Hydrogen Safety Project Reviews

presented by

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Overview

- **Why we perform reviews ?**
- **How do we perform reviews ?**
- **Who has been reviewed ?**
- **Project safety reviews**
  - **Description of site**
  - **Safety methodology**
  - **Topic question highlights**
  - **Panel member questions/PI responses**
  - **Conclusions**
- **Status**

ENERGETICS

Why Do We Perform Reviews?

- DOE Program is important to realize the Hydrogen Economy
- Hydrogen safety has enough “perceived” issues; real issues need to be addressed and/or minimized
- One or two hydrogen-related “incidents” of sufficient magnitude or publicity could adversely affect the Program and/or delay the Hydrogen Economy
- We can bring to the Program lessons learned and other teachings from across and outside the DOE Program.

ENERGETICS

How Do We Perform Reviews?

- Identify project
- Contact PI - arrange on-site visit
- Conduct literature search
- Develop and send to PI a list of topic questions/ discussion points
- Hold On-site meeting:
  - Presentation by PI
  - Tour/Demo wherever possible
  - Discussion of topic questions
  - Comments/questions/concerns of Panel Members
- Write report/ submit to DOE
- Develop lessons learned

ENERGETICS

How Do We Perform Reviews?

Topic Questions - Examples

- **Hydrogen Safety**:
  - Leaks – prevention, detection, containment/exhaust
  - Pressure issues
  - Ignition sources – identification, control
- **Safety planning**
  - ISV methodologies
  - Risk mitigation (MOC, safety monitoring, SOP, training, equip. maintenance)
  - Communication
- **Codes and Standards**
- **Specific system/component issues**

ENERGETICS

Who Has Been Reviewed ?

Current Program

- **Air Products – Las Vegas Hydrogen Energy Station (3/04)**
  With J. Schneider, D. Frikken, S. Weiner

- **United Technologies Research Center – High Density Hydrogen Storage System Demo Using $NaAlH_4$-based Hydrides (5/04)**
  With C. Bailey, J. Hansel

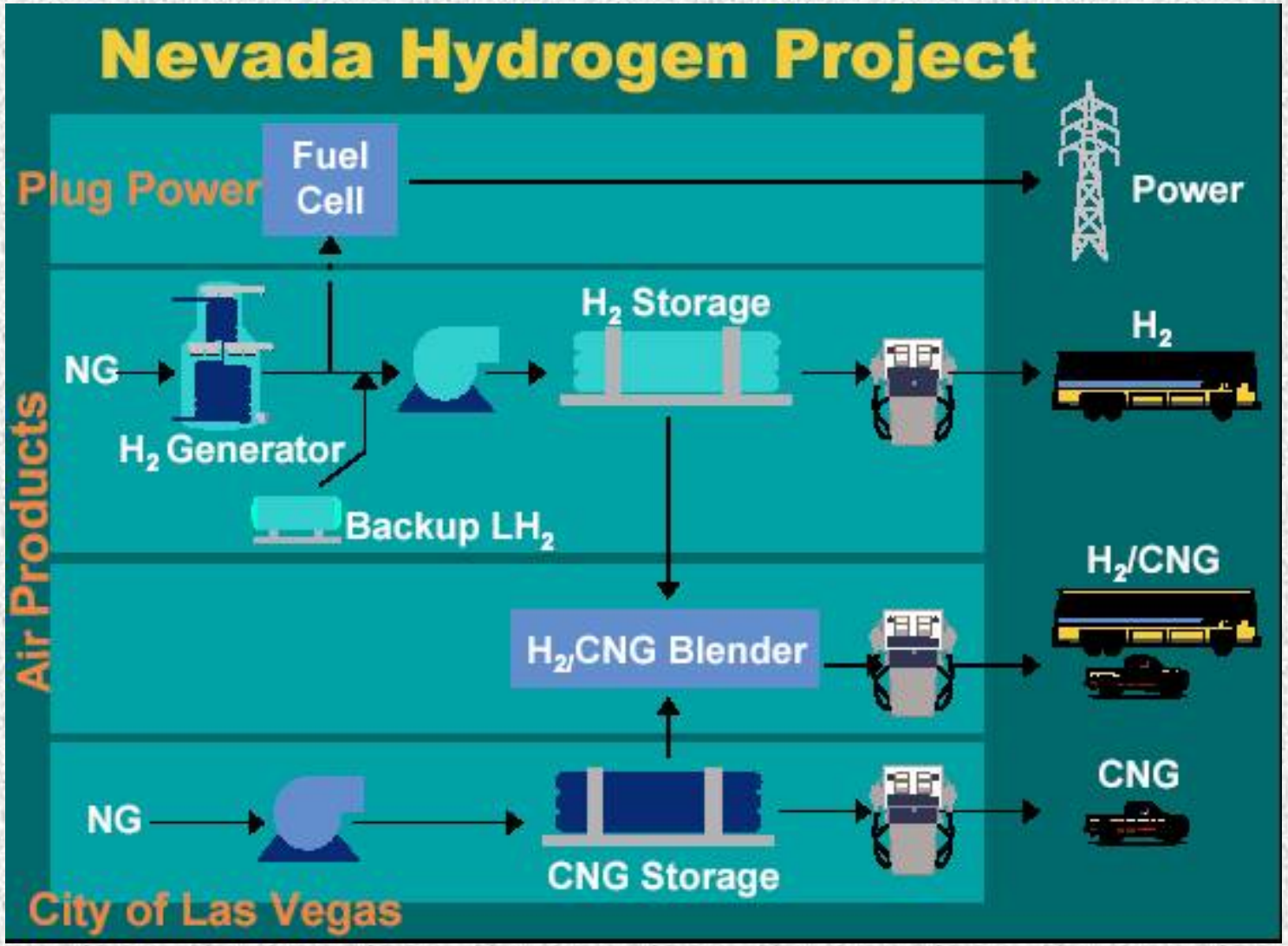
- **NREL - Algal Systems for Hydrogen Photoproduction (6/04)**
  With A. Bain, H. Phillippi, S. Weiner

- **NREL – Renewable Electrolysis Integrated Systems Development and Testing (6/04)**
  With A. Bain, H. Phillippi, S. Weiner

ENERGETICS

Project Safety Reviews

APCI/Las Vegas – Las Vegas Hydrogen Energy Station



APCI/Las Vegas Site Description

Hydrogen Generator

APCI/Las Vegas Site Description

Plug Power Fuel Cell

APCI/Las Vegas Site Description

Liquid Hydrogen Tank

APCI/Las Vegas Site Description

Hydrogen Dispensers

APCI/Las Vegas

Summary/Findings

- First safety review
- Chosen due to established APCI safety record
- Flowsheet level HAZOP and MOC to correct issues
- Good dialogue between station team and city fire marshals
- No serious concerns
- A few items being addressed

APCI/Las Vegas

Safety Methodologies

- APCI culture emphasizes safety
- "Wealth of knowledge" to identify hazards
- Key role of APCI safety group
- Statistical risk analysis based on:
  - standardized work processes
  - ISO certified engineering procedures for design development and systems engineering
- HAZOP (includes LV/Plug)
  - analysis run on flowsheets (T,P, composition, metallurgy, operator use.)
  - Considers interfaces with customer/end user
- MOC when proposed design/flowsheet changes

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Hydrogen Safety

- **Leaks**
  - – Prevention
    - Minimize mechanical connections
    - Considers connections as potential leak sources in design. (ventilation, ign. sources, elec. classification)
  - – Detection
    - Flammable gas detectors in enclosed areas
    - UV/IR detection
    - Portable detectors in work areas
  - – Containment /exhaust
    - Ventilation systems/air exchange
    - System shuts down with loss of ventilation
    - H2 generator in confined space
    - “safe access” indicator lights
    - Relief vents are placed at safe locations

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Hydrogen Safety (cont.)

- **Pressure issues**
  - Designed for mechanical integrity under op. press.
  - Piping meets ASME B31.3
  - Pressure vessels meet ASME Sec. VIII Div. 1
  - Mechanical relief devices for overpressurization
  - HAZOP includes “non-obvious” pressure issues
  - P/T conditions examined at the subsystem “node” level

- **Ignition sources (I.D. and control)**
  - HAZOPs include I.D. and control of ignition sources
  - Follow NFPA 50A, 50B, 70
  - Design follows NFPA classified areas
    (for types of electrical components in an area)

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Safety Planning

- **ISV**
  - HAZOPs
  - Would use FMEA if needed to verify safeguard adequacy

- **Risk Mitigation**
  - MOC
    - Required APCI work practice
    - Includes operations team, proc. eng., control eng., PI
    - Continues into operations phase
    - Includes operators in Sacramento
  - Measuring/monitoring of safety performance
    - Required APCI work practice
    - “Near Misses” must be reported

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Safety Planning (cont.)

- **Risk Mitigation (cont.)**
  - Training
    - LV staff trained by APCI personnel prior to system operation
    - LV staff contacts APCI for any requirements up to the nozzle
    - APCI experienced operators control APCI systems
    - Includes remote operations from Sacramento
  - Equipment Maintenance/Integrity
    - APCI conducts operational readiness inspection
    - APCI examines control system diagnostics
    - Periodic maintenance on APCI systems

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Safety Planning (cont.)

- **Communications**
  - Internal safety reviews
    - HAZOP analysis includes interface partners
    - Copies provided to partners
    - Reinforcement of the need for safe operations
  - "Incidents"
    - Reporting of incidents required by APCI
    - Incidents are used as a performance measure
    - "Near misses" also reported

ENERGETICS

APCI/Las Vegas – Discussion on Topics

Codes and Standards

"Notable" codes and standards applied:

- ASME B31.3 (Process Piping)
- ASME Section VIII Division 1 (Pressure Vessels)
- NFPA 50A (Standard for Gaseous Hydrogen Systems at Consumer Sites)
- NFPA 50 B (Standard for Liquefied Hydrogen Systems at Consumer Sites)
- NFPA 70 (National Electric Code)
- SAE J2600 (Standard for Compressed Hydrogen Surface Vehicle Refueling Connection Devices)

ENERGETICS

APCI/Las Vegas - Panel Questions

1. Vehicle fill-rate measurements validation

Issue:

- H2 heats up during filling of tank function of fill rate
- Recommended max temperature 85C (ISO, EIHP) adopted by CaFCP as refueling interface standard
- LV station designed to meet standard

ENERGETICS

APCI/Las Vegas - Panel Questions

1. Vehicle fill-rate measurements validation (cont.)

Panel member recommendation:

- APCI should provide P,T data to show 85C max.
- Use CaFCP fill/testing device for a witnessed test

APCI response:

- The energy station is a prior iteration of fueling technology. (Designed for use with vehicles w/o diagnostics on vehicle
- APCI/LV will conduct tests w/fill tank
- APCI also reviewing option of upgrading to communications-based fueling

ENERGETICS

APCI/Las Vegas - Panel Questions

2. Dispenser-related issues

A. Dispensing H2 includes a grounding step for user and vehicles generates a perception of “danger”

Studies show vehicle is grounded through concrete pavement.

Will make grounding location more identifiable

B. Fire extinguisher on a pole could obstruct a breakaway hose

Will relocate fire extinguisher

ENERGETICS

APCI/Las Vegas Site Description

Hydrogen Dispensers

APCI/Las Vegas - Panel Questions

2. Dispenser-related issues (cont.)

C. Pressure indicator on dispenser housing: what is it measuring, how is it tied into remote monitoring system? (Indicator deflects when housing is touched)

Monitors purge pressure within enclosure

Control system issues an alarm if purge pressure is below the satisfactory level

D. Control logic for dispenser: What determines availability of fuel?

APCI and LV has active line of communication to correct fuel availability issue or similar. (Moot point now; very little fueling)

ENERGETICS

APCI/Las Vegas - Panel Questions

3. Underground piping (ISO TR 15916 says “try to avoid buried lines”)

- Potential corrosion
- Inability to inspect
- Leak could be in an unforeseen place (poss. accumulation and explosion hazard
- APCI operates >300 miles of underground H2 piping
- Good engineering practices w/underground piping averts rather than causes hazards
- Most CNG piping underground
- Piping is carbon steel, coated and wrapped
- LV soil does not promote corrosion

ENERGETICS

APCI/Las Vegas - Panel Questions

4. Mechanical Joints (not a major concern/outdoors)

- High number
- ISO TR 15916 and CGA 5.4 calls for minimum of joints – especially threaded
- APCI agrees joint number should be minimized but practical

5. Liquid hydrogen area (potential for debris ignition)

- Debris in area may have organic content (mostly dirt, but a few leaves)
- May be in potential L-H2 leak path
- Extremely small amount of debris
- Will monitor debris and its removal

ENERGETICS

APCI/Las Vegas - Panel Questions

6. C-H2 tanks

- APCI needs inspection plan (determine inspection frequency, and what is to be inspected
- Should be based on failure modes including fatigue
- APCI personnel visually inspect the site frequently
- System only operating 18 months – shorter than standard span between inspections other than visual
- APCI does have standards for more rigorous inspection if station is operating long enough.

APCI/Las Vegas
Conclusions

- No “show stoppers”
- No incidents have occurred
- APCI will work with CaFCP to perform witnessed fill test
- APCI making other minor corrections as necessary
- Some items unable to evaluate
  - Plug power fuel cell was not operating
  - No pure H2 vehicles on site

We thank Mark Wait and his team for their time, hard work, and cooperation!

ENERGETICS

Project Safety Reviews

UTRC – High Density Hydrogen Storage System Demo Using NaAlH4-based Hydrides

- Demonstrating fabrication of hydride storage systems
  - $NaAlH_4$ is test material
  - Completed 50 g system
  - Currently building 1 kg system
  - Will then scale to 5 kg
- Testing hydrogen charging and discharging properties of hydride
  - Rates as function of T,P

ENERGETICS

UTRC – Project Description

Underlying safety Issue:

$$3NaAlH_4 \rightarrow Na_3AlH_6 + 2Al\ (+3H_2) \rightarrow 3\ NaH + Al\ (+3/2\ H_2)$$

- Pyrophoric in presence of water
- Dust is explosive, esp. when finely divided and dispersed
- DOT Hazard Class 4.3 (flammable solid; dangerous wet)

ENERGETICS

UTRC

Summary/Findings

- Controlled, well-marked laboratories to process alanates in isolated, water and oxygen-free glove boxes
- Testing in highly controlled facility
- Uses own substantive risk assessment methodology and multi-leveled inspection program
- Safety Team recognizes UTRC's concern with safety
- A few issues being assessed

ENERGETICS

UTRC – Site Description

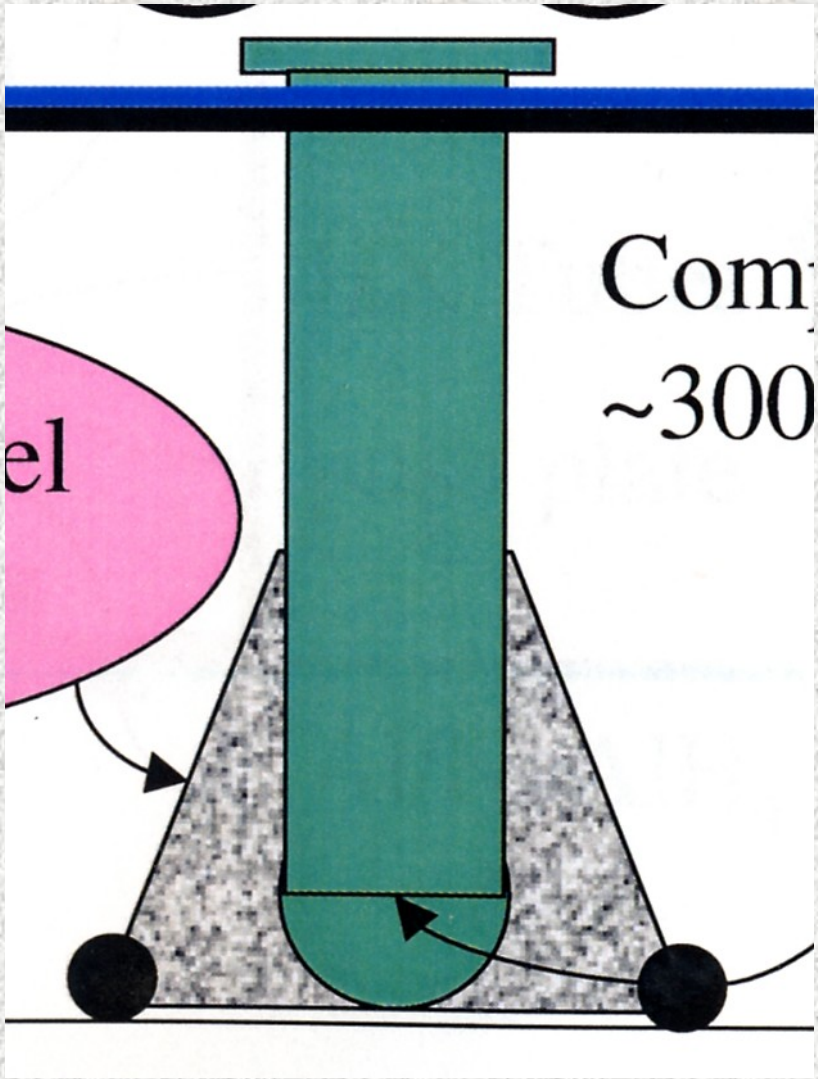
- **Material preparation and handling laboratories**
  - **“Storage” lab and “loading” lab**
  - **All work in positive pressure glove boxes (mixing, catalyzing, storing)**
  - **Sprinkler system in lab (would not affect work in glove boxes)**
  - **System heated with hot oil rather than hot water**
  - **Loading lab being furnished**
  - **300 lb composite vessel w/ special stand**
  - **Signs throughout lab show safety and ergonomic concerns**
  - **Shut-offs for entire system except nitrogen**

UTRC – Site Description

Glove Boxes for Hydride Handling

UTRC – Site Description

Schematic of Pressure Vessel and Stand



UTRC – Site Description

- **Jet burner test stand (JBTS)**
  - Cell is 18” thick reinforced concrete
  - Sheet-metal “blow-out” back wall
  - Secondary pressure vessel holds test vessel
  - H2 from tube trailers
  - Lines purged and pressurized with nitrogen
  - Entire test complex shut down at night
  - Separate monitor and control station

ENERGETICS

UTRC – Site Description

Secondary Containment Vessel

UTRC

Safety Methodologies

- **The UTRC Risk Assessment Process**
  - Substantive, self-devised “binning system
  - Every component, process step, potential failure considered
  - Likelihood vs. impact matrix developed
- **UTRC Five-level inspection process**
  - Each level involves higher level of management from hands-on people to UTC upper management
  - Level One inspection by hands on people – once/mo
  - Level Four (Directors’ level) inspection – once/yr

ENERGETICS

UTRC – Discussion on Topics

Hydrogen Safety

- **Leaks**
  - **Prevention**
    - **H2 stored outdoors; cylinders inspected upon receipt**
    - **When brought indoors, kept in vented (to outside) gas cabinet**
    - **System shut down if H2 flow is lost**
    - **Systems are leak and pressure tested**
    - **As few fittings as possible**
  - **Containment /exhaust**
    - **Exhaust diluted to 10% LFL**
    - **“Two-valve rule”: two valves between you and hydrogen before you break into a system**
    - **At least two people in the facility for operation**
    - **Check valves and flash arrestors on all hydrogen lines**

ENERGETICS

UTRC – Discussion on Topics

Hydrogen Safety (cont.)

- **Ignition sources**
  - High voltage sources are minimized
  - All solenoids are enclosed
  - Brass tools are used
  - Everything in “Gas Alley” is explosion proof
  - All sparkless systems employed

ENERGETICS

UTRC – Discussion on Topics

Safety Planning

- **ISV**
  - UTRC's Risk Assessment Process
- **Risk Mitigation**
  - Five-levels of inspection
  - Entire UTRC population takes 1 ½ day management systems training
  - All personnel go over safety once/yr
  - New employee "sat down" and made aware of risk issues
  - Visiting scientists go through a sign-off procedure

ENERGETICS

UTRC – Discussion on Topics

Safety Planning (cont.)

- **Communications**
  - Uses an E-Star process where everything is followed and checked off electronically
  - "Incidents"
    - Reported to materials lab or test stand's Group Leader
    - Written up (electronic) as "Incident and Near Miss Report" and reviewed by Senior Management
    - Continue to be tracked after report
    - No policy on informing DOE

ENERGETICS

UTRC – Discussion on Topics

Codes And Standards

- Project adheres to:
  - NGV2
  - ASME Sec. VIII (pressure vessels)
  - ASME B31.1 (Power piping)
  - NFPA 50A (compressed H2)

- Awaiting more information from UTRC

ENERGETICS

UTRC – Discussion on Topics

Materials Issues

- Heat transfer tests use oil instead of water as a medium
- Stainless steel (as per SNL) is used for anything that will come in contact with $NaAlH_4$

UTRC - Panel Questions

- Nitrogen leak (oxygen reduction)
- Particle Size of Hydrides – effect on testing results
- Contaminants (esp. O_2, H_2O)
  - Need ppm vs. temperature rise
- Spills – How do you handle a hydride spill?

UTRC

Interim Conclusions

- (Pre- UTRC edit)
- High dedication to safety at UTRC
- Strong risk assessment plan
- Strong internal inspection program
- Panel questions will be addressed by UTRC
- Sodium alanates (and similar) require much care in handling here and elsewhere

- We thank Don Anton and his Team

ENERGETICS

Project Safety Reviews

NREL projects

- Two projects reviewed
  - Algal Systems for Hydrogen Photoproduction
  - Renewable Electrolysis Integrated Systems Development and Testing
- Both reviews 1st week in June
- First safety reviews at a National Laboratory
- These reviews are very preliminary

NREL Projects

General Laboratory Safety

- ES&H group fully integrated into planning and budgeting
- Turns standards into ‘necessary and sufficient’ documents (Requirements Management)
- ES&H Policies and Procedures include:
  - Six ‘policies’ : e.g., Worker safety and health, environmental management, etc.
  - 51 hazard-specific ‘programs’ e.g., fire protection, chemical safety, radiation safety, etc.
  - 196 ‘safe operating procedures’ for individual or groups of similar procedures.
- Participate in construction design and review
- Risk assessment “binning” matrix (built on Mil Std. 882, and evolved at NREL)
- Zero tolerance for incidents that cause off-site impacts

ENERGETICS

NREL projects

Algal Systems for Hydrogen Photoproduction

- **Subtask 1. Engineer an algal hydrogenase that is resistant to O2 inactivation;**
- **Subtask 2. Develop and optimize a physiological method to promote culture anaerobiosis and subsequent H2-production activity in algae;**
- **Subtask 3. Introduce a bacterial hydrogenase with increased O2 resistance into a water-splitting photosynthetic cyanobacterial system**

Note: this is a laboratory project in which hydrogen production is measured in millimoles or less.

NREL projects - Photoproduction

Safety Precautions Taken

- H2 flammability: H2 kept between 2-3%
- Gas monitor inside the anaerobic chamber constantly monitors H2 and O2
- Palladium catalysts are activated routinely to ensure O2 removal
- Flammable gas detector is used to detect leak of H2 from the anaerobic chamber
- Laboratory is equipped with efficient ventilation systems
- Organisms destroyed by heat or bleach after use
- NREL Radiation Safety Guidelines for radioactive probes (DNA labeling)

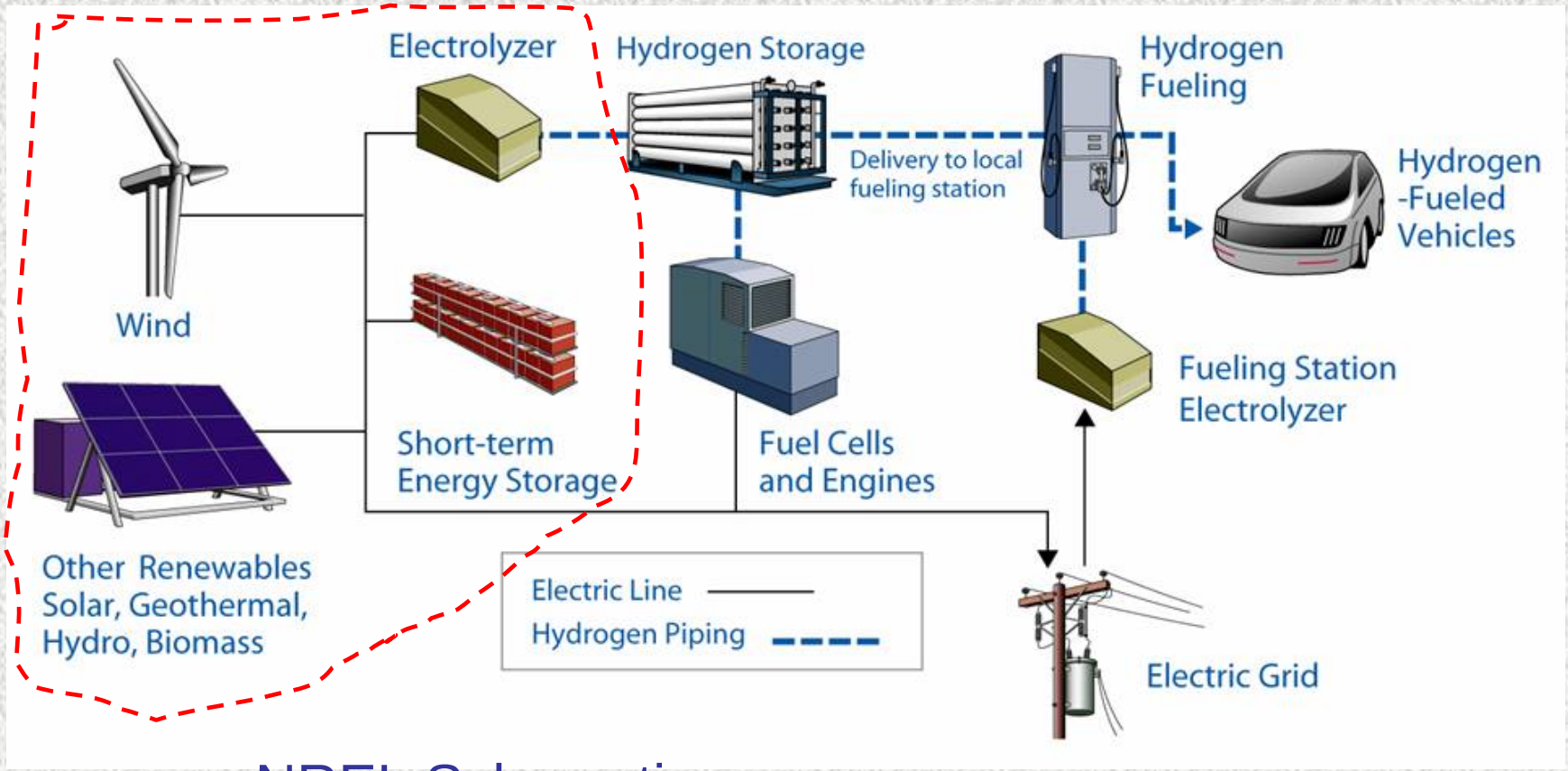
NREL projects - Photoproduction

Safety Issues

- 1999: One time build up of hydrogen in culture vessel overnight caused burst 250 ml flask. Corrected by adequate venting.
- 2000: Inadvertent connection of pure hydrogen to anaerobic chamber (instead of 10% H2 in N2) Could have been problem if O2 present. Corrected by dilution with N2. Corrected by additional training.
- When they develop O2 tolerant species H2/O2 combustion will be an issue.
- Potential issue with N2 in laboratory if it leaks

NREL projects

Renewable Electrolysis Integrated Systems Development and Testing



NREL Schematic

NREL projects - Electrolysis

- New project – Not all components installed and running, H2 and O2 currently vented to the outside.
- Hydrogen container holds 5 kW HOGEN™ electrolyzer (40 scfh, @ 200 psi), control panel and battery bank. (Container sized for a much larger system (75 kW)
- Two metal oxide hydrogen sensors on ceiling
  - Alarm at 10% LFL: partial shutdown, turns on emergency fan
  - Alarm at 20% LFL: total shutdown
- System will not turn on without test fan
- Thermocouple on ceiling would shut down system if there were a fire.

ENERGETICS

NREL projects - Electrolysis

Safety Issues

- H2 comes out at 200 psi – concern about pipes freezing (pressure controls would shut down system)
- Concern that more of system isn't connected yet – did we review too soon?
- When they start using the electrolyzer regularly they will have to relocate the oxygen vent.

We thank Carolyn Elam, Maria Ghirardi and both of their teams

ENERGETICS

Status

Already Visited Projects

- APCI/LV - Final report being prepared
- UTRC - Awaiting comments on first draft
- Two NREL Projects – First drafts started

Status

Planned Safety Review Site Visits

- 3M – Advanced MEAs for Enhanced Operating Conditions (7-8/04)
- Nuvera Fuel Cells Innovative Low Cost/ High Efficiency Hybrid PEM Fuel Cells Power System (7-8/04)
- SNL – Hydride Development for Hydrogen Storage (7-8/04)

ENERGETICS