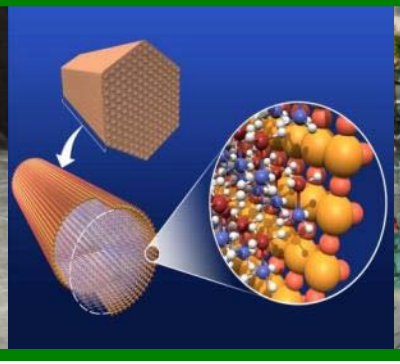
U.S. DEPARTMENT OF ENERGY



Hydrogen Production Sub-program
- Session Introduction -

Eric L. Miller

2011 Annual Merit Review and Peer Evaluation Meeting
May 11, 2011

Goal & Objectives

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Develop distributed and centralized technologies to produce H_2 from clean, domestic resources for a competitive cost, of 2–4/gge (dispensed)

Near-term: Distributed Production (up to 1,500 kg/day H_2)

(produced at station to enable low-cost delivery)

- *Natural gas reforming*
- *Renewable liquid reforming*
- *Electrolysis*

Longer-term: Centralized Production (up to 100,000 kg/day H_2)

(large investment in delivery infrastructure needed)

- *Biomass gasification*
- *Coal with sequestration*
- *Wind-and solar-driven electrolysis*
- *Solar high-temperature thermo-chemical water splitting*
- *Photoelectrochemical and biological production*

In the United States, about 9 million tons of hydrogen are produced annually for industrial purposes, and there are >1,200 miles of hydrogen pipelines.

Production Strategies

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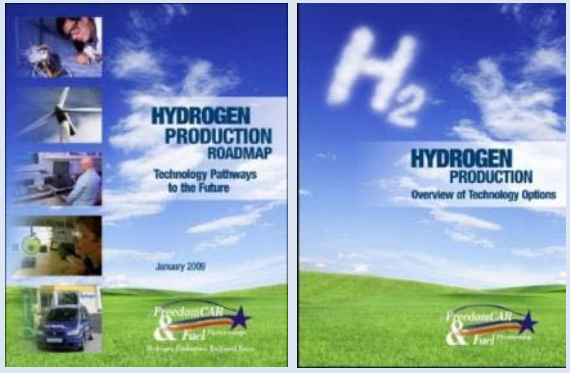
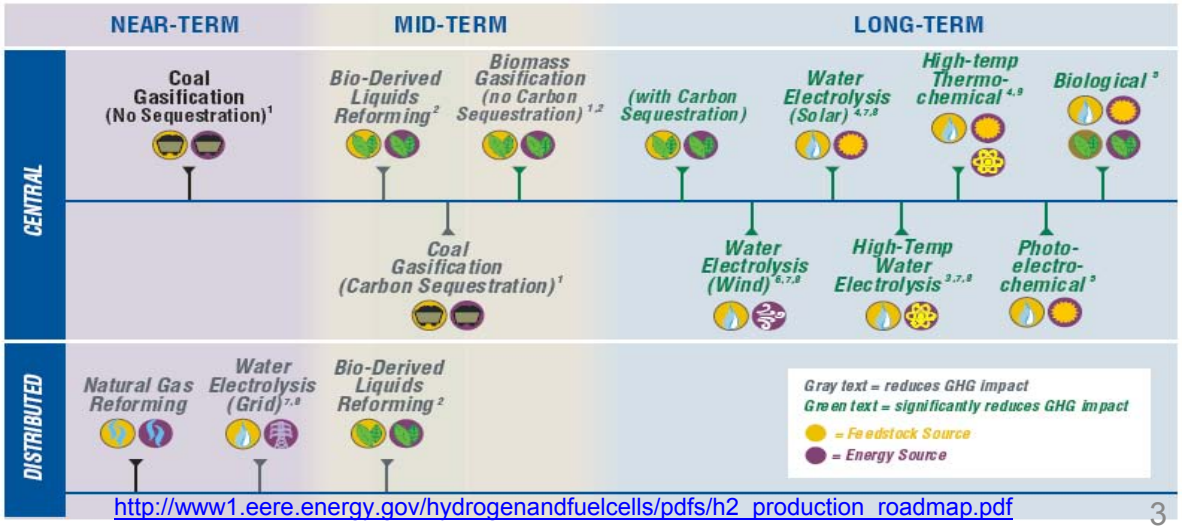
Informed prioritization of R&D needs in H_2 production pathways

- Targets and projected costs for H_2 Production portfolio pathways informed by independent analysis
- R&D needs for meeting targets in Production pathways are continually assessed and prioritized, as reflected in H_2 Production Roadmap



Pathway	Report
Steam Methane Reforming	*Distributed Hydrogen Production from Natural Gas, NREL, October, 2006*
Electrolysis - Distributed - Central (Wind)	*Current (2009) State -of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis, NREL, September, 2009.*
Photoelectrochemical	*Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production, Directed Technologies Inc., December, 2009.*
Biological	*Technoeconomic Boundary Analysis of Biological Pathways to Hydrogen Production, Directed Technologies Inc., September, 2009.*
Biomass Gasification	*Hydrogen Production Cost Estimate Using Biomass Gasification, Independent Panel Review, NREL, Draft, April, 2011*
Solar Thermochemical	*Cost Analyses on Solar-Driven High Temperature Thermochemical Water-Splitting Cycles, TIAX, February, 2011*



http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_production_roadmap.pdf

Challenges

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Materials performance & capital costs identified as key challenges in ALL distributed and central pathways in H_2 Production Roadmap

Distributed Natural Gas Reforming

Critical Challenges

- High capital costs
- High operation and maintenance costs
- Design for manufacturing

Bio-Derived Liquids Reforming

Critical Challenges

- High capital costs
- High operation and maintenance costs
- Design for manufacturing
- Feedstock quantity and quality

Coal and Biomass Gasification

Critical Challenges

- High reactor costs
- System efficiency
- Feedstock impurities
- Carbon capture and storage

➢ Materials durability and efficiency improvements and overall system capital costs reductions are needed in all pathways

Thermochemical

Critical Challenges

- Cost-effective reactor
- Effective and durable materials of construction
- Longer-term technology

Water Electrolysis

Critical Challenges

- Low system efficiency and high capital costs
- Integration with renewable energy sources
- Design for manufacturing

Photo-electrochemical

Critical Challenges

- Effective photocatalyst material
- Low system efficiency
- Cost-effective reactor
- Longer-term technology

Biological

Critical Challenges

- Efficient microorganisms for sustainable production
- Optimal microorganism functionality in a single organism
- Reactor materials
- Longer-term technology

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_production_roadmap.pdf; http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_tech_roadmap.pdf

Budget

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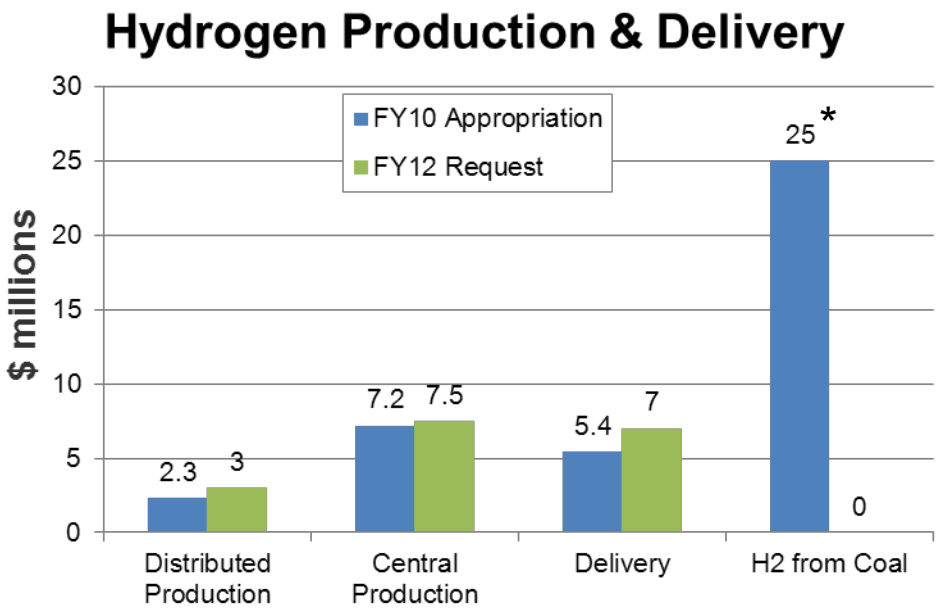
Production remains a high priority in the FY 2012 Request

FY 2012 Request = $17.5M

FY 2010 Appropriation = $15M



FY11 appropriation to be determined

*Includes coal-biomass-to-liquids R&D

Nuclear Hydrogen Initiative was discontinued at end of FY 2009 as a separate program. Development of high temperature electrolysis is continuing under the NGNP project, which is also looking at other end-use applications and energy transport systems

Emphasis:

- Update H2A P&D Pathway cost projections and update 2015 and 2020 targets
- Develop distributed production and forecourt technologies for early markets: Reduce capital costs of distributed production by 10% from 2010 baseline
- Continue to address key efficiency and materials needs for all Renewable pathways: Membranes, Catalysts, Semiconductors, Reactors, etc.
- Complete engineering-scale development of near term pathways

Progress: Separations

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Critical component optimizations demonstrated

Near term technology compatible with commercialized central and distributed systems

Pd Thin Film Ceramic Membrane WGS Reactor (Media and Process)

- <$100/ft^2 Pd membrane tube bundles
- 1000 PSI operations
- 87% H_2 recovery
- >99.99% H_2 permeate quality

Pd-alloy Membrane for Multi-tube Modules (Pall Corporation)

- achieved 270 SCFH/ft^2 flux in pure H_2/N_2
- <$1000/ft^2, 400 PSI operations
- 88% H_2 recovery
- 99.99% H_2 permeate quality

Achieved full-scale ceramic membrane bundle: low cost potting technique used to coat outside of Pd membrane tubes

Demonstrated 12-tube module with 12" elements: ~ 5 kW equiv. H_2 production

Performance Criteria	DOE Target	
	2010	2015
Pure Flux: SCFH/ft^2 @20 psi ΔP H_2 partial pressure	250	300
Membrane Cost $/ft^2 (total module costs)	$1,000	<$500
ΔP Operating Capability	400	400 - 600
H_2 Recovery	>80%	>90%
H_2 Permeate Quality	99.99%	>99.99%
Stability/Durability	2 years	>5 years

➢Performance targets being met: major focus in FY 11-12 on long term component testing

Progress: Electrolysis

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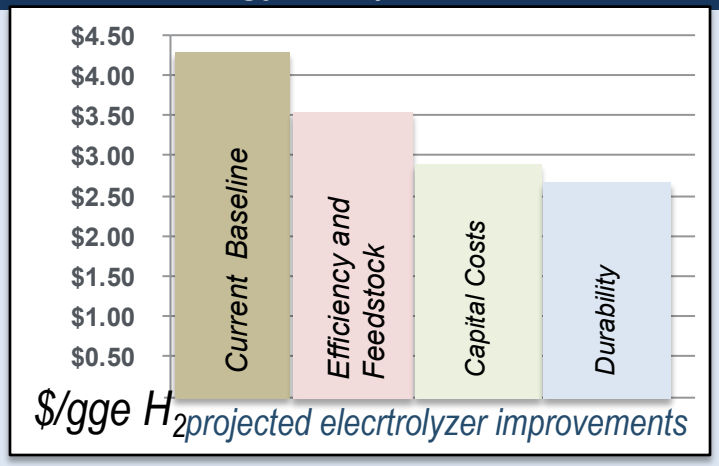
Demonstrated capital cost reduction and systems integration

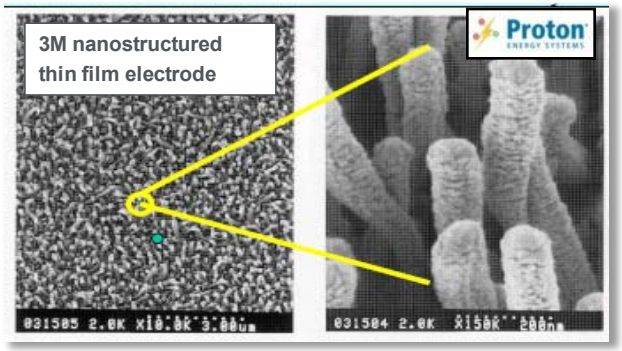
Technology compatible with renewable central and distributed: commercialized components



Projected cost reductions through electricity feedstock, capital costs, and durability*

- 15% electrolyzer capital cost reduction demonstrated through cell component optimizations (Proton, Giner)
- 370 hours operation of multiple commercial electrolyzer stacks in integrated systems study (NREL)

* Source: *Hydrogen Pathways: Cost, Well-to-Wheels Energy use, and Emissions for the Current Technology Status of Seven Hydrogen Production, Delivery and Distribution Scenarios*, NREL, September 2009 (from sensitivity analysis for distributed electrolysis)



New catalyst application techniques with 55% reduction on anode and >90% reduction on cathode

DSM MEAs fabricated with chemically etch supports for a 90% cost reduction

13 kg/day PEM electrolyzer running in integrated renewable systems with 24/7 stack monitoring

Progress: Photoelectrochemical

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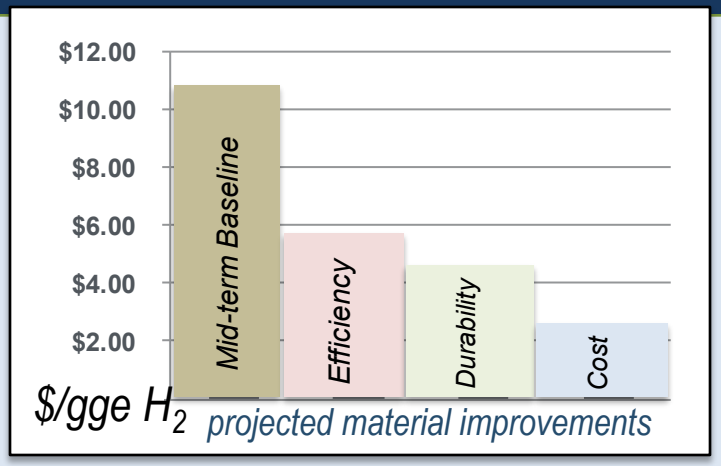
Record efficiencies observed in different materials classes

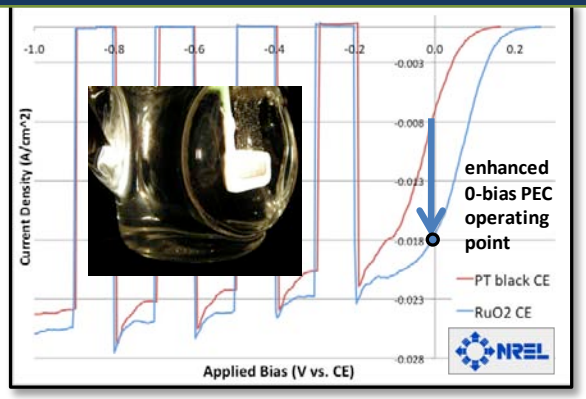
Promising technology for long-term central renewable production: component R&D needed



Projected cost reductions affected by material efficiency, durability & cost*

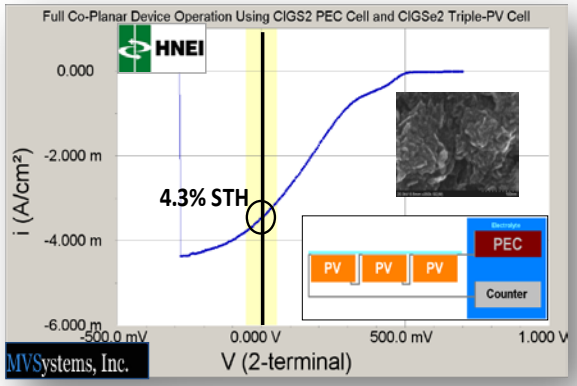
- Set new solar-to-hydrogen (STH) efficiency benchmarks in crystalline material systems (NREL), and in thin-film materials systems (MVSystems - UH)
- Developed models of III-V / water interface to facilitate corrosion mitigation progress (LLNL / UNLV)

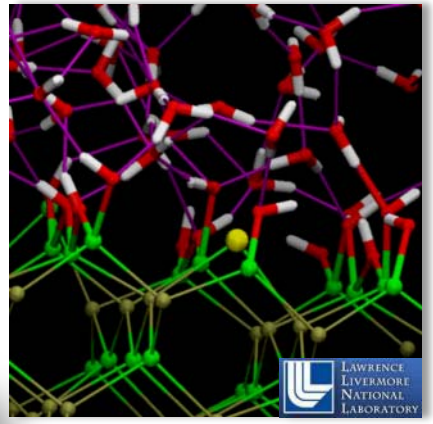
* Source: *Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production*. DTI , 2009 (from sensitivity analysis for Type 4 PEC reactor)



16%-18% STH observed in crystalline III-V device- *over limited lifetime due to corrosion*

Initiated III-V surface validation study to improve corrosion resistance and enhance lifetime





New 4.3% STH benchmark demonstrated in more durable low-cost thin-film CGSe device

Summary

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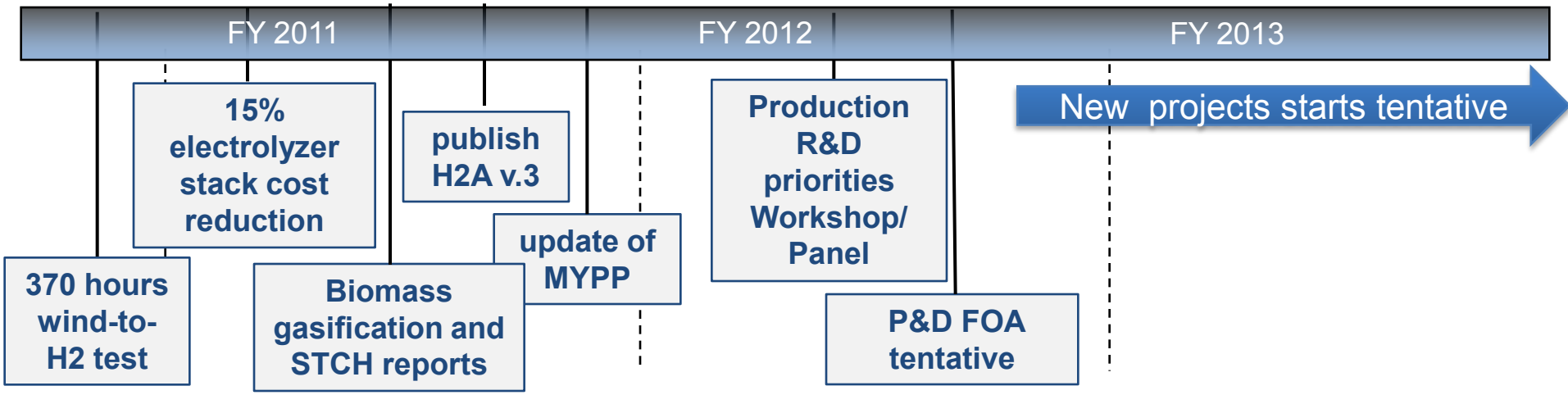
Major milestones & future solicitations

- Completed 370 hours of testing multiple commercial electrolysis stacks after completing installation into NREL's wind-to-hydrogen system
- Completed modeling and analysis of prototype electrolyzer cell stacks and prioritize approaches to reduce cell stack cost by 15%.
- Completed draft of independent review of costs for H_2 from Biomass Gasification.
- Completed report on cost analyses on Solar-Driven High Temperature Thermochemical Water-Splitting Cycles (TIAX, Feb 2011)
- Publication of updated H2A version 3 in progress
- Update of Production cost targets and Multi-Year Plan in progress



Collaboration

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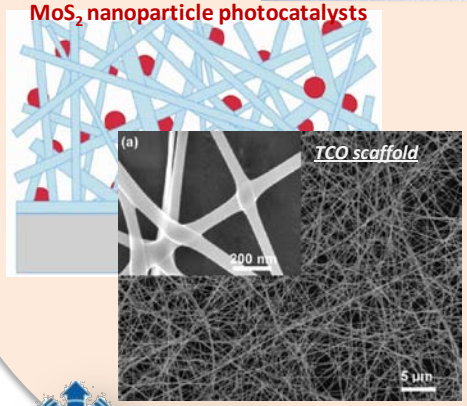
Cross-office collaborative successes in H_2 production

Office of Science
U.S. DEPARTMENT OF ENERGY

EFRC
ENERGY FRONTIER RESEARCH CENTERS

MoS_2 nanoparticle photocatalysts



NREL

Stanford University

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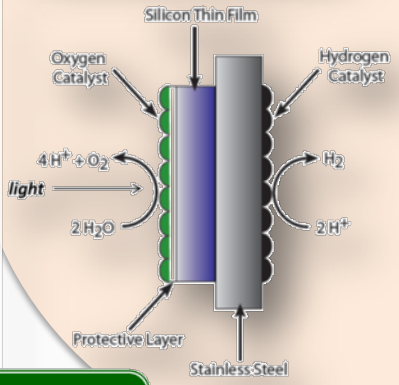
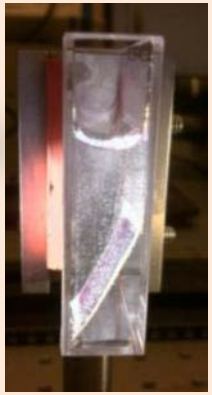
arpa·e
Advanced Research Projects Agency • ENERGY





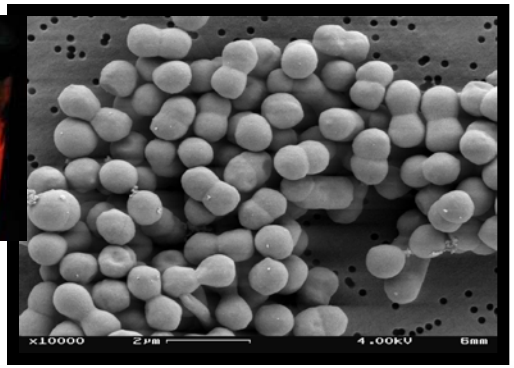
mwoe
Midwest Optoelectronics

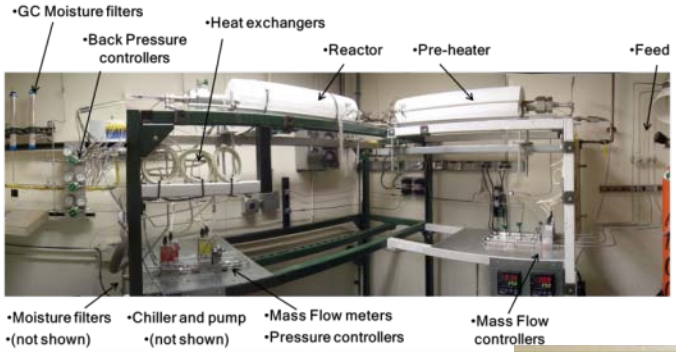
Sun Catalytix

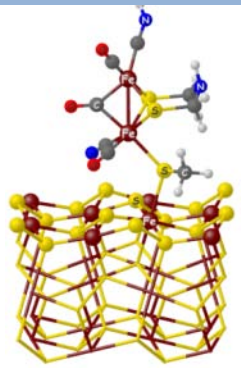
Fundamental and applied research at Stanford/NREL to develop quantum-confined photocatalyst nano-particles and meso-structured support scaffold

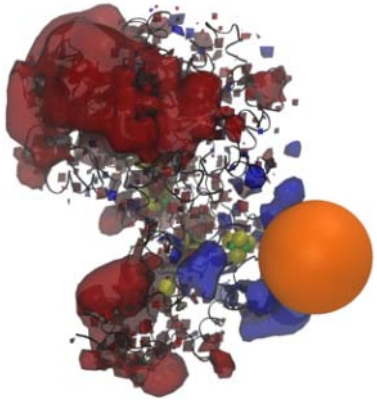
Integration of novel Sun Catalytix catalysts with MWOE multi-junction silicon cells to split water using sunlight

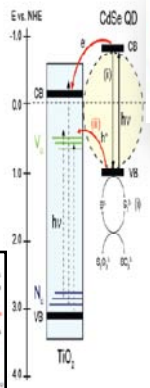
Welcome Offices of Science and Fossil Energy!











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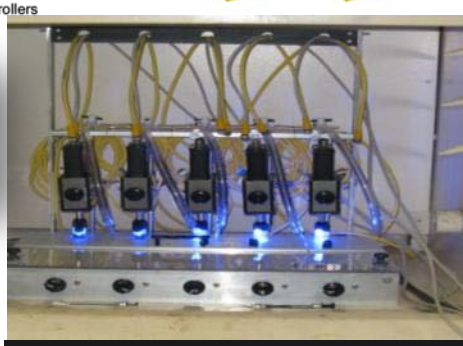
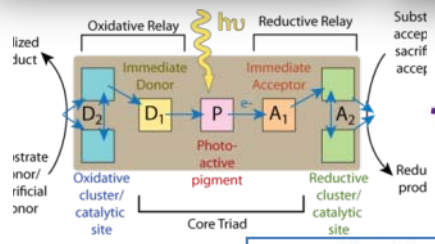
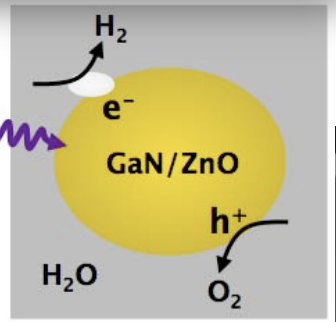
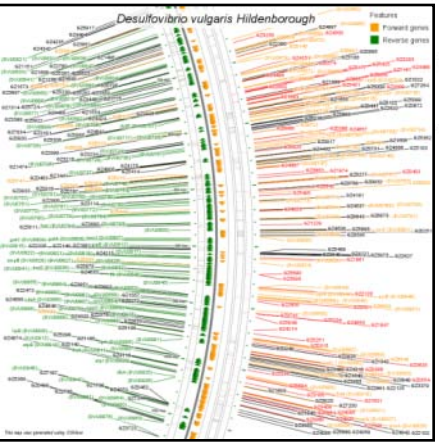
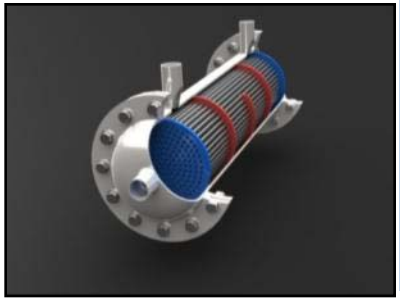
National Energy Technology Laboratory

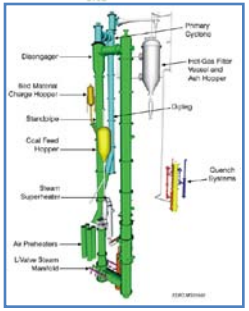


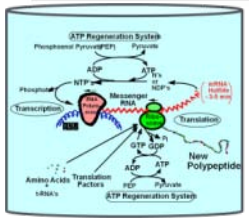












Integrated AMR sessions in Production technologies

Crystal Gateway Marriott Hotel

Salon	Tuesday May 10 I	II	III	IV	V	VI	Wednesday May 11 I	II	III	IV	V	VI	Thursday May 12 I	II	III	IV	V	VI	Friday May 13 I	II	III	IV	V	VI
7:15 AM	Continental Breakfast						Continental Breakfast						Continental Breakfast						Continental Breakfast					
7:45 AM	Reviewer Orientation Meeting						Reviewer Orientation Meeting						Reviewer Orientation Meeting											
8:15 AM	APE	AN		FC	PD	VSS		ST																
8:30 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST		FC	PD	TV
9:00 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST		FC	PD	TV
9:30 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST		FC	PD	TV
10:00 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST		FC	PD	TV
10:30 AM	Break																		Break					
11:00 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST		FC	PD	TV
11:30 AM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS		ST		FC	PD	TV
12:00 PM	APE	AN	ES	FC	PD	VSS	APE	ST	ES	FC	PD	VSS	LM		ES	FC	PD	VSS		ST		FC		
12:30 PM	Lunch						Lunch						Lunch											
1:45 PM	APE	AN	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS						
2:15 PM	APE	AN	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS						
2:45 PM	APE	AN	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS						
3:15 PM	APE	AN	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS	LM	ST	ES	FC	PD	VSS						
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Energy Efficiency & Renewable Energy

POSTER SESSION III: Electrochemical Storage, Propulsion Materials, Technology Integration, Hydrogen Storage, and Manufacturing R&D

POSTER SESSION IV: Technology Integration, Technology Validation, Lightweight Materials, Basic Energy Sciences Hydrogen Production and Storage and Solid State Energy Conversion

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Fossil Energy

- AN: Analysis
- VSS: Veh. & Sys. Simulation
- ST: Hydrogen Storage
- FC: Fuel Cells
- PD: Production and Delivery
- ES: Electrochemical Storage
- MN: Manufacturing
- LM: Light-Weight Materials
- TV: Technology Validation
- APE: Adv. Pwr. Electronics
- PM: Propulsion Materials
- FT: Fuels Technologies
- AC: Advanced Combustion
- TI: Technology Integration
- ED: Education
- SCS: Safety,Codes&Standards
- H2RA: H2 Am. Rec. & Rein. Act
- MT: Market Transformation

- Wednesday oral session combines EE & SC Biological and other talks
- Combined EE & SC poster session Wednesday evening
- Thursday oral session combines EE & SC PEC and other talks
- Friday oral session highlights FE presentations

Session Instructions

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- This is a review, not a conference.
- Presentations will begin precisely at the scheduled times.
- Talks will be 20 minutes and Q&A 10 minutes.
- Reviewers have priority for questions over the general audience.
- Reviewers should be seated in front of the room for convenient access by the microphone attendants during the Q&A.
- Please mute all cell phones, BlackBerries, etc.
- Photography and audio and video recording are not permitted.

Reviewer Reminders

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- Deadline for final review form submittal is **May 20th at 5:00 pm.**
- ORISE personnel are available on-site for assistance. A reviewer ready room is set-up in *The Rosslyn Room* (on the lobby level) and will be open Tuesday–Thursday from 7:30 am to 6:00 pm and Friday 7:30 am to 2:00 pm.
- Reviewers are invited to a brief feedback session – at 3:45 pm on Thursday, in this room.

For More Information

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Katie Randolph, GO

Support:

Jamie Holladay (PNNL)

Kristine Babick (Energetics, Inc.)

EERE Postdoc Fellowship Program

U.S. DEPARTMENT OF ENERGY

- Fuel Cell Technologies Program Opportunities Available
  - Conduct applied research at universities, national laboratories, and other research facilities
  - Up to five positions are available the areas of hydrogen production, hydrogen delivery, hydrogen storage, and fuel cells

- Applications are due June 30, 2011
- Winners will be announced mid-August
- Fellowships will begin in mid-November 2011

http://www1.eere.energy.gov/education/postdoctoral_fellowships/

Key Participants – Hydrogen Production

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Analysis & Testing
- ORNL
- TIAX
- PNNL
- UH
- SNL
- ANL

Bio-derived Liquids
- ANL
- PNNL
- NREL

Electrolysis
- Giner Electrochemical
- Avalence
- Proton Energy
- ORNL
- NREL

Membranes
- Media and Process Technology
- ASU
- Pall Corporation
- ORNL

Biomass Gasification
- UTRC
- GTI
- NETL

Solar High Temperature Thermochemical H_2 Production
- SNL
- ANL
- SAIC
- U of CO, Boulder

Photoelectrochemical H_2 Production
- LANL
- LLNL
- Midwest Optoelectronics
- MV Systems
- Stanford University
- NREL

Biological H_2 Production
- UC Berkeley
- J. Craig Venter
- NREL