2005 DOE Hydrogen Program Modular System for Hydrogen Generation & Oxygen Recovery

Iouri Balachov

SRI International

May 23, 2005

Project ID # PDP43

This presentation does not contain any proprietary or confidential information

Overview

Timeline

- Project start date – March 29, 2005
- Project end date – 4 years from the starting date
- Percent complete – N/A

Budget

- Total project funding $2,310,447
  - DOE share $1,828,274
  - Contractor share $482,173
- Funding received in FY04 - $0
- Funding for FY05 – expected $395K, exact amount will be defined upon completion of award negotiation in April – May 2005

Barriers

- Barriers addressed
  - low-cost generation of H_2 (<$2/kg)

Partners

- SRIC-BI
- IEP
- Praxair, Inc.

Objectives

- Develop a prototype of a modular industrial system for low-cost generation of H_2 (<$2/kg) by steam electrolysis with anodic depolarization by CO
- Project deliverables
  - a pilot electrolysis system for H_2 generation,
  - an economic analysis,
  - recommendations and technical documentation for field deployment

Approach

- Water will be decomposed electrochemically into H_2 and O_2 on the cathode side of a high-temperature electrolyzer.
- Oxygen ions will migrate through an oxygen-ion-conductive solid oxide electrolyte.
- Gas mixtures on the cathode side (H_2 + H_2O) and on the anode side (CO + CO_2) will be reliably separated by the solid electrolyte.
- Depolarization of the anodic process will decrease the electrolysis voltage 5-10 times, and thus the electricity required for H_2 generation and the cost of produced H_2.

Electrolyzer Energy Consumption

Component	Low temperature electrolysis	High temperature electrolysis
Electrolysis	53%	90%
Electrode polarization losses	19%	2%
Ohmic losses	28%	8%

High-temperature electrolysis with the anodic depolarization

- Lower electrolysis voltage is required
  - Energy consumption is lower
- Cathode
  - $H_2O+2e^- \rightarrow O^{2-}+H_2$
- Anode
  - $CO + O^{2-} \rightarrow CO_2 + 2e^-$

Technical Feasibility of the Concept

- Electrolyzer EMF

$$E = E^0_{H_2/H_2O} - E^0_{CO/CO_2}$$

$$E^0_{H_2/H_2O}(mV) = 1290 + 0.292T(K)$$

$$E^0_{CO/CO_2}(mV) = 1458 + 0.447T(K)$$

- Preliminary calculations indicate that *E* is very low in this case (< 0.05 V at 1000°C)
- Measured voltage < 0.2–0.3 V
  - YSZ 0.05–0.25 mm, a Ni anode and cathode
  - current density of 0.5-1 A/cm^2

Technical Feasibility of the Concept

- Estimated energy consumption
  - 5–6 kWh/kg H_2 (theoretical)
  - Experience in developing high-temperature electrolyzer systems indicates that energy consumption may be 20–40% higher
  - Energy efficiency:
    - Our experience and the estimates of others
    - 60–70% (with respect to primary energy consumption),
    - 75–90% (with respect to total energy into the electrolyzer)
- Expected energy consumption 6–8 kWh/kg H_2

Technical Feasibility of the Concept

- The cost to generate 1 kg H_2
  - Electricity \$0.46–\$0.75
    - assuming an electricity cost of \$0.07/kWh.
  - Cost of electricity is expected to be the major component (in the 50% range)
  - Our estimates indicate that the expected plant gate cost is in the \$1-1.50/kg H_2 range
- Target cost of \$2/kg H_2 can be met

Competitive Advantages

- Generate H_2 at a significantly lower cost
    - The process is expected to be at least 10 times more energy-efficient than low-temperature electrolysis and will generate H_2 at a cost of under $2/kg.
    - The operating economics of the system can be made even more attractive by deploying it at locations where waste heat is available; using waste heat would reduce the electricity required for heating the system.

Critical Targets and Barriers

- Critical targets
  - H_2 production cost below $2/kg,
  - scalable design of the pilot H_2 generation system.
- Envisioned technical barriers
  - Performance and stability of the electrolyzer cell materials and structural materials
  - Optimal geometry and heat transfer of the gas distribution system.
  - Electrical connections of the individual cells in the electrolyzer stack to minimize energy consumption and maximize H_2 output and purity.
  - Stack design to allow pilot system scalability to meet the target H_2 production rate.

Project Tasks

1. Selection of the electrode, electrolyte, and interface materials for the high-temperature electrolyzer.
2. Design of a single stack H_2 generator with minimized energy consumption.
3. Long-term performance tests and optimization of the operating regimes.
4. Development of a pilot system based on industry requirements.

Phase 1 Objective and Milestones

- Objective: develop a single cell electrolyzer, that meets the following two criteria:
    1. performance is stable within 1–3% during several thousand of hours of tests with multiple on/off and heat-up/cool-down cycles.
    2. the electrolysis voltage does not exceed 0.2–0.3 V (while maintaining current density of 0.5–1 A/cm2)
- Milestones
    1. Design drawings for the high-temperature electrolyzer cell (1 month after the start of Phase 1).
    2. Assembled electrolyzer test cell (5 months after the start of Phase 1).
    3. Successful tests of the electrolyzer cells (11 months after the start of Phase 1).

Phase 2 Objective and Milestones

- Objective: design, assemble, and test a single-stack H_2 generation system with anodic depolarization by CO
- Milestones
    1. Assembled electrolyzer stack (5 months after the start of Phase 2).
    2. Successful tests of the electrolyzer stacks: satisfactory endurance of the single stack electrolyzer capable of meeting the target H2 generation cost (end of Phase 2).

Phase 3 Objective and Milestones

- Objective: define operation regimes for the electrolyzer
  - temperature,
  - power level,
  - composition and pressure of the input [CO] and output [H2] gases
- Milestones
  1. Final design of the pilot system electrolyzer stack (3 months after the start of Phase 3).
  2. Assembled single-stack electrolyzer (6 months after the start of Phase 3).
  3. Satisfactory performance of the single-stack electrolyzer module for the pilot system in long-term stability tests (end of Phase 3).

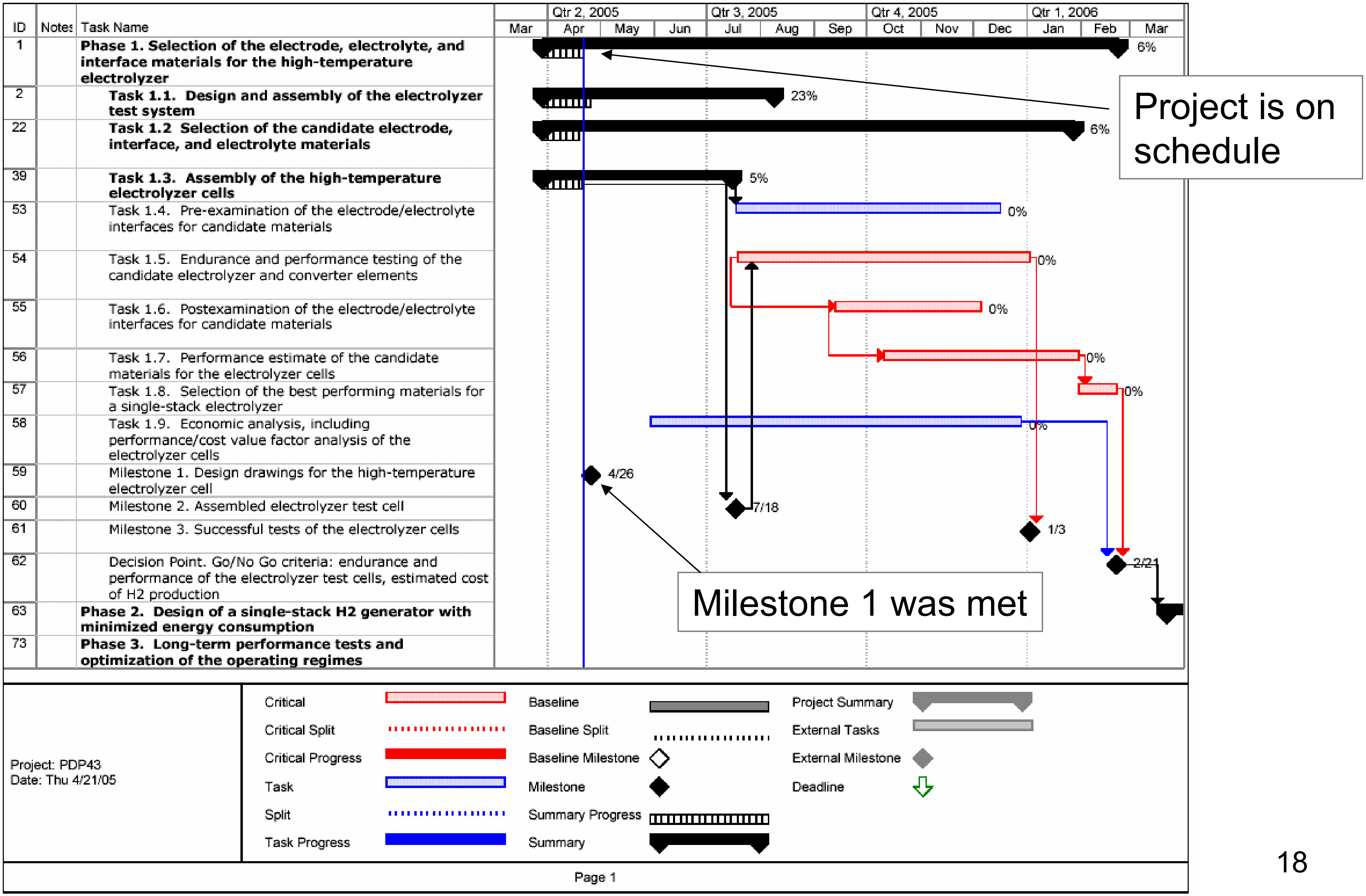
Phase 4 Objective and Milestones

- Objective: develop and demonstrate the pilot electrolysis system
- Milestones
  1. Assembled pilot electrolyzer system (4 months after the start of Phase 4)
  2. Achievement of target efficiency and target cost of H_2 generation (7 months after the start of Phase 4),
  3. Tested pilot H_2 generation unit (11 months after the start of Phase 4).
  4. Recommendations for deployment and operation (at the end of Phase 4).

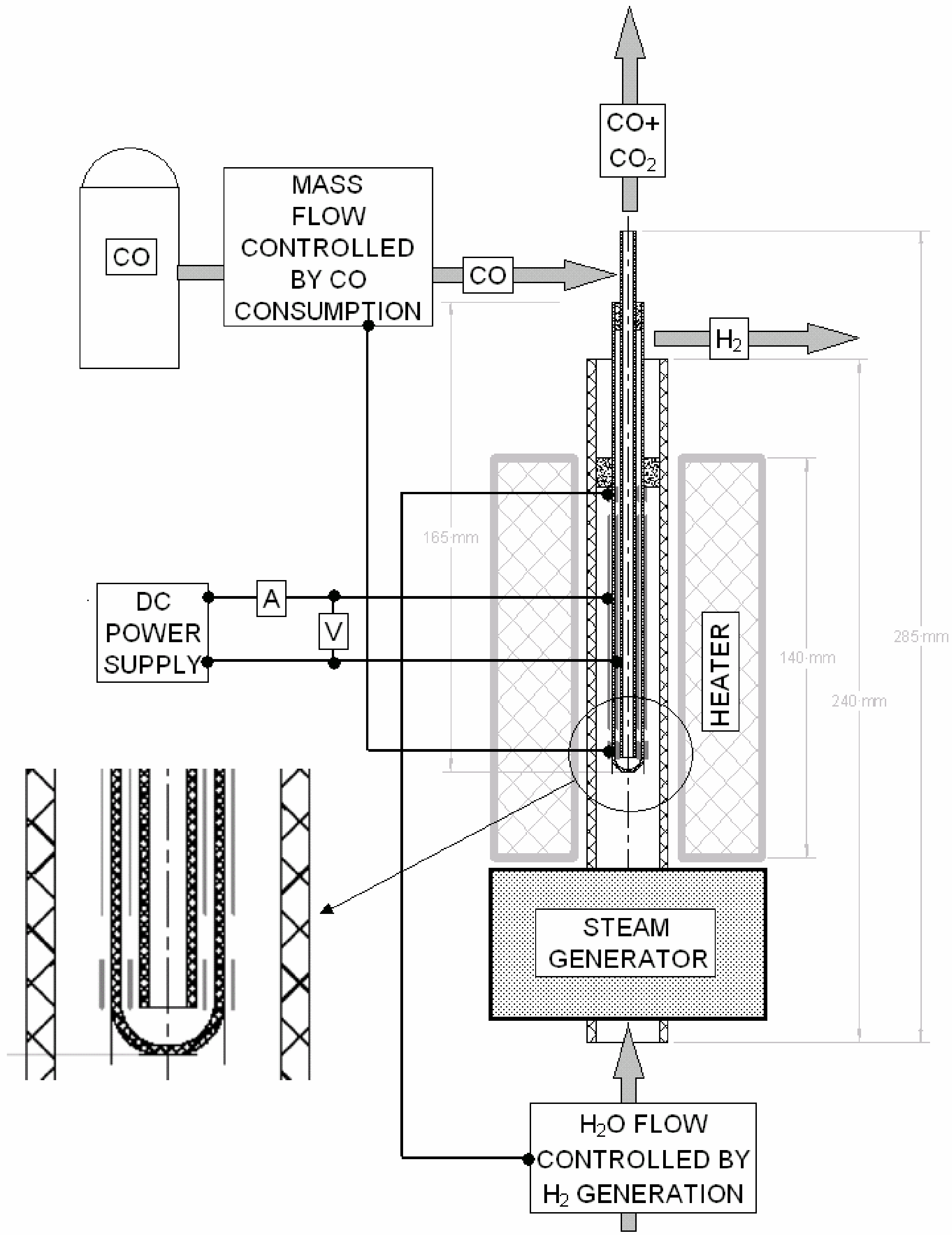
Technical Accomplishments/ Progress/Results

- Task 1.1. Design and assembly of the electrolyzer test system
  - Design of the electrolyzer test system
    - Completed on April 24, 2005.
    - Milestone 1 was met
  - Order equipment and parts
    - On schedule. Expected completion – end of June, 2005
  - Assembly test system
    - Planned start date – mid June, 2005
    - Planned completion date – mid July, 2005

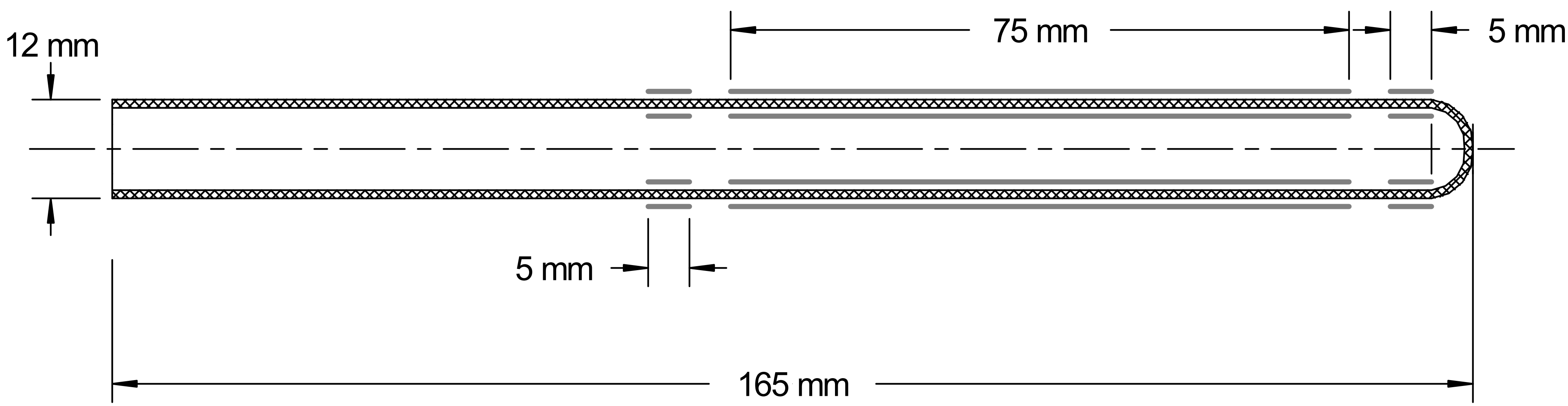
Project Schedule



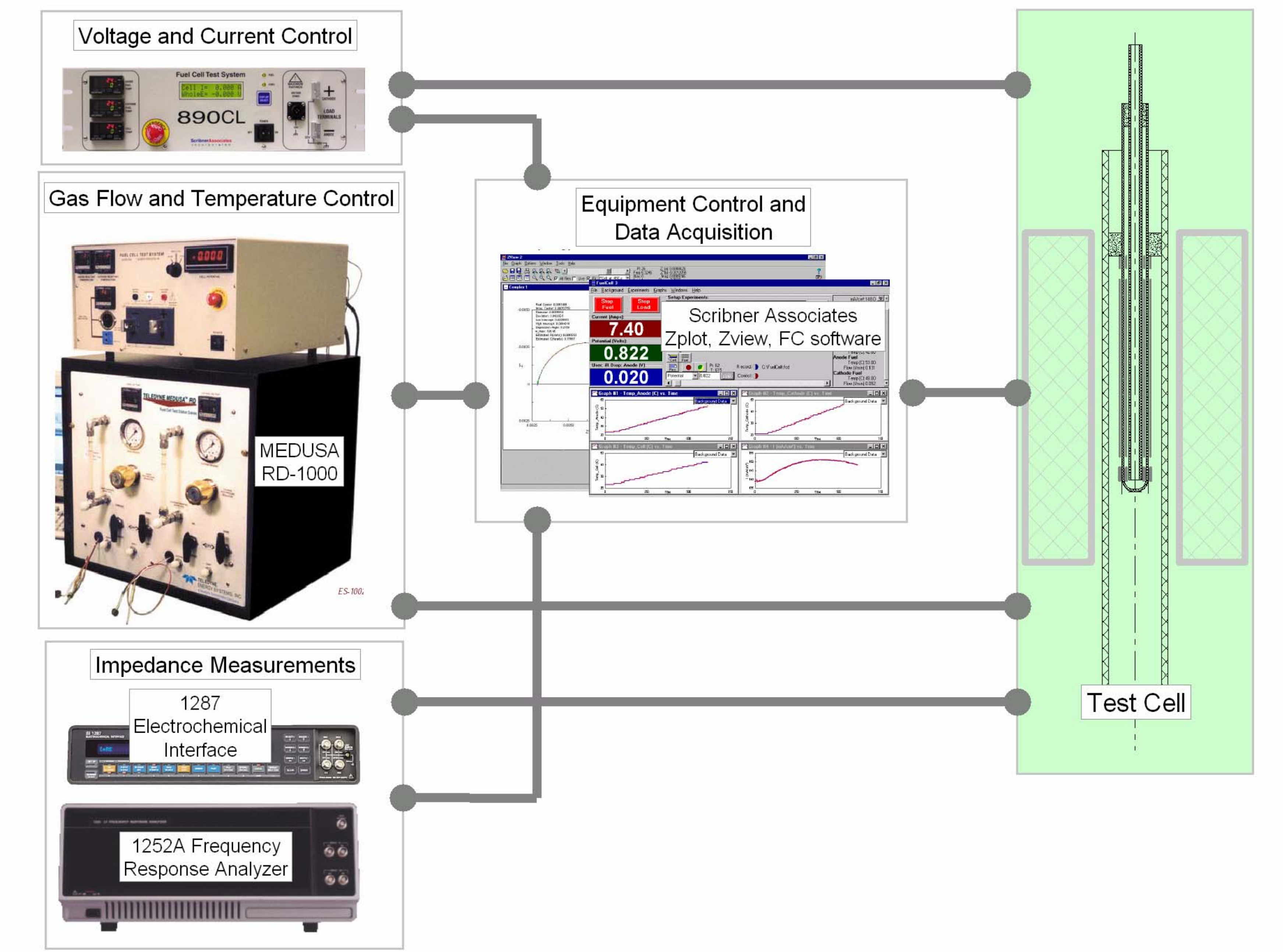
Experimental System



Electrolyzer Element



Instrumentation and Control



Future Work: Phase 1

Selection of the electrode, electrolyte, and interface materials for the high-temperature electrolyzer

- Tasks
  - 1.1. Design and assembly of the electrolyzer test system
  - 1.2. Selection of the candidate electrode, interface, and electrolyte materials"
  - 1.3. Assembly of the high-temperature electrolyzer cells
  - 1.4. Pre-examination of the electrode/electrolyte interfaces for candidate materials
  - 1.5. Endurance and performance testing of the candidate electrolyzer and converter elements
  - 1.6 Postexamination of the electrode/electrolyte interfaces for candidate materials
  - 1.7. Performance estimate of the candidate materials for the electrolyzer cells
  - 1.8. Selection of the best performing materials for a single-stack electrolyzer
  - Task 1.9. Economic analysis, including performance/cost value factor analysis of the electrolyzer cells"

Future Work: Phase 1

Selection of the electrode, electrolyte, and interface materials for the high-temperature electrolyzer

- Milestones
  - 1. Design drawings for the high-temperature electrolyzer cell
  - 2. Assembled electrolyzer test cell
  - 3. Successful tests of the electrolyzer cells
- Decision Point. Go/No Go criteria:
  - endurance and performance of the electrolyzer test cells, estimated cost of H2 production "

Supplemental Slides

Publications and Presentations

None

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Accumulation of Hydrogen gas from leaks or vented gas could lead to explosive or flammable gas mixtures in static or enclosed air spaces.

Hydrogen Safety

Our approach to deal with this hazard is:

- *Experiments will be conducted in a well-ventilated fume hood*
- *All gas connections will be leak checked with a combustible gas detector*
- *Total generation of hydrogen will limited to approximately 1ccm*
- *Vented hydrogen will be released directly into building exhaust to ensure adequate dilution*
- *Spark ignition sources will be kept outside of fume hood, well away from hydrogen sources*
- *Unattended operation involving generation of hydrogen will be prohibited*
- *Electrolyzer will be purged with inert gas before and after experiments*