PECSYS

Technology demonstration of large-scale photo-electrochemical system for solar hydrogen production

PECSYS

European Hydrogen Week

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Project Overview

- Call year: [2016]
- Call topic: [H2020-JTI-FCH-2016-1 - Development of processes for direct production of hydrogen from sunlight]
- Project dates: [01/01/2017- 31/12/2019]
- % stage of implementation 01/11/2019: [90 %]
- Total project budget: [2,499,993 €]
- FCH JU max. contribution: [2,499,993 €]
- Other financial contribution: [0 €]
- Partners: [Helmholtz Zentrum Berlin (DE), Forschungszentrum Jülich (DE), Consiglio Nazionale delle Ricerche (IT), Uppsala Universitet (SE), Enel Green Power (IT), Solibro Research AB (SE, until Oct 2019]

Project Summary

Main Objectives

- Develop new record PV-EC devices for thin film silicon, crystalline-Si and CIGS based approaches
- Develop electrolysis cells adapted for low and intermittent current densities
- Develop sealing concepts beyond state-of-the-art
- Demonstrate a 10 m^2 solar to hydrogen system with long lifetime

Performance measure	Target	Relevance
Hydrogen production rate	≥ 16 g/hr	Yield at maximum irradiance
Solar to hydrogen (STH) efficiency	> 6 %	Efficiency
Device stability, ΔSTH	< 10 % after ½ year	Service life, reliability
Cost target, LCOH	< € 5/kg*	Economic feasibility

* LCOH: Levelised cost of hydrogen production

Project Summary

Comparison with international state of the art and targeted application

	Thermally and electrially coupled photovoltaic - electrolysers using earth abundant catalysts*		Directly electrically coupled c-Si photovoltaic modules and PEM electrolyers	
Approach	State of the art (c-Si-PV) [1]	PECSYS (CIGS - PV)	State of the art [2]	PECSYS
Solar collection area	6	80 active of 100	1.5 m^2	10 m^2
STH efficiency (%)	10	13	9.4	10
H_2 production rate ($g/h/m^2$)	3.06	3.98	1.12	2.3
Stable operation (h)	168	~ 100	n/a	> 2500

* 1000 W/m^2 using sun simulators

[1] Cox, *et al*. 2014, Proc. Natl. Acad. Sci 111:4057. (Indoor tests, Harvard University and Massachusetts Institute of Technology, USA)

[2] Muhammad-Bashir, *et al*. 2020, Solar Energy 205:461. (Test site KAUST, Saudi Arabia)

Comparison with state of the art is difficult because of different measurement conditions -> need for standardized benchmarking protocols

Application in decentralized hydrogen production for storage of photovoltaic electricity for capacities in the 1-100s of kW range e.g. for residential or small commercial user/producers

Project Progress/Actions - Scale-up

Thermally and electrically integrated solar hydrogen generation using various photovoltaic technologies

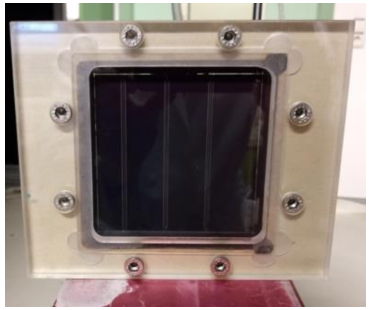
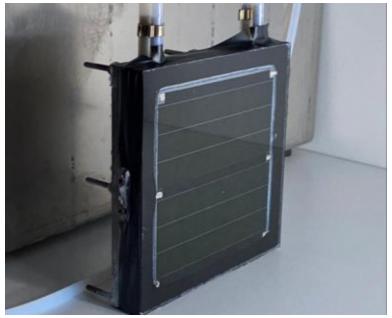
- Scale-up
- Enhanced solar to hydrogen (STH) conversion efficiency

~ 1 cm² → ~ 1 m²

n/a → > 8 %

25% 50% 75%

Thermal integration transfers excess heat from the photovoltaic module to the electrolysis part enhancing the hydrogen generation rate

Approach	Thin film silicon	CuInGaSe	Crystalline silicon heterojunction	
Solar collection area (cm^2)	64 active of 100	82 active of 100	242 active of 294	2500 active of 2601
STH efficiency (%)	4.5	13	4.5	4.64
Hydrogen production rate ($g/h/m^2$)*	1.38	3.98	1.38	1.42

* Irradiance at 1000 W/m^2, device temperature varies

Project Actions - Balance of plant innovations

Solar hydrogen generation using photovoltaic modules directly coupled to electrolyser with balance of plant innovations

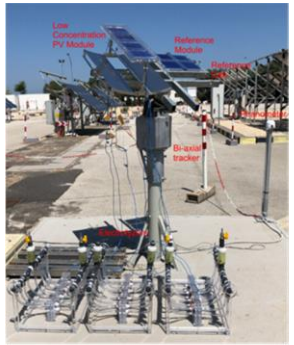
Solar to hydrogen (STH) conversion efficiency
Stable operation

n/a
n/a
n/a

25% 50% 75%

> 6 %
>1.6 g/h/m²
> 6 months

1. Water supply from the cathode side for PEM electrolyser
2. Use of low concentration and albedo effects with bifacial photovoltaics
3. Matching photovoltaics output to electrolyser demand
4. No active heating of electrolyser



Photovoltaic approach	Target	Bifacial + 1.63 Suns	Bifacial + 30% albedo effect	Crystalline silicon & CuInGaSe
Solar collection area (m^2)	10	0.12	0.073	10
STH efficiency (%)	> 6	10	13.5	10-11
H_2 production rate ($g/h/m^2$)*	≥ 1.6	2.5 - 4.0	4.2	2.3
Outdoor operation duration	> 6 months	-/-	-/-	> 6 months

* Irradiance and device temperature vary

Risks, Challenges and Lessons Learned

Challenge 1: Scale-up of integrated photovoltaic (PV) electrolysers to 1m² area delayed and eventually stopped because

- Thin film silicon production at 3SUN (now Enel Green Power) ceased
- CuInGaSe producer Solibro Research became insolvent in October 2019

⇒ All types of thermally and electrically integrated photovoltaic electrolysers scaled as far as was possible to enrich the diversity of the project results

Challenge 2: Insufficient data on costs, energy and material balance of production of critical components

Techno-economic and lifecycle analysis of integrated PV electrolysers challenging because most electrolysis components e.g. electrodes, catalysts and membranes, do not have a mature supply chain

Challenge 3: 6 -month outdoor operation of thermally integrated PV electrolysers cannot be done before project ends

Challenges with sealing because the use of glass on one side prevents use of mechanical compression by screws

Exploitation Plan/Expected Impact

Exploitation: Three key exploitable results

1. Photo-electro-chemical system based on direct coupling of bifacial photovoltaics to PEM electrolyzers for low cost green hydrogen generation
   - Next steps plan for a demonstrator with 100 kW of PV
   - Forschungszentrum Jülich (DE), Consiglio Nazionale delle Ricerche (IT), and Enel Green Power (IT), next steps plan for a demonstrator with 100 kW of PV
2. Interdisciplinary education in the fields of renewable energy production and electrochemical energy storage
   - Integration in existing university courses or short course formats for professional development
   - Uppsala University, Forschungszentrum Jülich and Helmholtz Zentrum Berlin
3. Integrated photovoltaic electrolyser design platform
   - Targeting researchers and developers of related technologies
   - Uppsala University, Forschungszentrum Jülich and Helmholtz Zentrum Berlin

Impact

1. Better understanding of the scale-up challenges and operation behavior of thermally integrated solar hydrogen generating devices based on photovoltaic electrolysers as well as photoelectrochemical and photocatalytic devices
2. Quantification of environmental impact of direct solar hydrogen generating devices based on actual rather than hypothetical devices
3. Technical and economic feasibility of using direct solar hydrogen generation using photovoltaic modules coupled directly electrically (and thermally) to electrolysers to reduce green house gas emissions

Thank you

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