MEMORIAL UNIVERSITY OF NEWFOUNDLAND - MARINE INSTITUTE

CASE STUDY #1

Hydro: From Utsira to Future Energy Solutions

Author:
John Paul HANDRIGAN

Professor:

April 14, 2013

MEMORIAL UNIVERSITY

Executive Summary

Hydro, a Norwegian energy company, has implemented a €5 million project to combine wind and hydrogen power and demonstrate the delivery of a renewable source of electricity on the small island of Utsira (Klassen & Mitchell, 2006, p. 5). Electricity generated from wind is used to power targeted homes in Utsira, and excess electricity is stored as hydrogen through the process of water electrolysis. During times when the wind cannot provide enough electricity, the backup hydrogen and diesel sources are used. As the project approaches its close-out date, the responsible managers are now faced with the task of defining their next steps.

The Utsira project faced a number of challenges, ranging from inadequacies in system efficiency to harsh environmental conditions experienced on Utsira. Project managers need to address these challenges if they want to continue to build on the success of the Utsira project, and make the system more efficient and appealing to the masses.

There is a sizable market of remote communities worldwide and in the European Union (EU), which could benefit from having access to an Utsira-like renewable energy system. It is estimated that there are 1.6 billion people worldwide living without electricity, and 300,000 households in the EU that have no direct access to an electrical grid.

Hydro could greatly benefit from partnerships with remote island communities in the EU. Greenland and the Azores, both dependent on diesel for their energy requirements, are both great candidates for an Utsira-like system. These communities have the opportunity to loosen the shackles binding them to fossil-fuel based energy sources, promote tourism through a green image, and potentially profit from new hydrogen-based industries, green certificate credits, or by selling excess electricity back to the grid. Other potential markets for Hydro's technology is in grid power balancing for transmission system operators.

Contents

List of Figures

List of Tables

1 Problem Identification

Fjermestad Hagen and Nakken of Hydro, a Norwegian energy company, have devoted the past number of years to the implementation of a €5 million renewable energy system on the remote island of Utsira, Norway (Klassen & Mitchell, 2006, p. 6). The energy system integrates wind and hydrogen power to serve 10 per cent of Utsira's inhabitants (Klassen & Mitchell, 2006, p. 1). The project is likely to run for another two years, and considerations for next steps are beginning to weigh on both Fjermestad Hagen and Nakken.

The next step for Fjermestad Hagen and Nakken is to reshape the Utsira project into something that is economically viable, scalable and adaptable. In developing their strategy to move forward, they will need to consider the challenges faced with the Utsira project, as well as work with parties interested in early adoption.

The wind and hydrogen system at Utsira has a number of inefficiencies. One significant issue is the loss of energy when retrieving stored energy from the hydrogen source. The process of converting wind-generated electricity to hydrogen, and then back again to electricity was wasteful. Other difficulties arose with the integration of the fuel cell stack into the overall system (Klassen & Mitchell, 2006, p. 8). These challenges are not unexpected for an innovative technology/solution.

The Utsira project was also challenged by environmental conditions. The project team faced difficult weather conditions, including low temperatures and high salt content in the air. Also, waves are another important environmental consideration. In the case of Utsira, the project team had to build a quay for receiving of shipped parts. The quay fell victim to a major storm (Klassen & Mitchell, 2006, p. 8). These issues will become important when choosing other Utsira-like projects.

Beyond the lessons learned from the nascent technology, lies the issue of finding suitable and interested parties for the next implementation of Hydro's wind/hydrogen coupling system. There is no shortage of remote communities in the EU or the World; however, due to the early nature of the technology it will be important to choose locations that are more likely to succeed. This will also give the project team an opportunity to further prove the technology, and make the necessary refinements to address some of its current issues. Other potential markets for Hydro's technology is in grid power balancing for transmission system operators.

The New Energy division at Hydro needs to use the experience gained from Utsira as a stepping stone to develop a solid business case that makes the energy solution appealing from a technological, ecological and financial perspective, as there would likely not be an opportunity for other R&D projects similar to Utsira (Klassen & Mitchell, 2006, p. 1).

2 Data Collection

The overarching objective of Hydro was to develop its core capacities in energy and aluminum on a global scale. Fittingly, Hydro divided its operations into two major divisions: Aluminum and Oil & Energy. The Oil & Energy division consisted of four functional areas, mainly exploration, projects, operations, and markets. Drilling down further into the corporate hierarchy to eke out the area relevant to the Utsira project, the markets division was divided into four subdivisions:

- Oil and Gas Market Trading
- Oil and Gas Products
- Power Production
- New Energy

The New Energy subdivision focused on wind power, hydrogen, R&D and funding ventures for renewable energy projects (Klassen & Mitchell, 2006, p. 4). The Utsira project fit well within these parameters. Utsira, with a small population of two hundred and forty, was an ideal location for Hydro to set up an innovative energy system based on wind power and hydrogen. The objective of the Utsira project was to power ten homes, which equated to roughly ten per cent of the island. For these ten homes, it was estimated that the peak power demand was between 50 to 60 kW and that the total annual energy consumption for these homes was 200,000 kWh, or 10 homes at 20,000 kWh each (Klassen & Mitchell, 2006, p. 6).

Environmental conditions at Utsira were also somewhat favourable for the project. The island was exposed to long periods of sustained wind, with an average annual wind speed of 10 m/s (Nakken, Strand, Frantzen, Rohden, & Eide, 2006, p. 3). The engineers at Hydro estimated that the longest period of consecutive days without wind within the last ten years was two days. The environment also caused challenges to the Utsira projects with temperatures in the range of zero to ten degrees Celsius, high salt content in the air, and severe storms/waves. These climatic conditions need to be studied in the early planning and designing stages for future implementations (Klassen & Mitchell, 2006, p. 5).

The functional basis of the energy system in the Utsira project rests in the renewable nature of wind and hydrogen for power production. The system consists of turbines, flywheel, fuel cells, and hydrogen storage tanks, among others. The total cost of the equipment was €2.25 million, or roughly forty-five per cent of the total costs. The remaining costs covered those associated with project management. Additional details can be found in Table A.2.

The Utsira project is conceptually easy to understand. Electricity generated from wind turbines is used to provide power to the targeted homes in Utsira. Prior to being delivered to the residents of Utsira, the electricity is transformed from 400 to 220 Volts AC, which is the standard in the EU. Excess electricity, in periods of high winds or low energy consumption, would be used to power a water electrolysis unit to convert water (H_2O) into its basic elements hydrogen (H_2) and oxygen (O_2). The hydrogen is then stored and could be used as an energy source in periods of low or non-existent winds, or sold back to the grid. Alternatively, the project team could have relied on the use of high-capacity sodium-sulfur batteries. The overall renewable energy system relied on a backup system consisting of flywheel, battery and permanent magnet synchronous motor to ensure grid balance and stability (Klassen & Mitchell, 2006, p. 6). Initial results for the Utsira project indicated that the system has a reliability rate of 80 to 90 per cent (Klassen & Mitchell, 2006, p. 7).

Hydro has significant experience working with both wind power and hydrogen. The company has been working with wind power since 2001 when it delivered its first wind farm in Northern

Norway. Since that time, it has been involved in setting up ten other wind parks, and in June 2005 it signed a joint agreement to build a large offshore wind farm. The capacities of these wind farms range from forty to one thousand megawatts. With regards to hydrogen, Hydro has an even longer working history. They have been using it in the production of ammonia for over 75 years. Hydro formed a separate legal entity in the 1990's to manage the sales of electrolysis units, for which they have been using since 1927 (Klassen & Mitchell, 2006, p. 4).

The World's energy needs are not being met with the current infrastructure. There are approximately 1.6 billion people worldwide living without electricity (Brown, 2004). Within the EU alone, it is estimated that there are 300,000 households that have no direct access to an electrical grid (Zoulias et al., 2006, p. 3). Some of these individuals without a reliable energy backbone have to rely on wood and dung for their basic needs such as heating and cooking (Brown, 2004).

Energy costs, including capital and fuel, can vary based on the source of electricity. For instance, a renewable system based on wind power and hydrogen is approximately sixty-seven times more expensive on a cost per kW basis than a diesel setup. The Utsira project team estimated that the installation cost of wind/hydrogen system was €1.05 per kWh. Nakken, one of the project managers, estimates that this cost could be brought down to €0.35 per kWh within five to ten years, which could make it relatively competitive to other energy solutions (Klassen & Mitchell, 2006, p. 9).

Renewable energy systems have the advantage of no fuel costs, as opposed to finite fossil fuel energy sources. It is also important to note that crude oil prices have increased steadily over the past years (Hydro, 2004, p. 22). Figure A.1 shows the steady increase in oil price since roughly 2002. A comparison of diesel and wind/hydrogen sources can be found in Table A.1.

Hydro has already been contacted by interested parties, including energy providers, wind farm operators, an energy institute, and a mining community (Klassen & Mitchell, 2006, p. 11). Of these potential customers, many depend on diesel-backed systems. Others have hybrid solutions, either diesel and access to a grid or wind-based energy source. Table A.3 highlights five EU areas that could potentially benefit from Hydro's renewable wind/hydrogen energy system. Green certificate credits are available for those systems relying on renewable sources of energy (e.g., wind/hydrogen systems).

3 Analysis of Facts

The Utsira project used an innovative approach to delivering renewable energy, and it was lauded for its success with the Platts Global Energy Award (Klassen & Mitchell, 2006, p. 8). Despite these successes, the Utsira project did contend with several problems. However, the R&D nature of the project was an ideal situation for the project team to discover and face these challenges, and use them as building blocks for subsequent system implementations.

Using wind to generate electricity brings with it several challenges. The lack of control and predictability of wind speeds requires the use of backup energy sources. In Utsira's case, the wind successfully generated excess energy and converted it to hydrogen for storage (Klassen & Mitchell, 2006, p. 8). Failure to have a backup energy source, such as Utsira's hydrogen, could lead to residents having no access to electricity for long periods of time. In the case of Utsira, the project team was experiencing a reliability rate of 80 to 90 per cent of the time. When failures occur, the system automatically shifts back to the grid (Klassen & Mitchell, 2006, p. 7).

The conversion of wind-generated electricity to hydrogen, and back again to electricity was severely inefficient for the Utsira project. Overall losses in energy ranged between 70 to 80 per cent. The Utsira project team had constructed a 2,400m^3 hydrogen storage tank that could theoretically provide 7.2 MWh to the homes of Utsira, but the useful yield was only 2.9 MWh of stored energy (Klassen & Mitchell, 2006, p. 8). This limited capacity potentially impacts the usefulness of hydrogen storage for an energy backup service.

The difference in costs should be highlighted as well. Utsira was capital-heavy at an estimated €20,000 per kW, whereas for a diesel system it was only €300. Ongoing fuel costs for diesel systems ranged between €0.15 and €0.50 kWh, whereas renewable energy systems have none (Klassen & Mitchell, 2006, p. 9). Many of the remote communities in the EU, and listed in Table A.3 have diesel as a fuel source, and the infrastructure to support such a system. A wind/hydrogen renewable energy system would involve new capital costs for turbines, hydrogen storage, and so on. Although the implementation of a renewable energy system would pay off as a long-term investment, it might be difficult for parties to see the benefits early on.

Using a cost per kWh comparison of wind/hydrogen systems to diesel-backed systems provides useful insight. Nakken indicated that the current cost per kWh at Utsira was €1.05. As Hydro's expertise in the field develops, and refinements are made to the system, he believes that the costs could be brought down to €0.35 per kWh within five to ten years (Klassen & Mitchell, 2006, p. 9). This is very competitive pricing when compared to current costs per kWh on island communities. On Azores, the cost per kWh for the diesel solution is €0.45, which is in fact higher than Nakken's predicted costs for the wind/hydrogen system. It's also important to note, that isolated communities such as Azores are subsidized by governments (Klassen & Mitchell, 2006, p. 9). The possibility of government stopping the subsidization of diesel solutions is not nil, and therefore the potential for even higher diesel costs could exist in the future. In addition, the high volatility of crude oil prices, as suggested by Figure A.1, should be considered.

Given that there are currently 1.6 people worldwide living without electricity, and 300,000 homes in the EU living in isolation from the electrical grid, it is evident that an energy market exists. And as Brown (2004) indicated, the potential growth of this market is likely to expand by the year 2030. With the potential of an even larger market, this seemingly bodes well for the Utsira project team.

One additional consideration, is the fact that Hydro's operating income for the oil & energy division is tightly bound to the price of oil. These high oil prices contributed to one of Hydro's best fiscal results in its hundred years of history (Hydro, 2004, p. 61). Due to this relationship, Hydro's overall operating revenues could potentially take a hit if oil prices drop. For this reason, it would be beneficial for Hydro to invest additional funding into their New Energy subdivision to continue to support projects like Utsira, and compensate for potential losses in operating income.

4 Solution Development

Hydro is seemingly well-positioned to benefit from the renewable energy market based on the analysis of facts and the preliminary results obtained from Utsira. Moving forward, Fjermestad and Nakken have many considerations to explore before deciding on a path, and ultimately arriving at a decision.

One possibility for the managers of the New Energy division would be to apply the lessons learned and the technology used from the Utsira project and seek to apply them to the more than 1,000 remote communities in the EU, or even globally. It is not necessary to define geographic limits for subsequent work, as similar renewable energy solutions have been implemented beyond the EU's borders in Australia, Bengal, Canada, India, and the United States (Klassen & Mitchell, 2006, p. 22). Of the five island communities listed in Table A.3, both Greenland and the Azores would be suitable parties for a Utsira-like system.

Another possibility for potential early markets, would be to help transmission system operators with grid power balancing. Transmission operators have a history of seeking out new technologies to stabilize the electrical grid, where instabilities increase as more renewable energy is supplied to the grid. Fluctuations in wind, as depicted in, also required additional grid flexibility (Klassen & Mitchell, 2006, p. 10). The use of more stabilized energy sources such as hydrogen-electrolyzer systems could be used. Hydro has a long history of working with electrolyzers, through its direct affiliation with Norsk Hydro Electrolysers A/S.

5 Findings and Managerial Recommendations

Although the Utsira project was successful in piecing together a standalone renewable energy system using wind power and hydrogen storage, there are still existing areas for improvement. The project team could improve on several system/operational components, such as the hydrogen storage tank sizing, The Utsira project made use of a hydrogen storage tank to store excess electricity generated from the wind. The design team responsible for the sizing of the tank might want to consider incorporating excess storage capacity into future designs. A larger hydrogen storage tank could potentially allow customers to benefit from selling hydrogen on the open market to support the automobile or public transit industries (Klassen & Mitchell, 2006, p. 11). For example, BMW, the German automobile company, prototyped a hydrogen car in 2005 that could potentially benefit from the excess hydrogen (Kiley, 2004, p. 275).

A larger hydrogen storage tank might also be necessary to compensate for the significant loss of energy (i.e., 70 to 80%) during the conversion of electricity to and from hydrogen. This inefficiency makes hydrogen less reliable as a backup energy source. Alternatively, management could seek out improved methods of storing excess electricity. For instance, high-capacity sodium-sulfur batteries might have higher overall efficiencies.

Management should pursue remote communities in the EU. In particular, the island communities of Greenland and Azores, Portugal, would be favourable locations to target. Both communities rely on diesel for their current solution. Of the five island communities listed in Table A.3, Greenland and the Azores pay the most on a cost per kWh basis for their energy at 0.25 and 0.45 € cents, respectively. Using these energy costs and the approximate power needs, this leads to €93.9 million for Greenland and €859.5 million for the Azores in annual fuel costs. Due to the large ongoing expenditures for fuel, it would indicate that these locations do have the potential to fund a renewable energy system.

The Azores could benefit from the EU's green certificate credits, which can be considered as a means to offset the high capital costs for wind/hydrogen energy systems. Greenland is not a member of the EU, but does have strong links with the entity through its relations with Denmark, who is an EU state (Loukacheva, 2007, p. 115). Although this link exists, it is unclear whether Greenland could benefit from the green certificate credits.

Hydro, and the management team for the New Energy division, may want to consider targeting only a small number of early adopters at this stage. The team has a number of issues it must address, and in order to limit the potential for failure, it would be best to concentrate resources on a small number of initiatives. Also, if the management team decides to target Greenland and the Azores, it will be dealing with a much larger consumer base. The team should ensure that the system is well-adapted for scalability, particularly due to the early nature of the technology.

In the pursuit of suitable parties for the wind-power and hydrogen energy solution, the project team should put an emphasis on the environmental benefits of its system. Often communities want to promote clean air, and encourage tourism. By reducing the carbon dioxide emissions associated with fossil-fuel energy systems, communities have the potential to accomplish just that (Klassen & Mitchell, 2006, p. 10).

The rise in oil prices, as depicted in Figure A.1, is another factor that should encourage the team to continue to move forward with its renewable energy system. As oil prices rise, alternative sources of energy will become more attractive to communities, which increases the potential for additional interested parties. If this is the case, then Hydro would have already gained years of experience working with renewable energy systems and could potentially profit from the market's demand for renewable energy.

The management team should continue to pursue remote communities, and attempt to address the needs of the 1.6 billion people without readily available sources of electricity. As a long-term investment, the wind power and hydrogen solution that Hydro has developed is a winning solution.

References

Brown, P. (2004, June 21). World bank rebuked for fossil fuel strategy. *The Guardian*. Retrieved from http://www.guardian.co.uk/environment/2004/jun/21/energy.renewableenergy1.

Hydro. (2004). Annual report 2004.

Kiley, D. (2004). *Driven: Inside bmw, the most admired car company in the world*. Wiley.

Klassen, R., & Mitchell, J. (2006). Hydro: From utsira to future energy solutions. *906M44*. London, Ontario: Richard Ivey School of Business Foundation.

Loukacheva, N. (2007). *The arctic promise: Legal and political autonomy of greenland and nunavut*. University of Toronto Press.

Nakken, T., Strand, L., Frantzen, E., Rohden, R., & Eide, P. (2006). *The utsira wind-hydrogen system - operational experience.*

Zoulias, M., Glockner, R., Lymberopoulos, N., Vosseler, I., Tsoutsos, T., Mydske, H., ... Taylor, P. (2006). *Market potential analysis for introduction of hydrogen energy technology in stand-alone power systems: H-saps final report*. Institute for Energy Technology. Retrieved from http://www.cres.gr/kape/pdf/download/HSAPS.pdf.

Appendices

A Figures & Tables

Table A.1: Diesel and Wind/Hydrogen Comparison (Klassen & Mitchell, 2006)

Energy Source	Capital Costs [€ per kW]	Fuel Costs [€ per kWh]	Operational Costs [% of capital costs]	Benefit from Green Credits
Diesel	300	0.15 - 0.50	2.5	No
Wind/Hydrogen	20,000	0	1.5	Yes

Table A.2: Components and Technical Parameters for the Utsira Project's Wind/Hydrogen Renewable Energy System (Klassen & Mitchell, 2006)

Main Components	Technical Parameters	Supplier	Cost	% of Total
Wind Turbines	600 kW	Enercon	750	15
Flywheel	5 kW	Enercon	100	2
Master Synchronous Machine	100 kVA	Enercon	100	2
Hydrogen Engine	55 kW (top load)	Continental	200	4
Fuel Cell	10 kW	IRD	100	2
Electrolyser	10 Nm^3/h, 48 kW	Hydro	500	10
Hydrogen Storage Capacity	2400 Nm^3	Hydro	500	10
Project Management	-	Hydro	2,750	55

Table A.3: Island Communities in the EU (Klassen & Mitchell, 2006)

	Country	Cost per kWh [€ cents]	Current Solution	Population	Number of Households	Approximate Power Needs [MWh]
Faero Islands	Independent Nation	0.15	Diesel	46,962	18,785	375,696
Greenland	Division of Denmark	0.25	Diesel	56,375	22,550	451,000
Azores	Portugal	0.45	Diesel	238,767	95,507	1,910,136
Greek Islands	Greece	0.15	Diesel/Grid	508,000	203,200	4,064,000
Scottish Islands	Scotland	0.15	Diesel/Wind/Grid	120,000	48,000	960,000

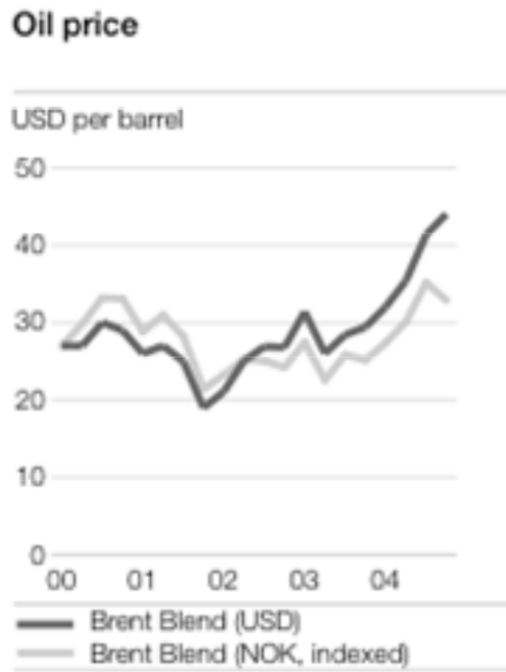

Figure A.1: 2000 to 2005 Oil Prices (Adapted from Hydro (2004, p. 22))