Renewable Electrolysis Integrated System Development and Testing

Ben Kroposki and Carolyn Elam
National Renewable Energy Laboratory

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This presentation does not contain any proprietary or confidential information.

Electrolyzer RD&D Needs

- Reduced capital costs, enhanced system efficiency, and improved durability.
- Component development and systems integration to enable electrolyzers to operate from inherently intermittent and variable-quality power derived from wind and solar sources.
- Partner with industry to create robust, efficient and cost-effective renewable-electrolysis-hydrogen systems that will be ready for deployment as the distributed hydrogen infrastructure begins to develop.
- By 2010, verify renewable integrated hydrogen production with water electrolysis at a hydrogen cost of $2.50/kg.

Expected Outcome and Significance to DOE

- DOE has identified integration of renewables with electrolyzers as one of the barriers for hydrogen production from electrolysis in the DOE Hydrogen Multi-year RD&D Plan.
- The outcome of this project will be to optimize the design of a renewable power – electrolyzer interface and system package.
- The design a single power electronics package and controller will eliminate redundancy, achieve gains in system efficiency and robustness, reduce overall system cost.
- Success in this area is imperative for DOE to meet it's cost goal of $2.50/kg for renewable integrated advanced electrolysis technologies. Current price is $13.60/kg (small forecourt).

Project Objectives

This project examines the issues with using renewable energy to produce hydrogen by electrolyzing water

- Characterize electrolyzer performance under variable input power conditions
- Test and evaluate the electrical interface with renewable (PV, Wind, Hydro, Geothermal, etc) and/or hybrid/grid power
  - Dedicated hydrogen production
  - Electricity/hydrogen cogeneration
- Design and develop shared power electronics packages and controllers to reduce cost and optimize system performance
- Develop and verify integrated renewable electrolysis systems
  - Through performance modeling, simulation and testing
  - Safety, Codes and Standards requirements

Project Background

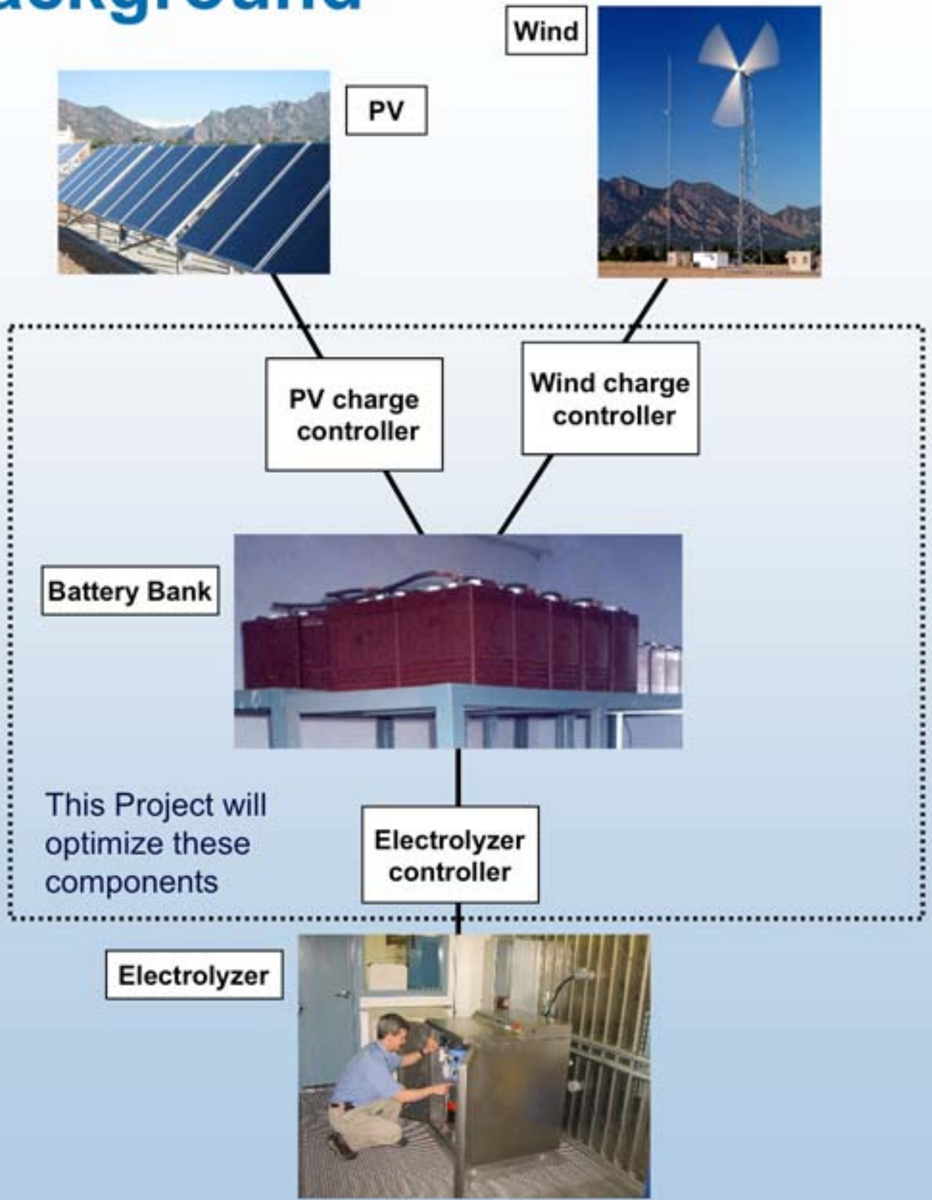
Past research on integrating electrolyzers with renewables has focused on integrating commercially available electrolyzers and renewables, both complete with their own dedicated power electronics and controller.

Designing a single power electronics package and controller will:

- Eliminate this redundancy
- Allow matching of renewable power output to electrolyzer power requirements leading to gains in system efficiency.

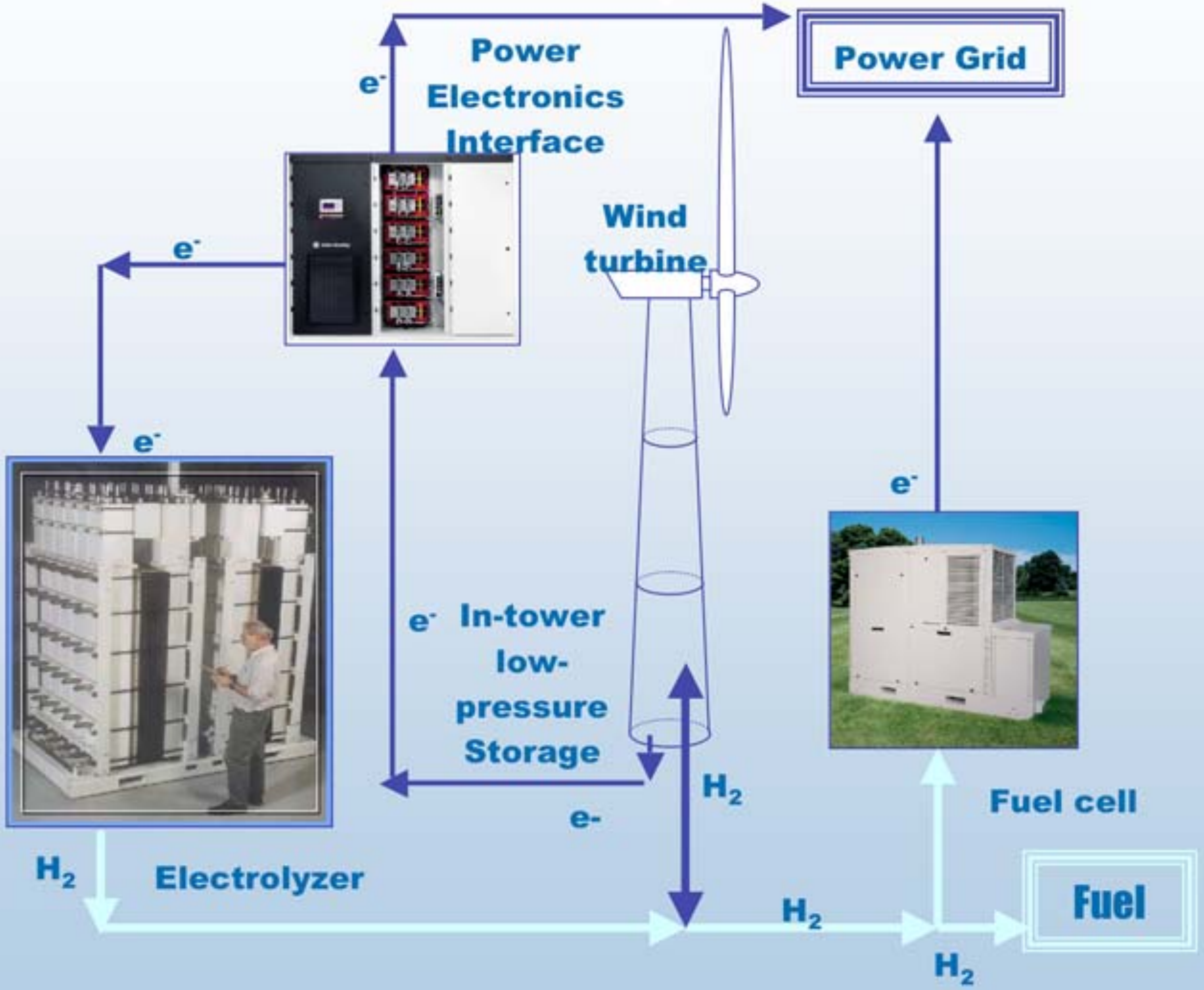
This new design will eliminate the need for a constant voltage DC bus and associated battery bank present in all systems previously studied.

Typically power electronics can be up to 30% of each system's cost.



Project Background

- Future use of renewable-electrolyzer system
- Storage system efficiency: 30% to 40%
- Conceptual design of wind-electrolyzer system for both hydrogen and electricity production



Budget

New FY04 Project – No FY03 Funding

Total FY04 funding for the project

- Planned: $400K + $100K(capital)
- Revised: $300K
  - Delays completing PEM electrolyzer testing and starting alkaline electrolyzer testing until FY05

Technical Barriers and Targets

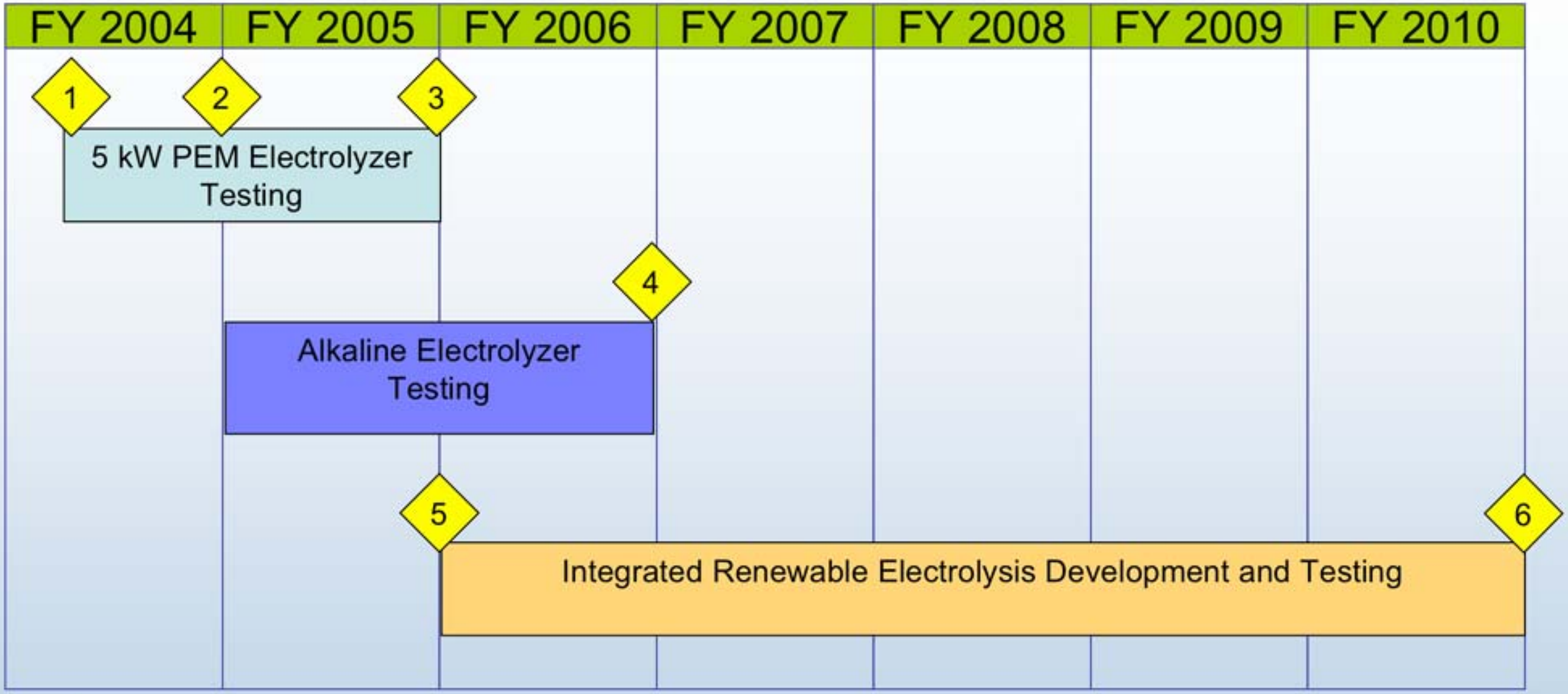
DOE Technical Barriers for Advanced Electrolysis Technologies

- Q (cost) - R&D is needed to develop lower cost materials with improved manufacturing capability to lower capital while improving the efficiency and durability of the system.
- R (system efficiency) - Development is needed for low-cost cell stack optimization considering efficiency, electrochemical compression, and durability.
- S (grid electricity emissions) – Low cost, carbon-free electricity sources are needed.
- T (renewable integration) - Development of small- and large-scale integrated renewable electrolysis systems is needed, including optimization of power conversion and other system components from renewable electricity to provide high-efficiency, low-cost integrated renewable hydrogen production.
- U (electricity cost) - Electrolysis systems that can produce both hydrogen and electricity need to be evaluated.

DOE Technical Target for Advanced Electrolysis Technologies

- By 2010, $2.50 per kg for renewable integrated hydrogen production

Project Timeline



1. Draft Test Plan for Characterizing Electrolyzer Performance
2. Characterize 5 kW PEM Electrolyzer Performance
3. 1st Generation Power Electronics Interface Developed for Wind
4. Design for Integrated Direct-Coupled Wind Electrolysis System
5. Draft Standards for Renewable Electrolysis Performance Testing
6. Verify renewable integrated hydrogen production - $2.50/kg

Approach – FY04

This project addresses the technical barriers in using renewables to produce hydrogen via electrolysis through the following tasks. The specific market barriers that are addressed are lowering system and electricity cost, improving system efficiency, and renewable integration.

Task 1 - Integrated System Test Facility

Task 2 - Electrolyzer Performance Testing

Task 3 - Power Electronics Development

Task 4 - PV-electrolyzer System Performance

Task 5 - Intermittent Electrolyzer Operation

Project Safety

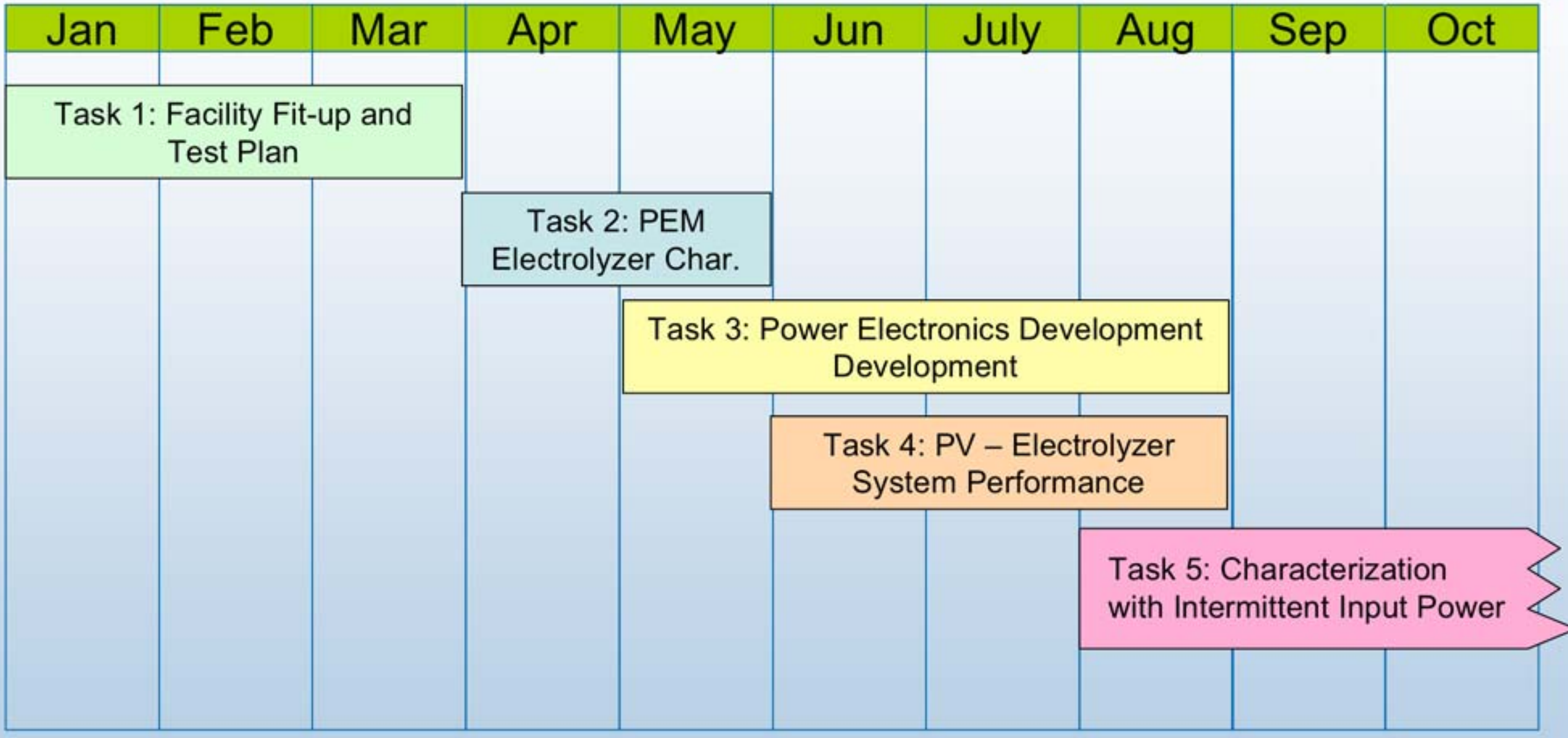
- Test environment for the electrolyzer was developed in accordance with NREL's risk assessment / hazard identification and controls protocols.

  This project used a failure mode and effects analysis (FMEA) in the analysis of the design and operation of the electrolyser and test area.

  This matrix led to the installation of redundant hydrogen sensors and a control program that will shut down the electrolyzer when 0.4% of hydrogen is detected and will activate an emergency fan at 0.8% hydrogen. (NREL uses the 0.8% hydrogen (20% LEL) as a standard level for emergency shutdown)

- Management of change (MOC) procedures are an aspect of the NREL Hazard ID and control program. Safe Operating Procedure documents are updated as process or scope of work changes.(annually) and test plans (project specific).
- This unit has just started operation, but safety-related lessons learned include *starting safety planning early* and *pre-testing of safety equipment and sensors*.

FY 04 Progress

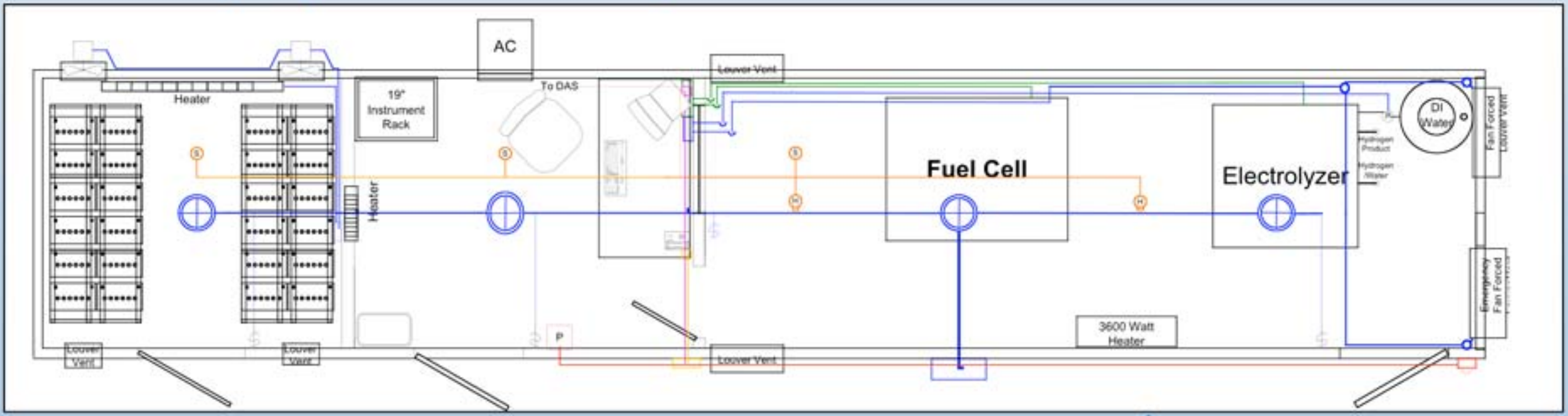


Currently FY04 Progress is on schedule

Technical Accomplishments

Task 1 – Integrated System Test Facility

- Completed Hydrogen Electrolysis Test Facility (at NREL National Wind Technology Center)
  - Designed control, safety, and data acquisition systems
  - Interconnection to on-site renewable/distributed/grid power
- Developed Renewable-Electrolyzer Test Plan (project milestone)



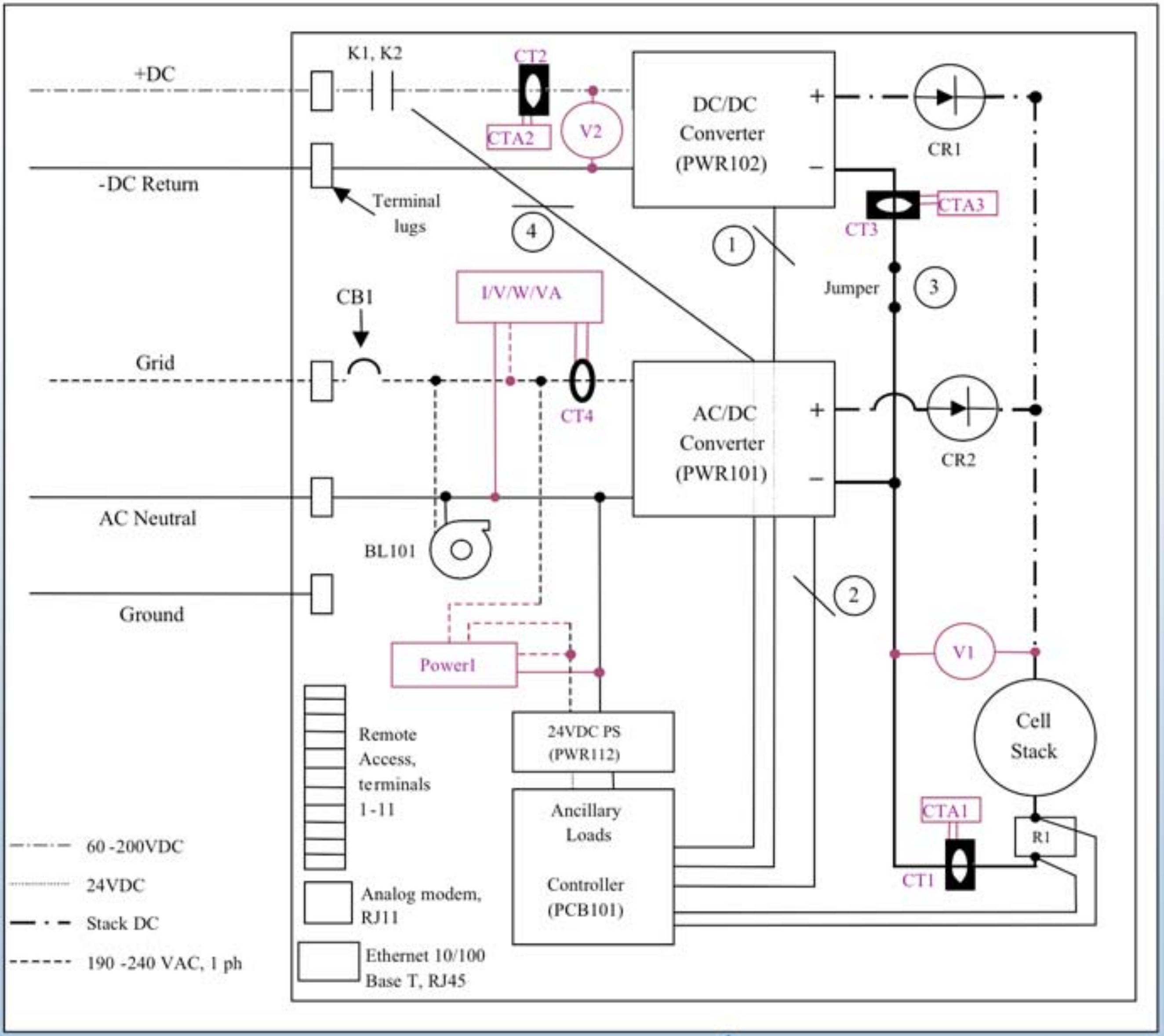
Technical Accomplishments

- Installed 10kW PV array
- Installed 10kW Windturbine

- Installed Hogen 40 Electrolyzer from Proton
  - 5 kW
  - 2 kg/day
  - 200 psi

Technical Accomplishments

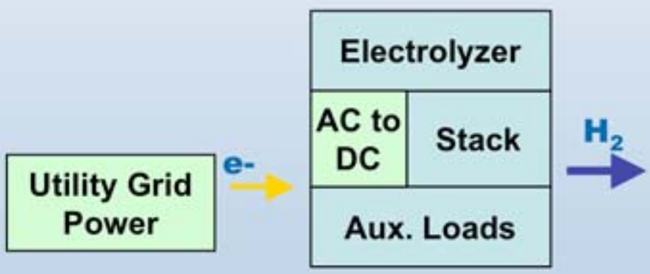
- DAS installation and calibration
  Sensors installed
  - **Gas/liquid flows**
  - **DI Resistivity**
  - **Temperature**
  - **Stack**
    - **Current**
    - **Pressure**
    - **Temperature**
- Control system
  - **Remote Start/Stop**
  - **Test Fan**
- Safety system
  - **E-Stop**
  - **Redundant H2 sensors**
  - **Exhaust fan at 10% and 20% LEL**

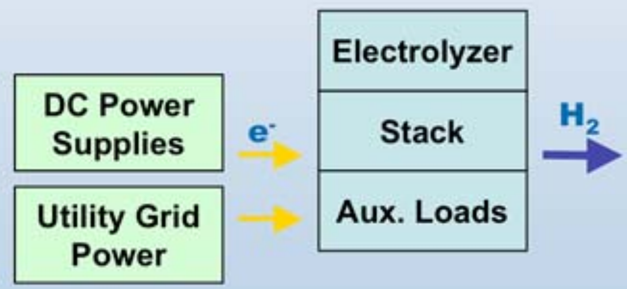


Technical Accomplishments

Task 2 - Electrolyzer Performance Testing

- Begun to characterize the electrolyzers under normal operation with utility grid and DC power in a variety of operating modes.





Remainder of FY04

Task 3 – Power Electronics Development

- Based on the characterization of the electrolyzer and wind turbine, design and model the optimum power electronics interface to work with the target wind turbine and electrolyzer.

Task 4 – PV-electrolyzer System Performance

- Test the packaged PV array controller interface on the electrolyzer under a variety of operating conditions. This information will be shared with Proton Energy to confirm performance and optimize controller operation.

Task 5 – Intermittent Electrolyzer Operation

- Determine the effect of intermittent operation on the efficiency and reliability of the electrolyzer.
- Develop draft testing protocols for operation of electrolyzers under intermittent conditions.

Interactions and Collaborations

- Proton Energy – Currently working with Proton on the development and validation of renewable energy inputs to 5kW electrolyzer

PROTON ENERGY SYSTEMS
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- DOE Wind and Hydropower Technologies Program – leveraging power electronics and wind turbine interface expertise

National Renewable Energy Laboratory NWTC National Wind Technology Center

- Focused on market barriers of reducing costs through system optimization and integration with renewables

Future Work

FY05 Plans

- Complete testing on 5kW PEM electrolyzer
- Complete first generation integrated power electronics and controller and test
- Start testing of alkaline electrolyzer system
- Start Model/simulation of renewable-electrolyzer performance
- Develop Draft Standard test protocol for electrolyzer performance and operation

FY06-FY10 Plans

Integrated Renewable Electrolysis Development and Testing

Power package design - Partners will be sought to procure and test a multi-megawatt electrolyzer/wind turbine system. Designs for renewable power packages will be developed for utility, residential, commercial, industrial and distributed generation markets.