ARTIPHYCTION

Fully artificial photo-electrochemical device for low temperature hydrogen production

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	ARTIPHYCTION
CALL TOPIC	SP1-JTI-FCH.2011.2.6: Low-temperature H_2 production processes
START DATE	1/05/2012
END DATE	31/10/2015
PROJECT TOTAL COST	€3,5 million
FCH JU MAXIMUM CONTRIBUTION	€2,1 million
WEBSITE	http://www.artiphyction.org/

PARTNERSHIP/CONSORTIUM LIST

POLITECNICO DI TORINO, HYSYTECH S.R.L., COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS, SOLARONIX SA, L'UREDERRA, FUNDACION PARA EL DESARROLLO TECNOLOGICO Y SOCIAL, TECNOLOGIA NAVARRA DE NANOPRODUCTOS SL, PYROGENESIS SA

MAIN OBJECTIVES OF THE PROJECT

The main project targets are:

1) 5 % Solar to Hydrogen (STH) efficiency (LHV basis) by exploiting improved and novel nano-structured materials for photo-activated processes.
2) Chemical systems for highly efficient low temperature water splitting using solar radiation with no noble metals employed.
3) A projected durability of >10,000 h.
4) A modular approach capable to cope with small to medium scale applications ranging from 100 W for domestic use (ca. 3 g/h H_2 equivalent) to 100 kW (ca. 3 kg/h H_2 equivalent) for commercial use.

PROGRESS/RESULTS TO-DATE

- Best results achieved with a CoPi-catalysed Mo-doped BiVO4 photo-anode and a Co NPs-based cathodic electro-catalyst.
- 3 % STH efficiency achieved in the final 1,6 m^2 Artiphyction prototype with a bias generated via PV tiles covering the reactor frame.
- <10 % performance degradation over 1,000 h operation could be achieved only when operting at about 2 % STH efficiencies.
- A modular PEC concept was conceived and developed to fit the entire span of production ranges targeted.
- No noble metals were employed.

FUTURE STEPS

- Re-design of the reactor to achieve 5 % STH efficiency. Model calculaitons show this can be achieved.
- Development of more resistant anode photocatalysts with less sensitivity to (photo)corrosion to achieve durability targets.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- The partnership believes that the above future steps should allow the fulfilment of the efficiency target with confidence.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Scale-up to cost effective capacity, as well more cost efficient, high performance materials for renewables based H_2 production	Applications ranging from 100 W for domestic use (ca. 3 g/h H_2 equivalent) to 100 kW (ca. 3 kg/h H_2 equivalent) for commercial use.		Test the smallest scale of the range aside is 100 % reached.	Test the smallest scale of the range aside is 100 % reached.	The project has been a worldwide reference for the scale reached (1,6 m^2 PEC area).
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2011
Sun-to-hydrogen conversion efficiency	5 %	3 % efficiency achieved	No chance within Artiphyction, high chance in a future project.		Higher efficiencies were obtained but at mush smaller scales and with higher cost materials (e.g. multijunction semiconductors)
Durability	10,000 h	10 % performance loss over 1,000 h operation.	This is very critical. Chances are moderate within a future project.		

BIONICO

BIOgas membrane reformer for decentralIzed hydrogen production

PANEL 5

Hydrogen production, distribution and storage: research and validation

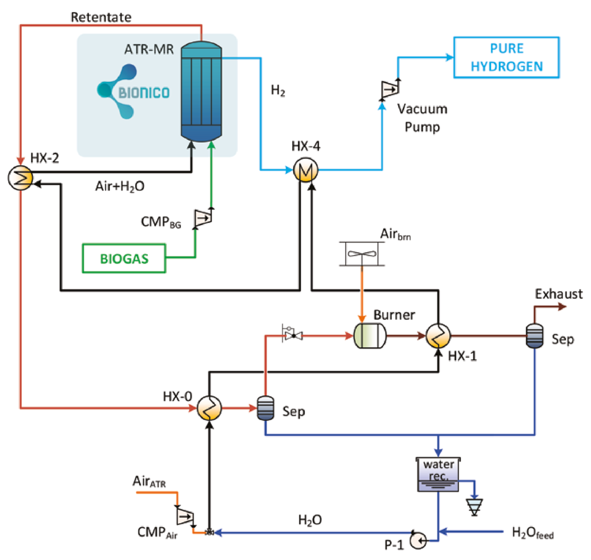
ACRONYM	BIONICO
CALL TOPIC	FCH-02.2-2014: Decentralized hydrogen production from clean CO_2-containing biogas
START DATE	1/09/2015
END DATE	31/08/2018
PROJECT TOTAL COST	€3,3 million
FCH JU MAXIMUM CONTRIBUTION	€3,1 million
WEBSITE	http://www.bionicoproject.eu/

PARTNERSHIP/CONSORTIUM LIST

POLITECNICO DI MILANO, FUNDACION TECNALIA RESEARCH & INNOVATION, TECHNISCHE UNIVERSITEIT EINDHOVEN, JOHNSON MATTHEY PLC, ABENGOA HIDROGENO SA, QUANTIS SARL, RAUSCHERT KLOSTER VEILSDORF GMBH, ENC POWER LDA

MAIN OBJECTIVES OF THE PROJECT

BIONICO will develop, build and demonstrate at a real biogas plant (TRL6) a catalytic membrane reactor integrating in a single vessel production and separation of 100 kg/day of H_2. Direct conversion of biogas to pure hydrogen is achieved in a single step, with increase of the overall efficiency (up to 72 %), strong decrease of volumes and auxiliary heat management units and reduction of operating temperature. Fluidization of the catalyst allows overcoming problems with temperature and concentration control and operating with smaller particles maintaining very low pressure drops.



PROGRESS/RESULTS TO-DATE

- Indetification of the preliminary BIONICO system design
- Identification and evaluation of the cost and performance of the reference technology for H_2 production from biogas to benchmarck BIONICO.
- Long term testing of the catalyst based on projecr FERRET under simulated biogas feed.
- Evaluation of two sealing methods – thin Pd-Ag dense membranes supported on Al2O3 and on ZrO_2 supports and selection of the best one.
- Test at lab scale of the first batches of catalysts and membranes.

FUTURE STEPS

- Final selection and manufacturing of the catalyst for the prototype.
- Final selection and manufacturing of the membrane for the prototype.
- Definition of the process flow diagrams of the pilot plant.
- Design of the membrane reactor.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2014-2020
Hydrogen production efficiency of 72 %	Innovation pillar 2, 1.b /Distributed H_2 production from biogas, efficiency (HHV) /70 % 2017	On-going	90 %	64 %	On-going. Tests at lab-scale will be used to assess the reactor performances and integrate them in the overall process flowsheet
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2014
Hydrogen production efficiency of 72 %	Increasing High Heating Value (HHV) efficiency up to 72 %	On-going	90 %	64 %	On-going. Tests at lab-scale will be used to assess the reactor performances and integrate them in the overall process flowsheet
Perform hydrogen production in one single step	Eliminate feedstock upgrading steps by developing more stable in time catalytic reactor systems	On-going	100 %	4 steps	
Demonstrate BIONICO concept at a landfill plant delivering 100 kg/day of hydrogen	Design, build, operate a reactor for continuous H_2 production at pre-commercial scale(50-250 kg/day)	On-going	90 %		

BIOROBUR

Biogas robust processing with combined catalytic reformer and trap

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	BIOROBUR
CALL TOPIC	SP1-JTI-FCH.2012.2.3: Biogas reforming
START DATE	1/05/2013
END DATE	31/08/2016
PROJECT TOTAL COST	€3,8 million
FCH JU MAXIMUM CONTRIBUTION	€2,4 million
WEBSITE	http://www.biorobur.org/

PARTNERSHIP/CONSORTIUM LIST

POLITECNICO DI TORINO, TECHNISCHE UNIVERSITAET BERGAKADEMIE FREIBERG, SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA (SUPSI), CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS, Erbicol SA, HYSYTECH S.R.L., UAB MODERNIOS E-TECHNOLOGIJOS, PIRELLI & C. ECO TECHNOLOGY RO SRL

MAIN OBJECTIVES OF THE PROJECT

The project objective is develop a robust and efficient biogas reformer aimed at covering a wide span of potential applications, from fuel cells feed (both high temperature SOFC or MCFC fuel cells and low temperature PEM ones, requiring a significantly lower inlet CO concentration) up to the production of pure, PEM-grade hydrogen. The nominal production rate of pure hydrogen of the BioRobur fuel processor is 50 Nm^3/h with an overall efficiency of the conversion of biogas to green hydrogen of 65 %.

PROGRESS/RESULTS TO-DATE

- 15-0,05 wt.% Ni-Rh/MgAl2O4 formulation was identified as a robust catalyst for autothermal reforming of biogas.
- LiFeO2 catalyst was selected as the most prominent candidate towards to carbon gasification in a reducing atmosphere.
- Homogenous SiSiC lattice structures composed of Cubic, Octet and Kelvin cells and the conventional foam structure supports were designed and tested.
- The Life-cycle analysis (LCA) has demonstrated that BioRobur is the most promising process to hydrogen production compared to other technologies.
- Preliminary tests in the demonstration BioRobur plant were performed.

FUTURE STEPS

- Final optimization of the biogas reformer.
- Tests with the integration of the catalytic trap downstream of the reforming reactor with the catalyzed foam and rotated cubic cell structures.

- Long duration test.
- Scale-up/marketing analysis and technology implementation plan.
- Dissemination and training activities.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Obtained results from the test-rig showed the rotated cube cell as the most suitable support structure for the BioRobur process.
- 15-0,05 wt.% Ni-Rh/MgAl2O4 and LiFeO2 catalysts were deposited over the auto-thermal reforming support and over the wall-flow filter, respectively.
- The Biorobur plant was able to reach the target with a nominal production rate corresponding to 50 Nm^3/h of hydrogen.
- Aspen results and LCA analysis showed that Biorobur concept is more efficient compared to other types of reforming process.
- Hazop and Safety Integrity Levels (SIL) analysis were performed.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:				MAIP 2008-2013
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:				AIP 2012
Nominal production rate of pure hydrogen (kg/day)	100 %	Target reached in the preliminary test using a noble metal based coated monolith.	During the preliminary test, the BioRobur plant was able to reach the nominal capacities corresponding to 50 Nm^3/h of hydrogen using as a noble metal based coated monolith.	Tests with Biorobur catalysts and supports are in progress.
CO concentration at the reformer exit (vol%) (dry basis)	<10 %	Target reached in the preliminary test using a noble metal based coated monolith.		
Biogas to hydrogen conversion efficiency (%)	>65 %	Target reached in the preliminary test using a noble metal based coated monolith.		
Materials costs for a 50 Nm^3/h hydrogen production rate (€)	<250,000 %			

BOR4STORE

Fast, reliable and cost effective boron hydride based high capacity solid state hydrogen storage materials

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	BOR4STORE
CALL TOPIC	SP1-JTI-FCH.2011.2.4: Novel H_2 storage materials for stationary and portable applications
START DATE	1/04/2012
END DATE	30/09/2015
PROJECT TOTAL COST	€4 million
FCH JU MAXIMUM CONTRIBUTION	€2,2 million
WEBSITE	http://bor4store.hzg.de/

PARTNERSHIP/CONSORTIUM LIST

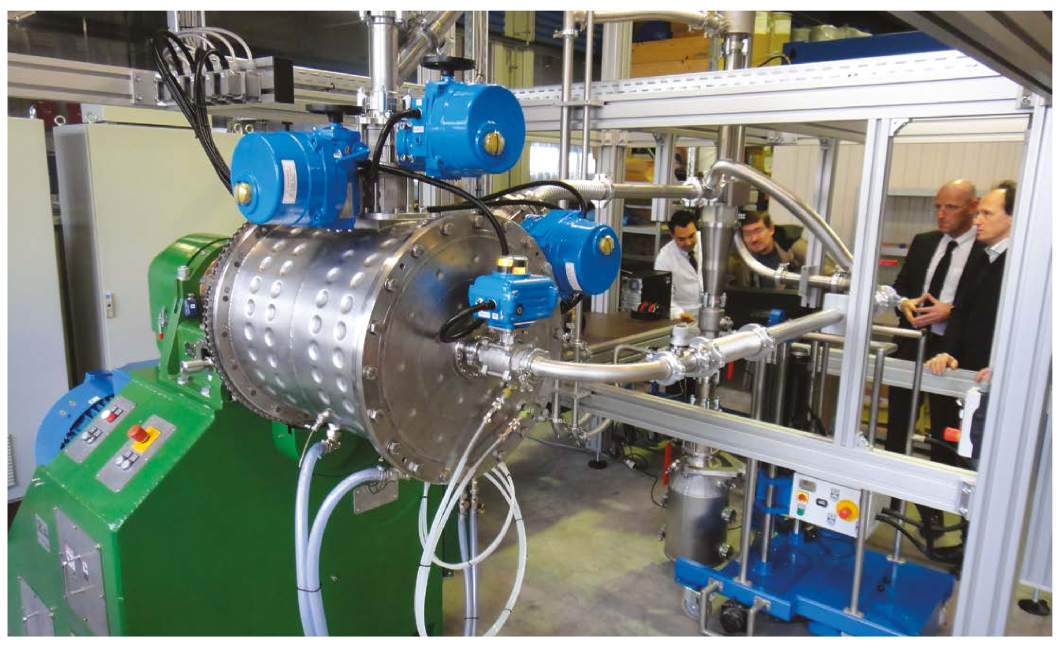
HELMHOLTZ-ZENTRUM GEESTHACHT ZENTRUM FUR MATERIAL- UND KUSTENFORSCHUNG GMBH, ABENGOA HIDROGENO SA, ZOZ GMBH, KATCHEM SPOL SRO, AARHUS UNIVERSITET, INSTITUTT FOR ENERGITEKNIKK, UNIVERSITA DEGLI STUDI DI TORINO, EIDGENOESSISCHE MATERIALPRUEFUNGS- UND FORSCHUNGSANSTALT, NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"

MAIN OBJECTIVES OF THE PROJECT

- Development of high capacity boron hydride-based compounds for H_2 storage.
- Fundamental investigations for understanding microstructures & hydrogenation properties.
- Selection of the most suitable material for use in H_2 storage tank
- Development of heat management system for heat transfer from an SOFC to the metal hydride store.
- Development of boron hydride-based solid state H_2 storage tank, thermally integrated with a SOFC, to demonstrate energy-efficient operation using SOFC off-heat only for H_2 release.

PROGRESS/RESULTS TO-DATE

- Fundamental understanding of reactions in a range of different high capacity boron hydride-based H_2 storage materials.
- Best storage material: LiBH4/MgH_2 RHC.: ca. 10 wt.%, 100 kg H_2/m^3. Loading time <1 h @ 50 bar, operating temp. 350-600 °C.
- Storage material mech.-chem. processing @<€1/kg. Prelim. successful evaluation of various waste as cheap raw materials.
- Integrated SOFC/metal hydride tank systems simulation model, analysis of different heat transfer options between SOFC.
- Single tank modules constructed & certified. Optimised integrated system heat exchange established, under construct.



FUTURE STEPS

- Finalisation of heat transfer system. Establishment of fully integrated system.
- Testing of fully integrated system planned for 2016/2017.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Certain boron hydride-based storage materials offer suitable properties for hydrogen storage in SOEC/SOFC systems.
- Critical points with these materials: supply safety (boron) and cost. Novel approach: use of metal waste as raw materials.
- Thermal integration @ 650 °C for safe system technically feasible, but costly. More cost effective solutions have to operate @ <= 450 °C.
- Promising: exploiting reaction heats of metal hydrides for heat management of reversible power-to-power systems (e.g. reversible solid oxide cells, rSOCs) for increased energy efficiency.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Capacity 1 kg of H_2, potential cost <€500/kg	Storage of H_2 in solid materials - 2015: 5 t capa., €1.5 M/t	Modular storage system. Current cost ca. €5 k/kg H_2 stored	N/A - project finished	Project results	Future cost prospects for boron hydride prod. unclear (unclear market situation)
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					project results
capacities of >80 kg H_2/m^3 and >8 wt.%	Storage materials with capacities >6 wt.%, >60 kg H_2/m^3	Ca. 100 kg H_2/m^3, 9 – 10 wt.% on materials basis	100 %	Project results	
Release temperature 450 °C (compatible with SOFC)	Reversible H_2 release at operating temp. compatible with PEM FC, HT PEM FC or SOFC / MCFC	Release temperature 350-450 °C	100 %	Solid state H_2 storage systems, operating at <=50 bar: max.ca. 1-2 wt.%, ca. 35-50 kg H_2/m^3	
Loading time <1 h	Appropriate H_2 loading/unloading kinetics for the application	Loading time < 1 h in materials testing	100 %	C.f. above	
Prototype storage system with capacity >4 wt. %, >40 kg H_2/m^3	Small prototype syst. w/improved storage capa. vs compressed gas (>4 wt.%, >40 kg H_2/m^3)	Storage tank module construction, building & certification finished	N/A – project finished	Solid state based hydrogen storage systems, operating at <= 50 bar: max.ca. 1-2 wt.%, ca. 35-50 kg H_2/m^3, e.g. J.M. Bellosta von Colbe et al., Int. J. Hydrogen Energy 37 (2012) 2807-2811.	Exact storage weight & vol only known when system construction is finalised
Potential for reaching long-term target: system cost €500/kg H_2	Demonstrate potential for reaching long-term target: system cost €500/kg H_2	Prototype system under construction	N/A – project finished		Future cost prospects for boron hydride prod. unclear (unclear market situation)

COMETHY

Compact multifuel-energy to hydrogen converter

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	COMETHY
CALL TOPIC	SP1-JTI-FCH.2010.2.2: Development of fuel processing catalyst, modules and systems
START DATE	1/12/2011
END DATE	31/12/2015
PROJECT TOTAL COST	€4,9 million
FCH JU MAXIMUM CONTRIBUTION	€2,4 million
WEBSITE	http://www.comethy.enea.it/

PARTNERSHIP/CONSORTIUM LIST

AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, Processi Innovativi SRL, ACKTAR LTD., TECHNION – ISRAEL INSTITUTE OF TECHNOLOGY., FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V, UNIVERSITA DEGLI STUDI DI SALERNO, CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS, ARISTOTELIO PANEPISTIMIO THESSALONIKIS, UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA, STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND, GKN SINTER METALS ENGINEERING GMBH, UNIVERSITA CAMPUS BIO MEDICO DI ROMA

MAIN OBJECTIVES OF THE PROJECT

CoMETHy aimed at developing a new hydrogen production technology combining different energy sources (solar, biomass and fossil fuels). The steam reforming process has been revised to exploit renewable energy: the aim was to power the process with a mixture of molten salts widely used in Concentrating Solar plants. Hence, a steam reforming reactor operating at temperatures up to 550 °C had to be developed. This result was achieved after extensive research, from the development of specific catalysts and membranes, to their integration in an innovative membrane reformer heated with molten salts.

PROGRESS/RESULTS TO-DATE

- Catalysts for methane & bioethanol steam reforming of up to 550 °C developed exhibiting low pressure drops, enhanced heat transfer & shift activity.
- Pd-based composite membranes tested for the membrane reformer with permeability/stability within project targets.
- Catalysts and membranes identified coupled in integrated membrane reformers proved up to pilot scale (3,5 Nm³/h H_2).
- The fuel-flexible approach successfully proved with feed methane/ethanol changeover over the same catalyst.
- Strategies to couple the reformer with a concentrating solar plant were positively evaluated from a techno-economic perspective.

FUTURE STEPS

- The project has been positively concluded.
- Next steps will consist of technology validation in demonstration follow-up projects.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Possibility to power a steam reforming process with solar energy has been proved.
- Besides environmental benefits (CO_2 emission red.) CoMETHy technol. proved attractive from techno-economic perspective.
- Developed technology can be interestingly applied for centralized and decentralized hydrogen production for different uses.
- Thermochem. fuel conversion (methane, biogas, bioethanol, etc.) represents a sustainable route alternative to water electrolysis.
- Demonstration of the technology in real industrial environment will boost market penetration.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
38-100 % CO_2 emissions & fossil fuel use red. in steam reforming using renewable energy sources (RES)	Up to 50 % of the hydrogen energy supplied from renewables	>40 % CO_2 emissions reduction proved; reforming of biofuels proved too (100 % renewable H_2)	100 %	Solar reforming developed by EU project SOLREF with a solar receiver reactor, same CO_2 emissions, CoMETHy technol. eases process mgmt	
Methane reforming efficiency >70 %	Methane reforming processes efficiencies >67 % for decentralized production	68-80 % steam reforming efficiency for a 1,500 Nm³/h methane steam reforming plant incl. CO_2 capture	100 %	Solar reforming developed by EU project SOLREF with a solar receiver reactor, same CO_2 emissions, CoMETHy technol. eases process mgmt	Efficiency of solar reforming defined as produced H_2 thermal power (LHV) / (feed + fuel + thermal power input)
Lowering the hydrogen production costs	Lowering the hydrogen production costs	H_2 prod. cost approach traditional process @ plant scale >1500 Nm³/h	100 %	Ref. cost for traditional process (€1,7/kg) determined in the process	
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2010
Reforming catalysts w/shift activity to get CO <10 vol%	Reforming catalysts w/shift activity to get CO <10 vol%	2-5 vol%	100 %	Not available	
Catalyst replacement time <4 hours	Catalyst replacement time <4 hours	Reactor catalysts & membranes replaced in <4 hours	100 %	Not available	
Plant compactness: hydrogen production and separation in n.1 unit	Reactor compactness & design simplification	>99,8 % hydrogen produced in n.1 unit (membrane reactor)	100 %	3 units [main reformer, water gas shift reactor, PSA, etc.]	
Scalability 2-750 Nm³/h (hydrogen production rate)	Scalability from 2 to 750 Nm³/h (hydrogen production rate)	Shell-and-tube heat exchanger eases scalability from 1,5 Nm³/h (CoMETHy pilot unit) to >1,500 Nm³/h	100 %	Not available	
(c) Other project objectives					
Reforming temperatures <550 °C	Not applicable	400-550 °C	100 %	>850 °C (current technology)	

DON QUICHOTE

Demonstration of new qualitative concept of hydrogen out of wind turbine electricity

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	DON QUICHOTE
CALL TOPIC	SP1-JTI-FCH.2011.2.1: Demonstration of MW capacity hydrogen production and storage for balancing the grid and supply to a hydrogen refuelling station
START DATE	1/10/2012
END DATE	31/03/2018
PROJECT TOTAL COST	€4,8 million
FCH JU MAXIMUM CONTRIBUTION	€2,9 million
WEBSITE	http://www.don-quichote.eu/

PARTNERSHIP/CONSORTIUM LIST

HYDROGENICS EUROPE NV, HYDROGEN EFFICIENCY TECHNOLOGIES (HYET) BV, WaterstofNet vzw, ETABLISSEMENTEN FRANZ COLRUYT NV, TUV Rheinland Industrie Service GmbH, JRC -JOINT RESEARCH CENTRE-EUROPEAN COMMISSION, THINKSTEP AG, ICELANDIC NEW ENERGY LTD, FAST – FEDERAZIONE DELLE ASSOCIAZIONI SCIENTIFICHE E TECNICHE

MAIN OBJECTIVES OF THE PROJECT

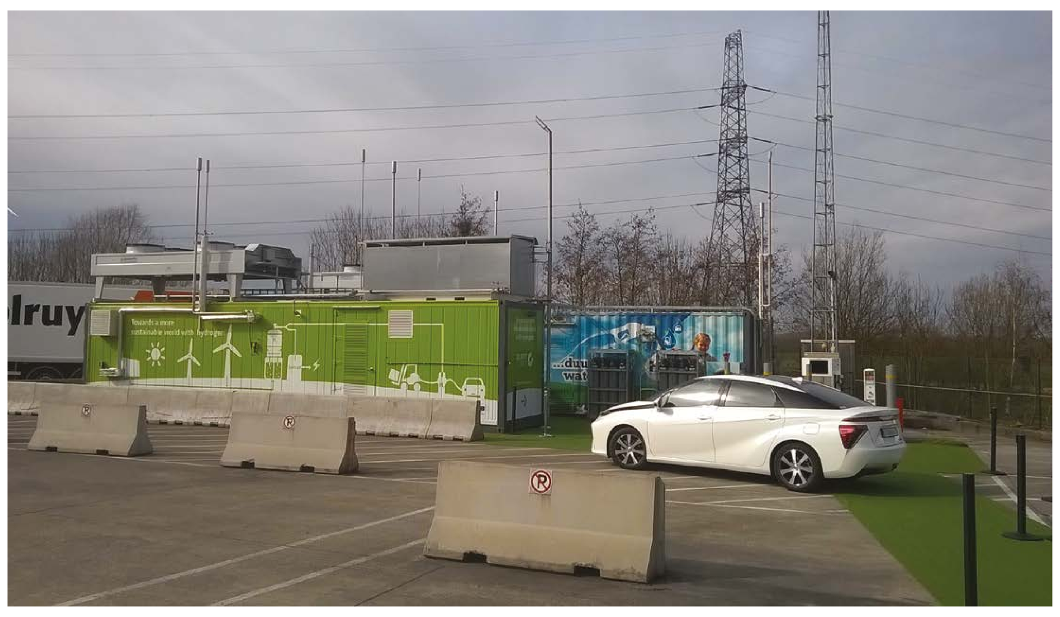
The Don Quichote (DQ) project complements and expands existing hydrogen refuelling system in Halle, Belgium, with innovative, components: a PEM electrolyser and a fuel cell re-electrification unit. Integration with a windmill realizes hydrogen-based energy storage. The hydrogen fuels forklifts at 350bar or produces electricity. The whole system is evaluated in terms of performance, carbon footprint, regulation issues and business potential. It combines targets on increasing renewable electricity, grid balancing, sustainable mobility and using 100 % green hydrogen in an obvious way.

PROGRESS/RESULTS TO-DATE

- Regular performance and cost monitoring via validated LCA (Life Cycle Analyses) software.
- Development, construction, delivery and site operation of a PEM electrolyser (30 Nm³/h, 10 bar).
- Development, construction and operation of a Fuel Cell outdoor system (120kW).
- LCA analysis performed.
- Development of registration plan and operational diary for TCO (Total Cost of Ownership).

FUTURE STEPS

- Continuous monitoring of extension including PEM electrolyser and fuel cell stack.



- Construction and on-site installation of a new compressor.
- Continuous performance monitoring of the system with a new compressor (final phase).
- Detailed yearly datasets on the performance of the plant.
- Complete upscaling scenario's deliverable 6.2.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Good view of regulatory hurdles.
- Realistic costing of hardware and installation.
- Excellent performance of PEM electrolyser and ease of operation.
- Prospect on detailed data for TCO assessment.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Wind as well as solar electricity	...develop a portfolio of sustainable H_2 production...	Power based (energy supply side) steering of electrolyser implemented	100 %		Installed and tested
Alkaline as well as PEME	R&D in innovative H_2 production and supply chains	PEM units constructed, ready for upscaling to MW's	100 %		Operational since Q3;2015
Modular systems for H_2 storage	Storage, distribution processes which can meet incr. share H_2 demand for applications	Installed and tested carbon fibre storage solution	100 %		Operational since Q3, 2015
H_2 for transport, controllable load		Forklift base extension, infrastructure adaptions in permitting process.	100 %		Ca. 80-100 fuelings every month since start of operation.
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2011
Efficiency (WtT; well to tank)	>55 %	Electrolyser 69 % Compressor 85 %	90 %	70 % (60kWh/kg compressed hydrogen)	Stack at 77% efficiency. Intermittent operation optimization ongoing.
Cost of H_2 delivered	<€15/kg	<€13/kg	10 %		Relatively low H_2 use and occupation makes bad OPEX case. Phase 2 TCO analysis in progress, Phase 3 demo cost unclear
H_2 production facility turn-key CAPEX	€3,5 M/(t/d) (i.e. €1,7 M/MWel)	€3,5 M/(t/d) (i.e. €1,7 M/MWel)	80 %	NA	To be assessed during economical evaluation
H_2 quality	ISO/DIS 14786-2 compliant	ISO/DIS 14786-2 compliant	100 %		PEM unit qualified. Compressor to be done
Availability	>95 %	>95 %	100 %		Succesfull site acceptance test. Measurements phase II started Q3, 2015

EDEN

High energy density Mg-based metal hydrides storage system

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	EDEN
CALL TOPIC	SP1-JTI-FCH.2011.2.4: Novel H_2 storage materials for stationary and portable applications
START DATE	1/10/2012
END DATE	30/06/2016
PROJECT TOTAL COST	€2,6 million
FCH JU MAXIMUM CONTRIBUTION	€1,5 million
WEBSITE	http://www.h2eden.eu/

PARTNERSHIP/CONSORTIUM LIST

FONDAZIONE BRUNO KESSLER, MBN NANOMATERIALIA SPA, CIDETE INGENIEROS SL, MATRES SCRL, PANCO – PHYSIKALISCHE TECHNIK ANLAGENENTWICKLUNG & CONSULTING GMBH, UNIVERSIDAD DE LA LAGUNA, JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION

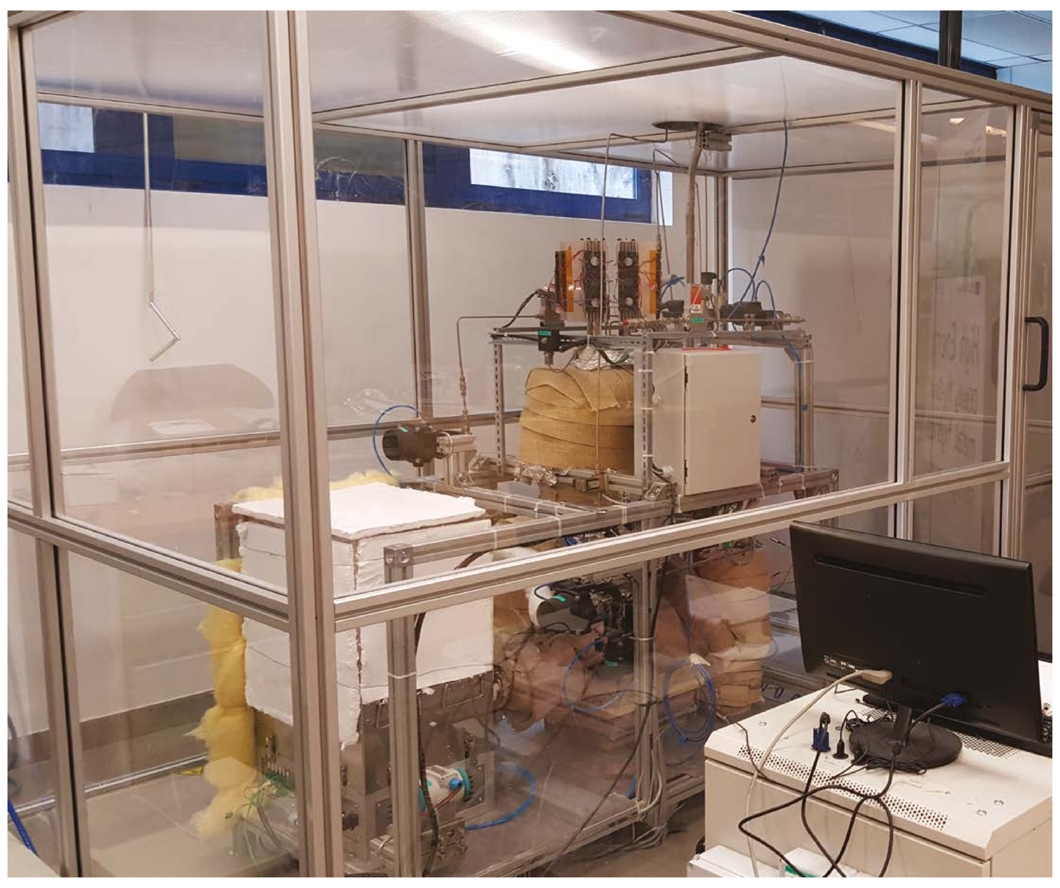
MAIN OBJECTIVES OF THE PROJECT

Develop a new storage material with high hydrogen storage capacity, manageable in real-time, for distributed applications. It will be interlinked to an energy provision system able to match intermittent sources with local energy demand. Target values are:

- Material: Storage capacity: >6,0 wt.%, Density: >80 g/l, Desorption rate: >3 g/min, Cost: <€30/kg.
- Tank: Storage capacity: 4,0 wt.%, Density: 40 g/l, Absorption heat recovery: 25 %, Hydrogen stored: 600g, Desorption rate: 1,5g/min.
- System: Heat recovery, Safety, SOFC performance: >300 mW/cm^2, Performance loss: <10 %/year.

PROGRESS/RESULTS TO-DATE

- Mg-based powder produced by High Energy Ball Milling, with 7,1 wt.% H_2/MH storage capacity and desorption rate >1 gH_2/min/kg at 320 °C and 1,2 bar.
- Consolidation method of Mg-based powder, suitable for enhancing thermal and mechanical properties, to full exploit its storage properties in a tank.
- Intermediate and full Storage Tanks realized, integrated of thermal and hydrogen management able to release more than 1,5 litres per minute.
- System integration layout comprised of all auxiliaries to properly manage hydrogen and thermal power between the hydrogen tank and the SOFC.
- Full scale power-to-power system, using high temperature electrolyzer / fuel cell and solid state integrated storage.



FUTURE STEPS

- Conclude demo tests in Barcelona, in a site managed by the local Energy Agency. It is controlled both at local level and from remote.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Storage properties of Mg-based material validated with a tank prototype in urban environment: capacity 815 g H_2, 37 g H_2/l storage density.
- Realization of prototype coupling reversible solide oxide cell (rSOC) with hydrogen storage tank Mg-based. System Efficiency 25 %. Power production: 1,5 kW.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
€500/kg of stored hydrogen, a capacity of 0,6 kg H_2 and 100 cycles in system lifetime	Cost of hydrogen delivered to retail station €5/kg	Storage capacity 0,8 kg H_2, €500/kg (estimated in the long run), 20 cycles performed (including preliminary tests) = €25/kg of H_2 delivered to SOFC	80 %		Proceed with demonstration activities in urban environment, validating a longer lifetime of EDen system. Cost of delivered H_2 based on system lifetime: number of performed cycles will increase during last period of demonstration
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2011
A material having: H_2 storage capacity >6,0 wt.%, H_2 sorption density >80 kgH_2/m^2, desorption rate >3g/min	Storage material with capacities >6 wt.% and >60 kg H_2/m^3, reversibly releasing hydrogen at operating temperatures compatible with PEM FC, HT-PEM FC or SOFC / MCFC or other applications and appropriate hydrogen loading and unloading kinetics for the envisaged application	ED011 material: 7,1 wt.% storage capacity, 130 kgH_2/m^3 sorption density, desorption rate 1 g/min (per kg material at 320 °C and 1 bar = operating conditions). Storage material consolidated in pallet and loaded in storage tank shown appropriate kinetics for coupling with reversible SOFC	100 %		Achieved desorption rate is referred to operative condition and not to characterization conditions (pressure <1 bar) as indicated in project objectives
A material having cost <€30/kg	Cost effective production routes of the materials, giving opportunities to SMEs in the field of materials production	Projected material cost at industrial scale (1 ton/year) = €42/kg. Manufacturing route validated at pilot scale (100 kg/year) by the SME MBN.			Scale up of production will be driven by market demand
A tank having: H_2 storage capacity > 4,0 wt.%, H_2 sorption density >40 kg/m^3, absorption heat recovery 25 %, H_2 stored 600g, desorption rate 1,5 g/min	Small scale prototype storage systems with significantly improved storage capacity compared to compressed gas storage (>4 wt.%, >40 kg H_2/m^3), taking into account the reversible charge/discharge cyclability	Tank sorption density 37 kg/m^3, H_2 stored 815g, desorption rate 1,7 g/min		Gravimetric target not relevant for addressed application.	Validate the cyclability of storage system during latest demonstration period

ELECTRA

PANEL 5
Hydrogen production, distribution and storage: research and validation

ACRONYM	ELECTRA
CALL TOPIC	SP1-JTI-FCH.2013.2.4: New generation of high temperature electrolysers
START DATE	3/03/2014
END DATE	2/03/2017
PROJECT TOTAL COST	€4 million
FCH JU MAXIMUM CONTRIBUTION	€2,2 million
WEBSITE	http://www.mn.uio.no/smn/english/research/projects/chemistry/electra/index.html

PARTNERSHIP/CONSORTIUM LIST

UNIVERSITETET I OSLO, AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS, STIFTELSEN SINTEF, MARION TECHNOLOGIES S.A., PROTIA AS, ABENGOA HIDROGENO SA, CRI EHF

MAIN OBJECTIVES OF THE PROJECT

The main objective of ELECTRA is to develop scalable fabrication of tubular High Temperature Electrolyser (HTE) cells with proton conducting electrolytes. The robust tubular cells will be assembled in a flexible multi-tube module to produce pure dry pressurised H_2 more efficiently than competing technologies. The cells will reliably operate at temperatures of 600-800 °C in steam electrolysis mode to promote efficient integration of proton ceramic electrolyser (PCE) technology in geothermal and solar heat power plants. ELECTRA will also perform proof-of-concept test of CO_2 and steam co-electrolysis enabling novel concepts for economical production of dimethyl ether (DME).

PROGRESS/RESULTS TO-DATE

- Fabrication of fully assembled single-cell tubular proton ceramic electrolyser.
- Anode performance of <0,2 Ohm cm^2.
- Single cell with total resistance of 2,5 Ohm cm^2.
- Multi-tubular module with individually monitorable tubes designed, commisioned and built.
- proof-of-concept of segment-in-series design.

FUTURE STEPS

- Production of 3rd generation segmented-in-series PCE.
- Evaluation of different electrode materials and processing conditions.
- Electrolysis tests of segment-in-series tubes.
- Testing multi-tube reactor with single and segmented cells.
- DME production by PCEs.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Suitable anode materials have been developed.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Module capacity: 250 L/h	2015 target: Unit capacity ~1,5 t/day	Module designed, commissioned and built	80 %	No value for proton conducting electrolyser cells (PCECs) exist.	Production of tubes is challenging. Currently pursuing Generation 1, 2, and 3.
Total efficiency: 68 %	2015 target: 68 % efficiency	Module not scheduled for testing yet	80 %	No value for proton conducting electrolyser cells (PCECs) exist.	faradayic efficiency reduced by electronic conduction – mainly p-type at anode side – and this may lower overall H_2 production efficiency.
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2013-1
Fabrication of 25 cm length tubular cells with a total area specific resistance (ASR) of 1 Ωcm^2	Cells operating at >1 Acm-2	2,5 Ωcm^2 at 700C	80 %	No value for proton conducting electrolyser cells (PCECs) exist.	Currently limited by narrow set of production parameters and currrent collection. Both expectedly possible to optimise.
Co-ionic co-electrolysis of syngas and DME production. Overall efficiency >85 % incl. BoP	Proof-of-concept co-electrolysis, with efficiencies in the 85-90 % range	Tests not scheduled yet	100 %		
Degradation of <0,5 % per 1,000 hrs	<0,5 % per 1,000 hrs	Tests not scheduled yet	100 %		
(c) Other project objectives					
Anode performance <0,2 Ωcm^2 at 700 °C	Not applicable	<0,2 Ωcm^2 at 700 °C	100 %	This is state-of-the-art for PCECs	

ELYntegration

Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	ELYntegration
CALL TOPIC	FCH-02.8-2014: Improvement of electrolyser design for grid integration
START DATE	1/09/2015
END DATE	31/08/2018
PROJECT TOTAL COST	€3,2 million
FCH JU MAXIMUM CONTRIBUTION	€1,8 million
WEBSITE	http://www.elyntegration.eu

PARTNERSHIP/CONSORTIUM LIST

FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON, INDUSTRIE HAUTE TECHNOLOGIE SA, VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK N.V., FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V., INSTRUMENTACION Y COMPONENTES SA, RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN

MAIN OBJECTIVES OF THE PROJECT

The strategic goal of the ELYntegration project is the design and engineering of a robust, flexible, efficient and cost-competitive single stack multi-megawatt High Pressure Alkaline Water Electrolysis of 4,5 T H_2 /day capable to provide cutting-edge operational capabilities under highly dynamic power supplies expected in the frame of generation/ transmission/ distribution scenarios integrating high renewable energies (RE) shares.

PROGRESS/RESULTS TO-DATE

- Dissemination and awareness plan in progress (web of the project published, public presentation, presentation of the project in conferences).
- Technical, regulatory framework and requirements for electrolysers providing additional services (ramps, dynamic, control) studied.
- Electrodes and membranes for alkaline water electrolysis: first batch of developed materials tested in lab, first selection to be tested in-situ.
- Business models and market assessment in progress.

FUTURE STEPS

- Selection of components/next candidates to be tested in next stack's scale.

- Identification of most attractive business models.
- Second batch of materials to be developed according to first assessment of results.
- Selection of materials to be tested in dynamic operation (medium scale).

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Non consistent regulations and grid services within Europe, different requirements and specifications.
- It is needed to mark a set of recommendations (response time, bids, communication with operator) at EU level.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2014-2020
Efficiency 52 kWh/kg at higher current densities	52 kWh/kg. MAWP [2020]	52 (kWh/kg)	100 %	52 (kWh/kg) [Study on development of water electrolysis in the EU (2014) for Alkaline, for 2015 at system level, including power supply, control, gas drying]; 57-60 range in MAWP (2014)	The KPI in MAWP is referred to nominal rate, for a production >1,000 kg/day. Current status has been measured for lower current densities than the ones to be reached within the project
CAPEX <€1,3 M at higher current densities, whilst providing higher system flexibility	€2 M/(t/d) MAWP [2020] at rated power including ancillary equipments and comissioning	<€1,6 M (extrapolated value for the same production as reference)	95 %	MAWP for CAPEX (2017) is ~€3,7M/(t/d); Value from "Study on development of water electrolysis in the EU (2014) for Alkaline", for 2015 at system level is €930/kW	Previous calculations indicated that considering the actual value of <€750/kW, the estimation for a ton/day production is possible to reach in the project framework
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2014
CAPEX <€1,3 M at higher current densities, whilst providing higher system flexibility	€630/kW 2020 central KPI as expressed in AWP 2014	<750	95 %	Value from "Study on development of water electrolysis in the EU (2014) for Alkaline", for 2015 at system level is €930/kW	Challenge: keep CAPEX inline with technological improvements, changes in current densities and flexibility
(c) Other project objectives					
Design of a stack capacity >9,5 MW	Not applicable	3,5MW	95 %	Manufacturer's stack size (state of art)	Current design up to 6,5 MW per stack (not tested at full power scale, but in pilot scale)
Stack lifetime >10 years	Not applicable		95 %	Literature (Electrolysis study, 2014) indicates an average demostrated lifetime of >60,000h. Increasing lifetime has an impact on cost (CAPEX) and efficiency	The project will study the impact on the materials developed to achieve the improved capabilities of working with high flexibility. It will be used to extrapolate the impact on expected lifetime

HELMETH

Integrated High-Temperature electrolysis and methanation for effective power to gas conversion

PANEL 5
Hydrogen production, distribution and storage: research and validation

ACRONYM	HELMETH
CALL TOPIC	SP1-JTI-FCH.2013.2.4: New generation of high temperature electrolysers
START DATE	1/04/2014
END DATE	31/03/2017
PROJECT TOTAL COST	€3,8 million
FCH JU MAXIMUM CONTRIBUTION	€2,5 million
WEBSITE	http://www.helmeth.eu/

PARTNERSHIP/CONSORTIUM LIST

Karlsruher Institut fuer Technologie, POLITECNICO DI TORINO, SUNFIRE GMBH, European Research Institute of Catalysis A.I.S.B.L., ETHOSENERGY ITALIA SPA, NATIONAL TECHNICAL UNIVERSITY OF ATHENS – NTUA, DVGW DEUTSCHER VEREIN DES GAS- UND WASSERFACHES – TECHNISCH-WISSENSCHAFTLICHER VEREIN EV

MAIN OBJECTIVES OF THE PROJECT

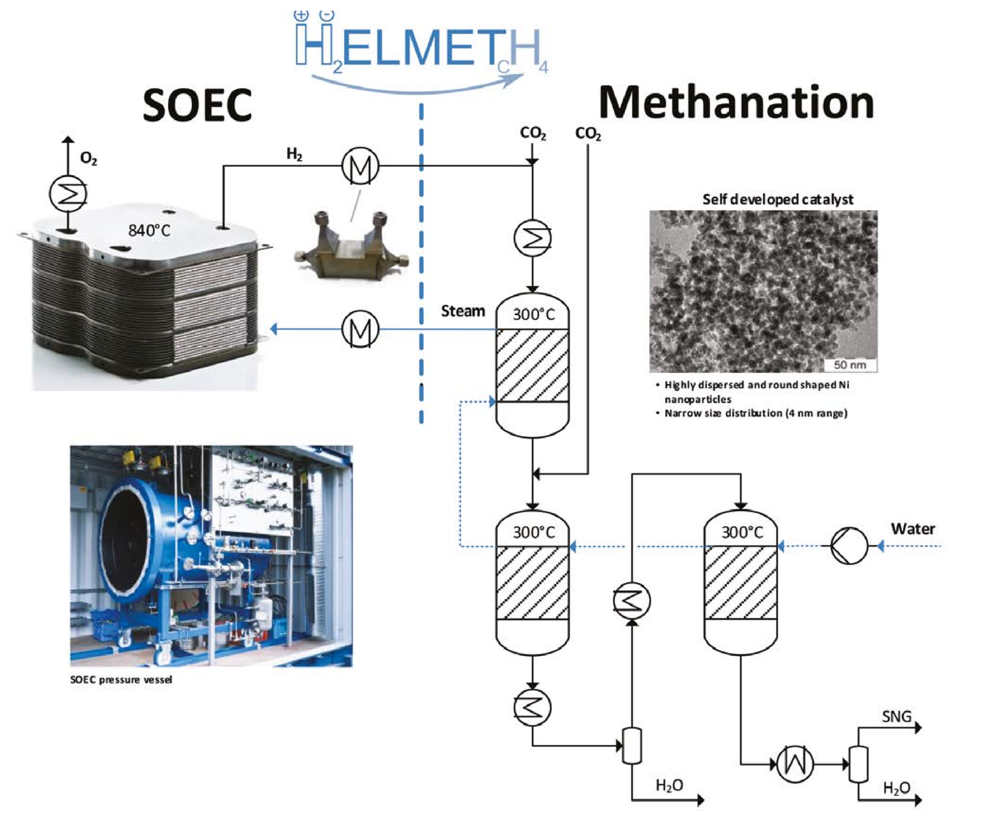
The objective of the HELMETH project is the proof of concept of a highly efficient Power-to-Gas (P2G) technology with methane as a chemical storage, and by thermally integrating high temperature electrolysis (SOEC technology) with CO_2 methanation. The aim is to prove and demonstrate that high temperature electrolysis and methanation can be coupled and thermally integrated towards highest conversion efficiencies >85 % from renewable electricity to methane by utilizing the process heat of the exothermal methanation reaction in the high temperature electrolysis process.

PROGRESS/RESULTS TO-DATE

- SOEC short stack tests show voltage degradation rates <0,5 %/ 1,000 h and feasibility of co-electrolysis.
- Multiple nickel-based catalysts for the methanation were developed, tested at up to 30 bar and optimized.
- A multistep methanation module has been designed with a boiling water cooling. The thermal coupling with the SOEC is realized by the generated steam.
- Lab tests confirm that Synthetic Natural Gas (SNG) quality requirements are met with the chosen methanation module concept.
- Process simulation of HELMETH concept confirm efficiencies >85 % for large scale plants based on realistic assumptions.

FUTURE STEPS

- Manufacturing of the methanation module will soon be completed.
- The methanation and SOEC modules are at first tested separately.
- Operation of complete PtG prototype at the beginning of 2017.



CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Total efficiency of coupled SOEC and methanation module is expected to exceed 85 % at a SOEC steam conversion of 80 %.
- Higher efficiencies can be reached with higher SOEC steam conversions and/or with SOEC co-electrolysis.
- A boiling water cooling of the methanation at 300 °C is optimal considering the SNG quality requirements and the coupling with the SOEC by steam.
- Minimal heat losses can be reached by combining catalytic reactors in one pressure vessel.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2013-1
High-temperature (800-1,000 °C), high current density (>1 A/cm²), pressurised conditions	High-temperature (800-1,000 °C), high current density (>1 A/cm²), pressurised conditions	Electrodes and interconnector protection layers feasible for HTE under pressurized conditions	100 %	Pressurized operation only proven at cell and short stack level, sunfire is first institution to prove it on full-scale, thermally self-sustained stack	1 A/cm² achieved with cell tests, integration of high-performance cells in stack ongoing
HELMETH will deliver a proof of concept towards large scale systems	Manufacture of dedicated HTE cell and stacks for use in large systems	The durability has been proven by short stack tests and will be verified in the final prototype	95 %	For non-pressurized operation, sunfire has already produced a system in the 100 kW range; scalability can be reached effectively with the common sunfire cell size, which is applied also within HELMETH	The operation of final prototype is planned for the beginning of 2017
Degradation rates around 1 %/1,000 h (0,5 %/1,000 h for short stacks) for a 10-15 kW class system	Degradation rates around 1 %/1,000 h (0,5 %/1,000 h for short stacks) for an HTE system in kW size	First SOEC short stack tests confirm degradation rates <0,5 % / 1,000 h	100 %	Kerafol cells (sunfire supplier) achieved 20,000 h in electrolysis mode -->SOEC world record	
Conversion efficiencies >85 % from electricity to methane	Total efficiencies for co-electrolysis, syngas production or chemical product in the 85-95 % range	Detailed simulations including BoP predict a total conversion efficiency of 86 % (large scale plant)	95 %	The efficiency of a combination of low temperature electrolysis and a methanation would result in total conversion efficiencies around 60 % in the best case	Efficiency of prototype plant will be lower due to heat losses, which are dependent on size of plant; the difference is predictable

HyBalance

PANEL 5
Hydrogen production, distribution and storage: research and validation

ACRONYM	HyBalance
CALL TOPIC	FCH-02.10-2014: Demonstrating the feasibility of central large scale electrolysers in providing grid services and hydrogen distribution and supply to multiple high value markets
START DATE	1/10/2015
END DATE	30/09/2020
PROJECT TOTAL COST	€15,1 million
FCH JU MAXIMUM CONTRIBUTION	€7,9 million
WEBSITE	hybalance.eu

PARTNERSHIP/CONSORTIUM LIST

AIR LIQUIDE ADVANCED BUSINESS, Ludwig-Boelkow-Systemtechnik GmbH, NEAS ENERGY AS, CEMTEC FONDEN, COPENHAGEN HYDROGEN NETWORK AS, AIR LIQUIDE GLOBAL E&C SOLUTIONS FRANCE, HYDROGENICS EUROPE NV

MAIN OBJECTIVES OF THE PROJECT

HyBalance is a project that demonstrates the use of hydrogen in energy systems. The hydrogen will be produced from water electrolyses, enabling the storage of cheap renewable electricity from wind turbines. It will thus help balance the grid, and the green hydrogen will be used for clean transportation and in the industrial sector. HyBalance will be one of Europe's largest and most advanced facilities for production of green hydrogen and will contribute to accelerating the development of clean mobility in Denmark.

PROGRESS/RESULTS TO-DATE

- Danish minister of energy cut the first sod in April 2016.
- Piping and Instrumentation Diagram frozen – Electrical architecture validated – Plot plan finalised.
- Permiting in progress.
- Website launched.

FUTURE STEPS

- Electrolyser Factory Acceptance Test.
- Plant Acceptance Test.
- Optimisation test phase including grid balancing features.
- Continuous monitoring of the operations.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Grid balancing features bring technical constraints which need to be included in the design of the plant.
- The project will demonstrate the complete value chain from hydrogen renewable energy production to end users, including hydrogen charging stations.
- Expectations related to highly dynamic PEM electrolysis will be validated in a real-industrial environment.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2014-2020
Cost goal	€1,570/kWel	€1,810/kWel	85 %	No 2016 competitive/ public information available.	Slightly >than programme target because of: – first-built including non-recurrent engineering – two stack platform for reliability
Efficiency	57,5 kWhel/kgH_2	designed for target	97 %	Smaller installation 150 kW / 30Nm³/hr performs at 59 kWh/kg (Don Quichote FP7-project 303411)	Unit is designed for >20khrs performance within this target.

HYDROSOL-PLANT

Thermochemical hydrogen production in a solar monolithic reactor: construction and operation of a 750 kWth plant

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	HYDROSOL-PLANT
CALL TOPIC	SP1-JTI-FCH.2012.2.5: Thermo-electrical-chemical processes with solar heat sources
START DATE	1/01/2014
END DATE	31/12/2016
PROJECT TOTAL COST	€3,4 million
FCH JU MAXIMUM CONTRIBUTION	€2,2 million
WEBSITE	http://www.hydrosol-plant.certh.gr/

PARTNERSHIP/CONSORTIUM LIST

CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS, DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV, CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT, HyGear B.V., ELLINIKA PETRELAIA AE

MAIN OBJECTIVES OF THE PROJECT

The HYDROSOL-PLANT project comes as the natural continuation of the successful HYDROSOL project.

Main objectives:

– Define all key components and aspects
– Develop tailored heliostat field technology that enables accurate temperature control of the solar reactors.
– Construct a 750 kWth solar hydrogen production demonstration plant to verify the developed technologies for solar water splitting.
– Operate the plant and demonstrate hydrogen production and storage on site.
– Techno-economic study for the commercial exploitation of the solar process.

PROGRESS/RESULTS TO-DATE

- Definition of key components.
- Completion of process flowsheet layout and piping/ instrumentation diagram.
- Procurement of redox porous structures-building blocks for the H_2 production reactor.
- Completion of H_2 purification unit.
- Completion of the adaptation of solar tower platform for the reactor, peripherals and components integration.

FUTURE STEPS

- Construction of the H_2 reactors.
- Placement of the reactors on the solar tower.
- Integration of the reactors with the other BoP and sub-BoP units.

- Thermal-only and solar hydrogen production campaigns of prototype plant.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- A piping & instrumentation diagram (P&ID) was elaborated in order to define the control strategy of the plant including the 3 parallel reactors.
- The design of the reactor was revisited to cover certain limitations (such as platform space and weight, reactor volume, budget).
- The final reactor design will include redox foam structures and involves a set-up of 3 reactors put in a triangular arrangement.
- Within this period a redox monolith was subjected to 740h of consecutive cycling in the laboratory with no significant degradation.
- Preparation of the solar tower platform for integration of the HYDROSOL-plant (structural changes at the 27m height platform, new heliostat facets).

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2012
Materials with performances suitable for economic operation, life timesmore than 1,000h operational	1,000 h	740 h	90 %	N/A	
Solar hydrogen generator in a demonstration range @ 0,5-2 MW scale	0,5-2 MW	0,75 MW	100 %	N/A	
Demonstration of hydrogen production and storage on site (>3kg/week)	3 kg H_2/week	3,3 kg H_2/week (average value based on lab-scale experiments)	90 %	N/A	

HYTRANSFER

Pre-normative research for thermodynamic optimization of fast hydrogen transfer

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	HYTRANSFER
CALL TOPIC	SP1-JTI-FCH.2012.2.6: Pre-normative research on gaseous hydrogen transfer
START DATE	1/06/2013
END DATE	31/12/2016
PROJECT TOTAL COST	€3 million
FCH JU MAXIMUM CONTRIBUTION	€1,6 million
WEBSITE	http://www.hytransfer.eu/

PARTNERSHIP/CONSORTIUM LIST

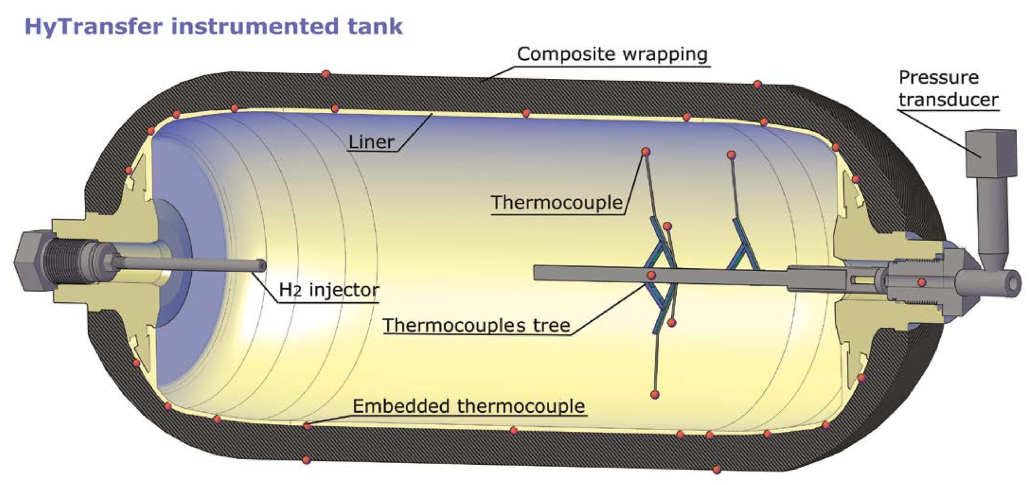
Ludwig-Boelkow-Systemtechnik GmbH, L'AIR LIQUIDE S.A, THE CCS GLOBAL GROUP LIMITED, RAUFOSS FUEL SYSTEMS AS, HONDA R&D EUROPE (DEUTSCHLAND) GMBH, JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, TESTNET ENGINEERING GMBH

MAIN OBJECTIVES OF THE PROJECT

HyTransfer aims to develop and experimentally validate a more practical approach for optimized fast filling of compressed hydrogen, meeting the material temperature limits of the tanks taking into account the container and system's thermal behaviour.
This project aims to create conditions for an uptake of the approach by international standards, for wide-scale implementation into refuelling protocols. The new approach will be evaluated and its benefits quantified with regards to performance, costs, and safety. Recommendations for implementation into international standards will be proposed.

PROGRESS/RESULTS TO-DATE

- Tanks with temperature measuring devices in the tank walls were manufactured by two different tank manufacturers.
- Thermocouples were strategically placed according to Computational Fluid Dynamics (CFD) calculations.
- 65 filling and emptying experiments on three different kinds of small tanks have been performed at three different labs in Europe.
- A simple model predicting all temperatures is in very good agreement with the experiments. The error is in the magnitude of 3 °C.
- Existing RCS and opportunities for improvements by the project are continuously monitored.



FUTURE STEPS

- Experiments on tank systems with up to 5 tanks of different sizes will be performed in June 2016.
- Finalizing new refuelling approach based on experimental results.
- Techno-economical evaluation of results.
- Prepare recommendations for RCS.
- Prepare final documents including public results.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Optimized and more efficient refuelling protocol
- Guidance and simple model for optimized temperature control during hydrogen transfer.
- Reduction of HRS operational expenditures (OPEX) and capital expenditures (CAPEX).
- Increased reliability and life time of technical HRS components.
- Recommendations for international RCS.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
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(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2012
Identification of opportunities for optimization	Not specified	Optimization by focussing on heat transfer	100 %		
Identification of existing RCS and opportunities for improvement	Not specified	Work in progress	100 %		
Improved approaches for carrying out the transfer with less pre-cooling	Not specified	Work in progress	100 %	SAE J2601	
Recommendations for implementation in international standards	Not specified	This will be the final result of HyTransfer	100 %		
Evaluate the influence of tank construction on the maximum allowable filling speed	Not specified	A variety of tank sizes from two tank manufacturers were evaluated.	100 %		

INSIDE

In-situ Diagnostics in Water Electrolyzers

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	INSIDE
CALL TOPIC	SP1-JTI-FCH.2013.2.2: Diagnosis and monitoring of electrolyser performance
START DATE	1/11/2014
END DATE	31/10/2017
PROJECT TOTAL COST	€3,6 million
FCH JU MAXIMUM CONTRIBUTION	€2,1 million
WEBSITE	inside-project.eu

PARTNERSHIP/CONSORTIUM LIST

DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV, NEW NEL HYDROGEN AS, ACTA SPA, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, HOCHSCHULE ESSLINGEN

MAIN OBJECTIVES OF THE PROJECT

In-situ online monitoring of current density distributions for three water electrolysis technologies: PEM, Alkaline and anion exchange membrane. A 2-dimension segmented printed circuit board (PCB) replaces a regular bipolar plate of the electrolyser system. The PCB is adapted to the specific requirements (physical, chemical, analytical) of each technology. Three stages of prototypes are planned. Implementation and evaluation of Advanced Stress Test (AST) protocols, and correlation with ex-situ analytics are planned to allow harvesting hidden potential and avoiding critical operation modes.

PROGRESS/RESULTS TO-DATE

- PEM water electrolyser: feasibility demonstrated in single test cell.
- PEM water electrolyser: hardware supplier on stack level coudl be identified.
- Alkaline water electrolyser: Design of first prototype fixed.
- Anion Exchange Memerane (AEM) water electrolyser: First prototype is under construction.
- Analytics: Ex-situ ambient pressure photoemission spectroscopy cell for electrochemical cycling was developed.

FUTURE STEPS

- PEM water electrolyser: Design and construction of first prototype.
- Alkaline water electrolyser: Construction and integration of first prototype into short stack.
- AEM water electrolyser: Integration of first prototype into stack and test operation.
- First feasibility studies of AST in AEM water electrolyser.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Segmented PCB technology is working in PEM water electrolyser.
- Perspective: Evaluation and adaptation of stressors over the length of the project.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Online diagnostics for PEMWE, AE, AEMWE	Distributed production of Hydrogen by water electrolysis	10 %	90 %		Project does not directly aim for MAIP targets, but provides the tools for targeted developments.
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2013-1
Online diagnostics for PEMWE, AE, AEMWE	2.2 Diagnosis and monitoring of electrolyser performance	10 %	90 %	Feasibility for 1D [Dedigama, JPS 2014] and 2D [García-Navarro, submitted] locally resolved current density measurement in PEMWE was shown.	PEMWE: feasibility of diagnostics tool proven, design pending; AE: design for diagnostics tool present, construction pending; AEMWE: construction of diagnostic tool under progress.
(c) Other project objectives					
Development, harmonisation, and evaluation of accelerated stress tests for water electrolysis	Not applicable	10 %	80 %	No published AST for water electrolysis as of 2016. JRC has started harmonisation inside EU.	The diagnostics tool will allow – in a later stage of this project – to monitor and evaluate proposed ASTs.

MEGASTACK

Stack design for a Megawatt scale PEM electrolyser.

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	MEGASTACK
CALL TOPIC	SP1-JTI-FCH.2013.2.3: Large capacity PEM electrolyser stack design
START DATE	1/10/2014
END DATE	30/09/2017
PROJECT TOTAL COST	€3,9 million
FCH JU MAXIMUM CONTRIBUTION	€2,1 million
WEBSITE	http://www.sintef.no/Projectweb/megastack/

PARTNERSHIP/CONSORTIUM LIST

STIFTELSEN SINTEF, FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V, ITM POWER (TRADING) LIMITED, COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES

MAIN OBJECTIVES OF THE PROJECT

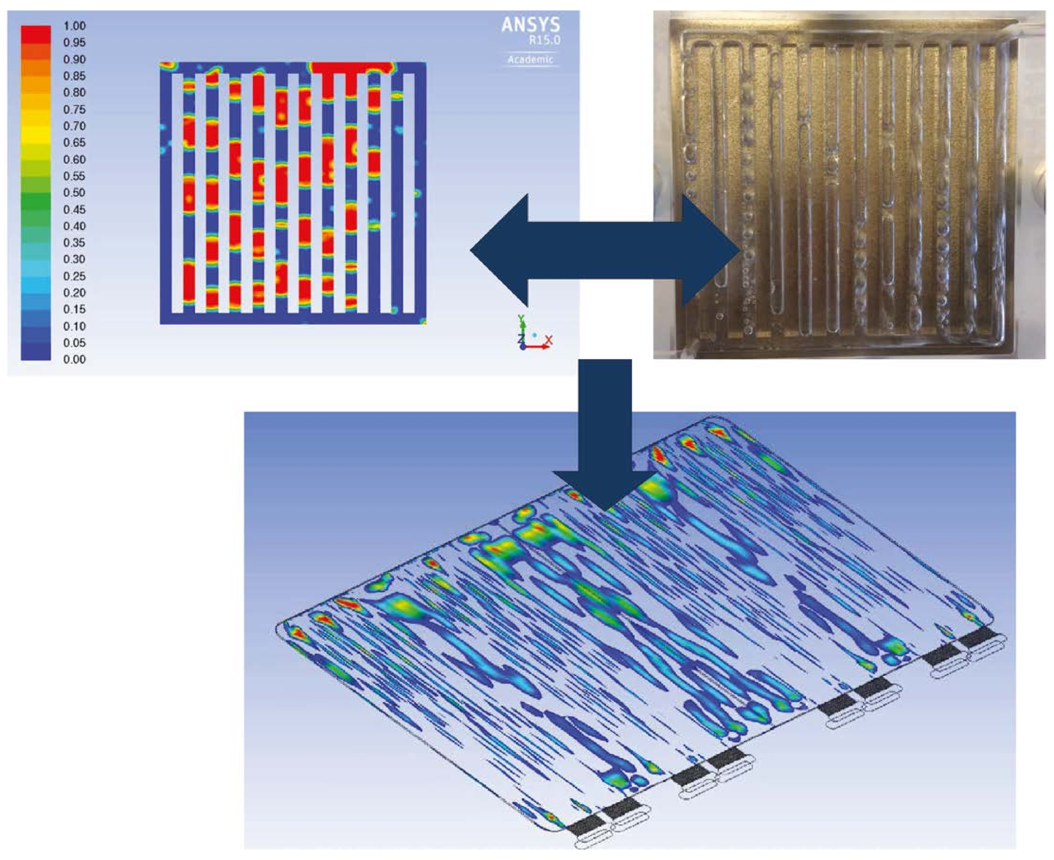
The main objective of MEGASTACK is to develop a cost efficient stack design for Megawatt-sized PEM electrolysers and to construct and demonstrate a prototype of this stack. The prototype will demonstrate a capability to produce hydrogen with an efficiency of at least 75 % (LHV) at a current density of 1,2 Acm-2 with a stack cost below €2,500/Nm3h-1 and a target lifetime in excess of 40,000 hours (<15 µVh-1 voltage increase at constant load).

PROGRESS/RESULTS TO-DATE

- Organised PEM electrolyser cost workshop.
- Selection of supplier of MEA for MW stack concluded.
- Mathematical stack model and single cell multiphase flow model completed.
- 1st generation stack design completed.
- Protoype production.

FUTURE STEPS

- Component level testing on single cell and short stack level.
- Further optimisation and validation of mathematical models.
- Evaluation of stack design by mathematical models.
- Stack construction and testing.



CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Further cost reductions of PEM electrolysers possible through manufacturing and supply chain improvements.
- More knowledge on micro-scale transport processes in MEAs and porous transport layers needed.
- MW scale PEM electrolyser design launched by ITM Power.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
2015 target: 10-20 % of H_2 demand produced via carbon free/carbon lean sources	Stack <€2,500/Nm³/hn lifetime in excess of 40,000 h 1,2 A/cm² with n >75 % (LHV)	<€2,500/ Nm³/h capacity	90 %		As this is a RTD project there is always a certain risk that project objectives are not achieved within the timeframe of the project.
2015 target: Cost of H_2 delivered at refuelling station <€5/kg (€0,15/kWh)			90 %	$3,64/kg ($0,057/kwh) (Giner DOE annual review 2013)	As this is a RTD project there is always a certain risk that project objectives are not achieved within the timeframe of the project.
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2013-1
Hydrogen production capacity of single stack >100 Nm³/h	60 Nm³/h	60 Nm³/h	100 %		
Modular stack cost <€2,500/Nm³/h capacity	€2,500/Nm³/h capacity	<€2,500/ Nm³/h capacity	100 %		
Stack availability >99 %	N/A	Not available, no stack constructed for testing.			Target too vague to be relevant KPI. How is "availability" defined?
Lifetime >40,000h	>40,000h	Not available, no stack constructed for testing.	95 %		

NOVEL

Novel materials and system designs for low cost, efficient and durable PEM electrolysers

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	NOVEL
CALL TOPIC	SP1-JTI-FCH.2011.2.7: Innovative Materials and Components for PEM electrolysers
START DATE	1/09/2012
END DATE	30/11/2016
PROJECT TOTAL COST	€5,9 million
FCH JU MAXIMUM CONTRIBUTION	€2,6 million
WEBSITE	https://www.sintef.no/Projectweb/NOVEL/

PARTNERSHIP/CONSORTIUM LIST

STIFTELSEN SINTEF, FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V, COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, AREVA STOCKAGE D'ENERGIE SAS, JOHNSON MATTHEY FUEL CELLS LIMITED, Teer Coatings Limited, BENEQ OY, PAUL SCHERRER INSTITUT, AREVA H2GEN

MAIN OBJECTIVES OF THE PROJECT

The main objective of NOVEL is to develop and demonstrate an efficient and durable PEM water electrolyser utilising the new, beyond the state-of-the-art materials developed within the project. The electrolyser will demonstrate a capability to produce hydrogen with an efficiency of at least 75 % (LHV) at rated capacity with a stack cost below €2,500/Nm³h-1 and a target lifetime in excess of 40,000 hours (<15 µVh-1 voltage increase at constant load).

PROGRESS/RESULTS TO-DATE

- Identified degradation mechanisms in PEM electrolysers.
- Membranes and MEAs with lower H_2 crossover and lower costs.
- Oxygen electrocatalysts with higher activity.
- Oxide coatings for Ti bipolar plates.
- Demonstrator stack under testing.

FUTURE STEPS

- Further testing of demontrator stack.
- Evaluation of conductive supports and microporous layers.
- Upscaling and process optimisation of bipolar plate coating process.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- A new generation polyaromatic membranes for PEM electrolysers with significant potential for cost reduction.
- New oxygen evolution catalysts with improvement in catalytic activity and potential for noble metal thrifting.
- Further development of low cost materials and components are needed for PEM electrolysers.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:				MAIP 2008-2013
stack cost below €2,500/Nm³h-1 and a target lifetime in excess of 40,000 hours	Cost of H_2 delivered at refueling station €5/kg	>2,500/Nm³h-1 at a stack efficiency of 67 %	90 %	NOVEL hydrogen cost calculations show costs of delivered H_2 to be at €3,55/kg at an electricity price of €0,057/kWh. The overall cost target in the programme has been achieved.
efficiency of at least 75 % (LHV) a stack cost below €2,500/Nm³h-1 and a target lifetime in excess of 40,000 hours	1,5 t/d cap. 68 % eff €2,8 M/ (t/d)	>2,500/Nm³h-1 at a stack efficiency of 67 %	80 %	Efficiency target will not be reached. But is unnecessary in order to reach the overall programme objectives. Lifetime target will not be reached.
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:				AIP 2011
More efficient catalysts for the oxygen evolution reaction presenting lower activation overpotential as well as new catalyst structures or metal alloys resulting in lower noble metal loadings	Improved catalysts with 200 % mass activity vs. state of the art demonstrated. Fibrous catalyst supports and the use of alternatives to Pt for hydrogen evolution is being evaluated	Catalysts with 300 % mass activity vs. state of the art demonstrated ex situ. Fibrous catalyst supports and the use of alternatives to Pt for hydrogen evolution has been evaluated	100 %	Increased mass activity has been reached, but catalysts have lower conductivity which is challenging when implementing them in electrolyser MEAs
Polymer membranes with improved conductivity, low gas crossover and high mechanical stability	Thinner, more conductive and reinforced PFSA membranes. Radiation grafted membranes.	Membranes with a higher ratio of conductivity vs hydrogen crossover has been developed	80 %	Long term stability of the membranes under high pressures of oxygen and the production of electrodes on the membranes with good performance
Alternative materials for bipolar plates and current collectors, replacing the use of titanium	Development of coatings. The goal is to reduce the contact resistance of Titanium	Decreasing the passivation of Ti to increase the lifetime of the electrolyser stack	60 %	The achievement of this target is challenging due to the very oxidative environment and the transient operation of PEM electrolysers.

PECDEMO

Photoelectrochemical demonstrator device for solar hydrogen generation

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	PECDEMO
CALL TOPIC	SP1-JTI-FCH.2013.2.5: Validation of photoelectrochemical hydrogen production processes
START DATE	1/04/2014
END DATE	31/03/2017
PROJECT TOTAL COST	€ 3,3 million
FCH JU MAXIMUM CONTRIBUTION	€ 1,8 million
WEBSITE	http://pecdemo.epfl.ch/

PARTNERSHIP/CONSORTIUM LIST

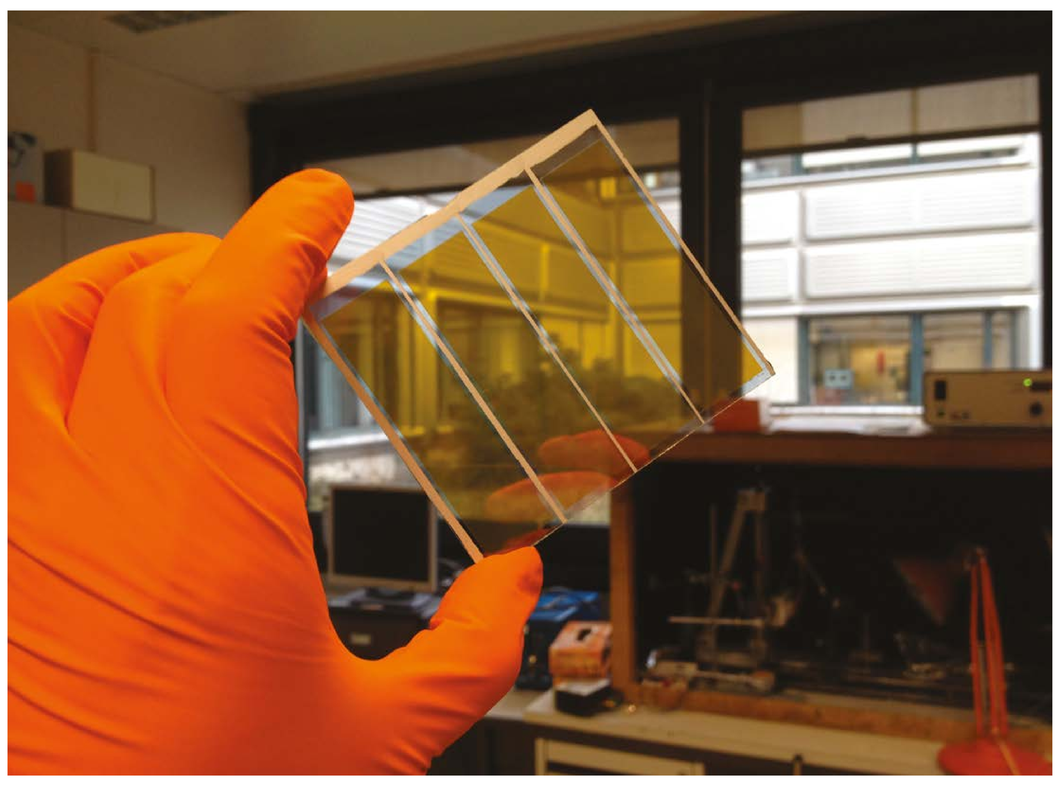
HELMHOLTZ-ZENTRUM BERLIN FUR MATERIALIEN UND ENERGIE GMBH, ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, TECHNION ISRAEL INSTITUTE OF TECHNOLOGY, DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV, UNIVERSIDADE DO PORTO, EVONIK INDUSTRIES AG, SOLARONIX SA

MAIN OBJECTIVES OF THE PROJECT

To address the challenges of solar energy capture and storage, we will develop a hybrid photoelectrochemical-photovoltaic (PEC-PV) tandem device for light-driven water splitting with an active area of <50 cm^2 and a solar-to-hydrogen (STH) efficiency of 8-10 % that is stable for more than 1,000 h. In parallel we will work on an extensive techno-economic and life-cycle analysis based on actual performance characteristics. This will give a reliable evaluation of the application potential of photo-electrochemical (PEC) hydrogen production, and further strengthen Europe's leading position in this growing field.

PROGRESS/RESULTS TO-DATE

- Efficiency of 7,5 % achieved for small-area device based on BiVO4 and 3-HIT Si cell, 8 mA/cm^2 photocurrent achieved for Cu_2O nanowires.
- Large-area (50 cm^2) BiVO4 and Cu_2O photoelectrodes fabricated.
- Light management and power management strategies developed.
- Angled cell design developed that shows improved bubble transport, avoids need for selective membrane, and allows use of segmented electrodes.
- Process flow sheets constructed and analyzed for three hydrogen production scenarios, predicting overall systems efficiencies between 7,7-8 %.



FUTURE STEPS

- Efforts to improve the efficiency of large-area electrodes will be increased.
- Various approaches to improve the stability and lifetime will be pursued .
- First large-area modules will be constructed.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Improvements in efficiency are encouraging, modeling efforts show that target efficiencies can be reached.
- The efficiency of large-area electrodes is mainly limited by resistive (ohmic) losses.
- Combination of power management and active light management can result in efficiencies that exceed those of PV-electrolyzer systems.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2014-2020
PEC-PV tandem device with active area <50 cm^2, STH-efficiency 8 %, stable for more than 1,000 h	Development and testing of new hydrogen production pathways (not quantitative)	The best efficiency achieved so far is 7,5 % (HHV) for a <1 cm^2 device.			
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2013-1
Active area >50 cm^2	Active area >50 cm^2	Photoelectrodes of 50,4 cm^2 were fabricated.	100 %	9 cm^2 (est. individual panel size in EU ArtipHyction project)	
Solar-to-H_2 efficiency of 8 %	Solar-to-H_2 efficiency of 8 %	7,5 % for small area BiVO4 device, 5,3 % for large-area Cu_2O photocathode (no device tests yet)	90 %	9,7 % for nanowire BiVO4 with expensive GaAs/InGaAsP PV cell (Sci. Rep. 5:11141, 2015).	Ohmic losses in conducting substrates limit the efficiency of large-area cells.
1,000 h lab test	1,000 h lab test	Tests will start in M28	100 %		

SElySOs

Development of new electrode materials and understanding of degradation mechanisms on Solid Oxide High Temperature Electrolysis Cells.

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	SElySOs
CALL TOPIC	FCH-02.1-2014: Research in electrolysis for cost effective hydrogen production
START DATE	2/11/2015
END DATE	1/11/2019
PROJECT TOTAL COST	€2,9 million
FCH JU MAXIMUM CONTRIBUTION	€2,9 million
WEBSITE	http://selysos.iceht.forth.gr/

PARTNERSHIP/CONSORTIUM LIST

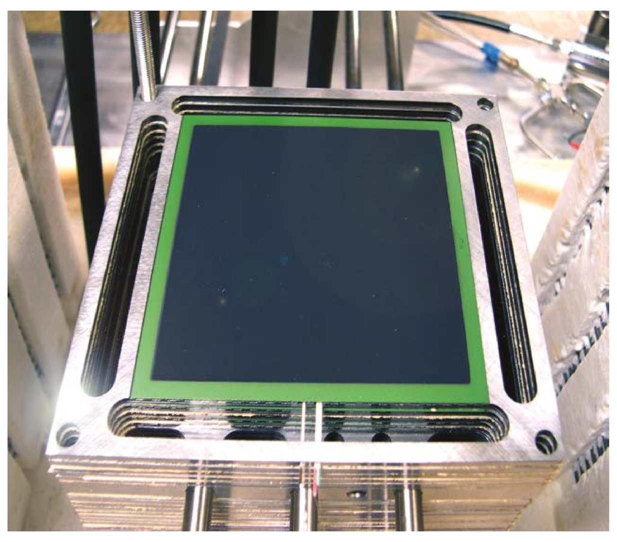
FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, FORSCHUNGSZENTRUM JULICH GMBH, VYSOKA SKOLA CHEMICKO-TECHNOLOGICKA V PRAZE, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, Prototech AS, PYROGENESIS SA

MAIN OBJECTIVES OF THE PROJECT

To improve/develop new, more efficient electrodes and understand the reaction mechanisms & processes that cause degradation on both SOEC electrodes combining experiments/theoretical modelling. To identify the design parameters to guide the development of new SOECs less prone to degradation with better performance and stability.

PROGRESS/RESULTS TO-DATE

- Modified SoA Ni-based and novel perovskite-type materials are under development/investigation as new electrodes for H_2O electrolysis.
- Advanced physicochemical characterization of the electrodes is in progress.
- The definition of the mathematical model for the H_2O electrolysis electrode is in progress.



- Investigation of the degradation phenomena/reaction mechanisms at the O2 electrode.
- Manufacture and testing of a first short SOE stack, under H_2O electrolysis conditions.

FUTURE STEPS

- Fabrication of SOEC comprising the new H_2O electrode materials by applying SoA and novel techniques.
- Performance evaluation of single SOECs comprising SoA O2 electrodes and modified Ni-based H_2O electrodes.
- Performance evaluation of single SOECs comprising SoA O2 electrodes and novel perovskite-type H_2O electrodes.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Development of new electrodes with better performance & lifetime.
- Development of a mathematical model accounting for all reactions taking place in a SOEC.
- Long-term operation of SOECs with the best combination of electrodes for at least 3000 h.
- Manufacture of stacks, which will operate for at least 2000 h under standardized conditions.
- Produced cells&stacks as a competitive&commercially viable advantage.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2014-2020
Long term system electrical eff >90 % (HHV)	72 % (HHV) in 2023	Data are not yet available	Data not yet available	74 % (HHV) for SoA H_2O electrolysis tech. Eff. could reach 101-108 % (HHV). FCH JU Report "Development of Water Electrolysis in the European Union"	Results not available yet
Improvement on the eff. degrdation rate	< 1 %/y in 2023	Data are not yet available	Data are not yet available	2 % - 5 %/y [1] MAWP, [2] J Power Sources 269 (2014) pp. 927-936, [3] FCH JU Report "Development of Water Electrolysis in the European Union"	Results not available yet
Increase of TRL	TRL = 5 in 2020	Data are not yet available	Data not yet available	TRL = 3	Results not available yet
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2014
New materials and component design less prone to degradation	Not applicable	Data are not yet available	Data are not yet available	Not applicable	Results not available yet
Understanding of degradation mechanisms	Not applicable	Data are not yet available	Data are not yet available	Not applicable	Results not available yet
(c) Other project objectives					
Reduction of electricity consumption by 10 %	Not applicable	Data are not yet available	Data are not yet available	53 kWh/kg H_2 (HHV) conventional electrolysis.[1] FCH JU Report "Develop. of Water Electrolysis in the EU", [2] Int. Energy Agency 2007 "H_2 Prod. & Distrib."	By 2025 or latest 2030 Results not available yet
Development of improved SOEC	Not applicable	Not applicable	Not applicable	Not applicable	Results not available yet

SOL2HY2

Solar to hydrogen hybrid cycles

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	SOL2HY2
CALL TOPIC	SP1-JTI-FCH.2012.2.5: Thermo-electrical-chemical processes with solar heat sources
START DATE	1/06/2013
END DATE	30/11/2016
PROJECT TOTAL COST	€3,7 million
FCH JU MAXIMUM CONTRIBUTION	€1,9 million
WEBSITE	sol2hy2.eucoord.com

PARTNERSHIP/CONSORTIUM LIST

ENGINSOFT SPA, AALTO-KORKEAKOULUSAATIO, DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, Outotec (Finland) Oy, Erbicol SA, OY WOIKOSKI AB

MAIN OBJECTIVES OF THE PROJECT

1) Development of the key hybrid plant components (SO_2-depolarized electrolyzer (SDE), solar-powered sulphuric acid cracker and heat storage).
2) Multi-objective design and optimisation and testing of improved critical materials solutions and processes.
3) Designing and running field tests of key blocks of the hybrid cycles their performance analysis.
4) Technical-economic evaluation of the new process concept.
5) Development of the flexible centralised H_2 production plant options using interfaces to running industrial process as the starting point for renewable H_2 by-production.

PROGRESS/RESULTS TO-DATE

- Multi-cell SDE stack was constructed and tested in the lab for hydrogen and sulphuric acid co-production.
- Acid decomposition chamber, acid evaporator and gas handling were made and run in field demo tests at solar tower.
- Hybrid solar plant flowsheets were analysed and made available for dynamic conditions.
- Multi-objective design and optimization software tool was produced for any suitabel locations.
- Several BoP solutions were developed for the virtual plant model for specific locations.

FUTURE STEPS

- Final procesisng of SDE test data in different conditions.
- Release of DEMO tests of efficient catalysts for sulphuric acid cracking.

- Release of multi-objective optimization software of the SOL2HY2 plant.
- Starting the exploitation plan activities.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- The hybrid plant design was demonstrated: flexibility for selected locations and input parameters, able to adjust with solar input.
- SO_2-depolarized electrolyzer was successfully designed and tested.
- Molten salt technology is able to ensure continuous operation for H_2 production, with high-temperature solar power only used for acid cracking.
- Virtual plant model linked with multi-objective design and optimization provides opportunity for user-tailored solutions.
- Combination of closed (hybrid sulphur) and Outotec open cycles allows greater cost-efficiency at high power utilization.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET (%)	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Cost of H_2 delivered at refuelling station <€5/kg (€0,15/kWh)	Not directly addressed	Potential for decreasing of the hybrid cycle H_2 costs by €3-4/kg EXW	100 %		
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2012
Catalysts with better activities +30 %	Electrocatalysts with 50 % better efficiency vs. Pt/Pd	Catalyst load were decreased by 100-300 times	100 %		
Redox materials with doubled conversion rate	Redox materials not used	N/A	100 %		
Development of key components with enhanced efficiency in relevant scale	>0,5 MW at daily solar input 20 MWh	Plants design is made according to the program objectives	100 %		
(c) Other project objectives					
Electrolyser operational conditions	Not applicable	25 °C, 1 bar, 15-20 % acid, catalyst load <1 µg/cm^2	100 %	70-105 °C, 1-50 bar, 50-70 % acid, catalyst load ~100-500 µg/cm^2	Target reached in 2015

SOPHIA

Solar integrated pressurized high temperature electrolysis

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	SOPHIA
CALL TOPIC	SP1-JTI-FCH.2013.2.4: New generation of high temperature electrolysers
START DATE	1/04/2014
END DATE	31/03/2017
PROJECT TOTAL COST	€6 million
FCH JU MAXIMUM CONTRIBUTION	€3,3 million
WEBSITE	http://www.sophia-project.eu/

PARTNERSHIP/CONSORTIUM LIST

HyGear B.V., HTceramix SA, COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV, ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, Teknologian tutkimuskeskus VTT Oy, ENGIE, SOLIDPOWER SPA

MAIN OBJECTIVES OF THE PROJECT

Design, fabrication, and operation on-sun of a 3 kWe-size pressurized High Temperature Electrolysis (HTE) system, coupled to a concentrated solar energy source as proof of principle. Proof of concept of co-electrolysis at the stack level, and pressurized.
Development and manufacturing of optimized large area cells for HTE operation targeting at high performance, and improved durability. Degradation analysis. Design of a stack for pressurized operation.

PROGRESS/RESULTS TO-DATE

- Market analysis and case studies done.
- Solar receiver build and tested.
- Models developed and improved cell microstructure proposed and made.
- Cell, Single Repeating Units (SRUs) and stack tests done in electrolysis and co-electrolysis mode at atmospheric and pressurized conditions.
- SOE system designed and being build.

FUTURE STEPS

- Large area cell and stack testing.
- Degradation studies, and optimisation of electrode microstructure.
- Validate segmented test set-up.
- SOE system testing at 15 bar.
- Full system testing.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Hydrogen production using a solar powered HTE-system can be ecomically viable.
- For systems producing hydro-carbons the availability of CO_2 is not limiting, but the solar power is.
- Extensive microstructural models of the electrodes have been made.
- Electrolysis and co-electrolysis shown at elevated pressures.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:				MAIP 2008-2013
Proof of pupose (pOp)of a HT SOE system at kW size under realistic conditions.	Appropriate H_2 supply chain	Performance curves of several SRUs and stacks obtained		
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:				AIP 2013-1
Development of cells with tailored electrode microstructure and compositions	Develop cells for high current loads, high durability and reliability, high temperature	Cell performances close to 1 A/cm² at the thermoneutral voltage in steam and co-electrolysis modes	100 %	
Optimise cell structures for low degradation rate	Demonstrate low degradation rate (<0,5 % per 1,000 h)	Several long term cell experiments have been done with variable degradation rates	100 %	
develop different case studies as potential strategies for the concept industrial development.	Develop concepts for pressurised electrolysis for more economical systems	Fuel production via co-electrolysis SOEC and syngas upgrading has been studied.	100 %	

UNIFHY

Unique gasifier for hydrogen production

PANEL 5

Hydrogen production, distribution and storage: research and validation

ACRONYM	UNIFHY
CALL TOPIC	SP1-JTI-FCH.2011.2.3: Biomass-to-hydrogen (BTH) thermal conversion process
START DATE	1/09/2012
END DATE	31/03/2016
PROJECT TOTAL COST	€3,4 million
FCH JU MAXIMUM CONTRIBUTION	€2,2 million
WEBSITE	http://www.unifhy.eu/

PARTNERSHIP/CONSORTIUM LIST

UNIVERSITA DEGLI STUDI GUGLIELMO MARCONI – TELEMATICA, UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA, UNIVERSITA DEGLI STUDI DELL'AQUILA, HyGear B.V., AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, UNIVERSITE DE STRASBOURG, ENGINEERING, PROCUREMENT & CONSTRUCTION UG, PALL FILTERSYSTEMS GMBH, AIR LIQUIDE HYDROGEN ENERGY

MAIN OBJECTIVES OF THE PROJECT

To develop a cost-competitive, efficient and sustainable thermochemical biomass-to-H_2 (BTH). To develop feedstock analysis, indirectly & oxygen biomass gasification with integrated catalytic hot gas conditioning; Water Gas Shift (WGS) with low pressure catalytic ceramic foams; Pressure Swing Adsorption (PSA); Portable Purification System (PPS); techno-economic, LCA and business & exploitation analysis.

PROGRESS/RESULTS TO-DATE

- Conceive a cost competitive/efficient/sustainable system to produce H_2 from biomass.
- 6 representative feedstock characterized .
- Designed/built/operated 0.1 MW indirectly heated and 1MW gasification pilot plants with hot gas conditioning.
- Designed/built/operated PPS, integrating ZnO, WGS and PSA reactors coupled to the plant.
- Simulation/optimization, techno-economic, LCA and business& exploitation analysis done.

FUTURE STEPS

- Developments on the hot gas conditioning tar removal systems.
- Increasing BTH thermal conversion process eff. via additional methane reforming and/or sorbents.
- Decreasing PPS cost.
- Conducting demonstration in real and operational environment.
- Increasing the pilot plants number and the operative hours.

CONCLUSIONS, MAJOR FINDINGS AND PERSPECTIVES

- Catalytic filter candles tests showed 99 % w particulate removal; low-pressure drop; gas yields and H_2 increase; CH4, tar and NH3 decrease.
- New Fe-Cu/Foam allowed efficient (43 %) WGS at low pressure.
- Stable and continuous 1 MW and PPS tests lasting more than 12 h, achieving 99,99 % of concentration.
- The economic and LCA analysis showed that H_2 target cost/emissions are reachable.
- The analysis of Safety, RCS showed that BTH permitting procedures/standards are missing.

CONTRIBUTION TO THE PROGRAMME OBJECTIVES

PROJECT OBJECTIVES / TARGETS	CORRESPONDING PROGRAMME OBJECTIVE / QUANTITATIVE TARGET (SPECIFY TARGET YEAR)	CURRENT PROJECT STATUS	PROBABILITY OF REACHING INITIAL TARGET	STATE OF THE ART 2016 – VALUE AND REFERENCE	COMMENTS ON PROJECT PROGRESS / STATUS
(a) Project objectives relevant to multi-annual objectives (from MAIP/MAWP) – indicate relevant multi-annual plan:					MAIP 2008-2013
Europe at the forefront of BTH thermal conversion technologies	Number of plants	2 gasifiers + 1 PPS built and operated	100 %	0 (no industrial-scale plant [1])	Only few hours of continuous H_2 production
Eff. >70 % (simulated)	Eff.>64 % (for all BTH conversion)	38 % (exp.)-50 % (sim.)	75 %	54 % (speculative and for size >35 tH_2/day) [2] 50 % (speculative and for 1,5-35 tH_2/day size) [3]	Sim. eff. is based on experimental data & industrial configuration at best parameters
50-500 kg/d production capacity	1,5 t/d	36-360 kg/d, best scenario	100 %	35-160 t/d (speculative centralised) [2] 1,5-30 t/d (speculative distributed) [3]	Project results based on best scenario. Distributed generation advantages make convenient lower size
€3 M/(t/d)	€3,8 M/(t/d)	€2-22 M/(t/d) for 3,6-0,3 t/d	100 %	€4,2 M/(t/d) [3], €0,8 M/(t/d) [2]	Decrease 02 production. Intensifying the process. Increase catalyst lifetime
H_2 cost delivered to HRS <€5/kg (€0,15/kWh)	H_2 cost delivered to HRS €5/kg (MAIP 2014-20: €13/kg)	€2-10/kg (indirectly heated 10-0,1 MW)	100 %	€4,7/kg (speculative >1,5 t/d) [3], €1,8/kg (speculative >35 t/day) [2]	The results coming from best scenario
(b) Project objectives relevant to annual objectives (from AIP/AWP) if different than above – indicate relevant annual plan:					AIP 2011
Feedstock analysis	Feedstock analysis	Lignocellulosic equivalent, agro-industrial and wood waste cheaper	100 %		
<20 y (160kh) av. >95%.	Durab. >10 y (80kh), av. >95%	10-20 y with maintenance items	50 %	Gasifier durab./av. known, unknown for the WGS and PSA fed by wood gas	Evaluate the purification system durab. and plant av. The tests done dont reach the target.
LCA analysis (ILCD compliant)	LCA/LCI analysis (ILCD compliant)	LCA/LCI analysis was conducted. 0,0134 kg CO_2/MJH2	100 %	0,002 kg CO_2/MJH2 farmed and waste wood (-0,055-0,0185) kg CO_2/MJH2 forestry and agricultural waste [4]	Best scenario results, agro-industrial residues deal with cultivation operation