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ADVANCING PROPULSION

"Opportunities And Challenges For Hydrogen Propulsion Systems Research In The UK. An Automotive And Aviation Perspective"

FUTURE PROPUSLION CONFERENCE 2025

13th March 2025

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Research Director IAAPS,

University of Bath

Introduction-

- IAAPS Introduction
- Why use Hydrogen?
- Why can’t we use Hydrogen?
- Efficiency of Utilisation
- Current Hydrogen Research activities
  - H2ICE, Fuel Cells, Aviation
- Hydrogen Research opportunities
- Hydrogen Research Challenges
- Liquid Hydrogen- Why and challenges?
- Conclusions

IAAPS- Designed for collaboration

University of Bath - Institute for Advanced Automotive Propulsion (IAAPS)/ AAPS Centre for Doctoral Training

Shaping the transition to clean, sustainable affordable mobility.
Delivering fundamental research and innovation.
Funded industrial collaborative research projects.
Training the next generation of leaders and engineers.

IAAPS Limited

Leading collaborative engagements with industry.
State-of-the-art physical and virtual research and test facilities.
Global test centre for propulsion technology.

Today

Collaborating with a range of automotive, heavy duty, aerospace and marine organisations and supporting propulsion development programmes across a range of sectors. ISO 9001, ISO 27001, ISO 14001 & ISO 45001 certified

Hydrogen & Cryogenics

- Green Hydrogen production – 500kW PEM electrolyser with on-site storage –10kg/h @ 30bar
- H_2 Storage – 270kg storage tank @ 15-30 bar + facility for a tube trailer
- 3 hydrogen safe propulsion facilities to ~450kW
- Hydrogen Research (EPSRC HyRes) Bench Lab (Q2 2025)
- Cryogenerator – Sterling SC4T – 20K Helium cryo cooling capability for superconducting research
- LH2 in 2025 to support aerospace research
  - Planning approved
  - 6000L tank installation (~400kg of LH2)

Why Use Hydrogen?

- Because we have been given no alternative!
- We are seeing unparalleled change across the propulsion systems industry with the drive to net zero CO_2
- Electrification has been effectively mandated as the chosen technical solution by a number of governments particularly in the light duty sector (automotive)
- Other transportation sector can be particularly hard to decarbonise
- A mixed technology approach should be considered especially when the energy eco-system includes other transport vectors
- Hydrogen, ammonia and net zero replacement fuels ***"should"*** be considered
  - **Assuming that tailpipe CO2 is not the only measure!**
  - **For now, H2 would appear the most viable**
  - **Legislation in the UK is unclear and not helping H2 uptake in transport**

Vehicles that are hard to Electrify

- High energy consumers
- Off grid applications
- High utilisation applications
- High availability applications







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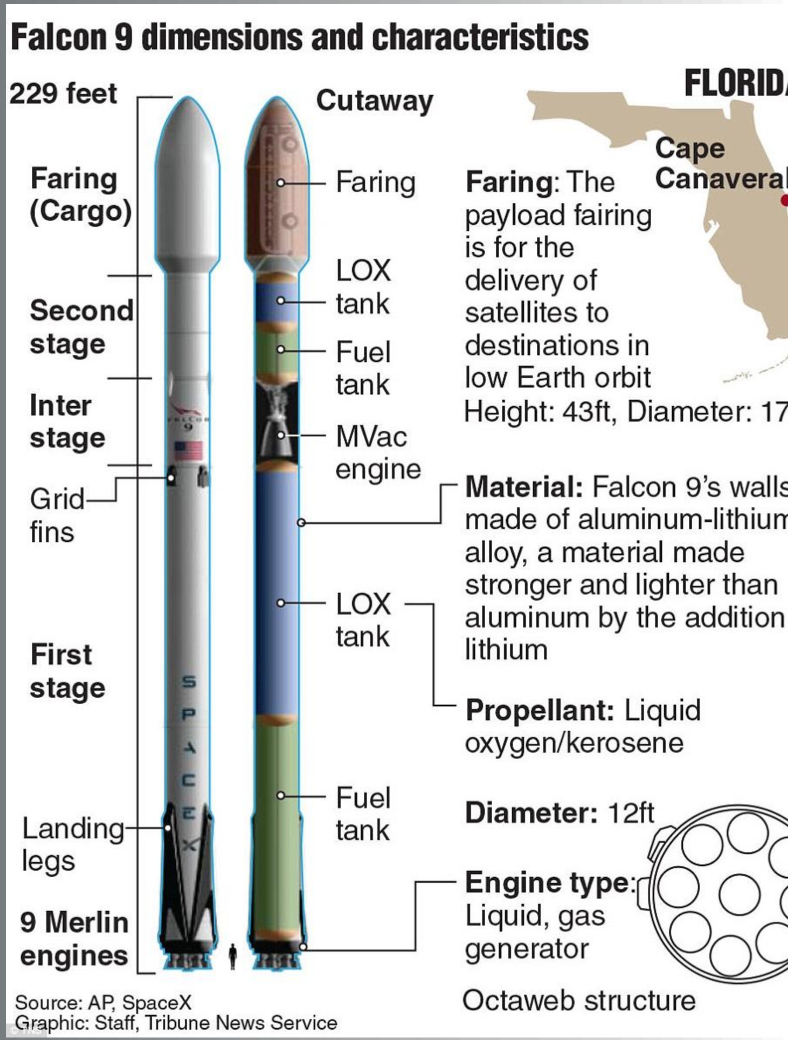
Even the most ardent supporters of BEVs know some things can't be electrified

The Promise

So far delivered

The greatest mind of our time?



You can't make Hydrogen work- there's no infrastructure

"I give up– there aren't any angular contact bearings available"

"I can't see this working we have no transmitters"

We have been here before!

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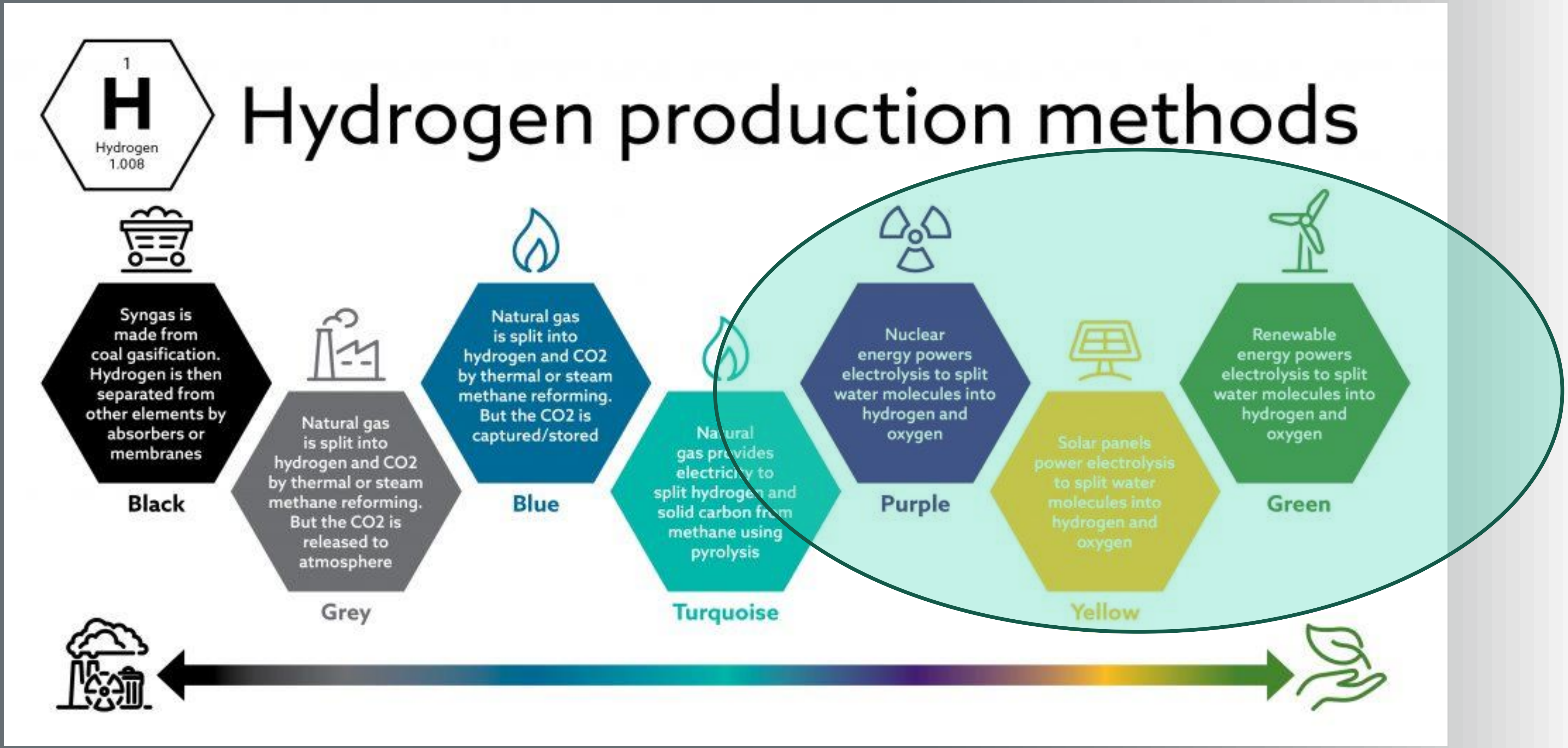
Hydrogen Challenge- You can’t use Hydrogen it’s not clean!



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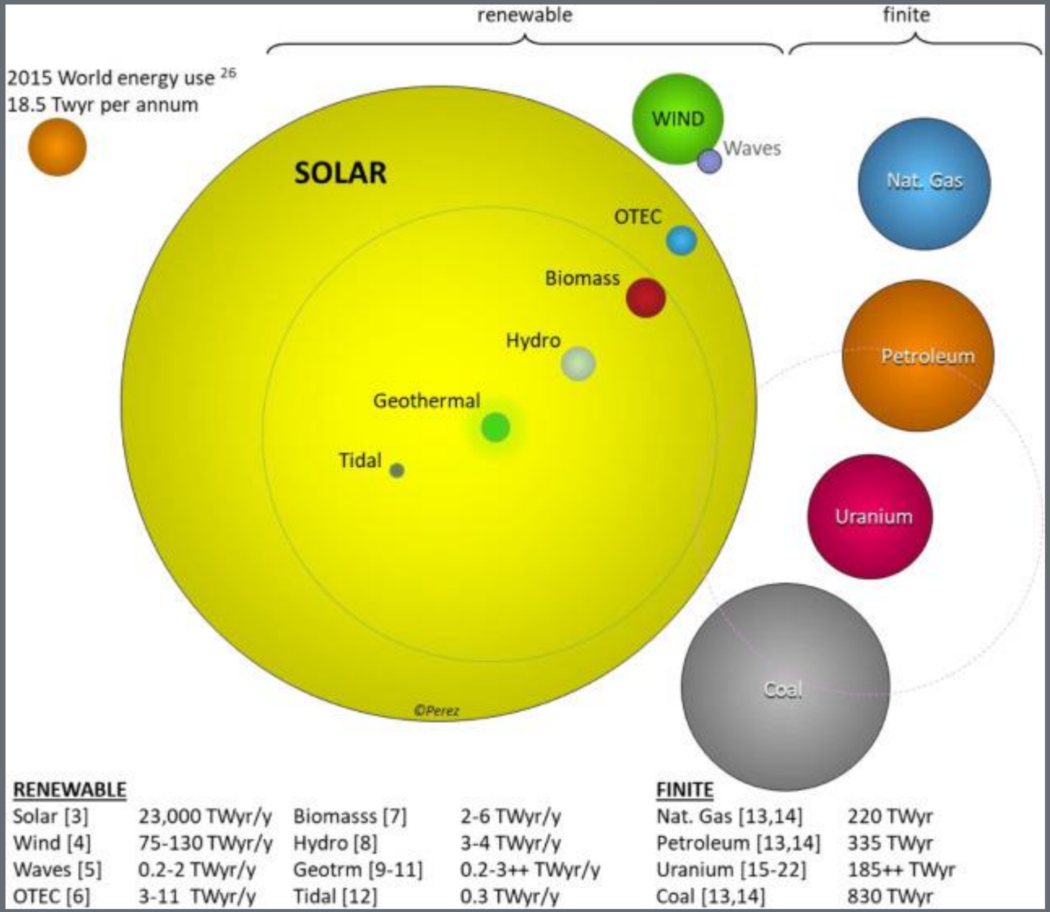
Efficiency of Utilisation

- "You can't use hydrogen, it's not efficient"
- We need to consider how and when we can use energy available to us and ***how it is best utilised*** not just consider the efficiency path- although that is important
- Utility in Generation of Energy
- Utility in Distribution and storage of Energy
- Utility in End Use of Energy

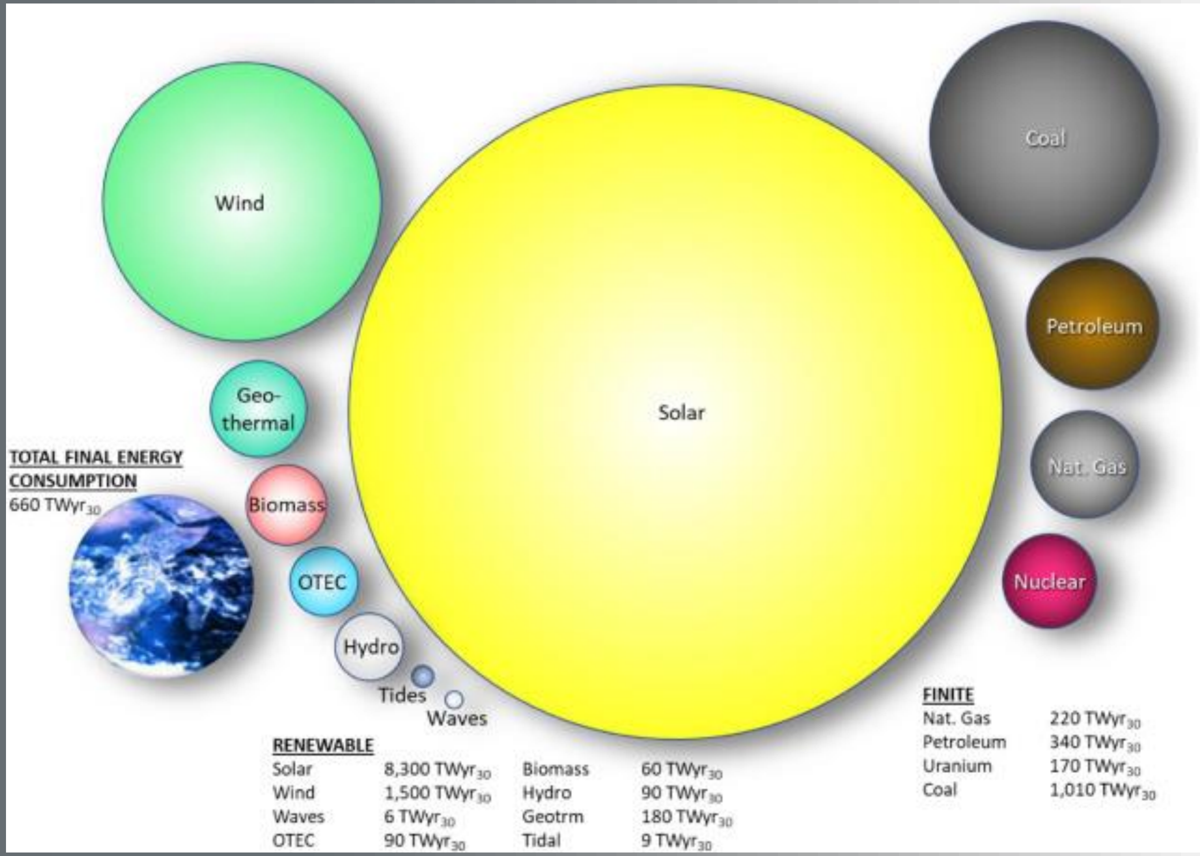
Efficiency of utilisation- Generation- We have enough Energy

Annual Scenario



2015 annual Prediction

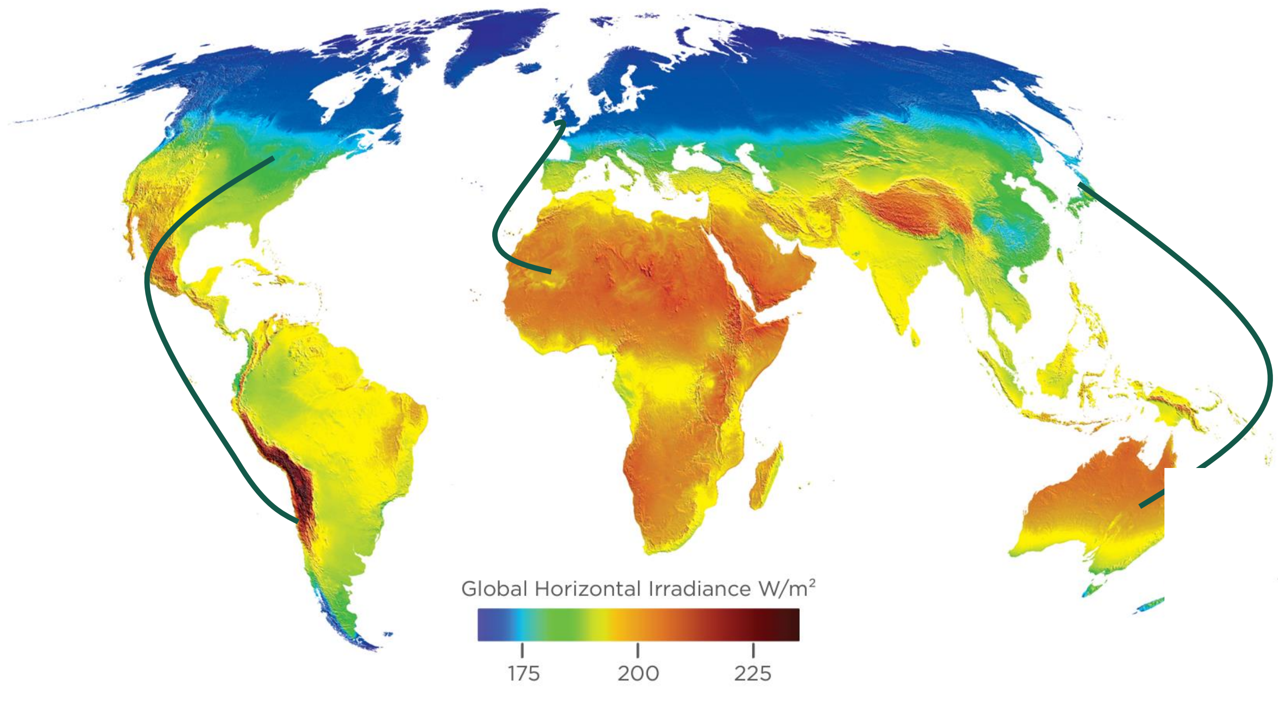
30year Scenario



Reasonably assured recoverable energy reserves from both finite and renewable resources over the next 30 years

Marc Perez, Richard Perez, Update 2022 – A fundamental look at supply side energy reserves for the planet, Solar Energy Advances, Volume 2, 2022, 100014, ISSN 2667-1131, https://doi.org/10.1016/j.seja.2022.100014

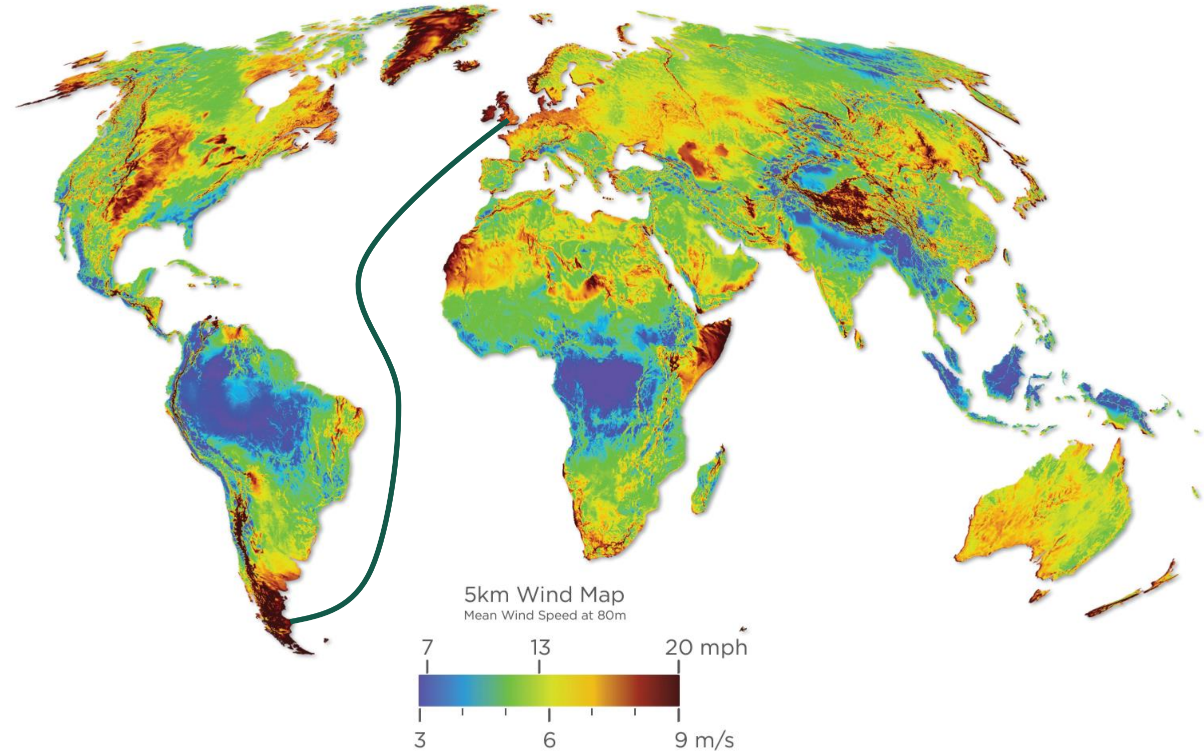
The Energy is not where we need it at the time that we need it!



HVDC links may be efficient, but they do not allow storage or flexibility of distribution

The Wind does not always blow

The Sun does not always shine!



Local Generation of hydrogen and/or liquid fuels to be transported/stored for use at points of consumption

Storage and distribution is a challenge

- Converting electricity into hydrogen and other fuels is a good way to store energy and move it
  - ***Not the most efficient, but that's not the most essential criteria***
  - Availability of scalable storage and mass transportation is more critical
  - Batteries can be part of the solution here, but due to cost and availability- they will be a scarce resource that must be targeted where most essential

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Efficiency of Utilisation- Charging/storage and distribution- Consider 1MW of electrical connection

Utility in BEV Charging

	Demand			
	≤ 18 kVA	≤ 54 kVA	≤ 276 kVA	≤ 1000 kVA
Suitable for	up to 2 Fast Chargers	up to 6 Fast Chargers or 1 Rapid Charger	up to 37 Fast Chargers or 5 Rapid Chargers	up to 135 Fast Chargers or 20 Rapid Chargers
Spacial requirement (mm)	350(W) x 500(H) x 210(D) [1]	450(W) x 700(H) x 225(D) [1]	609(W) x 754(H) x 250(D) [2]	3300(W) x 2400(D) (s/s) x 1000(W) x 2200(H) x 390(D)(metering) [3]

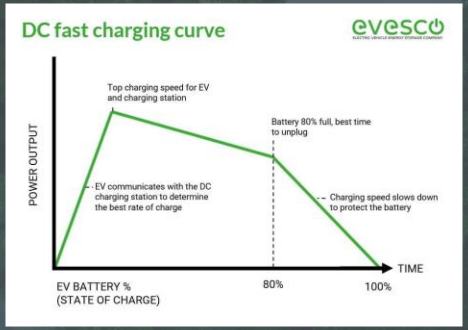
A guide on electric vehicle charging and DNO engagement for local authorities
https://www.nationalgrid.co.uk/downloads/29134

10 off 150kW chargers

Average time-based utilisation (%)					
	Q2 2022	Q4 2022	Q2 2023	Q4 2023	Q1 2024
Slow (3-6kW)	13.7%	13.7%	12.6%	13.6%	12.9%
Fast (7-22kW)	15.0%	15.7%	11.7%	11.5%	12.5%
Rapid (25-99kW)	13.3%	14.8%	11.4%	12.0%	11.3%
Ultra-Rapid (100kW+)	12.9%	16.1%	13.2%	15.1%	14.1%

Energy-based utilisation rates:

Estimated energy-based utilisation (%)							
	Weighted kW (2022)	Q2 2022	Q4 2022	Weighted kW (2023-2024)	Q2 2023	Q4 2023	Q1 2024
Slow (3-6kW)	4	10.3%	10.3%	5	7.6%	8.2%	7.7%
Fast (7-22kW)	12	8.8%	9.2%	12	6.8%	6.7%	7.3%
Rapid (25-99kW)	49	9.5%	10.6%	49	8.1%	8.6%	8.1%
Ultra-Rapid (100kW+)	183	3.5%	4.4%	183	3.6%	4.1%	3.9%



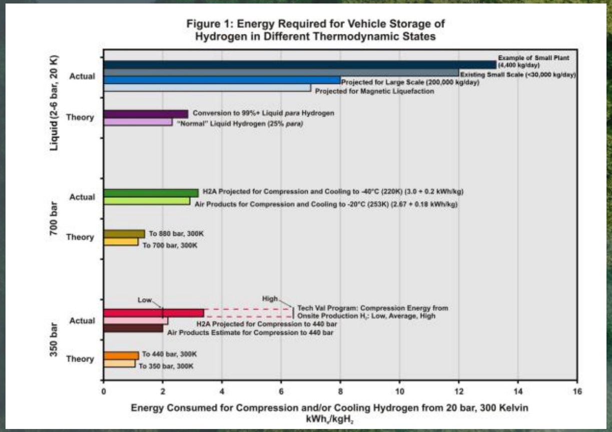
When are vehicles accessing the chargers?
What power is the charger running at?

Utility in Hydrogen

The electrolyser- may be less efficient but it is in continuous use

Typically, equivalent to 20kg/hr of H2 produced 50kWhr/kg

Compressing hydrogen to 800 bar consumes about 3 kWhr/kg



<u>Total Energy Delivery will be ~62% of installed Utility</u>

<u>Total Energy Delivery may be only 5% of installed utility</u>

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https://www.greenfinanceinstitute.com/wp-content/uploads/2024/09/Demystifying-Utilisation-2024-Update.pdf

Vehicle Utility Efficiency- an example

- Total cost of ownership critical in many difficult to decarbonise applications
  - How many vehicles needed to undertake duty
  - Cost of vehicle(s)
  - Cost of fuel and Driver(s)
  - Example Transit here but could apply to other applications
  - Can the BEV derivative deliver the Utility required?
  - For some application the E-transit would be ideal
    - Urban deliveries
    - Low average vehicle speeds
    - Lots of regen opportunities
  - For other applications the Utilisation efficiency may prevent adoption of the BEV solution
    - Significant high speed driving
    - Longer duration trips i.e. delivery routes
    - Highly laden applications

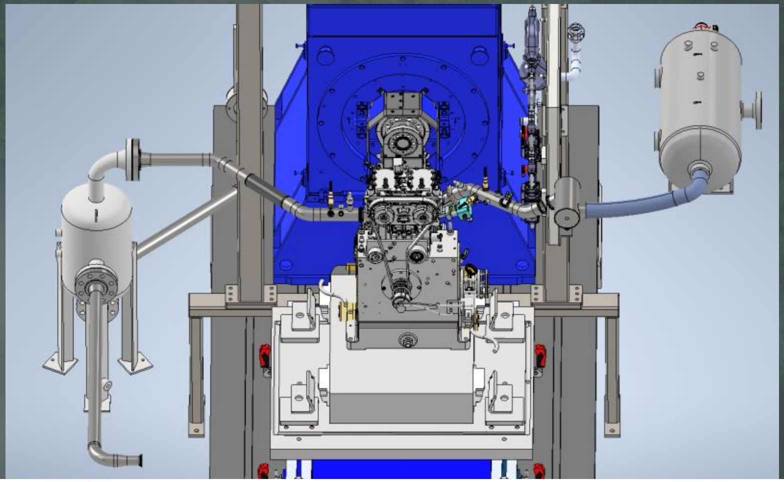
	E-transit Custom	Diesel Transit Custom	Transit Custom PHEV
Cost	£46,000+VAT -£5,000 grant	£32,000+VAT	£41,000+VAT
Range (WLTP) Real world	203 combined 119 motorway ~150 Real world	70L tank @8.1L/100km ~ 500miles	23-35miles EV ~300miles
Payload	1088kg	1384kg	1300kg
Towing Capacity	2300kg	2500 to 2800kg	2400kg

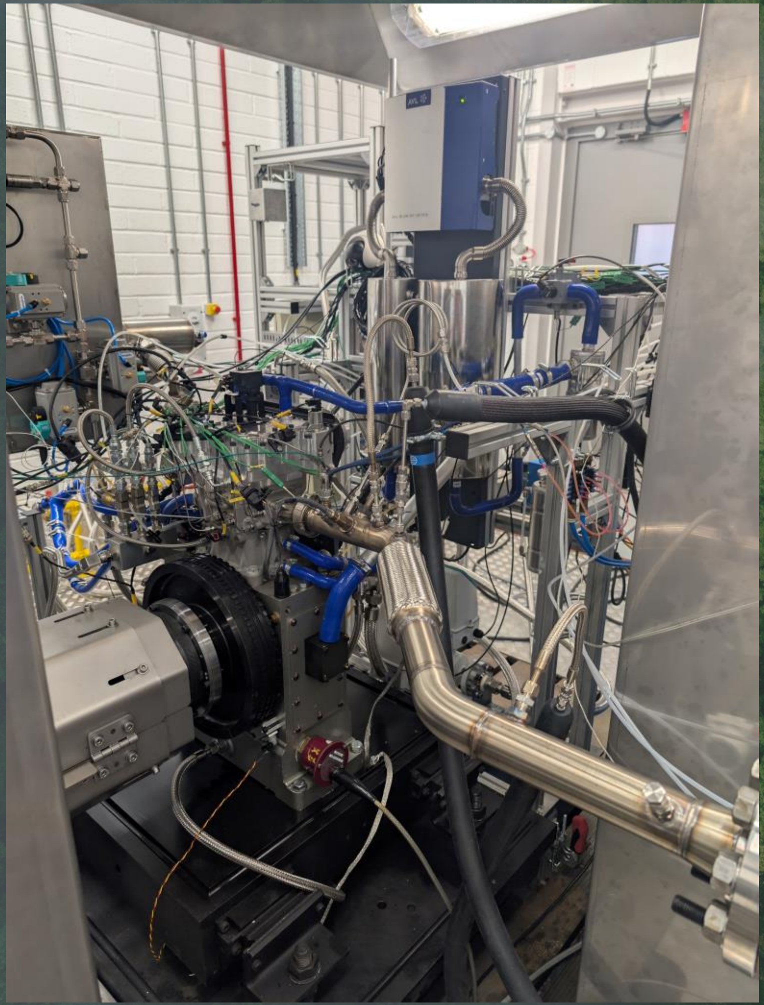
A hydrogen fuelled solution could

	H2 Fuel Cell- Transit Custom	H2 ICE- Transit Custom
Cost	??? Significant on cost for fuel Cell	£37,000+VAT Assuming £5k on cost
Range (WLTP) Real world	8kg of H2 ~370mile range	8kg of H2 ~300mile range
Payload	TBC	TBC
Towing Capacity	2500 to 2800kg	2500 to 2800kg

UKRI Prosperity Partnership (EPRSC, JLR, Oxford University, University of Bath, Bosch, Siemens Digital)

- Lean burn H_2 for passenger car
- Single cylinder 0.5L research engine
- Direct Injection
- Novel combustion strategies
- Effect of EGR
- Used to support H2ICE model validation and improved model development

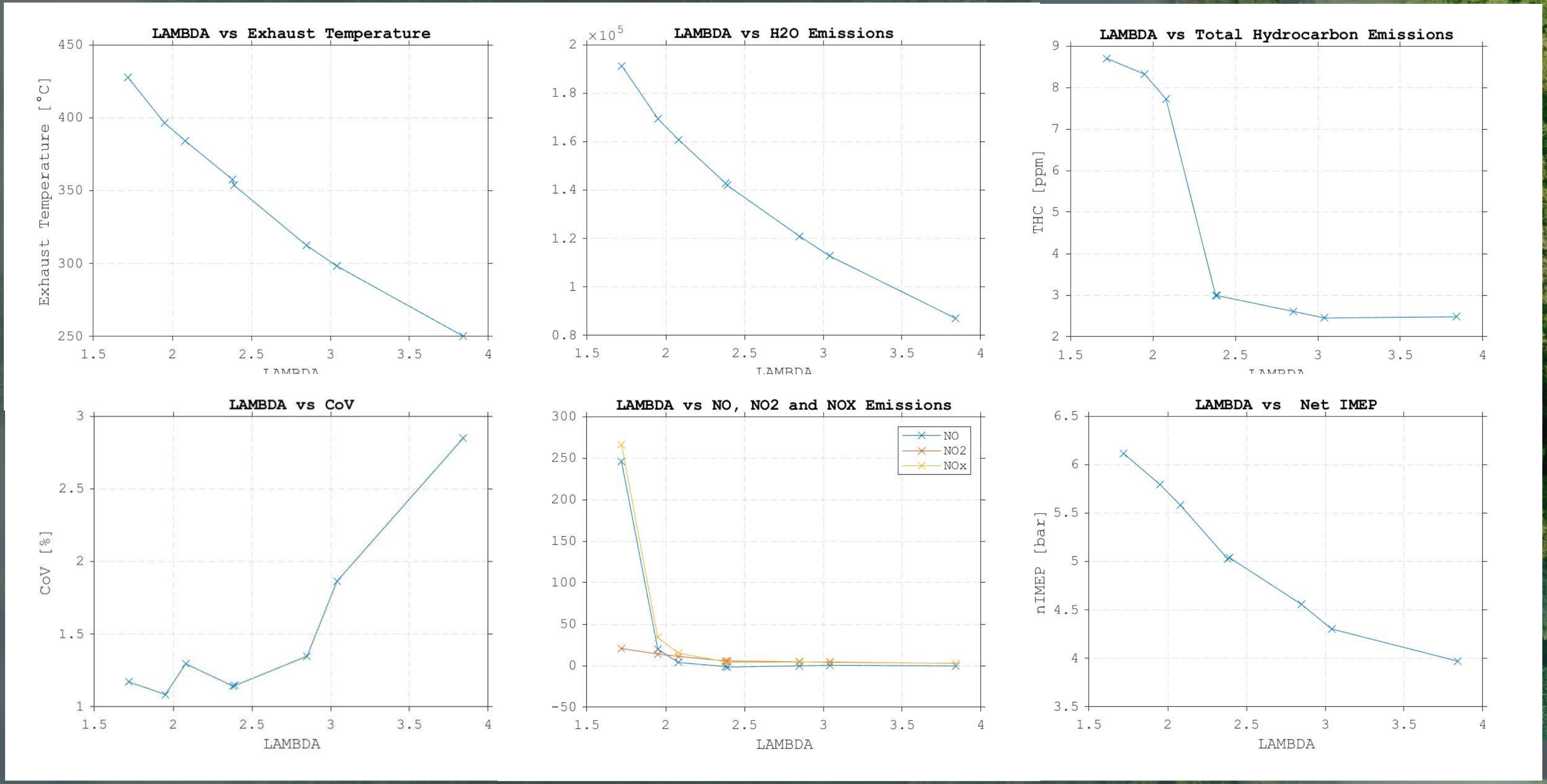




Engineering and Physical Sciences Research Council | JAGUAR | LAND ROVER | SIEMENS | UNIVERSITY OF OXFORD | BOSCH Automotive | IAAPS | UNIVERSITY OF BATH

H2ICE early findings and Research Challenges

- Easy to manage combustion out to very lean conditions, beyond λ=3.7
- Combustion stability very good
- Very low engine out NOx levels achieved <10ppm under some operating conditions



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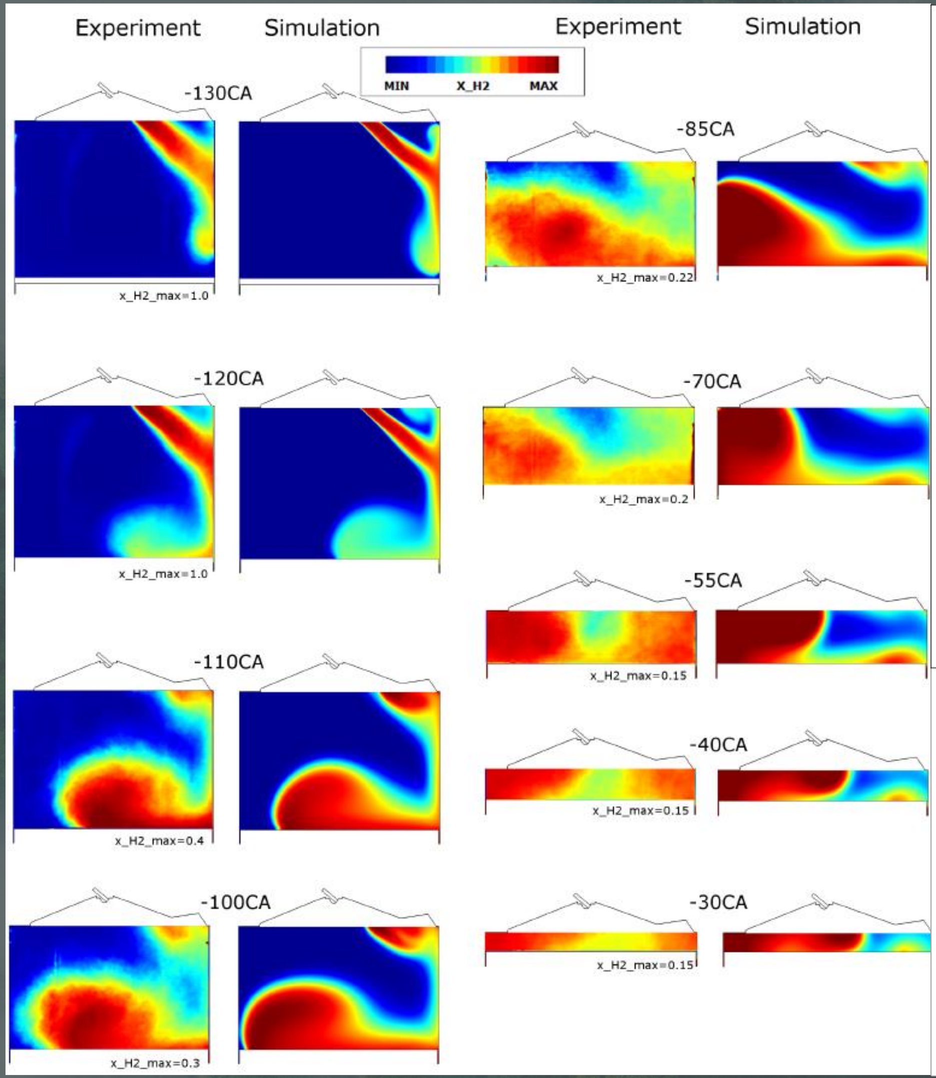
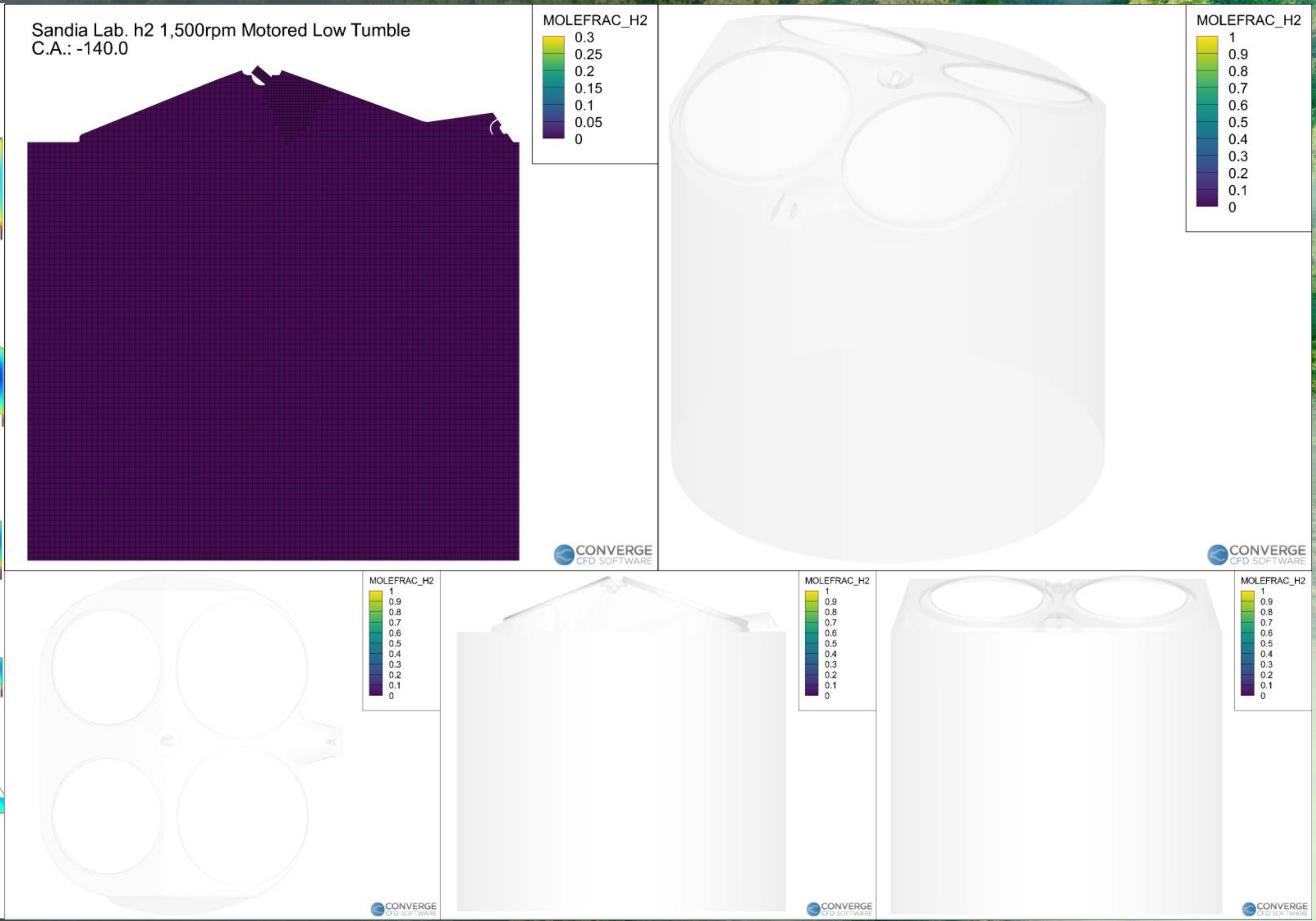
H2 ICE research challenges

- Long campaign of testing to develop robust modelling approaches
  - Heat transfer
  - Predictive combustion models
  - Knock
  - Emissions formation
- Multiple compression ratio builds
- High tumble and lower tumble head designs
- High power density at high load required
  - Study interactions of lean vs EGR dilution
  - Develop solutions for multi-cylinder boosting system architecture
  - Understand requirements for after-treatment systems

Can we simulate Hydrogen effectively?





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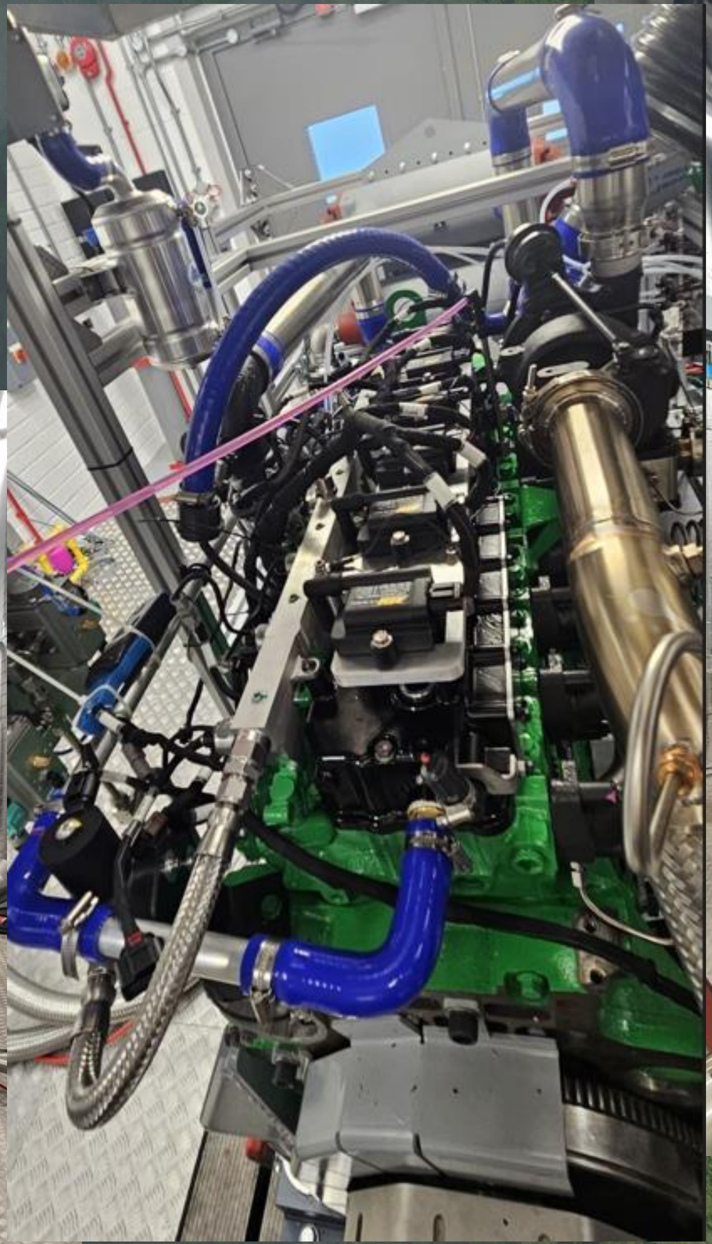
H_2 ICE

- Medium duty application
- For truck, bus and off-highway use
- On track for EU zero emission standard



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Hydrogen Aviation Research, H2Gear, FETCH and HyFIVE


GKN Aerospace and IAAPS to partner on development of hydrogen propulsion systems for aviation

IAAPS to support GKN Aerospace's ground-breaking H2GEAR Programme to develop a megawatt scale cryogenic electric drive system using PEM fuel cells

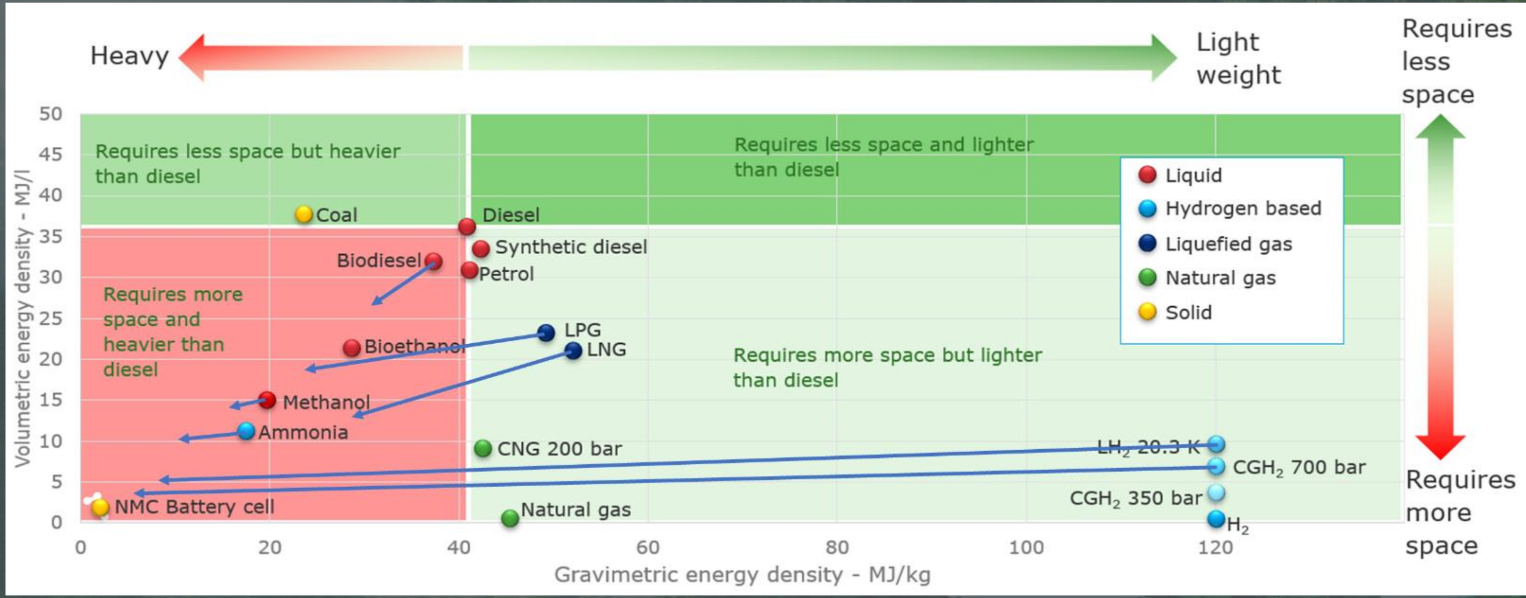
Testing and validation to be conducted at new IAAPS R&I centre with both green H2 production and liquid H2 storage facility

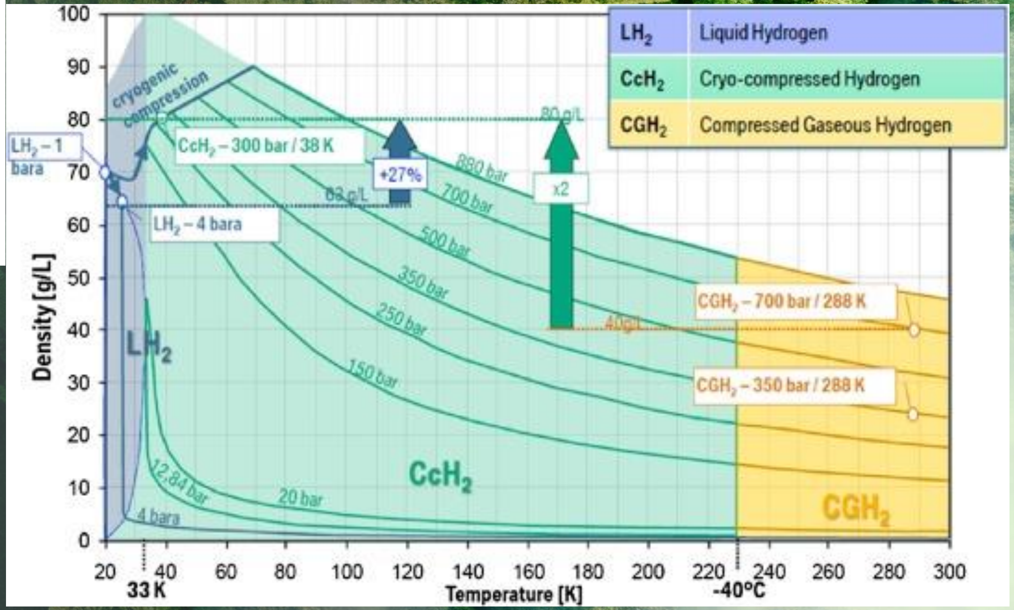
The FETCH project is led by Moog together with the partners University of Bath, Cranfield University, sensor specialists Druck/Curtiss Wright and bearing specialist Carter Manufacturing. UoB/IAAPS responsible for developing H2 flow test facility and modelling of valve system.

- Led by Marshall Aerospace with GKN Aerospace, Parker Meggitt, University of Manchester, University of Bath, and Cardiff University in the HyFIVE consortium
- HyFIVE's ultimate goal is to develop, test, and validate a modular, scalable cryogenic hydrogen fuel system architecture that is suitable for multiple aircraft classes and compatible with either hydrogen electric propulsion or hydrogen combustion powertrains.

Hydrogen Challenges- Storage is still a challenge- as well as energy density

"Hydrogen, the worst way to store Hydrogen!"





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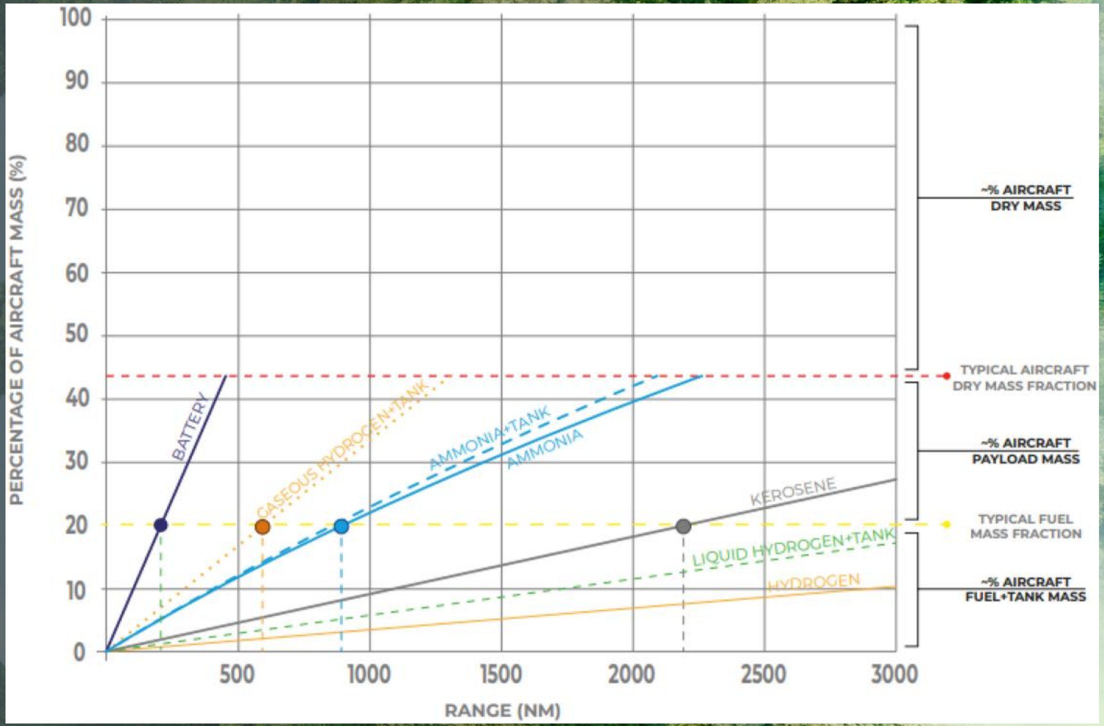
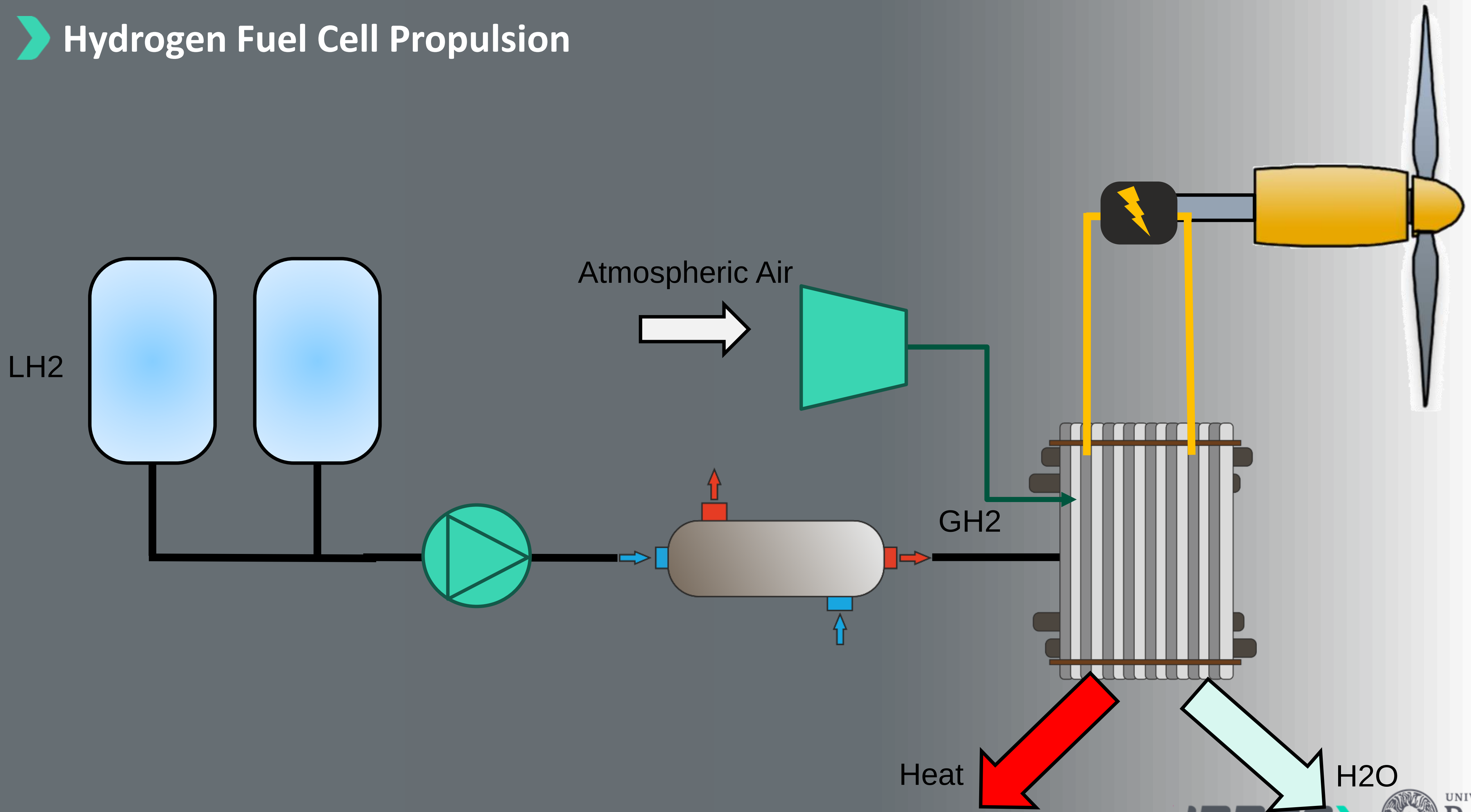
Why Liquid Hydrogen?

- Significant improvement in energy storage ability
- Improved delivery logistics
- Improved refuelling speed
- Enables adoption of “super-conducting” technologies
- Lower electrical losses (increased range)
- Significant reduction in electrical component size
- Significant reduction in electric component mass
- Electrical system can work at lower voltage
  - Challenges with di-electric breakdown at altitude conditions

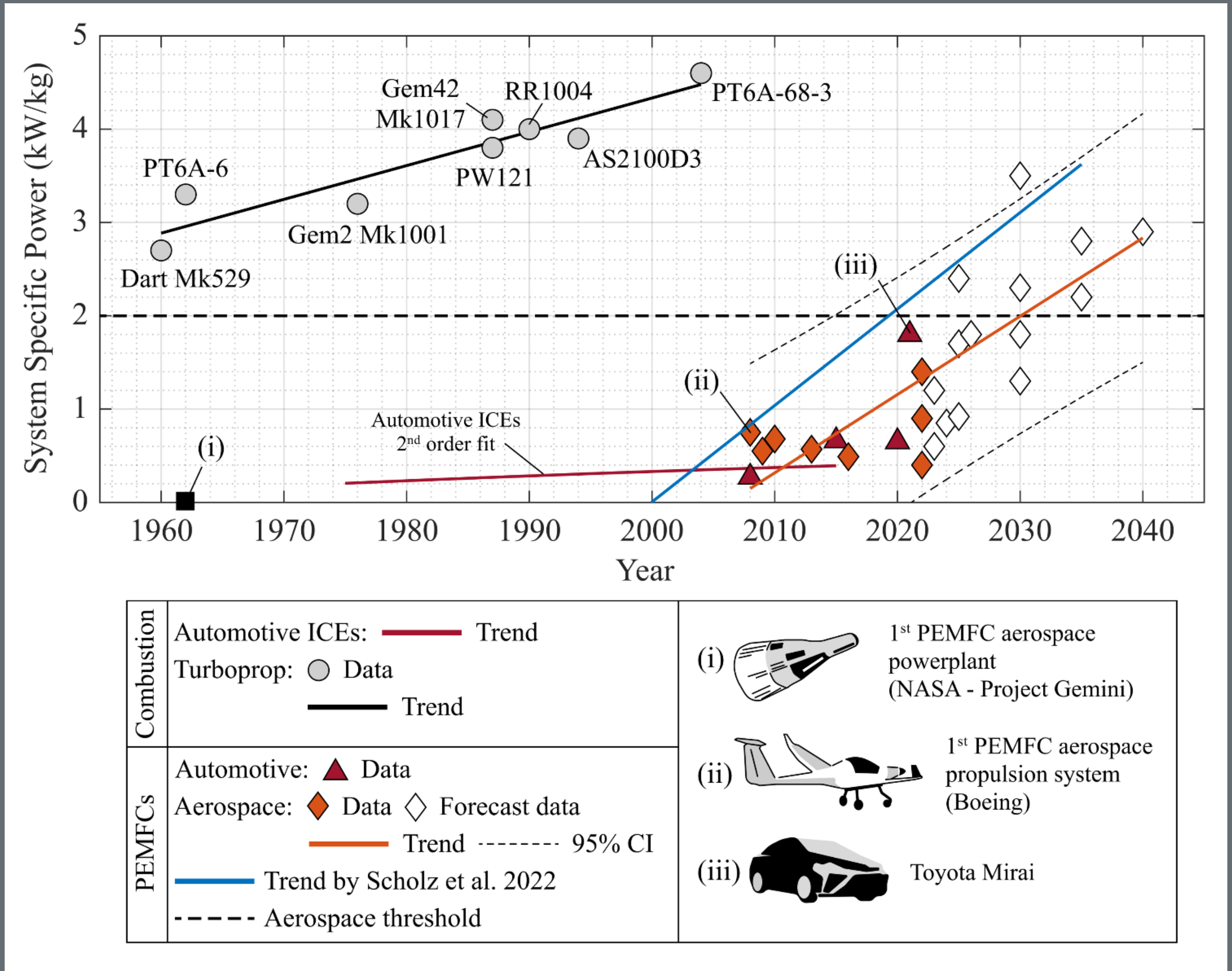


https://www.ati.org.uk/wp-content/uploads/2021/10/FZ_0_6.1-Primary-Energy-Source-Comparison-and-Selection-FINAL-230921.pdf

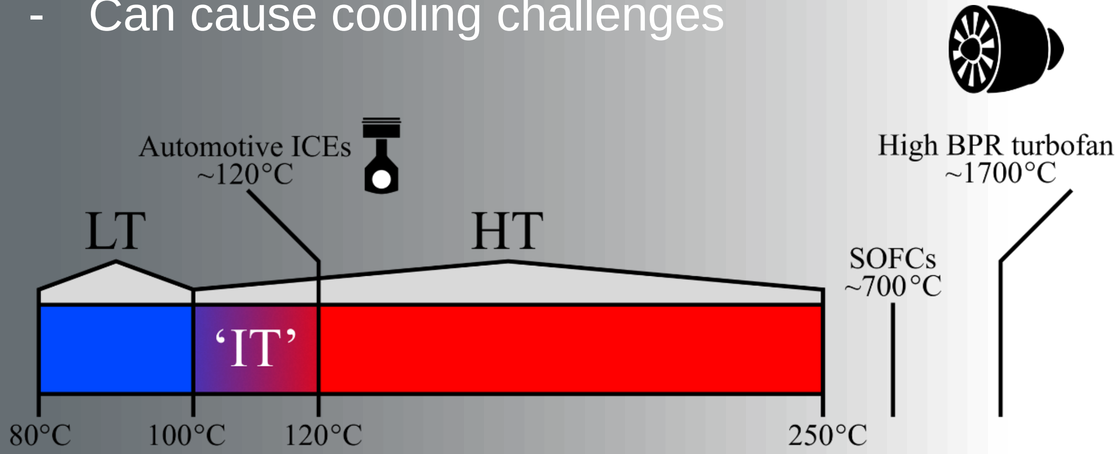
Hydrogen Fuel Cell Propulsion



Where does Hydrogen fit in Aviation?



Two Approaches
- Direct fulling of gas turbines
- Fuel Cell powered electric propulsors
  - Std. or superconducting electric architecture
- Fuel cells despite their efficiency reject heat at a low grade
- Can cause cooling challenges



Challenges for Liquid Hydrogen

- We don't liquify hydrogen in the UK at scale
  - it's not new (outside of the UK)
- All significant UK LH2 is delivered from Europe
  - Used in semiconductor manufacture
  - ~1 truck per day with 2.5 to 4 tonnes
- Safety Case
  - A Liquid hydrogen leak leads to
  - Liquefaction of O2 in air
  - High volumetric expansion ratio >850:1

SWRI in San Antonio 65000 Litres of LH2 storage ~4.5 tonnes
~10-15 tube trailers of compressed H2 depending on pressure

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Liquid Hydrogen Research Challenges

- How do we liquify hydrogen and store it in an efficient way at different scales
- Liquid hydrogen components- pumps, valves and heat exchangers need to be developed
  - Existing research driven by space exploration
  - Short durability requirements
  - Less cost constrained
- Fundamental Challenges
  - Can we model phase change and mixed phase of LH2 as it turns to gas?
  - How do materials behave
    - Under exposure to hydrogen
    - At extremely low temperatures
    - Under thermal cycling
  - Component building blocks
    - Seals
    - Bearings (lubrication)

Conclusions

- Decarbonising certain vehicles is extremely challenging, The “difficult” or “impossible” to electrify category
- The current constraint of ***No Carbon tailpipe*** mandates that we have to use Hydrogen or Ammonia as fuels for these applications
  - We should be technology agnostic and be targeting the end game-
  - Life cycle CO2 reduction not tailpipe CO2
  - Government strategy needs to align to Europe and the rest of the world, or we will struggle to support UK industry and be left behind
- Efficiency of Utility is often more important than energy efficiency for many applications
  - Utility of generation, storage/distribution and use
- Hydrogen has many challenges
- Hydrogen is a very effective fuel both in fuel cell applications, but also H2ICE
- In some ways it is perhaps the ‘ideal’ fuel, i.e. lean limit, laminar burning velocity
- But it is difficult to store, compress and/or liquify- we need to improve these processes
- It is expensive to make
  - Improvements in electrolyser efficiency will decrease cost of H2
  - Efficiency of end use is important – it influences range and operational cost.
- Hydrogen ICEs are an easy to reach interim solution assuming fuel cell technology matures and becomes cost competitive
- H2ICE can deliver in the very near term with near “Zero tailpipe” pollutants and competitive efficiency
- We need to consider a systems approach to hydrogen
- Maximising the adoption and use of hydrogen is the best way to drive down cost
- Therefore, do not preclude hydrogen from any application

A bit of fun… It's not a matter of if, it's a matter of when, hydrogen

Thank You
Questions?