A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Hydrogen Reactor Development and Design for Photofermentation and Photolytic Processes

2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

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Objectives for FY04

Solar production of hydrogen by photocatalytic or photobiological processes will require large area reactors with transparent coverings that have low hydrogen permeability.

- Identify three transparent material candidates
- Begin accelerated and outdoor weathering tests
- Measure key properties for the photolytic reactor application

Budget

- Total Funding: $130K (Project started in FY2004)

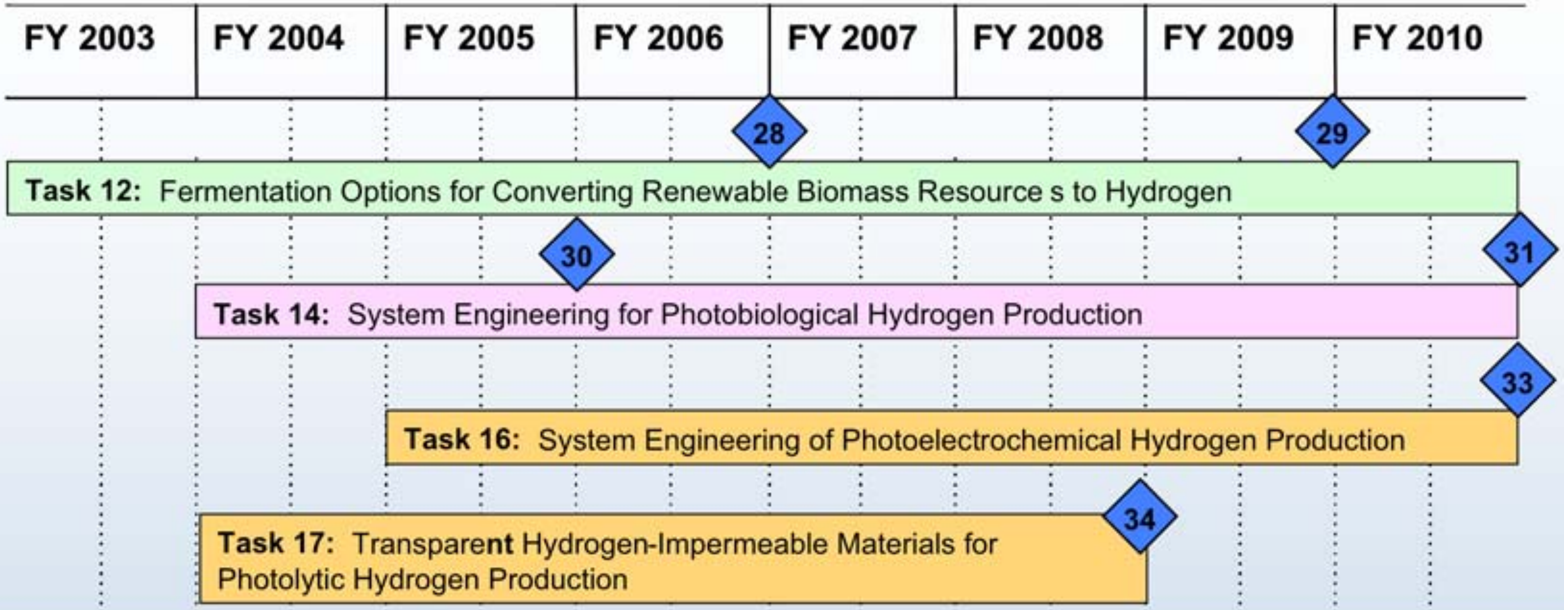
Technical Barriers and Targets

- Photobiological and Photoelectrochemical Hydrogen Generation Barriers
  - L. Systems Engineering
  - N. Materials and System Engineering
- Targets
  - By 2015, demonstrate an engineering-scale biological system that produces hydrogen at \$10/kg plant gate cost
  - By 2015, demonstrate direct PEC water-splitting at \$10/kg plant gate cost

Approach

- Identify transparent materials for use as the cover for photolytic water splitting reactors
  - Identify promising candidates based on existing durability information and new materials from vendors
  - Evaluate material durability using accelerated and outdoor weathering tests
  - Measure key physical and mechanical properties as a function of time in the durability tests
  - Identify materials properties that require modification or improvement to meet the system requirements
  - Build on 25 years of experience in evaluation of materials for solar applications at NREL

Project Timeline



Legend

- Milestone
- Output
- Input
- Go/No-go

28. Select fermentation technologies to be developed for converting renewable biomass resources to hydrogen.
29. Downselect fermentation technologies for converting renewable biomass reso urces to hydrogen.
30. Develop a photobiological system with the potential for 10% utilization efficiency of absorbed light energy and 0.5% absorbed light to hydrogen energy efficiency that produces hydrogen (at laboratory scale) continuously for 500 hours at a p rojected cost of $100/kg.
31. Demonstrate (at laboratory scale) photobiological system with 20% utilization efficiency of absorbed light energy and 5% absorbed light to hydrogen energy e fficiency that produces hydrogen continuously for 1500 hours at a projected cost of $30/ kg.
33. Verify (at laboratory scale) a photoelectrochemical water-splitting system that could produce hydrogen at a projected cost of $9/kg at the plant gate with technology concepts identified for further cost reduction.
34. Select cost-effective transparetn hydrogen impermeable material for photolytic production.

Technical Progress

- Identified baseline operating requirements for the photolytic water splitting processes
- Mined existing data on performance of polymers in solar and outdoor applications
- Initiated accelerated and outdoor testing of polycarbonate, acrylic, polyethylene teraphthalate, and teflon polymers
- Setting up oxygen and hydrogen permeability tests to evaluate materials

Technical Accomplishments
General Observations

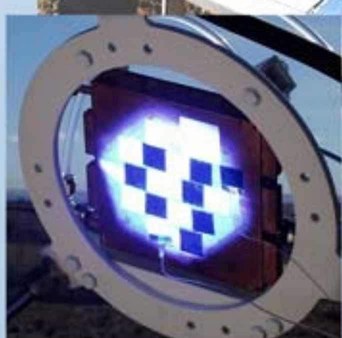
- Some acrylics have good outdoor durability but are brittle and subject to hail damage
- Polycarbonates are tough but “yellow” and crack outdoors
- PET formulations have not yet proven durable outdoors
- Low-cost polymers like polyethylene, polystyrene, and polypropylene have poor outdoor performance

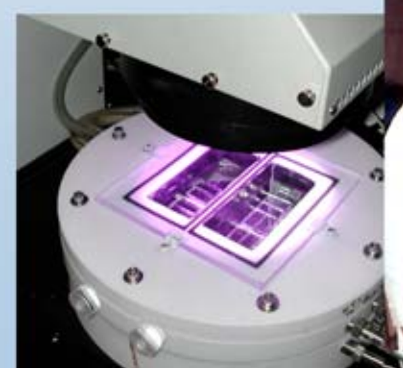
Durability Testing

- Outdoor Test Network

Site	Stress Conditions
1. Miami, Fl	Hot/Humid
2. Phoenix, AZ	Hot/Dry
3. Golden, CO	Cool/Mild

- Accelerated Weathering
  - Atlas Ci65 (~1 sun) and Ci5000 (~2 suns) WeatherOmeters
  - 1-kW and 1.4-kW Solar Simulator (~2.5 suns and 200-500 nm)
  - Q-Panel QUV (UVA or UVB)





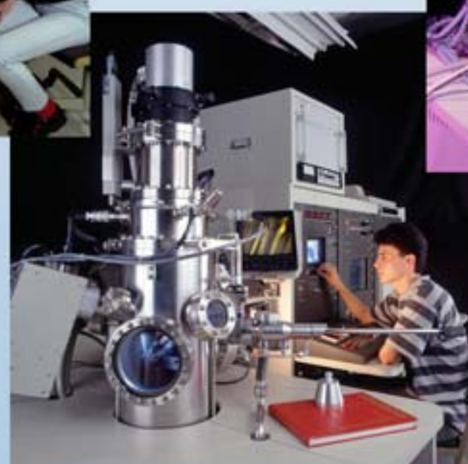
- Ultra-Accelerated Natural Sunlight

Analytical Characterization

- Guide material formulation
- Failure analysis of exposed samples
- Strong industry support capabilities

SEM

FTIR



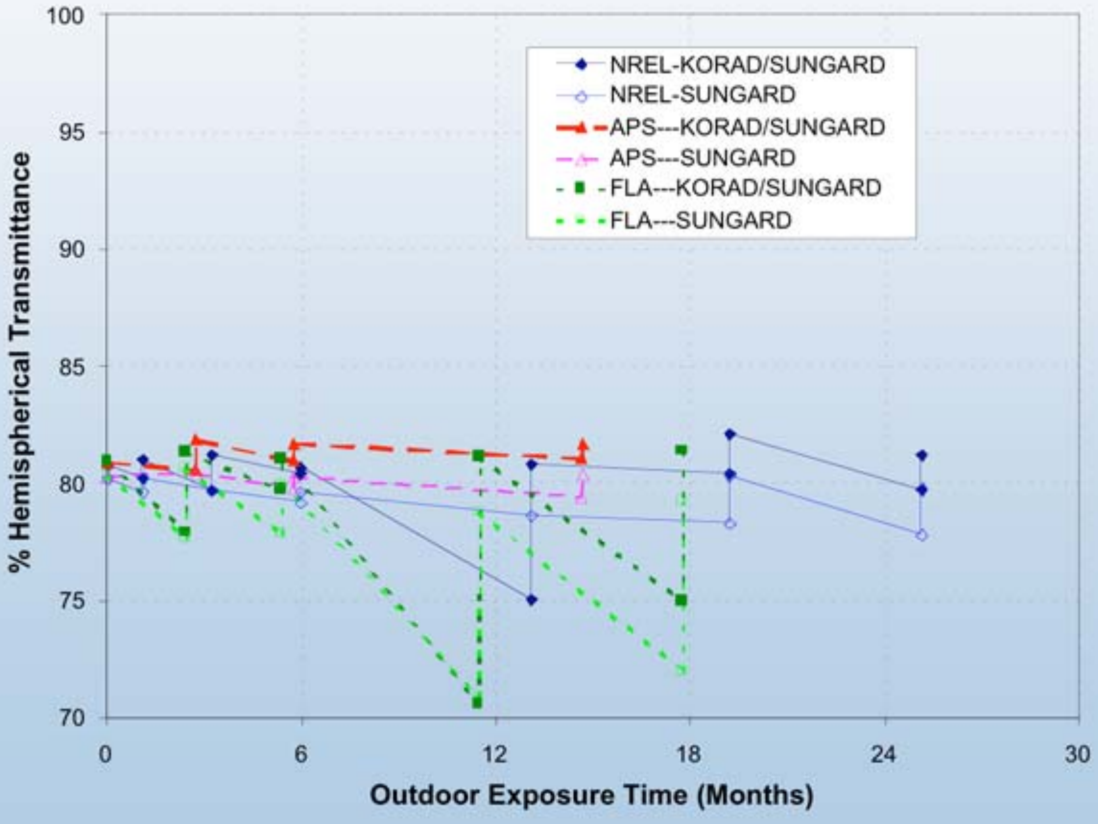
Auger

XPS

SIMS

Technical Accomplishments
Data from Materials already in Test

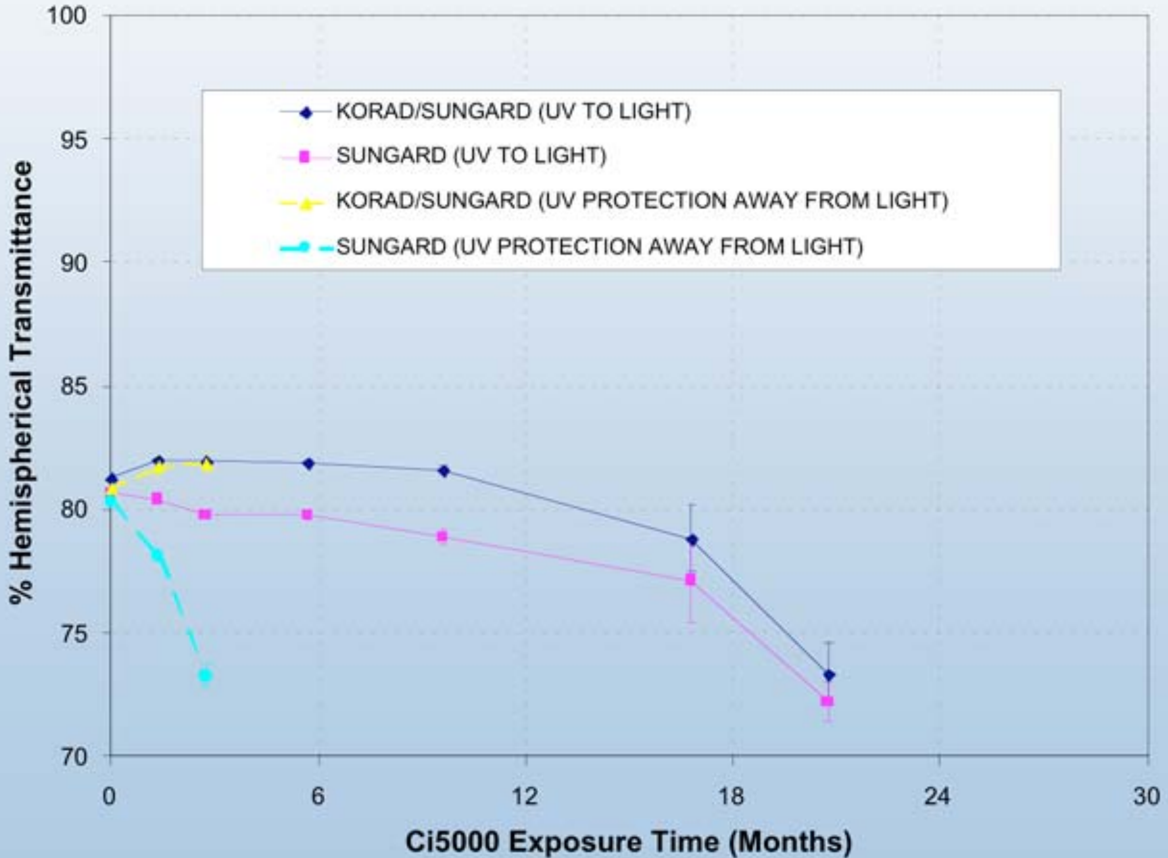
Outdoor weathering in CO, AZ, and FL



These are polycarbonates and protective layers. The step changes result from cleaning the samples when they come in for evaluation.

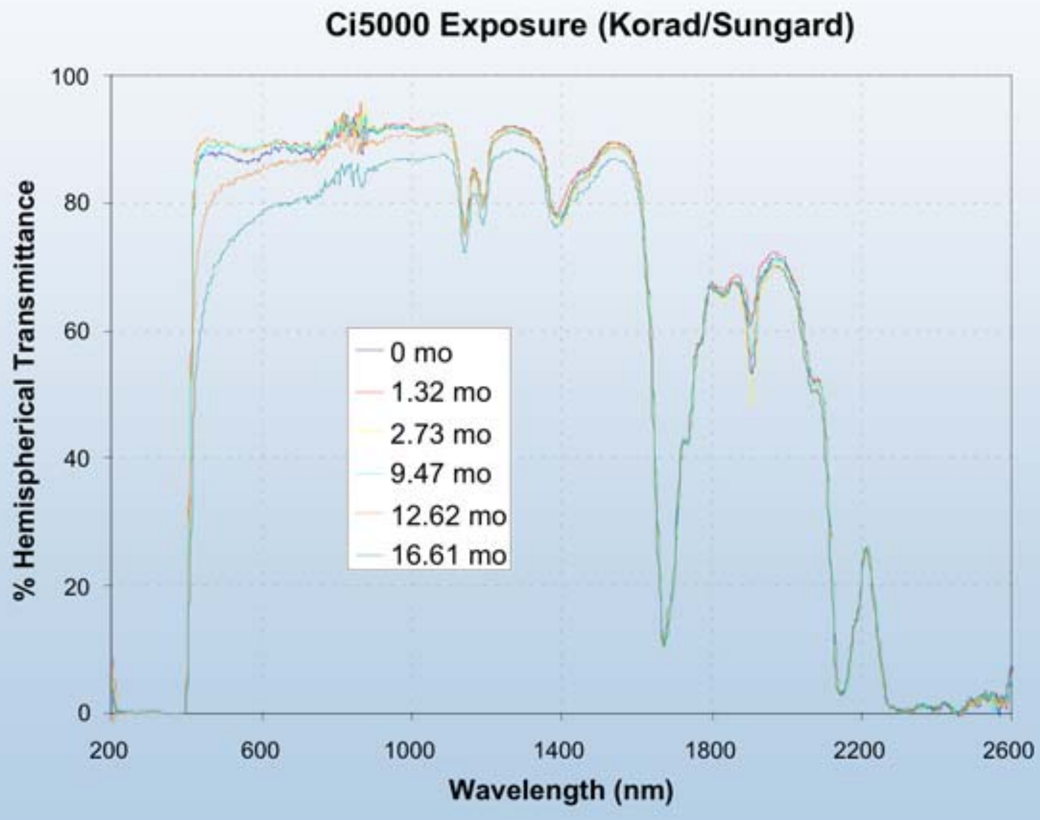
Technical Accomplishments
Data from Materials already in Test

Polycarbonate with protective acrylic layer – Accelerated test



The UV screen is only on one side so there is more performance loss when the unprotected side is toward from the light. (Approximately 6X acceleration for light effect over outdoors)

Technical Accomplishments
Data from Materials already in Test



This demonstrates loss of transmittance for the polycarbonate formulation in the visible part of the solar spectrum.

Interactions and Collaborations

- NREL has an extensive list of material suppliers that provide samples of materials for solar applications
- NREL has outdoor test space at sites in Golden, CO, Phoenix, AZ, and Miami, FL

Response to Previous Year Reviewers' Comments

- New project – not reviewed last year

Future Work

- Balance of FY 2004
  - Time zero properties of polymers – polycarbonate, acrylic, polyethylene teraphthalate, and teflon (solar transmittance, O_2 and H_2 permeability, tensile strength, and cost)
  - Start accelerated tests of three polymers
  - Start outdoor tests
- FY 2005
  - Continue accelerated and outdoor tests of the three polymers and new candidate materials that are identified
  - Devise and begin to test strategies for reducing hydrogen permeability, if necessary

Safety

- A hazard identification and control program is employed to identify possible failure modes and associated risks. Redundant engineering and procedural controls are used to ensure that acceptable levels of risk are not exceeded.
- Accelerated weathering, outdoor testing, and evaluation of optical, chemical, and physical properties are done using standard equipment and procedures.
- For hydrogen permeability testing, the sample chamber volumes on either side of the sample will be on the order of 10-20 mL. We have begun to evaluate accidental release scenarios and appropriate engineering controls.
- The durability of physical, optical, and oxygen and hydrogen permeation properties are all critical to safety and economics of photo-processes.