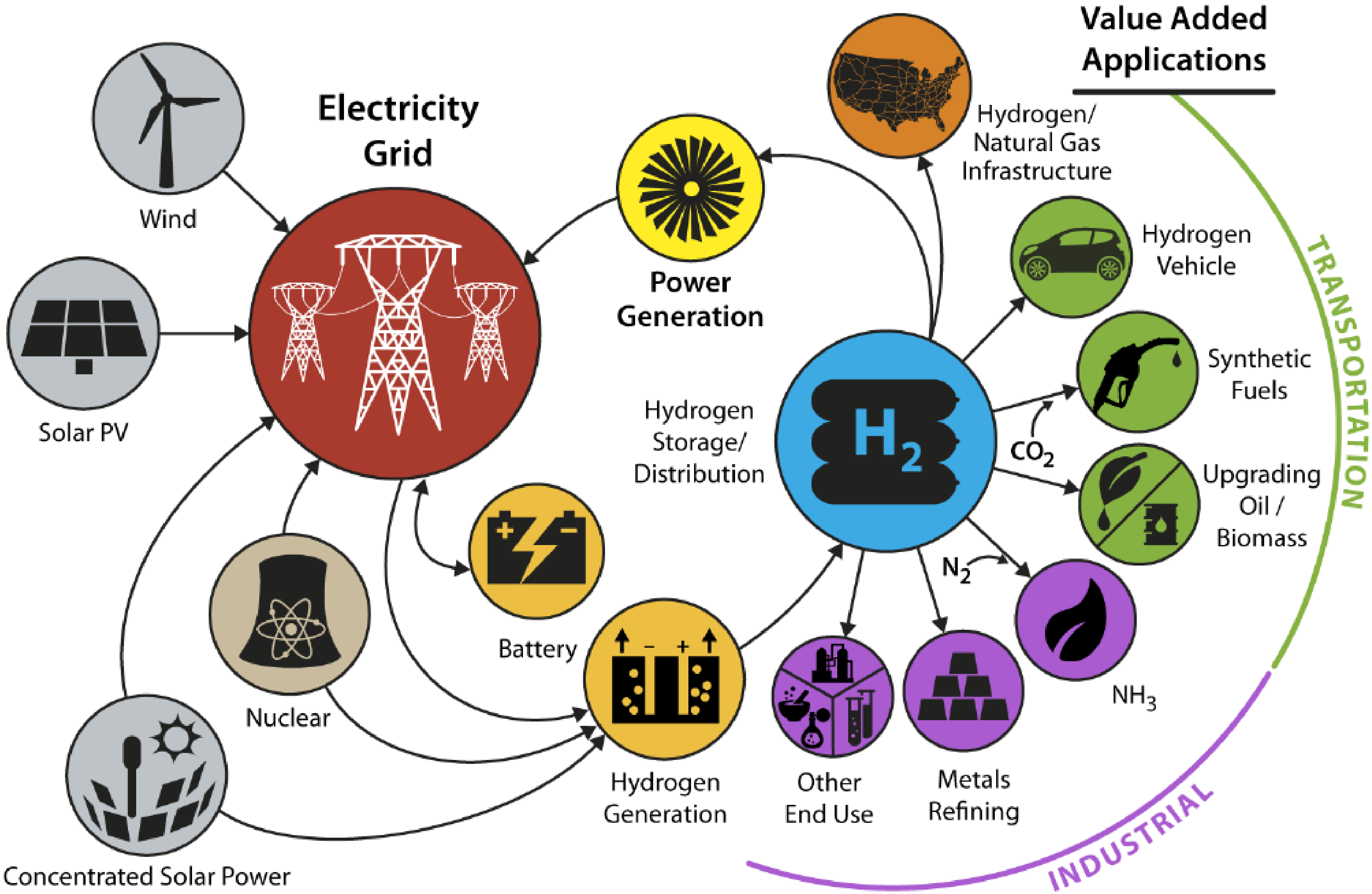
# U.S. DOE plans: H2@SCALE



# Inevitable questions (A partial list..)

- How do we demonstrate that it’s safe?
- How do we design appropriate regulations/safety standards/etc.
- How do we balance safety & economics?
- How will the system adapt as vehicle infrastructure changes?

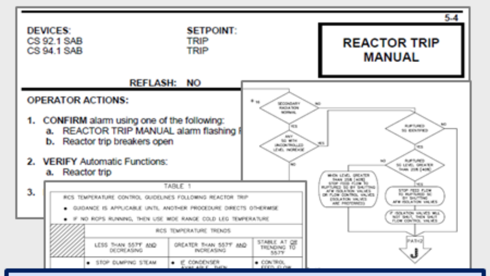
# Systems Risk and Reliability Analysis (SyRRA) lab

- Development of rigorous methods to *support decision making* on complex systems with *multiple types of data & knowledge*
  - Human + system + environment + complex phenomena

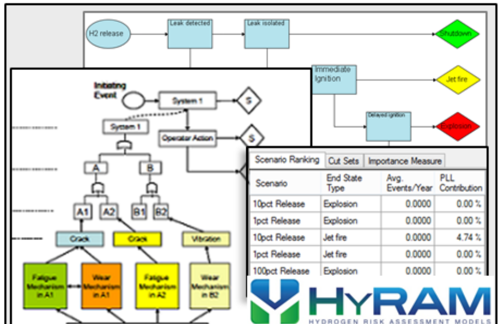
| Scientific capabilities | Specific problem spaces |
|---|---|
| • Structured thinking, logic<br>• System decomposition<br>• Probability & Bayesian modeling<br>• Data analysis<br>• Artificial intelligence for prognostics; operator decision support systems | • Data fusion & model integration at multiple scales<br>• Bayesian Networks<br>• Human Reliability Analysis<br>• HyRAM (Hydrogen quantitative risk assessment)<br>• Nuclear power<br>• Hydrogen & NG infrastructure |

# Fundamental question: How can we use the data revolution to solve system-level problems?

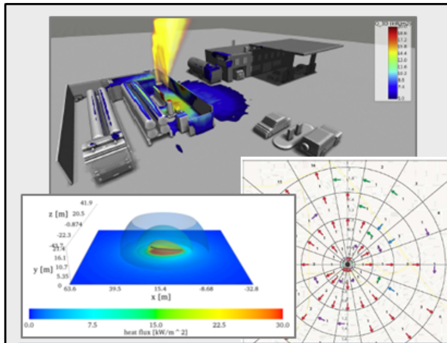
- QRA has always been a data-integration problem. But the data is changing.

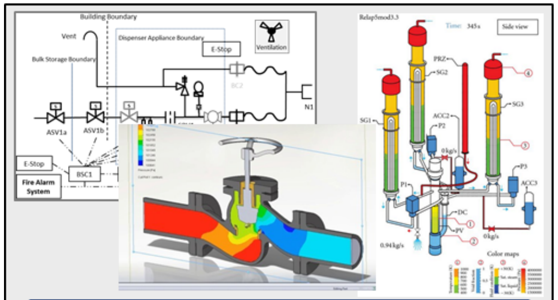


Written information, (e.g., operating procedures)

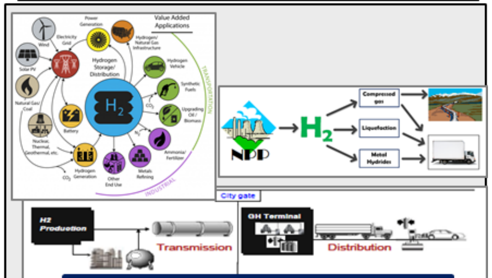


System reliability data & risk assessments


Release & consequence models & simulation


System physics simulation


Control room simulation



System interaction models & simulation

# Completed work: HyRAM: Making hydrogen safety science accessible through computational tools

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

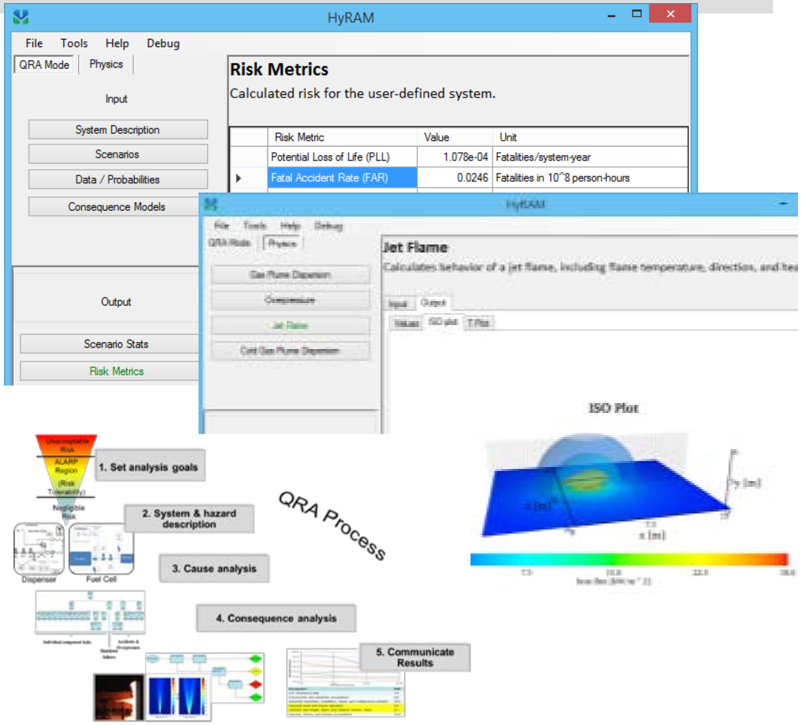
**First-of-its-kind integration platform** for state-of-the-art hydrogen safety models & data - **built to put the R&D into the hands of industry safety experts**

**Core functionality:**

- Quantitative risk assessment (QRA) methodology
- Frequency & probability data for hydrogen component failures
- Fast-running models of hydrogen gas and flame behaviors

**Key features:**

- GUI & Mathematics Middleware
- Documented approach, models, algorithms
- Flexible and expandable framework; supported by active R&D

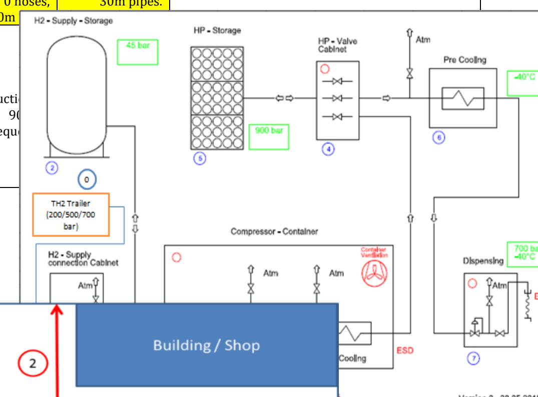


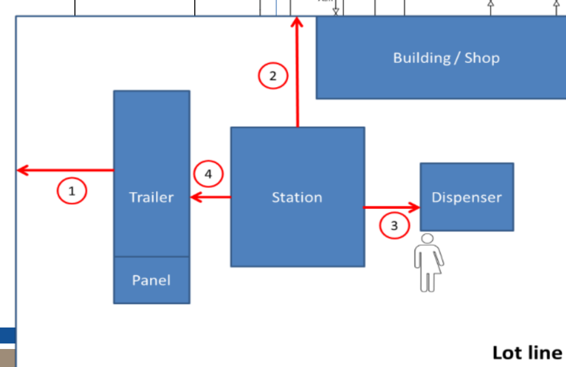

**Free at http://hyram.sandia.gov**

# Completed work: Using scientific QRA to harmonize safety distances: ISO19880-1 Annex A

- **International agreement on approach, safety examples**
  - Sub-team: US, UK, Japan, Germany, France – all agreed to the approach; brought regional choices & assumptions
  - All calculations using HyRAM
- **Impact:**
  - US benefits from harmonized NFPA-ISO
  - EU: Reducing cross-border regulatory challenges
- **HyRAM directly enabled progress:**
  - Real-time use of HyRAM was a key reason for coming to consensus;
  - Collaborators HyRAM usability, speed combined with methodology flexibility and transparency, as ***more beneficial to permitting than the resulting distances***.

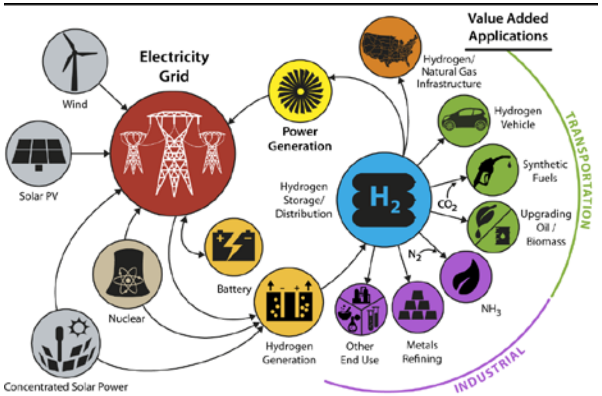
| | Case2A | Case2B | Case2C | Case2D | Case2E |
|---|---|---|---|---|---|
| Calculation approach | QRA | QRA | Conseq. only | Conseq. only | Conseq. only |
| Acceptance criterion | AIR<1.0e-5 | AIR <1.0e-5 | < 3.0W/m2 | < 1.26kW/m2 | < 1.26kW/m2 |
| Pipe maximum flow diameter (either the ID or effective ID based on flow restriction) | 0.3125in (ID from modules3-5) | 0.3125in (ID from modules3-5) | N/A. System design is not considered in consequence-only approaches. | | |
| Release diameter considered | [All releases from 0.003125in – 0.3125in] | [All releases from 0.003125in – 0.3125in] | 1mm | 1mm | 1mm |
| Internal Temp. | 15° C | 15° C | 15° C | 15° C | 15° C |
| Internal Pressure | 700 bar | 700 bar | 700 bar | 700 bar | 700 bar |
| External Temp. | 15° C | 15° C | 15° C | 15° C | 15° C |
| External Pressure | 1 atm | 1 atm | 1 atm | 1 atm | 1 atm |
| System configuration (sources of releases) | 2 Compressors, 40 Cylinders, 20 Valves, 8 Instruments, 0 filters, 0 flanges, 24 (non-welded) joints, 0 hoses, 20m | 2 Compressors, 48 Cylinders, 32 Valves, 12 Instruments, 0 filters, 0 flanges, 44 (non-welded) joints, 0 hoses, 30m pipes. | N/A. System design is not considered in consequence-only approaches. | | |
| Credit for additional mitigations (e.g., gas or flame detection) or other documented considerations (e.g., direction of release) | (reducti 9 frequ | | | | |
| Number of exposed persons | | | | | |
| | | | | | consequence-only approaches. |
| | | | | m | 2.75 m |

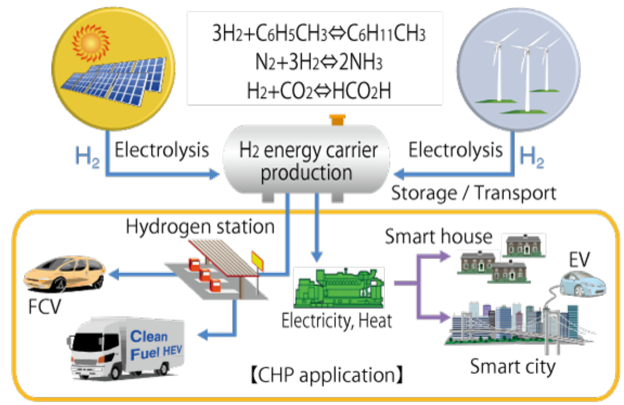


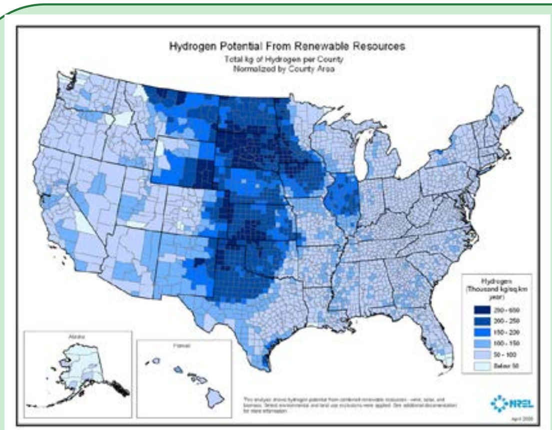



# Proposed research: Optimize location of H2 infrastructure within NG pipelines

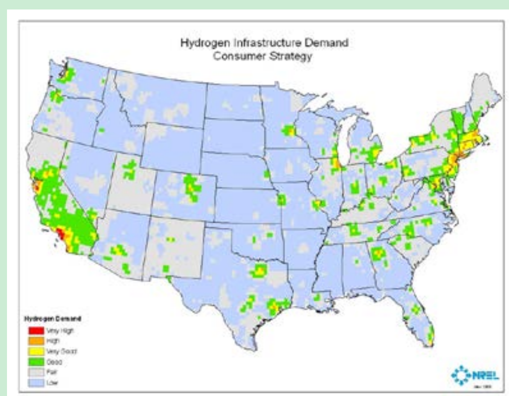
- Where should we place H2 extraction stations to minimize cost of early H2 infrastructure and still maintain required reliability of both H2 and LNG users?



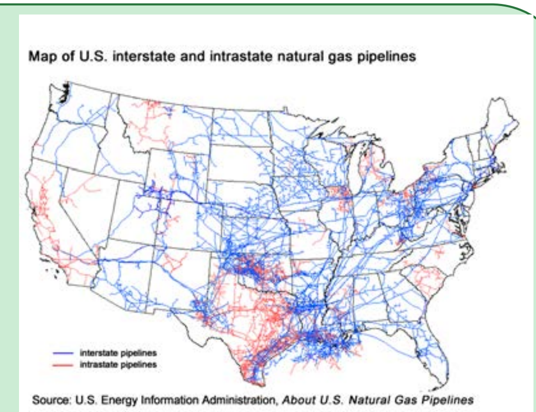




Renewable H2 production



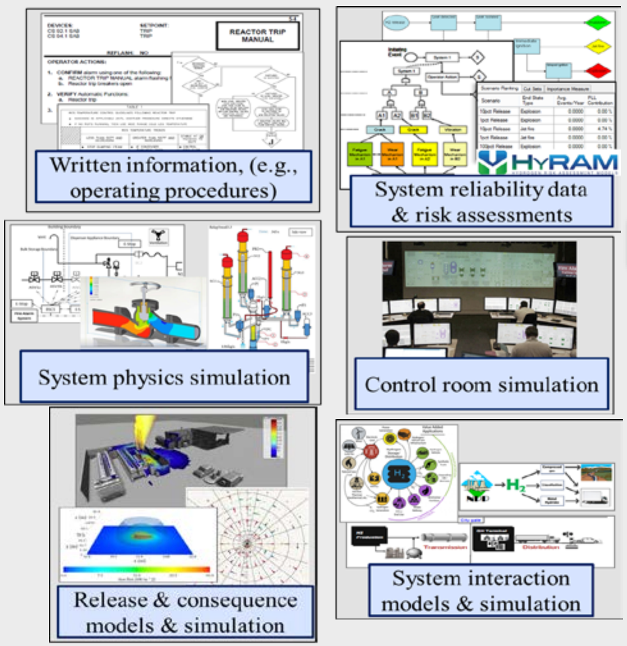

H2 consumer demand




Existing NG pipelines

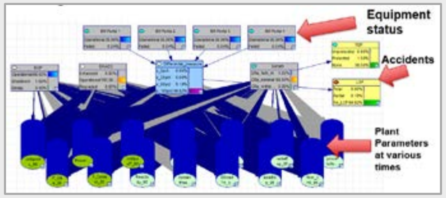
# Proposed research: Develop comprehensive framework for automation-assisted operator support based on fusion of knowledge and data.

## Multi-source, multi-modality data




**Human strengths:** strategize, judgment, innovation, error correction

**Bayesian data fusion, causal & probabilistic models, AI**




**Balanced automation & human**

Improvements in operator support (monitoring, diagnosis & response planning)

- Putting the power of big data into the hands of critical infrastructure operators
- Helping prepare operators for the current & future “known-unknowns” and “unknown-unknowns.

# Backup

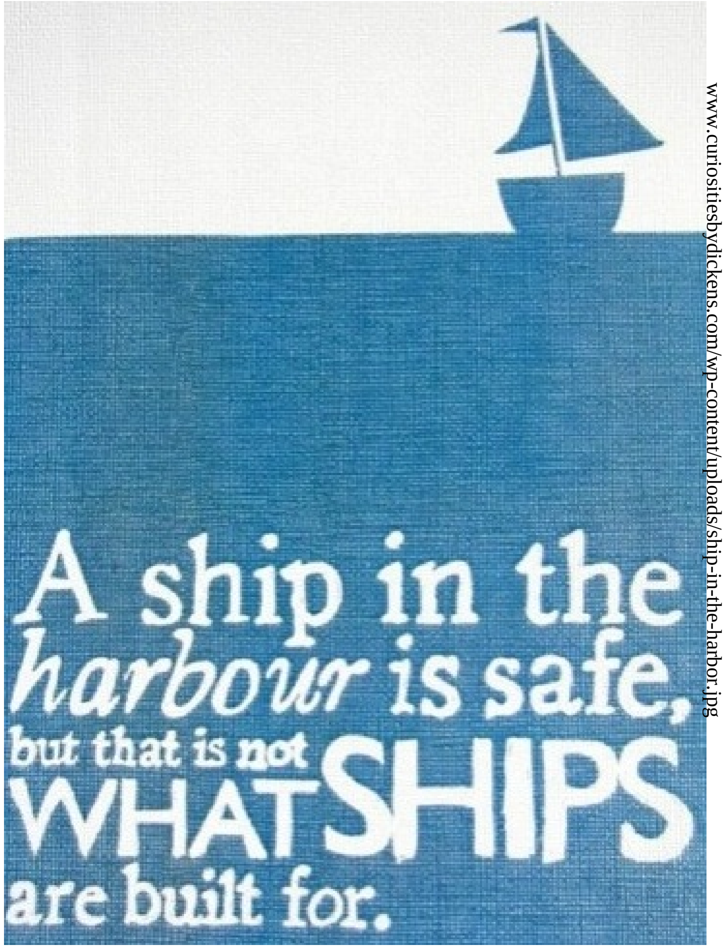
# Research Questions & Partnering

- Questions
  - Control room simulation + process physics simulation + artificial intelligence
    - E.g., for designing & optimizing human-machine collaboration
  - System-level diagnostics / prognostics using multiple sources of data

- Seeking partners with..
  - Physical process simulation data sets
  - Control room simulation capabilities (gas?
  - Condition monitoring data

# Reliability engineering supports decision-making

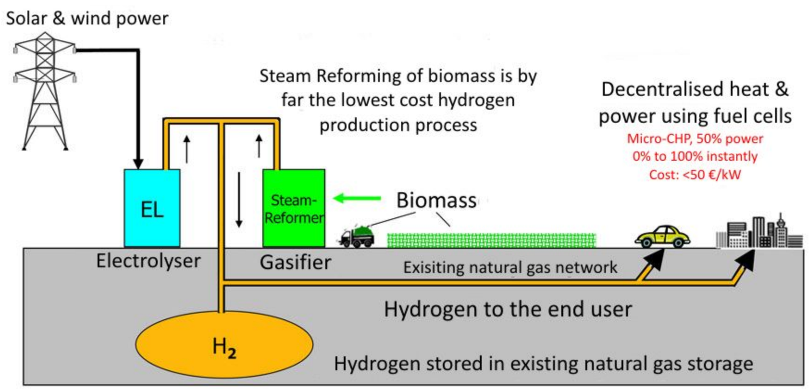
- A process **to explore priorities,** to **build consensus**, **to encourage discourse** among interested parties, **to build a common basis for safety discussions**
- By building an understanding of:
  - What the system is supposed to do (performance)
  - The sources, causes, and likelihood of failures (physics based, human, computational, etc.)
  - Strategies to reduce failure (e.g., design, operation, maintenance)

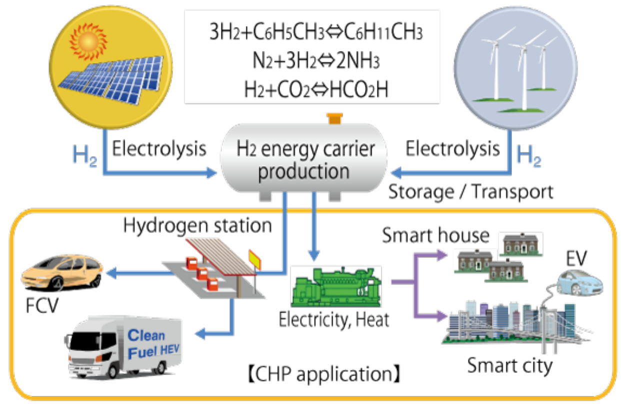


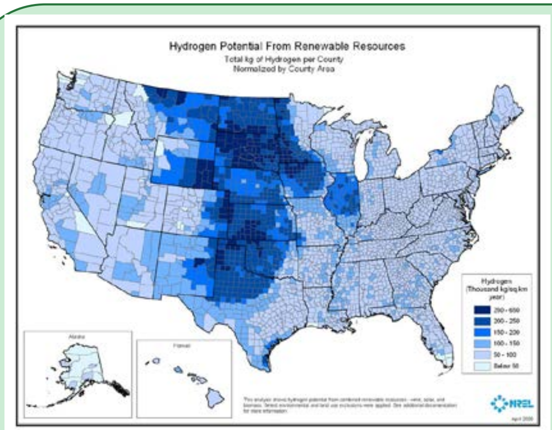

www.curiositiesbydickens.com/wp-content/uploads/ship-in-the-harbor.jpg

# Proposed research: Optimize location of H2 infrastructure within NG pipelines

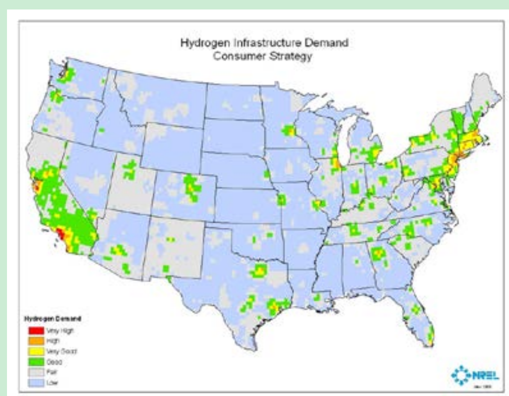
- Assessing the economics and reliability of hydrogen distribution via NG pipelines. Extractions units, delivery to end users, Local storages, …



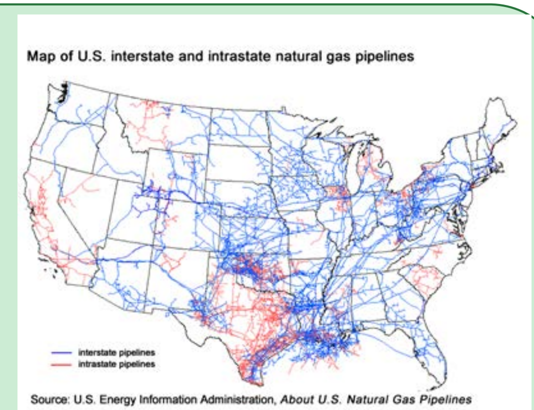




Renewable H2 production




H2 consumer demand




Existing NG pipelines