Technology Challenges for Hydrogen Fuel Cells in Agricultural Applications

DOE Off-Road Workshop

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DOE Hydrogen Workshop

Agenda

- Advantages of hydrogen for agricultural applications
- CNHi history with fuel cell tractors and lessons learned
- Technology requirements and challenges
- Summary and recommendations

Advantages for Hydrogen in Agricultural Applications

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Emissions

10 to 15 Min Refuelling
(for a large vehicle)

Up to 9X

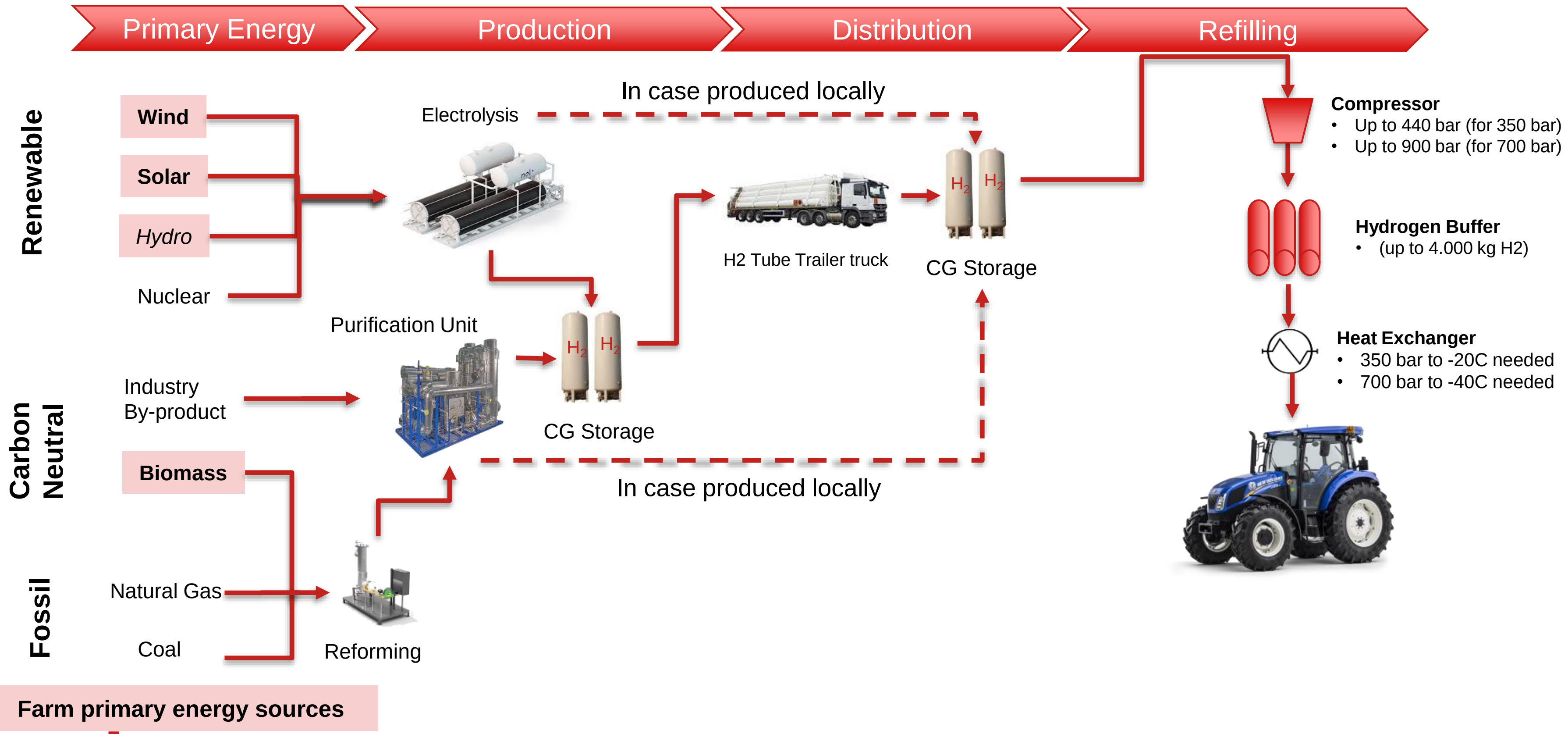
Lighter powertrain than batteries
(for a large vehicle with liquid H2)

Reduced Noise & Vibration

Low TCO
(if H2 costs < 5 US$/kg)

Distributed Energy Generation
(Independent Farm)

Hydrogen in the Agriculture Context– Compressed Gas (CG)



Customer Use Cases

Where does Hydrogen make sense for agricultural applications

50 to 100 kW

- Typically used in small farms
- Utility tractor
- Low energy use

FC/Storage Technology today allows us to build in this range

100 to 200 kW

- Typically used in medium farms
- Dairy and livestock
- Mid energy use

200 kW to 450+ kW

- Typically used in big farms
- Crop farming
- High energy use

Hydrogen is most interesting here

Degree of innovation required to bring product to market

Early Phase Demonstrators

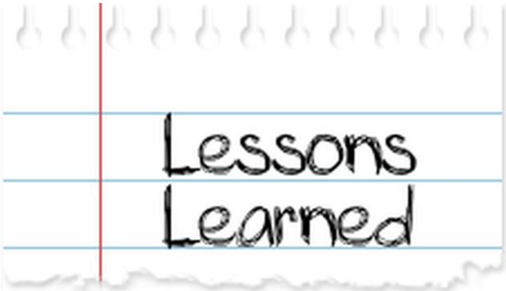
CNH Hydrogen Fuel Cell Experience

1st Generation – 2009

- 50kW Hydrogen Fuel Cell
- 2 electric motors 50kW ea., 400V
- Low energy battery
- Lower performance with respect to power-equivalent conventional tractors
- Low runtime

2nd Generation – 2011

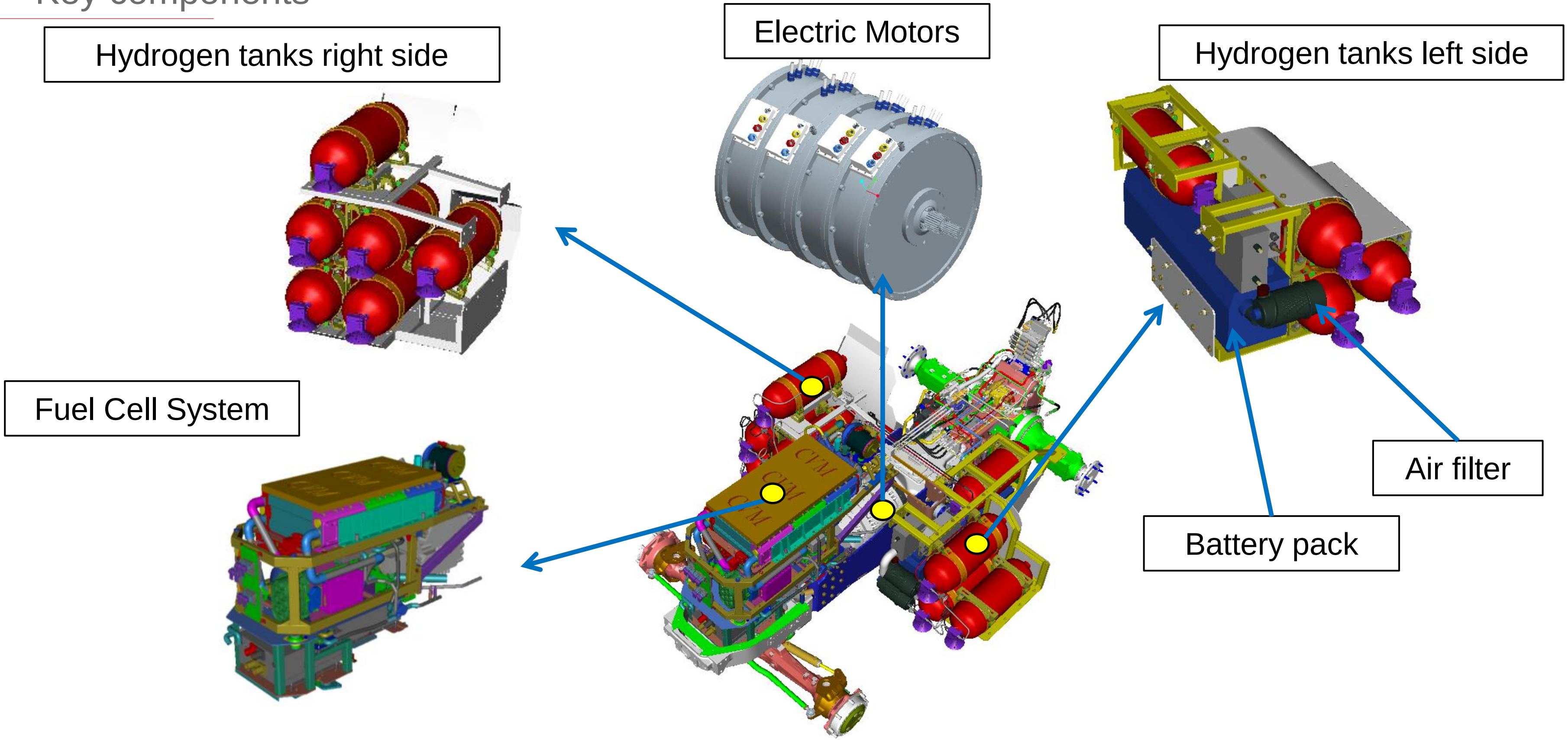
- 100kW Hydrogen Fuel Cell
- 2 electric motors 100 kW ea., 700V
- Battery pack 40kWh
- Similar performances with respect to the conventional tractor
- Limited runtime – 10 hydrogen tanks @ 350 bar – 8kg stored



- Fuel cell power not enough
- Not enough runtime due to low amount of H2 stored
- Fuel cell power frequently derated due to cooling issues
- Component cost (prototype only)
- Very hard to test in remote, real customer areas due to lack of hydrogen infrastructure
- Hydrogen safety aspects: on-board and off-board

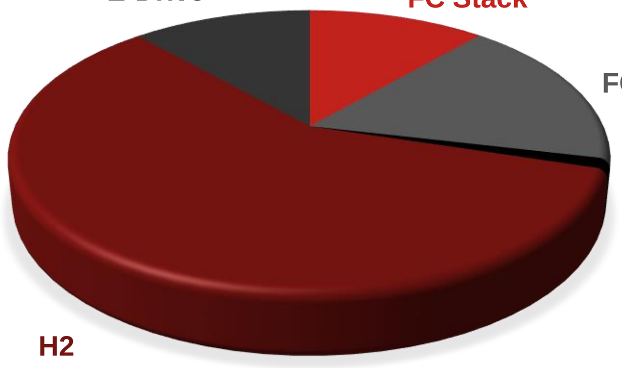
Hydrogen tractor

Key components



Challenge: Drivetrain Cost

Cost Distribution Fuel Cell Drivetrain for a 300 kW Tractor (at high volumes)



Cost Drivers

H2 Storage

- Carbon Fiber

FC BoPs*

- Compressor, DC-DC converter
- Modularization with low power modules (duplication of BoPs)

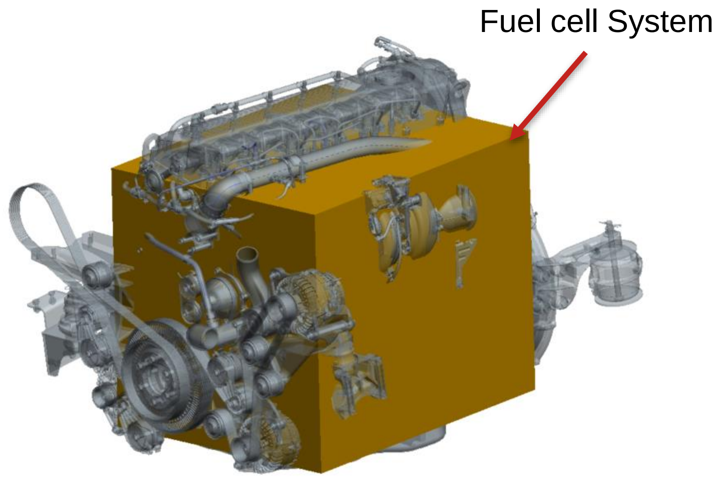
Stack

- Platinum
- Bipolar Plates

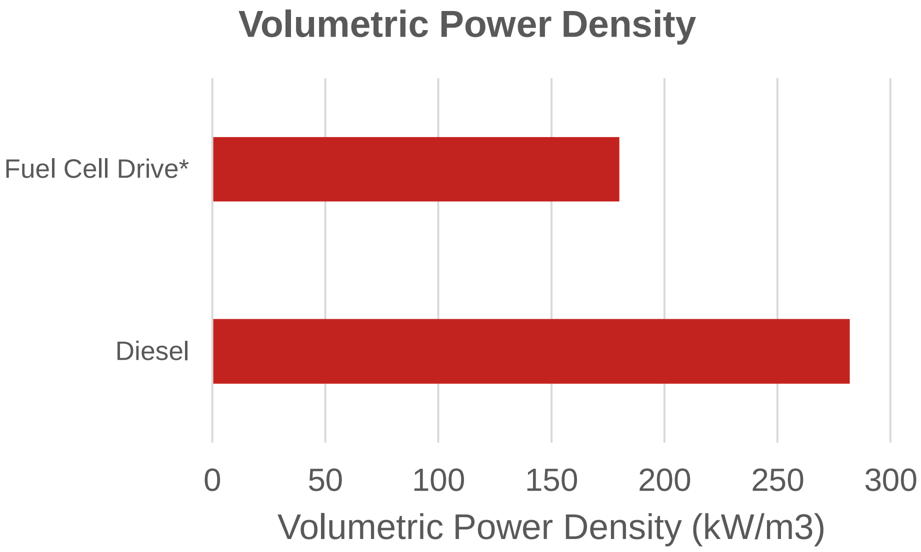
**BoPs: Balance of Plant (Auxiliary components)*

- Total drivetrain cost today would be 15X more expensive than a diesel powertrain (due to low production volumes)
- If the DOE fuel cell system and storage targets are reached, then cost can be in parity with diesel
- Still hydrogen storage would represent 60% of the drivetrain costs
- Need cheaper H2 storage technology going forward

Challenge: Volumetric Power Density of Fuel Cell System



Typical FPT C9 Engine (305 kW) in Comparison with Fuel Cell Box (200 kW)



** FC System + E-motor+Inverter*

- Packaging space is very limited and very defined in a tractor. Need redesign of vehicle to increase packaging space
- Current fuel cells are not far off in terms of volumetric power density, but this is frequently rated at lower efficiency points (e.g. 0,6 V/cell)
- Increase in fuel cell volumetric power density **while** increasing efficiency is key (rated at higher efficiency points, e.g. 0,7 V/cell)

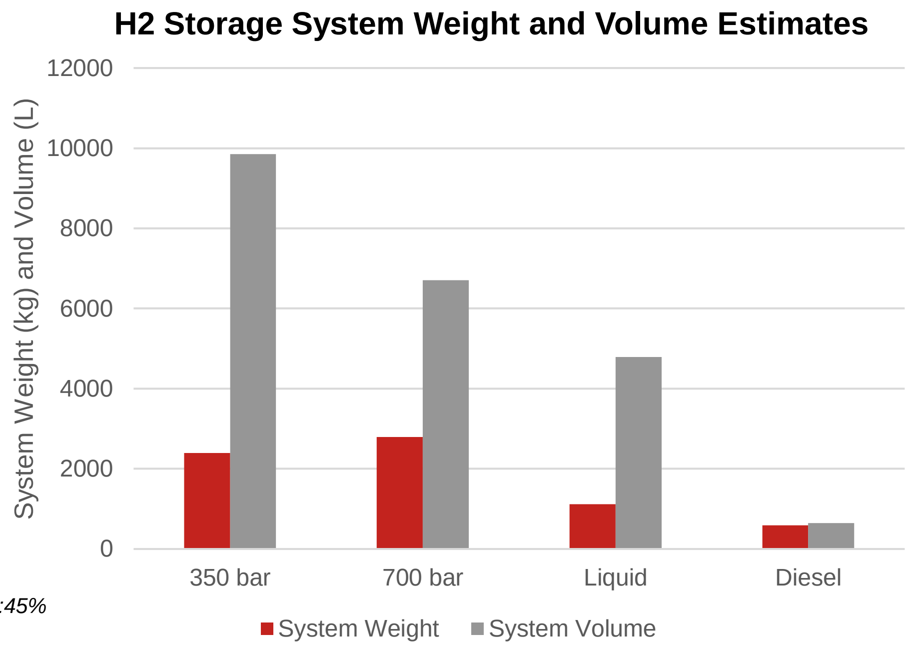
Challenge: Volumetric & Gravimetric Energy Density of H2 Storage

Current Diesel Tank Size: 647 L

Net useful Energy*: 2.420 kWh

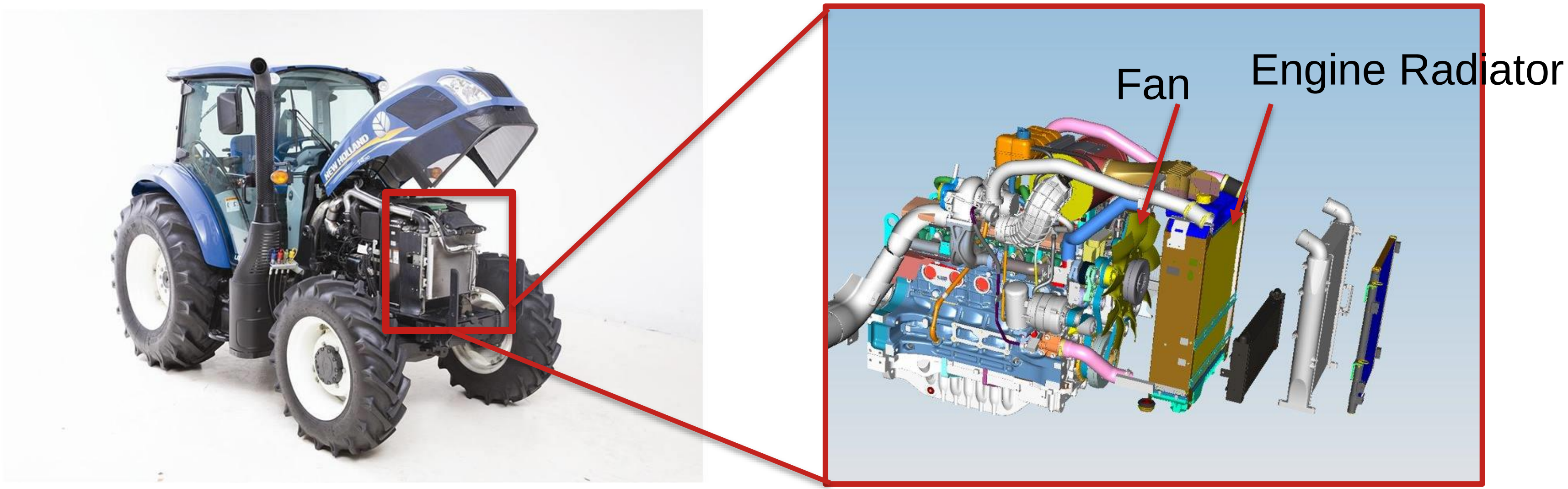
Equivalent H2 Mass: 167 kg

** Diesel Energy Density: 10,7 kWh/L, Diesel Drivetrain Efficiency: 35%, FC Drivetrain Efficiency:45%*



- Gaseous hydrogen storage is about 2 tons heavier than diesel and liquid H2 about 500 kg heavier.
- Volume of the system is however the major barrier to achieve similar runtime
- Even liquid hydrogen would be ~ 7X larger in volume than a diesel fuel storage system

Challenge: Cooling



- A fuel cell system of 300 kW would require a radiator with **5X** larger heat rejection capacity than the available ones
- Potential ways to solve this problem:
  - Add more radiators
  - Increase in fan power (comes at the expense of fuel cell system power)
  - Increase operating temperature of stacks (from 80 ºC today to 105 ºC) **while** maintaining lifetime targets

Challenge: Lifetime

	Crop Farming	Sugar Cane Harvester
		
Powertrain Lifetime Time to engine retrofit	10.000 h	20.000 h
Estimate FC Today		

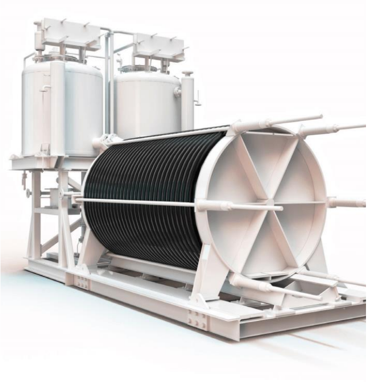
- Lifetime estimates of fuel cell systems in agriculture will impacted by longer operation at higher temperatures
- Lifetime can be engineered into the system, but with higher costs
- Development of durable materials operating at higher temperatures is key to achieve the targets

Challenge: Fuel Supply and Infrastructure

Option A: H2 Delivery to the Farm

- Passenger car H2 Stations in US are mostly located in non-farming locations and are supplied by trucks
- This limits the potential solution of delivering H2 to the farms via trucks (since there is no synergy with other applications close to the farm)

Option B: H2 Production at the Farm

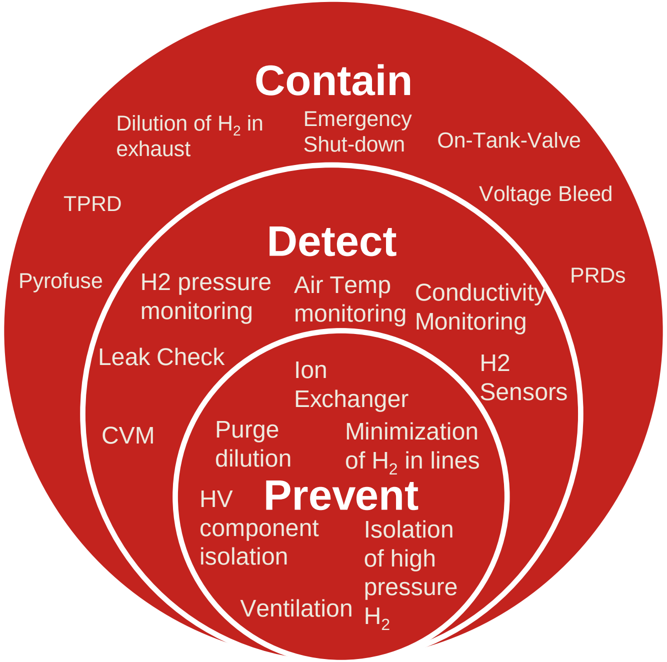


- Very high investment costs for small/medium farms: capital costs in the order of 1,200 US$ to 3,000 US$ per kg of H2 dispensed daily *
- Additional investments for renewable infrastructure to be considered (if not possible to be supplied by the grid)

** DOE Hydrogen Fueling Stations Cost, 2021 – Mariya Koleva & Marc Melania*

Challenge: Safety

Fuel Cell Safety Design Philosophy @ CNH



Existing Safety related standards for fuel cell vehicles (selection)

Standard	Description
R134	Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen fuelled vehicles (HFCV)
GTR13	Global Technical Regulation concerning the hydrogen and fuel cell vehicles
SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety
SAE J2601	Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

- Hydrogen safety has been successfully implement on on-road applications
- Same level of standardization and best practices need to be agreed, including H2 infrastructure at farms

Summary and Recommendations

- **Summary**
  - Hydrogen and fuel cells can play an important role in the electrification of agriculture machines
  - CNH has already worked on 2 tractor demonstrators and has a large experience with the challenges to be solved to enable widespread adoption
  - Main challenges are in the areas of powertrain cost, H2 storage volumetric energy density, fuel cell durability, cooling as well as availability of refilling infrastructure
- **Recommendations**
  - Fund technology projects to:
    - ✓ increase energy density of hydrogen storage systems and reduce its cost
    - ✓ reduce fuel cell system cost, increase its efficiency and its volumetric power density
    - ✓ enable operation of fuel cell system at higher temperatures continuously
  - Support build up of infrastructure to produce hydrogen at farms OR have a distribution network for other applications (e.g. H_2 ICEs) that can be used for farms

Thank you for your attention!

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