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THE UTSIRA WIND/HYDROGEN DEMONSTRATION SYSTEM IN NORWAY: ANALYSIS AND OPTIMISATION USING SYSTEM MODELLING TOOLS

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ABSTRACT

A wind/hydrogen demonstration project located at the island of Utsira, ca. 20 km off the west coast of Haugesund in Norway, was officially launched by StatoilHydro and Enercon in July 2004. The realisation of the project came after several years of concept development, system design and project planning undertaken by several partners. A set of wind/hydrogen energy models was used in the early concept development and subsequent system design phases. The autonomous wind/hydrogen energy system at Utsira, the first of its kind in the world, was designed to meet the entire energy demand for 10 households (about 55 kW peak) using wind energy only, either directly or indirectly via hydrogen. An Enercon 600 kW wind turbine is dedicated to the demonstration. The hydrogen system consists of a 10 Nm^3/h alkaline electrolyzer, a hydrogen compressor, a 2400 Nm^3 hydrogen gas storage (200 bar), and a 55 kW hydrogen engine. This gives 2-3 days of full energy autonomy for 10 households. Over the past 3 years a significant amount of operational experience and data has been collected from the system at Utsira. The main objective of this study is to evaluate the technical concept demonstrated, both with respect to system design and operation. The method chosen is to use actual operational data to validate a set of wind/hydrogen energy system modelling tools using HYDROGEMS and TRNSYS. Finally, calibrated system models are used in system simulations to identify improved system designs and control regimes. The models are used to optimise the design of the plant in order to guarantee a 100% stand-alone operation.

INTRODUCTION

Hydrogen can be used to store intermittent renewable energy, such as solar and wind energy. Wind/hydrogen energy systems have a strong potential in remote areas where they can be used as stand-alone power systems. Remote communities are already experiencing relatively high fuel costs and locally produced renewable hydrogen should be able to compete with traditional fossil fuels sooner in these places than in more densely populated areas. Isolated areas with high wind resource are therefore logical targets for wind energy based hydrogen systems.

Some examples of wind/hydrogen energy systems are listed in Table 1.

Table 1: Overview of wind/hydrogen systems installed world-wide, 2000-2008

Location	Project	Year
ENEA Research Centre, Italy	Prototype wind/electrolyzer testing system	2000
University of Quebec, Trois-Rivières, Canada	Renewable energy systems based on hydrogen for remote applications	2001
Utsira Island, Norway	Demonstration of autonomous wind/hydrogen systems for remote areas	2004

West Beacon Farm, Loughorough, UK	HARI – Hydrogen And Renewables Integration	2004
Unst, Shetland Islands, UK	PURE – Promoting Unst Renewable Energy	2005
IFE, Kjeller, Norway	Development of a field-ready small-scale wind-hydrogen energy system	2006
NREL, Golden, Colorado, USA	Wind-to-hydrogen (Wind2H2) demonstration project	2006
Pico Truncado, Argentina	Wind/hydrogen demonstration plant	2007

The system installed on the island of Utsira, about 20km off the west coast of Haugesund in Norway, is a good example of autonomous wind/hydrogen system. This island was chosen for its excellent wind conditions and small but representative electrical power demand. The island also provides a great opportunity to test autonomous renewable power systems as back-up power from the main land is only available through a subsea cable.

The project was realized after several years of concept development, system design, and project planning. The decision to build the Utsira plant was made in April 2003 and the project was officially launched by Norsk Hydro (now StatoilHydro) and Enercon, the two main partners in the project, in July 2004. The system is still in operation and a significant amount of operational data and experience has been collected since the commissioning of all of the systems during the winter 2004/2005.

The autonomous wind/hydrogen system at Utsira, the first of its kind in the world, was designed to meet the entire energy demand for 10 households using wind energy only, either directly or indirectly via hydrogen. The objective is to demonstrate how renewable energy and hydrogen systems can provide safe and efficient power supply to communities in remote areas. The system is shown on Figure 1:

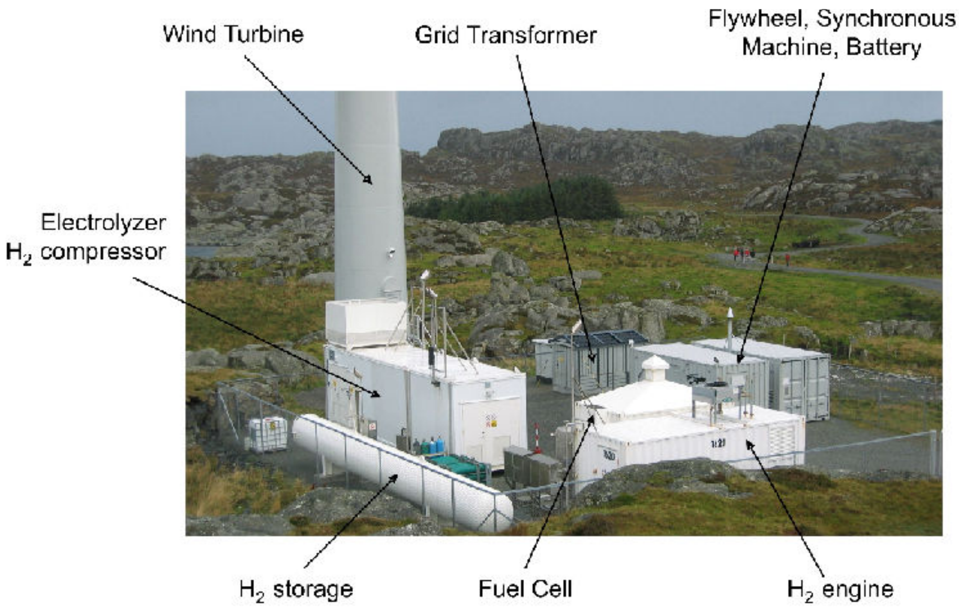

Figure 1: Wind/hydrogen energy system at Utsira, Norway (Photo: Ulleberg, 2005)

The objective of this study was to evaluate the operation and performance of the Utsira plant using actual operational data and a set of system modelling tools. Operational data (10-minute data) from the Utsira plant were used to calibrate a set of hydrogen energy models (HYDROGEMS) suitable for energy system simulations in TRNSYS. The models verified in this study were used to simulate the operation of the Utsira plant and to identify improved system designs.

SYSTEM DESCRIPTION

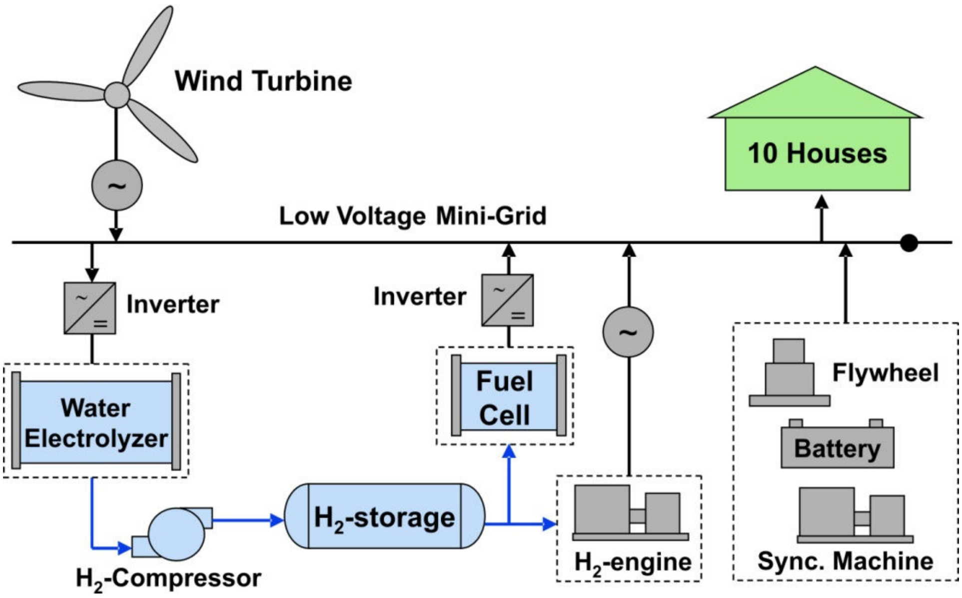

Figure 2: The energy system installed at Utsira

Two wind turbines (Enercon E-40 with a rated power output of 600kW have been installed on the Utsira island, but only one of these is dedicated to the autonomous power system. The other turbine feeds power directly into the local grid. The turbine is connected to the autonomous system via a separate 300kW one-directional inverter. In practice, this means that there is a cut-off in power from the wind turbine at 300kW, and surplus power is fed to the local grid in parallel to the second wind turbine.

The main components in the hydrogen system is a 10Nm^3/h alkaline electrolyzer (12bar), an 11Nm^3/h hydrogen compressor (12-200bar, 2-stage), a 2400Nm^3 hydrogen gas storage (200 bar), and a 55kW hydrogen engine generator system. A 10kW PEM fuel cell was also part of the system, but it is currently not in use. The wind power available varies with the wind speed so grid stabilizing equipment was required for the autonomous system. It consists of a flywheel (5kWh) for frequency control, a master synchronous machine (100kVA) for voltage control and short circuit power, and a battery (50kWh) for redundancy. The system is designed to provide 2-3 days of full energy autonomy for 10 households located on the island.

The characteristics of the main components are summarized in Table 2:

Table 2: Main components of the Utsira system

System component	Rated capacity	Supplier/Manufacturer
Wind turbine	600kW	Enercon, Germany
Hydrogen engine	55kW	Continental, Belgium
Fuel Cell	10kW	IRD, Denmark
Electrolyzer	$10Nm^3/h$, 50kW	Hydrogen Technologies, Norway
Hydrogen compressor	5.5kW	Andreas Hofer, Germany
Hydrogen storage	$2400Nm^3$, 200bar ($12m^3$)	Martin Larsson, Sweden
Flywheel	5kWh	Enercon
Battery	50kWh	Enercon
Master synchronous machine	100kVA	Enercon

ANALYSIS OF OPERATIONAL DATA

The system at Utsira has been working properly for the past 3 years and a significant amount of data from stand-alone operation has been collected. The exception was the fuel cell system, which gave some technical difficulties right from the start.

This study was based on operational data (10-minute averages) measured at Utsira in the period 1-30 March 2007 shown on Figure 3. The top plots in Figure 3 show the wind power production and user load power demand, while the bottom plots present the power produced by the hydrogen engine and power consumed by electrolyzer (including auxiliaries and compressor) versus pressure in the hydrogen storage. A decrease in the hydrogen pressure from 145 to 33bar can be observed during this period; the pressure increases up to 165bar during a period with high levels of wind energy before it decreases at times with less wind energy.

Data from March 2007 shows that 100% stand-alone operation is only achieved about 65% of the time (long-term performance shows stand-alone operation about 50% of the time). The data also shows that during periods of low wind speed the electrolyzer frequently needed to operate on grid-electricity in order to produce extra hydrogen and level out the storage pressure, which otherwise would have decreased very rapidly. This indicates that plant is not producing enough hydrogen.

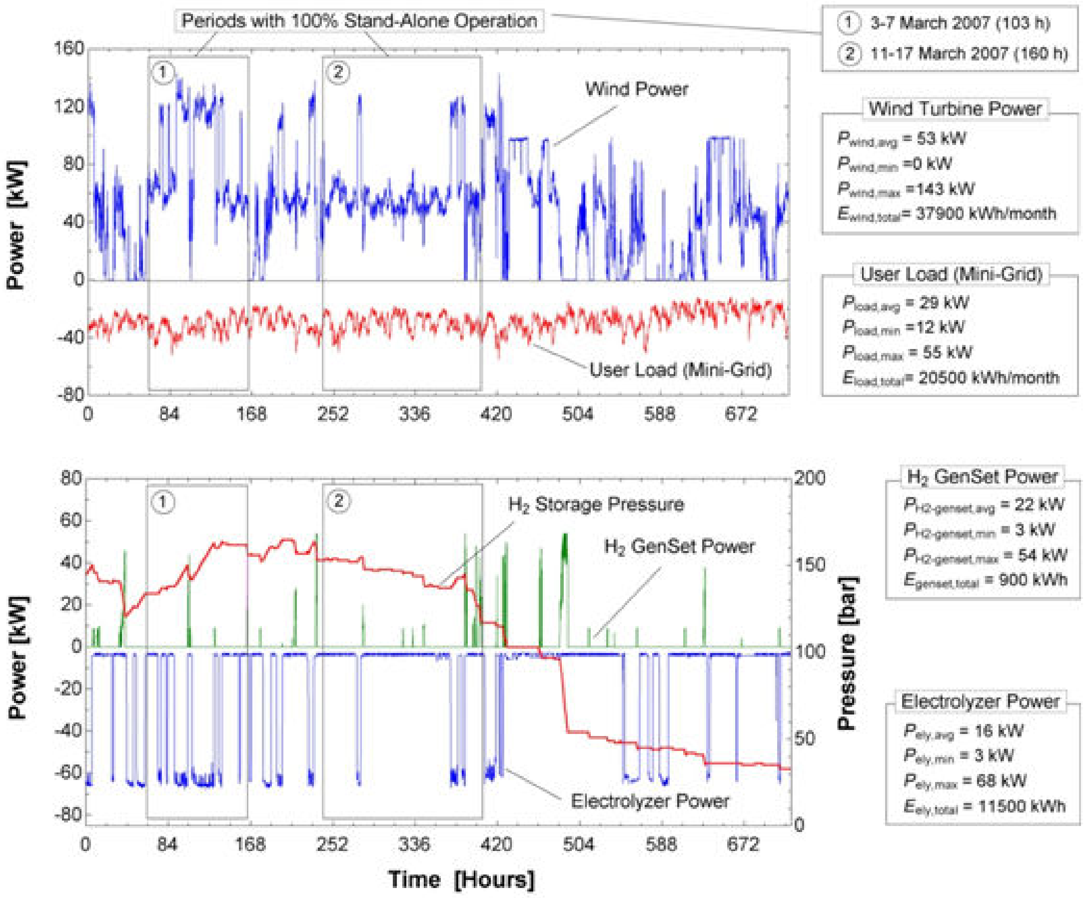

Figure 3: Operational data (10-minute averages) from Utsira, 1-30 March 2007

A significant part of the work in the Utsira project has been dedicated to the development of the power conditioning system. A flywheel, a synchronous generator, and a battery ensure that the voltage and frequency on the local mini-grid are kept within standard limits and tolerances. The performance of the system is best illustrated by taking a closer look at data for a shorter time period (5 March). Figure 4 shows the on/off switching of the electrolyzer and hydrogen engine as a function of the net available power (wind power minus user load). Figure 4 shows that the flywheel is constantly being charged and discharged in order to limit the number of on/off switching of the electrolyser and hydrogen engine (which would reduce their lifetime). This explains the highly cyclic behaviour of the power (hour 103–107).

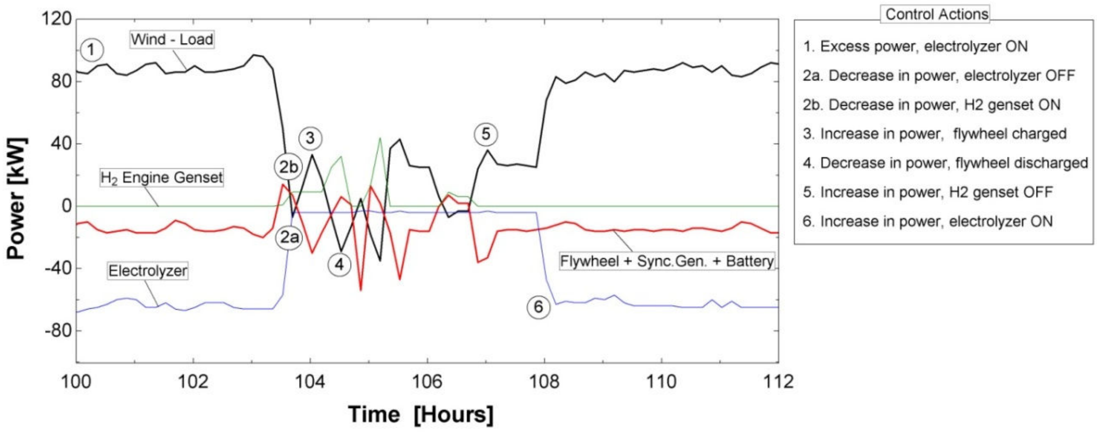

Figure 4: Operational data (10-minute averages) measured at Utsira, 5 March 2007

MODELLING OF MAIN HYDROGEN COMPONENTS

Modelling and characterization of the electrolyzer system and hydrogen engine were performed in this study (Figure 5). The models were calibrated based on both operational data and technical specifications. The overall hydrogen production system efficiency is around 53% (electrolyzer, compressor, rectifier/transformer, and other auxiliaries); the electrolyzer can only operate between 50 and 100% of its rated capacity. The maximum efficiency of the hydrogen engine is around 30%, but in practice this is much lower due to frequent part-load operation.

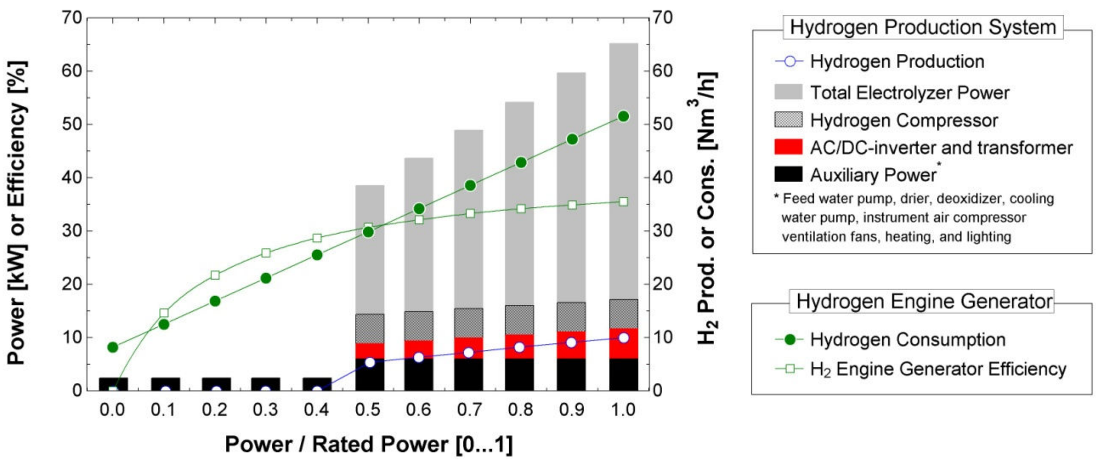

Figure 5: Modelling of electrolyzer system and hydrogen engine

SYSTEM SIMULATION RESULTS

In order to assess the performance of the system and identify possible improvement to its design a set of system simulations were performed using calibrated models for the wind turbine, electrolyzer system, and hydrogen engine. Simulations of the Utsira plant (reference system) and three alternative wind/hydrogen system designs were performed, based on hourly wind speed and power demand measured at the site in March 2007 (Figure 6).

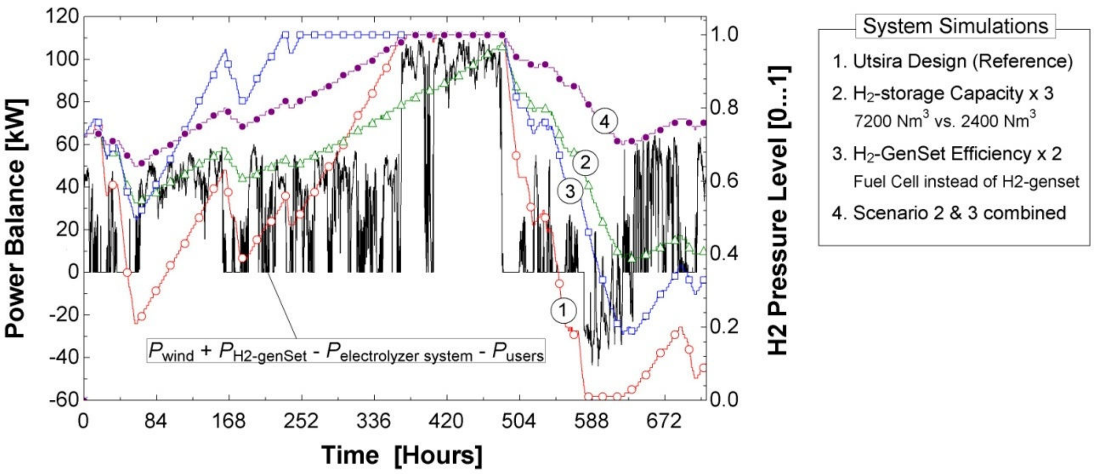

Figure 6: Wind/hydrogen system simulation results for (input data from Utsira, March 2007).

The system simulations show that it is not possible to achieve 100% stand-alone operation for long periods of time with the existing design. Full autonomy can only be achieved by improving the overall efficiency of the hydrogen production system (electrolyzer), by increasing the hydrogen storage size, and/or by increasing power generating efficiency of the unit for example by switching from hydrogen engines to fuel cells.

The annual performance of alternative system configurations that have the potential to reach 100% stand-alone operation was also simulated based on hourly operational data for 2005 and cost-estimated based on the general cost parameters shown in Table 3. A comparison of the performance of two optimised system configurations, one based on a fuel cell and the other on a hydrogen engine, is shown in Figure 7. The results show that a system including a fuel cell requires a relatively small electrolyzer (10Nm^3/h) and hydrogen storage (4,800Nm^3) compared to a system with a hydrogen engine, which requires a larger electrolyzer (20Nm^3/h) and hydrogen storage (11,000Nm^3).

In summary, the annual simulations confirm that changes in the Utsira system design were required to reach full energy autonomy for long periods of time and show that a wind/hydrogen system based on a fuel cell will be more compact and efficient than a system based on a hydrogen engine.

Table 3: General cost parameters for wind and hydrogen technologies

Component	**Lifetime (years)**	**Capital Costs (€/kW or €/m³)**	**O&M Costs (% of Capital Costs)**
Wind turbine	20	800 €/kW	1.5
Electrolyzer	20	2000 €/kW	2.0
Compressor	12	5000 €/kW	1.5
Hydrogen engine	10	1000 €/kW	2.0
Fuel cell	10	2500 €/kW	2.0
Hydrogen storage	20	4500 €/m³	2.5

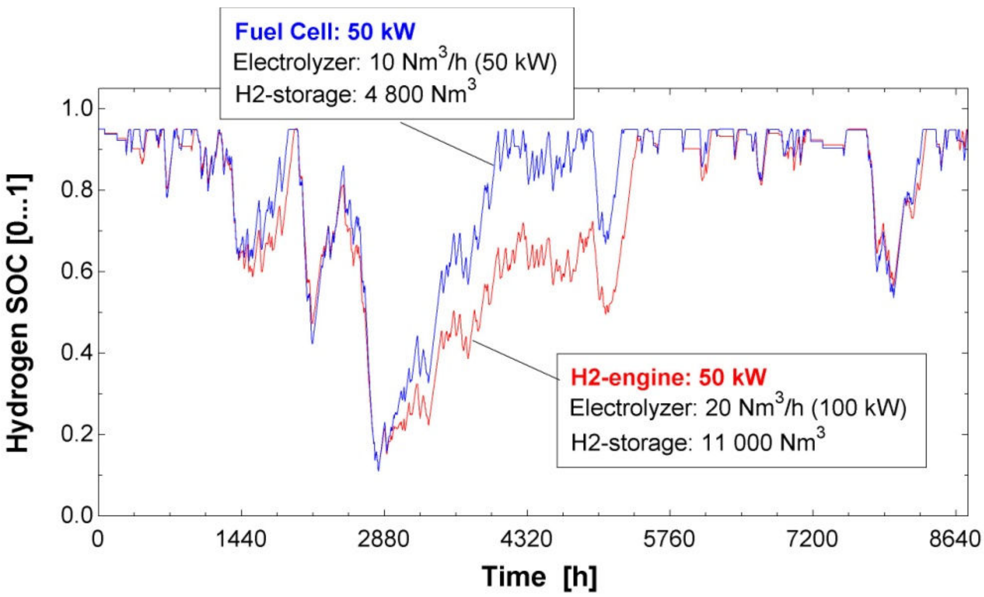

Figure 7: Comparison of two alternative system configurations: fuel cell versus hydrogen engine

CONCLUSIONS AND RECOMMENDATIONS

This study has shown that the system installed at Utsira needed to be modified in order to achieve fully autonomous operation for long periods of time. Increasing the size of the hydrogen storage and replacing the hydrogen engine by a more efficient fuel cell could help achieving this objective.

For the past 3 years the Utsira system has demonstrated that wind and hydrogen systems can be used to supply power to remote area communities. However, further technical improvements and cost reductions are necessary before wind/hydrogen systems can be viable and compete with existing commercial solutions, for example wind/diesel hybrid power systems. Meanwhile, hybrid system solutions based on more than one energy source (e.g. wind, solar, bioenergy) should be developed to reduce the need for large and costly energy storage. For a hydrogen system based only on wind energy, it is particularly important to choose a location with a steady wind energy resource.

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