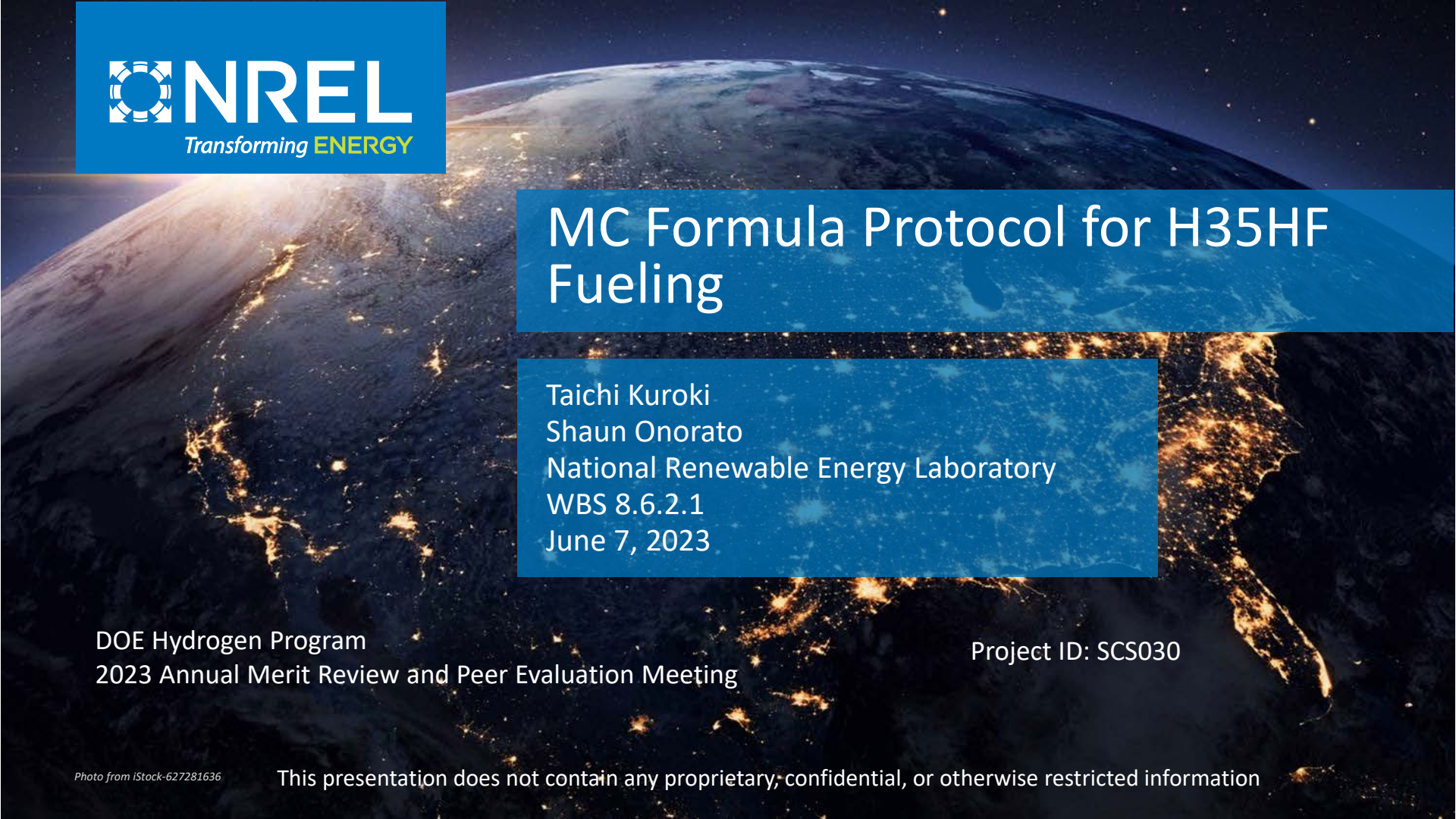

MC Formula Protocol for H35HF Fueling

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Project Goal

- Develop a fully tested and validated H35 high-flow (H35HF) MC Formula fueling protocol for medium-duty (MD) and heavy-duty (HD) buses and trucks.
- The developed protocol will be reflected in SAE J2601-2.
- NREL's hydrogen fueling model, H2FillS, will be upgraded for H35 MD and HD fueling and will be openly available to the public.

Overview

Timeline and Budget

- Project start date: 10/01/2021
- Project end date: 9/30/2023
- Total project budget: $699K
- DOE share: $545K
- Cost share: $154K
- DOE funds spent: $270K
- Cost share funds spent: $0K

(The funding from the industry partners will be used to perform fueling tests under a subcontract)

* As of 03/01/2023

Partners

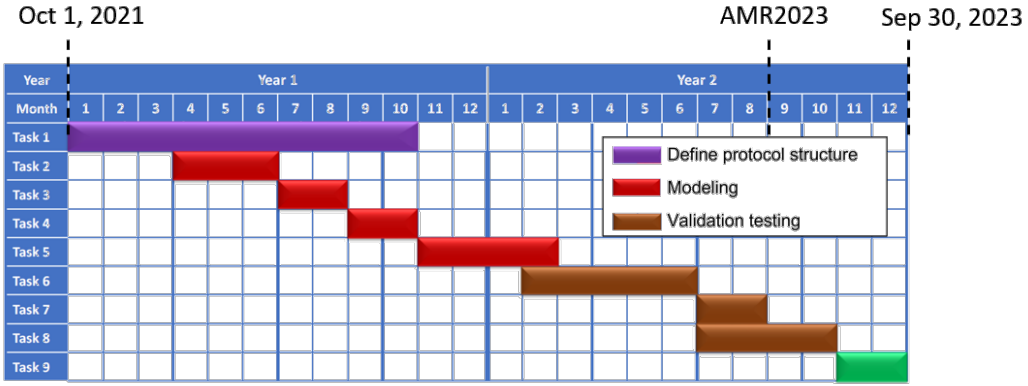
- Taichi Kuroki (PI, NREL)
- Shaun Onorato (Co-PI, NREL)
- Frontier Energy Inc. (Industry lead)
  - ElDorado National
  - Gas Technology Institute
  - Luxfer Gas Cylinders
  - New Flyer of America
  - South Coast Air Quality Management District
  - Sunline
  - SoCalGas
  - Shell
  - Trillium

Relevance/Potential Impact

- A publicly available and verified high-flow fueling protocol for H35 MD and HD hydrogen-powered buses and trucks does not exist. This could lead to the following issues:
  - Transit agencies need to select suppliers for purchase of new fleet vehicles, and multiple providers could respond with incompatible vehicle designs in the future.
  - With the expansion of MD/HD vehicles using 35 MPa storage, there will be a need for publicly accessible H35HF stations, and these will require the use of a standardized prescriptive fueling protocol.

- The development of an H35HF protocol helps:
  - Provide guidelines to design H35 stations and vehicles
  - Enable other manufacturers and vehicle original equipment manufacturers (OEMs) to enter this space, which will accelerate to grow the hydrogen market.

Approach – Project Schedule and Structure



Theme 1

Determine boundary conditions of H35 high-flow fueling protocol through surveys

- e.g., Define the allowable upper limit hose pressure

Theme 2

Upgrade H2FillS to assist protocol development

- Create capability to generate MC Formula fueling tables

Theme 3

Validate reliability of fueling maps at NREL and commercial stations

Theme 4

Document developed protocol so that it can be reflected in SAE J2601-2

Approach – Theme 1

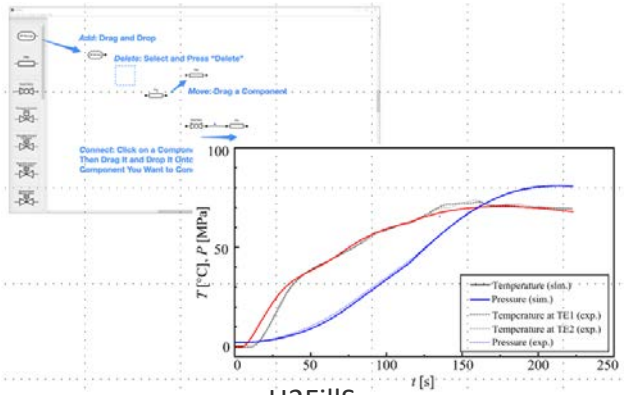
We will determine on optimal H35 high-flow fueling protocol structure

- Conduct surveys for H35 station operators and vehicle OEMs
- Integrate the survey results to define boundary conditions for H35 stations and vehicles. For example:
  - Pressure drops caused from components on both station and vehicle sides
  - Thermal masses for both station and vehicle sides
  - Range of allowable mass flow rate supplied from H35 dispenser
  - Upper limit hose pressure

Approach – Theme 2

We will upgrade H2FillS so that it can assist the protocol development.

- H2FillS's capabilities will be expanded
  - Create the capability to run simulations under defueling, "cold" case conditions
  - Integrate H2FillS with NREL's high-performance computing (HPC) system
  - Combine the fueling and defueling process simulations and automate the generation of MC Formula fueling tables
- MC Formula fueling tables will be generated to install H35 MD and HD dispensers



H2FillS

NREL's HPC

Approach – Theme 3

We will validate the reliability of the H35 high-flow fueling protocol.

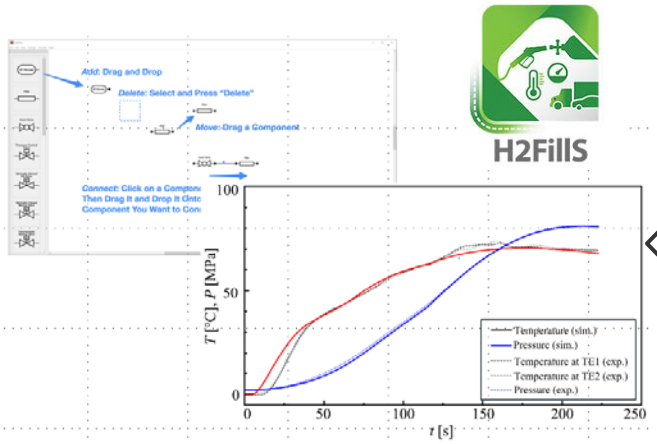
- The H35 MC Formula fueling tables will be validated
  - The fueling tables in Theme 2 will be installed in the **NREL and commercial stations' dispensers**, and the reliability of the tables will be validated
  - We will confirm that:
    1. The compressed hydrogen storage system (CHSS) gas temperature and pressure increase up to expected values and do not exceed the upper limits
    2. The supplied mass flow rate is controlled within the allowable range
    3. The pressure drop from the dispenser through the CHSS is below the allowable range

Accomplishments and Progress –Theme 1–

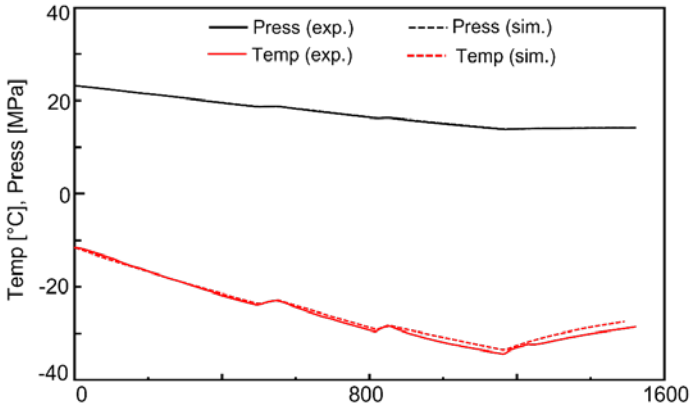
Theme 1: Define boundary conditions for H35 high-flow fueling protocol

- Surveys to define protocol structure
  - Made surveys for H35 station operators/manufacturers and vehicle OEMs and distributed them (completed)
  - Collect the survey responses (completed)
- Define boundary conditions for H35 high-flow fueling protocol through the survey results(completed)

Accomplishments and Progress –Theme 2–



Integration of H2FillS and NREL's HPC



Validation of defueling algorithm

Theme 2: Modeling work

- Develop a consumption (defueling) algorithm and validate the algorithm against test data (completed)
- Integrate H2FillS with NREL's HPC system so that this project can rapidly generate fueling tables (completed)
- Automate the process of H35 MC Formula fueling table generation on NREL's HPC (completed)

Accomplishments and Progress –Theme 3–

Theme 3: Validation testing

- Collect thermal mass and Cv value information about H35HF hardware (incomplete)
  - Subcontracting with German's H2 testing facility, ZBT Gmbh, to perform flow testing with H35HF hardware.
  - The flow testing will be completed by the end of April 2023, and then the flow data will be provided to NREL to derive the thermal mass and Cv value information.

- Validate the H35HF protocol at NREL's HD station (incomplete)
  - Implement MC Formula control logic in NREL's HD dispenser (expected timeline: May 2023).
  - Generate fueling tables with the derived thermal mass and Cv value information about H35HF hardware and then install those tables in the deepener (expected timeline: May 2023).
  - Perform H35HF MC Formula fueling testing (expected timeline: June through Sept 2023).

* As of 04/01/2023

Accomplishments and Progress:
Response to Previous Year Reviewers' Comments

- This project has not been previously reviewed at an AMR.

Collaboration and Coordination

Administrative Role:

- Frontier Energy

Industry Partners:

- ElDorado National
- Gas Technology Institute
- Luxfer Gas Cylinders
- New Flyer of America
- Shell
- South Coast Air Quality Management District
- Sunline
- SoCalGas
- Trillium

- Bi-monthly technical meetings
- Provide feedback on H35 high-flow fueling protocol structure
  - The feedback assists NREL to integrate the survey results
- Provide fueling and defueling data collected with H35 vehicles
  - The actual measurement data make it possible to validate the reliability of H2FillS against H35 fueling

Remaining Challenges and Barriers

- Derive the thermal mass and Cv value about the H35HF hardware, which is crucial information to generate fueling tables to be installed in commercial station dispensers.
  - NREL subcontracted with ZBT ZBT Gmbh having the capability to perform H35HF fueling testing with H35HF hardware, so NREL will have them collect the thermal mass and Cv value information at their
- Validate the H35HF protocol at NREL's HD station.
  - NREL is implementing the MC Formula control logic in the HD dispenser to perform the protocol validation testing.
  - Coming up with a strategy of how to control the dispenser pressure according to the MC Formula method would be a crucial challenge. This is because flow control valves that can support for high-flow HD fueling do not exist.

Proposed Future Work

Future work for rest of FY23

1. Collect the thermal and Cv value information about H35HF hardware.
2. Derive fueling tables based on the thermal and Cv value information for the installation into commercial station dispensers
3. Perform fueling testing with the fueling tables and then confirm to see if the dispenser pressure is correctly controlled according to the MC Formula method.
4. Perform fueling testing at a commercial station then confirm to see if the dispenser pressure is correctly controlled according to the MC Formula method.
5. Reflect the developed protocol in SAE J2601-2.

Note that any proposed future work is subject to change based on funding levels.

Summary

- This project is developing a fully tested and validated H35 high-flow MC Formula fueling protocol for MD and HD buses and trucks that will be reflected in SAE J2601-2.
- Accomplishments in this review period include:
  - Defined boundary conditions for the H35HF fueling protocol.
  - Upgraded H2FillS to help develop H35HF fueling protocol.
  - Started implementing the MC Formula control logic in NREL's HD dispenser to perform protocol validation testing.
  - Subcontracted to collect the thermal mass and Cv value information about H35HF hardware.

Thank You

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NREL/PR-5700-85921

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Technical Backup and Additional Information

Technology Transfer Activities

- NREL has a license agreement with Kyushu University and continues to improve the H2FillS model – a new version of H2FillS will be released at the end of the project.

- The experimental and simulation data collected at NREL's HD station to validate the reliability of the fueling tables are expected to be published as a journal article.