Design of pilot plants for hydrogen production via solar water splitting employing hybrid photoelectrochemical-photovoltaic tandem devices

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Background

Photoelectrochemical water splitting is a promising route for renewable hydrogen production. Abundant but intermittent solar energy is captured and finally stored in a chemical energy carrier which may be consumed according to the demand. The development and demonstration of hybrid photoelectrochemical-photovoltaic (PEC-PV) tandem devices made from earth-abundant materials and providing a solar-to-hydrogen efficiency of at least 8% are objectives of the European project PECDEMO. An important part of the project is an extensive techno-economic analysis which shall evaluate the potential for large-scale commercialization of the technology.

Hydrogen production scenarios

Three different scenarios concerning the utilization of produced hydrogen are considered: a refuelling station for transportation purposes and an industrial process based on [1] as well as a single home application covering a wide range of plant sizes with an average capacity of 400 kg/day, 4000 kg/day, and 1 kg/day, respectively. Basic information about the three scenarios can be found in Fig.1. A high level of global solar irradiation promotes an economic plant operation. Seville (Spain) and the Negev (Israel) have been chosen for the techno-economic analysis as promising sites. The sizes of the collector fields were calculated based on the average global solar radiation provided at the different locations. The procedure of calculation and results can be extracted from Table 1.

Process design and simulation

Preliminary plant designs including the main components required by the process were elaborated and simulated employing Aspen Plus® for thermodynamic analysis. An initial flow sheet of the hydrogen refuelling station with the irradiated PEC-PV-unit operated at 45°C and an internal absolute pressure slightly above 1 bar, the water separation unit, the compression block, and further elements is shown in Fig.2. Part of the water stream introduced to the PEC-PV-unit is split into hydrogen and oxygen. The remaining fraction is recycled after passing a temperature control unit (HX1). The design point is characterised by a total electricity consumption of the process – involving compressors, pumps and the blower – of 1.07 MW. Accordingly an overall design point efficiency of 7.7% was estimated regarding the chemical exergy of generated hydrogen based on the higher heating value (HHV).

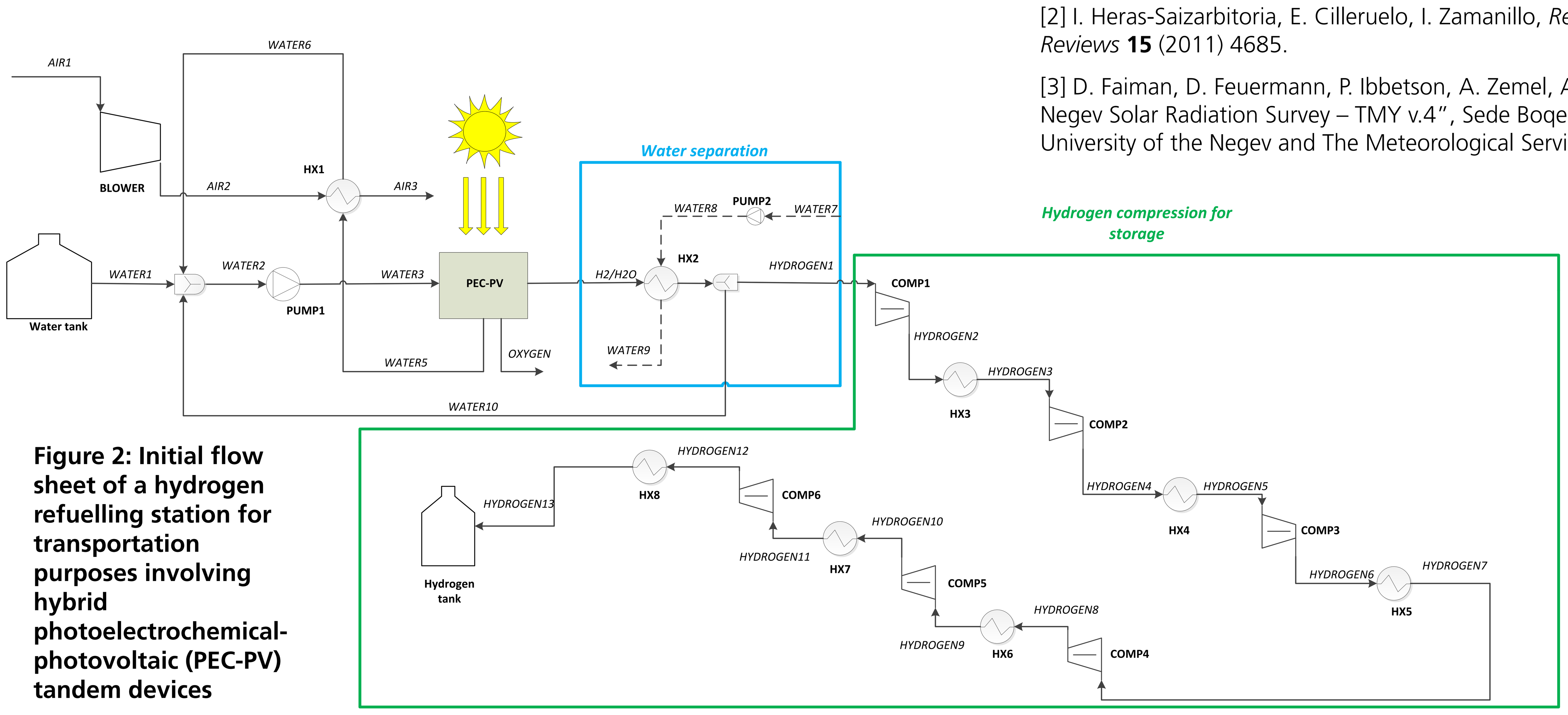

Figure 2: Initial flow sheet of a hydrogen refuelling station for transportation purposes involving hybrid photoelectrochemical-photovoltaic (PEC-PV) tandem devices

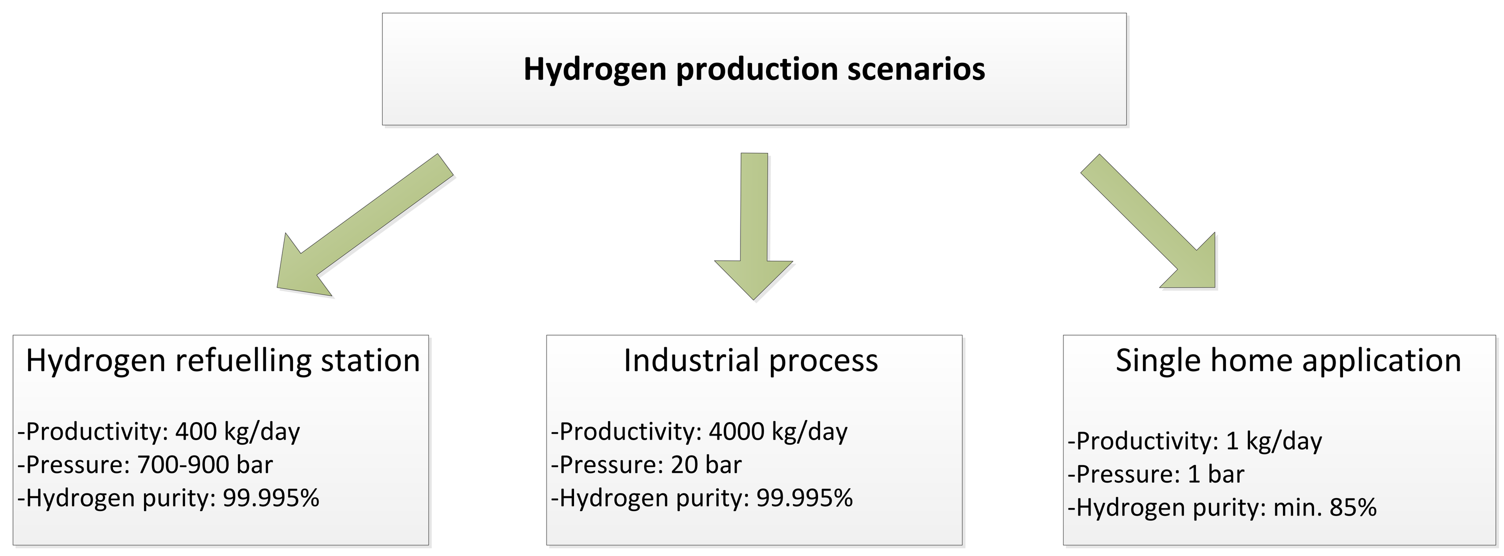

Figure 1: Basic figures of the considered scenarios concerning the production and utilization of hydrogen

Table 1: Calculation of collector field sizes for the three considered scenarios: hydrogen refuelling station (1), industrial process (2), and single home application (3)

	Scenario		
General	**1**	**2**	**3**
Efficiency (solar-to-hydrogen) [%]:	8		
HHV_{H2} [kJ/mol]:	286		
Average daily operation of the plant [h/day]:	8		
Average operation of the plant [h/year]:	2920		
Productivity of the plant [kg/day]:	400	4000	1
Average hydrogen production [mol/s]:	6.88	68.8	0.0172
Average solar input power [MW]:	24.6	246	0.0615
Total solar energy input [MWh/year]:	71,846	718,464	179
Seville (ES)			
Annual global irradiation [kWh/m²/year]:	1900 (derived from [2])		
Size of collector field [m²]:	***37,814***	***378,139***	***94.5***
Negev (IL)			
Annual global irradiation [kWh/m²/year]:	2017 (derived from [3])		
Size of collector field [m²]:	***35,620***	***356,204***	***89.1***

Conclusion

The elaborated initial flow sheets and the conducted simulations concerning the design points represent reliable references for further evolution of the plant designs. The next steps will comprehend an inventory analysis and component sizing finally aimed at competitive hydrogen production in the context of benchmarking processes.

References

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