LEAK DETECTION STRATEGY FOR HYDROGEN EMISSIONS MONITORING

Element One, Inc.
Mission and Needs

Focusing first on hydrogen and then on hydrogen sulfide and other hazardous gases, Element One will become the supplier of the next generation of very low-cost gas detectors.

Element One in Hydrogen Research

Element One personnel have over **80 years** aggregate hydrogen R&D experience, multiple **PhD researchers**, **Harvard Business** school graduate, and technical **commercialization experts**.

Why Hydrogen Leak Detection?

Safety	Personal Public Asset
Economics	Even at $2/kg or less, leaking hydrogen could result in excessive, preventable losses. Columbia University Estimated $59B in losses in 2050
Environmental	Hydrogen 100-year GWP is roughly 11. Excessive leaks could negate the positive benefits hydrogen provides
Codes	Codes exist for safety related leak detection Codes are coming that will regulate overall hydrogen emissions for environmental concerns

Safety Concerns With Hydrogen

Personal Safety

- Protect personnel from deadly flammable/explosive conditions

Public Safety and Acceptance

- In the past, undetected hydrogen leaks have put public safety at risk. As more hydrogen is used, these occurrences must be minimized!

Asset Protection

- Fires and explosions can cost millions in emergency response and property/asset damages

Learning From Methane

Natural gas was seen as cheaper and “cleaner” than coal at the time

NG promised lower CO2 and sulfur emissions

Methane leaks made this energy transition much harder and “dirtier” than it needed to be

Leaking as little as 2 – 5% could completely negate the benefits of switching from coal to NG.

As the next energy transition comes, we must ensure hydrogen leaks don’t cause similar problem

Excessive hydrogen leaks could cancel out the positive environmental benefits hydrogen offers

Currently Leak Detection Technologies

- During construction and initial pressure testing
  - Pressure hold, soapy water, sniffers
  - Labor intensive, but functional for initial leak testing
  - Not sufficient for long-term leak prevention. Fittings loosen and soapy water or sniffers are too labor intensive for continual monitoring

Currently Leak Detection Technologies (cont.)

Area Monitors are currently standard and required in most cases

Regularly fails to detecting outdoor leaks

Reasonable for indoor use, but can't locate leak point

Ultrasonic is getting better, but still has issues

False positives and missed leaks are still an issue

Air/nitrogen leaks, hydrogen flow through valves, weather, etc.

Flame Detectors

By the time a fire eye signals, you already have a fire

Blind spots and false positives

Related Strategies

Indoor Leak Detection

- Point sensors in HVAC can signal when there is excessive hydrogen leaks
  - No leak location
- Hydrogen entrainment from outdoors
- For smaller containers – open doors and increase exchange rates

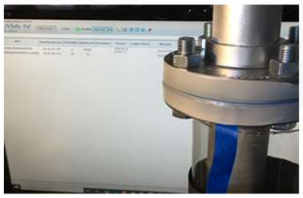
Outdoor Leak Detection

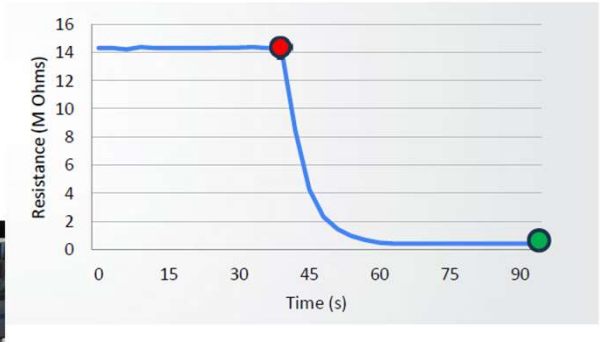
- Check for leaks during construction then assume it won't leak again – bad assumption
- Outdoor area monitors and ultrasonic detectors are insufficient
- Larger leaks can be signaled with mass loss alarms. System ID but no location typically
- Most outdoor leaks go unnoticed because they don't present the same level of danger

Visual and Remote Hydrogen Leak Detection

- **Self-fusing tape** that rapidly changes color when exposed to hydrogen (chemochromic reaction)

- **Wireless sensors** provide a rapid, drastic reduction in measured electrical resistance when exposed to hydrogen

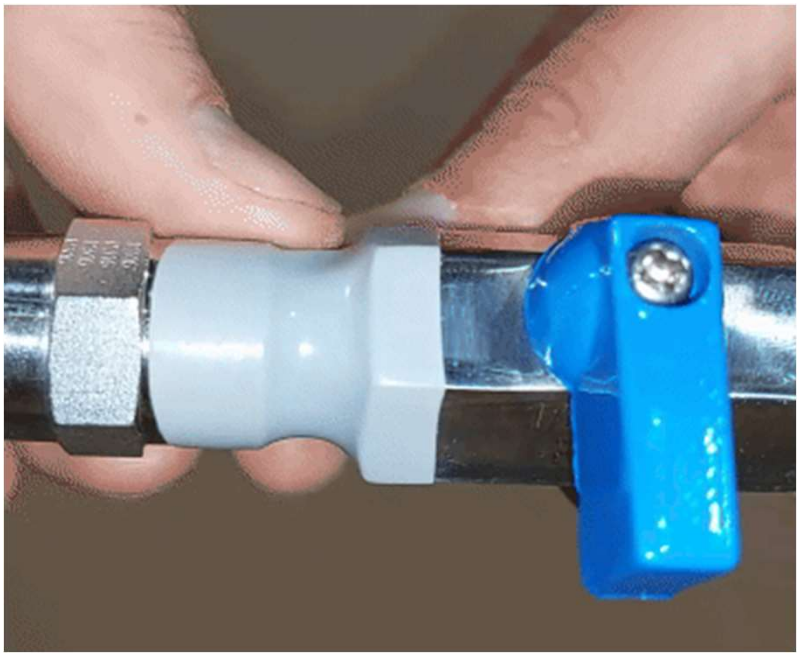


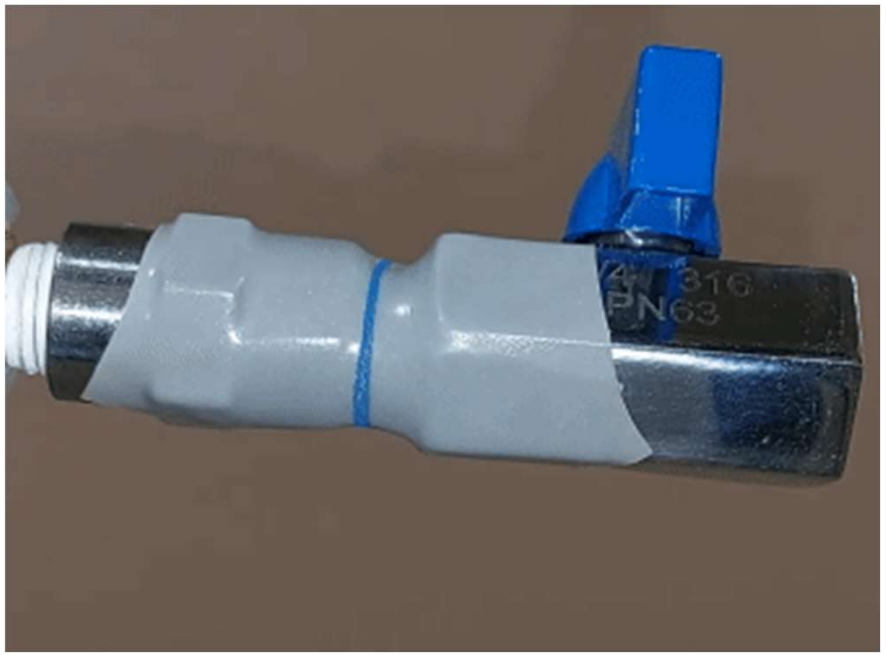


Element One's methodology is simple and reliable, and is complementary to proposed leak detection technologies

DetecTape Reaction

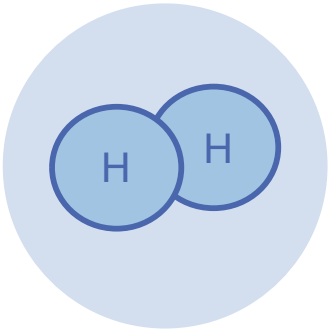
1” and 2” DetecTape reacting to hydrogen at 100mL/min (1g/hr)





Detection/Quantification Strategies

SOURCES OF HYDROGEN EMISSIONS



PARTS PER BILLION STRATEGY

ELEMENT ONE'S STRATEGY

Sources of Emissions

Intentional emissions/venting – known location and amount

- Electrolyzers, fuel cells, compressors, dryers, etc.
- Flow rate and concentration data can be used to calculate total amount vented
- System operators are best for handling this – can be automatically calculated

Unintentional leaks – very hard to locate and quantify

- Leaky fittings, flanges, etc.
- Difficult to know that the leak exists
- Even after you know you have a leak, hard to locate without lots of man-hours

Parts Per Billion (ppb) Strategy

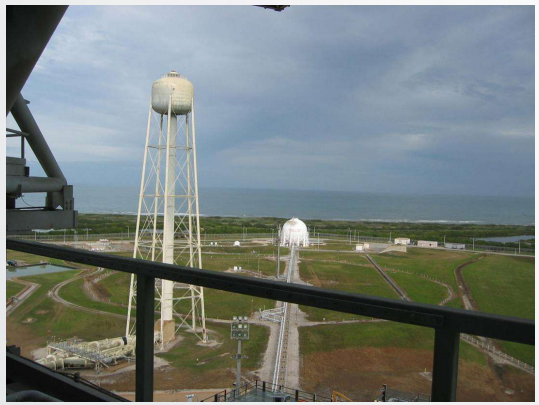
- DOE/ARPA-E has recently invested $18 million dollars into "Advance Research in Hydrogen Detection Systems"
  - This funding opportunity was geared towards ppb detection strategies.

- This detection strategy generally includes:
  - Develop hydrogen sensors that can detect down to 500ppb +/- 5ppb
  - Feed sensor and weather data into a model
  - Use the model to back calculate emissions amount and location

ARPA-E/DOE Strategy Problems

- Such sensors are often expensive, unstable, and require extensive field calibration.
- Multiple hydrogen sensors and substantial weather data would be required to get meaningful data.
- Models need extensive support for validation.
- Troublesome conditions: No wind, high wind, rain, turbulence, construction, etc.
- Extensive training required to ensure accurate data.
- Not simple or inexpensive
  - ARPA-E / DOE funding projects to quantify hydrogen emissions – Regulations are coming
  - PPB sensors and strategy will be insufficient to quantify and locate small-medium leaks.

NASA/KSC H_2 Supply Dewar and pipeline



- ~ 800,000 gallon liquid hydrogen tank
- ¼-mile supply vacuum jacketed
- pipeline
- Area evacuated during refueling
- Numerous electronic sensors
- Line purged with helium after fueling space shuttle
- Leak detection difficult after the fact

NASA/KSC Hydrogen Detectors

Electronic hydrogen detectors have difficulty detecting leaks as little as a few inches away from the leak source due too rapid dispersion, wind direction and direction of leak.

Even when a leak is detected by an electronic sensor, it does not tell you where the leak source is. It can be quite labor intensive and time consuming to locate the leaking fitting.

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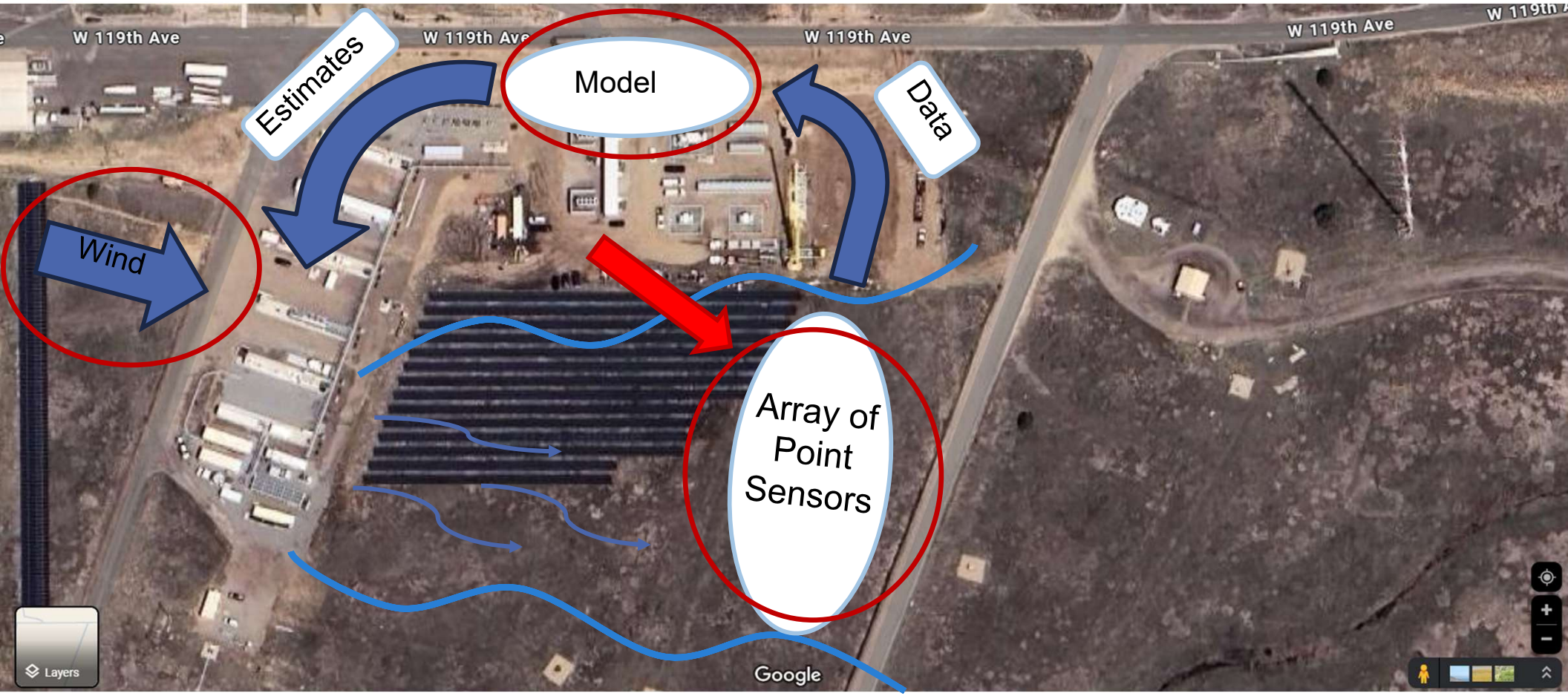
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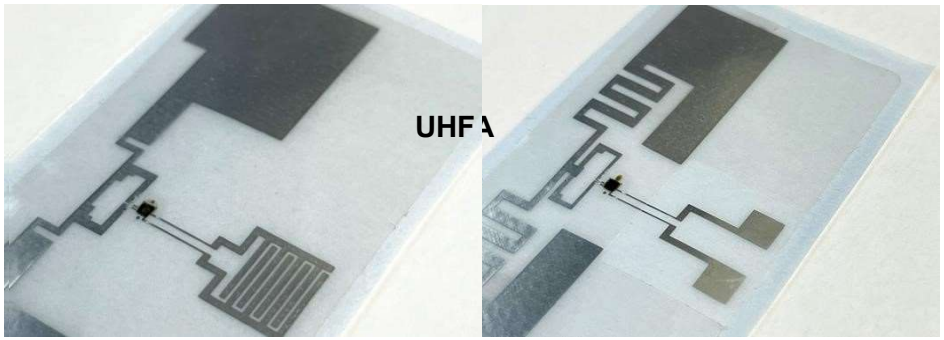
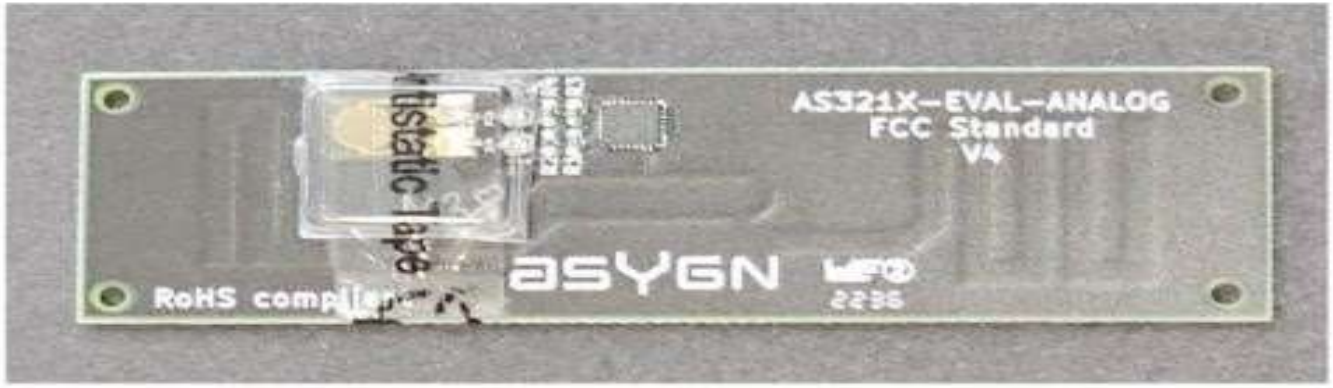
Estimates
Model
Data
Wind
Array of Point Sensors
Layers
Google

Sensor and E-Guard UHF Tag



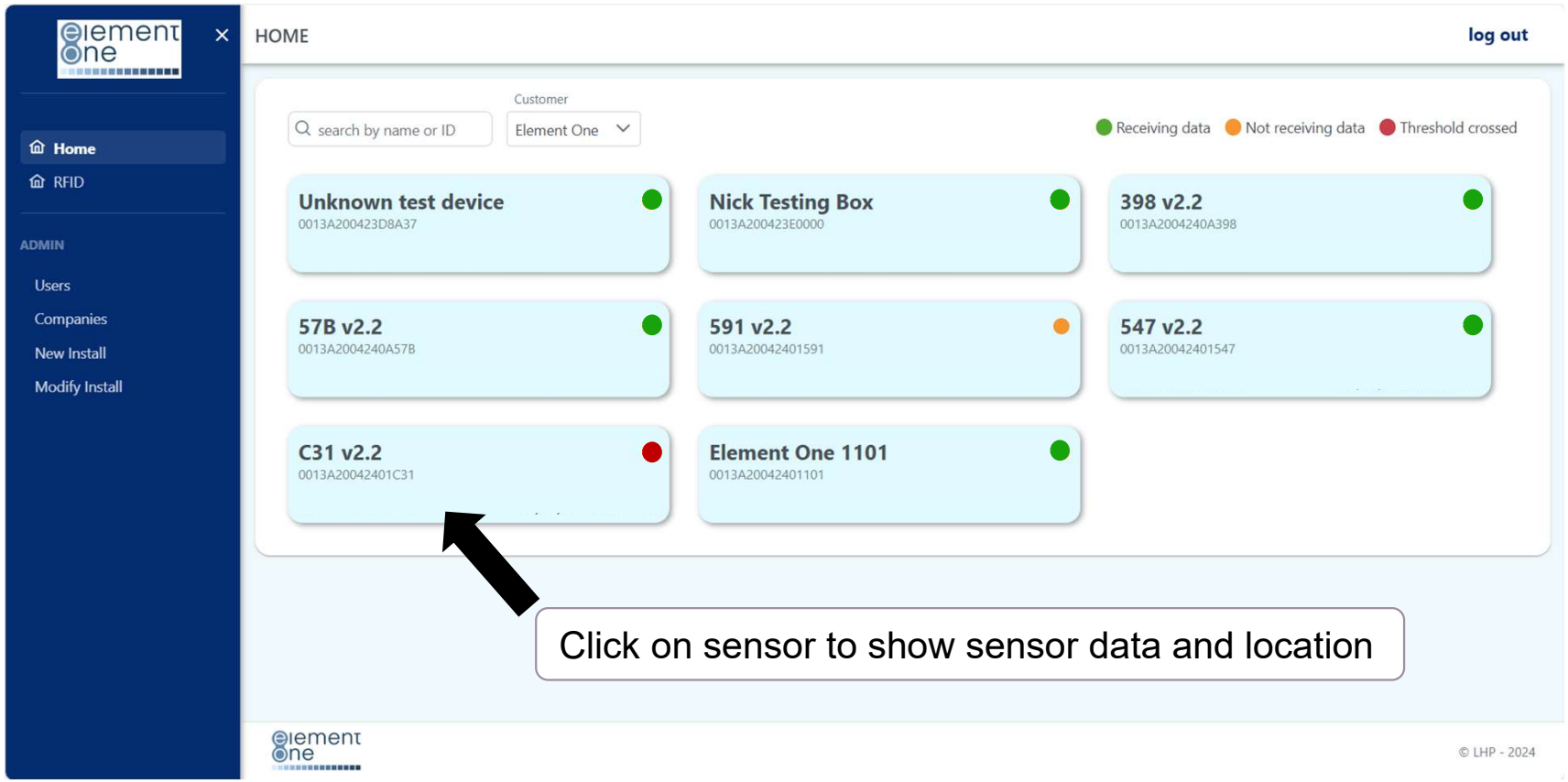


Element One - Detection Simplicity

- The closer the sensor is to the leak, the more reliable the response will be.
  - Tape/sensors will be exposed to 100% gas concentration regardless of conditions

- Widely populating sensors at potential leak points greatly reduces the chance that hydrogen will escape to the atmosphere without first passing over a sensor

IoT Sensor Interface



Needs for Successful Emissions Reduction

- Low cost – must lower the price of hydrogen
- Easily adaptable for many different applications
- Complementary to other proposed solutions
- Designed with industry in mind – simple and easily integrated into existing infrastructure

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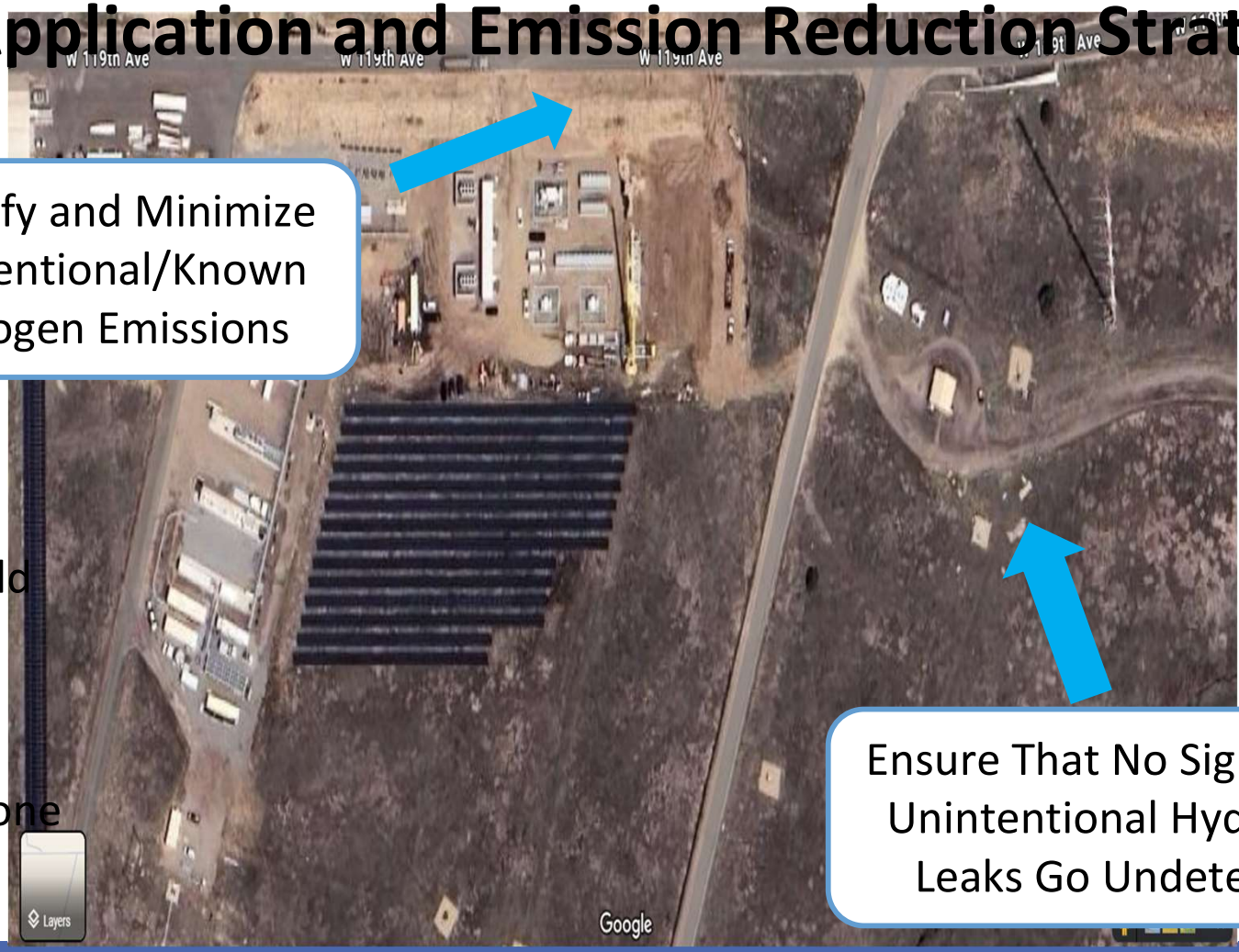
Thank you!

Element One would like to acknowledge the support
of the DOE SBIR program and
the cooperation of the National Renewable Energy
Laboratory

Application and Emission Reduction Strategy



Quantify and Minimize All Intentional/Known Hydrogen Emissions

- No modeling or field calibration needed
- Strategy is easily transferable from one system to the next

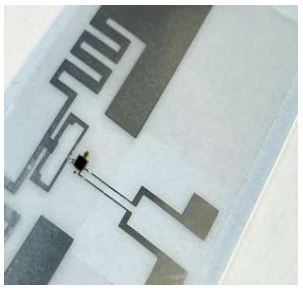
Ensure That No Significant Unintentional Hydrogen Leaks Go Undetected

Element One in Hydrogen Research

Bill Hoagland
Founder and President

45 years of Hydrogen R&D

Formerly Hydrogen Program Manager at NREL



David Pearman
Detection Research Engineer

4 years of Hydrogen Leak Detection Research

Formerly a Hydrogen Research Engineer at NREL

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