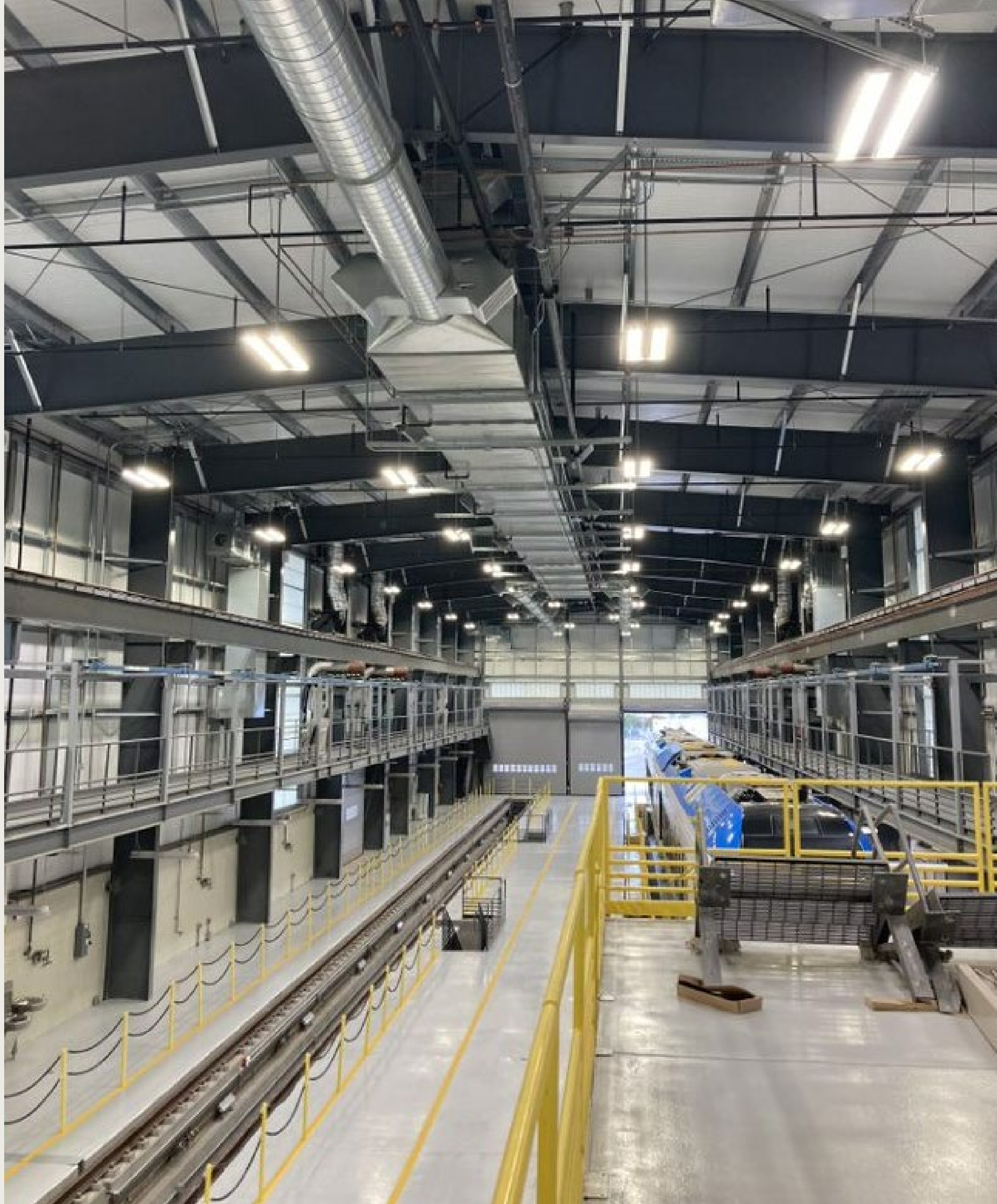
MOTT MACDONALD

San Bernardino County Transportation Authority

Maintenance Facility Considerations

Transitioning to a Zero Emission rail fleet

Presented by: Nick Laverick



Maintenance Facilities

- Maintenance facilities are necessary to support all rail fleets
- Each must be configured for the type and size of rolling stock utilized
- The type and configuration of on-board vehicle systems determine facility interfaces, layouts, equipment, functionality and safety system requirements.

Facility layout [Source: Mott MacDonald]

Train lifting system [Source: Mott MacDonald]

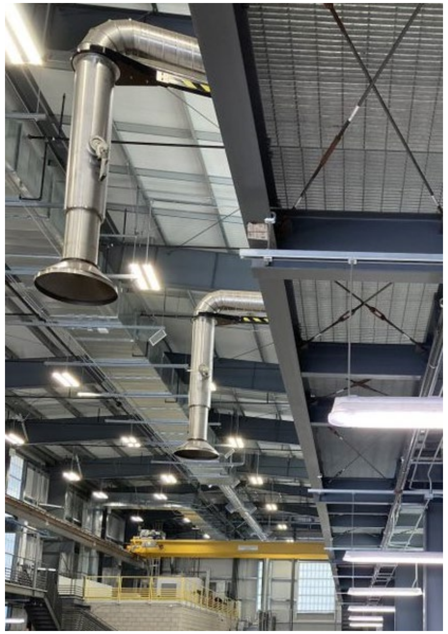
Traditional Facilities

Most existing facilities in the US are setup for traditional propulsion systems.

- Overhead Catenary Systems (OCS)
  - High voltage systems integrated in building, electrocution / shock hazard
  - Roof access restrictions, lockout / isolation switchgear, fire/smoke detection
  - Specific procedures and training

- Diesel-Electric
  - Toxic exhaust gases, combustible liquid, pools on ground, dangerous fumes
  - Exhaust extraction, NO_2/CO/smoke detection, static fire protection (sprinklers), ventilation strategies
  - Specific procedures and training

Facility OCS [Source: Mott MacDonald]



Diesel exhaust extraction [Source: Mott MacDonald]

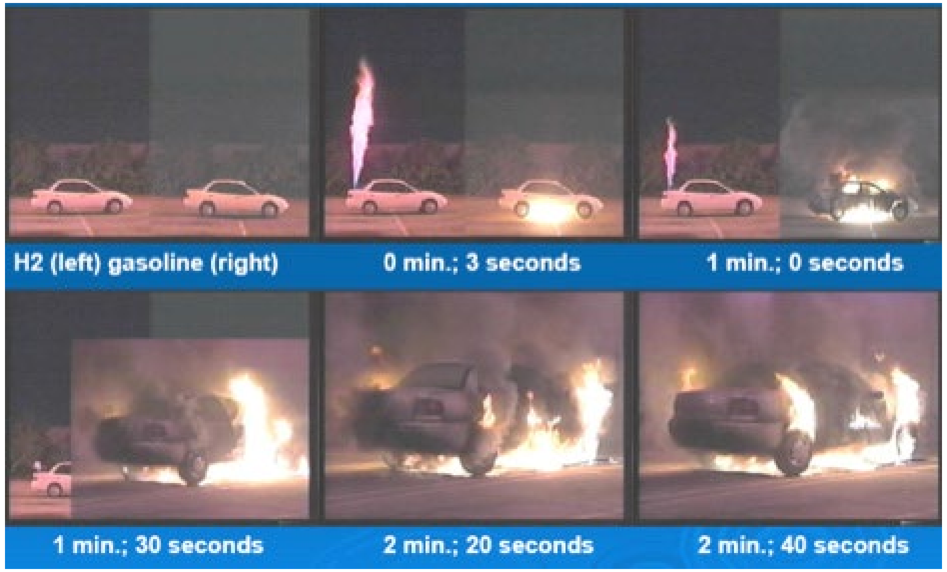
Hydrogen Characteristics

- H2 is colorless, odorless, tasteless, non-toxic, not a GHG
  - Very low harmful emissions if combustion with air (small amount of NOx)
- Lightest element on Earth - dissipates quickly
  - Does not pool on ground, i.e., dissipates away from people
- Largest energy density by mass
  - 1kg of H_2 ≈ 1gallon of diesel (energy content basis)
  - Requires high compression to be energy dense by volume!
- Combustion range in air is 4% to 75% concentration
  - Minimum concentration in air is four times higher than gasoline for combustion
- Low radiant heat during combustion

Hydrogen Hazards

Hydrogen hazards to consider:

- Lighter than air, leaks pool in ceiling rather than floor
- Pooling can lead to flammable mixture of H2 in air
- Burns with an invisible flame and is odorless and non-toxic
- Compressed hydrogen is stored at high pressures
- Hydrogen can embrittle certain metals
- Hydrogen Fuel Cell (HFC) vehicles use high electrical currents which can cause electric shock
  - Electrical currents can ignite on-board hydrogen storage if there are leaks



Breach Test hydrogen tank (left) compared to petrol powered car (right) [Source: Swain (2001)]

Typical Mitigation Measures

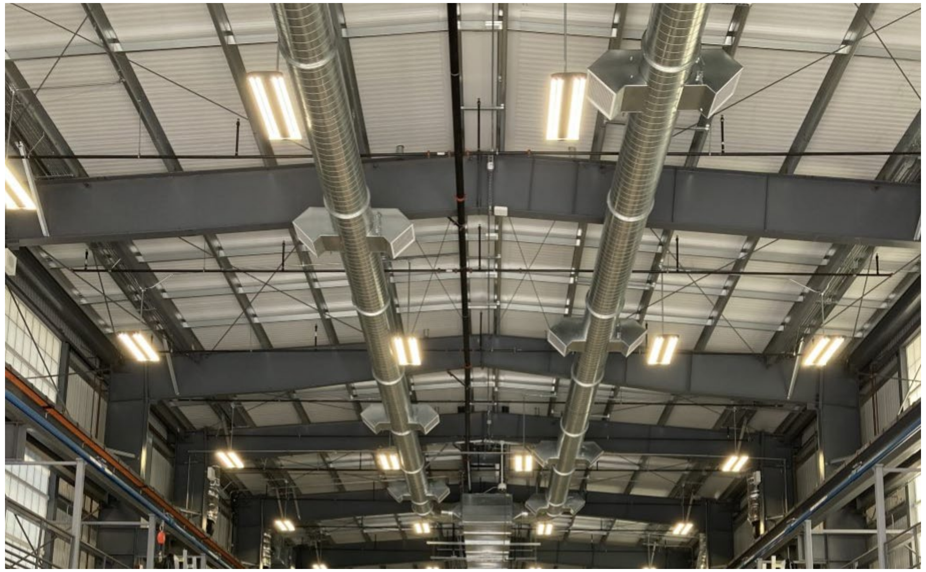
Hydrogen vehicles have the potential to permeate, leak or vent hydrogen into the surrounding space.

Severity and likelihood vary depending on each scenario considered.

Maintenance facilities will typically need the following:

- Ventilation, natural or forced
- Leak detection systems
- Flame detection systems
- Electrical classification – certain areas
- Upgraded fire suppression systems
- Updated procedures and training

Hydrogen detector [Source: eepowersolutions.com]



Ventilation system [Source: Mott MacDonald]

Battery Characteristics

Wide range of different cell chemistries

Characteristic	Unit	Lead Acid	NiCD	NiMH	Lithium-ion
Cell Voltage	Volts	2	1.2	1.2	2.4-3.8
Specific Energy	Wh/kg	30-40	35-80	55-110	100-300
Energy Density	Wh/l	50-90	50-70	160-420	125-600+
Power Density	W/kg	100-200	100-150	100-500	500-5000
Maximum Discharge	Rate	6-10C	20C	15C	80C
Useful Capacity	Depth of Discharge	50	50	50-80	>80
Charge Efficiency	%	60-80	60-80	70-90	>95
Self-Discharge	%Month	3-4	15-20	15-30	2-3
Temperature Range	◦C	-40 to 60	-20 to 70	-20 to 65	-30 to 70
Cycle Life	# of Cycles	200-400	300-1000	500-1000	>2000
Memory Effect		No	Yes	Yes (<NiCd)	No
Micro-Cycle Tolerance		Deteriorates	Deteriorates	Yes	Yes
Robustness		Yes	Yes	Yes	Needs BMS

Battery Hazards

Hazards

- Electrocution - significant stored energy, not easily discharged
  - Completely discharging may damage the battery and reduce its life
- Fire and toxic gas release
  - Thermal runway can occur due to overcharging, overheating, physical damage, short circuit etc.

Typical Mitigation Measures

- Electrical circuit safety; though battery remains “live”
- Control systems and chemistry selection and testing
- Fire enclosures, barriers
- Gas / fire detection, ventilation and fire suppression
- Updated procedures and training

Tesla NMC battery fire [Source: www.businessinsider.com]

Rail LTO battery module [Source: abb.com/railway]

Zero Emission Facility Case Study

SBCTA's Zero Emission Multiple Unit (ZEMU) Project will incorporate:

- Hydrogen Fuel Cell Systems
- Hydrogen Storage Systems
- Energy Storage Systems (Li-Ion batteries)

Mott MacDonald led the following tasks:

- Assessed codes & standards
- Analyzed hazards
- Designed a retrofit scope

For SBCTA's Arrow Maintenance Facility

AMF and DMU [Source: Mott MacDonald]

Existing Facility Ventilation Design – Options Considered

Facility is required to accommodate a Hydrogen and Battery vehicle per applicable code requirements

The existing facility is designed for diesel rail vehicles

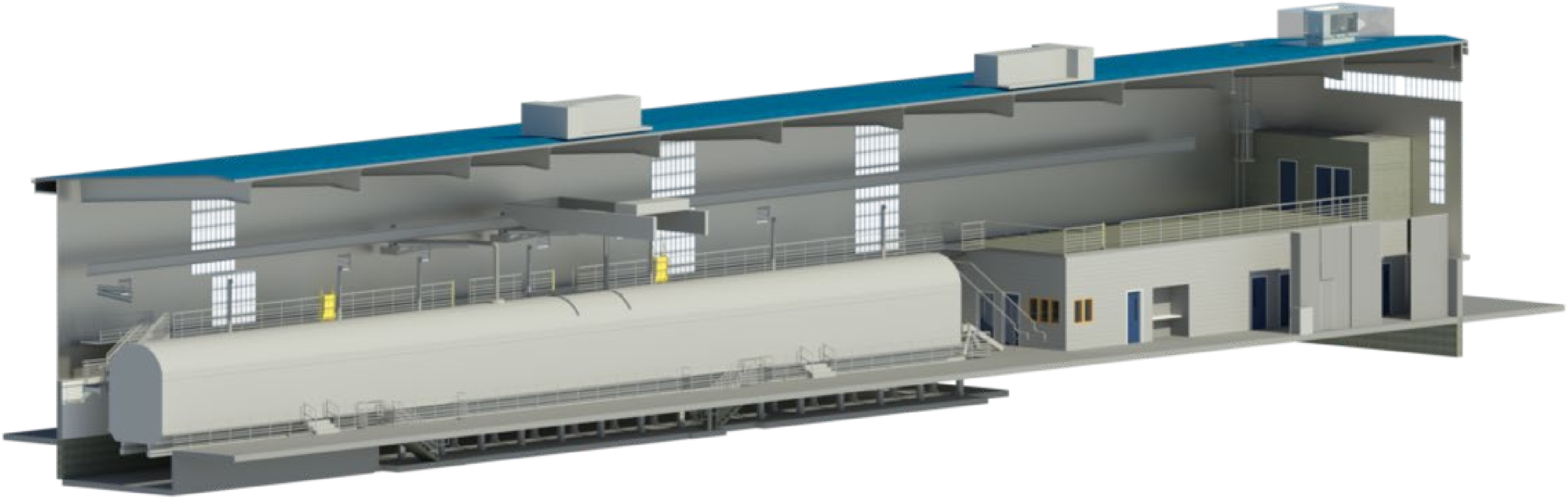
Major Applicable Codes:
California Building Code
NFPA 2

ID	Options	Code Compliant	Retrofit Feasibility
1	Leave as is	No	N/a
2	Natural roof ventilation – permanently open	Possible	No – facility conditioning issues, conflict with diesel fire suppression strategy
3	Natural roof ventilation – opening upon detection	Possible	No – major structural implications, downtime and costs
4	Dedicated ventilation system	Yes	Yes – retrofittable
5	Focused hood ventilation or extraction system	Possible	No – equipment conflicts (crane, jacks, etc), power consumption, coverage issues

The outcome is highly dependent on existing facility conditions; new build facilities have the most flexibility.

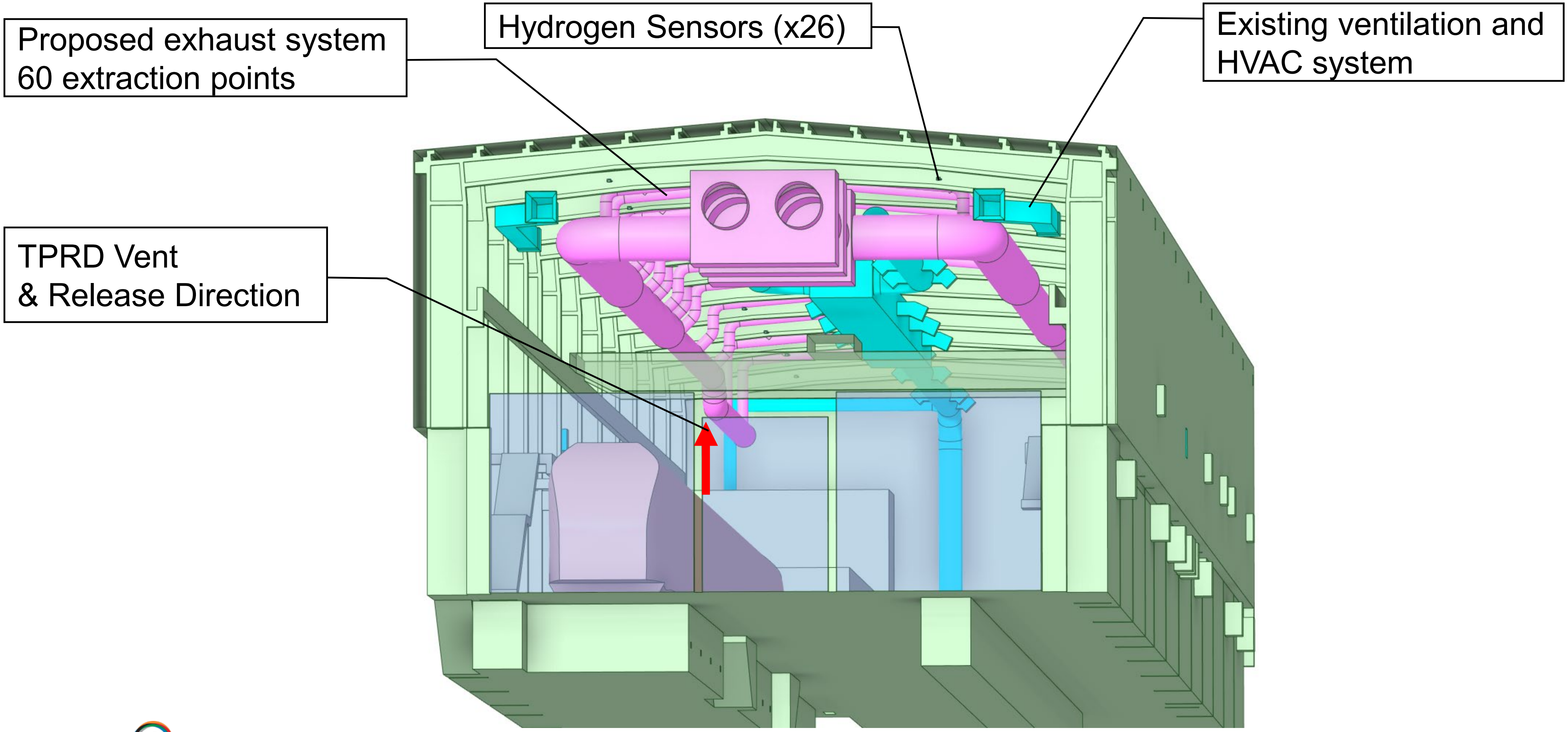
Maintenance Facility Retrofit – 3D Design and Modelling

- **Mott MacDonald worked in Revit to deliver retrofit design in 3D**
- **CFD Modelling for H2 was completed for various leak scenarios**



AMF Model [Source: Mott MacDonald]

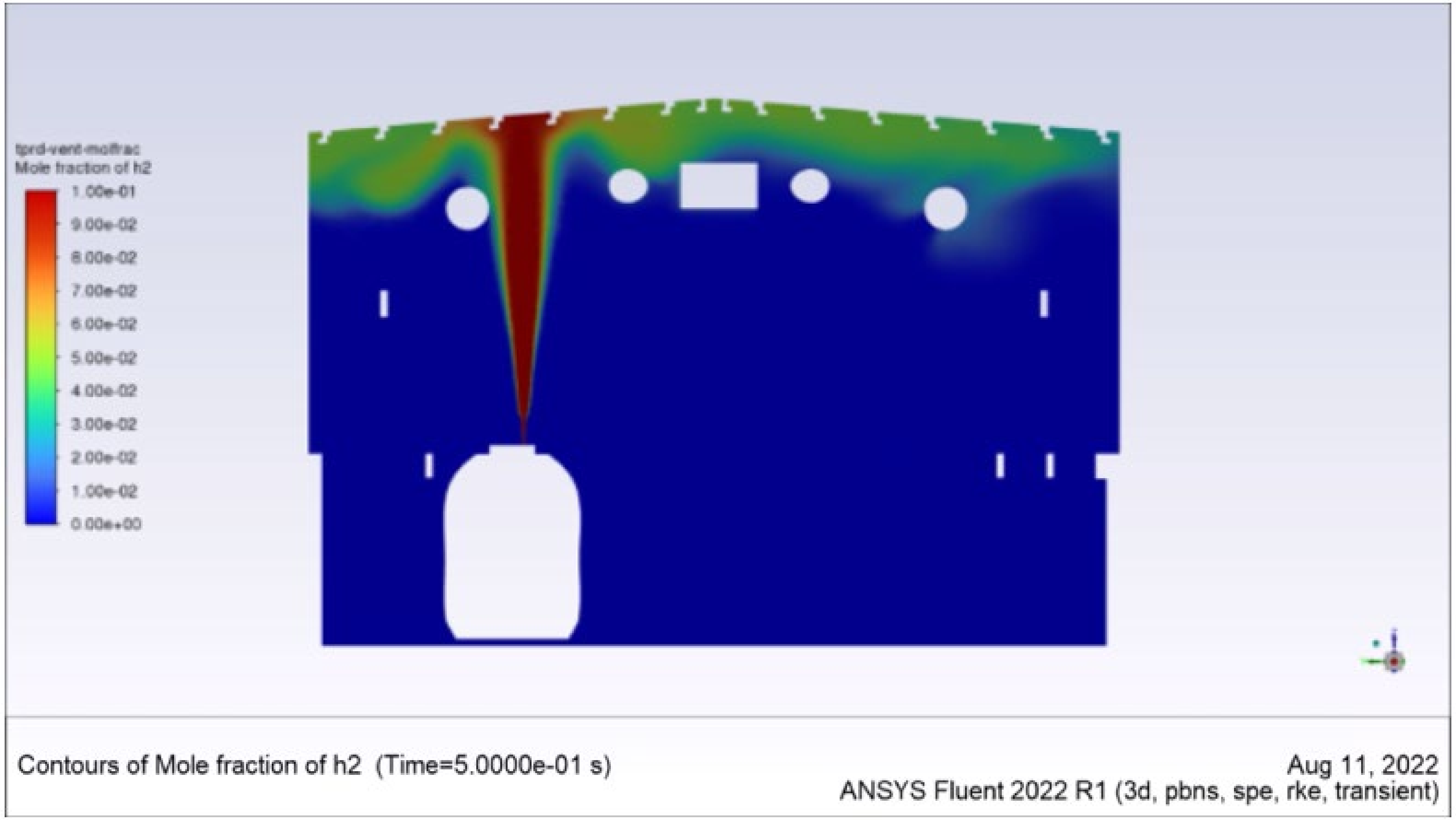
CFD Model Setup – 3D View



AMF Model [Source: Mott MacDonald]

Maintenance Facility Retrofit - CFD Modelling

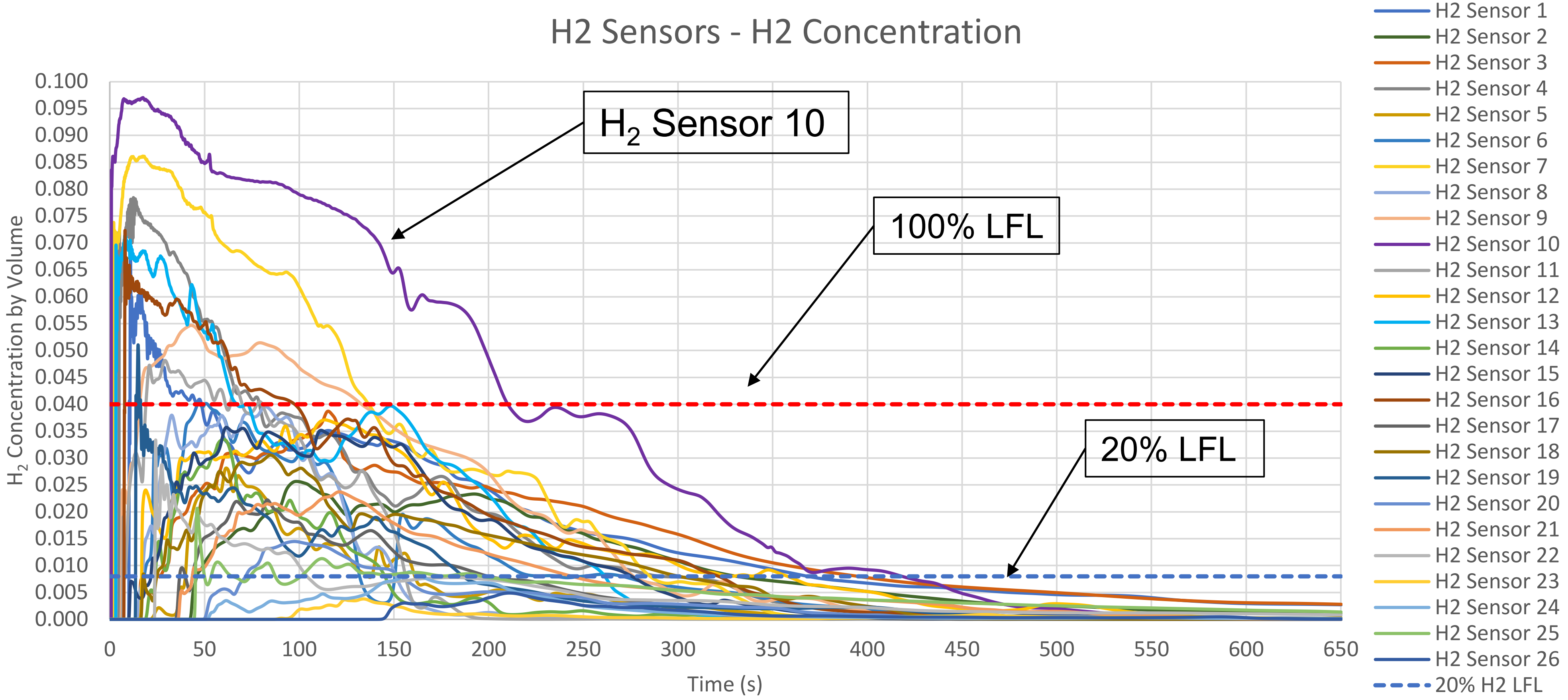
- Three scenarios run to determine release behavior of H2 and inform design concept
- Support adherence to design codes or adjustment to suit application



AMF CFD Model [Source: Mott MacDonald]

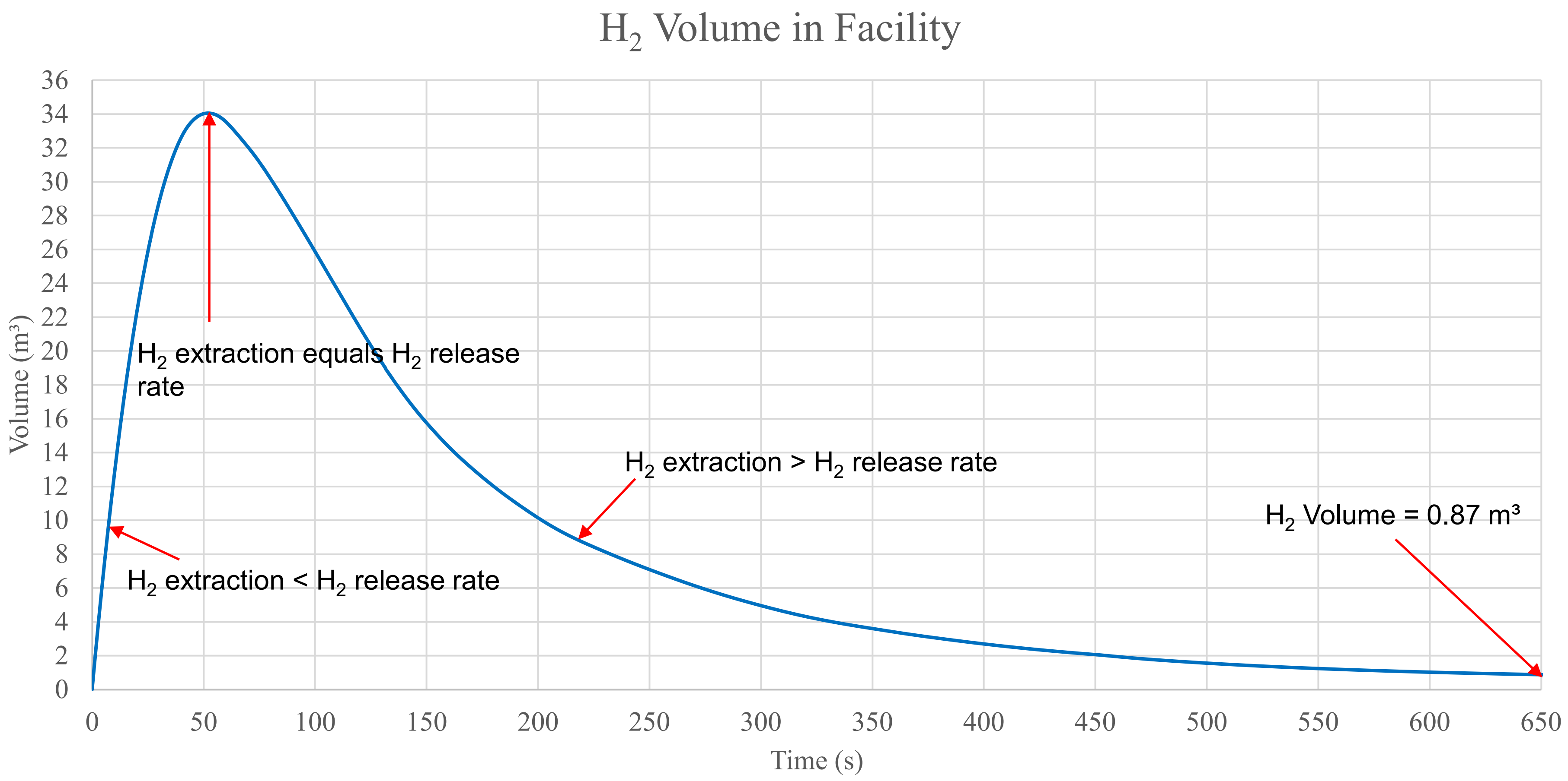
H_2 Concentration Plot for H_2 Sensors : 0-650 Seconds

- **Residual H_2 gas mixture (>= H_2 LFL) was detected until ~220 seconds**



Cumulative Hydrogen Volume in Facility

- Volume of H_2 gas reaches maximum at ~52 seconds

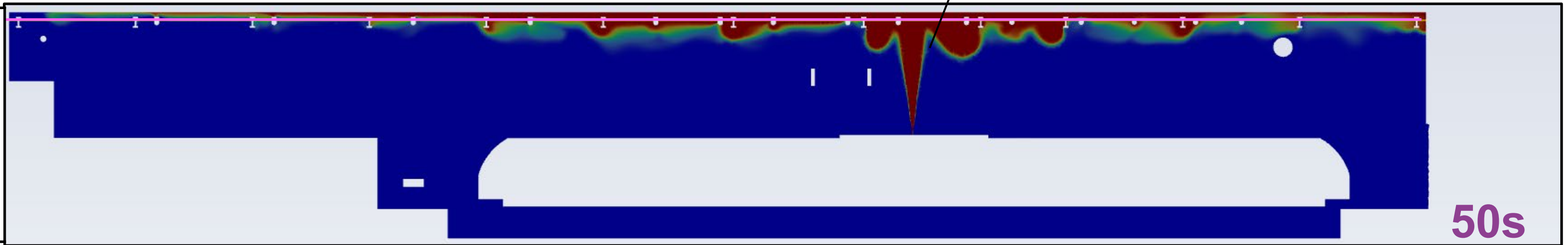
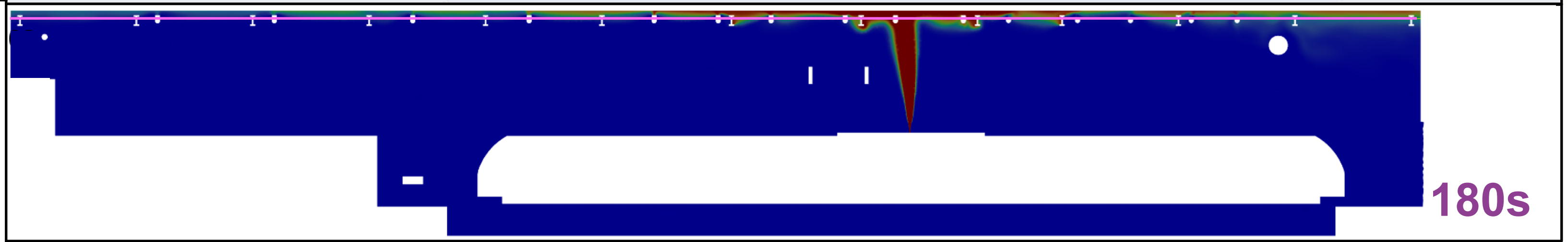
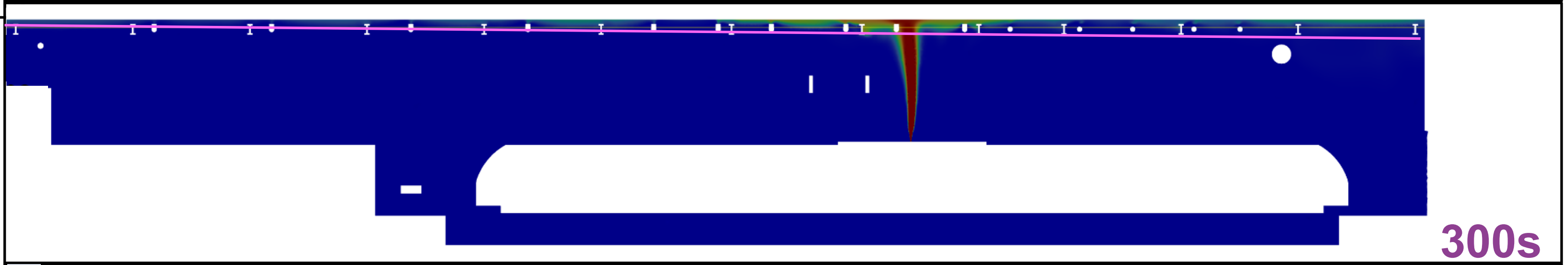
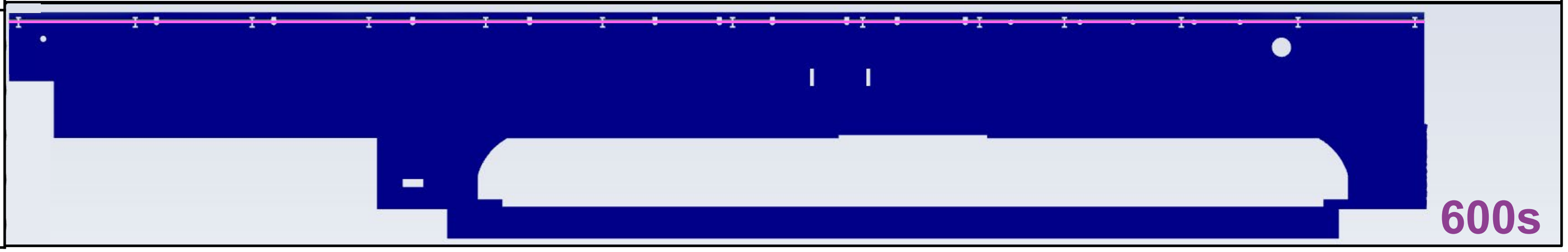


CFD Results [Source: Mott MacDonald]

Post-processing: Evaluating 18” Classified Space

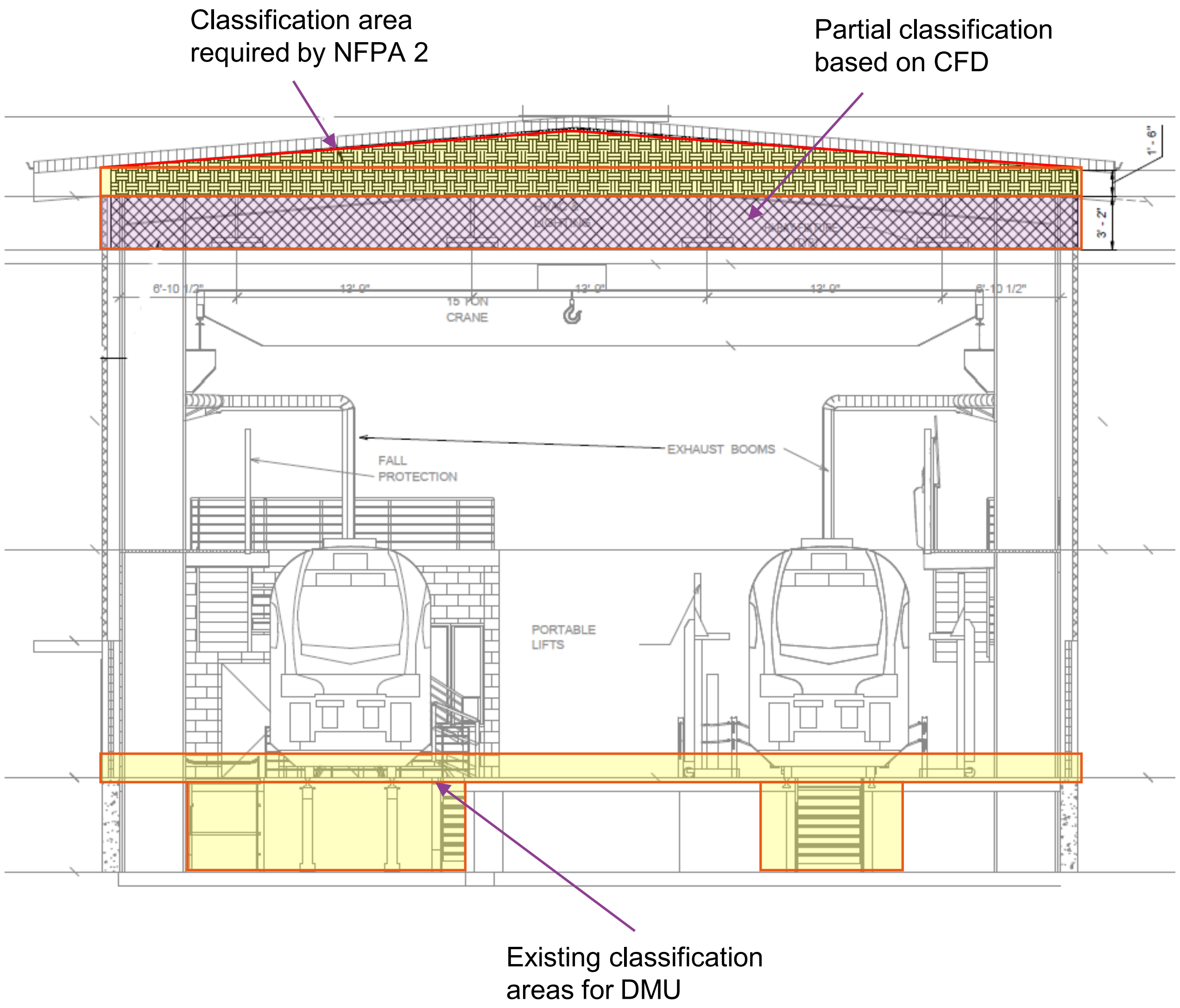
18 inches below ceiling

Red: >= 100% LFL

H_2 volume with flammable concentration is below 18” limit below the ceiling	
H_2 volume with flammable concentration is mostly above 18” except near the releasing point. Ventilation system is functioning at max capacity	
H_2 volume with flammable concentration is above 18”	
No H_2 at 100% LFL visible in this view	

Arrow Maintenance Facility Retrofit – Scope of Changes

- **Ventilation designed to meet CBC and NPFA 497 recommended practices; exceeds NFPA 2 minimum**
- **Electrical classification area adjusted to be greater than minimum requirement in NFPA based on CFD modeling results (top 50")**
- **H2 and flame detection systems**
- **Upgrades to fire suppression systems to target hydrogen specific hazards – Focused nozzle spray system to reduce risk of fire adjacent to vehicle and potential high-pressure release**
- **Ventilation, fire suppression and detection for battery fires and outgassing in battery storage areas**
- **Ancillary and utility work to support these changes**



AMF Drawing [Source: Mott MacDonald]

Key Take Aways

- All maintenance facilities need to be configured for the vehicle type(s) and hazards presented by the technologies utilized.
- For the US, codes and standards exist that will guide agencies in identifying future facility needs in supporting hydrogen and battery rail fleets.
- Existing codes may not be directly relevant to rail applications; a gap analysis may be required and hazards from specific vehicle types should be addressed.
- Preferred solutions are highly dependent on existing facility conditions; new build facilities will have the most flexibility/options.
- Other countries may take a different approach, depending on their codes or alternative risk-based analyses.

MOTT MACDONALD

sbcta
San Bernardino County Transportation Authority

Thank you