AMR Project ID: **IN043**
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# DEtection system Comprising Inexpensive Printed sensor arrays for Hydrogen gas Emission monitoring and Reporting (**DECIPHER**)

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SRI

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# Project Goal

Develop a distributed **network of hydrogen sensors** comprising **low-cost** sensor arrays printed with **carbon nanotube-based** transducers chemically modified to selectively detect low-concentrations of hydrogen gas with **<10 ppb sensitivity** in ambient conditions. The system will use a signal processing and data-analysis platform powered by machine-learning (ML) to **identify, quantify, and report** hydrogen concentrations with **high accuracy** and enable environmental monitoring.

# Overview

## Timeline

Project Start: September 2023

Project End: August 2026

## Partners

Pacific Gas and Electric Company®

## Budget

| | |
|---|---|
| Total FY23-FY26 | $ 1,949,450 |
| DOE share | $ 1,499,799 |
| Cost share | $ 449,651 |
| Funds spent | $ 128,897* |

**As of 02/29/2024*

## Barriers

- Low $H_2$ sensitivity and selectivity
- Inaccurate concentration quantification
- Lack of low-cost technologies

# Relevance and Impact

- DECIPHER will bridge the existing technology gap for economically viable accurate measurement and quantification of ppb-level changes in concentration of ambient $H_2$ and allow thorough analysis of the indirect impact of hydrogen-intensive economy on climate change.
- Advancing $H_2$ sensor technology for high $H_2$ sensitivity and selectivity using configurable and robust low-cost distributed sensor network with concentration quantification abilities.

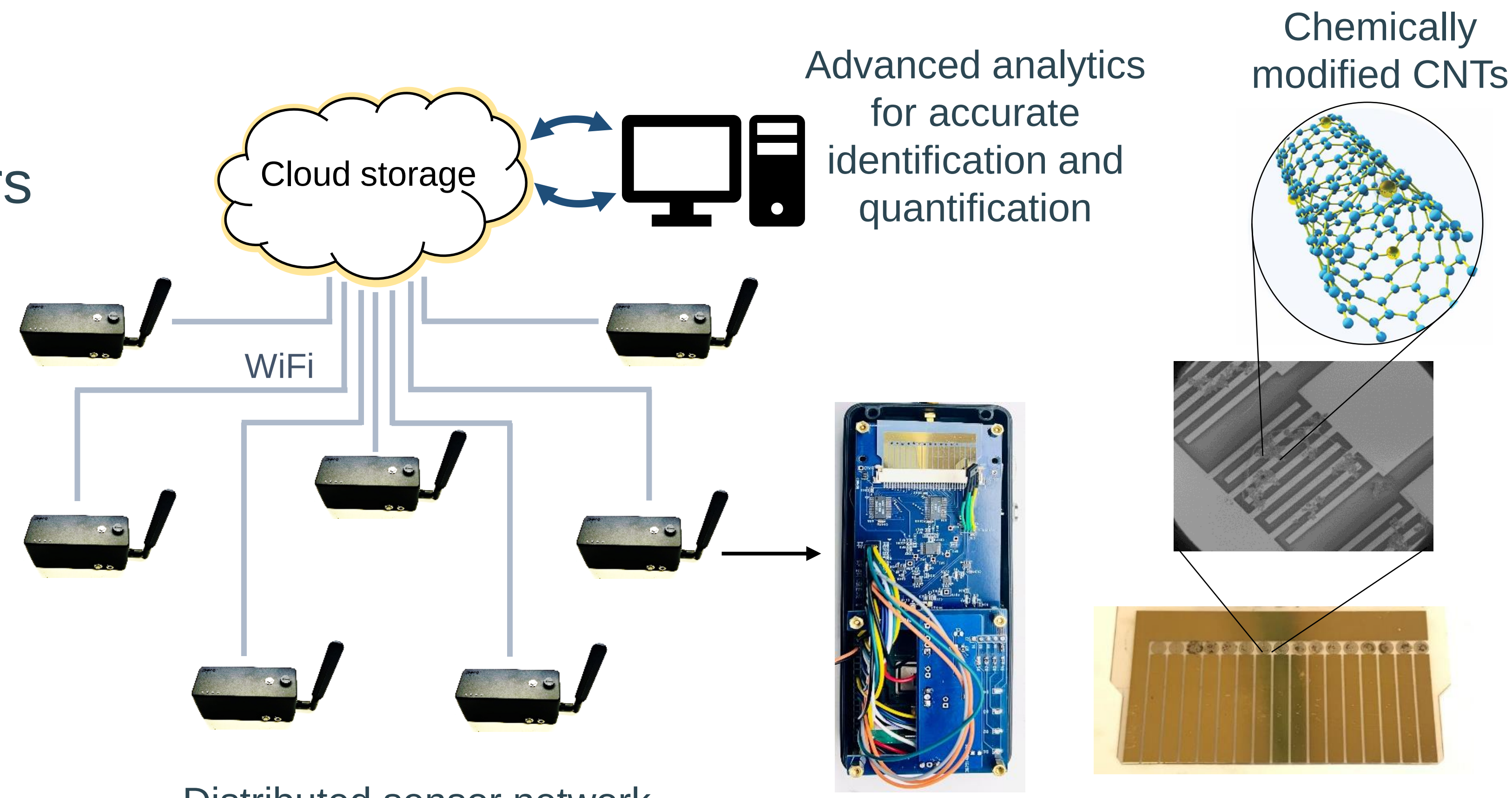
| Metric | Commercial $H_2$ Safety Sensors | Expected Advance |
|---|---|---|
| $H_2$ Sensitivity | ppm-level | < 10 ppb |
| $H_2$ Selectivity | Moderate | High |
| Life | >5 years | > 10 years |
| Quantification | NA | Yes |
| T/RH* influence | Moderate | Low |
| Cost | $500-$10k | <$150 |

**T: Temperature*
*RH: Relative humidity*

# Approach: Overview

- Novel CNT-based sensors
- Low-cost sensor device
- ML-powered analytical platform

- Hydrogen-to-Infinity project site for field-tests
- Infrastructure for field tests




Distributed sensor network in a field-test

Sensor device

Printed sensor array

# Approach: Milestones

| Key Milestones and Go/No-Go decisions | Target Month | Status |
|---|---|---|
| • >80% accuracy in predicting sensor response to T/RH change | 6 | In-progress |
| • $H_2$ limit-of-detection <50 ppb in air | 9 | In-progress |
| • >80% accuracy of $H_2$ selectivity in air | 12 | In-progress |
| **Go/No-Go:** $H_2$ sensitivity ≤15 ppb in air | **12** | |
| • Sensor device can detect ≥5 ppb change in $H_2$ concentration | 15 | In-progress |
| • Sensor lifetime >1 year | 18 | In-progress |
| • Fabricate devices and system integration for Field Test 1 | 21 | |
| • >80% accuracy of $H_2$ concentration quantification | 21 | |
| **Go/No-Go:** $H_2$ sensitivity ≤10 ppb in air | **24** | |
| • Demonstrate system capabilities: Field Test 1/Field Test 2 | 27/33 | |
| • Sensor response time ≤30 s, recovery time <60 s | 33 | |
| • Sensor lifetime >10 years | 33 | |
| • Technology evaluation and cost analysis | 36 | |

# Approach: Safety Planning and Culture

## Safety Plan

**Required:** Yes

**Comments:**

- Changes implemented as recommended, safety plan updated, and conference call scheduled with Hydrogen Safety Panel (HSP) to address all comments.
- Safety plan will be updated again and resubmitted for review after PG&E facility safety survey in Q6.
- General lab-safety training completed by all team members.
- New oxygen and VOC sensors installed in lab to detect leaks.
- New pressure transducers and gauges installed on pressurized lines.

## Prioritizing safety/analyzing hazards

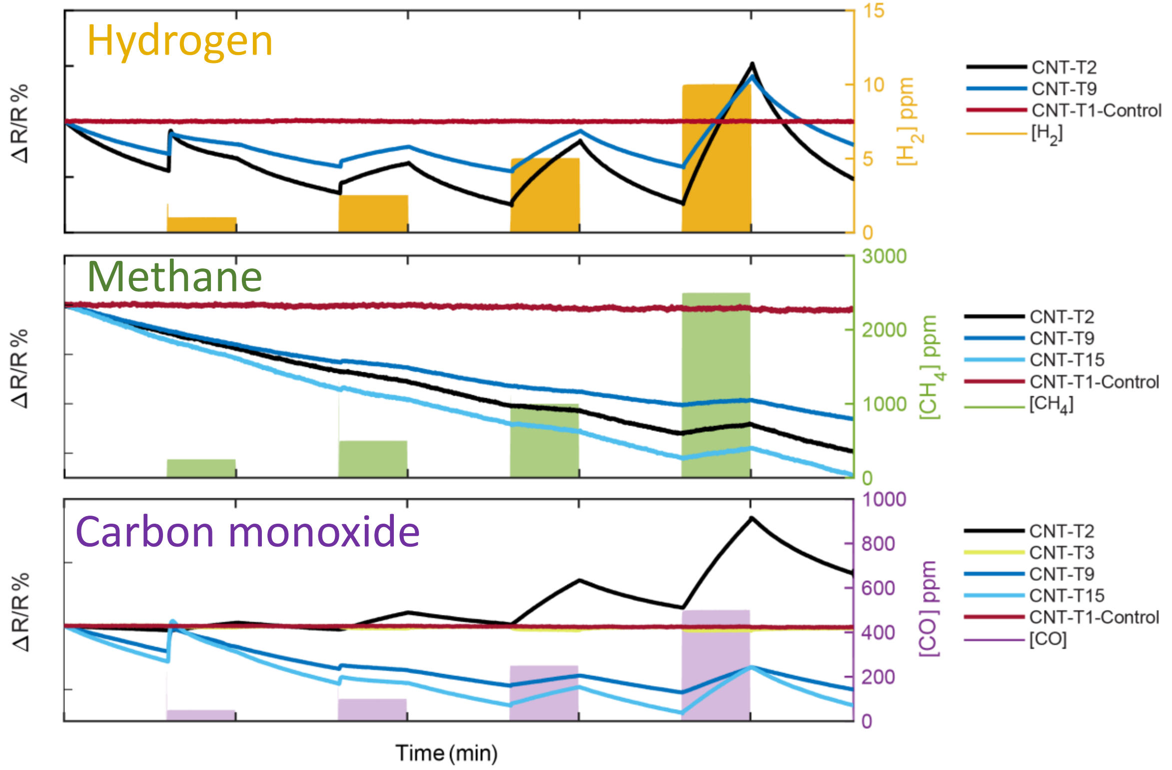
- PI and team will complete hydrogen safety training course as recommended by HSP before Q9.
- Conduct HAZOP of system operations after every maintenance and modifications.
- Field Test facility and operations safety survey and review will be conducted by PI along with safety professionals from PG&E.
- SRI has lab safety practices and training available to all team members.

## Best Practices/ Lessons learned

- Monthly safety meetings to track and address safety related changes, issues and resolution.
- All team members have been trained to identify and report lab-safety concerns.

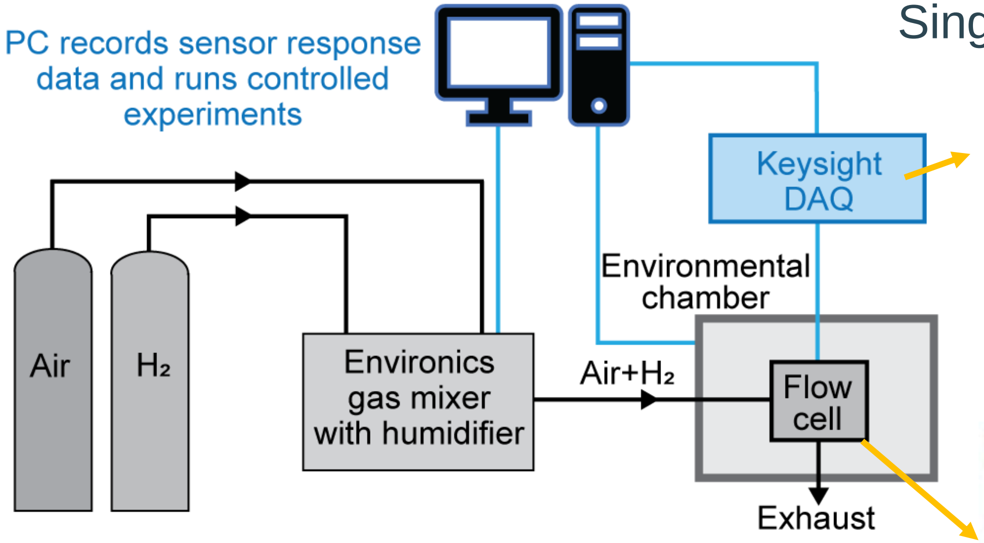
# Accomplishments: Task 1-Gas sensing material development

- 15 different CNT-based transducers were chemically synthesized.
- CNT-based transducers were drop-casted on a sensor array and tested against hydrogen ($H_2$) and interferents like methane ($CH_4$) and carbon monoxide (CO).
- Observed $H_2$ detection = 1 ppm.



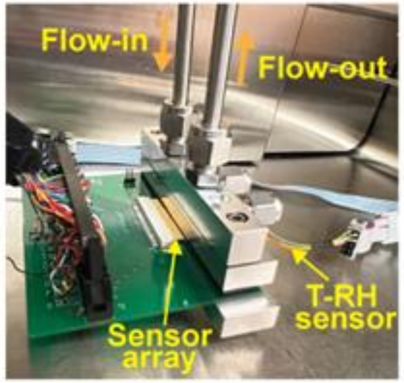

*Only the CNT-based transducers that exhibited a response to each gas are presented here*

# Accomplishments: Task 2- Analytical model development for high selectivity

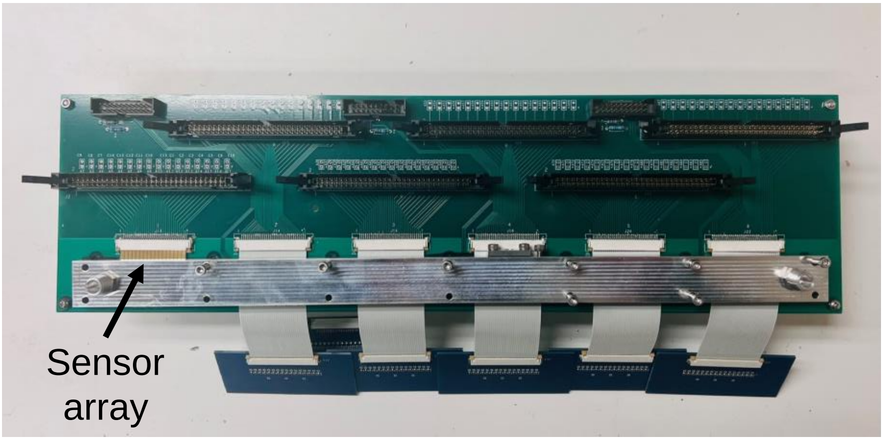



Single port data acquisition

Six ports data acquisition




Single sensor port flow cell




Fabricated six sensor ports flow cell

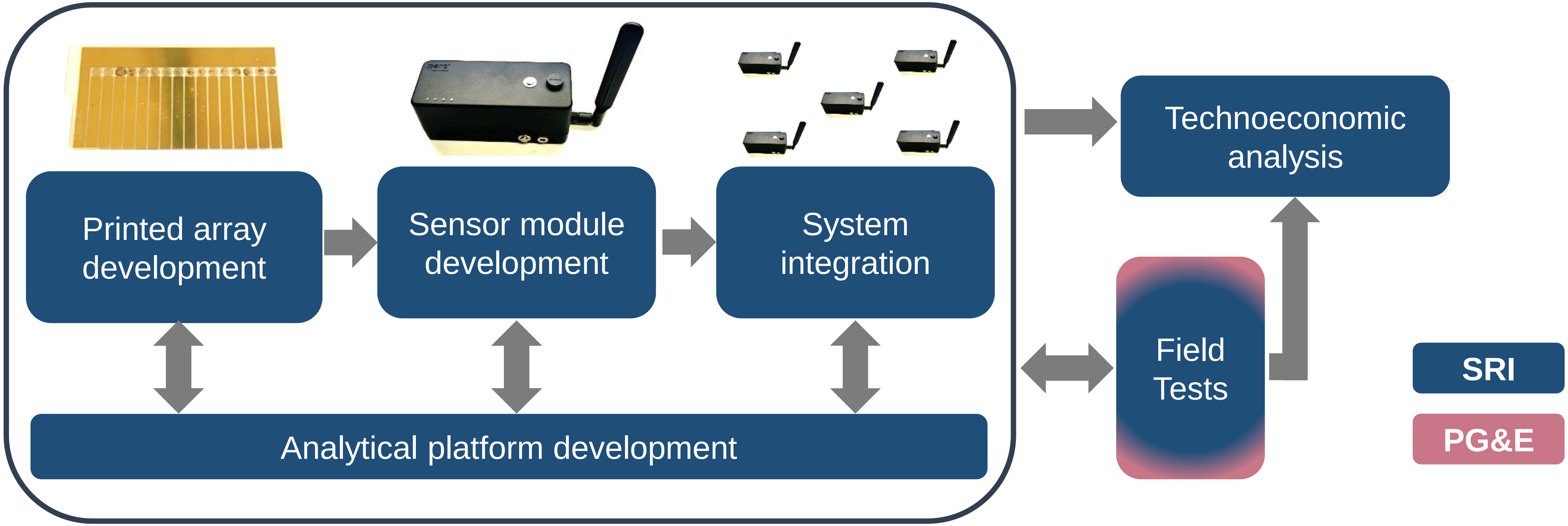
- System upgrade in-progress to enable testing six sensor arrays in a single experiment.
- System upgrade will enable large amount of data collection required for ML-based models.

## Accomplishments and Progress

# Responses to Previous Year Reviewer's Comments

- This project was not reviewed last year.

# Collaboration and Coordination



# DEIA/Community Benefits Plans and Activities

- DEI plan required: Yes
- **Equity impact:** Disadvantaged or low-income communities are disproportionally located close to high-risk areas for exposure to fugitive emissions. Low-cost H2 monitoring can safeguard such communities against unintended consequences of emissions.
- **Diversity:** Hiring at SRI is designed to promote diversity and inclusion.  All employees are educated through mandatory trainings, workshops, recognitions and policies to ensure diversity and inclusion principles are well communicated.
- Three SMART milestones created for the project to create diverse project team and increase awareness about DEI within team and in local community.
  - Completion of at least one DEI training/year by project team.
  - Encourage and report efforts for hiring from minority serving institutions (MSI).
  - PI will participate in at least one volunteer activity for STEM outreach in MSI.
- **PG&E** strives to support DEI culture through hiring policies, trainings, workshops and awards. PG&E supports, collaborates with and sponsors events for DEI community and organizations.

# Remaining Challenges and Solutions

- **Maximizing $H_2$ sensitivity:** CNT-based transducer development and optimization of chemical modifications.
- **Maximizing selectivity**: Development of array with selected CNT-based transducers for maximum sensitivity to $H_2$ and orthogonality to interferents.
- **Engineering a robust and safe sensor device:** Low-power and low-voltage devices designed to transfer data securely to a cloud database.
- **Minimizing cost:** Low-cost sensor array, ultra-low quantities of transducers, low-power device, and minimal installation and maintenance cost.
- **Maximizing accuracy of identification and quantification:** Data-based models powered by ML for accurate pattern recognition and quantification.
- **High adaptability of distributed sensor network:** Integrating distributed sensor network of strategically installed stationary point sensors.

# Proposed Future Work

- **CNT-based transducer development for:**
  - <10 ppb $H_2$ sensitivity with high selectivity in presence of interferents.
  - Minimize degradation for long sensor lifetime.
  - Estimate and improve sensor lifetime.
- **Sensor device development for:**
  - Low-power and low-voltage requirements.
  - Able to read resistance change for $H_2$ concentration change ≤10 ppb.
- **Creating large sensor data sets:** For development of databased models using ML for enabling >80% accuracy in identification and quantification.
- **Field Tests:** Deploying distributed sensor network at PG&E facility for demonstrating and improving system capabilities.

# Summary

- Synthesized 15 CNT-based transducers used for detecting hydrogen and interferent gases.
- Printed sensor arrays with 15 CNT-based transducers and tested against hydrogen, methane and carbon monoxide.
- Hydrogen concentrations down to 1 ppm detected using CNT-based transducers.
- Sensor testing system upgrade in-progress to enable large data set generation for developing robust databased models.
- Sensor device designing in-progress to fabricate a safe low-power device.

# Thank you!

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