Nanocomposite Advanced Surface Protection (HydroPel) for Safe and Efficient Hydrogen Transport in Existing Steel Pipelines

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Project Overview

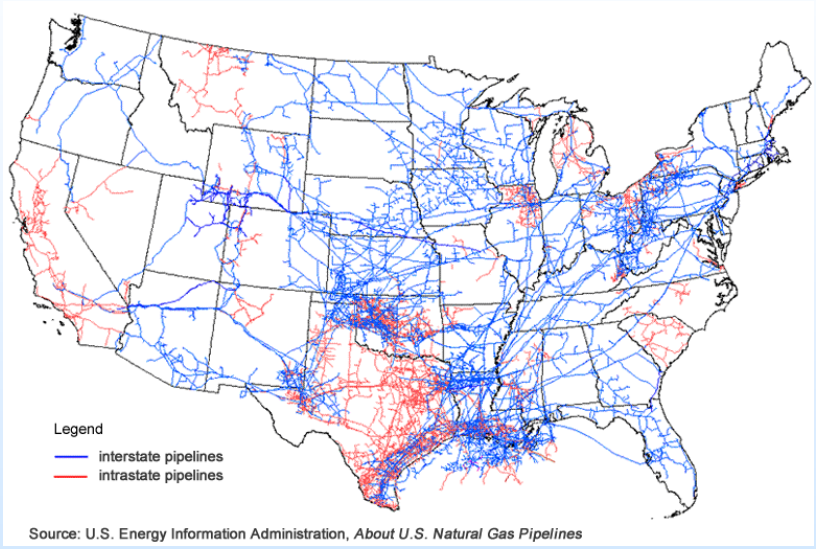
- DOE SBIR $250k (Phase I), $1,600k (Phase II)
- 06/28/2021 to 08/21/2024
- Oceanit, Hawaii Gas, Pipeline Operator
- Project Objectives
  - Develop and demonstrate an advanced nanocomposite surface treatment (HydroPel) for H_2/CH_4 blending in new & existing pipelines (Phase I)
  - Material and process improvement through testing and validation in an industry-relevant simulated lab testing, long-term performance evaluation, and subscale field testing (Phase II)

Technology Background

- Hydrogen – Carbon Free Energy Carrier
- Fossil fuel accounts for ~98% H_2 production
- **<u>Transportation in existing natural gas pipelines?</u>**
- >300,000 miles of Interstate Natural Gas pipeline available in the US
- 5-20% H_2 Blending
- Safety, Leaks, Fractures, <u>Hydrogen Embrittlement (HE)</u>
- Current estimate **<u>>$1.5 Trillion</u>** for building new H_2 infrastructure
  - **<u>$4.65M/mile</u>**

Need new technologies to enable H_2 blending in existing natural gas pipelines

Natural Gas Pipelines[1]

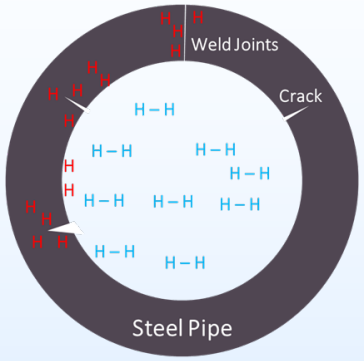


H_2 Pipeline[2]

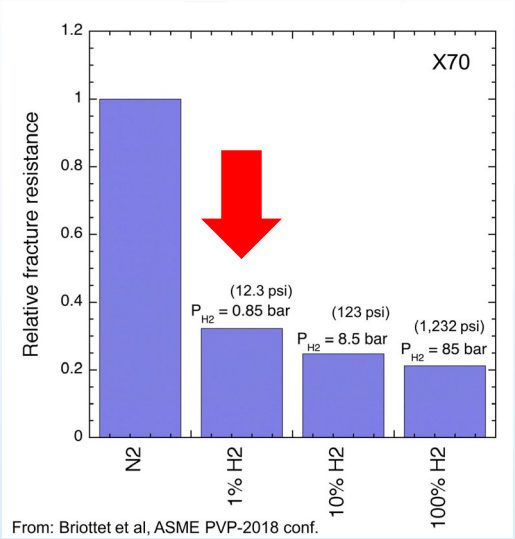
Technology Background

- HE accelerates fatigue by 10X
- Blending or neat hydrogen can induce cracking, and fractures in steel
- HE impacts high strength steel API-5L X70 or higher [3]

1% H_2 in Natural Gas can reduce specified minimum yield strength (smys) by 40%



H_2 Diffusion in steel pipe



Embrittlement[4]

Fracture[5]

Technology Background

- **How to prevent HE?**

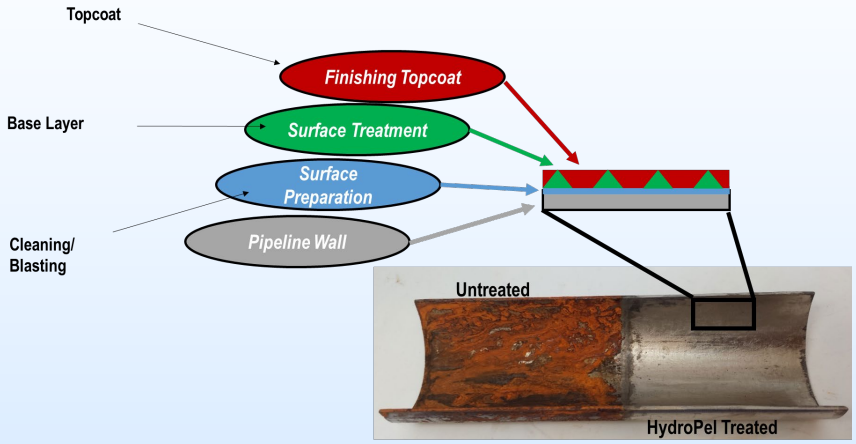
Barrier to prevent hydrogen diffusion into steel

Metal	Inorganic	Polymer
• Cd • Ni • Sn • Zn	• Al_2O_3 • TiO_2 • TiC • Si_3N_4	• Polyethylene (HDPE) • PVC • Epoxy • Rubber(ABS)

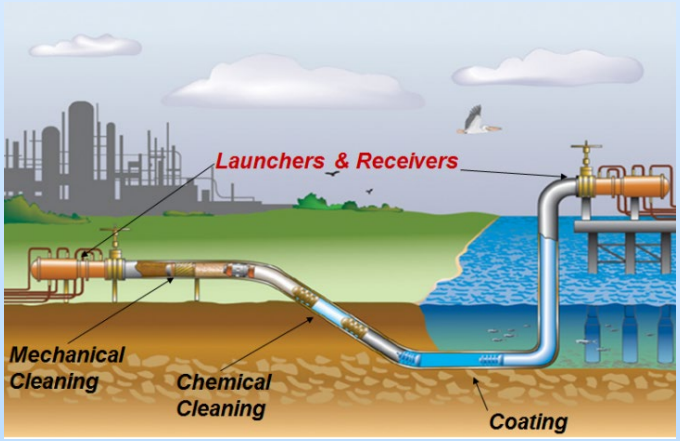
Need a low-cost, easy-to-apply, low H_2 diffusive barrier material for existing and new pipelines

Technical Approach

- Advanced Nanocomposite HydroPel In-Situ Surface Treatment
- Applicable to pipes of varying diameter bends, weld joints, etc.,
- Extremely thin 2-4 mils (50 to 100µm)
- Strong Hydrogen Barrier
- HE prevention
- Superior Drag Reduction
- Scalable and industry-accepted application



In-Situ Pigging Process



Project Objective

- Demonstrate Proof of Concept through standard laboratory testing
- Advance Technology Readiness of HydroPel through testing under simulated pipeline conditions, sub-scale and field testing with industry partner

Key Questions:

1) How to transform natural gas pipeline suitable for safe and efficient hydrogen transport with minimal modification?
2) What is the best way to protect existing steel pipelines, weld joints, and other pipeline infrastructure from hydrogen?
3) What are the performance and safety benefits of modifying existing pipeline infrastructure?
4) How can the process be scaled up?
5) What are the technoeconomic benefit of modifying existing steel pipeline?

Overall Workplan and Milestones

Lab scale Development and Feasibility Assessment (9 Months)

- Application process & material fabrication
- Standard testing & evaluation
- Feasibility confirmation
- Go/No-Go

Simulated Testing, Subscale, Field Testing & Validation (24 Months)

- Material and Process refinement
- Simulated testing
- Subscale flow testing
- Field exposure
- Go/No-Go

Scale up & Field Deployment (TBD)

- Manufacturing Scale Up
- Field deployment

Project Timelines

Tasks	Target Date	Achieved Date
Application Process & Material Fabrication	8/31/2021	8/31/2021
Internal Testing and Evaluation	11/30/2021	11/30/2021
Techno-economic Analysis	2/28/2022	3/10/2022
Materials Refinement	2/22/2023	
H_2 Diffusion Studies	8/22/2023	
Simulated Testing	11/30/2023	
H_2 Flow loop Testing	02/22/2024	
Field Testing	05/21/2024	
Commercialization & Industry Outreach	07/30/2024	

Progress and Current Status of Project

Application Process & Material Fabrication

HydroPel-D	HydroPel-H
• Existing Infrastructure • Limited Surface Preparation • In Field Application	• New/Existing Infrastructure (Joints/welds) • Extensive surface preparation • Factory Application

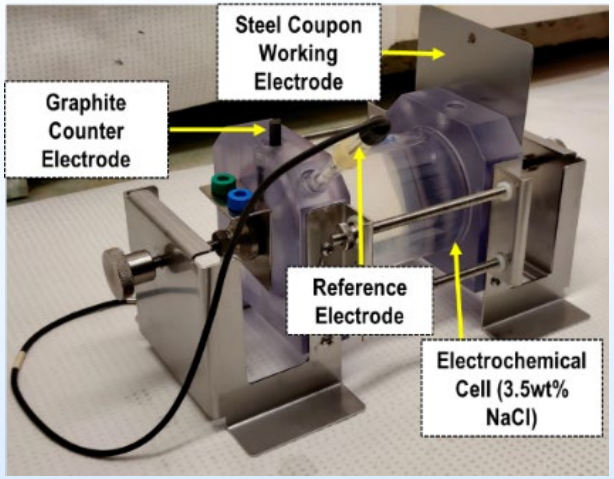
Application Process & Material Fabrication

Property	Target	Status
Surface roughness	Final roughness <40uinch	Achieved
Thickness	Overall thickness <4mil	<2 mil
Adhesion	PASS – crosshatch tape adhesion	PASSED
Pinholes	No Pinholes/holidays	Verified
Corrosion Rate	<0.1mil/year	Achieved
Embrittlement Resistance (ASTM F1624)	>50% compared to bare steel	Achieved

Material Testing & Evaluation

- Electrochemical Corrosion Studies
  - Corrosion potential and corrosion rate calculated

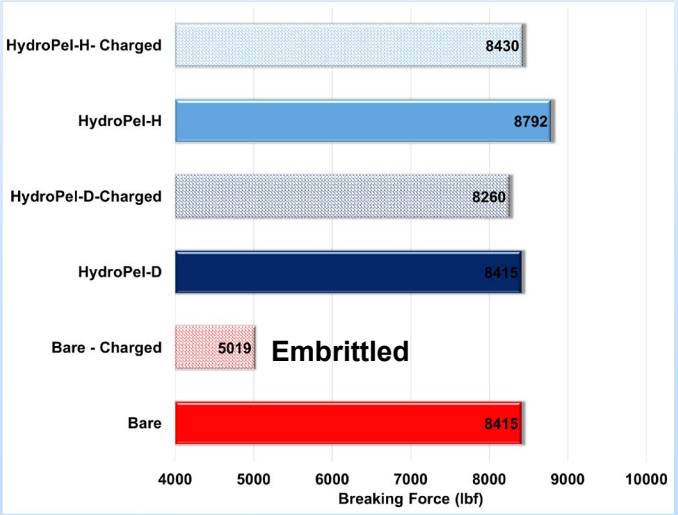
HydroPel shows 5 orders of magnitude more corrosion resistance than bare steel



	Control (Bare)	HydroPel-D	HydroPel-H
Corrosion Potential (V)	-0.67	0.19	-0.61
Corrosion Rate (mpy)	5.6	29e-6	18.5e-6

Material Testing & Evaluation

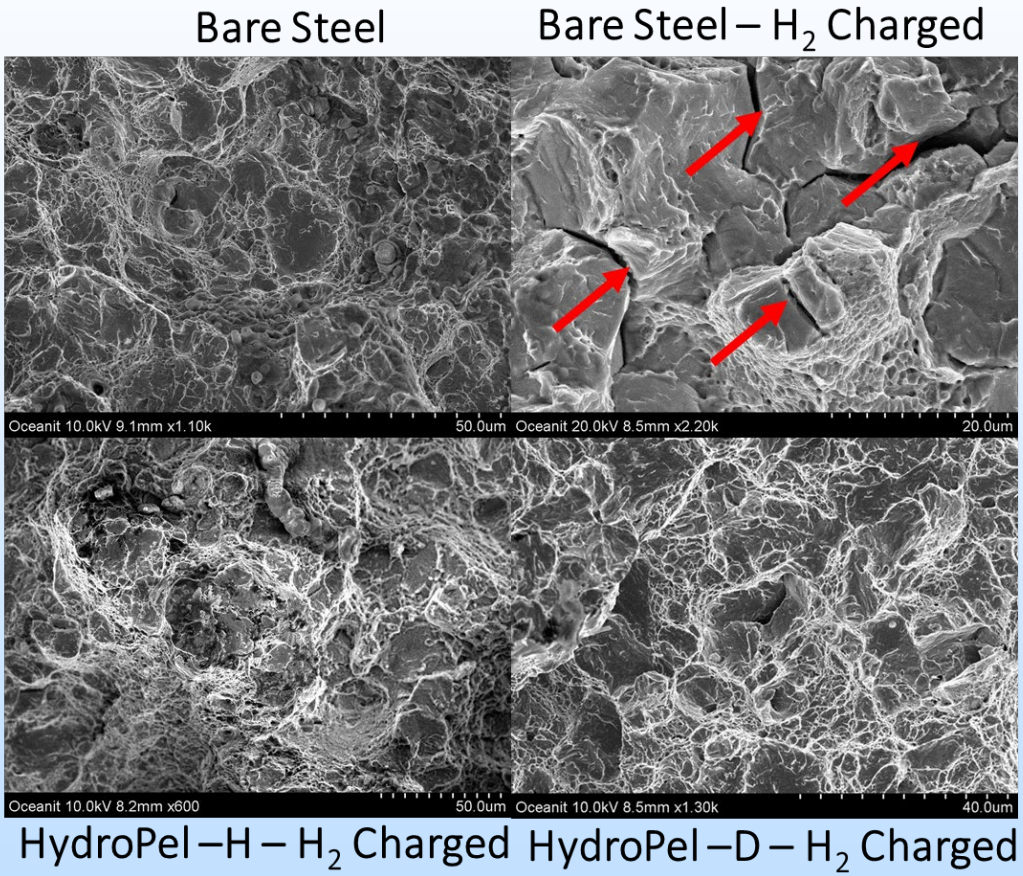
- Electrochemical Hydrogen charging on steel bars with and without HydroPel
- ASTM F1624 Slow Strain Rate Test (SSRT) Incremental step loading of hydrogen-charged and uncharged steel bars
- Electrochemical charging can produce hydrogen pressures >100 bar (1450psi)



HydroPel shows strong resistance against Hydrogen Embrittlement

Material Testing & Evaluation

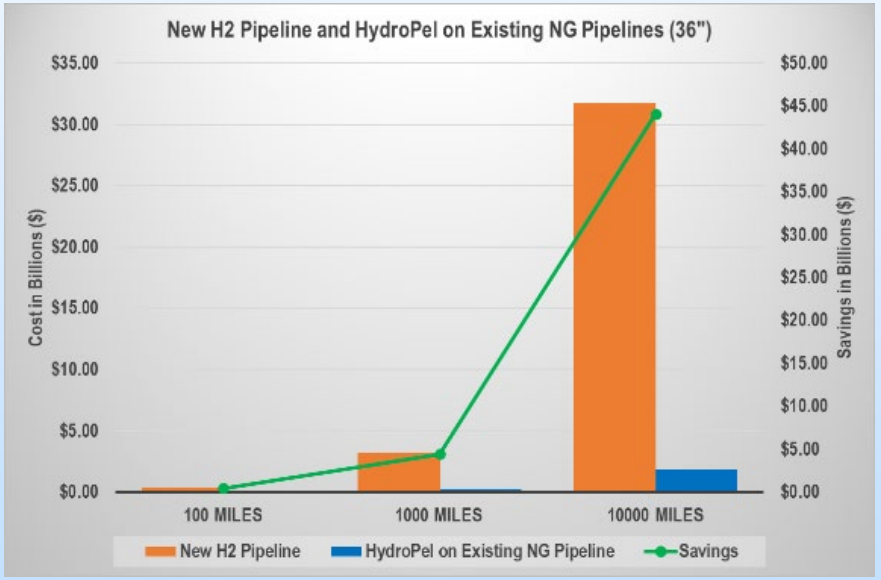
- Scanning Electron Microscopy (SEM) to investigate H_2 diffusion
- Post fracture testing, bare vs H_2 charged Samples imaged in SEM



Confirmation of brittle fracture in bare steel vs ductile fracture on protected steel

Economic Impact of Refurbishing Existing Natural Gas Pipelines

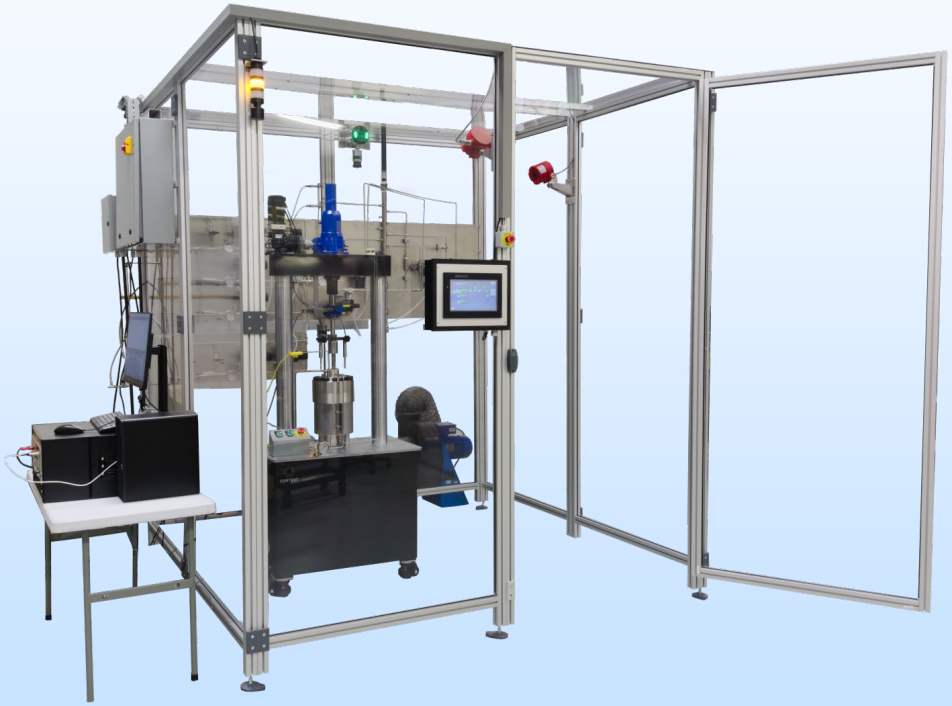
- Natural Gas Pipelines readily available (routes, ROW, no new permitting)
  - **HydroPel Material and Application only cost ~5% of New Pipe Installation**
- Reduces downtime by **3%**
- Reduces overall operation and maintenance cost by **15%**
- Tied up with PHMSA 192 Mega Rule for reapplication **every 7 Years if required**



Planned Activities

Simulated Testing

- High-pressure exposure and long-term studies on hydrogen environments
- Mechanical property evaluation under high pressure condition (Fracture/Fatigue)
- H_2-Methane Blends
- API-5L-X70 substrates



Flow Loop Studies

- Sub-scale flow loop set up for simulating actual hydrogen-natural gas flow
- Evaluate the performance of HydroPel and unprotected steel under blended gas flow

Field Exposure with industry partner

- Install HydroPel treated coupons in in-service gas pipeline
- Exposure to Methane/H_2 Blends
- Long-term performance monitoring (mechanical strength & microstructure)

Summary

Key Accomplishments

- Multimodal H_2 fracture testing shows strong H_2 resistance from HydroPel on steel
- HydroPel offers superior corrosion resistance and can be applied to new and existing pipelines
- Lab-scale demonstration confirmed Technology Readiness Level 5
- HydroPel costs ~5% of installing a new pipeline

Future Efforts

- Testing under relevant conditions (High Pressure, H_2:Methane Blends)
- Flow Performance Evaluation
- Sub-scale Field Testing with industry partner

Take - Away

- HydroPel is a scalable and high-performing solution for refurbishment of the existing natural gas pipelines for H_2 blending to promote decarbonization

Outreach

- Achieving Decarbonization Through the Transformation of Existing Pipelines for Hydrogen - Methane Blends, ADIPEC, 2022, SP-210959-MS
- https://www.bizjournals.com/pacific/inno/stories/news/2022/10/03/oceanit-and-hawaii-gas-pilot-hydropel-tech.html

Acknowledgements

- DOE SBIR
- NETL
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- Hawaii Gas

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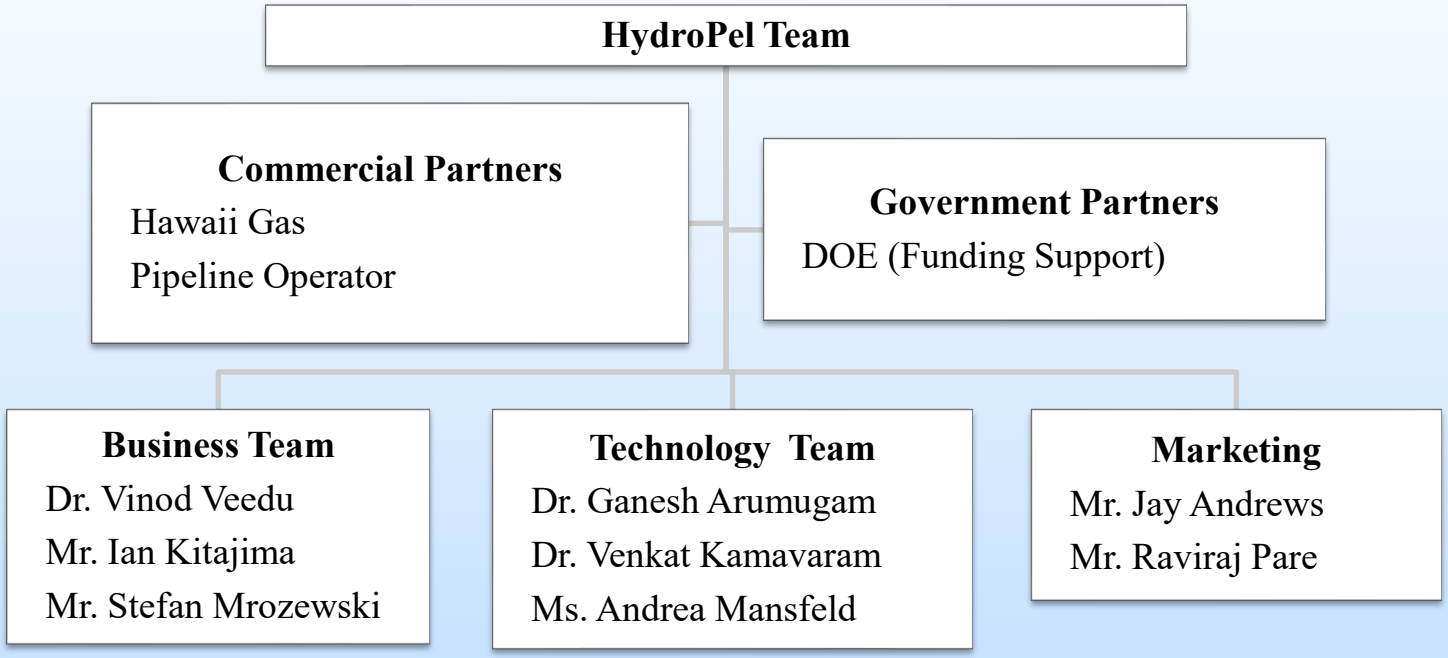
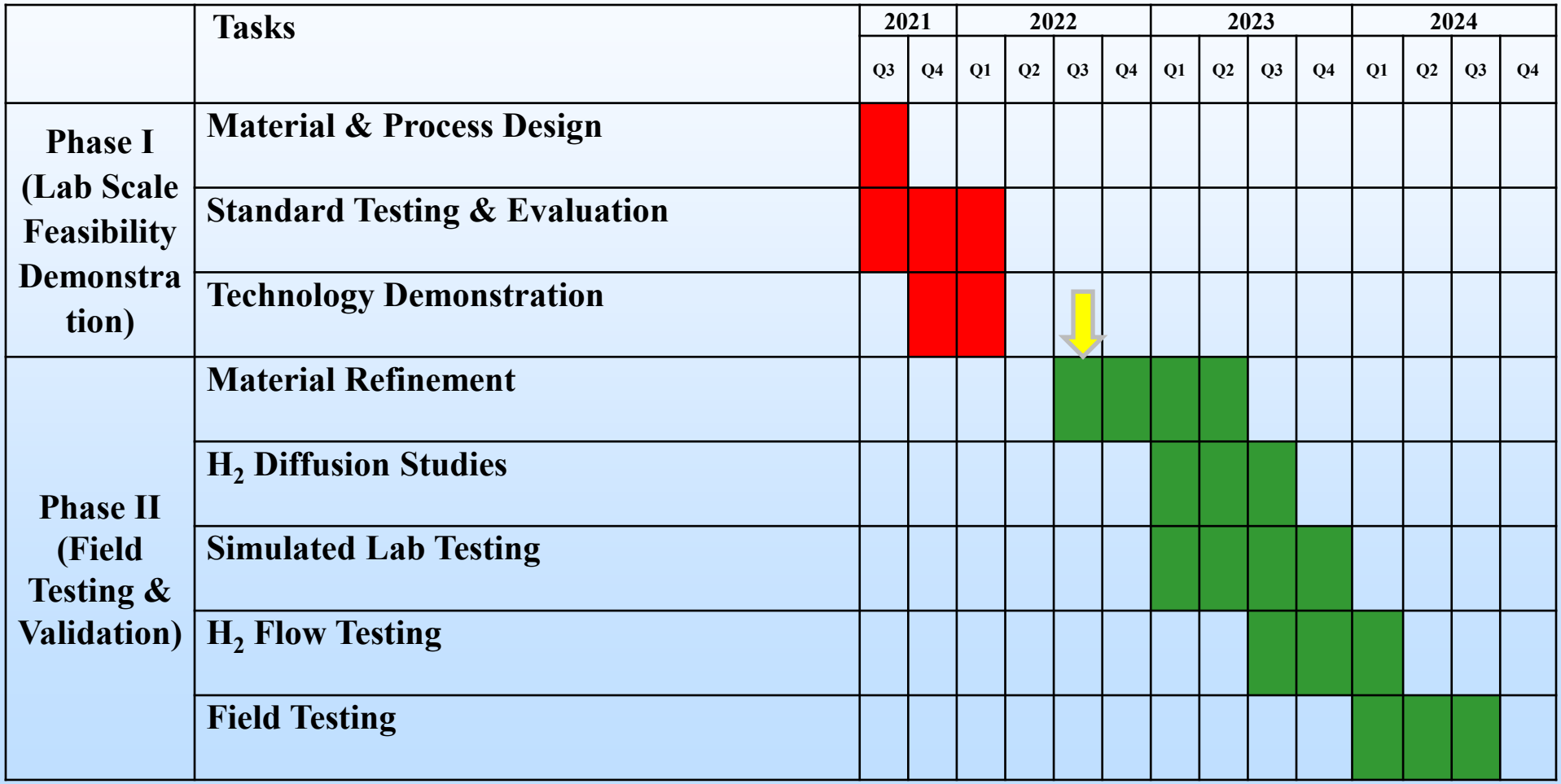
Organization Chart



Gantt Chart


Tasks
2021
2022
2023
2024
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Phase I (Lab Scale Feasibility Demonstration)
Material & Process Design
Standard Testing & Evaluation
Technology Demonstration
Phase II (Field Testing & Validation)
Material Refinement
H_2 Diffusion Studies
Simulated Lab Testing
H_2 Flow Testing
Field Testing