Modeling of H_2 Dispersion at ARIES

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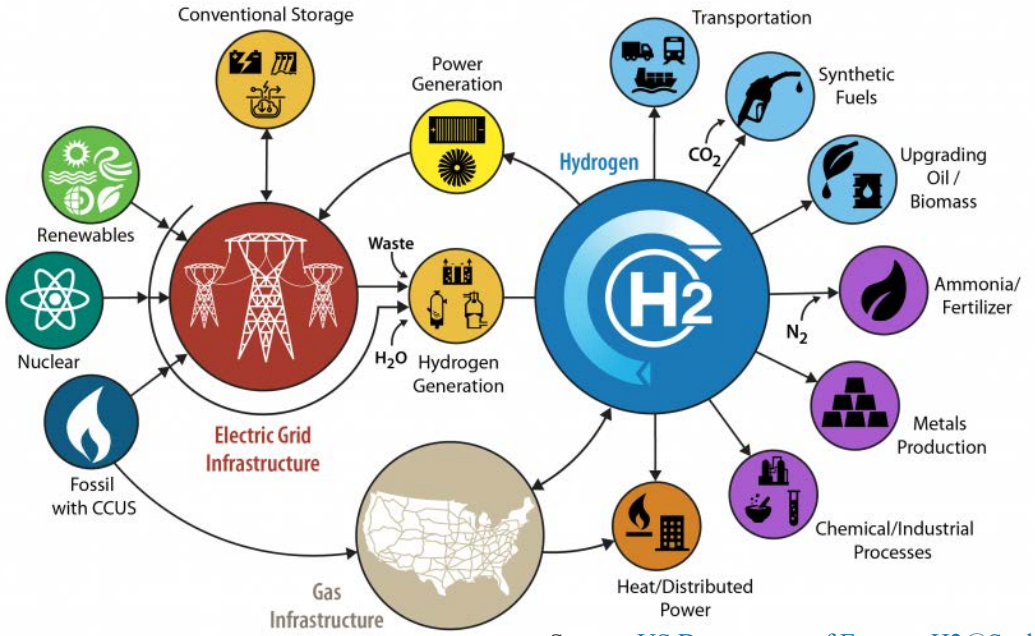
Hydrogen emissions



Source: US Department of Energy, H2@Scale

Important questions:

1. where does emissions go and in what concentrations? How much hydrogen was lost?
2. Where should facilities place sensors to detect leaks? How many sensors?
3. Can you do wide area monitoring for hydrogen emissions?

and more…

Hydrogen emissions monitoring

Safety

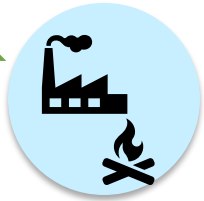
- Small scale (<100 m) monitoring
- Economic impact
- Local regulations

Environmental

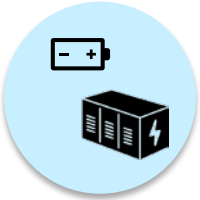
- Large scale monitoring (>100m)
- Global warming impact
- Broad environmental regulations

Aspects of sensing and monitoring

Where?



Production



Storage

Transportation

Refueling stations

How?

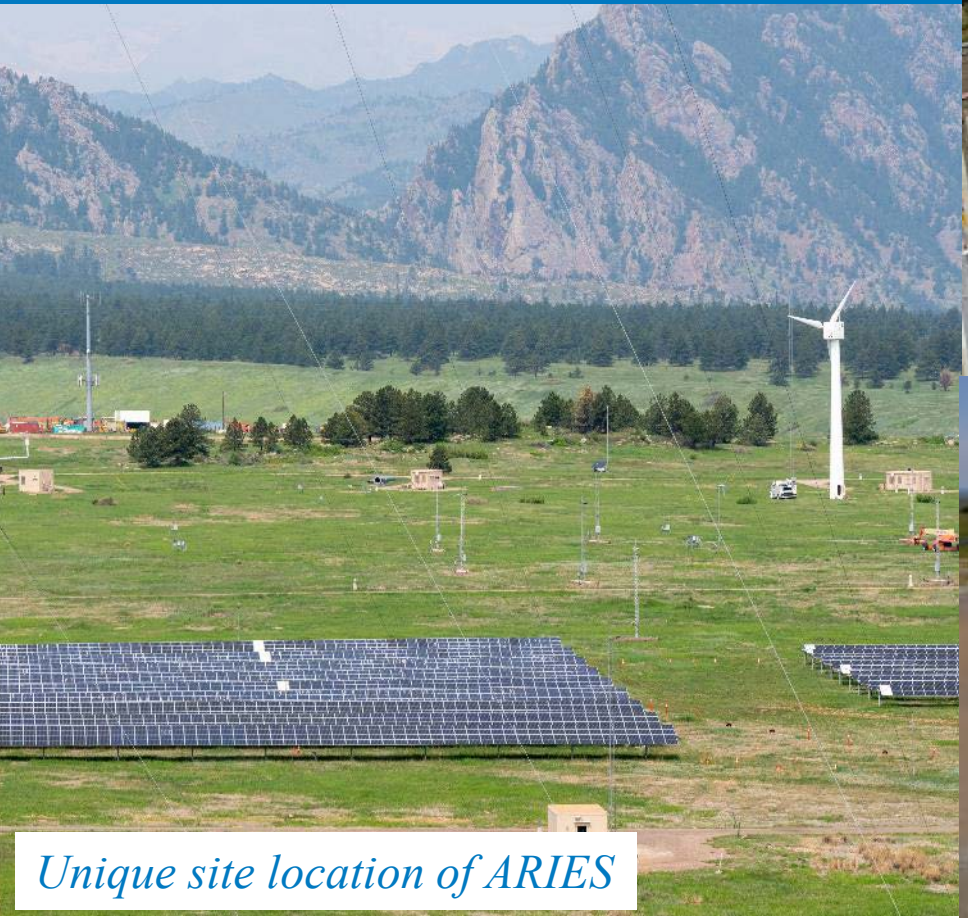
- Mass spectrometry
- Thermal conductivity
- Electrical conductivity
- Metal oxide sensor
- Combustible gas sensor

What?

- Detection
- Measurement

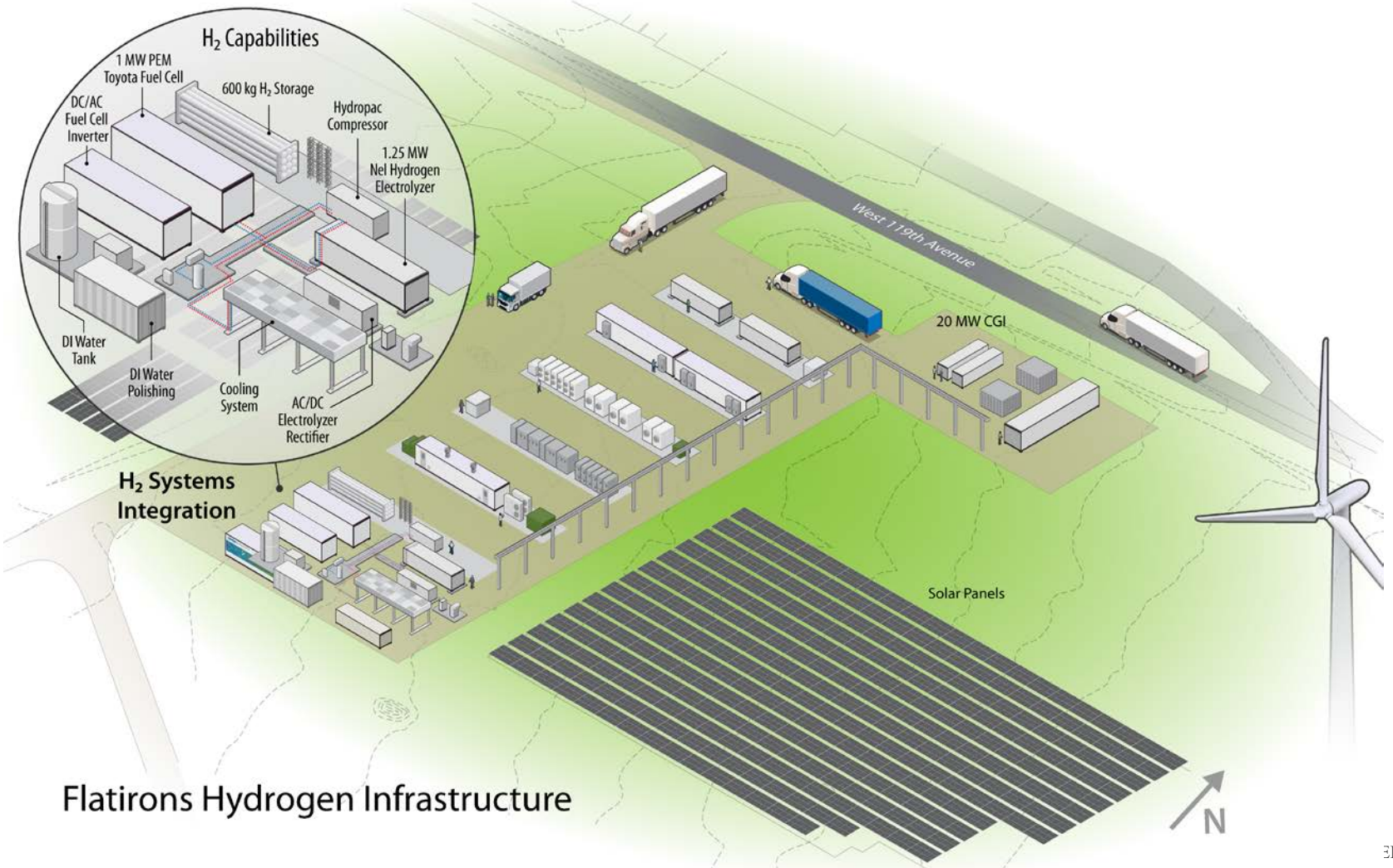
- Detection and measurement strategies changes with each use case
- Economic viability, desired resolution and confidence in measurement instrument are important.

NREL Flatirons Facility

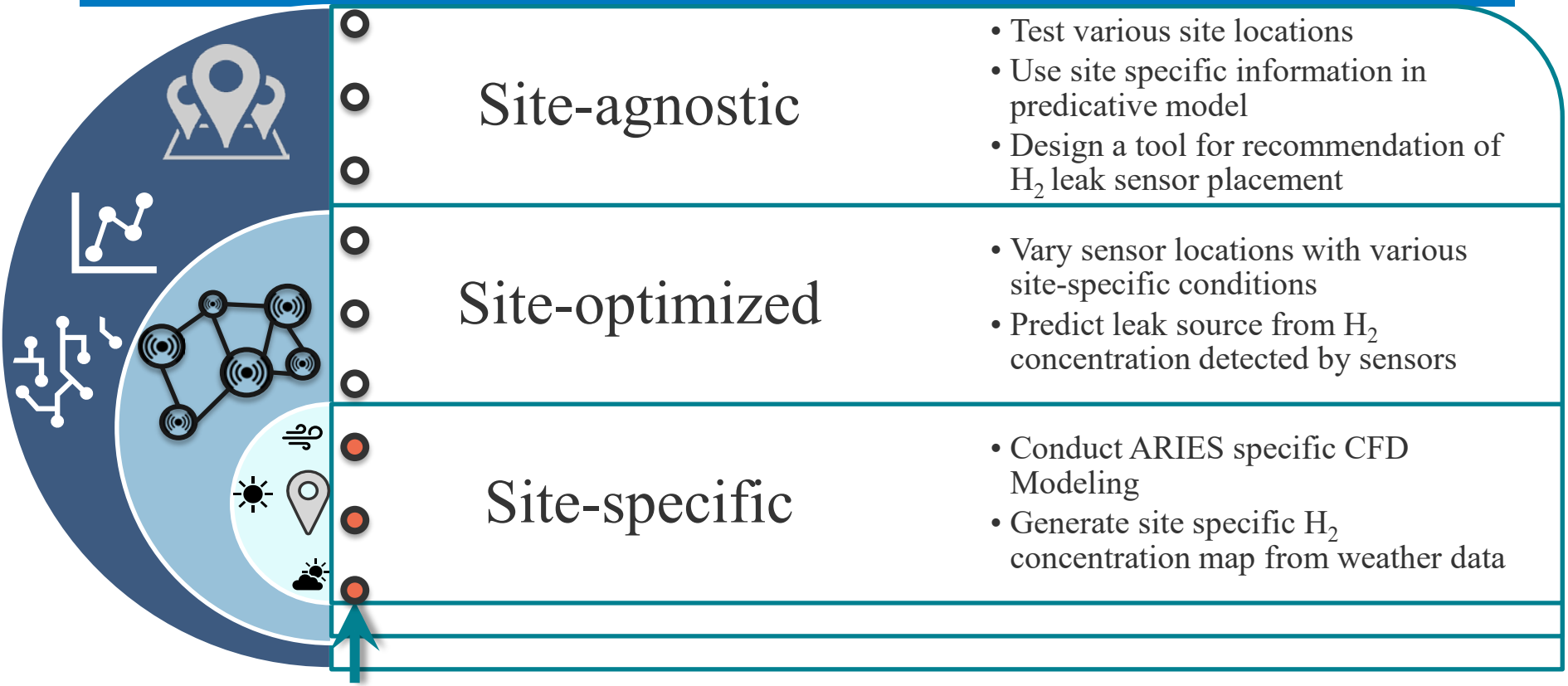


Unique site location of ARIES

Aerial view of the hydrogen infrastructure and grid integration research pads at National Renewable Energy Laboratory's (NREL's) Flatirons Campus.


H2 Capabilities
1 MW PEM
Toyota Fuel Cell
600 kg H2 Storage
DC/AC
Fuel Cell
Inverter
Hydropac
Compressor
1.25 MW
Nel Hydrogen
Electrolyzer
DI Water
Tank
DI Water
Polishing
Cooling
System
AC/DC
Electrolyzer
Rectifier
H2 Systems
Integration
West 119th Avenue
20 MW CGI
Solar Panels
N
Flatirons Hydrogen Infrastructure

Dispersion modeling - Long-term goals



Site-agnostic

- Test various site locations
- Use site specific information in predicative model
- Design a tool for recommendation of H_2 leak sensor placement

Site-optimized

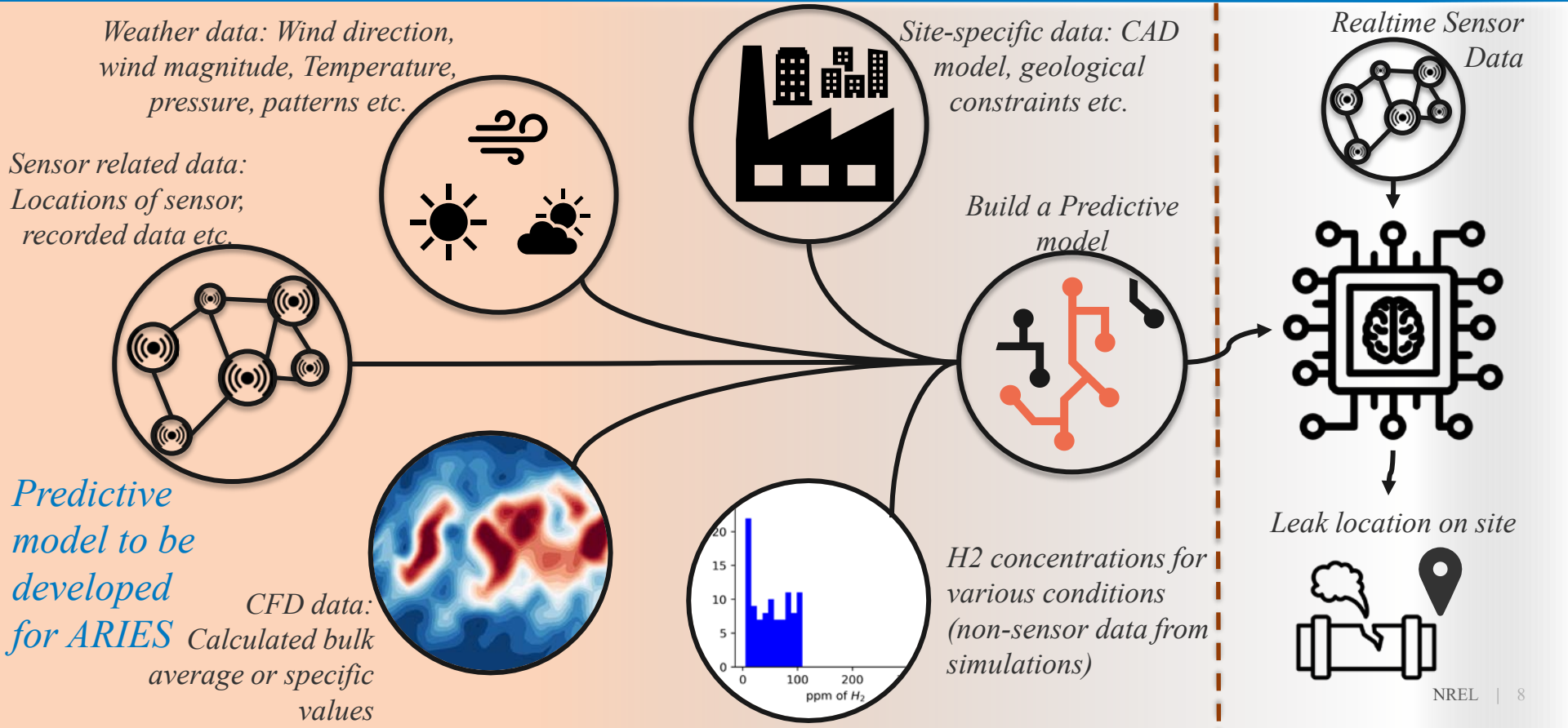
- Vary sensor locations with various site-specific conditions
- Predict leak source from H_2 concentration detected by sensors

Site-specific

- Conduct ARIES specific CFD Modeling
- Generate site specific H_2 concentration map from weather data

Three stage plan for hydrogen dispersion modeling

Hydrogen Dispersion modeling: Blocks for predictive model

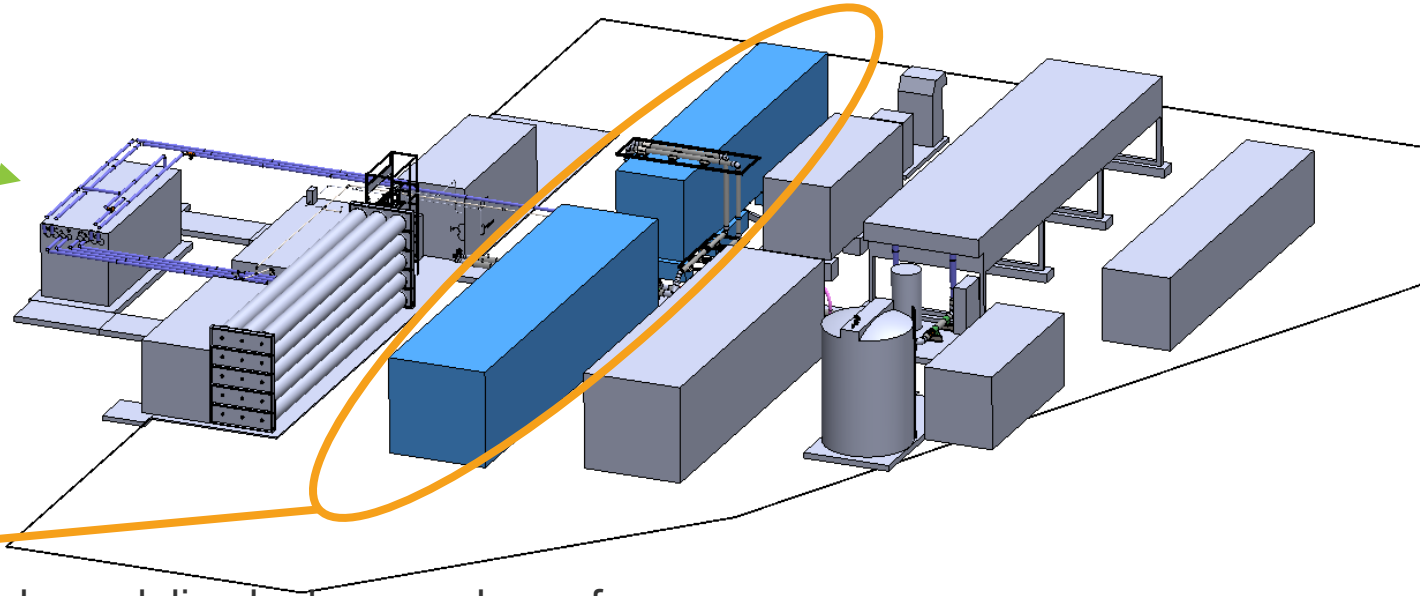


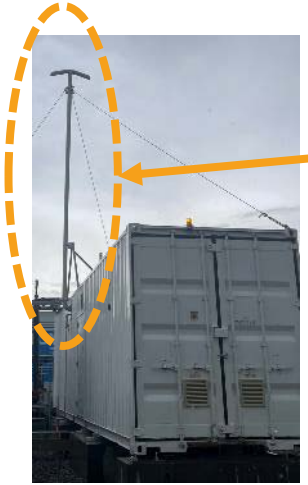
Ongoing Efforts

Small scale (<100 m) monitoring → <5 ppm
Small scale (<100 m) monitoring → >20000 ppm

Large scale monitoring (>100m) → Gaseous tracer compounds (NO2,C2H6) based monitoring

Hydrogen Dipsersion modeling at ARIES





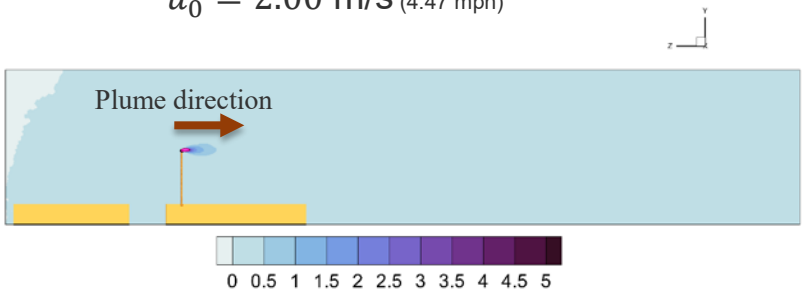
Example modeling hydrogen release from vent (dashed oval to left):

- 27 kg/hr release rate
- 0.84 bar avg. ambient pressure
- Historically representative wind speed/direction

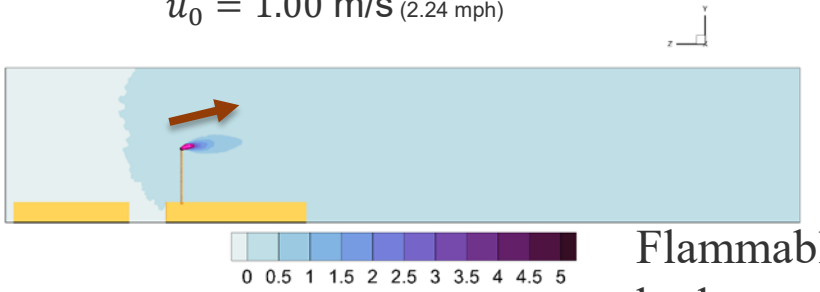
Controlled release scenarios can be performed at ARIES

H_2 dispersion behavior

$u_0 = 2.00$ m/s (4.47 mph)

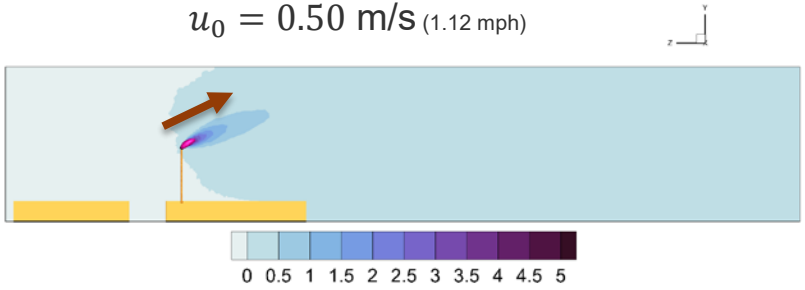


$u_0 = 1.00$ m/s (2.24 mph)

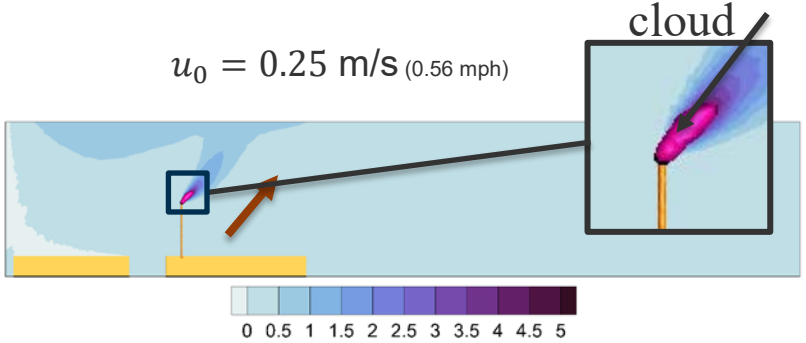


Flammable hydrogen cloud

$u_0 = 0.50$ m/s (1.12 mph)



$u_0 = 0.25$ m/s (0.56 mph)

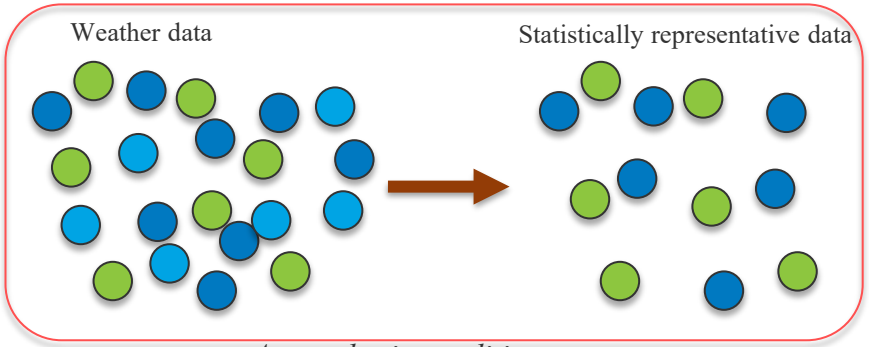


Hydrogen dispersion nature is wind dependent

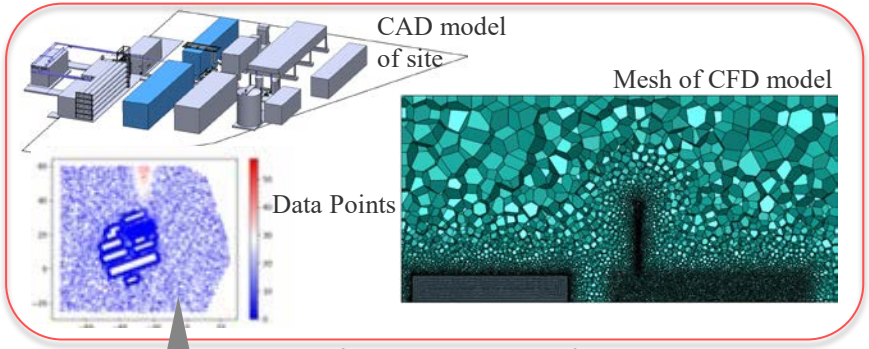
Stages of Hydrogen leak Modeling

Developed pipeline for sensor placement strategy

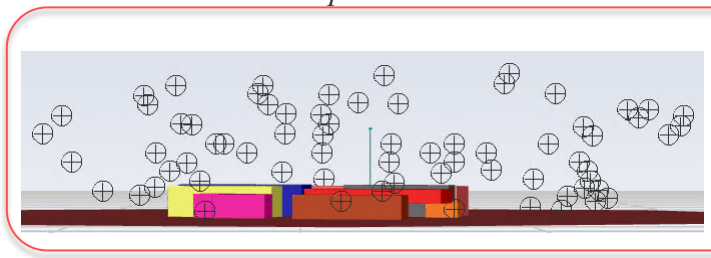
Site specific weather information → Site specific CAD and CFD modeling → Data processing of H_2 concentration → Sensor locations



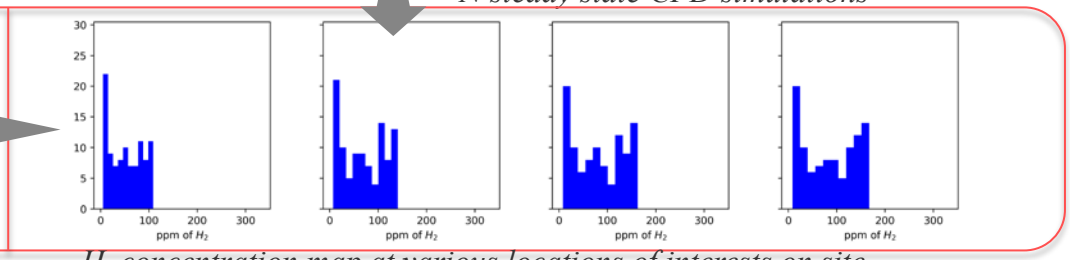
Atmospheric conditions



*~ **N** steady state CFD simulations*

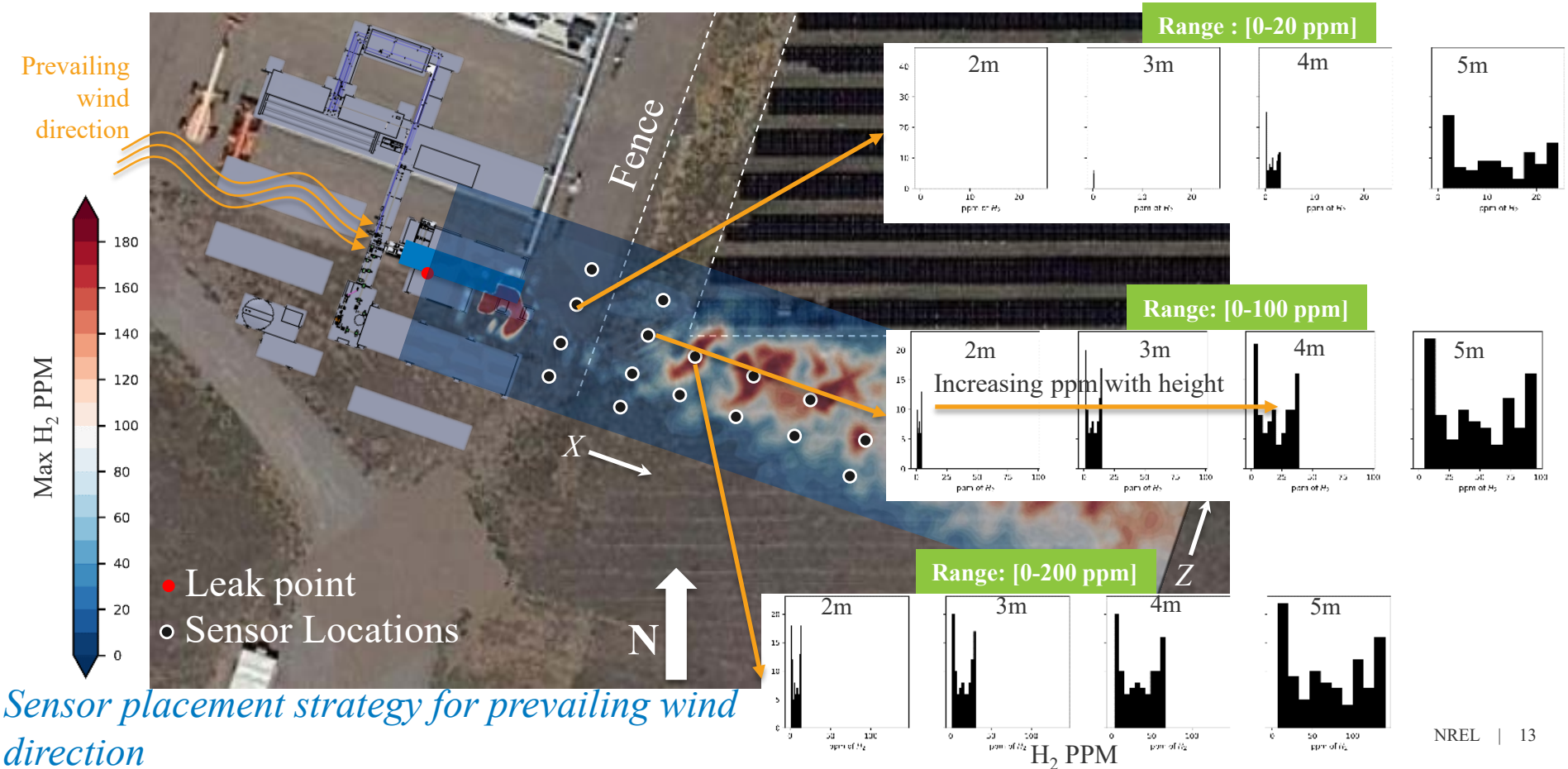


Approximate sensor map



H_2 concentration map at various locations of interests on site

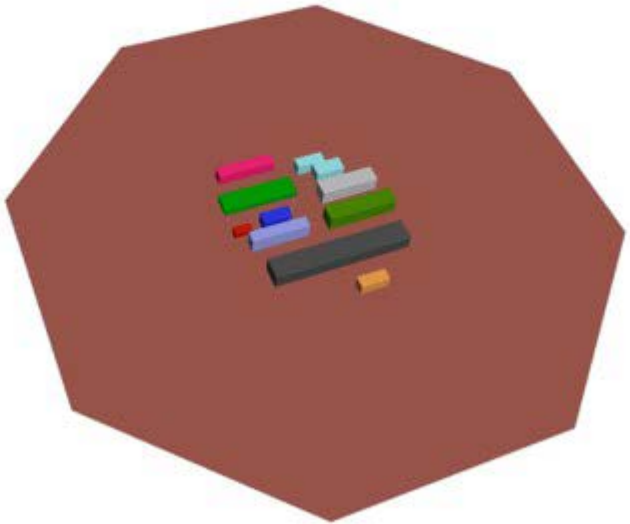
Hydrogen dispersion and deployment of sensors

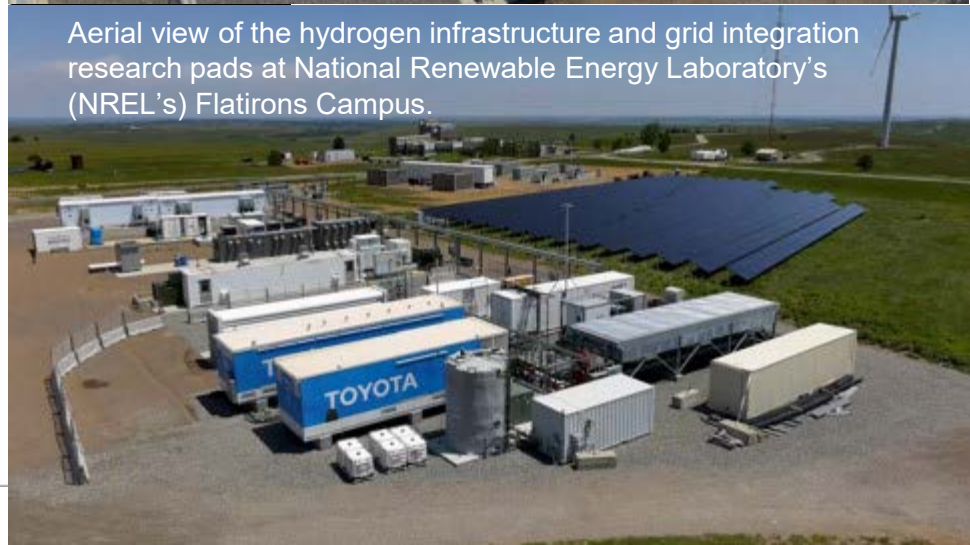


Sensor placement strategy for prevailing wind direction

Simulation Domain

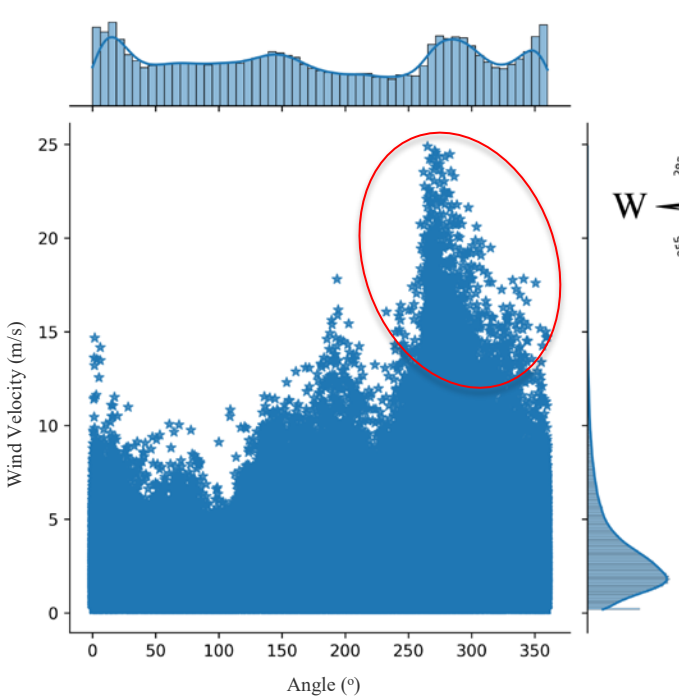
Site-specific and accurate representation of ARIES in modeling

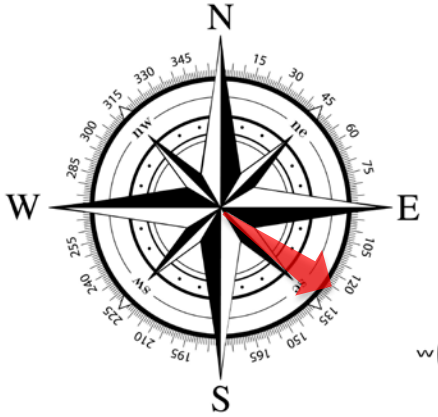


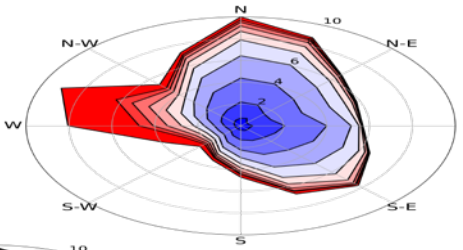


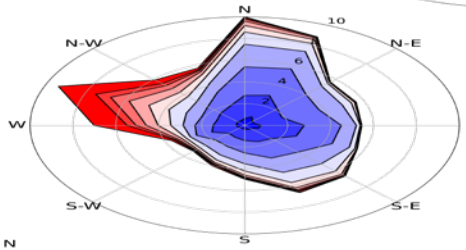
Aerial view of the hydrogen infrastructure and grid integration research pads at National Renewable Energy Laboratory's (NREL's) Flatirons Campus.

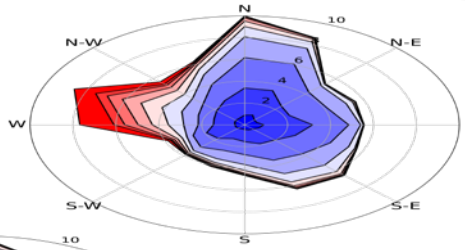
Windrose plots at various heights (2,5,10,50 m)

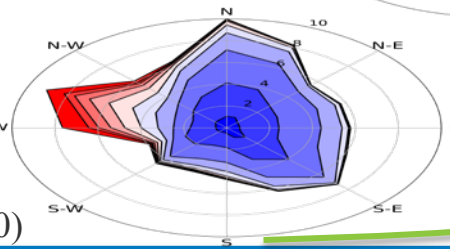












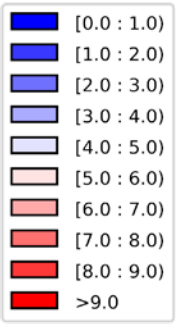
Y =50 m

Y= 10 m

Y= 5 m

Y= 2 m

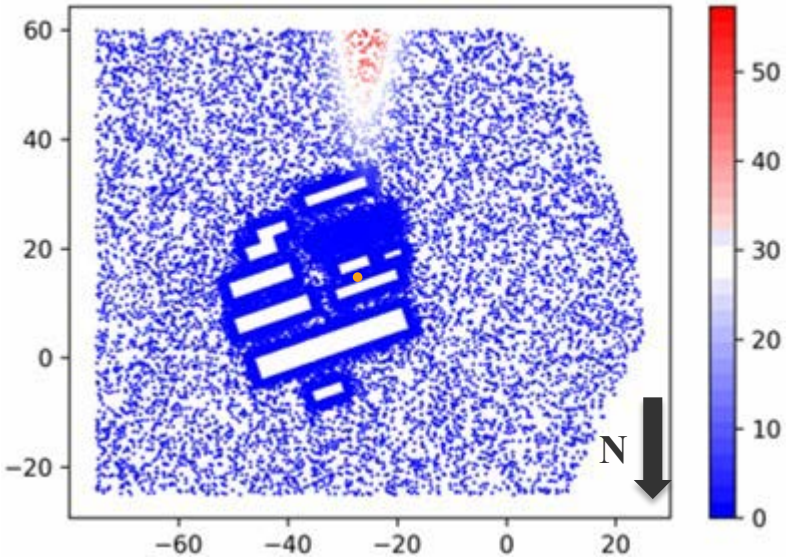
Ground (Y = 0)



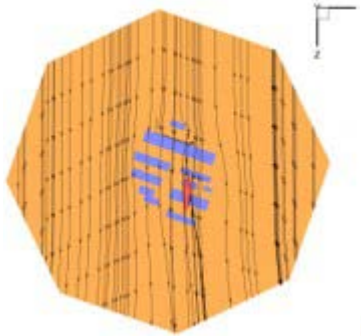
ARIES site has low to extreme wind scenarios Up to 55 MPH

CFD modeling and statical sampling

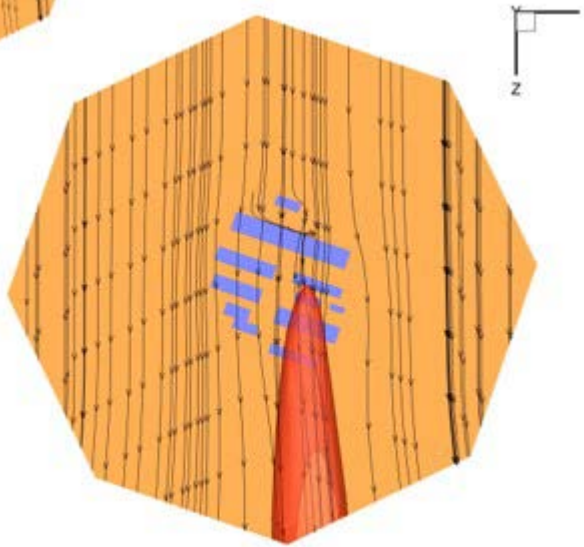
- 240 simulations for 1 year weather data (30 unique wind conditions) and 8 wind directions (45^{o} interval)



~1 M data point tracked over 240 simulations



Propagation of hydrogen cloud after leak at 26 mph of wind

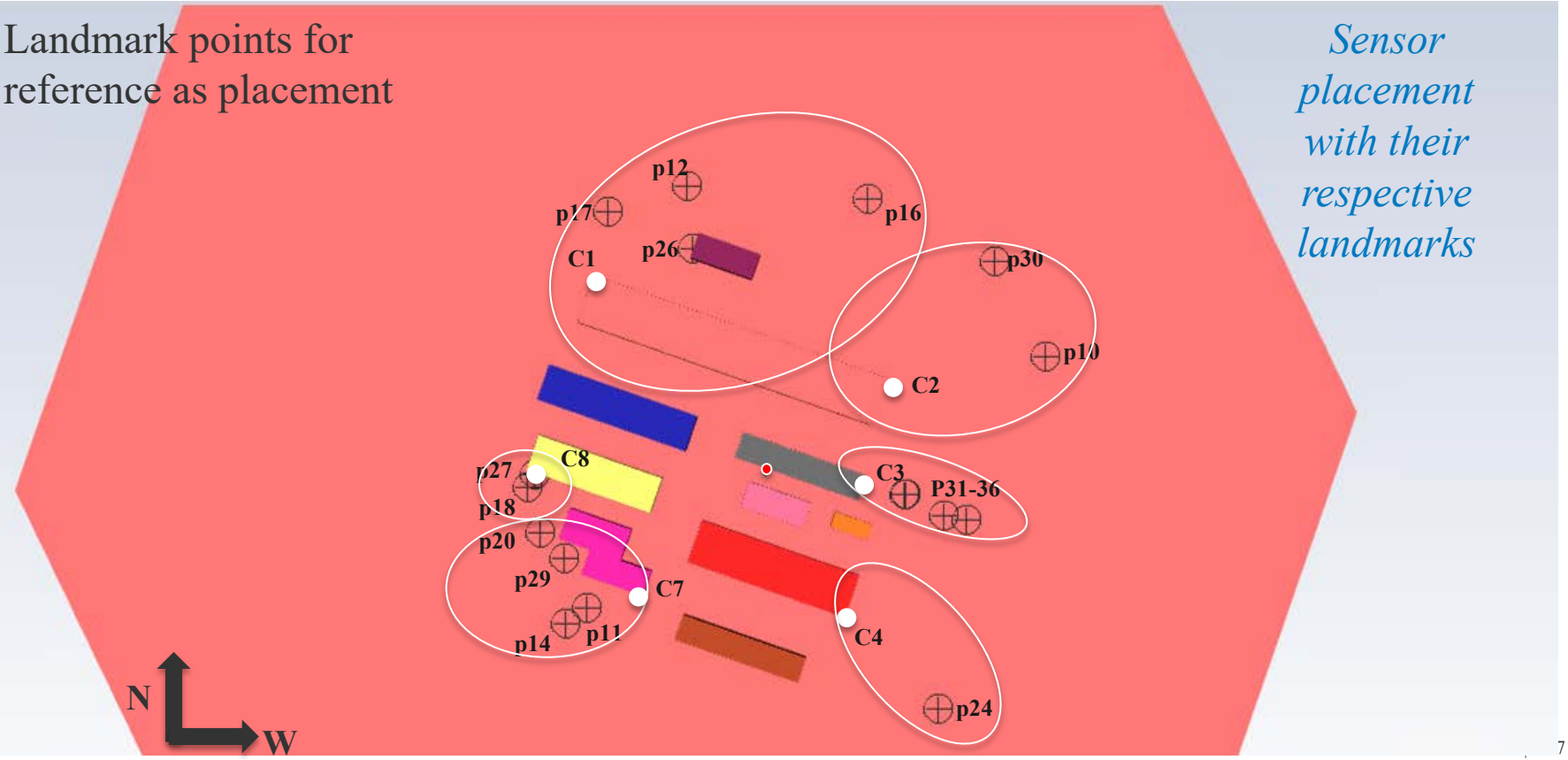


H2 leak simulation for ARIES site. Red region highlighting cloud of hydrogen above 20 ppm.

Large data ensemble and processing techniques for simulation-based approach

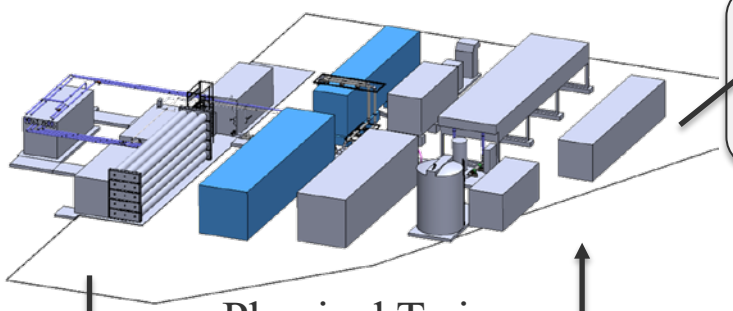
Sensor placement map- Current status of the project

- Landmark points for reference as placement



Sensor placement with their respective landmarks

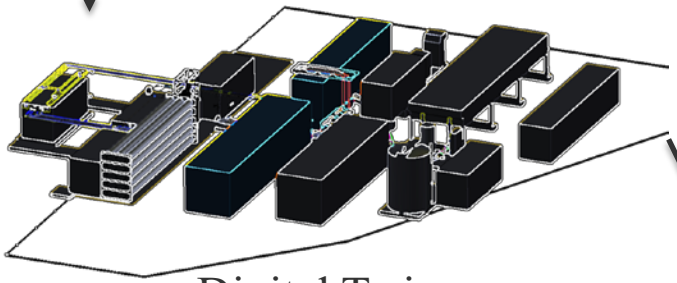
Digital Twin development
(Industry partner : GTI energy)



Physical Twin

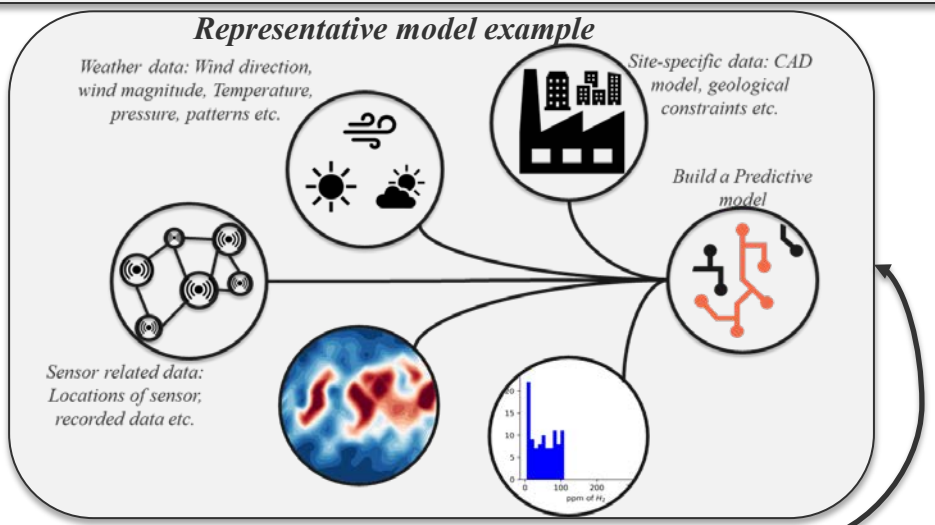
Data Collection

Information & Decisions



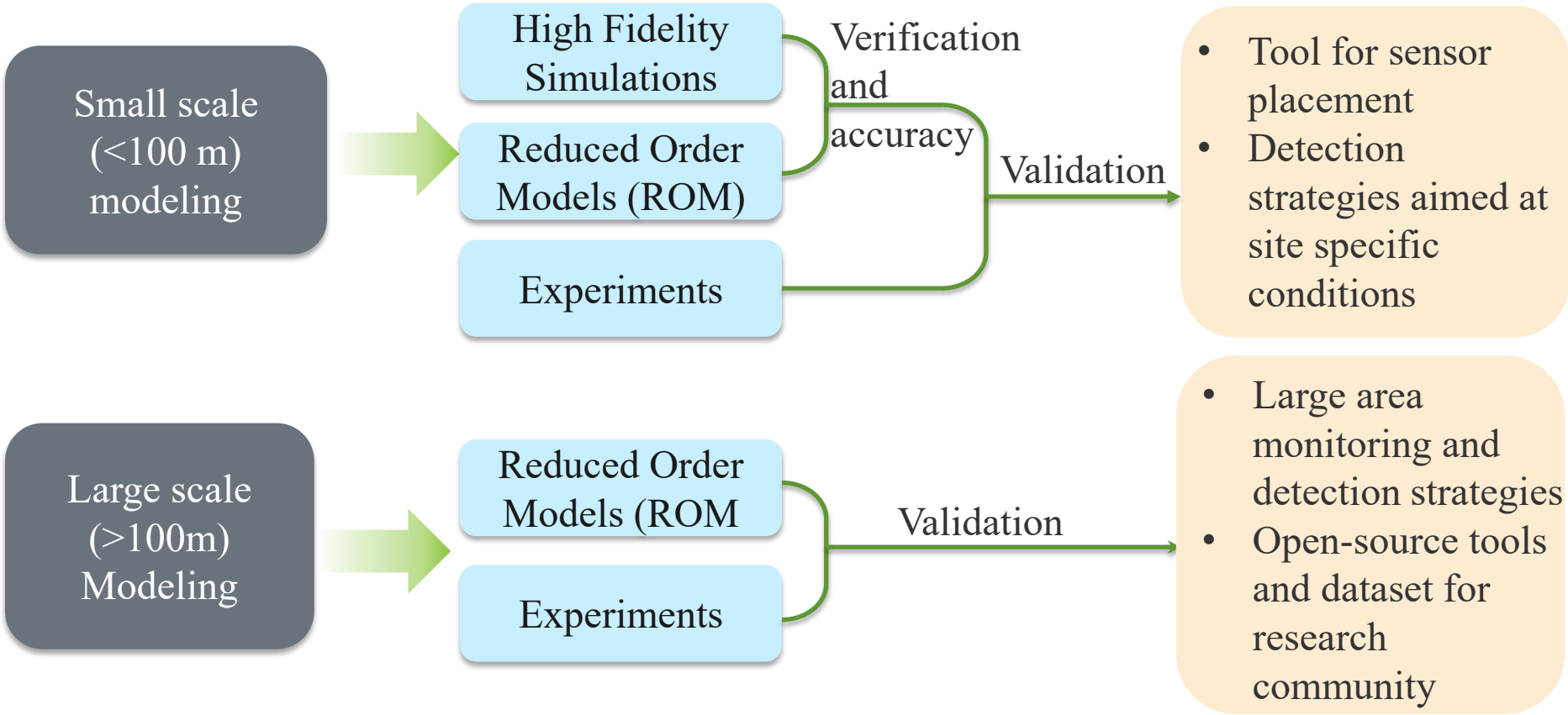
Digital Twin

- Objects (site physical data etc.)
- Processes (Leak rate, location etc)
- Various systems and conditions (e.g. Site weather data)



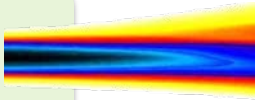
- Representative models (e.g. Predictive models)
- Data management (e.g. on demand data for users)
- Data analytics (e.g. risk factors, probability maps)

Modeling Strategy

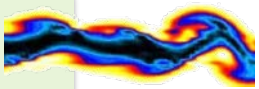


Future work and Planned activities

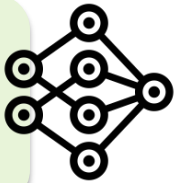
RANS based CFD simulations



High Fidelity simulations in OpenFOAM



Explore Reduced order models (ROM) for >100 m for large scale dispersion



ARIES CFD/ROM based Leak source predictor models

Develop ARIES as testbed for hydrogen sensor testing and validation

Build dataset/Digital twin to as benchmark for the other academic and partner institutions for hydrogen dispersion

Continuous improvement in analysis and modeling strategy while incorporating stakeholder engagement and interest for ARIES and hydrogen capabilities at NREL

Support for the NREL HSR&D Program is through the DOE HFTO Safety, Codes & Standards (Laura Hill, Technology Manager and Christine Watson, Technology Manager)

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Pending: ARPA-E Funding Opportunity No. DE-FOA-0002784 "H2Sense"

For more information, contact: Munjal.Shah@NREL.GOV

www.nrel.gov

Thank You

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