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Engineering solutions unlocked with Hydrogen facility

30th March 2023 Hydrogen Tech Expo

Major milestones achieved!

How did we
get this far?

19 OCTOBER 2022

Ricardo celebrates opening of state-of-the-art hydrogen test facility in Shoreham

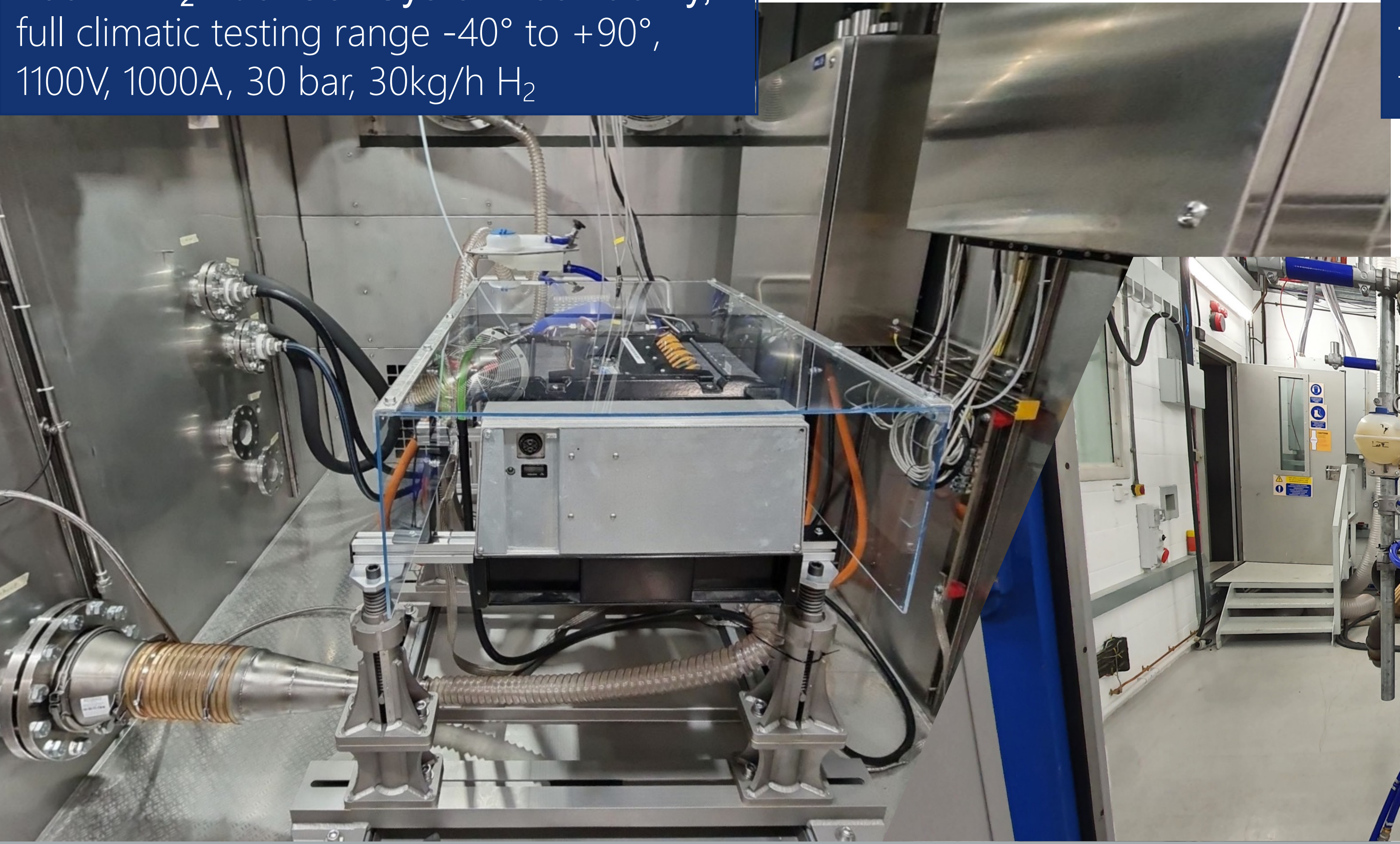
How is the facility enabling
engineering solutions?

Sir Harry Ralph Ricardo (26 January 1885 – 18 May 1974) was an English engineer who was one of the foremost engine designers and researchers in the early years of the development of the internal combustion engine.


Requirement
Planning & budget
Supplier contracting
Build
Commissioning
Insurance and processes
Training

2023 Hydrogen Engines and Fuels Cell Operating at Sir Harry Ricardo's original factory

400kW H_2 Fuel Cell System test facility, full climatic testing range -40° to +90°, 1100V, 1000A, 30 bar, 30kg/h H_2



460kW H_2 Internal Combustion Engine transient test facility, 60 bar, 35 kg/h H_2 flow rate

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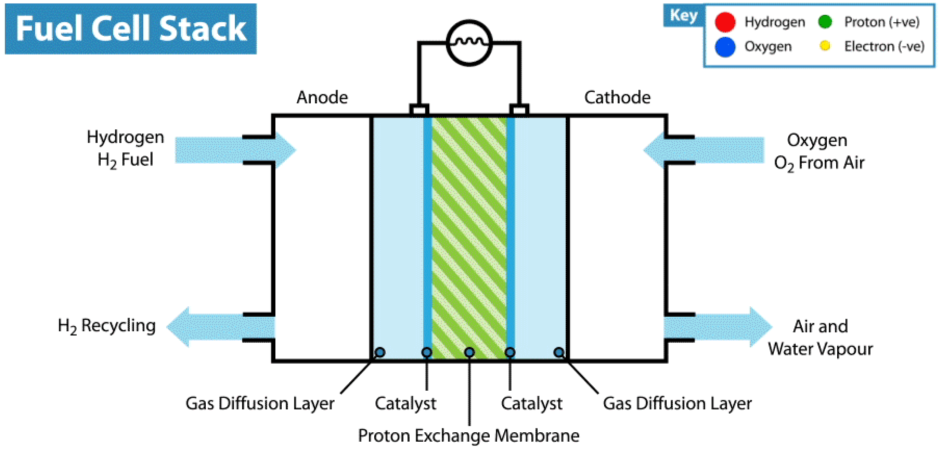
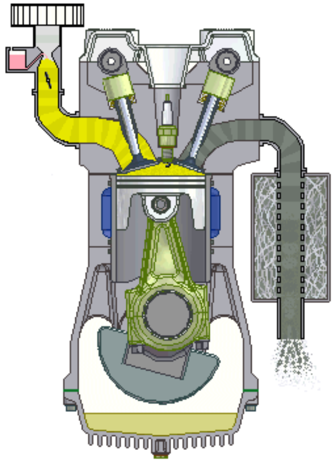
Hydrogen as propulsion – both FC and H2 ICE have its challenges

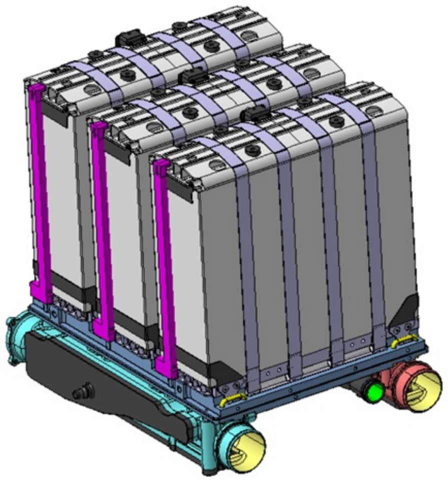


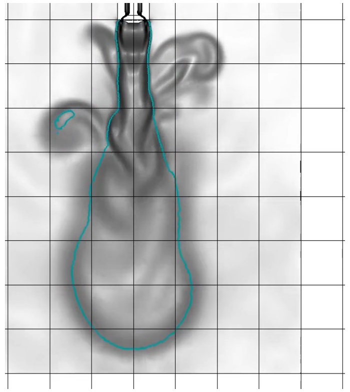
Source: Intelligent Energy, https://www.intelligent-energy.com/our-products/stationary-power/fuel-cells/

Hydrogen Internal Combustion Engine



Source: https://commons.wikimedia.org/wiki/File:4-Stroke-Engine-with-airflows.gif





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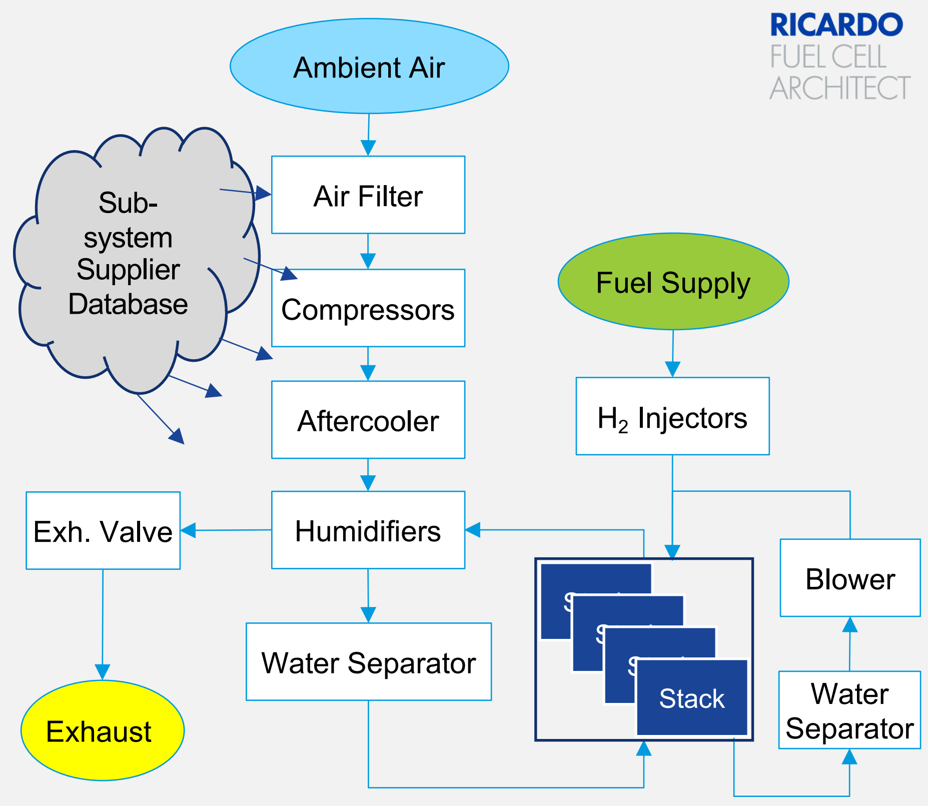
FC challenge: Many real life applications require bespoke multi-stack solution



Mass flow, pressures and temperatures modelled at all interfaces

Component efficiencies modelled

Simplified diagram indicating how the 0D model assesses the cathode and anode circuits

Cranfield Aerospace
Bespoke multi stack fuel cell system development for aerospace

Viking Cruise ship
Bespoke Multi-MW modularized FC system for cruise ship

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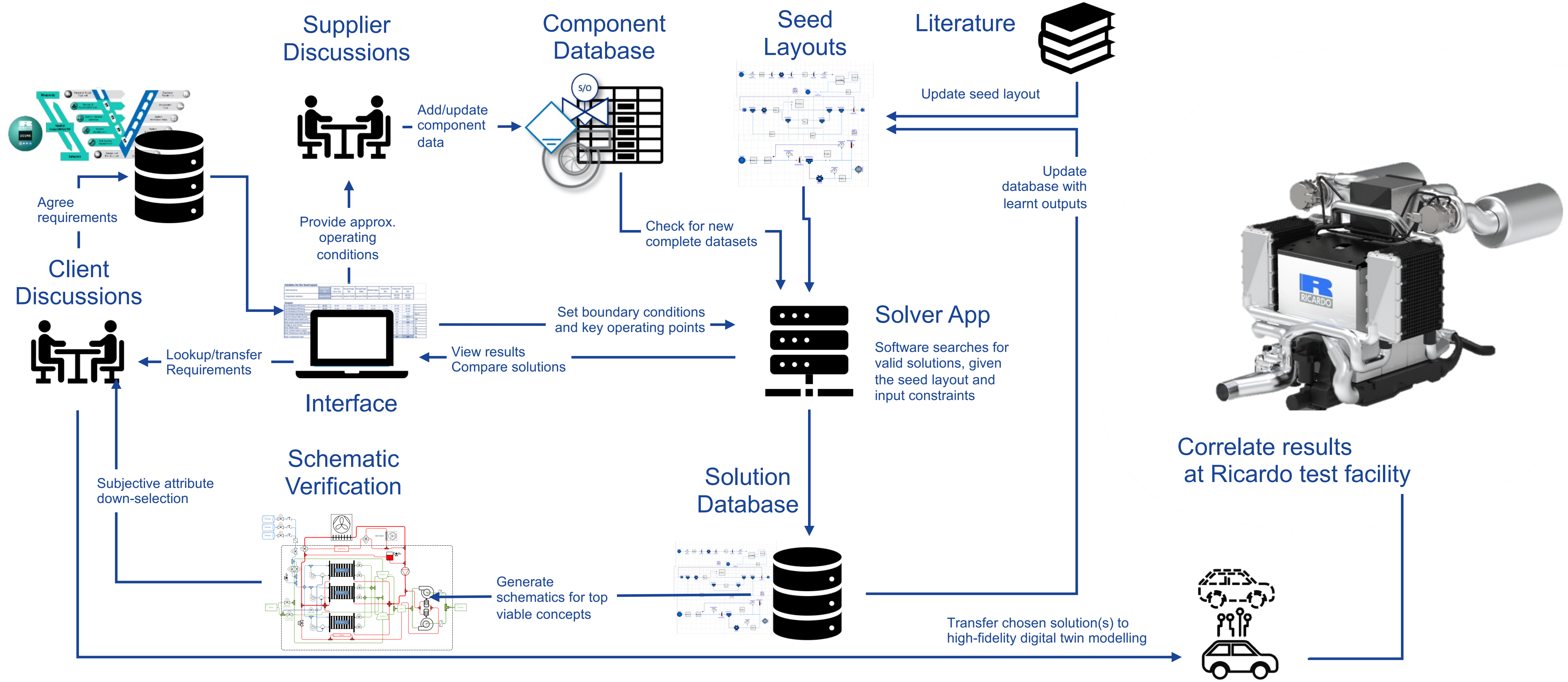
Accelerated system development with Ricardo's Fuel Cell Architect



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FROM MOON TO EARTH

"… Because of its **high efficiency,** the Bacon cell was licensed by the Pratt and Whitney Division of United Aircraft and used in a successful bid to NASA for a $100 million proposal to build the power source for Apollo 11.

The Bacon fuel cell was perfect for powering NASA's spacecraft: it was **lighter and much less bulky** than batteries of the time, it was more efficient than 1960's solar panels, and hydrogen and oxygen were already going to be on board the ship for use as rocket fuel."

60 years later…

Clients still want the **most efficient** reliable system…and they want it **fast.**

Solver App

Software searches for valid solutions, given the seed layout and input constraints

Fuel Cell Architecture delivers result clients want.

Hydrogen ICE - how did we solve the challenge

Ricardo Responsibilities

- Specify, procure, build, commission and demonstrate the **performance, efficiency and emissions** potential of a marine propulsion engine
- Demonstration at Ricardo's new hydrogen engine test facility at Shoreham Technical Centre

Challenge

- Reuse existing technology where possible
- Retrofit the existing engine to run on pure hydrogen
- Select appropriate doner engine applicable to propulsion requirements of Shapinsay Island RORO ferry MV Shapinsay
  - Currently has 2 x 270kW diesel engine

Doner Engine Selection

- Scania OC13 CNG engine
- 13l , 302kW, 6 cylinder engine

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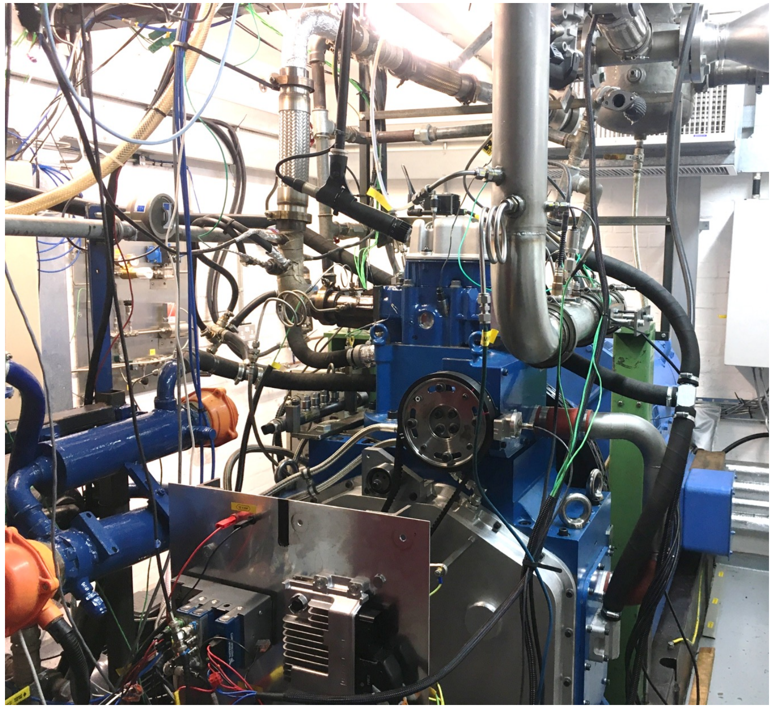
New fuels require new data generation and validation

Single-cylinder engine (SCE) :
Ricardo & University of Brighton H_2 SCE Research

2.1 litre (13 litre L6) converted Proteus engine is currently installed in the Sir Harry Ricardo Laboratories at University of Brighton (UK):

- Direct Injection H_2 injection with EGR



Steady state combustion and emissions investigations

Multi-cylinder engine (MCE):
Ricardo HIMET H_2 MCE Research

HIMET converted 13 litre Scania engine installed at Ricardo Shoreham Technical Centre (UK)

- Direct Injection and Port injection H_2 with EGR

HIMET : Hydrogen in an Integrated Maritime Energy Transition

Difference in gas behaviour demands new data validation for H2

Fuel Injector

- Engine already has port fuel injectors (PFI)
- We need to add direct fuel injection (DI)

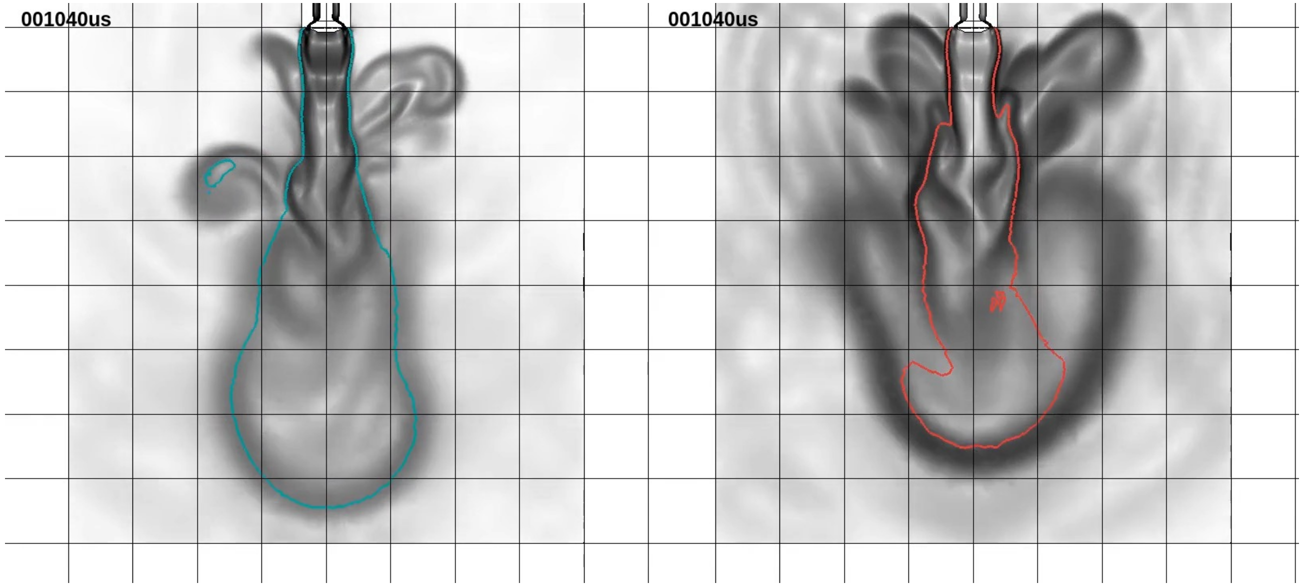
Challenge

- Select suitable H2 DI Injector
- Study how hydrogen flows through injectors

Injector Selection

- BorgWarner 35bar H2 injector

Comparison of CFD simulation results for CH_4 and H_2 injection
Coloured outline shows fuel vapor extent at a mass fraction of 0.1



CH_4 injection at 16bar **H_2 injection at 16bar**

Homogenous mixture achieved with optimized air and fuel injection

Fuel Injector

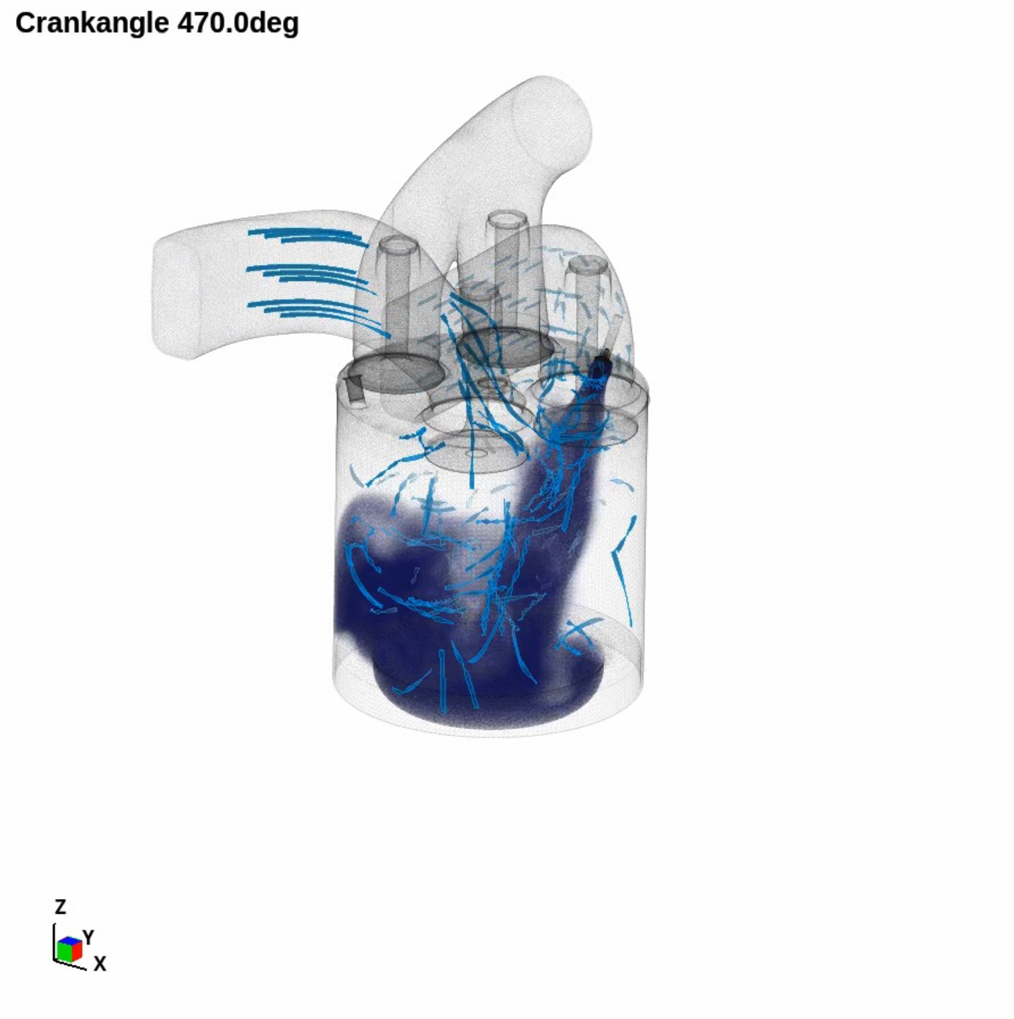
- Engine already has port fuel injectors (PFI)
- We need to add direct fuel injection (DI)

Challenge

- Select suitable H2 DI Injector
- Study where to fit the DI injector to ensure homogeneous mixing

Injector Selection

- BorgWarner 35bar H2 injector



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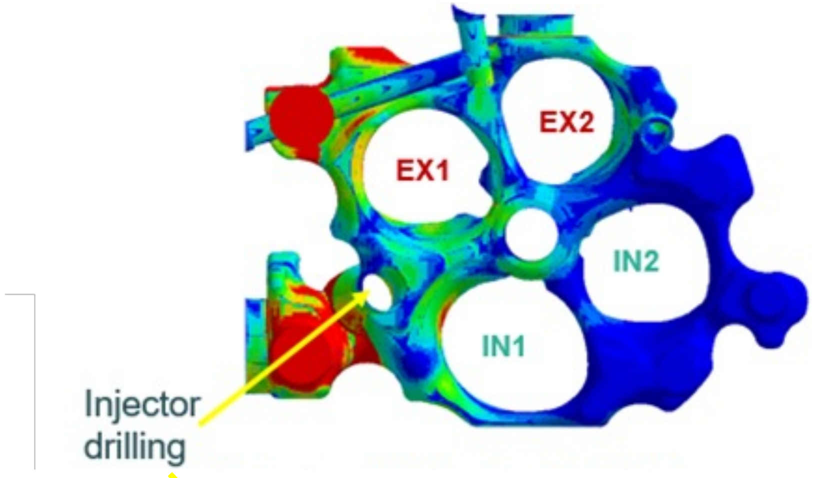
CFD analysis confirmed sufficient colling of cylinder head

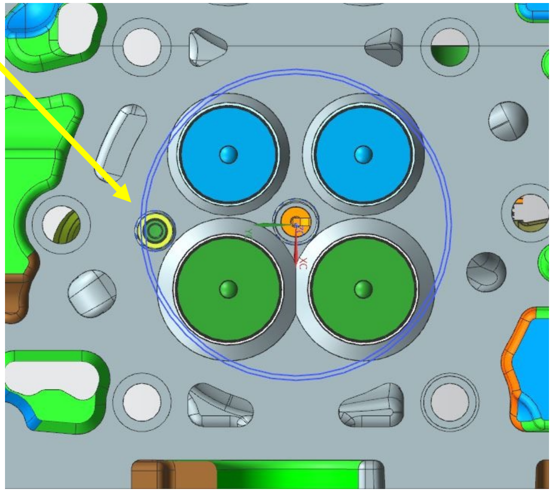
Fuel Injector

- Engine already has port fuel injectors (PFI)
- We need to add direct fuel injection (DI)



Challenge

- Confirm cooling circuit can :
  - protect the injector
  - was itself not negatively impacted by addition of the injector



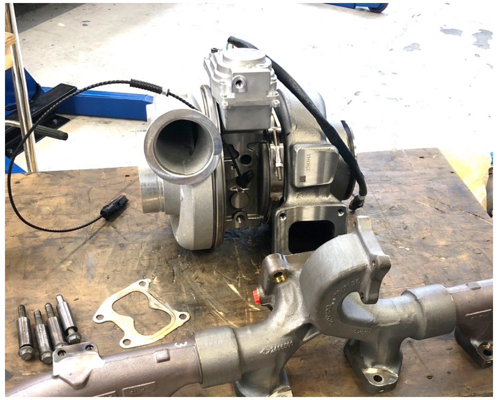
Solution

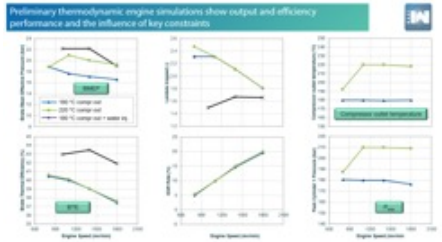
- CFD analysis of cylinder head cooling circuit

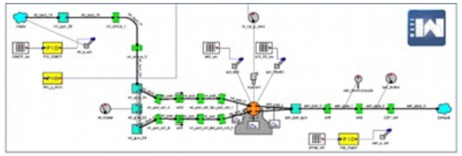
Final adjustment to the donor engine

Boost challenge

- Engine already has turbocharger fitted
- 1D analyses carried out to assess performance prediction
- Choose to replace with larger VGT turbo to allow for higher air/fuel ratios expected





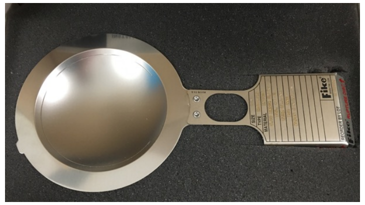


Ignition challenge

- Wanted to avoid platinum plugs as expectation is they are reactive with hydrogen
- Non platinum, copper central electrode plug chosen for early stages of development

H&S

- As added layer of protection we added burst-disks to engine to minimise engine damage risk during early stages of development



Installation in Test facility

Installation

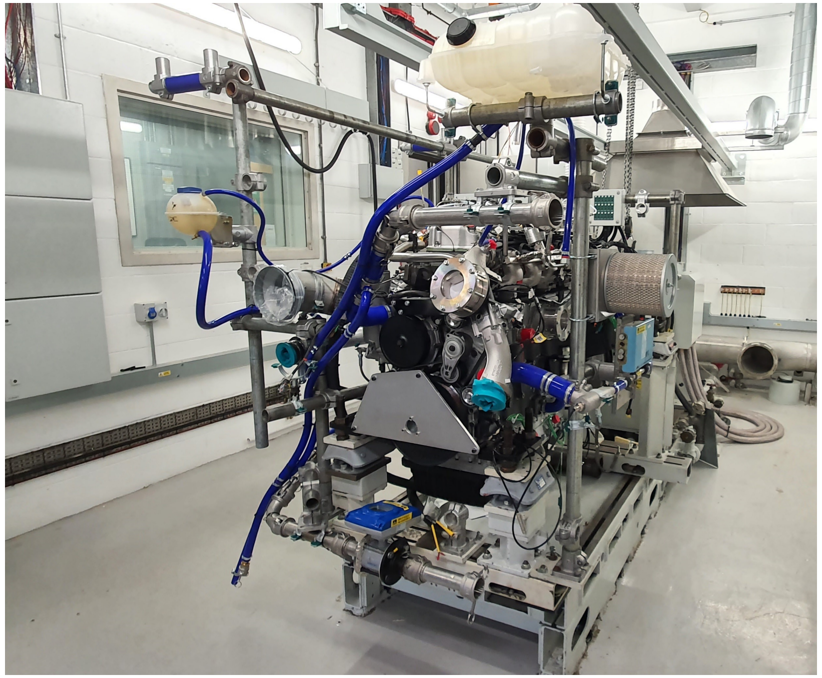
- Engine is installed in a new state of the art hydrogen test facility at Ricardo Shoreham Technical Centre
- Testing is ongoing

Facility

- SoA facility with H_2 and Nitrogen purge
- 10-50bar(g) gas supply pressure with up to 35 kg.hr flow capacity
- Temperature pressure and humidity controlled intake air system and Upgraded ventilation, fire detection systems

Fuel Supply

- H2 fuel is supplied in “tube trailers” and manifolded cylinder pallets (MCPs) in new dedicated ATEX zone
- 175-250bar trailers of H_2 fuel cylinders



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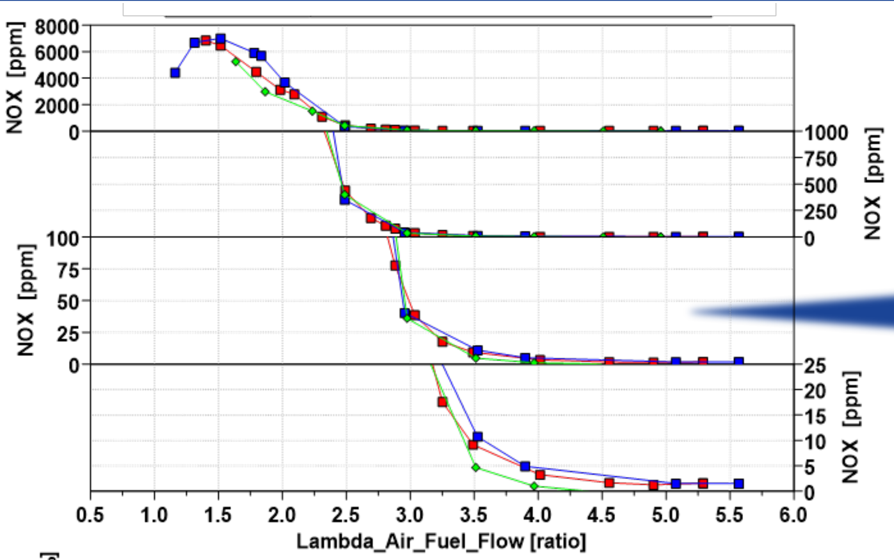
Managing Engine Out Emissions: Lambda impact

Ricardo & UoB H2 SCE results

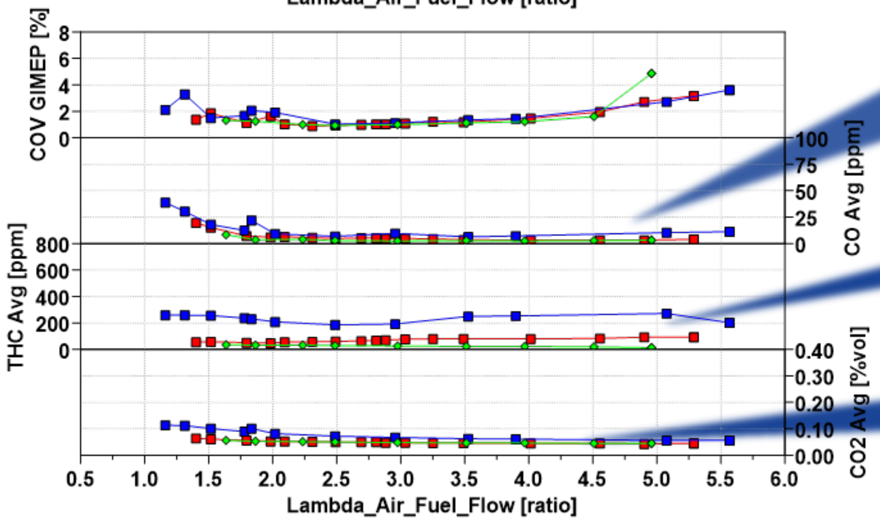
(blue circle)	Lambda Sweep 900rpm
(red square)	Lambda Sweep 1400rpm
(green diamond)	Lambda Sweep 1800rpm

NOX levels drop as lambda increases : increased trapped mass cools the combustion



COV <3 = V-Good stability
Good combustion stability even at lambda >4.0

HC derived emissions reduced to only those formed from oil consumption



Typical benchmark nominal hot tailpipe emissions examples from Ricardo combined databases*

NOx : combined
CNG, Diesel, Gasoline levels ~5-250ppm

CO : combined
CNG, Diesel, Gasoline levels ~2-4000ppm

THC : combined
CNG, Diesel, Gasoline levels ~3-800ppmC

CO_2 : combined
CNG, Diesel, Gasoline levels ~5-15%

*For simplistic reference only , sample from Ricardo database HD/LD nominal values

2023: Hydrogen engine digital twin

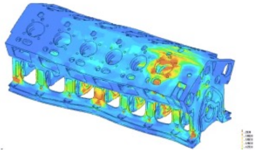
Initial Simulation

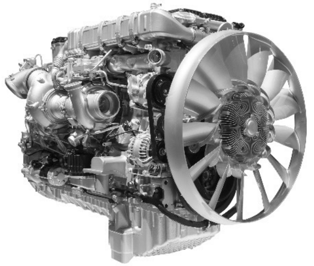
Single-cylinder Engine

Combustion prediction validation

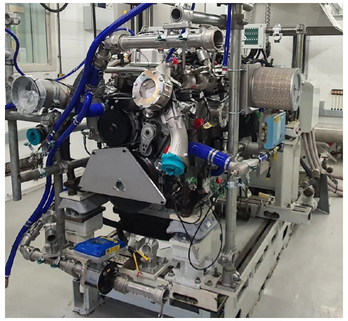
Air system development validation

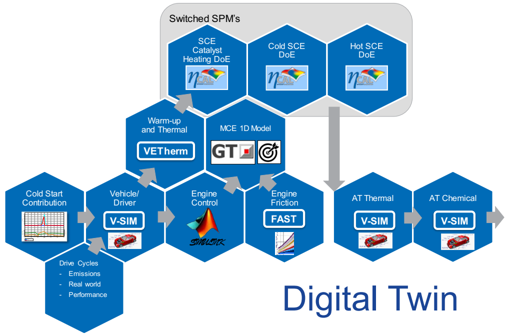
Thermo-structural analysis development



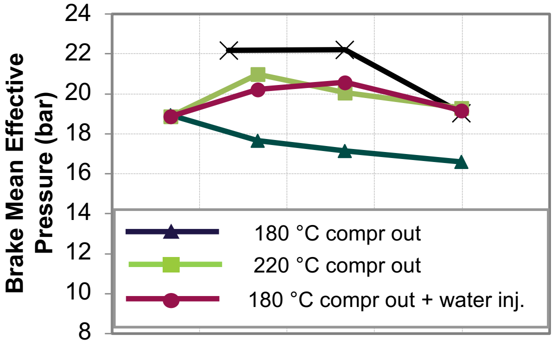


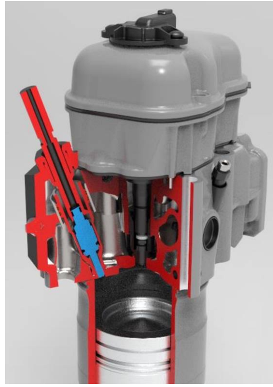
Multi-cylinder Engine

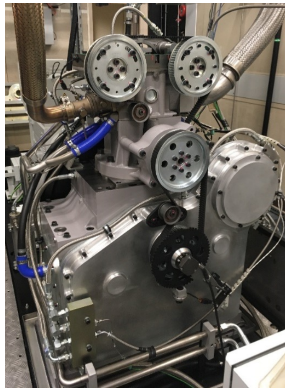


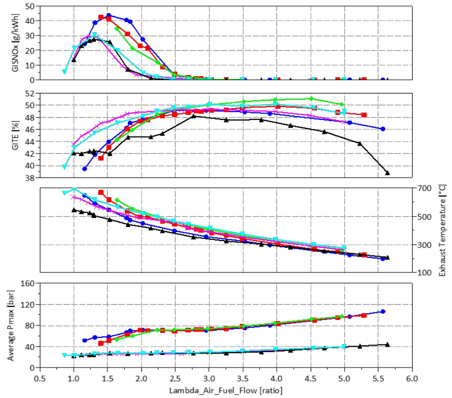


Digital Twin









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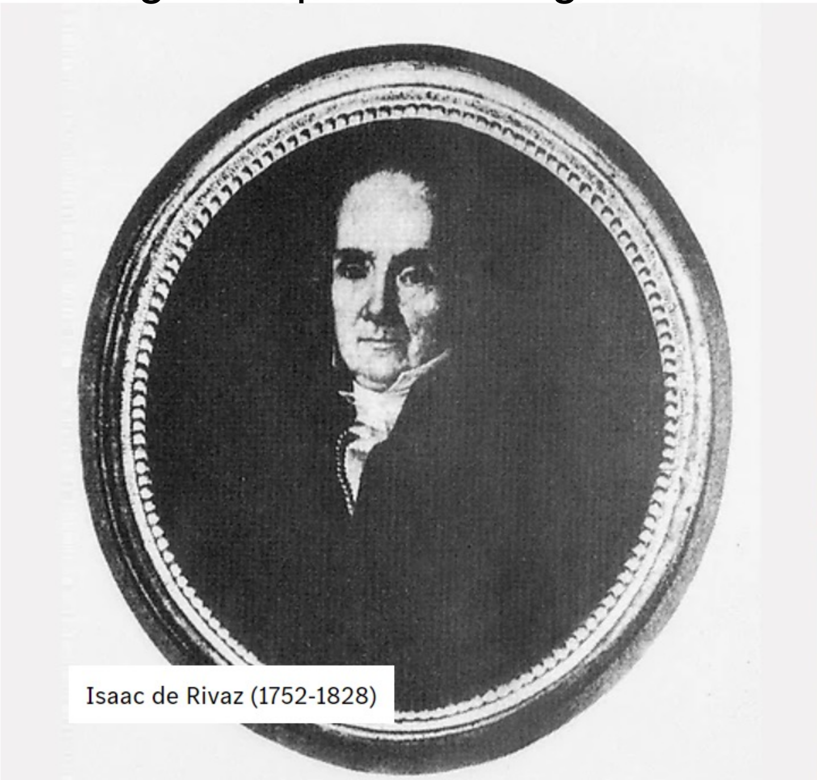
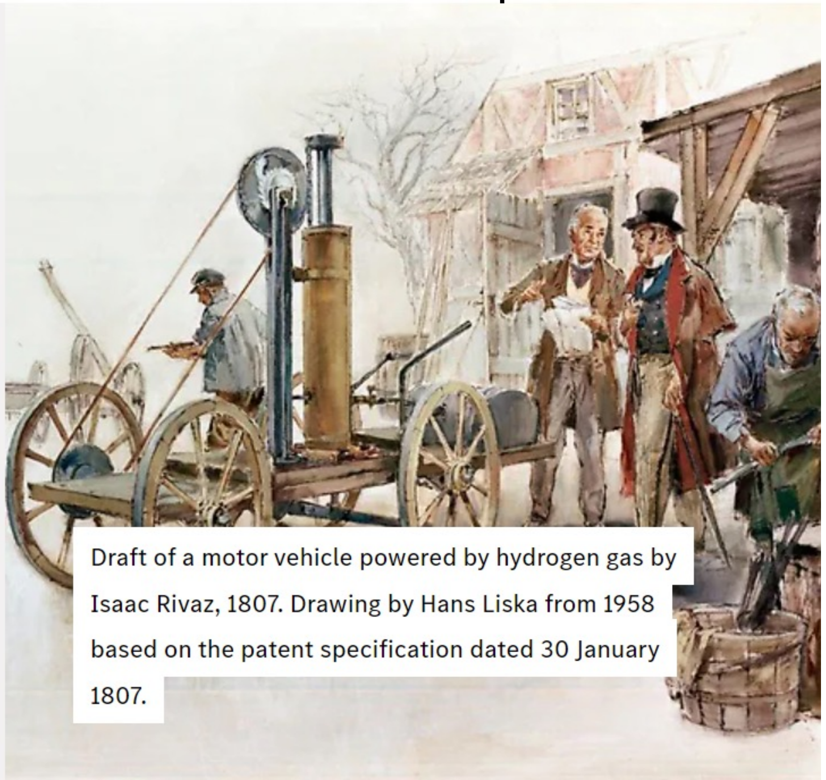
THE WORLD’S FIRST VEHICLE DRIVEN BY AN INTERNAL COMBUSTION ENGINE USED HYDROGEN

Isaac de Rivaz
Franco-Swiss inventor
? using an explosive charge—instead of steam – to drive the piston



Isaac de Rivaz (1752-1828)



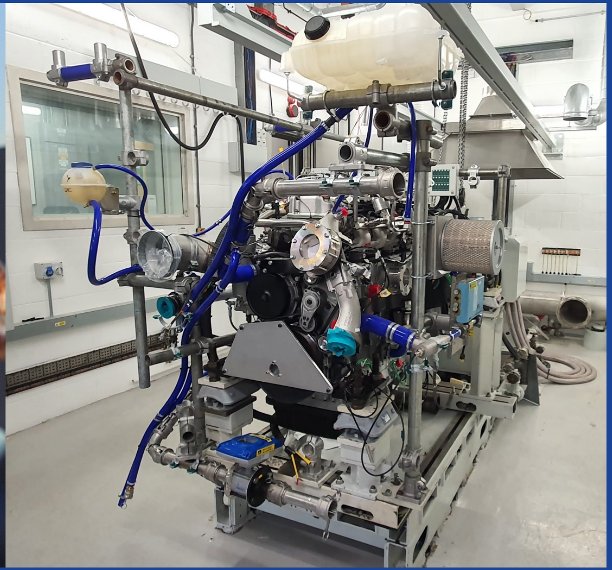
Draft of a motor vehicle powered by hydrogen gas by Isaac Rivaz, 1807. Drawing by Hans Liska from 1958 based on the patent specification dated 30 January 1807.

He used a **mixture of hydrogen and oxygen gases** to ignite this explosion

1807
Experimental prototype engine was used to propel a carriage a short distance.

Have we really reached a major milestone?

Forerunners to the automobile: Company history. | Mercedes-Benz Group > Company > Tradition > Company History



Thank you

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