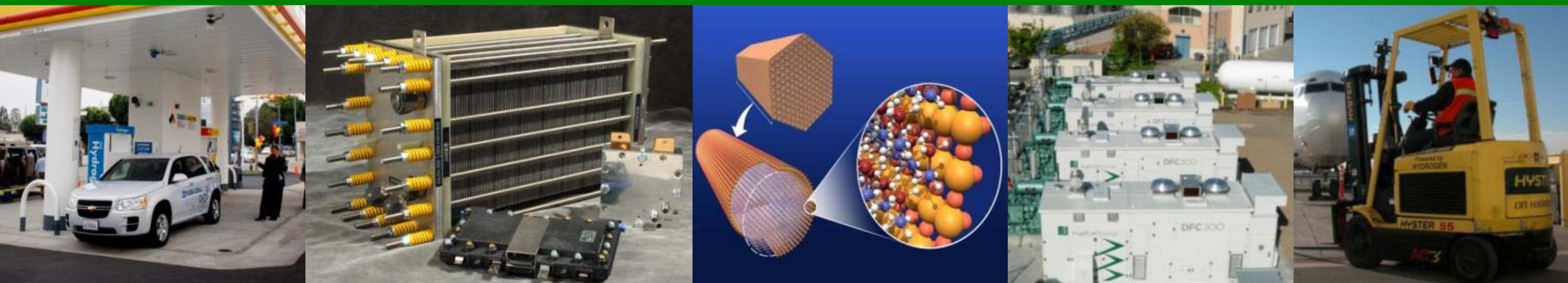
U.S. DEPARTMENT OF
ENERGY



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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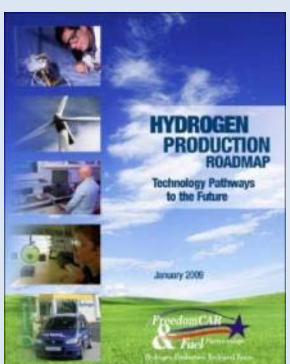
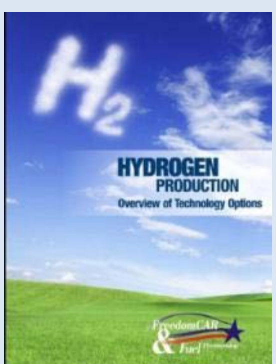
Informed prioritization of R&D needs in H_2 production pathways

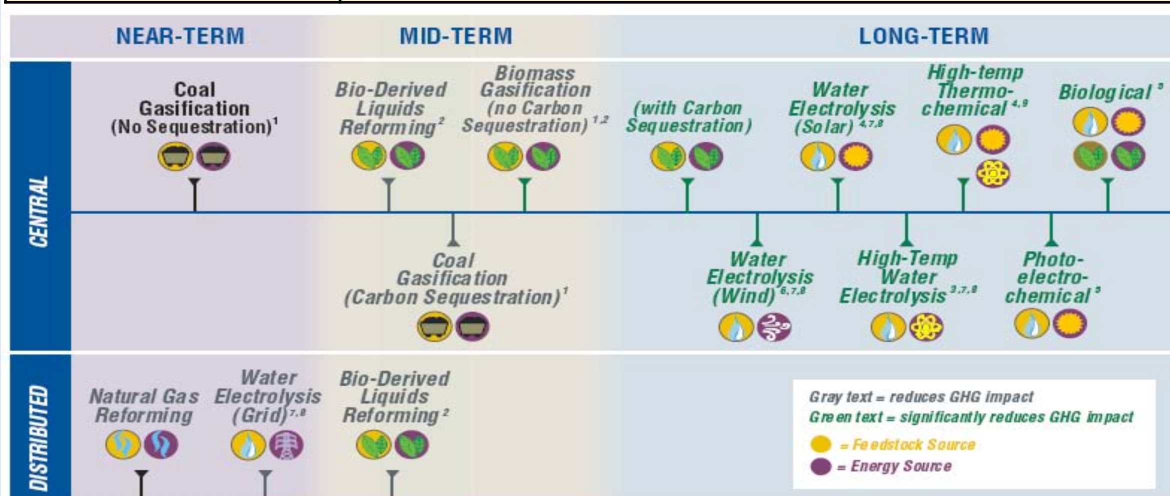
- Targets and projected costs for H_2 Production portfolio pathways informed by independent analysis

- 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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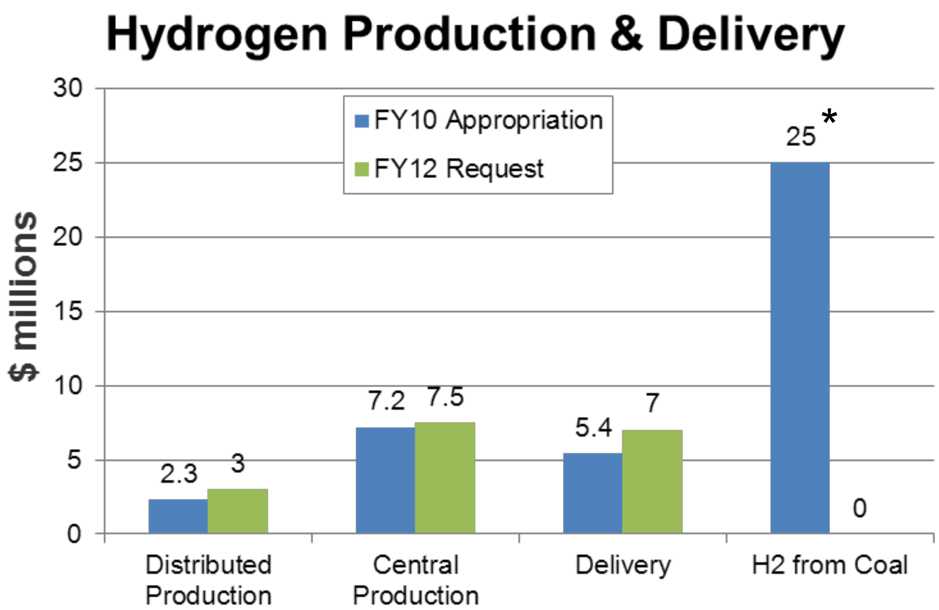
Production remains a high priority in the FY 2012 Request

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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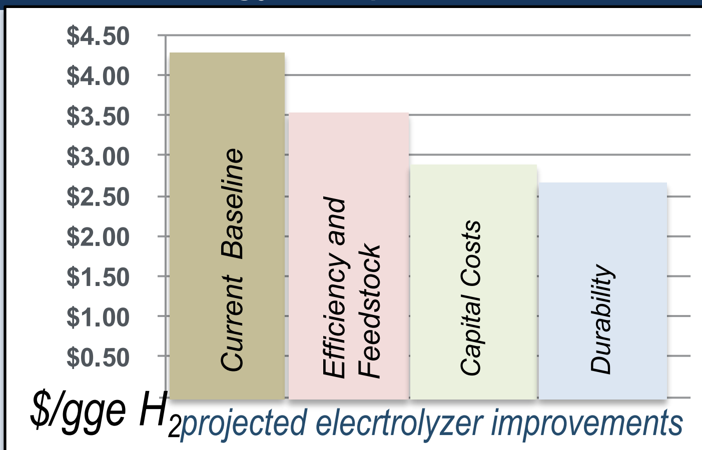
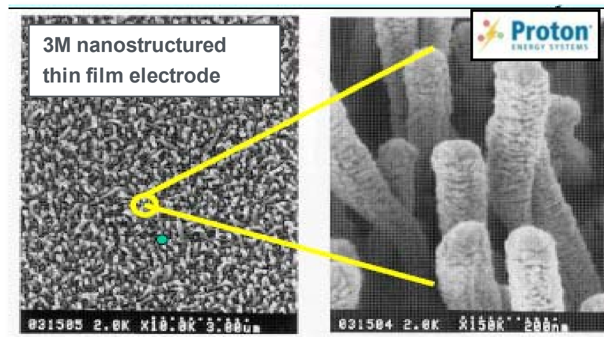
Demonstrated capital cost reduction and systems integration

Technology compatible with renewable central and distributed: commercialized components



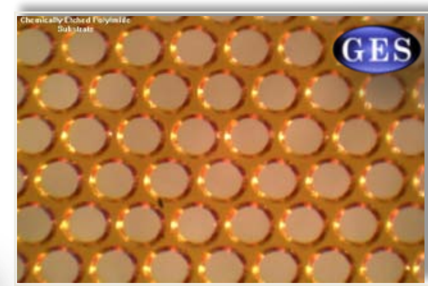
Projected cost reductions through electricity feedstock, capital costs, and durability*

- 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)



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



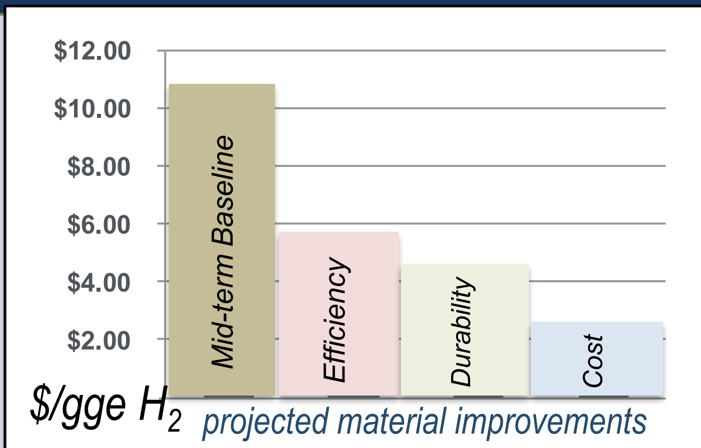
13 kg/day PEM electrolyzer running in integrated renewable systems with 24/7 stack monitoring

* 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)

Progress: Photoelectrochemical

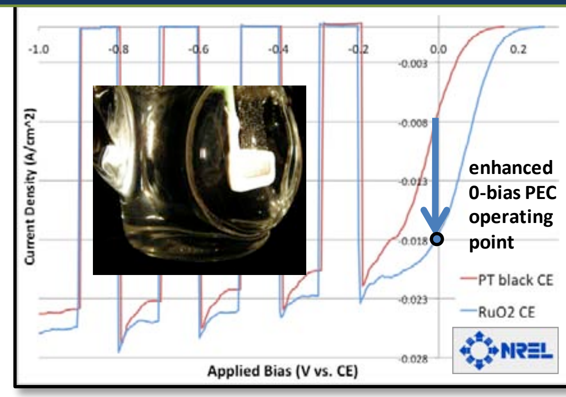
Record efficiencies observed in different materials classes

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



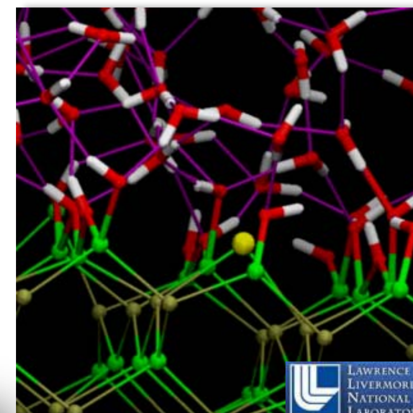
Projected cost reductions affected by material efficiency, durability & cost*

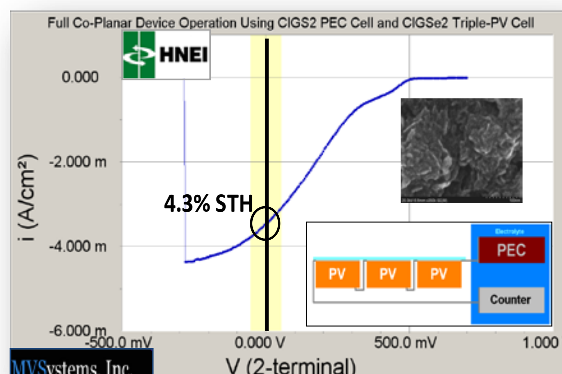
- Set new solar-to-hydrogen (STH) efficiency benchmarks in crystalline material systems (NREL), and in thin-film materials systems (MVSystems - UH)
- Developed models of III-V / water interface to facilitate corrosion mitigation progress (LLNL / UNLV)



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





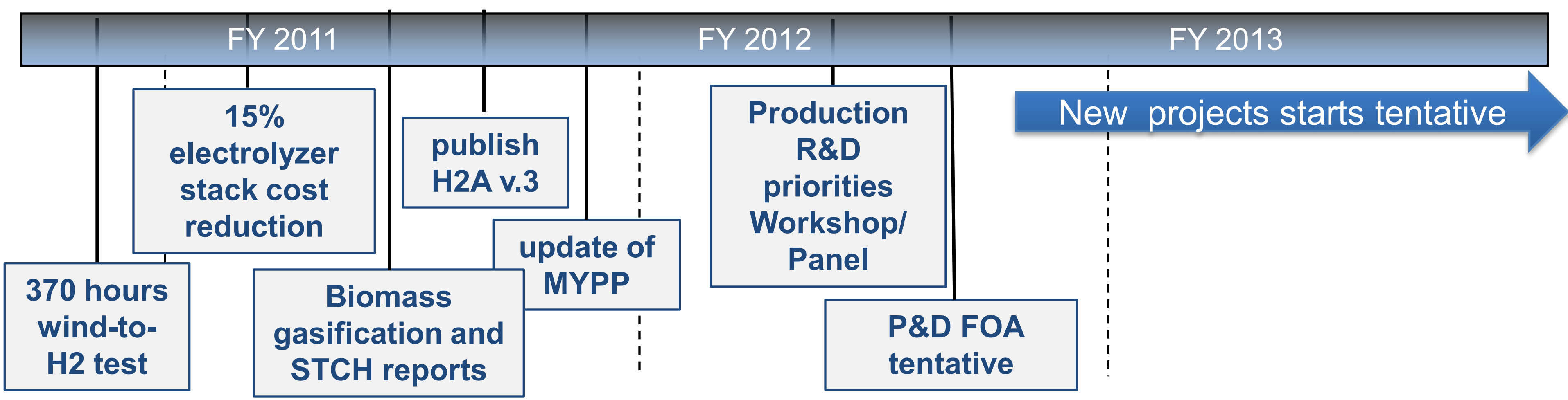
New 4.3% STH benchmark demonstrated in more durable low-cost thin-film CGSe device

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

Summary

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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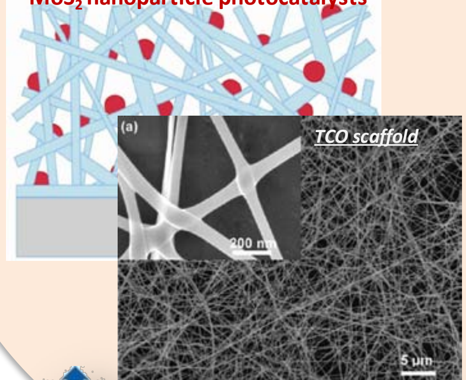
Cross-office collaborative successes in H_2 production

Office of Science
U.S. DEPARTMENT OF ENERGY

EFRC
ENERGY FRONTIER RESEARCH CENTERS

MoS$_2$ nanoparticle photocatalysts



NREL

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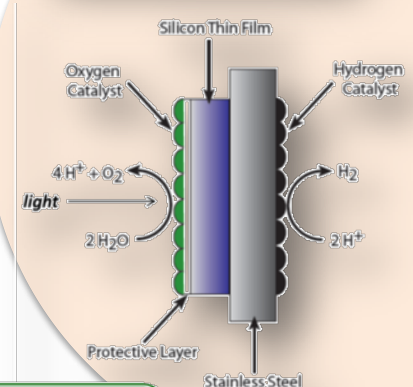
Energy Efficiency & Renewable Energy

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

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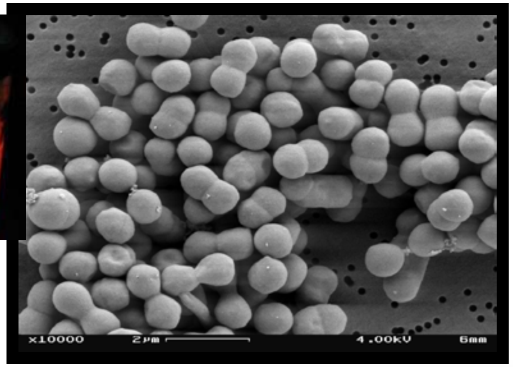
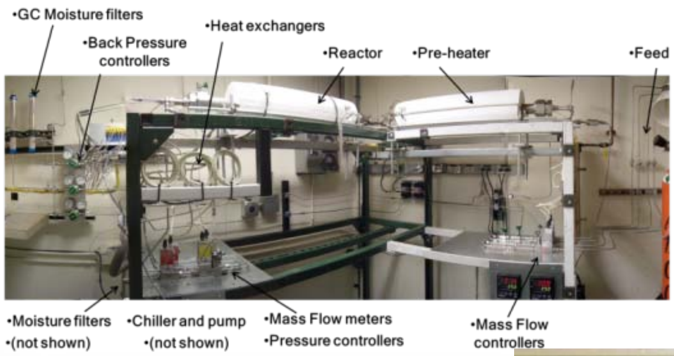
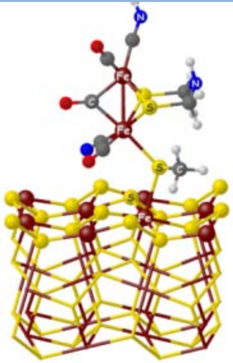
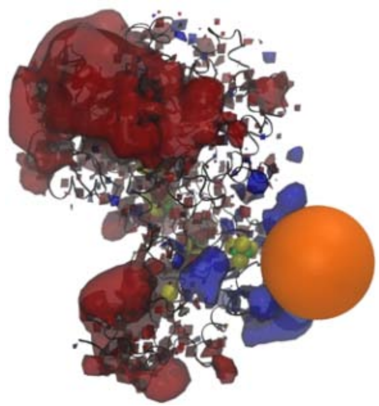
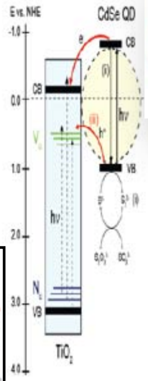
Welcome Offices of Science and Fossil Energy!





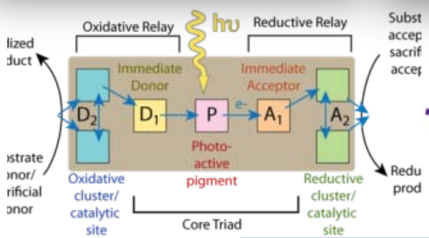


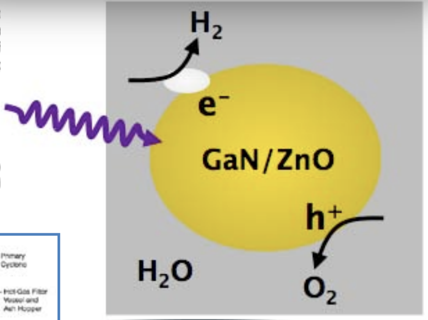


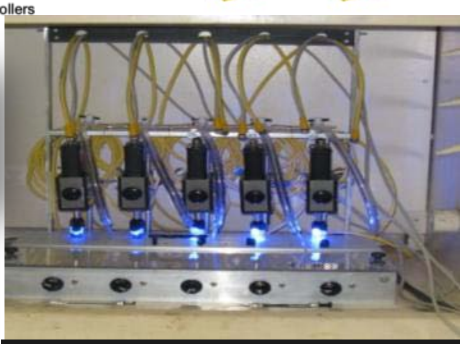


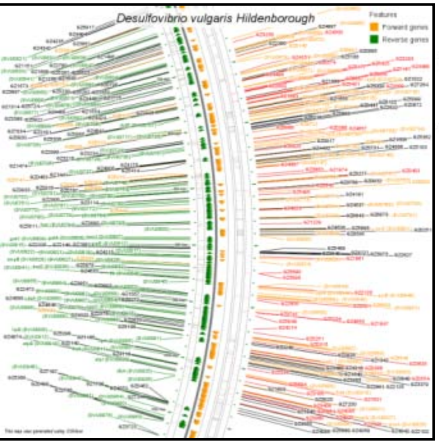
Office of Science
U.S. DEPARTMENT OF ENERGY

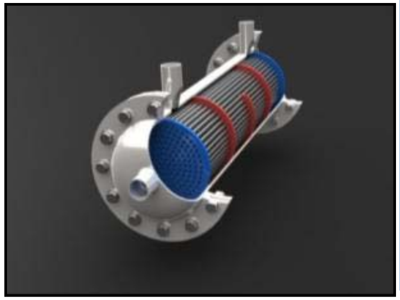
U.S. DEPARTMENT OF ENERGY Fossil Energy
National Energy Technology Laboratory

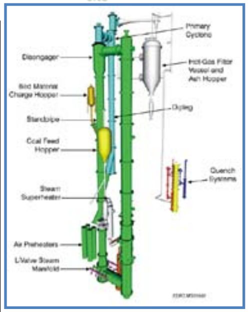


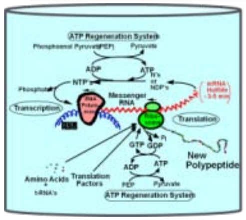












Integrated AMR sessions in Production technologies

Crystal Gateway Marriott Hotel

	Tuesday May 10						Wednesday May 11						Thursday May 12						Friday May 13					
Salon	I	II	III	IV	V	VI	I	II	III	IV	V	VI	I	II	III	IV	V	VI	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						
							Break						Break											
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							LM		ES	FC	PD	VSS	LM		ES	FC	PD							
							LM				PD		LM			FC	PD							

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

POSTER SESSION IV:
Technology Integra on, Technology Validation, Lightweigh Materials, Basic Energy Sciences Hydrogen Production and Storage and Solid State Energy Conversion

- 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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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