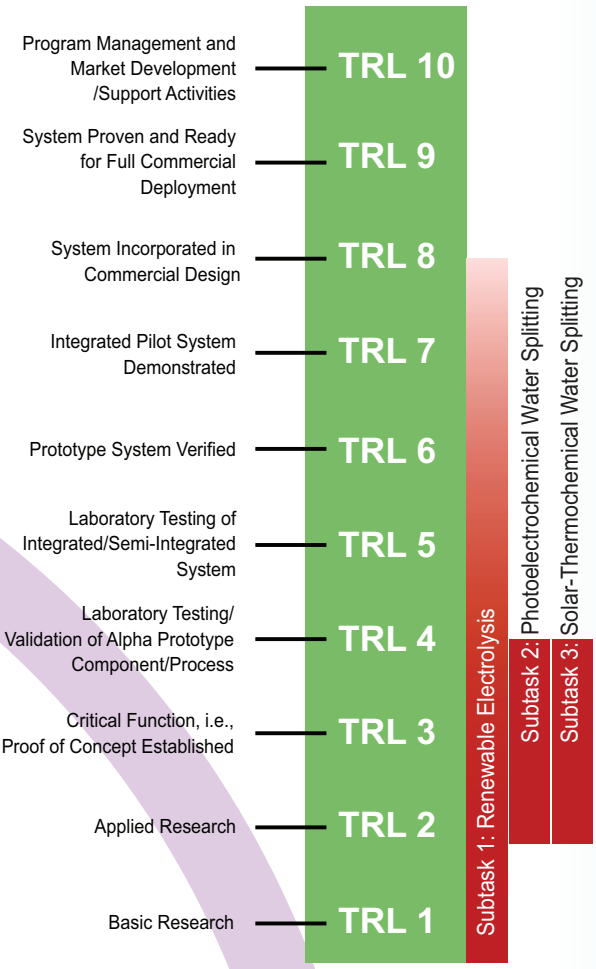
PURPOSE OF TASK

The past several years have witnessed significant progress in fuel cell technology advancement and cost reduction. As a result, rollouts of fuel-cell vehicles by major automotive manufacturers have already begun. With these rollouts, enabling technologies for the widespread production of affordable renewable energy has become increasingly important. Near-term utilization of current reforming and electrolytic processes is necessary for early hydrogen markets, but transitioning to industrial-scale renewable hydrogen production remains essential to the longer term. Central to the long-term vision are renewable hydrogen conversion processes, including, for example, the photoelectrochemical and thermochemical water splitting as well as photo-assisted electrochemical water-splitting. The long-term viability of such hydrogen production pathways needs to be assessed using broader techno-economic analytic approaches to help identify key materials- and system-level cost drivers with the associated research and development (R&D) needs. The IEA-HIA Task 35 – Renewable Hydrogen Production is bringing together leading world experts covering a broad spectrum of key renewable hydrogen technologies in a well-organized network to facilitate progress toward needed solutions.

STATUS OF THE TECHNOLOGY

OVERVIEW

- **Subtask 1: Renewable Electrolysis** Low-temperature electrolyzers are commercially available and in use at some hydrogen fueling stations. The cost of the resulting hydrogen is still high and dominated by electricity cost and can thus significantly benefit from efficiency enhancements.
- **Subtask 2: Photoelectrochemical Water Splitting** The state of the art material used in this technology is quickly approaching suitable efficiency. However, durability remains a significant barrier to commercial use. This technology is still in relatively early stages of research and development.
- **Subtask 3: Solar-Thermochemical Water Splitting** This technology requires the identification and development of efficient and durable materials to design a cost-effective reactor system.



TASK 35

RENEWABLE HYDROGEN PRODUCTION

RENEWABLE ELECTROLYSIS

Everett Anderson
Subtask 1 Leader

Proton OnSite

PHOTOELECTROCHEMICAL WATER SPLITTING

Wilson Smith
Subtask 2 Leader

Delft University of Technology

SOLAR-THERMAL WATER SPLITTING

Christian Sattler
Subtask 3 Leader

German Aerospace Center

VITAL STATISTICS

Term

Dates (2014–2017)

Members

USA, EU, The Netherlands, Switzerland, Germany, UK, Denmark, Australia, Japan, Korea, Italy

Expert Participants

42

2014 Meetings

April 2014, San Francisco, CA
July 2014, Berlin, Germany
September 2014, Zurich, Switzerland
September 2014, Bejing, China
October2014 Cancun, Mexico

TECHNOLOGY READINESS LEVEL (TRL)

- **Subtask 1: Renewable Electrolysis** as a hydrogen pathway is up to TRL 8. This technology has been proven to work and is sold commercially. However, research is still required to bring the resulting hydrogen cost down, especially using intermittent renewable energy sources.
- **Subtask 2: Photoelectrochemical Water Splitting** is at TRL 2–4. While components are being integrated at the Joint Center for Artificial Photosynthesis (TRL 4), significant R&D is still required to identify a suitably efficient and durable material (TRL 3).
- **Subtask 3: Solar-Thermochemical Water Splitting** is at TRL 2–4. While components are being integrated (TRL 4), significant R&D is still required to identify a suitably efficient and durable material (TRL 3).

FRAMEWORK SUMMARY OF TASK

- **Subtask 1: Renewable Electrolysis** (Subtask Leader: Everett Anderson, USA) This Subtask is planned to be a 'shared' Subtask with the IEA-Advanced Fuel Cells Implementing Agreement, providing further cross-cutting opportunities for leveraging synergies among related technology Experts.
- **Subtask 2: Photoelectrochemical Water Splitting** (Subtask Leader: Wilson Smith, The Netherlands)
- **Subtask 3: Solar-Thermochemical Water Splitting** (Subtask Leader: Christian Sattler, Germany) This Subtask is planned to be a 'shared' Subtask with the IEA SolarPACES, providing further cross-cutting opportunities for leveraging synergies among related technology Experts.

MEMBERS

Recruitment of International IEA HIA Task 35 Experts has been successful, and remains in full force. Experts have been recruited from the numerous participating countries each with specific expertise in different areas of Renewable Electrolysis, Photoelectrochemical Water Splitting and Solar-Thermochemical Water Splitting indicated below:

RENEWABLE ELECTROLYSIS	PEC WATER SPLITTING	SOLAR-THERMOCHEMICAL WATER SPLITTING
Everett Anderson, US	Wilson Smith, NL	Christian Sattler, DE
Bryan Pivovar, US	Roel van de Krol, DE	Anthony McDaniel, US
Monjid Hamdan, US	Fatwa Abdi, DE	Ellen Stechel, US
Marcelo Carmo, DE	Renata Solerska, PL	Martin Roeb, DE
Tom Smolinka, DE	Jae Sung Lee, KR	Peter Loutzenhiser, US
Jurgen Mergel, DE	Kazuhiro Sayama, JP	Aldo Steinfeld, CH
Jim O'Brien, US	Nicolas Gaillard, US	Tatsuya Kodama, JP
Pierre Millet, FR	Thomas Jaramillo, US	Nate Siegel, US
Kevin Harrison, US	Shane Ardo, US	Al Weimer, US
Erik Christensen, DK	Kazunari Domen, JP	Ivan Ermanoski, US

ACTIVITIES AND RESULTS IN 2014

PROGRESS AND ACCOMPLISHMENTS

Subtask 1: Renewable Electrolysis

- Meeting Participation:
  - 2014 Electrolytic Hydrogen Production Workshop held by The US DOE Fuel Cell Technologies Office on February 27–28, 2014, at The National Renewable Energy Laboratory (NREL) in Golden, Colorado.
  - 2014 Fall ECS Meeting Electrolysis Section held in conjunction with the 2014 Fall ECS Joint International Meeting on October 5–9 2014 in Cancun, Mexico.
- White Papers and Special Projects:
  - Initial discussions on the development of Renewable Electrolysis White Papers were held.

Subtask 2: Photoelectrochemical Water Splitting (PEC)

- Meeting Participation:
  - 2014 Hu'a Iki SF: April 21st, 2014 Co-located IEA HIA Renewable Hydrogen PEC subtask meeting and the DOE PEC WG Meeting, held at Stanford University, in conjunction with PEC session organizers at the 2014 Spring MRS Meeting in San Francisco.
  - 2014 Hu'a Iki Berlin: held in conjunction with the 20th International Conference on Photochemical Conversion and Storage of Solar Energy (IPS-20), 27 July–1 August 2014 in Berlin.
- White Papers and Special Projects:
  - Ten existing PEC White Papers were updated.
  - Five new PEC White Papers were published in a special edition of Energy & Environmental Science titled "Status of Photoelectrochemical Water Splitting: Past, Present, and Future".

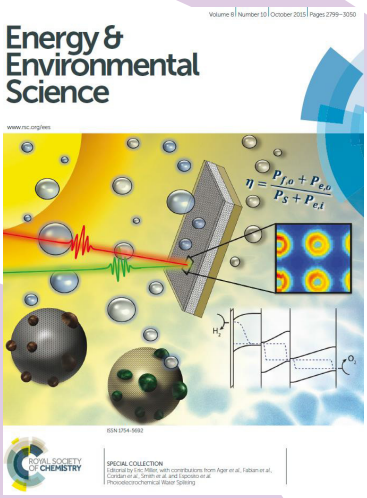


Figure 1. Cover of Special Issue in Energy & Environmental Science for PEC water splitting (left).

Figure 2. The magazine Foreign Policy has selected members of Subtask 2 as some of the top global thinkers of 2014 (right).

Subtask 3: Solar-Thermochemical Water Splitting

- Meeting Participation
  - International Workshop on Reaction Kinetics of Solar Thermochemical Redox Cycles for Splitting H_2O and CO_2 held on 11 September 2014 in Zurich, Switzerland.
  - Solar Fuels Session of the 2014 SolarPACES conference held on 16–19 September 2014 in Beijing, China.
- White Papers and Special Projects
  - Initial discussions on the development of STCH White Papers were held.

MILESTONES

- Renewable Hydrogen Sharepoint Site built with home sites for each of the three current Subtasks
- Subtask leadership established for each of the three current Subtasks
- Sharepoint Site functions and operations introduced to Subtask leaders
- International meetings held in each of the three current Subtasks, and meeting summary information uploaded to the Sharepoint Site
- Cross-cutting "task coordination" efforts initiated (i.e., with SolarPACES to 'share' the STCH Subtask, and with IEA-AFCIA to 'share' the Renewable Electrolysis Subtask)

FUTURE WORK

- Continue upgrades and updates of Sharepoint Site
- Continued discussion and summaries results from Subtask meeting participation in 2014
- Organization of key technical meetings for 2015 in each of the Subtasks
- Continued development of White Papers in each of the three current Subtasks

REFERENCES

Selected Key Publications

- Particle Suspension reactors and materials for solar-driven water splitting, D. Fabian, S. Hu, N. Singh, F. Houle, T. Hisatomi, K. Domen, F. Osterloh, S. Ardo.
- Experimental demonstrations of spontaneous, solar-driven photoelectrochemical water splitting, J. Ager, M. Shaner, K. Walczak, I. Sharp, S. Ardo.
- Methods of photoelectrode characterization with high spatial and temporal resolution, D. Esposito, J. Baxter, J. John, N. Lewis, T. Moffat, T. Ogitsu, G. O'Neil, T. Pham, A. Talin, J. Velazquez, B. Wood.
- Methods for comparing the performance of energy-conversion systems for use in solar fuels and solar electricity generation, R. Coridan, A. Nielander, S. Francis, M. McDowell, V. Dix, S. Chatman, N. Lewis.
- Interfacial band-edge energetics for solar fuels production, W. Smith, I. Sharp, N. Strandwitz, J. Bisquert.