Hydrogen as a route to zero emissions for off highway heavy duty applications

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The need for change


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Science & Environment

Climate change: IPCC report is 'code red for humanity'

By Matt McGrath
Environment correspondent

9 August 2021 | Comments

COP26

Human activity is changing the climate in unprecedented and sometimes irreversible ways, a major UN scientific report has said.

The landmark study warns of increasingly extreme heatwaves, droughts and flooding, and a key temperature limit being broken in just over a decade.

The report "is a code red for humanity", says the UN chief.

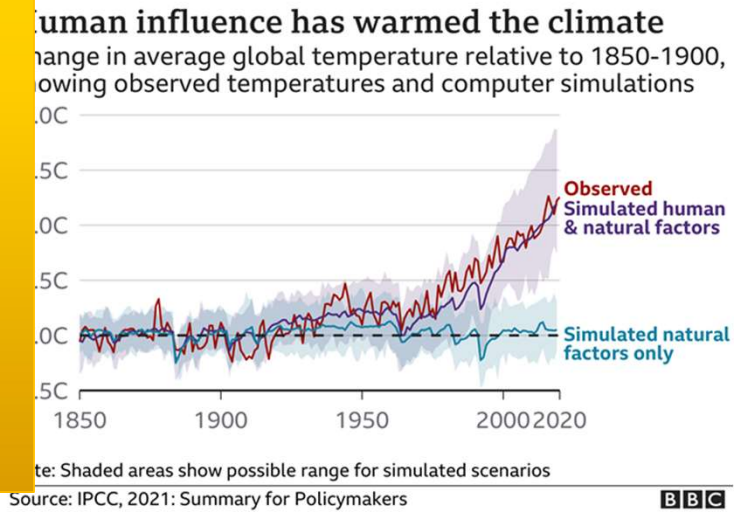
But scientists say a catastrophe can be avoided if the world acts fast.

There is hope that deep cuts in emissions of greenhouse gases could stabilise rising temperatures.

Echoing the scientists' findings, UN Secretary General António Guterres said: "If we combine forces now, we can avert climate catastrophe. But, as today's report makes clear, there is no time for delay and no room for excuses. I count on government leaders and all stakeholders to ensure COP26 is a success."

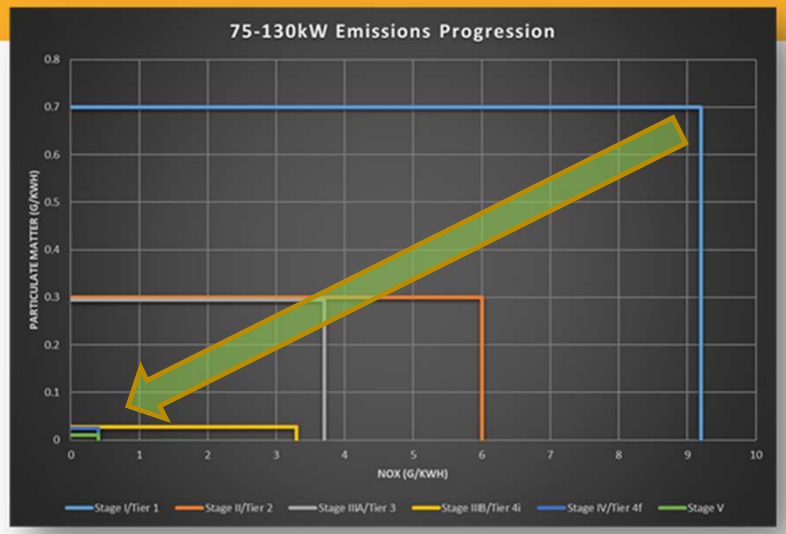
The sober assessment of our planet's future has been delivered by the UN's

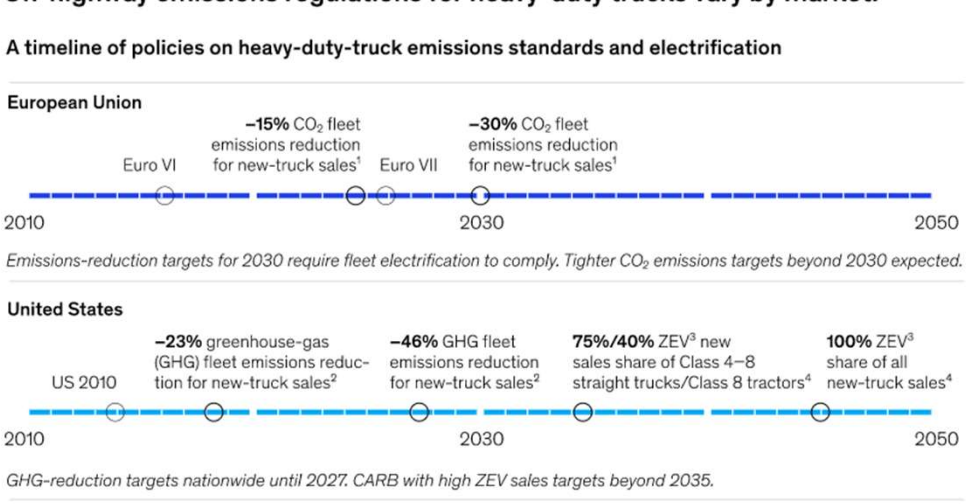
- **Climate change is a real emergency requiring urgent solutions.**
- **As Engineers and technologists, we have a pivotal role to play in meeting this challenge.**
- **The commitments made at COP26 need urgent activity to be achieved.**



The need for change

- **For the last two decades the focus in the off-highway sector has been about meeting ever more stringent Air Quality requirements**
- **CO2 reduction has not been a primary focus.**
- **The challenge now is to continue to leverage the successes of the improved AQ performance, whilst also moving to a low Carbon solution.**





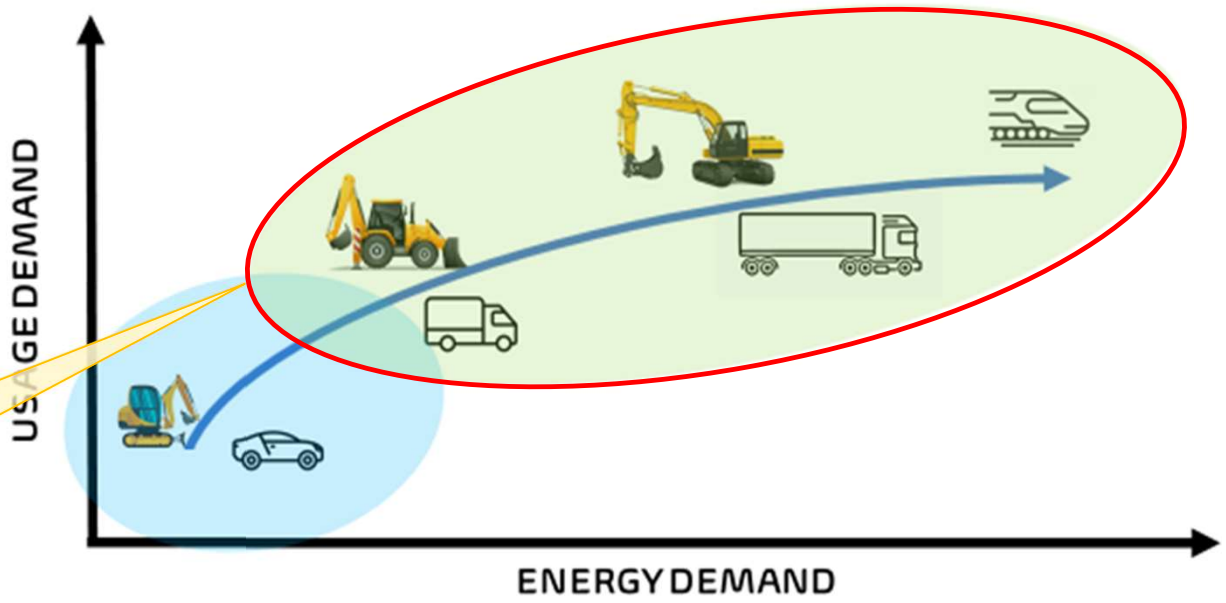
- **Heavy duty on-highway regulations are in place to mandate a progressive reduction in CO2 over the next decade.**
- **Off-highway do not yet face an equivalent challenge via regulation, however, increasingly there is customer demand for "Zero Emissions" solutions for specific tenders. This demand is predicted to grow.**
- **<u>Off-highway heavy duty powertrains need a cost effective, robust & fast to implement solution to meet this challenge</u>**

Zero Carbon technologies

- Electrified off-highway machines offer a route to Zero Carbon
- JCB have pioneered the introduction of fully electric off-highway machinery
- Since 2019 JCB has launched a range of seven compact segment machines.
- Initially lead-by the 19C -1E a 2T compact excavator.
    - An award-winning machine that has quickly gained critical acclaim.
- Electrified machine applications require charging infrastructure
- Battery technology is expensive compared with existing powertrains

Zero Carbon technologies

- For low demand machines, Battery Electric can be deployed as a Zero Carbon capable solution
- As machines become larger with higher demands, batteries become non-viable.
- A mobile, fast to replenishment fuel, is required for higher demand applications.
- Hydrogen offers a sustainable, mobile, fast refuelling, Zero Carbon solution.

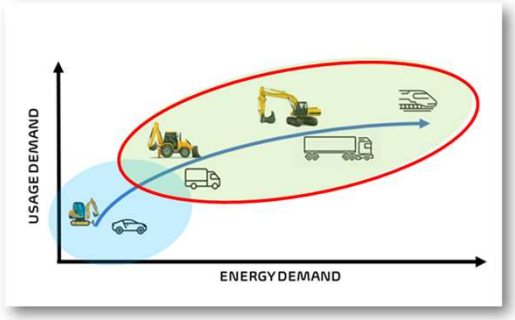


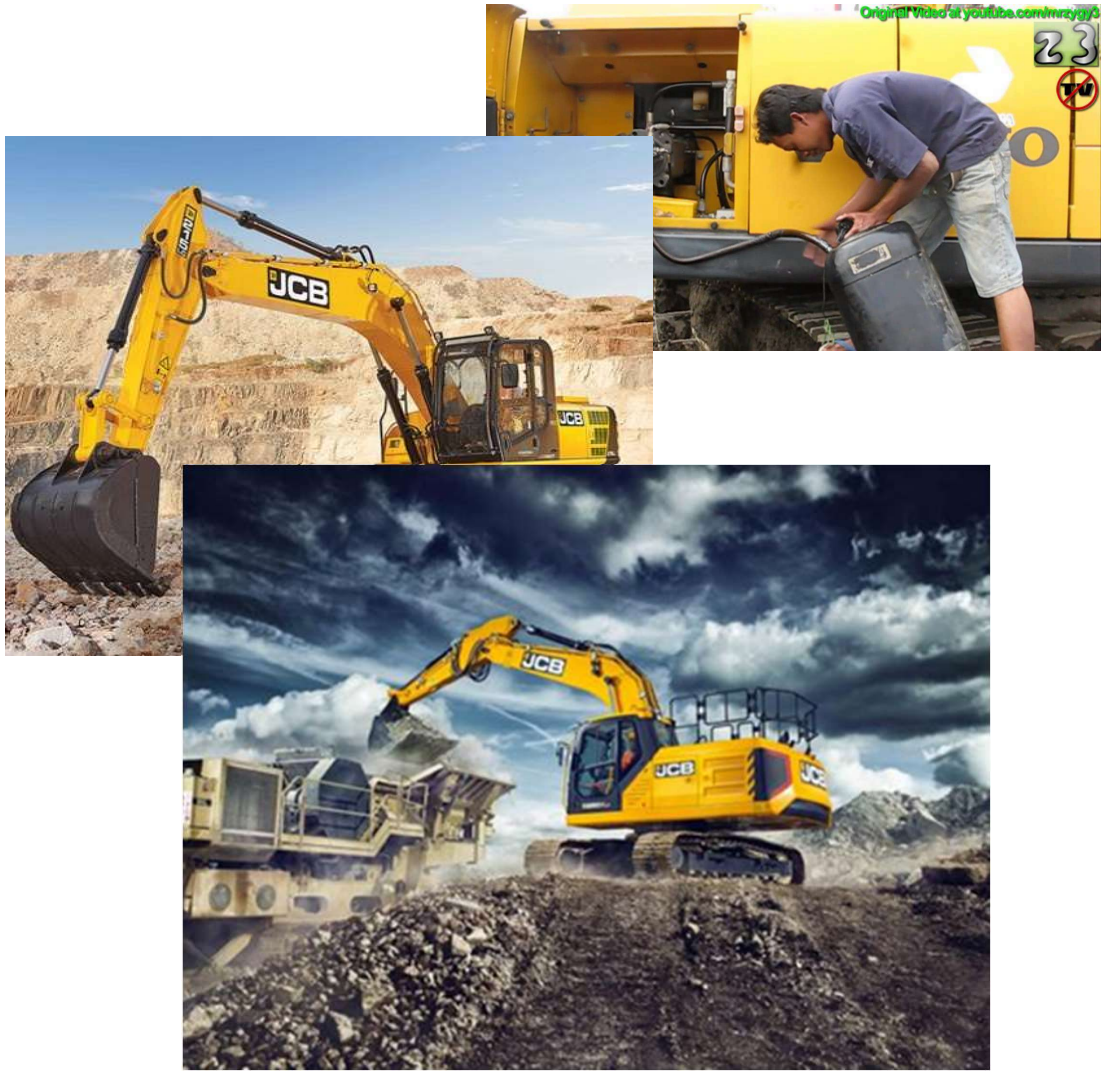
As machine mass, daily hours and duty factor increase, Hydrogen becomes the viable zero Carbon fuel

Off-highway Hydrogen powertrain requirements

Heavy duty off-highway applications differ from on-highway in several critical areas

- **The machines are exposed to very arduous environments**
- **They are a quasi-static application, with little or no air-flow for cooling.**
- **The purity of the fuel and air can not always be assured**
- **Non-optimal maintenance procedures are common**
- **There is a strong customer requirement for simple, robust & cost effective technology.**





Off-highway Hydrogen powertrain technologies

H2 Fuel Cells

Positives

- Zero CO2
- Zero AQ Emissions
- Higher levels of PEM stack efficiency at part load

Challenges

- High Capex
- Large Space demands
- Lower Service life
- Low tolerance of arduous operating environments
- Cooling system requirements are significant

H2 Internal Combustion Engines

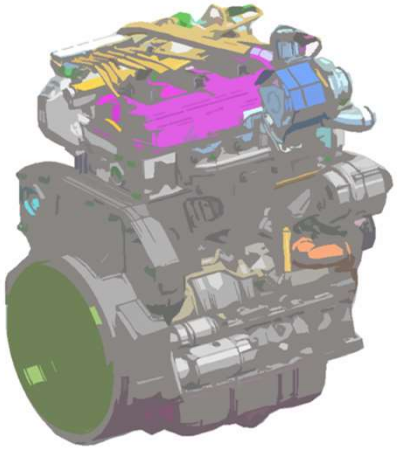
Positives

- Zero CO2
- Close to Zero AQ Emissions
- Lower Capex for Engine
- Lower Space claim for engine
- Long service life & High reliability
- High tolerance of arduous operating environments
- Lower cooling system demands

Challenges

- Part-load efficiency

Emissions	H2-ICE	H2 Fuel cell	Battery Electric
CO2	Zero CO2, with Green H2	Zero CO2, with Green H2	Depends on Grid factor
Air Quality	No significant NOx, with Lean burn & SCR	Zero emissions	Zero emissions
TCO	**H2-ICE**	**H2 Fuel cell**	**Battery Electric**
Efficiency (tank-to-wheel)	Best point ~ 45%	Best point ~ 60%	Best point ~ 85%
Powertrain Capex	H2ICE similar to Diesel ICE, H2 storage required	H2 FC & battery has high capex, plus H2 storage	High capex if large batteries required, no economy with scale
Space requirements	H2 ICE same as Diesel, but extra demand with H2 storage	FC & peripherals occupy more space than ICE, plus H2 storage	Higher mass than ICE, may restrict usage subject to application
Uptime/refuelling	<15 mins, similar to Diesel ICE	<15 mins, similar to Diesel ICE	3~8 hours, depending on ability to fast charge
Service life	10years+, same as Diesel ICE	5~10 years, PEM stack may require overhaul	5~10 years useful battery life
Reliability	Similar reliability to Diesel engine.	Complex technology, susceptible to contamination in working fluids	BEV technology, similar reliability to ICE



Common concerns with H2-ICE

Hydrogen Internal Combustion Engines often have two criticisms levelled against them: -

1. **What about the NOx emissions from burning H2?**

2. **What about the efficiency of a H2 Internal Combustion Engine?**

H2-ICE NOx performance

- **Using a non-carbon Fuel such as H2 in an internal combustion engine, allows for a no CO2 solution.**
- **Hydrogen is a Zero Carbon fuel and can be used in an internal combustion engine in a relatively straight forward manner.**
- **Through optimisation of the combustion system levels of NOx can be reliably controlled to single digit ppm levels, offering a near zero solution.**

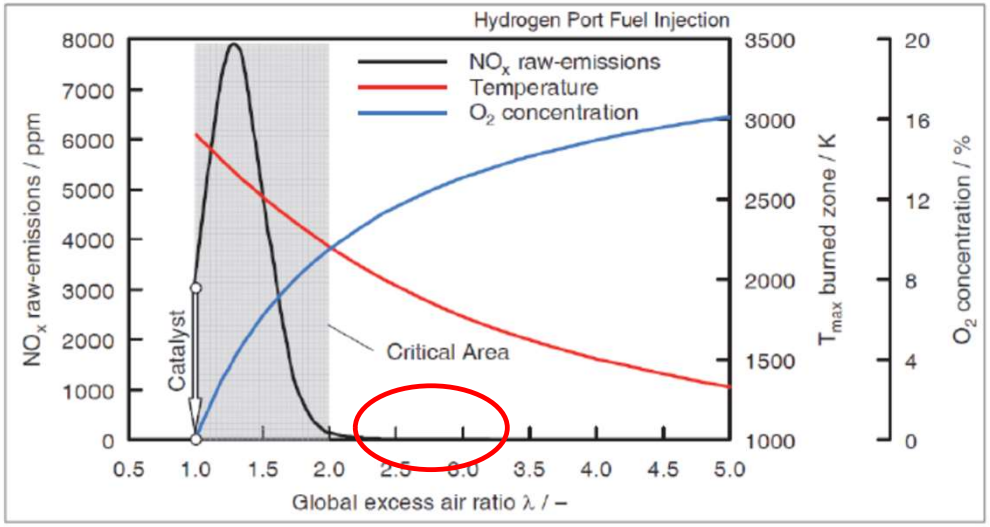


Fig. 7: H_2 combustion process - emissions (e.g. nitrogen oxide formation during lean combustion), Eichlseder, H.; Klell, M.

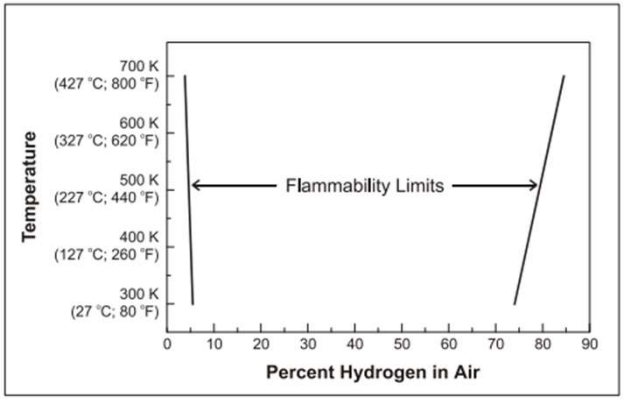


Figure 1-6 Variation of Hydrogen Flammability Limits with Temperature

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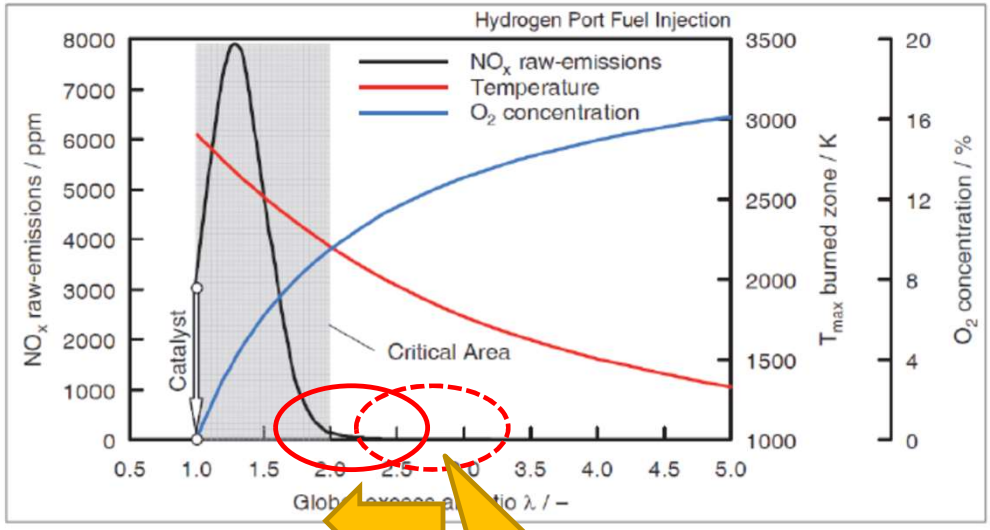

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Transient loads can present a challenge to AFR

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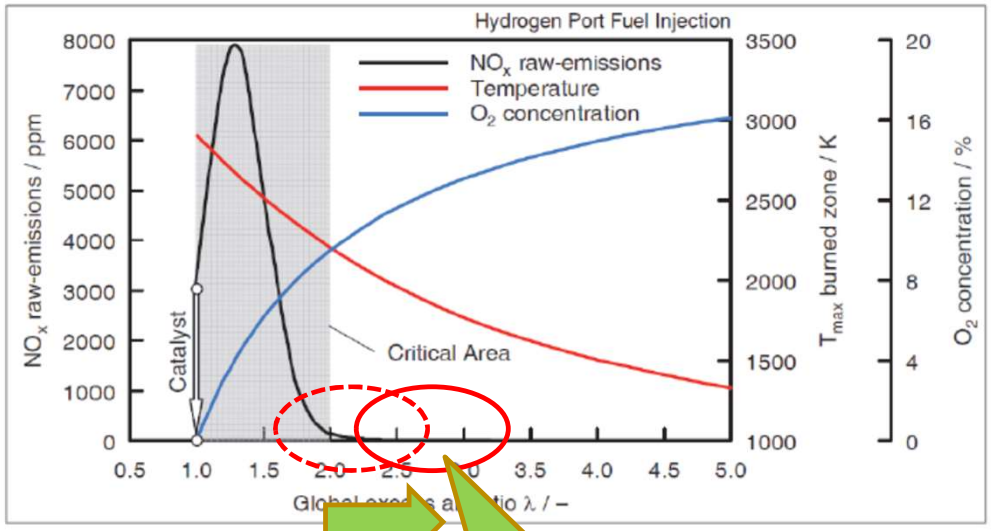
- **Use of advanced boosting & hybridisation to mitigate.**



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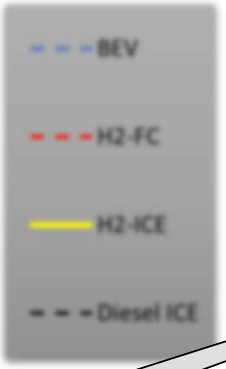
Use of advanced boosting & hybridisation to maintain AFR

Off-highway H2-ICE Efficiency

- When assessing efficiency full system efficiencies must be compared.
- The Fuel cell shows good efficiency at part load
- The fuel cell efficiency diminishes as load increases
- H2-ICE has reduced part load efficiency
- The H2-ICE has an efficiency characteristic similar to Diesel at higher loads
- H2-ICE efficiency is stable as the unit ages and at high ambient temperatures



H2FC @ high ambient temperature in static off-highway application

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Alternative combustion, such as HP DI, allows for further improved efficiency.

Off-highway H2-ICE Efficiency

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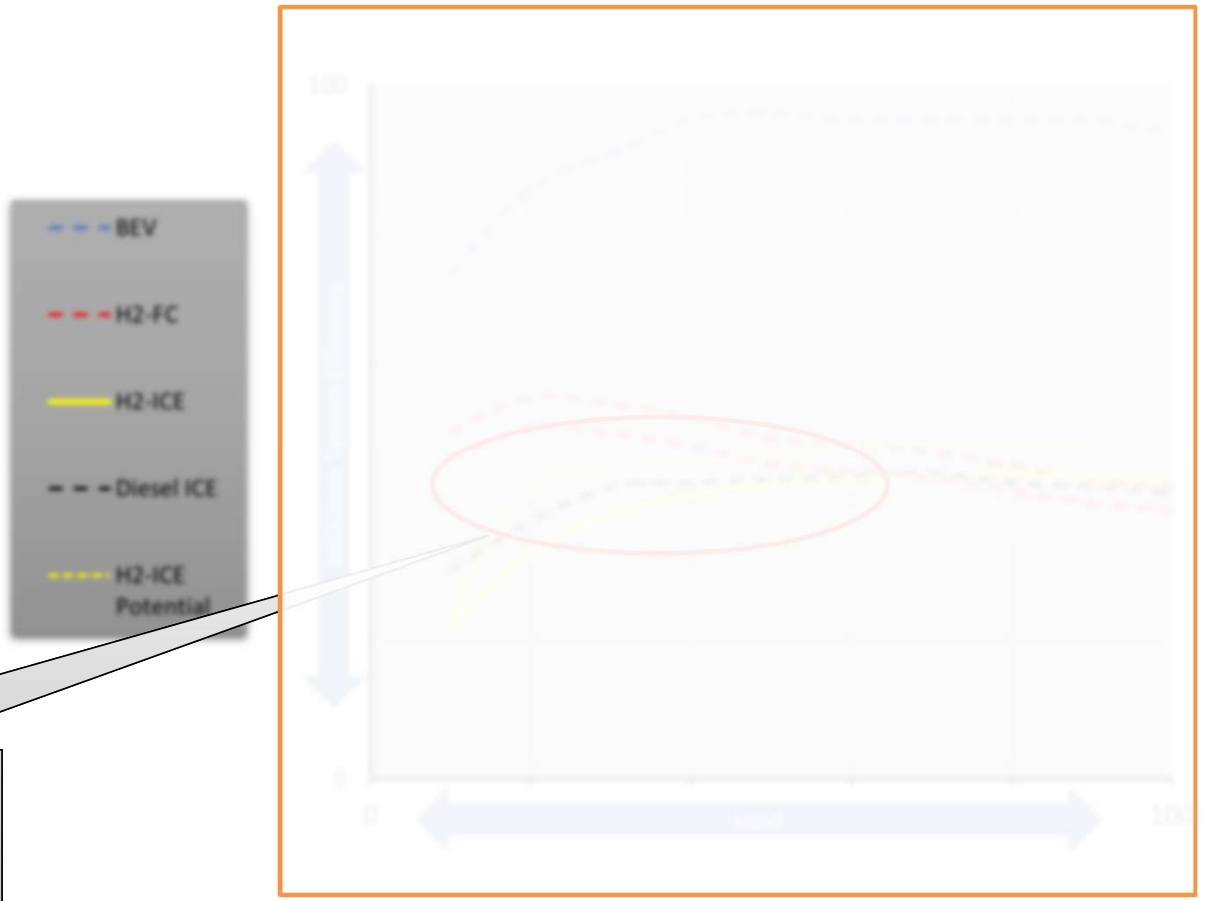


Hybridisation allows improvement of H2-ICE Powerplant's part-load efficiency

Common concerns with H2-ICE

1. What about the NOx emissions from burning H2?

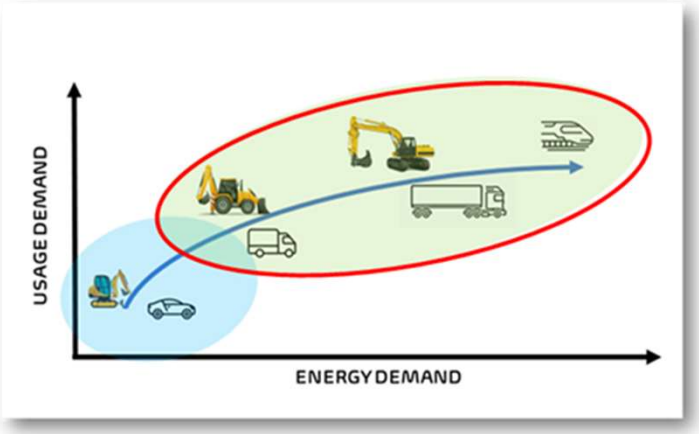
- By running H2ICE at high Lambda the NOx emissions can be controlled to very low levels.
- Advanced Boosting, Hybrids & EATs will enable NOx to be managed to extremely low, difficult to detect, levels in real world conditions.

2. What about the efficiency of a H2 Internal Combustion Engine?

- Initial launches with PFI H2 ICE will have similar levels of efficiency to today's medium duty Diesel engine. With product launch planned in the next 1~2 years.
- Further ahead use of HPDI, higher compression ratio & through the incorporation of techniques such as WHR, future H2ICE will see BTEs of 45~50%, being available by the middle to late part of the decade.
- The use of Hybridisation will allow installed efficiencies in machines to increase further. With additional energy recovery on machine, maximise the use of the H2ICE at best point SFC & offer further opportunity for WHR.

Summary

- Electrification of large, high productivity machines in remote locations, is typically non-viable
- Hydrogen is a mobile fuel, suitable for use on high demand off highway applications, in remote locations
- Hydrogen allows for fast re-filling times, maximising product utilisation, which is important to TCO.
- Hydrogen can be used in a Fuel cell or Internal combustion engine
- <u>Off-highway applications, are often in very arduous environments, fuel cells are not compatible with these requirements.</u>
- Fuel cells are still expensive, with high demands on the purity of the fuel & air used



Summary

- **A Hydrogen Internal Combustion engine has attributes that are a good match for heavy duty off-highway applications:**
  - **A Zero Carbon fuel solution, required to mitigate global warming**
  - **Near Zero NOx and air quality emissions**
  - **A cost point that is very similar to existing Diesel Powertrains**
  - **Packaging requirements in application that are similar to Diesel Products**
  - **Long Service life**
  - **High levels of robustness & reliability**
  - **High tolerance of arduous operating environments**
  - **Cooling requirements, that are compatible with quasi-static applications**
  - **Fast to market**

JCB Always looking for a better way