Refueling Processes

Mission Innovation Hydrogen Fuel Cell Off-Road Equipment and Vehicles Virtual Workshop

National Renewable Energy Laboratory
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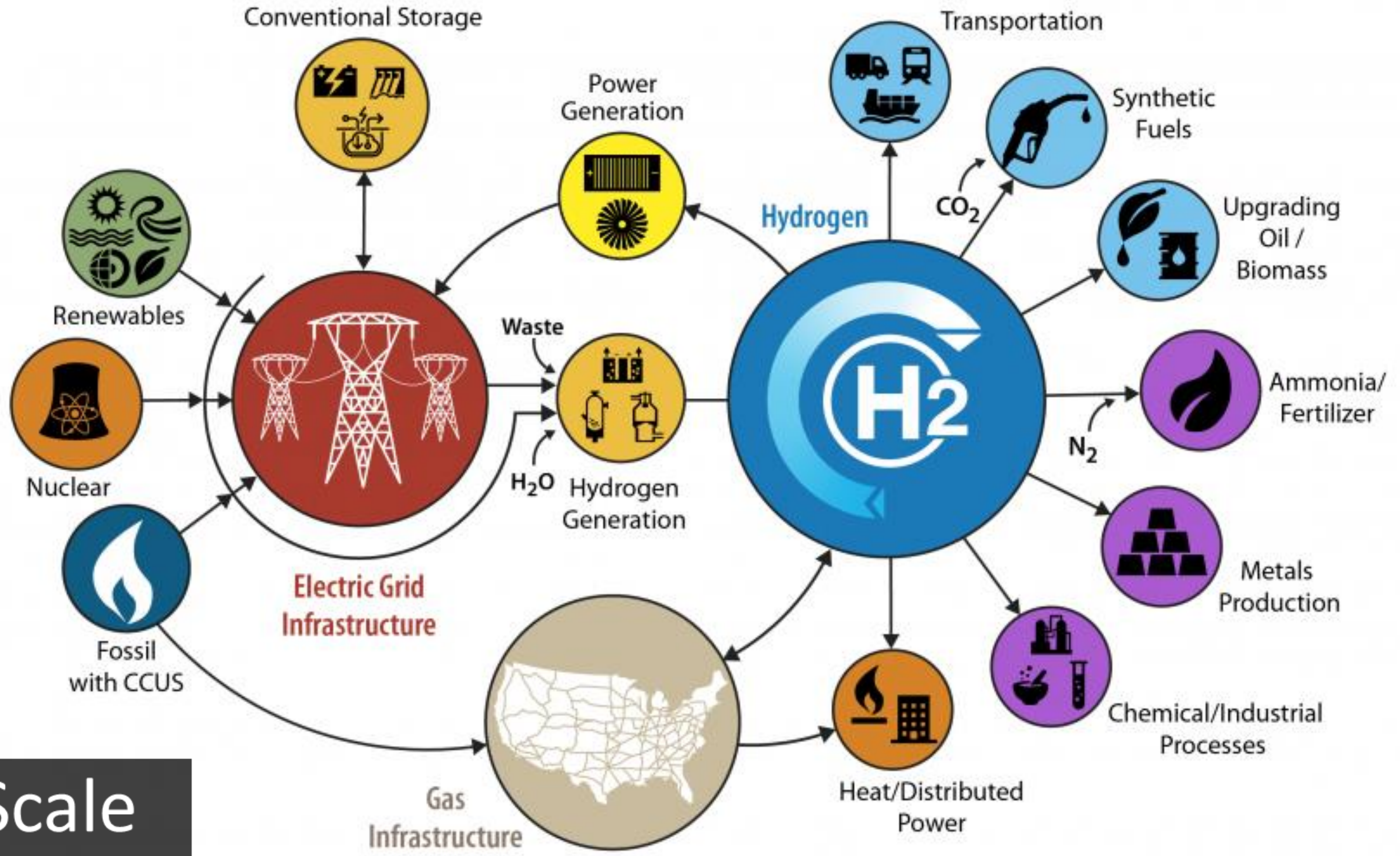


H2@Scale

Hydrogen integrated with U.S. energy sectors

https://www.energy.gov/eere/fuelcells/h2scale

Power Hardware-in-the-Loop Electrolysis and Energy Storage

Grid Services

Dispatchable loads (electrolyzers and stations) for grid services

Renewables

Transient operations with AC and DC power operation and analysis

Control

Includes power conversion, system integration, remote, real-time response, simulation, demand response, and safety

Cell/Stack

Multiple stack test beds capable of variable sizes and operation conditions, including BOP

Molecules

Gas fermentation with hydrogen

Images: NREL

Hydrogen Infrastructure

Life Cycle

Autonomous accelerated life cycle experiments for hydrogen station components

Benchmarking

Performance with near-term and future operating conditions

Operation

Power, energy, demand, and optimization operation experiments

Failure Investigation

Root cause investigation

Prototype

Development of emerging technology

Images: NREL

Hydrogen Safety R&D

Integration

Integrate safety research into codes and standards

Components

Study component performance and failures from the field and in the lab

Sensors

Verify, validate, and develop prototype sensors with high accuracy and low cost

Monitoring

Study requirements for safe operation, handling, and use of hydrogen

Outreach

Connect users to safety requirements to advance safe deployment

Images: NREL

NREL's Innovating Hydrogen Stations Project (IHS)

A research and industry partnership for an experimentally validated high flow rate fueling model and near-term hydrogen station innovations

- Multi-year effort, $3M+ DOE and industry parnership:
  - Sponsors: DOE HFTO, Air Liquide, Honda, Shell, Toyota
- First-of-its-kind, experimental research capability for 10 kg/min, 60+ kg fueling
- Comprehensive high flow rate fueling models validated with experimental data
- Publicly available tools and data for the benefit of hydrogen station stakeholders

Three Key Aspects

Experimental Data

Computational Fluid Dynamics

Simplified Fluid Model H2FillS

DOE Truck Targets

Experimental Data

- Fast fill data into representative Medium- or Heavy-Duty storage systems (multiple tanks) is not available, likely doesn't exist
- October 31, 2019: DOE released Hydrogen Class 8 Long Haul Truck Targets

Table 1. Technical System Targets: Class 8 Long-Haul Tractor-Trailers (updated 10/31/19)

Characteristic	Units	Targets for Class 8 Tractor-Trailers	
		Interim (2030)	Ultimate[9]
Fuel Cell System Lifetime[1,2]	hours	**25,000**	**30,000**
Fuel Cell System Cost[1,3,4]	$/kW	**80**	**60**
Fuel Cell Efficiency (peak)	%	**68**	**72**
Hydrogen Fill Rate	kg H_2/min	**8**	**10**
Storage System Cycle Life[5]	cycles	**5,000**	**5,000**
Pressurized Storage System Cycle Life[6]	cycles	**11,000**	**11,000**
Hydrogen Storage System Cost[4,7,8]	$/kWh ($/kg H_2 stored)	**9** **(300)**	**8** **(266)**

Station and Vehicle Research

Source: https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf

Modeling to Inform Decisions

Modeling

- Flexible, fast, easy to use modeling tools are needed to accommodate options within the M/HD market
  - Long-haul, drayage, vans, etc.

- Need for detailed 3D modeling to avoid unsafe conditions during the filling process
  - Hot spots, stratification, etc.

Approach

Experimental

- ✓ Use type IV (primary) and type III tanks (limited)
- ✓ Be conducted under a variety of fueling conditions.

Validation

Validation

1D model

- ✓ Update 1D fueling model

Validation

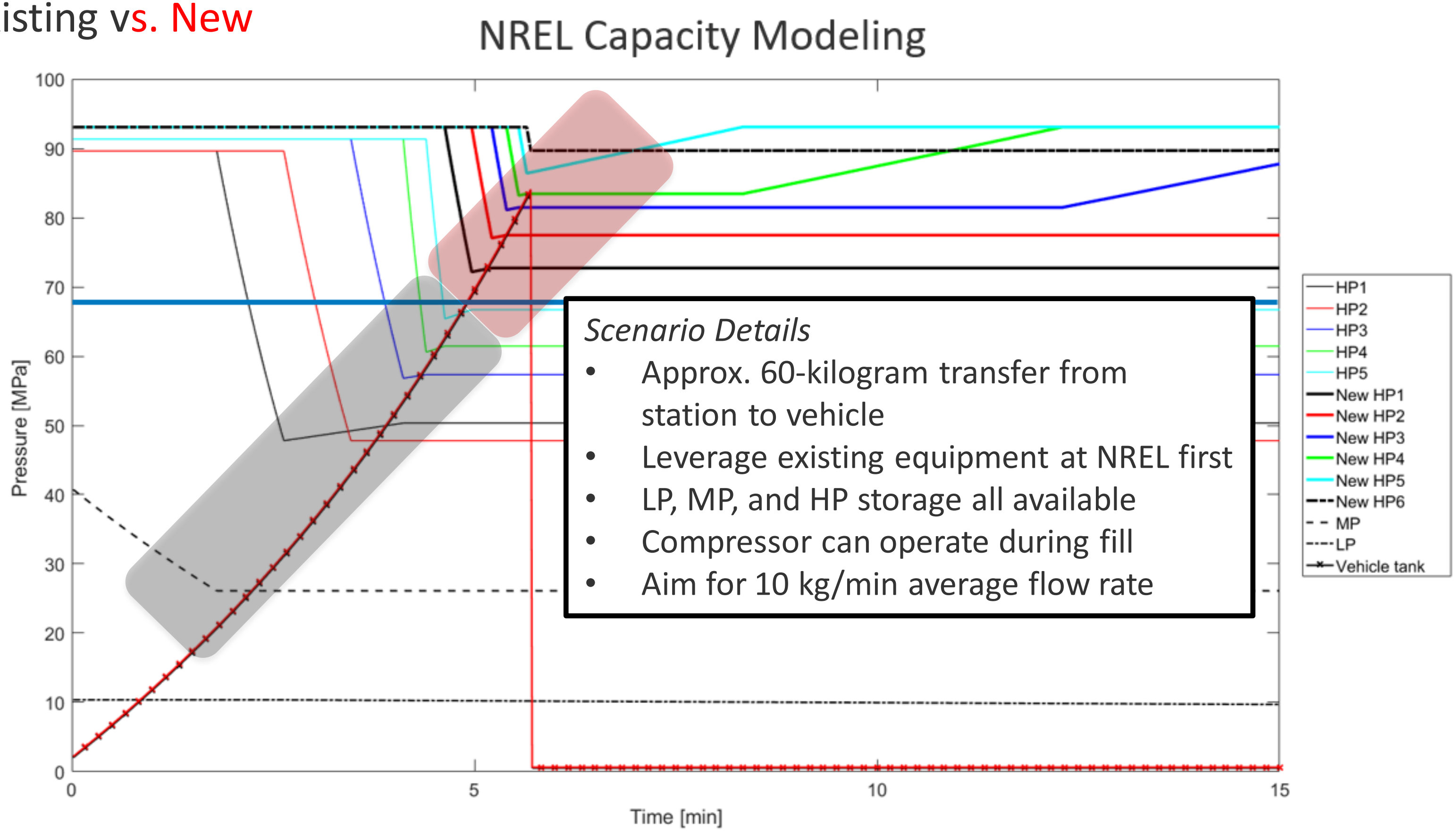
CFD

- ✓ Build type III and IV tank models
- ✓ Perform 3D simulations

CFD simulations and experiments are conducted to make the 1D model reliable.

High-pressure Ground Storage for a Single HD Fill

*Existing vs. New



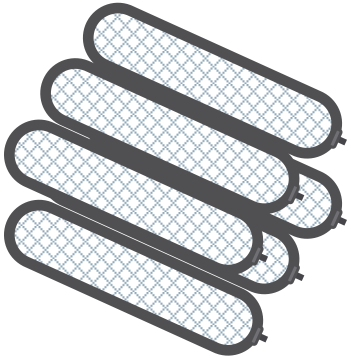
Scenario Details

- Approx. 60-kilogram transfer from station to vehicle
- Leverage existing equipment at NREL first
- LP, MP, and HP storage all available
- Compressor can operate during fill
- Aim for 10 kg/min average flow rate

High-pressure Ground Storage for a Single HD Fill

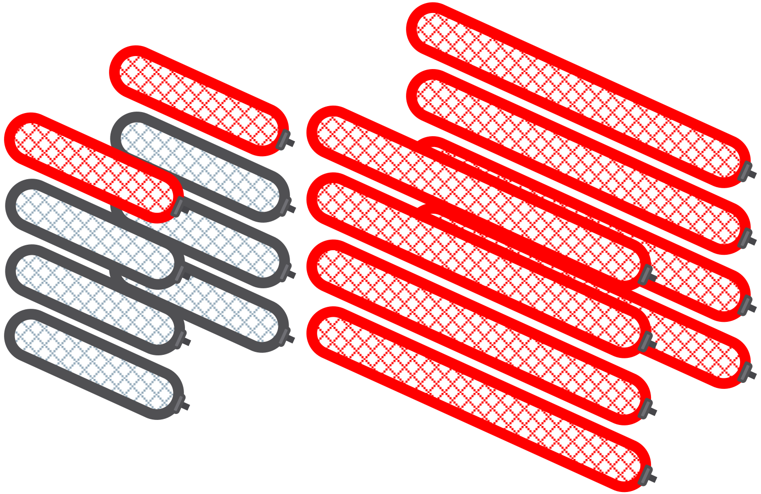
*Existing vs. New

MP Storage



13.5 kg each x 6
81 kilograms total

HP Storage



16 kg each x 8
128 kilograms total

32 kg each x 8
256 kilograms total

Quick Summary

- Disclaimer: there are many ways to fill a FCEV
- For a GH2 gaseous cascade setup, with a 60+ kilogram transfer at ~10 kg/min average flow rate our modeling shows that you need:
- **~80 kilograms at 40 MPa**
- **~380 kilograms at 90 MPa**

This doesn't include back-to-back filling!

Site Balance of Plant Upgrades

Experimental Data

High pressure ground storage

- Requires increase of high-pressure capacity ~300-kg + existing 90-kg hp + existing 80-kg medium-pressure

Pre-cooling system

- Modeling shows 300+ hp chiller needed for back-to-back fueling at T40
- System will leverage thermal storage for single fills

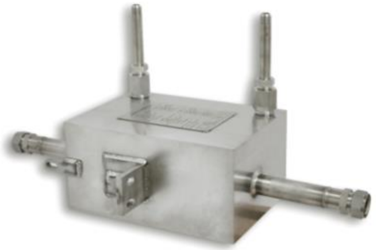
HD dispenser

- Hard tube connection from station to vehicle with "hooks" in place if nozzle, hose, breakaway, flow meter, filter become available

BoP upgrades

- Minimum upgrades are needed to ¾" tubing, 1" is safer choice

60 horsepower chiller at NREL's site



VPE Microchannel Heat Exchanger

HD Vehicle Simulator

Experimental Data

Vehicle Simulator

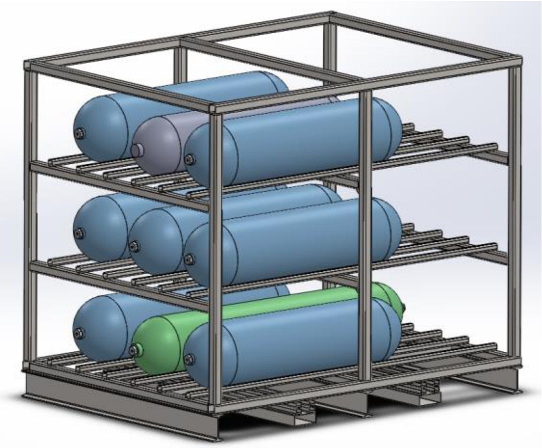
Design and Build Progress:

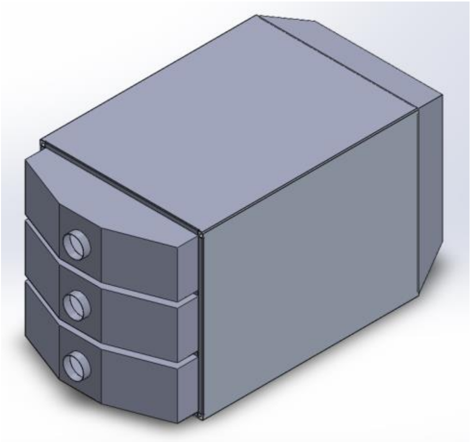
- 7 Type IV tanks (60+ kg fill), 2 Type III
- 9 tanks (80+ kg fill), Any configuration (HV isolation)
- Thermal chambers for ambient conditioning
- Highly instrumented tanks -> thermocouple trees

Hexagon

Worthington

Worthington





NREL's Site Upgrades

Experimental Data

All major equipment installed, commissioning in-progress

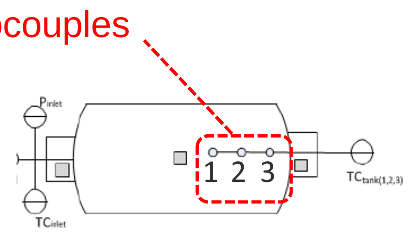
Build Progress

3D Modeling Update

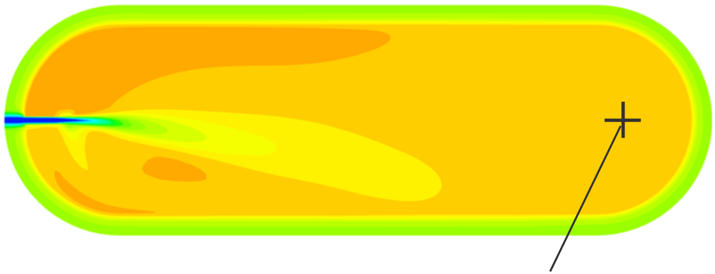
CFD

Integration with HPC

- Completed 6 full fills on NREL HPC
  - 3 different tanks modeled
    - 36 L, 116 L, 244 L
  - Two simulations per tank
- ***Validation in-progress***
  - Early results indicate CFD is matching experimental data and H2FillS closely



Temp. measurement positions


Temp. evaluation position in CFD

Evaluating Hot Spots

CFD

Slow Fill

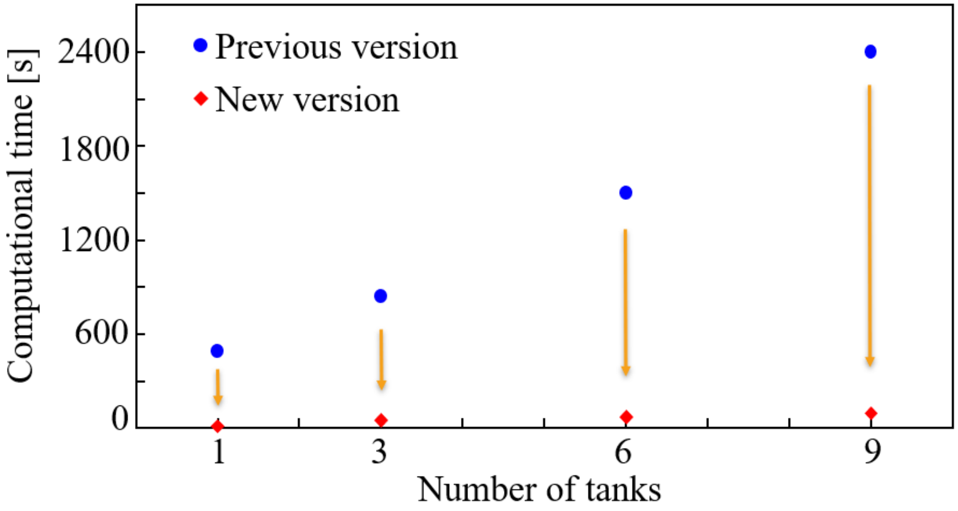
Select scenario: evaluating stratification and severity

Fueling conditions

- APRR = 3.8 MPa/min - T_{soak} = 40.0°C
- T_{amb} = 40.0°C - T_{fuel_ave} = -37.0°C

Making Tools Public

H2FillS



Speed Improvements

# of tanks	Computational time [s]	
	Previous	New
1	490	12
3	840	49
6	1500	68
9	2400	95

New version is **20 to 40 times faster** than the previous.

Previous Version:

- Slower computational speed
  - single tank matched real fill time
  - e.g., 8 min fill = 8 min model run

New Version:

- Significantly improved computational speed
  - single tank far faster than real time
  - e.g., 8 min fill = **12 second** model run
- Multi-tank hits very fast metrics

Continued Collaboration

- **Industry:** Air Liquide, Honda, Shell, Toyota
  - Monthly updates on progress
  - Provide feedback on technical approach
- **International Japan:** Kyushu University
  - Continued collaboration on H2FillS

Source: https://prhyde.eu/

PRHYDE is a European based project, funded by the FCH2 JU under the Horizon 2020 programme, looking at the current and future developments needed for refuelling medium and heavy duty hydrogen vehicles, predominantly road vehicles, but also other applications such as rail and maritime.

- **International EU:** IHS team joined EU PRHYDE project as a technical expert
  - Received additional funding from HFTO to participate
  - Dedicated test days with NREL's hardware system, multiple tank data is of value to the group

Summary

Goals:

- First-of-its-kind, experimental research capability for 10 kg/min, 60+ kg fueling
- Comprehensive high flow rate fueling models validated with experimental data
- Publicly available tools and data for the benefit of hydrogen station stakeholders

Progress:

- All major equipment installed, commissioning on-going
- A total of 6 Computational Fluid Dynamic fills have been completed on NREL's HPC
- H2FillS is in the process of being upgraded for HD applications including improvements in computational speed with multiple tank scenarios

Thank You

www.nrel.gov

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