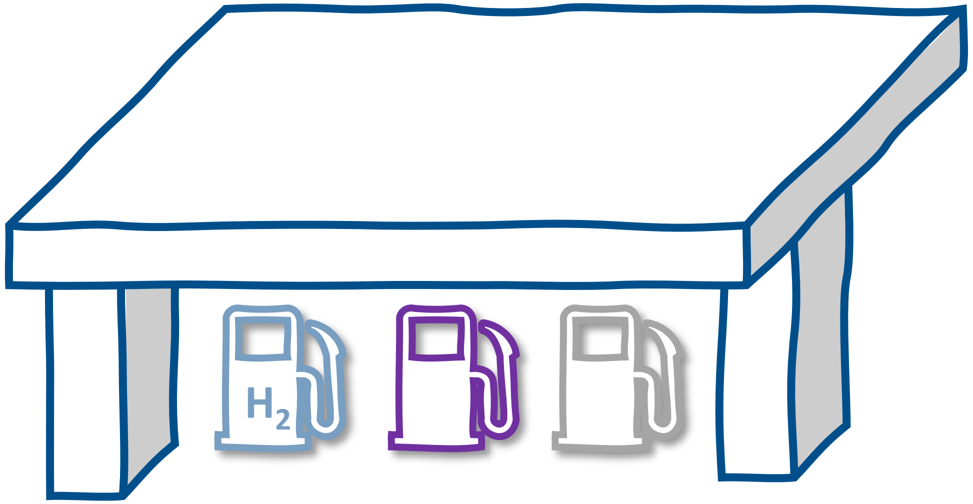
Increasing the efficiency

HRS: A business case

Starting in a captive demand scenario



Item	Magnitude	Unit
End use	5	buses
Power	80	kW
Operation	10	h/d
Energy needed	4000	kWh/d
Hydrogen needed	120	kgH_2/d
Supply frequency	2	times/week
Hydrogen per refill needed	480	kgH_2



1

Hydrogen logistics in cylinders at 500 bar

Cylinder to bus directly

2

Ammonia logistics in tanks in liquid form

Ammonia to cracker to compressor to H2 buffer

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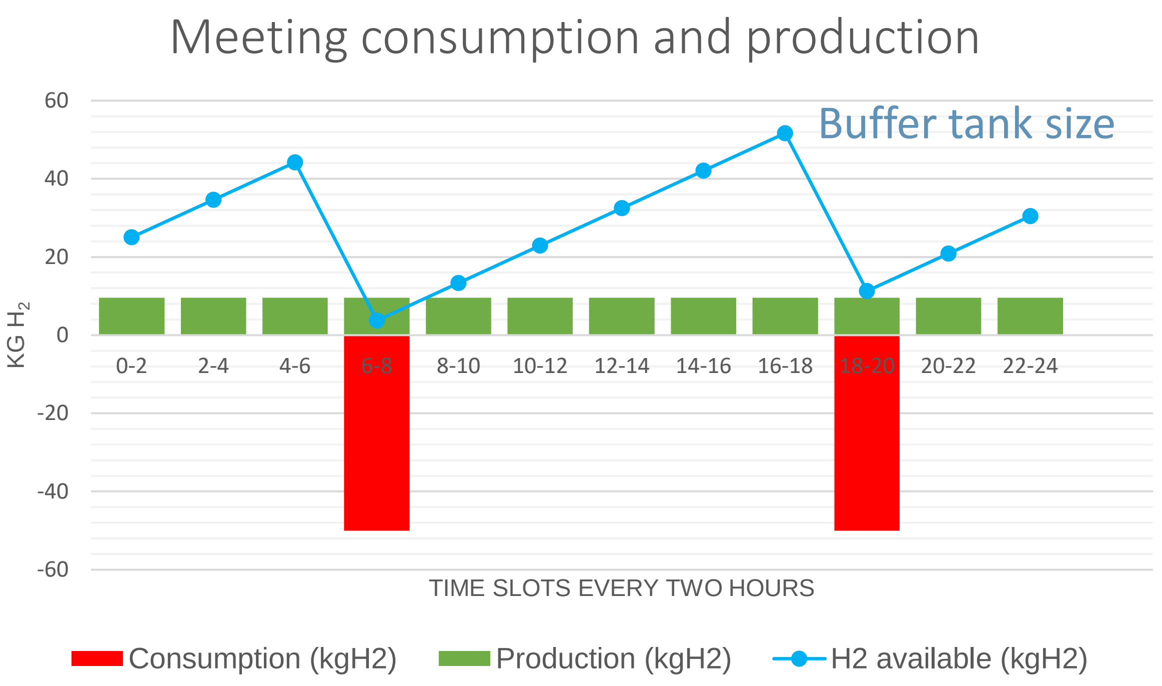
Optimizing the production

Aligning production & consumption patterns



Results for ammonia cracker on site

120 kg/d cracker to meet the demand

60 kg H_2 vs 480 kg for hydrogen tank for refueling

2x 500 kg NH_3 tanks needed (~3 m_2)

1

Around 12 m^2 for racks storage

(depending on delivery pressure)

Multiple compressions needed:

H_2 production + transport + cylinder

2

Cracker + Compressor + Buffer

in 20 ft container (+ clearance)

Just last H_2 compressor needed before refuel

Higher efficiency for reducing ammonia needs

Conclusions

Similar solutions but more potential to ammonia
Extra compressions to make hydrogen less cost-effective
Logistics with liquids easier than gases
Base case to compare with real deployments

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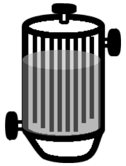
What about membrane reactors

Technology is key to tackle issues

Challenges	Membrane Crackers
 H_2 Logistics & Storage in cylinders	Ammonia Storage onsite
 Up to 30% cylinders dead volume	Ammonia cracking onsite
NH_3 reconversion costs (70% cost is feedstock)	Invest in Energy efficiency and NH3 conversion
 NH_3 to H_2 cracker system	Technology suitable for distributed apps.

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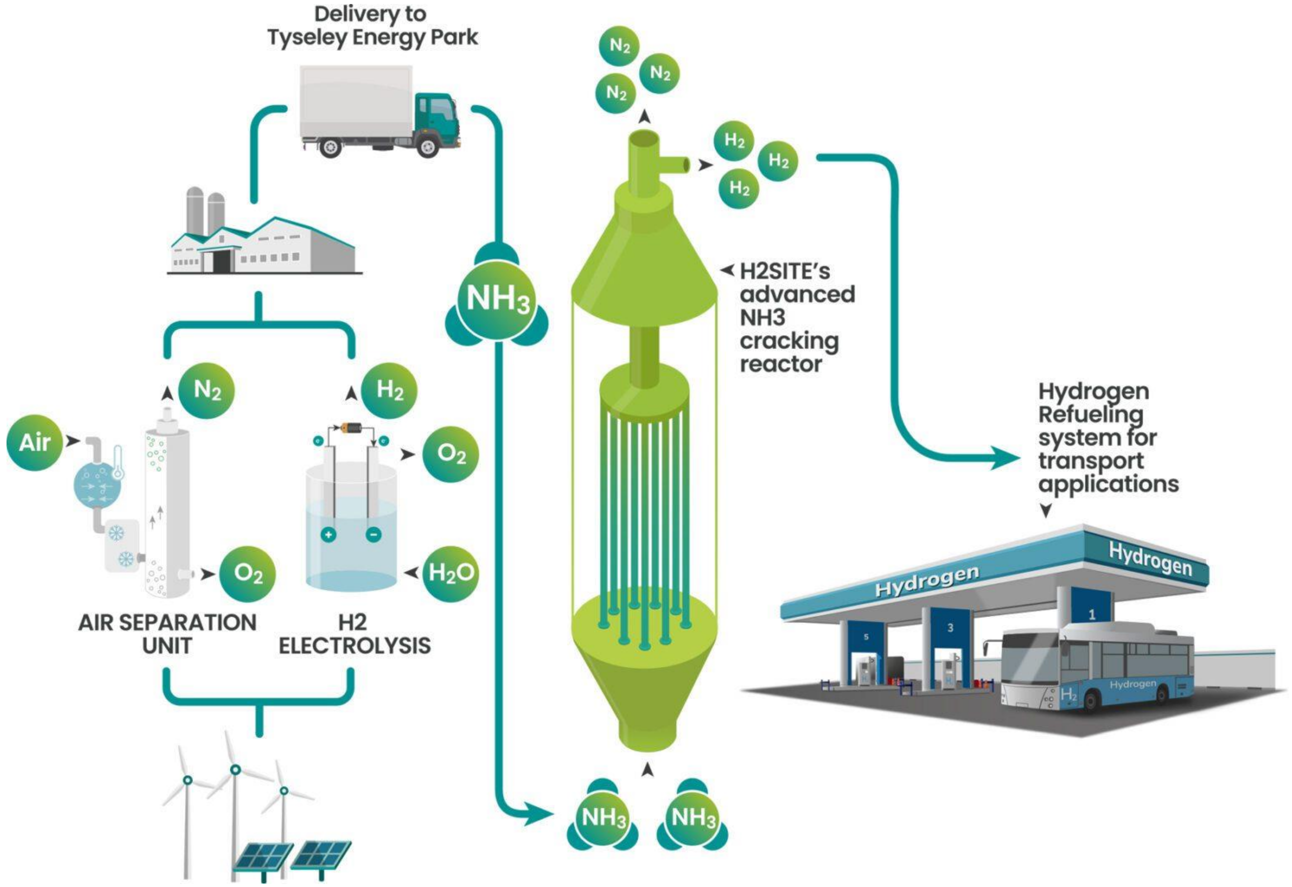
Ammogen current status

Our business case brought to reality



Item	Properties
Ammonia cracker	200 kgH_2/d capacity
End use	Mobility (ISO 99.97% H_2)
Location	Tyseley Energy Park (Birminham, UK)

Ammogen cracker beginning FAT tests in Spain

Commissioning in SAT tests expected in Jan '24

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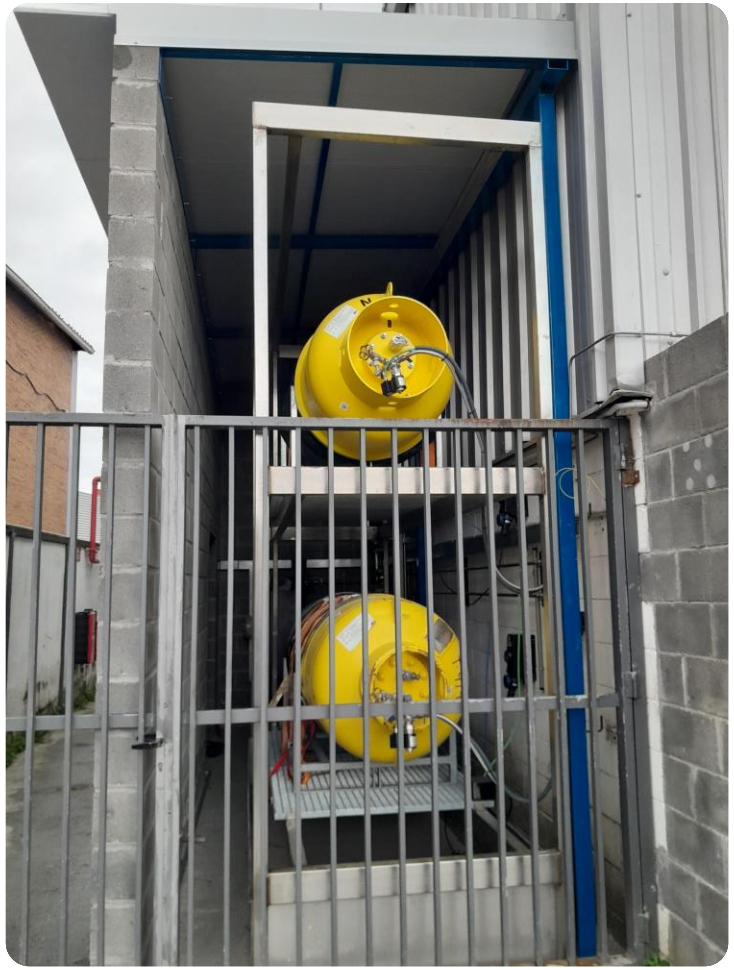
Handling Ammonia on site



2x 500 kg Ammonia tanks at H2SITE’s site

Testing crackers in FAT Oct – Dec ‘23

Safety logistics handled in installation phase

- ✓ When planned logistics, ammonia always ready
- ✓ Preparing for green ammonia logistics
- ✓ No safety faults whatsoever

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Ammogen project specifics

Safety & value chain main points to watch

Element	What evaluates	Comments
HAZID	Potential risk and mitigation strategies	Risk matrix evaluated frequenly
HAZOP	NH_3 Storage and cracker	Internally and integrated with offtaker facilities
Operating modes	Partial workloads System response time	Once validated, the system Works in nominal load
NH_3 logistics	Feasibility of delivery	Away from urban áreas. Trucks with replacement tanks.
Anticipated challenges	Topics to be further consider in the deployment	Non technical but technoeconomics are key. Policies & offtaker evaluation are essential

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H2SITE Roadmap

Scaling up from distributed to large-scale

Looking for partnership with engine and fuel cells developers

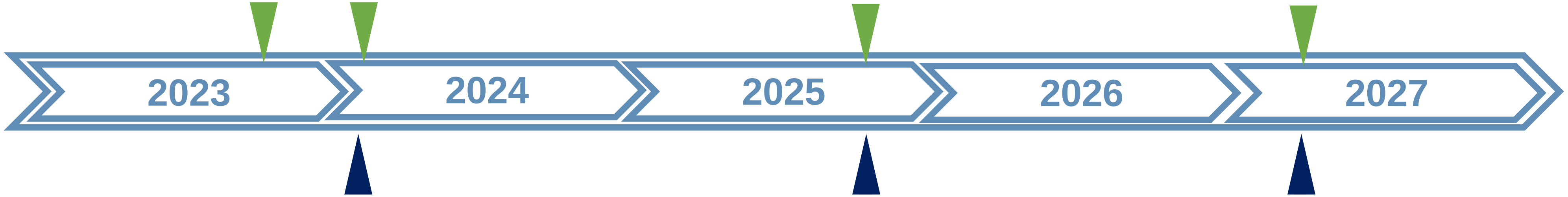
- Project developments (green markers)
- Technical milestones (blue markers)

H2OCEAN:
Small ammonia installed in a ship
2x20 kgH2/d

AMMOGEN:
Medium ammonia cracking for HRS
200 kgH2/d

2 t/d cracker:
Larger Ammonia cracker for industry
2 tonH2/d

10 t/d cracker:
Ammonia cracker for onboard
10 tonH2/d



Validation of cracking technology
160 kW systems

Decentralized cracking for HRS, SMR and onboard working
1.6 MW systems

Centralized cracking
10 MW systems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THE KEY TO UNLOCK THE
HYDROGEN TRANSPORT
CONTACT DETAILS
www.h2site.eu
eduardo.briales@h2site.eu
+34 613 448 339


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On-site hydrogen solutions