Integration of Intermittent Renewable Energy Sources using Hydrogen: System Development and Market Opportunities

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Summary

The “Cluster Pilot Project for the Integration of Renewables into European Energy Sectors using Hydrogen” (RES2H2 in brief) is concerned with the design, installation, operation and optimisation of two different wind-hydrogen systems. This paper focuses on the current status of system engineering for the unit to be installed near Athens, Greece.

Furthermore, market opportunities for “green” hydrogen, i.e. hydrogen produced from renewable electricity or renewable energy sources in general, are addressed. These results form part of one of the accompanying studies performed in parallel to the hardware-related tasks.

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1 Introduction

The intermittent nature of renewable electricity sources poses problems to their integration into existing supply networks:

- Unscheduled renewable generation increases the demand for flexible control power to keep the grid stable in terms of voltage and frequency.
- Most renewable power production is “unsteady”, thus requiring conventional (e.g. fossil fuel based) power stations as back-up in times of low production; conventional power is therefore not made redundant at full scale.
- From a certain level of renewable energy penetration into a grid, surplus energy production will occur.

This is especially significant in regions with weak grids and/or in relatively small (isolated, e.g. island) networks. Hydrogen as a storage and buffer medium can provide a solution to these problems. It can either be re-converted to electricity for short-term load following and at times of low renewable generation or high electricity demand or it may be utilised for alternative purposes, namely mobile applications.

This paper reports on a project concerned with the technical and non-technical aspects of using hydrogen as a storage medium for electricity from wind power. Two wind-hydrogen systems are being developed with different characteristics [Gómez Gotor 2003]. The undertaking is named “Cluster Pilot Project for the Integration of Renewables into European Energy Sectors using Hydrogen”, or “RES2H2” in brief. This five-year R&D activity started in January 2002. One unit is to be installed on Gran Canaria, Spain, the second near Lavrion, approximately 40 km south of Athens, Greece. They will both be erected in the year 2004 and operate for two years.

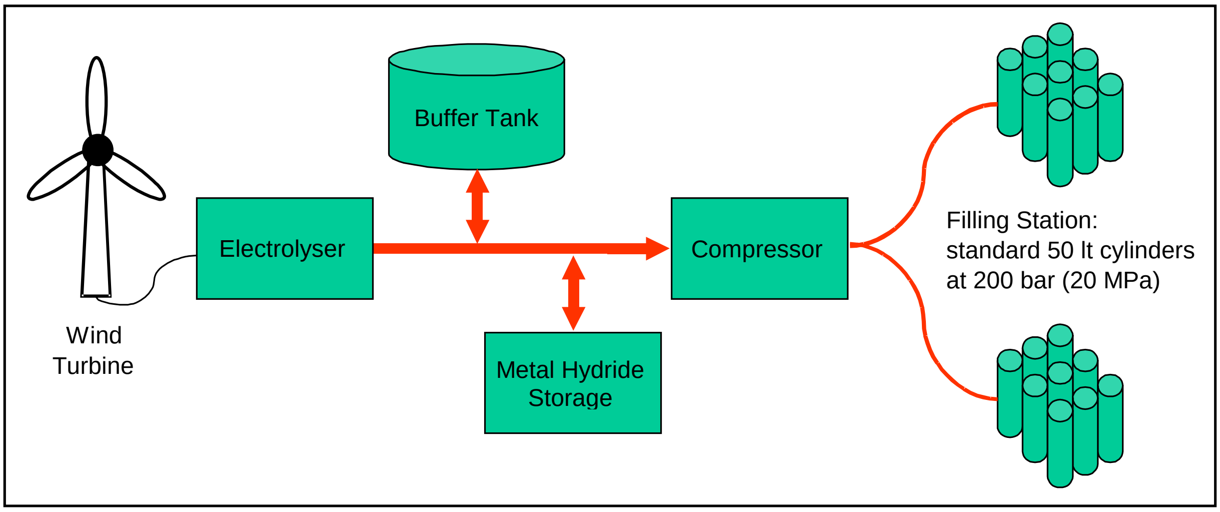

Fig. 1: Schematic of the wind-hydrogen system to be installed near Athens, Greece, showing the major components and their interconnection. Details of individual units can be found in subsequent figures and sections. Due to relationship of rated power of wind turbine and hydrogen unit, respectively, the wind turbine and therefore the entire system will be grid-connected, other than shown here for simplicity; cf. Figure 2 and section 2.1.

Immediate aims of the project are to prove technical feasibility of the respective concepts and to evaluate and enhance system efficiency. The first part of the paper focuses on the Greek installation. A key feature of this facility is the integration of a metal hydride storage. Among the non-technical aspects covered by RES2H2 a study of the market opportunities (apart from re-electrification) for “green” hydrogen, i.e. hydrogen produced from renewable electricity or renewable energy sources in general, was performed. The second part of the paper introduces some of the results of this investigation.

2 System Design & Component Characteristics

The system to be built at the wind park of the Greek Centre for Renewable Energy Sources (CRES) will consist of an electrolyser (including a hydrogen purification unit), a conventional hydrogen tank serving as buffer, a metal hydride storage, a compressor, and a filling station for 200 bar steel cylinders (Figure 1) as well as a power conditioning unit and a central control (Figure 2). The plant will be fed by an existing Enercon E-40 500 kW wind turbine from its low-voltage AC line. (For ease of the experimental set-up the internal DC link of turbine is not used to supply the electrolyser directly.)

2.1 Operational Strategy

The standard mode of operation will be that the electrolyser (rated capacity 5 Nm^3/h at max. 20 bar g) generates hydrogen which is compressed and filled into high-pressure vessels (Figure 1). The buffer tank de-couples the electrolyser output and compressor input in terms of gas flow and pressure as necessary (for example during start-up). As the system is an experimental set-up there will be no customer who would use the gas at a fixed load schedule. The hydrogen will simply be vented to the atmosphere in order to reset the steel cylinders for renewed intake.

The more interesting case will be part-load operation and the study of system performance and component interaction during such periods. When wind power output is low the electrolyser will reduce hydrogen production. In this case, the buffer and/or the metal hydride storage may have to cut in to supply the compressor at least with its lowest possible intake rate (3 Nm^3/h) which is higher than the minimum production rate of the electrolyser (0,75 Nm^3/h). Periods of low wind may last for seconds only but can also persist over longer time intervals. Central control may then decide to either switch the system off entirely or just put the electrolyser into stand-by and keep the compressor running for a set time in order to prevent frequent start-up and shut-down cycles which may induce increased tear and wear. The compressor can then be fed from the metal hydride tank.

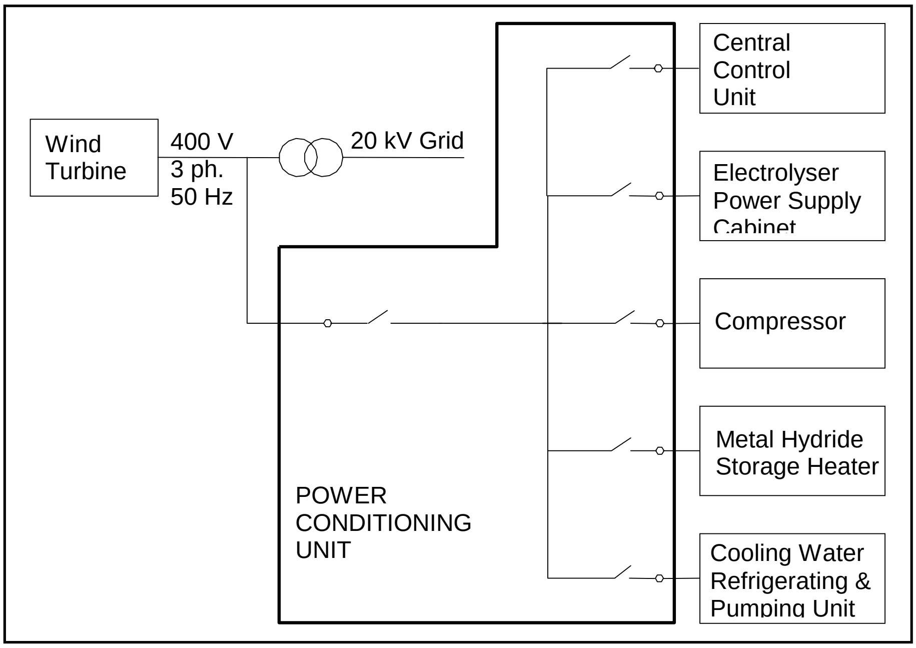

Fig. 2: Simplified scheme of the power conditioning unit and main electricity flow paths.

The maximum power demand of the hydrogen unit is going to lie in the range of 40 – 45 kW including auxiliaries, like pumps and cooling/heating water. On the other hand, an existing 500 kW wind turbine will be employed, rather than building a new, smaller one, in order to save investment. The system must thus operate grid-connected to get rid of surplus energy (Figure 2). Moreover, the power conditioning unit will not simply serve as a distribution board that takes power from the wind turbine and distributes it to the various users as appropriate. It also serves to induce fluctuations of power input onto the system as would be the case for a stand alone wind-hydrogen plant. This can, for example, be achieved by “dividing” the wind power output by a factor of about 11 (500 kW ---> Ψ 45 kW) and use this as a control signal for the power input of the hydrogen unit.

As the plant has to be grid-connected anyway, the hydrogen facility has no integrated backup unit for controlled shut down in cases of sudden drop in wind power (the electrolyser possesses a battery, though, for safety reasons, cf. section 2.2). As far as required, it will thus draw power from the grid. This backup consumption will be balanced and one key element of the operational strategy has to be keeping backup demand as low as possible as it would be the case if there was a limited internal backup source of energy.

So, for example, central control may on one hand decide for continued operation of the compressor when suddenly wind power decreases, as explained above. On the other hand, discharging the metal hydride storage to supply the compressor will require hot water which then has to be generated from fossil fuel-based electricity. Discharging this storage should thus be avoided as much as possible in order to a) keep system efficiency high in terms of total average energy requirement per unit of hydrogen delivered to the high-pressure cylinders and b) keep the ratio between backup (fossil) and renewable energy consumption as small as possible[1]. This makes it clear that the strategy for optimised operation of the system is not trivial.

A dynamic simulation study provided insight into system characteristics and led to modifications of the envisaged operational strategy. The final properties of the power conditioning and control units have not been detailed yet, though.

Due to its nature of an R&D facility, the system will be designed for semi-automatic operation. It is not planned to run the plant in unattended mode except for regeneration of the hydrogen drier (cf. following section). All technical and non-technical safety precautions & provisions will be foreseen.

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[1] In a future system, heat and cooling energy could be made available form a solar thermal installation, depending on location and season.

Tab. 1: Technical specifications of the electrolyser.

Nominal capacity of purified hydrogen	5 Nm^3/h H_2
Capacity controllable in the range	15% - 100%
Specific power consumption of the stack at full load	4,5 kWh/Nm^3 H_2
Specific power consumption of the purifier at full load	0,01 kWh/Nm^3 H_2
Total AC power demand of the plant at full load	25 kW
Hydrogen delivery pressure (maximum)	20 bar g
Hydrogen delivery temperature	P 40ºC
Hydrogen purity after purification	Σ 99,98%vol (wet)
Oxygen content after purification	P 10 ppm
Atmospheric dew point after purification	P - 40ºC

2.2 Electrolyser

The advanced alkaline electrolyser has a rated production capacity of 5 Nm^3/h hydrogen at a delivery pressure of up to 20 bar g. Output pressure may be set at any level between 2 and 20 bar g via an automatic backpressure regulator. The nominal operating temperature of the electrolysis is 80ºC, but the power supply unit has enough capacity to allow the starting-up of the electrolyser at full load even at relatively low temperature (30ºC).

The presence of special electrodes, developed for the powering of electrolysis from solar and wind energy, enables the unit to withstand rapid variations of its power input. The electrolyser will accept power variations in the range 15% to 100% of the nominal value within 1 second of time, producing hydrogen at a rate varying from 0,75 to 5 Nm^3/h (Table 1).

Safe operation is guaranteed by a special shut-down procedure, actuating a balanced pressure release, and reverting the electrolysis unit into stand-by conditions. This automatic sequence is of the hard-wired type, transparent to the electrolyser's control unit, according to standard safety regulations. In case of lack of energy, the control system is powered by a back-up battery. The electrolyser automatically shuts down should battery charge be low.

In principle, the metal hydride storage requires absolutely pure hydrogen because it irreversibly absorbs all impurities which in parallel diminishes its ability to store hydrogen. In order to slow down this degradation to a reasonable level, a hydrogen purification unit is integrated to the electrolyser. At the exit of the electrolysis cell and prior to purification, hydrogen is delivered saturated with water at the operating pressure and temperature (i.e. at max. 20 bar g, 30ºC, humidity = 1,6 g/Nm^3). The hydrogen contains also some oxygen (approximately 0,2% vol. O_2 in H_2 at full load). This hydrogen purity is generally acceptable for supplying a fuel cell, but the oxygen and humidity values are too high for filling a metal hydride tank. (The metal hydride could serve as a purifier itself as it absorb all impurities but will not release them. However, its ability to absorb hydrogen diminishes the more other substances it accumulates.)

The purification unit is composed of a hydrogen deoxidiser unit, based on a catalytic reactor, and a drier. In the deoxidiser, the oxygen content in the hydrogen flow is reduced to the ppm level for any load change of the electrolyser (Table 1). In the drier, the humidity content in the hydrogen flow is reduced at least down to 0,1 g/Nm^3, or 126 ppmv, which corresponds to an atmospheric dew point of - 40ºC.

Operation of the purification unit is discontinuous. During the drying phase, hydrogen crosses a vessel equipped with molecular sieve, until 400 Nm^3 hydrogen have been treated, corresponding to 80 hours of operation at full plant capacity. Just before regeneration, which takes place at ambient pressure, hydrogen is vented out to release the pressure. Regeneration comprises a heating phase, up to a set temperature, followed by a cooling phase to a set temperature, under a nitrogen or hydrogen flow of circa 3 Nm^3/h. Its total duration after the 400 Nm^3 hydrogen is about 10 hours.

During regeneration, the electrolysis cell would have to stop production. So it will preferably be carried out overnight or at times of low wind (even when the molecular sieve may not be fully charged). In a commercial system, two purifiers would be installed in parallel to enable continuous hydrogen generation.

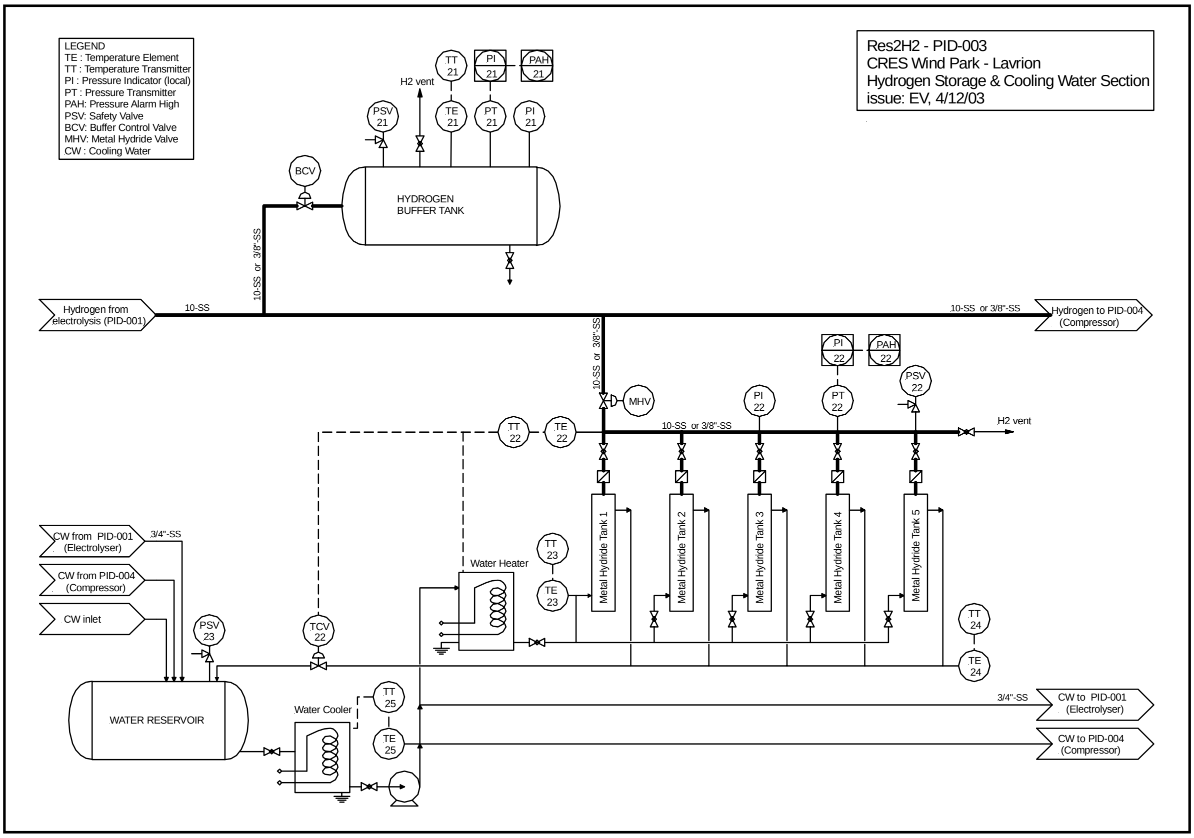

Fig. 3: Current draft for the P&I diagram of the hydrogen storage section.

Nitrogen, provided externally in high pressure cylinders and distributed at low pressure (5 - 7 bar g), will be used for

- Inertisation of the process unit whenever necessary,
- Pneumatic control valve actuation, which represents an estimated consumption of 15 Nm^3 over 24 hours at full load operation
- Regeneration of the drying unit (unless hydrogen is chosen to replace nitrogen, cf. below)

The use of nitrogen is usually foreseen as regenerating agent because hydrogen, when bought, is more expensive than nitrogen. However, in the frame of the project, it may be advantageous to replace nitrogen by hydrogen in order to reduce operating costs. The nitrogen vessels would have to be replaced less often, too. Hydrogen from the metal hydride tank would be perfectly suited for regeneration of the drier. The final choice between nitrogen and hydrogen for the regeneration has not yet been made.

2.3 Compressor and Filling Station

The compressor is planned to have an inlet pressure range between 10 and 18 bar g and an outlet pressure of 220 bar g. Within the inlet pressure range, the unit should display a variable throughput of 3 to 7 Nm^3 of hydrogen per hour, i.e. 5 Nm^3/h at 14 bar g, and thus stabilise the gas flow and pressure regime upstream the compressor. The supplier has not been chosen.

It was decided to fill individual cylinders manifolded to the outlet line of the compressor rather than stacks of such vessels because single cylinders can be moved more easily should need be. As the system is not designed for unattended operation, its maximum daily production will not exceed about 50 Nm^3. So 6 bottles of 50 litres geometric volume can take in one day's production at about 9 Nm^3 of hydrogen per cylinder. They will be emptied as required under safe conditions via a central release.

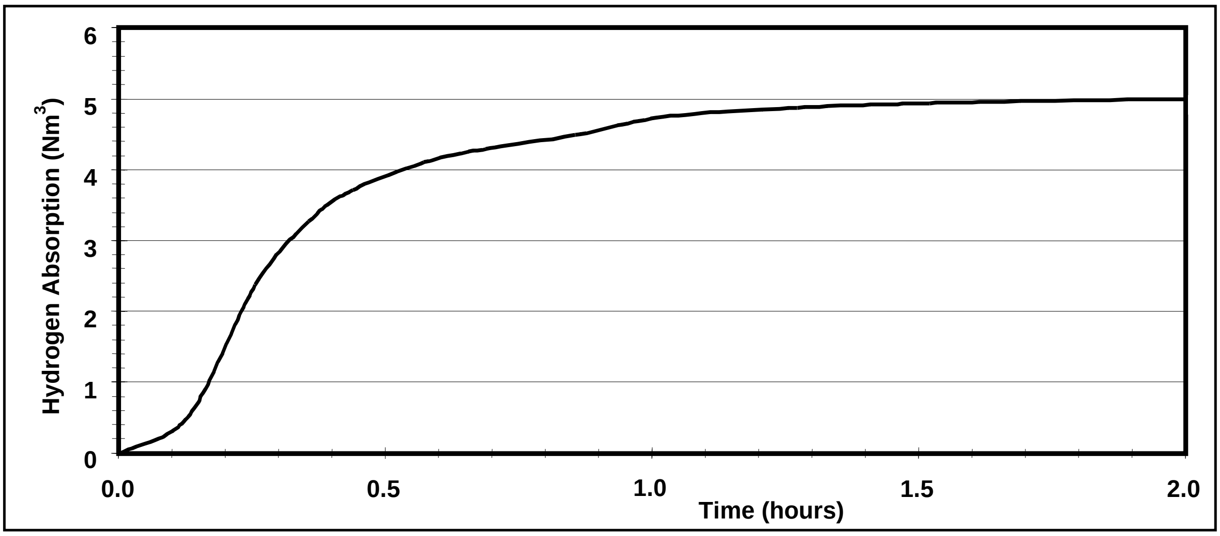

Fig. 4: Hydrogen absorption of the prototype under 20 bar abs with cooling water temperature of 30°C at the storage outlet (cooling water temperature at the inlet about 25°C).

2.4 Storage Section

The term storage section in the context of this paper refers to the buffer tank and metal hydride vessels downstream the electrolyser and upstream the compressor (Figure 3).

2.4.1 Buffer Tank

The buffer tank will be a conventional pressure vessel with 0,5 to 1 m^3 geometric volume. In the range between 10 and 18 bar g it can store 3,5 to 7 Nm^3 of hydrogen. So when fully charged it will guarantee at least thirty minutes of gas supply to the compressor, thus, for example, avoiding frequent start-stop cycles of the compressor under unstable wind conditions. It can further bridge the response time of the metal hydride storage whenever charging or discharging of the unit is initiated.

2.4.2 Metal Hydride Storage System

The metal hydride storage system will have a nominal capacity of 40 Nm^3 hydrogen (the size of the storage in our case is mainly determined by its discharge rate, cf. below). Its major elements are:

- Eight sub-units filled with a La-Ni based alloy, each of them having a capacity of 5 Nm^3 (in Figure 3 only five of these units are displayed for simplicity).
- A closed cooling water unit supplying water at 25°C and operated with an inlet and an outlet electromagnetic valve.
- A closed heating water unit supplying water up to 75°C and operated with an inlet and an outlet electromagnetic valve.
- Signal transmitters feeding the central control system of the plant with the H_2 pressure inside the metal hydride unit and the water temperatures at the inlet and at the outlet of the metal hydride unit.

After detailed alloy examination a high pressure alloy (HPA) was developed. To study the performance of this material under nominal conditions, a prototype unit of 5 Nm^3 hydrogen was designed, constructed and examined in terms of charging/discharging characteristics as a function of water temperature.

The charging characteristics of the HPA at 20 bar abs are displayed in Figure 4. It shows that the absorption rate of the prototype during the first hour of absorption when starting with an empty vessel is about 4,8 Nm^3 with 30°C cooling water (temperature at the storage outlet; water temperature at the inlet about 25°C). Therefore, one of the eight sub-units alone would almost be able to absorb the nominal amount of hydrogen generated by the electrolyser.

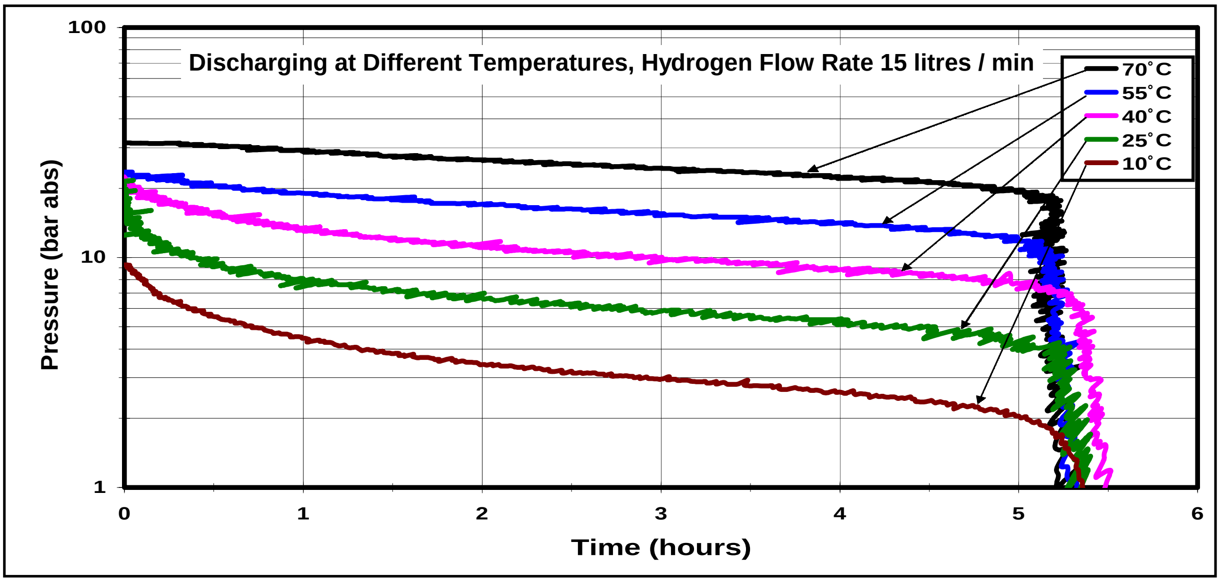

Fig. 5: Hydrogen pressure at a discharging rate of 15 litres hydrogen per minute (0,9 Nm^3/hr) under different heating water temperatures.

The discharging characteristics of the HPA under different temperatures are given in Figure 5. At 55°C the prototype can deliver hydrogen at pressures greater than 10 bar at 15 litres/min which is equivalent to 0,9 Nm^3 hydrogen desorption per hour. So, eight (sub-) units can supply the compressor at its planned maximum rate of hydrogen intake, releasing about 7 Nm^3 at 55°C. The nominal hydrogen capacity of the eight units is 40 Nm^3 which explains the stated size of the storage.

These results show that the HPA as developed satisfies the requirements of the system well.

The amount of heat that has to be exchanged in order to absorb or desorb 1 Nm^3 of hydrogen is 1.340 kJ, equivalent to 30 kJ per mole hydrogen. The response time after starting the heating or cooling water flow, respectively, will be between 1 and 5 minutes. During this interval, the buffer tank supplies hydrogen to the compressor or takes in volumes produced by the electrolyser. The buffer should thus usually be charged at about 14 bar g in order to promptly respond to the system needs, namely those of the metal hydride storage.

3 Market Study for Green Hydrogen

Hydrogen today is mainly derived from fossil energy sources. It can be characterised as an industrial gas which is produced and consumed in large quantities at, for example, chemical plants. Merchant hydrogen which is sold to third parties only plays a limited role.

Contrary to the present situation, future scenarios for a fully developed hydrogen economy envisage a broad application of the gas on retail level, like combined heat and power production in residential houses and as a vehicle fuel. Up to now only rudimentary elements of such a hydrogen economy exist. The question arises who will be the actors that establish a hydrogen infrastructure and what development paths may be taken.

The market study that was carried out within the RES2H2 framework investigated the prospects of green hydrogen in a general perspective. It revealed that the introduction of this gas into existing market segments (both industrial and merchant) does not appear to be realistic.

On the other hand, mobility was identified as promising new market opportunity. Its exploitation could be initiated in alliances between independent petrol stations and producers of wind power (section 3.1). Hydrogen may thus develop as an additional source of revenue for the latter but also improve returns for their immediate product, renewable electricity, in future liberalised markets (section 3.2). An example calculation for the island of Crete may illustrate the economics of green hydrogen in mobile applications in competition with hydrogen gas based on conventional sources (section 3.3).

3.1 Introduction of Alternative Fuels: Lessons Learned

Hydrogen is considered one of the prime future energy vectors in traffic. This is due to the fact, that hydrogen-fuelled vehicles will only emit water vapour which again would alleviate inner city pollution levels dramatically. Also, the potentially high efficiency of energy conversion in fuel cells would improve the energy balance of road vehicles. The margin is such that even if hydrogen was produced from natural gas by steam reforming (including all conversion losses this implies) the energy balance of a fuel cell would be superior to that of an internal combustion engine [Feck et al. 2001].

The prime problem, though, is that in order to support the operation of the first vehicles an oversized network is needed servicing the whole region in question. Fleet operation where vehicles return to their base daily will not solve this dilemma since it is essential for the market development of hydrogen fuel to serve individual mobility.

The analysis of the market development of RME (rape methyl ester or “biodiesel”) and natural gas fuel in Germany [Steinberger-Wilckens 2002] renders two major insights :

- Suppliers of novel fuels tend to be the producers/distributors of these fuels or companies related to them, and independent petrol stations. The share of large petrol companies in the total number of stations supplying RME or natural gas is below 10% although their total market share exceeds 90%.

Wind energy developers & operators and independent petrol stations therefore might be “natural” partners in establishing a first hydrogen infrastructure. Other parties could be the suppliers of technical/industrial gases. There is no point in trying to market hydrogen to large gasoline station companies in order to achieve a high supply density. Few but intelligently placed filling stations will suffice in the beginning. The major problem is to acquire the finance for the supply network (which will pre-date the vehicle market).

- Motorists with developed ecological awareness and thus potential interest in hydrogen fuel closely inspect the possible environmental benefits of fuel alternatives. If their ecological advantages are continuously questioned (as was the case with RME in Germany) they will not be able to attain relevant market shares with this clientele.

Life cycle assessment (LCA) studies have shown that only hydrogen derived from renewable energy sources significantly serves to reduce the emission of carbon dioxide equivalent and pollutant gases. Natural gas reforming, in this context, clearly scores inferior [Feck 2001, Höhlein et al. 2001, Pehnt 2000, Wagner et al. 2000, Wurster 2003]. It will thus be necessary to state the environmental performance of “green” hydrogen very clearly and find a brand for marketing this fuel in order to attract and bind the customers.

3.2 Hydrogen from Wind Power

Wind electricity obviously has a fluctuating nature depending on meteorological conditions. As a result it is not considered a controllable (“firm”) source and prices paid for wind electricity are comparatively low in deregulated markets (e.g. Ireland).

The figures in Table 2 amount to a total of 27% of electricity generation coming from wind energy sources in the time span 2006 to 2015 within EU-15 (depending on the development of the onshore potential and the further exploitation of offshore sites post-2006). For single countries the generation depicted in this table constitutes a considerable problem and/or a limiting factor to further wind energy development. Realising this (still theoretical) wind power potential will cause two major problems:

- occurrence of surplus wind energy resulting in “wasted” power potential which will either not be produced (by reducing power output of wind farms) or not be remunerated – in both cases the economics of the wind power production are affected
- rising requirements for flexible control power in the distribution grids due to the increasing amount of unscheduled generation [Eckert 2002].

Tab. 2: Net electricity production in the year 2000 and extrapolated wind energy production in ca. 2010 (denoting the time span 2006/2015) for selected countries and EU-15. The last column shows the percentage of wind energy in the total electricity deliveries (net production). These figures include all grid losses. Electricity consumption in Germany, for instance, currently amounts to approx. 490 TWh/a ([Stolzenburg et al. 2003] and references cited therein).

Country	Electricity Production 2000 [TWh/a]	Wind Electricity Production ca. 2010 [TWh/a]	Renewable Penetration
Denmark	35	28	80%
Germany	534	100	19%
Greece	50	45	90%
Ireland	23	46	200%
Portugal	42	15	36%
Spain	215	87	40%
UK	359	118	33%
EU-15 Total	2.474	675	27%

Hydrogen offers a solution to both problems in that surplus production from wind can be used to produce hydrogen electrolytically. It can then be either stored and eventually re-converted to electricity or marketed/distributed as a separate commodity. Re-conversion of hydrogen to electricity could supply control capacity (including peak shaving) as well as a means of guaranteeing power output from a wind farm. Conversion could either take place in adapted gas turbines or in fuel cells. The start-up and response times of fuel cells are similar to those of hydro power stations and thus suitable for load following and even some frequency stabilising functions.

When employing hydrogen as a fuel it could be produced on-site at filling stations, also by electrolysis. Wind electricity would be distributed via the conventional (and well developed) grids governed by delivery contracts as used today in the deregulated electricity market, i.e. the origin of the electricity can reasonably be proven. Other options like central pipeline delivery or reforming fossil fuels will result in the loss of flexibility and ecological impetus which are both essential in the first market phase (cf. previous section).

Growing installed wind power will cause surplus wind energy production in the coastal distribution networks [Steinberger-Willms 1993]. Assuming a 50% share of wind energy in electricity supply for the German coastal regions in about 2010 leads to an excess electricity production in the range of 6.500 GWh per year. (These 50% for the coastal regions should not be confused with the 19% average for the entire country that is displayed in Table 2.) Converting this to hydrogen via electrolysis decentrally results in a hydrogen supply for approximately 450.000 fuel cell passenger vehicles. Assuming further that the total potential of 30 GW coastal wind sites is exploited up to 2025 a hydrogen supply for approx. 3,5 million vehicles could be served from excess wind energy in Germany alone.

3.3 Hydrogen for Mobile Applications on the Greek Island of Crete

A rough estimate may illustrate the economics of hydrogen derived from various sources for an area where a high potential of wind energy exists that will induce the problems as established in section 3.1. Suitable for such a study is the island of Crete, since it is the rather large, quite far away from the mainland and it has a good resource of renewables. Crete is around 500 to 600 km south of Pireus, port of Athens, with a population today around 580.000 people. It is assumed that from 2001 to 2010 the number of passenger cars within Crete will increase by another 160.000 vehicles out of which 1%, or around 1.600 vehicles, will be hydrogen-powered. Hydrogen requirements of these vehicles are estimated to be in the order of 60.000 Nm^3/week. This demand could be covered by the existing mainland refineries, maybe with some upgrading. It is further assumed that three initial hydrogen stations in Crete are foreseen, near the cities of Irakleion (capital), Rethimno and Chania, which are at a distance of about 70 to 80 km one from another.

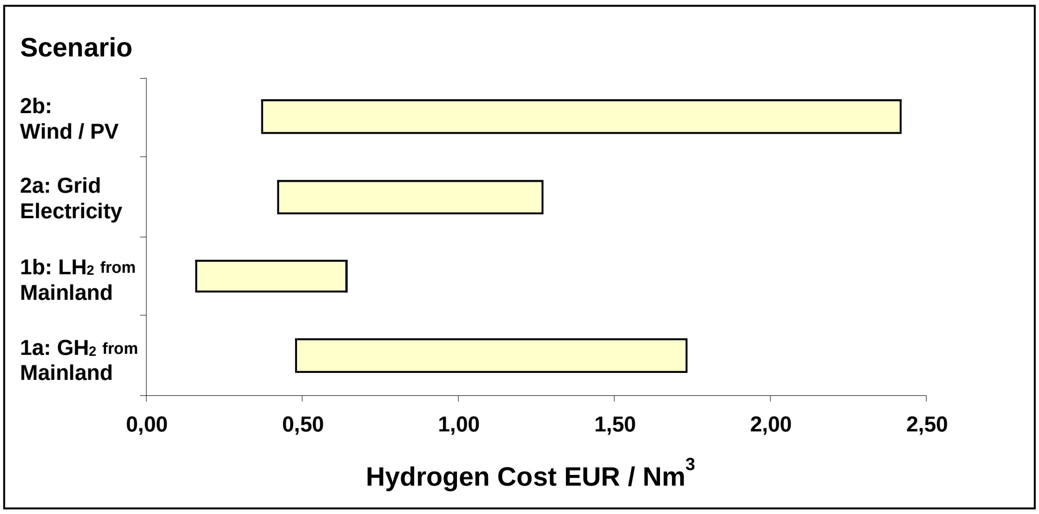

Fig. 6: Accumulated costs of hydrogen production, transportation and storage for three initial filling stations on the Greek island of Crete.

Scenario 1: Hydrogen from the Greek mainland

Hydrogen is produced in existing refineries near Athens and shipped to Crete. Within scenario 1a, trucks carry 4.000 to 5.000 Nm^3 hydrogen per trailer at 200 bar, within scenario 1b about 20.000 to 25.000 Nm^3 liquid hydrogen. These trucks enter ferry boats in Pireus. Once they reach Crete they deliver hydrogen to the three stations.

Scenario 2 : Hydrogen production on site the station

Hydrogen production takes place on the site of the stations by electrolysis. It is based on conventional electricity derived from petrol (scenario 2a), or by utilising renewable energy sources. Each station would require an electrolyser in the order of 100 - 200 Nm^3/h.

Figure 6 shows the accumulated costs that result from hydrogen production, transportation (where applicable) and storage, based on literature data. It is interesting to note that all scenarios overlap in the range between about 0,50 and 0,65 EUR.

Scenario 2b includes both wind power and photovoltaics. The latter causes the “expensive” side of the cost bar. If only wind was considered, scenarios 2a and 2b would display rather similar ranges. The cost assumptions for wind-derived hydrogen were chosen rather optimistic. This is justified by fact that remuneration of excess energy will be low, as explained in section 3.1. Scenario 2 does not require any transport of hydrogen, which is an important advantage in terms of logistics.

Transporting liquid hydrogen to Crete (scenario 1b) could be significantly cheaper than carrying the substance in its gaseous state (scenario 1a) and could even beat on-site generation. Still, one has to bear in mind that scenario 1 in general makes only sense for a transitional phase in order to encourage the use of hydrogen vehicles. This holds because hydrogen production from mineral oil adds conversion steps to the supply chain which increase energy losses (especially when liquefying hydrogen) and, therefore, can hardly improve the environmental balance of motor car traffic.

A cautious summary of the exercise may be that for the case of Crete there are no immediate economic reasons that would exclude local hydrogen supply for mobile applications based on renewable energy sources compared to imports from the mainland. On the other hand, a retail price of 0,50 EUR/Nm^3 hydrogen (excluding taxes) would be equivalent, in terms of energy content, to almost 1,50 EUR/litre of unleaded petrol. Current prices are about 0,85 EUR/litre petrol including taxes. So, of course, political incentives will be required to introduce (green) hydrogen to individual mobility on this island.

4 Outlook

The engineering phase of the project will be completed in April 2004, to be followed by the procurement of the hardware, its installation, and commissioning of the system. The facility should be running from early 2005.

In parallel to the analysis of operational data, system optimisation and adaptation & refinement of the numerical model of the unit in 2005/2006, the “industrial package” will be carried out. It is concerned with establishing standard approaches for the design and engineering of wind-hydrogen systems in order to facilitate their commercialisation.

Dissemination activities are going to be sustained.

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Portraits of the Contributing Institutions

PLANET - Planungsgruppe Energie und Technik is an engineering company based in Oldenburg, Germany. In addition to rational use of energy and building services design, hydrogen technology has become a further field of business activity since 1997. The company was and is involved in several research and commercial hydrogen projects including EUHYFIS ("European Hydrogen Filling Station"), CUTE ("Clean Urban Transport for Europe") and NATURALHY ("Preparing for the hydrogen economy by using the existing natural gas system as a catalyst").

The Centre for Renewable Energy Sources (CRES) is the Greek national centre for Renewable Energy Sources, Rational Use of Energy and Energy Saving, founded in September 1987. It has a scientific staff of more than 120 highly experienced and specialised scientists. The Centre is a public entity with financial and administrative independence, supervised by the Ministry of Development. The RES & Hydrogen Technologies laboratory studies the integration of technologies for hydrogen production, storage and use with RES technologies.

C. ROKAS S.A., listed from 1990 in the Athens Stock Exchange, was founded in 1958 as a steel constructions industry and has specialised over the years in the design, construction and installation of lifting and transportation equipment, having constructed a large number of cranes for ports, steel mills and factories both in Greece and abroad. During the last decade the company has also been active in the renewable energy sector and is today the leader in wind energy in Greece, being the owner and operator of a total installed capacity of 145 MW or 45% of the Greek wind energy market.

The Frederick Institute of Technology (FIT) is a private, tertiary education institution in Cyprus. It assures high academic standards by offering a wide spectrum of quality programs in many fields of science and technology which are recognised at international level. Frederick Research Center (FRC) is the research and development department of FIT. Aims of FRC are the promotion of basic and applied scientific research, the establishment of collaborations with international research networks and the transfer of technology from the academia to industry.