Cogeneration of H$_2$Hydrogen & Power using solid oxide based system fed by methane rich gas

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 735692 (CH2P). This Joint Undertaking receives support from the European Union’s Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.
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Hydrogen is expected to play a leading role in the clean energy transition outlined in the European Green Deal. Hydrogen can be produced from low or zero carbon sources, including bio-gas. Over the past few years, new technological solutions have been developed across Europe for the transition to efficient and sustainable hydrogen production.

CH2P is a European project funded by the Clean Hydrogen Partnership that demonstrates a cogeneration system for hydrogen and power production. The CH2P prototype produces 20 kg/day of hydrogen and 25 kW of electric power using a high-temperature large stack module based on solid oxide cells fed by natural gas and biogas.

The prototype is a proof-of-concept that validates the integration of multiple components for hydrogen production, compression and purification. Two 40 ft containers were designed for application at hydrogen refueling stations. The CH2P project demonstrates a transition technology that is going to be upgraded for electrolysis operation in the SWITCH project.

Objectives

- 20 kg/day hydrogen production
- 25 kW electric power production
- 5 operating modes
- 7 bar hydrogen delivery
- 5.0 hydrogen purity level

Socio-Environmental

- Demonstrate a novel prototype for the transition from fossil fuels to low-carbon fuels
- Proof of concept for provide secured hydrogen production at hydrogen refueling stations
- Footprint assess environmental and CO2 avoidance of hydrogen production
- Multiple scenarios for evaluate system upscaling and upgrading to green hydrogen production
- Support the market penetration of hydrogen as an energy carrier in the mobility sector
- Open new business development opportunities for the exploitation of solid oxide cell fuel cell (SOFC) technology in stationary applications
- Provide viable scenarios for system upscaling to more than 100 kg of hydrogen per day at 4.5 €/kgH2

Mission

- **INTEGRATION**
  - Integration of a large stack module (LSM) in a flexible cogeneration system;

- **FLEXIBILITY**
  - Modulate hydrogen and power production according to demand profile;

- **HEAT RECYCLE**
  - Reduce heat loss and recycle waste heat for power generation;

- **H2 PURITY**
  - Proof of concept of solid oxide cells (SOC) for continuous hydrogen supply;

- **H2 CONTINUOUS SUPPLY**
  - Meet the hydrogen purity standards of the automotive industry for FCEVs refueling.
Project Overview

Hydrogen is expected to play a leading role in the clean energy transition outlined in the European Green Deal. Hydrogen can be produced from low or zero carbon sources, including bio-gas. Over the past few years, new technological solutions have been developed across Europe for the transition to efficient and sustainable hydrogen production.

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Objectives

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<th>Economical</th>
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<tbody>
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The CH2P system prototype is designed as a modular system that co-produces hydrogen, heat and power. It is based on the integration of multiple components in a stand-alone power system able to cover up to five production modes. The system combines methane reforming with the flexible use of the solid oxide fuel cell (SOFC) for hydrogen and electricity production. The SOFC is supported by an innovative balance of plant (BoP) wrapped around hot and cold sections. The system layout includes an efficient purification system consisting of a syngas compressor and a pressure swing adsorber (PSA), and a burner for the combustion of off-gas resulting from the purification process. The generated heat is re-used for fuel processing, thus optimizing the thermal balance of the system.

Concept & Value proposition

Prototype description

The CH2P prototype is structured in 4 main units (subsystems) that are placed in two 40 ft containers:

- **Preparation Unit**: it includes air supply, natural gas supply and treatment, and water supply and treatment.
- **“Hot BoP” Unit**: it consists of a steam reforming unit to convert pre-processed natural gas into syngas, heat exchangers to preheat air, fuel that are supplied to the SOFC stacks, and a burner.
- **Fuel Cell Unit**: called LSM (Large Stack Module), it consists of a SOFC stack array to generate electrical power that completes the steam reforming of the supplied fuel.
- **Purification Unit**: it is placed downstream the Hot BoP to post-process the fuel cell exhaust gas and to provide pure hydrogen complying with the norms for hydrogen refueling stations.

Production modes

- **Mode 1**: Minimal electric power and minimum hydrogen production
- **Mode 2**: Minimal electric power and maximum hydrogen production
- **Mode 3**: Maximum electric power and maximum hydrogen production
- **Mode 4**: Half electric power and half hydrogen production
- **Mode 5**: Maximum electric power and minimum hydrogen production
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Production modes

The hydrogen production and electric power generation can be modulated according to 5 operating modes:

<table>
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<tr>
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The flexibility of the CH2P system for electric power generation and hydrogen production allows for application and prototype upscale in vehicle refueling stations for FCEVs and BEVs.

Prototype description

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Preparation Unit:
it includes air supply, natural gas supply and treatment, and water supply and treatment.

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Purification Unit:
it is placed downstream the Hot BoP to post-process the fuel cell exhaust gas and to provide pure hydrogen complying with the norms for hydrogen refueling stations.
Prototype description

PSA: Pressure Swing Adsorber
E: Electric cabinet
W: Water storage tank
OF: Off gas vessel
B: Buffer vessel
D: Desulphurization vessel
COMPRES: Syngas compressor

LSM: Large Stack Module
BoP: Balance of Plant
A: Air suction blower
C: Steam condenser
WKO: Water know out
E: Electrical cabinet
P.E: Power electronics
Prototype cold section (Container A)

- PSA unit
- PSA auxiliary vessels
- Electrical cabinet
- Syngas compressor
- Water knock-out
- Power electronics
- Air dry cooler
- Auxiliary vessels: PSA offgas vessel, buffer vessel, desulfurization vessel
- Hot BoP
- Large Stack Module

Prototype hot section (Container B)
Results

- Large Stack Module (SOLIDPower SA)
  The CH2P project brought an important contribution to the development of the Large Stack Module (LSM) of SOLIDPower SA. Thanks to its flexibility in operating conditions, including hydrogen production, it may represent a key product for the clean energy transition. The LSM module has been successfully tested up to 22 kW of electric power generation and up to 25 kg/d of H₂ with a natural gas pre-reformed ratio from 20% to 80%. The four SOFC stacks integrated in a single module have been qualified individually, showing very homogeneous performances. Thermal losses have been measured and are in line with the simulation done during the design phase.

- Pressure Swing Adsorber (HyGear)
  A PSA-unit was designed that is able to produce hydrogen of fuel cell quality from the produced syngas, taking into account the wide range of syngas compositions and flow rates produced by the system. Expected hydrogen recoveries, based on modeling, are of the order of 85%. A special control algorithm was developed to cope with the wide variation of PSA feed flow rates and compositions. Tests with a laboratory scale PSA have been performed to validate the expected performance, and to provide data to support the development of the aforementioned control algorithm.

- Hot Balance of Plant (SOLIDPower SA)
  The first version of the Hot BoP has been developed and assembled. After a first test, showing a low heating rate and insufficient gas mixing at the burner exhaust, the Hot BoP has been upgraded to improve the operation performance. The burner has been partially redesigned in order to enhance the gas mixing to get more homogeneous temperature of the exhaust gas. To improve the thermal efficiency and allow a smooth start-up, the air-air heat exchanger has been doubled. This new heat exchanger configuration allowed to reduce up to 25% the chimney thermal losses at 560°C and to heat-up the system to the operating temperature with 10 kW of thermal power provided by the burner.
Applications

CH2P demonstrates a system prototype for application at refueling stations. It is a transition technology for the decarbonisation of the transport sector by 2030-2050.

Hydrogen production for the station, in combination to one of the following use cases:

+ power production to run the CH2P system itself
+ power to cover on-site electricity demand e.g. for the CH2P system, the hydrogen station and the conventional refuelling station (including lighting, car wash and shop)
+ power production for export (to the grid, including for power balancing, or to neighbouring electricity consumers)
+ power production for charging battery electric vehicles

Exploitation

“One system fits all” multiple services in a single, decentralized system

Stepping stones towards the hydrogen market
Grey hydrogen | Blue hydrogen | Green hydrogen with SWITCH
The CH2P Consortium is international and interdisciplinary, with two SMEs, two large enterprises and three research institutions from four European countries.
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Consortium

Member of the

Fondazione Bruno Kessler (FBK)

Italy

Project Coordinator

FBK coordinated the project and led the dissemination, communication and exploitation of results.

École Polytechnique Fédérale de Lausanne (EPFL)

Switzerland

System modeling

EPFL led the stack lifetime prediction task and the Life Cycle Assessment (LCA) task.

It extended its thermo-mechanical and electrochemical degradation models to evaluate the risks of failure during operation under CH2P mode compared to conventional SOFC mode.

Deutsches Zentrum für Luft und Raumfahrt (DLR)

Germany

Components validation and testing

DLR led the steady state system architecture modeling activity and the large stack module testing activity.

It carried out component scaling, identification of operation points and sensitivity analysis, energy and flow diagrams. It performed tests on the large stack module.

SHELL Global Solutions International (SHELL)

The Netherlands

Use cases

SHELL provided information on the targeted use cases and the initial scenario building for the system specification. It led the definition of required system interfaces with HRS and contributed to the market analysis for the future exploitation of the prototype.

SOLID Power SPA (SP)

Italy

Hot component development

SOLIDPower Italy led the manufacturing of the cells, the stack and the stack modules.

It contributed to the LSM integration with hot components including the hot balance of plant (Hot BoP) and the burner.

SOLID Power SA (SPSA)

Switzerland

Large Stak Module development

SOLIDPower Switzerland manufactured the large stack modules (LSMs), the SPLC and assembled the hot section in the system.

It provided the dummy and LSMs for system integration and collaborated on the testing of the prototype.

HyGear (HYG)

The Netherlands

Cold component development and system integration

HyGear led the realization of the fuel management (input and output) and integration of components into the prototype system.

It designed the control and built the purification section based on the PSA technology.

Contacts

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Visit the CH2P website to find out more information on the project

www.ch2p.eu

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