CAAP Quarterly Report

3/31/2024

Project Name: " Accelerating Transition towards Sustainable, Precise, Reliable Hydrogen Infrastructure (Super-H2): Holistic Risk Assessment, Mitigation Measures, and Decision Support Platforms"

Contract Number: 693JK32250007CAAP

Prime University: North Dakota State University

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Reporting Period: 1/01/2023 – 3/31/2024

Project Activities for Reporting Period:

In the previous report (Q1-Q5), Task 1, Task 2.1 was completed, Task 2.2 has set up the main framework, waiting for the following simulation, empirical result to validation and Task 3.1, 4.1 and 5.1 has acquired some preliminary results. In this quarter (Quarter 6), the research team has worked on Tasks 3.1, 4.1, 5.1 and 6.1. The summaries for the major activities that were completed during this reporting period are detailed below:

Task 3.1 During this reporting period, the research team, led by Mr. J. Anderson from EERC, made progress in preparing the near real-world testbed for hydrogen testing. Specifically, key equipment and space required for the testing setup have been successfully established. Below is a summary of the progress made by EERC during this reporting period:

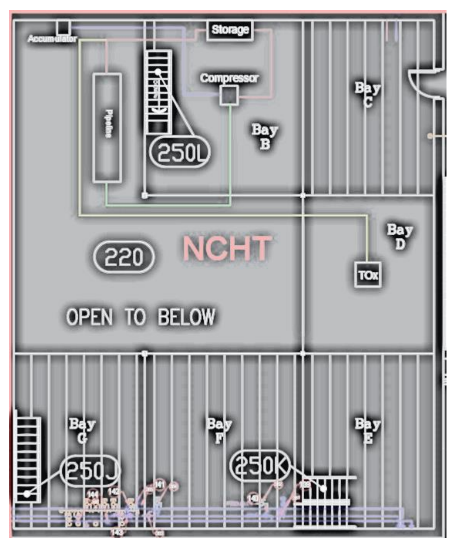

Figure. 1 The layout of EERC facilities for hydrogen testing

1) The General Arrangement Drawing (GAD) for layout within the EERC facilities has been made with instruction from EERC facilities on placement. Dependent on access to EERC natural gas lines, the location in what is known as Building R, or the National Center for Hydrogen Technologies (NCHT) is confirmed.
2) Pricing for API 5L X52 piping has been updated for SCH 40 at $68/ft. However, after reviewing ASME codes for process piping at pressure and going through calculations (using some conservative safety measurements), the current design will be unsafe by EERC standards if SCH40 is used. Currently awaiting an updated pricing for SCH80, which has calculated values that are within safe range. See the table for actual values.

Table. 1 The Electric Fusion Weld-Single Butt Weld stress according to ASME B31.3- 2016 (psi)

	SCH40	SCH60	SCH80
API 5L X52	1052	1369	1728
316L	799	1039	1312
316	956	1244	1571

3) PID has gone through some small updates, mostly focusing on the addition of adding a Mass flow controller (MFC) for controlled flow to the thermal oxidizer (TOx) for safe depressurization and being able to control the temperature within the TOx as needed to protect the internal refractory.
4) Materials needed to fabricate the pipeline are being gathered for what is currently on hand at the EERC so when ordering of materials begins, we won't be ordering a multitude of extra materials to keep procurement costs within reason.
5) The updated PID and GAD will be attached as PDF/picture.
6) A Standard Operating Procedure (SOP) has been drafted, laying out the potential way operation of the system will be performed. This SOP will be updated during shakedown of the system accordingly if the expected procedures need amending.
7) Currently working with multiple welding companies in Grand Forks to check over the pressure calculations for either confirmation that SCH80 is necessary or if something else will be needed/is acceptable. Pricing will be dependent on the type and size of pipe but is expected to be less than the original estimate due to the large size decrease and welds needed from the original design.

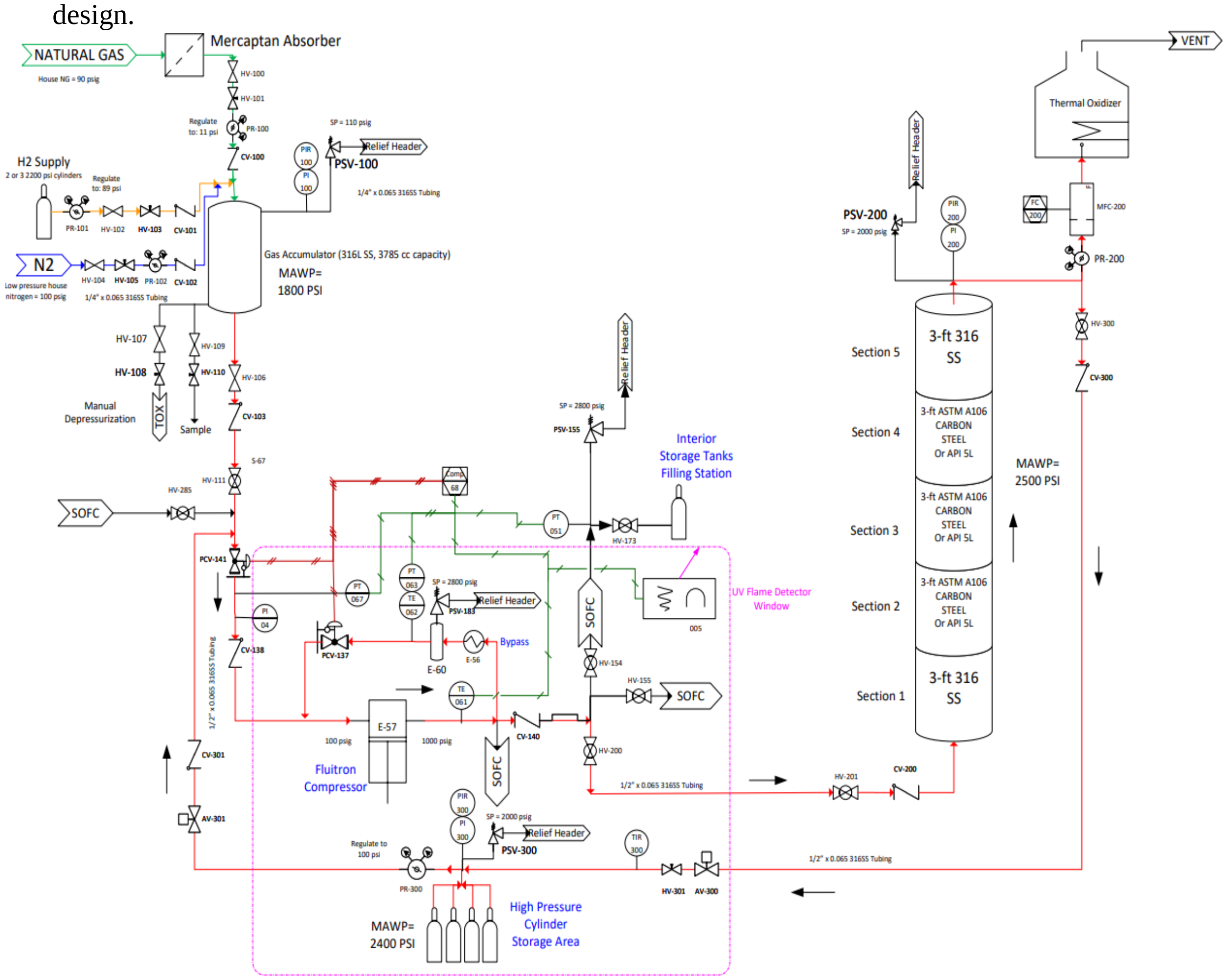

Figure. 2 The updated piping and instrumentation diagram for the near real-world testbed

Task 4.1 Gaining an understanding of long-term hydrogen impacts: In the reporting period, the Virginia Tech team (Dr. K. Wang from Virginia Tech) (Dr. K. Wang from Virginia Tech) has developed a computational model for simulating long-term hydrogen absorption in transportation pipes as summarized below:

1) We have implemented part of the model in their in-house research code, M2C (open source, C++, using MPI, PETSc, Eigen, etc.). Figures 3 and 4 present an overview of the model design. The main feature of this model lies in the adoption of detailed computational fluid dynamics (CFD) simulation that predicts the effects of surface roughness on the rate of hydrogen absorption. The working hypothesis behind this approach is that the small defects on the inner wall of pipes can become "hydrogen traps" that accelerate the rate of absorption, thereby increasing the speed of material degradation and damage.

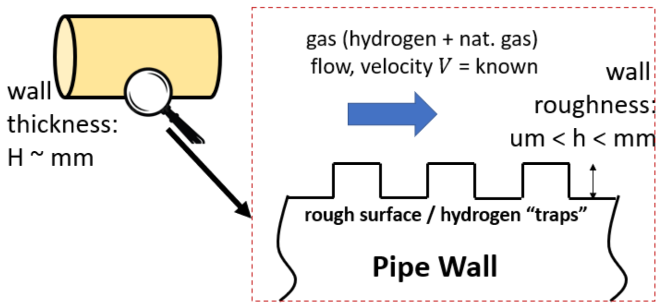

Figure. 3 Design of the model problem for predicting flow-induced hydrogen absorption over a rough pipeline surface.

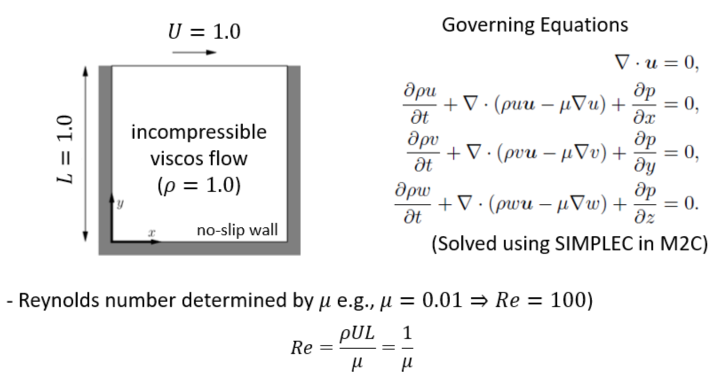

Figure. 4 Development of the model problem and a benchmark test case

2) Within the reporting period, the Virginia Tech team has designed and conducted a code verification study. In particular, the incompressible viscous flow solver in the M2C code is verified using a benchmark test case that features a fluid flow past a square cavity, which in the current context represents a small segment of a rough wall surface. The Reynolds number of the flow is varied from 10 to 10,000. The numerical results obtained using M2C are in good agreement with those obtained using COMSOL and OpenFoam. Figure 3 shows some of the simulation results.

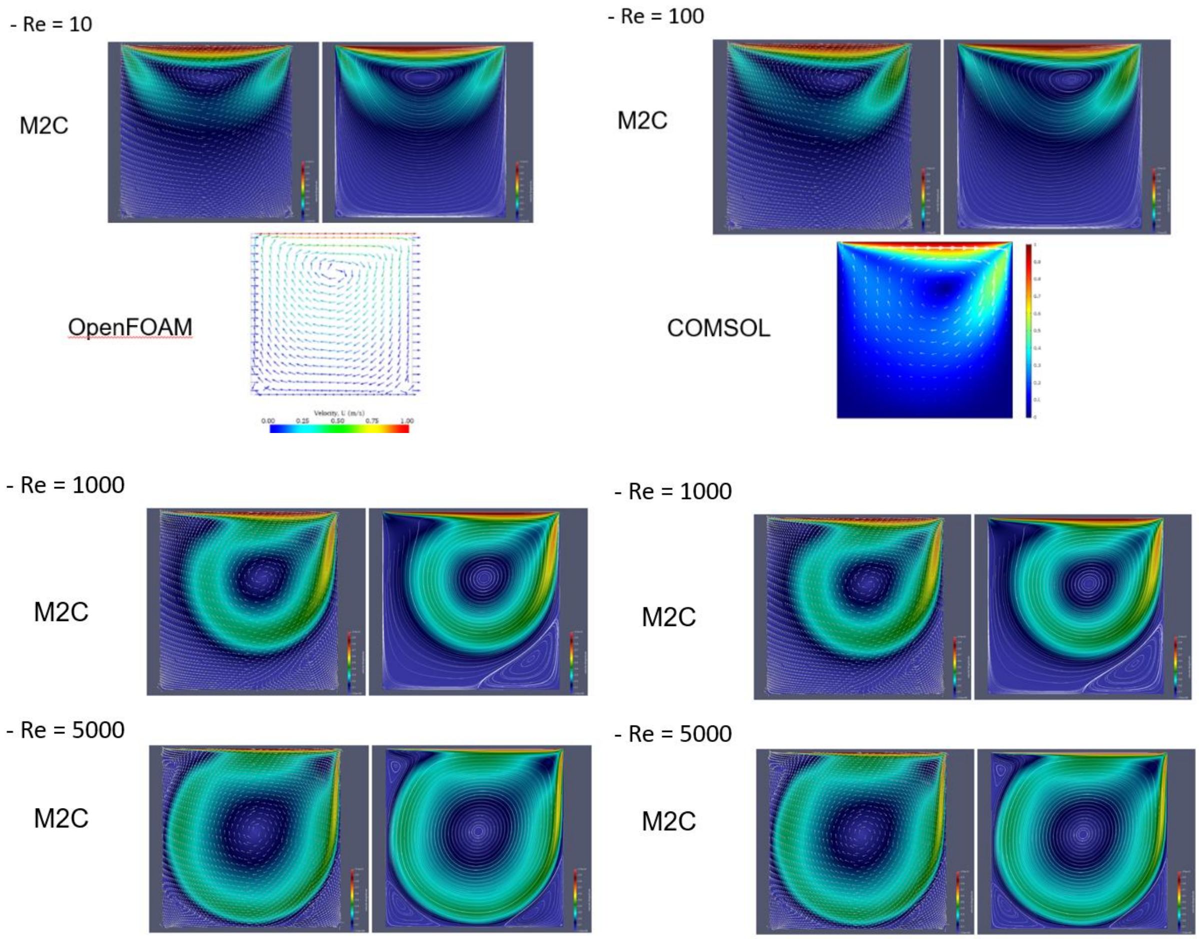

Figure. 5 Simulation results obtained from the verification study. Good agreement is obtained between results of our in-house research code (M2C) and references obtained using OpenFOAM and COMSOL.

Task 5.1 To determine component and system level factor affect the hydrogen in existing pipeline. In this quarter period, the research team (Dr. Zhibin Lin, Dr. Hong Pan, Mohsin Ali Khan, and Xuanyu Zhou from NDSU) has proposed a knowledge graph based neural query frameworks to evaluate the component and system level factor as summarized below:

1) The proposed knowledge graph-based neural query framework is structured to comprehensively assess the factors influencing hydrogen presence in existing pipelines as shown in Figure 6. It operates through a series of interconnected components, each serving a specific purpose in the evaluation process. The C/S Factor Query Module serves as the gateway for initiating queries concerning component and system-level factors influencing hydrogen presence. At the heart of the framework lies a sophisticated Knowledge Graph, housing a wealth of information concerning pipeline infrastructure and hydrogen behavior. Upon receiving a user query, the encoder transforms the input into a format suitable for processing within the Knowledge Graph. The encoded query is then directed to the processor, which harnesses the Knowledge Graph to extract relevant information and perform computations. Finally, a decoder within the framework interprets the processed data, generating comprehensive results for the user. Through the integration of these components into a cohesive framework, the research team endeavors to provide stakeholders with

the tools and insights required to make well-informed decisions regarding hydrogen management strategies.

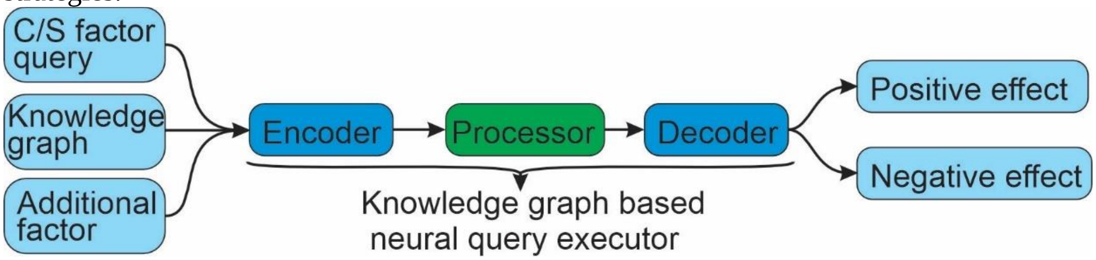

Figure. 6 The component and system level impact evaluation framework. C/S means component or system factors.

Task 6.1 The existing experimental and simulation studies conducted in this research provide valuable insights into the feasibility of blending hydrogen into existing pipelines. However, equally critical are the existing regulations, which serve as essential references for determining guidelines and best practices to comprehensively assess risks when repurposing these pipelines. During this quarter, the research team, comprised of Dr. Zhibin Lin, Dr. Hong Pan, Mohsin Ali Khan, and Xuanyu Zhou from NDSU, summarized the existing regulations relevant to blending hydrogen into existing pipelines, as outlined below:

1) Pipeline gas transmission is normally subject to rigorous regulations by different bodies worldwide. The operators are required to secure regulatory approval for blending and injecting hydrogen in natural gas networks. Clarity in regulations is necessary to ensure the proper operation of hydrogen blending and injection projects. Though regulations are likely informed by technical aspects, they may also encompass considerations beyond feasibility, that potentially limits the hydrogen blending opportunities.
   Current regulatory procedures for hydrogen blending vary and many countries lack specific approaches and treat hydrogen as a hazardous gas. The absence of standardized regulations and decentralized databases presents challenges to understand the regulatory frameworks globally. Table 2 presents the summary of current requirements on the maximum threshold of blended hydrogen in natural gas networks. Even in countries lacking in defining clear stated limits, operators should follow the recognized safety standards, with restriction on hydrogen blending to levels below 10% by volume.

Table 2. The country imposed a regulatory threshold for using blended hydrogen presented as a percentage of the total volume, HyLaw, California Public Utilities Commission (CPUC), International Energy Agency (IEA), Agency for the Cooperation of Energy Regulators (ACER), National Research Council (NRC).

Reference	**Threshold**	**Country**	**Comments**
HyLaw	6%	France	France has begun reviewing and modifying the laws and regulations for blended hydrogen.
HyLaw	10%	Germany	Networks that have compressed gas stations for filling or other consumers that need special care remain restricted to a maximum of 2%.
HyLaw	4%	Austria	
IEA	2%	Lithuania	Blending is permissible solely when the pressure in the pipeline exceeds 16 bar.

HyLaw	1%	Finland	
HyLaw and ACER	2%	Belgium	There are no formalized limits, although operators consider 2% to be considered a reasonable limit. At present, hydrogen introduction is prohibited, although the regulators are assessing its feasibility.
NRC	2%	Canada	The actual threshold beyond which further restrictions could be imposed is the energy content requirements set by the Alberta gas operator, which effectively limit blend amounts to a maximum of 5%.
ACER	2%	Slovakia	There is no specific restriction; hydrogen is allowed in imported gas; however, it cannot be directly injected.
ACER	2%	Czach Republic	The scientific specification permits a maximum of 2% but does not prescribe the measurement of hydrogen.
ACER	1%	Italy	The limitation only pertains to the hydrogen component of bio-methane, whereas the direct introduction of hydrogen is not particularly monitored.
HyLaw	0.10%	Latvia	
HyLaw	0.50%	Netherlands	There is no specific restriction imposed at the distribution stage, however, the gas provided to the consumer must comply with an upper limit of 0.5%. The allowable limit for gas transmission both in and out locations is 0.02%. The introduction of hydrogen in its pure form is prohibited.
HyLaw	0.10%	United Kingdom	
ACER	0.10%	Ireland	
HyLaw	0.10%	Sweden	Blending in the transmission network needs to be categorized as natural gas, with the possibility of permitting hydrogen levels of up to 2% being under review.
IEA and CPUC	0.10%	California (U.S.)	There is no specified legal limit but blending that exceeds 0.1% will result in the implementation of extra compliance and monitoring measures.
IEA	0.10%	Japan	

Project Financial Activities Incurred during the Reporting Period:

The cost breakdown during the reporting period in each category according to the budget proposal is shown in Table 3. Note that the cost, particularly from subcontracts of the Co-PIs could be delayed from the process between organizations.

Table 3 Cost breakdown during the reporting period (Q6)

Category	Amount spent during Q6
Personnel	
Faculty	$10200

Postdoc	$9,000
Students (RA and UR)	$9,000
Benefits	$8,910
Operating Expenses	
Travel	$0,000
Materials and Supplies	$0
Recharge Center Fee	$0
Consultant Fee	$0
Subcontracts	Subawards issued
Indirect Costs	$16,700

Project Activities with Cost Share Partners:

The Match fund from NDSU for this project is coming from faculty academy hours of NDSU and Virginia Tech, and two Ph.D. students' RA tuition waivers. The matching fund from Dr. Lin (NDSU) and Dr. Wang (Virginia Tech) during Q6 is estimated to be $13,341, and the students' RA tuition waiver is about $16,560, so the total amount of match is estimated at $30,3901.

Project Activities with External Partners:

During this reporting period, the research team meets regularly bi-weekly, and the sub-universities have researched as planned.

Potential Project Risks:

No potential risks were noticed during this reporting period.

Future Project Work:

During the upcoming quarter, the research team will persist in their efforts on Tasks 3.1, 4.1,5.1, and 6.1, with a specific emphasis on expanding the scope of work outlined in Task 5.1, in accordance with the established plan.

Potential Impacts on Pipeline Safety:

The summary of the existing regulation provides reference and guidance to determine the safety of hydrogen blending.