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Executive Summary

The Desert Research Institute (DRI) has completed Phase 1 of a Department of Energy contract to employ hydrogen as an energy storage medium for remote, renewable utility applications. The goal of this two-phase project is to bring about technologies to accelerate the use of clean, renewable energy worldwide in an economically feasible and technically viable way. The goal is being met through the development of design and analysis tools, assembly of a test system, and ultimately, installation of a full prototype system in Phase 2 of the project. This approach takes advantage of hydrogen's ability to store large amounts of intermittent energy in a dispatchable and cost effective way. The design and control system tools developed from this project will provide the basis for smart control technology critical for future distributed power systems. The test and full prototype systems will serve as pathfinders for using hydrogen as a utility energy storage medium. The expected location of the prototype system is Kotzebue, Alaska, a village with a remote yet growing wind farm as well as realistic loads and environmental conditions.

Technology has evolved during the past two decades allowing us to take this first step in combining components from diverse technical areas into independent, renewable power systems. These on-demand power systems require only a renewable power input and can range in size from a few watts (small enough to power weather monitors) to hundreds of kilowatts (large enough to power villages, buildings, or off-grid neighborhoods). We are pursuing the first applications of these systems in remote regions where wind or solar power is integrated with adequate storage to provide a steady supply of electricity to communities or any other load requiring on-demand power. The energy storage component will provide power to the community when the renewable source is quiescent.

Phase 1 of the project had three primary objectives:

1. To begin the modeling process for generalizing ways to bring about integrated hydrogen power systems in the most timely way;
2. To design and install a renewable hydrogen test system of a useful scale and begin evaluation of various system designs and controls; and
3. To evaluate the possibility of deploying a remote hydrogen power system, and, if reasonable, to complete a conceptual system design.

The first objective has been completed and is based on TRNSYS integrated system software. The use of models developed by DRI and Stuart Energy Systems has shown the benefit of the research direction planned under this project. The second objective has also been met through the installation of a test system at the DRI Northern Nevada Science Center in Reno, Nevada. This system is capable of performing as a flexible, physical model of a renewable power system using hydrogen or any other energy storage. Since the originating DOE solicitation excluded any new renewables as part of the project, and DOE expressed the desire to consider Alaskan possibilities, the Village of Kotzebue, Alaska was selected as the location for the first system design and evaluation, and is the subject of objective 3. The Kotzebue Electric Association (KEA) is a forward looking local utility intent on successfully employing clean energy technologies while benefiting the community economically and environmentally.

Introduction

Project Background

Fundamental to this project are two principles. First, without energy storage, renewable power from intermittent sources cannot provide a base load supply or completely penetrate a power grid. Given the cost and performance of the storage technologies, however, global availability of these systems is many years away. Second, the current and near-term states of renewable power and energy storage technologies permit niche opportunities to deploy small-scale renewable hydrogen utility systems in high-value applications, usually for the production of remote power. The first principle relates to the long-term opportunity for hydrogen and other utility energy storage methods to provide increased growth of renewable power throughout the world. The second principle relates to the near-term opportunities for hydrogen and other energy storage methods to be employed with existing renewable energy sources. This project is intended to accelerate the hydrogen, fuel cell, and renewable energy opportunities based on the second principle.

The project is a collaboration with team members from industry, university, utility, and government sectors. The team members, their capabilities, and the nature of their participation are described later in this report.

A study of existing modeling resources was performed, and the platform TRNSYS was chosen as the basis for the system modeling necessary for this project. A spreadsheet model was assembled at DRI, and a model at Stuart Energy Systems (SES) specific to hydrogen systems was run to validate the general direction of the project. Analysis with the spreadsheet and SES model validated the rationale for renewable hydrogen utility power systems. The progress in developing the detailed models is described later in this report. As a project activity supporting the final design and decisions for the Phase 2 utility system planned for installation in Alaska, additional modeling and analysis for system designs and performance are planned. These models are expected to complement the suite of models available for renewable and integrated power systems. The models derived in this project will be specific to systems that use energy storage in the form of hydrogen, later generalized to other storage devices. Additional features will be added to the TRNSYS-based model will be completed and used to fully test the design scenarios for Alaska system configuration during Phase 2.

Hydrogen Storage Systems

Hydrogen is one of several candidates that can be used as a utility energy storage medium in non-grid applications. Examples of storage mediums include batteries, pumped hydroelectric, flywheels, compressed gas, and zinc or halogen electrochemical systems. As part of this project, we have developed tools to analyze hydrogen storage systems that can also be used to analyze the cost and performance expectations of all the other potential energy storage systems. For any application, there is an optimum method of energy storage based on cost and performance criteria, recognizing that the cost and performance parameters will evolve over time. The general format for these systems is depicted in Figure 1, with the options for components from source to load.

Figure 1 - Source, Process, Storage, and Load Options for Remote, Renewable Power Systems.

Under conditions where pumped hydroelectric is feasible, that method will usually be the most efficient and cost effective for storing renewable energy. For short periods of stored energy use, batteries are usually more cost effective than other options. For conditions where credible periods of renewable power unavailability exceed two to three days, however, hydrogen energy storage is expected to compete with batteries based on component capital cost. In remote, renewable energy systems, the energy storage medium is required to buffer the intermittency of, and phase differences between, the time-varying renewable resource and the load. As in the application of any new technology, the use of hydrogen as a storage medium will have its earliest market in high-value applications, such as premium power or in niche applications in isolated locations.

The energy storage element of hydrogen systems is more complex than either battery storage systems or fossil-fueled fuel cell systems. For a battery system, the battery is both the energy storage and the power input and output element. In a fossil fuel system, there is one energy storage element, the fuel tank, and one power element, the internal combustion generator set or the fuel cell, reformer set. A hydrogen energy storage system is comprised of an input power electrolyzer, a hydrogen storage vessel and compressor, and an output fuel cell or internal

combustion engine generator. Single-component systems such as batteries cannot separate the power and energy elements for optimization, and fossil-fueled systems still require a fossil fuel delivery infrastructure serving remote locations. A hydrogen system permits optimization of input and output power as well as energy storage elements for any given application and, ideally, will never require a fossil fuel delivery infrastructure.

We have included the option of hydrogen-fueled, optimized, internal combustion (ICE) generator sets as a possible choice for the output power element. For several years, optimized ICE generator sets have been considered as a transition power plant for the fuel cell. They can have similar efficiency and emission performance as a fuel cell and can be significantly less expensive in today's marketplace. However, there are still no manufacturers of ICE hydrogen generators, while the performance and cost of fuel cells are evolving rapidly. As a result, we expect that the output power element for hydrogen systems will shift toward fuel cells almost exclusively during the next decade.

Fuel cell systems using diesel fuel or other fossil fuels still require a fuel delivery infrastructure, as well as a water supply for the CO shift reactor. The presence of a reformer for the primary hydrogen supply also reduces the efficiency of the power system to the range of a conventional diesel generator. While reducing the air pollution impact, fossil fuel cell systems do not significantly reduce the fuel supply needs or environmental risks of fuel storage and shipping. A renewably powered system provides pure, electrolytic hydrogen to the fuel cell, eliminating concern for contamination of the fuel cell anode catalyst.

Project Overview

For the past six years, DRI faculty have recognized that the remote villages in Alaska and Native American communities in the West and Southwest are the best locations in the United States to test the market for fuel cells and integrated, renewable power systems. Nevada utilities have more than 10,000 customers without access to the central power grid; New Mexico has a greater number. The state of the technology today allows us to provide renewable electricity to locations currently without it. These systems can also provide on-demand electricity to pristine environments with no emissions.

Power systems employing fuel cells can be configured in several ways, all of which require the delivery of hydrogen to the fuel cell power generator. The hydrogen can be supplied from several different sources and there are five different fuel cell technologies that can be employed to produce power from the hydrogen. The options for power system configurations is shown in Figure 2. The top two hydrogen delivery options in Figure 2 are the "linear systems" described elsewhere in this report. In comparison, the presence of an alternative power path in the renewable hydrogen option is the source of the optimization opportunities also described in this report.

Figure 2. The possible configurations for fuel cell utility power systems, showing the source options for hydrogen. The five fuel cell options are: PEM (proton exchange membrane) SOFC (solid oxide fuel cell) PAFC (phosphoric acid fuel cell) MCFC (molten carbonate fuel cell) and AFC (alkaline fuel cell).

The products from this project will significantly benefit the U.S. industries that have carried the key technologies to the point of commercialization. The successful development of commercial, integrated power systems will expand the market for each component technology. This is particularly true for the fuel cell, solar, and wind power industries. New industries will evolve to supply renewable power systems to the one-third of the world that currently has no access to utility electricity. These industries will also increase the ability of wind and solar power to penetrate the central power grid market. A key objective of this project is to integrate the hydrogen energy storage system with stand-alone wind turbines in realistic, isolated situations independent of a power grid.

The industry, utility, and university team assembled by DRI is engaged in several parallel efforts to identify pathways for successful commercialization of these power systems. We are accomplishing this goal by employing a physical model of a complex system for the purpose of performing system analysis of potential design and control scenarios as well as systematically developing approaches to remove technical and economic barriers.

This project goes beyond the use of fuel cells, or internal combustion generator sets, and fossil fuels for power production in isolated utility applications. Instead, we are seeking to develop a system that provides for the long-term use of hydrogen as a storage buffer for utility energy. Systems integrated to do this are significantly more complex than the linear systems using reformed fossil fuel and fuel cells. This complexity creates a design and control challenge but also offers several coupled parameters for optimization of the design and control methods. Renewable systems with storage will provide on-demand power without the need for a fuel supply infrastructure, something that is very important in the isolated locations of the world.

This project was designed to be implemented in two phases. The purpose of Phase 1, which has been completed, was to identify some of the numerous system configurations, applications, and market approaches for renewable, hydrogen utility systems. Phase 2 involves completion of the system testing, design and control system method development, determination of codes and standards, and water management design necessary for successful installation of a utility system in Alaska. This phase of the work has yet to be undertaken.

Phase 1 Project Description

Phase 1 had three primary objectives:

1. To develop models that are specifically designed to optimize hydrogen storage systems for remote, renewable applications. The intent was to use the models to compare hydrogen systems with all other storage systems and to permit rational selection of the best system for a given application. The models were intended to be used to optimize the system design for a specific application, and once the system was designed, to optimize control to provide the most reliable and lowest cost electricity to the customer. Note that models have yet to be developed for optimization of design and control of a hydrogen system. DRI is developing these models and relating them to available models for similar systems.
2. To design, purchase, and construct a small-scale, complete hydrogen renewable energy system. The system was to be sized appropriately to realistically test out any design and control models and methods. The purpose was to enhance understanding of design, control, and interface issues.
3. To design and cost out a complete prototype system for a remote village in Alaska. Such a system would be finalized, purchased, and installed in the Phase 2 of this project.

Two additional objectives in Phase 1 were:

1. To identify and discuss any codes and standards appropriate to the deployment of integrated renewable hydrogen utility systems and provide recommendations that can aid in their commercialization. develop a business plan.
2. To develop a business plan indicating how this project would lead to the development, financing, operation and growth of a business that markets and deploys integrated renewable hydrogen utility systems.

Phase 1 Implementation

Economic Evaluation/Systems Analysis

We needed a robust, simulation software system for this analysis activity. To meet our objective, we had to be able to model the behavior of the individual components of a system as well as their complex interactions. The simulation platform software also had to be able to model electrolyzers, hydrogen storage, and fuel cells directly. With these as our criteria, we chose TRNSYS as the system simulation software platform on which to base our models.

Before selecting TRNSYS, we considered other similar software packages including HOMER, ViPOR, and HYBRID2. HOMER is designed to determine optimum system configurations, but it is not able to model the behavior of individual components of the system and their complex interactions. ViPOR is primarily focused on optimizing a grid layout. Although we concluded that HYBRID2 can approximate the operation of our renewable hydrogen system and examine the behavior of individual components over time, it currently models only wind, photovoltaic, diesel, and battery systems and is not capable of modeling electrolyzers, hydrogen storage, or fuel cells directly.

Economic modeling and analysis of system costs were accomplished by Stuart Energy and a summary of results are provided in Attachment 2. DRI established a model based on a first-order operating optimization where the power to the load can simultaneously come from the renewable and the fuel cell. This begins to reduce the renewable power requirement. Since, the electrolyzer is also sized to the renewable peak source, this reduction is important in lowering the capital cost of the full system. Improvements in the model, and in resulting physical systems, are expected in the second phase of this project.

The first-order model uses an electrolyzer with a peak power the same as the renewable resource:

$$P_E = P_R$$

When the renewable is available, as much renewable power as possible is directed to the load; and the excess is sent to storage, ranking batteries higher than electrolysis. The renewable capacity factor Cf_R defines the fraction of time that is possible. As a result, the total power required, then, to assure renewable power with a direct and storage route is a function of the average load power Pl_{AV} ; the renewable capacity factor; and the conversion efficiencies for the electrolyzer, the fuel cell, and the compressor (η_E , η_F and η_C).

$$P_E = P_R = \frac{(1 - Cf_R) Pl_{AV}}{Cf_R \eta_E \eta_F \eta_C}$$

The above relationship is a part of the complex description of the combined design and control

algorithms that are necessary to assure the best opportunity for deployment of renewable hydrogen utility power systems. The development of this complex modeling capability will also support the intelligent systems necessary for more general integrated and distributed power systems. Figure 3 shows a partial set of interrelationships that are necessary to optimize the design of an integrated, remote, hydrogen power system. The system interrelationships necessary to optimize the control system that will be used to operate an integrated hydrogen power system can be described in a similar way.

Figure 3. A sample of the relationships necessary for optimization of the design of a renewable, hydrogen power system.

One important modeling improvement that will be made in Phase 2 is the addition of mesoscale climate modeling and data analysis. The addition of the information provided by mesoscale modeling can assure a given confidence integral for expected wind availability for some forecasted period of time. The confidence integral-projection time relationship is site dependent and, once known, can be employed to reduce both the system capital cost and the operating cost.

Examples of economic and systems analysis for potential installations in Alaska are included in this report (Figure 8 and Attachment 1). These analyses indicate that the concept of hydrogen storage can be economically viable and is technically feasible. Early trade studies have shown that the system cost can be reduced with the addition of standby fuel or power. This can be a

separate diesel generator, or fuel supply and reformer connected to the existing system fuel cell. Operation of the standby power is not necessary; but, as an option, it softens the engineering constraints on the full system.

We have evaluated the component cost range for the return power components within a hydrogen system specifically designed for an application in Alaska (powering the local radio transmitter). The load would vary from 13.5 to 20 kW. The hydrogen-fueled power sources evaluated included PEM fuel cells, alkaline fuel cells, and internal combustion (ICE) generator sets. We received cost estimates for each technology, and the costs ranged from \$60,000 to \$600,000. The lowest cost was represented by an alkaline and PEM fuel cell option. The ICE was approximately \$120,000 for a first developed prototype, and a first developed prototype PEM fuel cell was the highest at \$600,000.

Small-Scale, Complete Hydrogen Renewable Energy System

To test our models and others, such as HYBRID2 and HOMER, we have designed, purchased, and installed a complete, small-scale, renewable, hydrogen, fuel cell power system. This effort was accomplished using funds appropriated by the Nevada Legislature in a program (Applied Research Initiative) designed to encourage economic development in the state. The system includes the following:

- two 1.5 kW wind turbines
- 2 kW of solar PV on trackers
- a 2 kW PEM fuel cell stack
- a 5 kW unipolar electrolyzer
- a hydrogen storage tank and compressor
- a 5 kW computer-programmable load, a data acquisition system,
- a computer-based control system with analysis software

Because the output of the system is sufficient to power the average home, this system is classified as a residential-scale, renewable hydrogen fuel cell utility system (RRHFUS). The system configuration is shown in Figure 4.

All of the components for the RRHFUS were purchased in early FY 99. The wind turbines were installed on 80-foot tall towers in June 1999 and are operational. The rest of the system was completed in October 1999. The wind turbines have anemometers associated with them, and the solar panels will have pyrenometers so that the system performance can be related to the actual input of solar and wind power.

This system also permits the interchange of individual components, allowing performance analysis and comparison of these components in a system environment, critical for future system designs. The intent is not to validate product performance of specific vendors as much as it is to identify which components are best for specific applications, recognizing that the breath of applications covers the specifications of all vendor products.

Figure 4. Schematic showing completed test facility and refueling station at DRI's Northern Nevada Science Center.

Separate, high-current power lines from each of the two solar arrays and each of the two wind turbines run into the laboratory so that any combination of wind or solar renewable resource can be connected to the power control system. All of the renewable power input, the power to the electrolyzer, the power from the fuel cell, and the power to the inverter and load are connected in common to a 24 VDC bus bar. The configuration for this is shown in Figure 5, with photographs of the primary components.

The following is a detailed description of the system and each primary component:

System Design Concept: The system is designed around a DC bus bar. The bus bar allows electricity to come from multiple sources and go to multiple sinks all from one point (or electrical "node"). Electricity produced by the solar photovoltaic panels and wind turbines flows to the bus bar. A continuously variable, resistive electric load draws electricity off the bus bar. If the amount of power being produced by the renewables is greater than the amount being drawn by the load, then the computer control system turns on the electrolyzer. The electrolyzer draws electricity from the bus bar and uses the power to electrolyze water into hydrogen and oxygen. The oxygen is vented to the atmosphere, while the hydrogen is compressed to 125 psi and stored

in a tank. If the amount of power being produced by the renewables is less than the amount being drawn by the load, then the computer control system turns off the electrolyzer and turns on the fuel cell stack. Hydrogen flows from the storage tank to the fuel cell stack, producing electricity. That electricity goes to the bus bar and then to the load. A small set of batteries is connected directly to the bus bar to help regulate the bus bar's voltage and to provide "peak power" during the brief periods when the load draws more power than the fuel cell can produce. With this system design, the load is always supplied with renewable electricity.

Figure 5. Interrelationships of primary components in RRHFUS

Wind Turbines: Two Bergey Wind Corporation BWC1500 wind turbines produce a total of 3,000 watts of electricity in full wind. Each turbine is mounted on an 80-foot tall Rohn 25G lattice tower. The turbines produce unregulated AC electricity, which is conditioned and regulated by a rectifier before it is sent to the DC bus bar.

Solar Photovoltaic Panels: Two arrays of PV panels produce a total of 2,000 watts of electricity in full sun. Each array consists of ten Siemens SR-100 single crystal modules mounted on a Zomeworks passive tracker. The trackers use refrigerant in tubing to track the sun throughout the day, allowing the PV panels to receive more insolation than if they were fixed on the ground,

but with a simpler mechanism than a computerized, motor-driven tracking system. A battery charger regulates the electricity from the PV panels before it goes to the bus bar.

Load Simulator: The load simulator is a Simplex Swift-E test load bank. The simulator can draw a maximum of 5,000 watts of AC electricity and is meant to simulate a house. The load bank contains six resistors that draw different amounts of power when switched on. The resistors are controlled by solid state relay switches, which are in turn activated by the system's control computer. In this way, the test load can be used to simulate the varying amounts of electricity drawn over time by a real load, such as a house. Between the bus bar and the load is an inverter, which converts the 24VDC electricity from the system into 120VAC electricity for the load.

Electrolyzer: The electrolyzer is a Stuart Energy SunFuel 5000. It can draw a maximum of 5,000 watts of power and uses that power to produce up to one normal cubic meter of hydrogen per hour. It produces the hydrogen in 13 potassium hydroxide (KOH) cells. The cells with their "balance of plant" (e.g., water seal, compressors, pumps, plumbing, etc.) are housed in a modified ISO shipping container, similar to those transported on 18-wheel trucks. The electrolyzer's operations are controlled by its own "programmable logic controller," or PLC built in by the manufacturer.

Fuel Cell Stack: The system uses an Analytic Power FC-3000 proton exchange membrane (PEM) fuel cell stack. It has 64 cells and can produce approximately 2,000 watts at full power. The stack requires "balance of plant" equipment to operate including a coolant pump, heat exchanger, fan, and an air compressor.

Batteries: Four Trojan L-16 deep cycle batteries are used for peak power.

Data Acquisition and Control Computer: National Instruments' LabVIEW software runs on a personal computer to collect data from the system and control the fuel cell stack and electrolyzer. The computer is ruggedized to allow it to be used in cold climates. National Instruments' FieldPoint hardware is used to process the incoming and outgoing signals.

Simulation Software: All the system simulation work will be accomplished using TRNSYS 14.1. This software was developed by the University of Wisconsin and is used worldwide for simulation of energy systems.

Prototype System for a Remote Village in Alaska

The concept of a remote hydrogen renewable power system in Alaska originated with DRI faculty in 1993. Motivation for installation and use of such a system in Alaska includes the following:

- Alaska has about 200 separate utilities, 95% of which use delivered diesel fuel.
- Power costs outside the large Alaskan cities is \$.25–\$1.00/kWh.

- Federally mandated cleanup of diesel fuel sites is estimated to cost more than \$700 million.
- The components necessary for an integrated renewable hydrogen power system are available and financially viable for use in remote applications.
- Rural Alaska exhibits important characteristics common to a large fraction of the world where natural energy sources and local economics favor remote, renewable power.

DRI, in conjunction with the Kotzebue Electric Association (KEA), has begun exploring the opportunity to install a renewable hydrogen power system for practical use in Kotzebue, Alaska. Working with the KEA, we have developed a plan for the installation of this first system in conjunction with an already operating wind turbine array. KEA has led the world in demonstrating viable, renewable energy options for remote regions by installing ten 65 kW wind turbines and displacing a significant quantity of more costly and polluting diesel fuel. Currently, diesel generators are still required to provide power when the wind turbines are not operating. DRI and KEA have agreed in principle to install a hydrogen energy storage system in conjunction with the wind turbines. This will power a load in Kotzebue, independent of the diesel generators and regardless of the wind.

Kotzebue exhibits the characteristics of numerous remote communities worldwide where integrated renewable energy systems have yet to be deployed. First is the existence of an operating and abundant renewable wind source. Second is the presence of a well-trained workforce as well as physical plant and operating resources within KEA. Another important consideration is that the Village of Kotzebue has at least one commercial load whose management has agreed to isolate the load from the local grid to test the system under real conditions.

A team of representatives from DRI and DCH Technology met with the KEA, local permitting authorities, and other Alaska entities in June 1998. A complete discussion of that visit is included in the September 21, 1998 Status Report included as an attachment to this report. We developed a plan to integrate a 20 kW hydrogen power system with the output of three 65 kW wind turbines and a local utility load. Initial options and specific designs have been completed and are described in Figures 6 and 7, which show two of several different system designs for remote Alaska.

Additionally, we considered two other villages (Kivalina and Wales) which are also serviced by KEA. Both have greater wind capacity than the Village of Kotzebue. Discussion on the issues associated with these two villages is in the attached September 21 report.

In the first Kotzebue example (Figure 6), the complete hydrogen storage power system is geographically located at the wind turbine site, approximately three miles from the village. Adjacent to the wind turbines is the transmitter for the local commercial radio station KOTZ, which has a power requirement of approximately 14 kW. In this system, a 20 kW fuel cell is used to power the transmitter and heaters used periodically to maintain temperature within the transmitter shack. The electrolyzer will draw power from the equivalent of three wind turbines, proportional to the wind turbine output at any time. This design is a self-contained, remote, renewable power system using hydrogen storage supplying a variable utility load.

Figure 7. Wind-hydrogen scenario for piping hydrogen into Kotzebue Village for powering independent loads with fuel cells

The use of a fossil fuel storage system, such as propane, and a reformer to soften the design requirements on the system is shown in both figures 6 and 7. The use of fossil fuel back-up may not need to be employed in either of these two examples however. Instead, in the KEA prototype systems, the use of a switchover to the main village diesel power grid can simulate the use of a standby fuel reservoir and a reformer attached to the fuel cell.

Costing of System Options in Kotzebue

Cost estimates for the installation of the system configuration for powering the KOTZ radio transmitter were obtained using a model that does a first-order optimizing of the renewable resource power and electrolyzer power required based on the system efficiencies. The operation that provides parallel power delivery to the load and the electrolyzer was considered to reduce the peak power requirements. The model provided the system capital, installation, and permitting costs.

Three other examples of capital and installation costs (Kivalina Village, St. George Island and Kotzebue Village) were considered to show the effects of economy of scale and situational opportunities, such as renewable capacity factors.

Sixty miles north of Kotzebue on a barrier island is the Village of Kivalina, Alaska. Kivalina has a 125 kW average load and is currently powered by diesel generators. Recently, Kivalina residents elected to move the entire village and power system several miles to the mainland. An early estimate of the cost for this move is \$50,000,000. Kivalina is in a very good wind regime, so we looked at the possible cost of a completely autonomous, non-fossil power system for the village. Since there are no pre-existing wind turbines in this case, we included the cost of a wind turbine array in the model. This estimate shows that the entire town can be powered with wind energy and a hydrogen fuel cell with the system cost that adds approximately 10% to the cost of the move of the village.

Three hundred miles north of the Aleutian Islands are the two Pribilof Islands of St. Paul and St. George. Several years ago, we studied the possibility of deploying a wind-hydrogen power system to that community. The Village leaders and the local Aleut Corporation were supportive of the concept. The wind capacity factor there is well in excess of .35 and there are several local advantages to the addition of new and independent power. The community load averages 125 kW with a 195 kW peak.

The Village of Kotzebue has a population of approximately 3200, and has an average power consumption of 3,300 kW. The utility (KEA) has 11,000 kW of installed diesel generating capacity with a 4,200,000 gallon diesel fuel supply in the village. KEA recently installed ten 65 kW Atlantic Orient wind turbines in an area approximately three miles from the village. Power from the turbines is sent to the village on a 7000-volt transmission line and interconnected to the grid.

Model simulations were run for the four examples in three different time frames: today, the near-term (approximately 5 years out), and the far-term (approximately 10 years out). The expected capital costs of the major components were used in the out-year examples. These cost projections are based on statements from the electrolysis and fuel cell industries, and we believe the projections are reasonable. The results are plotted in Figure 8. The tabular information is shown in detail in Attachment 1, with key parameters highlighted in gray. For the example of the KOTZ radio transmitter, Table A1-1 includes two examples of the amount of energy storage. The data shows that increasing the energy storage by 200% only increased the installation and capital cost by 41%. This is a major advantage of hydrogen storage over battery energy storage for time periods greater than a few days, because with hydrogen the energy storage can be optimized separately from the power delivery.

Two significant variants, illustrated in Table A1, are the cost of the fuel cell and the amount of hydrogen storage capacity. For a 20 kW fuel cell stack, meeting predetermined performance standards, we have found that the price varies from \$60,000 to \$600,000 depending on the manufacturer. The large variation in fuel cell cost is an indicator of the youth of the industry, leading to the conclusion that near-term reductions will permit integrated hydrogen systems to be competitive. The 20 kW fuel cell cost chosen for the KOTZ transmitter scenario in today's time frame was \$180,000.

Figure 8. Model results for system capital cost scenarios at four possible locations. Each scenario was run for three different time periods to show the effects of expected cost reductions on the market possibilities for renewable hydrogen power systems. In all the examples other than the KOTZ radio transmitter, the model included the cost of renewable power production (wind energy in these examples).

In all the examples, (except for the Kotzebue radio transmitter) the installed capital cost projections for the near-term (less than \$15/W) and far-term (less than \$10/W) look favorable for isolated locations. One comparative example is a new diamond mine in Northern Canada that recently installed a 25,000 kW diesel power plant at approximately \$25/W.

It is expected that several factors will influence a reduction in the installed costs. Refinements in the integrated hydrogen system designs and the control methods are expected to play a major role in that cost reduction. Those refinements will be facilitated as more model improvements occur and as the operation of the RRHFUS physical system model shows the behavior of realistic, integrated systems.

Participation of Team Partners

The project team is made up university, industry, utility, and government participants. The partners, their capabilities, and the nature of their participation are described below.

DCH Technology (DCH)

DCH is a leader in advanced hydrogen sensors and safety system engineering. DCH has recently acquired rights to manufacture a PEM fuel cell design from Los Alamos National Laboratory (LANL). The new performance characteristics of this PEM stack are specifically beneficial to remote and arctic applications. DCH's contributions will include:

- Hydrogen sensor and safety systems
- Hydrogen safety engineering
- Hydrogen codes and standards development
- Adiabatic, 5 kW PEM fuel cell stack(s) licensed from LASL - with proprietary design features favorable for remote power systems
- Hydrogen safety training

Nevada State Energy Office (NSEO)

NSEO has been a major supporter of renewable, hydrogen, and fuel cell development in Nevada. The office is providing additional funding support for this project and is also experienced in the identification of market niche applications for distributed and remote power (Nevada currently has approximately 10,000 remote (non-grid) utility customers). NSEO has recently begun supporting DRI in project management related to advanced utility and transportation energy issues. Their contributions will include:

- Project management support
- Energy system site analysis - western U.S.
- Hydrogen energy system codes and standards development

Los Alamos National Laboratory (LANL)

LANL and DRI have been working together identifying applications for distributed power and isolated, renewable power systems for the western U.S. LANL is currently working with several near-term developers of remote neighborhood, reservation, and community power systems in New Mexico. We have met on several occasions with interested business and financial parties to understand the potential for hydrogen storage in the desert Southwest. LANL is also a major developer of PEM fuel cell technologies. Their adiabatic stack is a prime candidate for remote applications. Their contributions will include:

- Definition of reasonable, early sites for renewable, hydrogen utility systems in New Mexico and the desert Southwest.
- Design and development for a site in the Southwest.
- Strategic planning for distributed power systems worldwide
- Fuel cell system support

Stuart Energy Systems, Ltd. (SES)

Stuart has been a manufacturer of unipolar, potassium hydroxide electrolyzers for several decades. The company is currently developing a new design with acquisition costs low enough for use in utility power systems. Stuart was also the first U.S. electrolyzer company to

participate in the development of renewable, hydrogen utility systems for Alaska and remote locations. Company engineers began developing a model for remote, renewable, hydrogen, fuel cell systems in 1993 in support of our first approach to deploying such systems in remote Alaska. Stuart's contributions will include:

- Assisting in model development and running model alternatives
- Providing an electrolyzer for KEA with the same performance as the electrolyzer at DRI.
- Supporting of codes and standards development
- Developing of integration scenarios

Proton Energy Systems (PES)

PES is a developer of solid polymer electrolyzers and unitized regenerative fuel cells (URFC). The URFC is a single electrochemical component with potential for reasonable reversibility permitting both electrolysis of water and power production from hydrogen. PES's contributions will include:

- Providing a URFC to the DRI Reno facility to compare performance with conventional electrolyzers and fuel cells
- Providing a solid polymer electrolyzer for DRI's system to compare its performance to KOH electrolysis
- Offering a candidate electrolyzer for KEA system.

Kotzebue Electric Association (KEA)

KEA is a world leader in the use of wind power in small utility applications. The Association has a 3MW village load and currently have 0.65MW of wind power installed, with plans for an additional 1MW. KEA is a remote Alaska utility with a workforce capable of operating and maintaining a complex utility system with energy storage, something critical to the success of new systems such as the one planned in this project. KEA's contributions will include:

- Arctic engineering for the KEA system
- System engineering support
- Logistics support for system implementation in Kotzebue
- Provision of protective shelters for equipment
- Providing lodging for team members while in Kotzebue

Northern Power Systems (NPS)

NPS is a contractor to KEA and has extensive experience in designing, building, and deploying isolated power systems. The company is a wind turbine manufacturer with a product for small and isolated power markets. Company engineers have designed modifications of grid-connected wind turbines to permit grid-independent operation. NPS's contributions will include:

- Design of modifications for grid-independent operation of AOC 15/50 wind turbines.
- Power system integration
- Installation of grid independent modifications in KEA system

Northwest Power Systems (NWPS)

Northwest Power Systems is a developer of fossil fuel reformers capable of providing hydrogen for fuel cells with very low CO concentrations. This is the result of employing their palladium-silver membranes as hydrogen separators in the output stage. The presence of a diesel supply and adequate reformer reduces the cost of the rest of the renewable hydrogen system and still

permits it to be a renewable system. The company's contributions will include:

- Providing a 10 kW reformer as a hydrogen supply backup.
- Training in system operation and maintenance

NRG Technology

NRG is an energy system development company with experience in hydrogen engines. The company has completed a design for a high efficiency, hydrogen-specific ICE genset. NRG will provide a candidate hydrogen-specific ICE genset to operate in the same capacity as a fuel cell in the DRI Reno system or in the Alaska system, if selected

University of Nevada, Reno (UNR)

The Mechanical Engineering Department of UNR will provide engineering support for the thermal integration of renewable systems employing hydrogen production and power production from hydrogen. This support will be extended to the KEA system design. The Department will also provide engineering support for closed loop water management systems for hydrogen electrochemical systems.

Bergey WindPower Company (BWC)

BWC is a manufacturer of small wind turbines with thousands of turbines deployed worldwide. Their BWC-1500 turbines are used in the DRI test facility and are designed to be grid independent or intertied. The grid independence is important to future remote hydrogen installations. BWC will provide a 10 kW turbine for use in the wind profiler.

Codes and Standards:

Given the innovative nature of renewable hydrogen energy systems, it is not surprising that codes and standards for these systems are in a formative stage of development. The leading authority for development of these standards is the Organization for International Standardization under ISO TC197. As it stands today, project approval agencies considering a hydrogen energy project proposal would refer to the different component-specific codes which exist for industrial hydrogen applications and to the natural gas energy applications which form the precedent base for hydrogen energy standards currently under development. The relevant codes for reviewing the major components of the system proposed for Kotzebue are as follows:

Wind Turbines: The wind turbines would be constructed according to applicable building codes and would be designed for the applicable wind loading and temperature range. Underwriter's Laboratory (U/L) is developing a certification procedure for stand-alone inverter grid interconnect protection. The Society of International Electrical and Electronic Engineers is developing distributed power systems grid interconnect standards – IEEE SC 21.

Electrolyzer: Although no electrolyzer-specific codes exist, the electrolyzer would be built according to well-established hydrogen plant design principles. Electrolytic hydrogen plants have a "100 plus year" history of industrial operation. Stuart Energy, through its parent company, The Electrolyzer Corporation, has been supplying industrial hydrogen plants for more than 50 years.

In general, considering the design of an electrolysis plant, the interior of the plant is a Class 1 Div 2 Group B area for purposes of electrical classification and occupancy. For smaller plants, a certified hydrogen gas detection area sensor coupled to a continuous ventilation system of adequate capacity (at least five air changes per hour) could be installed to allow the occupancy to be de-rated to normal occupancy according to provisions in the National Electrical Code (NEC). Piping would comply with ANSI/ASME B31.3. Components, including valves are certified to meet or exceed working pressures in the system. The hydrogen produced should meet the purity specified in ISO/TC 197 “Hydrogen Fuel-Product Specification.” Hydrogen vents from pressure relief devices would have to be directed outdoors in compliance with NFPA 50 A.

In the long run, electrolyzers may become standard energy appliances; and development of product specific standards for manufacturing may evolve, whereby the electrolyzer will obtain product class approval by U/L or Factory Mutual (F/M).

Storage: The storage would be sited according to NFPA 50 A. The vessels themselves would be certified for the range of working pressures and temperatures and constructed according to the ASME Boiler and Pressure Vessel Code Section VIII. Following convention and given the remoteness of the site, a flame sensor would be used to detect if a fire is present.

General Piping: General piping would comply with ANSI/ASME: B31.3 Process piping standards, B31.8 Gas Transmission and Distribution Piping Systems, and B31.2 Fuel Gas Piping. A key issue to approval will be detection of leaks. In the case of residential piping for natural gas, an odorant is injected into the gas. As yet, no odorants have been identified for hydrogen as sulfur-based compounds used in natural gas (such as Mercaptans) are incompatible with PEM fuel cells. Electronic area detectors for hydrogen have been approved on a project-by-project basis. Generally speaking, detectors need to be certified for the application by a certification agency such as Underwriters Laboratories (U/L) or Factory Mutual (F/M).

Fuel Cell: Fuel cell codes and standards are under development including International Electrical Code (IEC 105) and domestically under the International Electrical and Electronic Engineers (IEEE SC21). The operation of the natural-gas-fueled ONSI Phosphoric Acid Fuel Cell provides a precedent for hydrogen fuel cells. One of the key issues in operating hydrogen fuel cells will be leak detection as indicated in the General Piping section. As with small electrolyzers, it seems likely that a product class certification will evolve for these systems.

Phase 2 System: The project at Kotzebue—as one of the first systems incorporating wind, electrolysis, compressed gas storage, and fuel cells in an arctic climate—will be an important precedent for acceptance of future systems. As part of design acceptance by the customer, the safety of the project will likely be considered through a structured safety design review process such as a system HAZOPS. Phase 2 of this project will involve a safety review as well as a review of codes to ensure adequate protection at reasonable cost in order to expedite approval of future projects of this type.

Business Plan

“Renewable Hydrogen Energy Consultants Group: A Consortium of Partners for Marketing Power Systems in Isolated Locations”

Introduction

Opportunity

The objectives of this project are to develop algorithms, models, and decision making tools that:

- provide the ability to identify market opportunities for renewable hydrogen utility systems,
- design optimum systems for any given location, and
- supply the operating control system for a renewable hydrogen system that minimizes the cost of electricity for the specific design and environmental conditions.

Once developed, these tools can be the basis for establishing a business the purpose of which is to market renewable hydrogen utility systems. The type of business envisioned would employ the decision making tools and models to identify situations where a sustainable market exists; identify the likely customers; secure contracts to provide a system; and then design, deploy and service renewable hydrogen power systems for the identified customers.

We anticipate that a business can develop as a result of this project through which team members with the appropriate combination of capabilities form a company taking advantage of the products and situational advantages developed during the course of this project. For the purpose of this business plan, we propose the formation of a company to be called the Renewable Hydrogen Energy Consultants Group (RHECG).

Mission

The primary mission of RHCG is to develop renewable hydrogen energy systems capable of providing power in isolated locations with new installations or by replacing the existing energy infrastructure in remote locations where fossil fuels are used today. The team assembled for this DRI project is exploring the possibility of evolving a business unit for the development and deployment of renewable hydrogen power systems, and related technologies. To achieve this goal, the RHECG will fund the development of this business unit from revenue earned initially by selling its technology and expertise.

In meeting its mission objectives, the RHECG will market its expertise and technology through consulting agreements and technology licenses to Renewable Hydrogen Utilities (RHU). Working with its suppliers and technology co-developers, the RHECG will also be able to

market system designs and equipment (and even “turn key” systems) to the RHUs through joint ventures formed with these partners.

Keys To Success:

Key to achieving the economic benefits of these systems will be meeting component cost targets including:

- Achieving cost targets in fuel cells. Important to near-term cost goals will be the successful adoption of fuel cells in the transportation sector, which will bring the cost of the fuel cell stack onto a pathway of \$50/ kW. Ford, GM, DaimlerChrysler, Toyota and Volkswagen have all announced their plans to market fuel cell vehicles in the 2003-2004 time frame. By achieving these stack costs, the fuel cell power plants should fall in line with fuel cell company estimates of \$500 - \$750/kW.
- Creation of a hydrogen supply infrastructure which will rely in part on electrolytic fuel appliances. This will result from the successful introduction of fuel cell vehicles and will broaden the business of fuel appliance supply reducing the cost of electrolytic hydrogen appliance systems to \$250/kW in the same time frame, reducing costs in synch with the fuel cell.
- Continued growth in volume of production of wind turbines (20% per year) should reduce cost, as well as improve product quality and reliability, meeting the near-term cost targets of \$1/W in 2005 and \$0.75 per W in 2010. The USDOE Windpowering America Program, with a goal of wind power providing 5% of the United States power demand by 2020, will help accelerate the pace of meeting these cost targets.
- Increasing volume of production of photovoltaics, thereby achieving cost targets of \$2 per watt by 2005 and \$1.50 per watt in 2010.

Underlying initiatives and environmental concerns which will contribute conditions for success include:

- The removal of government subsidies which reduce current electricity prices making renewable hydrogen energy systems less competitive.
- Governments want to shed responsibility for providing energy to remote communities.
- As the real cost of energy in remote communities is realized, and capital becomes available, alternatives such as renewable hydrogen will be considered more seriously.
- Awareness in remote communities, including the far North and island villages, of the impact of global climate change. For island communities, the concern of rising ocean water levels threatens their existence. For northern regions, where mean temperatures are expected to rise at a rate 3-4 times faster than medium latitude regions, the potential impacts on permafrost, vegetation, and wildlife threaten the future viability of existing communities. These communities want to find alternatives to fossil fuels so that they can voice their concerns from a position of strength.
- Excessive costs for permitting new fuel storage for diesel-fueled facilities in remote locations and in bringing noncompliant fuel storage sites into compliance.

Finally, success will depend on achieving the following milestones in DRI's business plan:

- Formation of strategic relationships with stakeholders in the industry - including local utilities such as the Kotzebue Electric Association, and key suppliers such as Stuart Energy USA and DCH Technology, Inc. - to develop, and market renewable hydrogen products.
- Successful demonstration of technology at the DRI test site in Reno, Nevada and in the prototype demonstration in Kotzebue, Alaska.
- Successfully building niche markets through providing energy systems for remote scientific research stations.
- Creation and access to key intellectual property arising from the development of these systems, including patented or proprietary know-how for design methodology in the form of computer models, measuring methods needed for site assessments and feasibility studies, energy planning tools, and hardware in the form of control systems needed for the system to operate.

Corporate Summary

Ownership

Founded in 1959, Nevada's Desert Research Institute is a nonprofit research center for environmental studies and "sustainable" energy technologies. DRI is a member of the University and Community College System of Nevada, which also includes the University of Nevada, Reno and the University of Nevada, Las Vegas. A profile of the Institute's activities is included in Attachment 4. One of the central initiatives undertaken by DRI is the creation of an Energy Research and Development Group to investigate and develop sustainable energy technologies. New technologies will address basic issues in three key areas related to energy:

- the environmental issues of global climate change and air quality
- the risk to energy security resulting from the imbalanced geopolitical distribution of world energy resources, and
- the challenge of international economic competitiveness for new energy technology markets.

One of the energy technology solutions being pursued by DRI is the use of hydrogen as an energy carrier for connecting renewable energy systems, such as photovoltaic and wind energy, to applications such as transportation, home cooking, heating, and light. The initial opportunity for these systems is in remote communities where high power prices are paid for electricity generated by diesel power plants.

The DRI team members are involved in development of fuel cell systems and integration of renewable energy with electrolysis for hydrogen production. Based on this initiative, DRI is working to increase its capabilities for research in hydrogen energy systems. Included is the basic research and training of graduate students in this field. The technology and "know-how" developed in this, and other, research projects will be available through technology licensing and technical consulting to the Renewable Hydrogen Energy Consultants Group (RHECG). The

Desert Research Institute has considerable experience marketing consulting services with more than 85% of its operating costs paid from research contracts. DRI contract-funded research and technical services are carried out throughout the United States and the world.

DRI has also established a research park to function as a business and high technology incubator. The on-site environment, coupled with access to DRI energy research resources and University of Nevada faculty and students will be a critical benefit to the RHECG. Being co-located with DRI, RHECG can access expertise, and technology from DRI through agreements and provide additional technology in support of its commercial mission.

In pursuing the opportunity of renewable hydrogen utilities, RHECG would develop expertise, designs, and software in partnership with key equipment suppliers. The technology in the form of patents and know-how then would be licensed to the users (Renewable Hydrogen Utilities). Revenues earned by RHECG would be in the form of payment for design consulting, project management, training and royalty payments on unit sales of system embodying technology developed initially by DRI, and by RHECG.

Locations and Facilities:

DRI is located in the Dandini Research Park in Reno, Nevada. The Institute provides an excellent test site for testing wind and solar energy systems, laboratories for equipment testing, and an excellent team of technical support personnel. When the activities of the RHECG grow from the two-phased development project, it is likely that RHECG would occupy a site in the incubator at Dandini Research Park.

Products/Service

Product Definition

The product is embodied in the design and control methodologies and the system integration engineering needed to build renewable hydrogen energy systems. The systems are based on intermittent renewable energy (such as wind or PV), an electrolytic fuel appliance with compressed gas storage, and a hydrogen fueled power source (such as fuel cell or motor generator set). The systems are designed to serve remote, off-grid applications currently met by diesel power generators and ranging in size from single load applications of 1 kW to the power needs of small towns with loads in excess of 10 MW. The product includes the design and installation of systems designed with the RHECG design and control methodologies.

The methodologies include the models and measurement techniques required to design a hydrogen energy process based on available renewable energy and the energy demanded by the application. This will allow us to estimate the size of the power system needed, in particular, the renewable generator, electrolysis appliance, volume of gas storage, and fuel cell. Controls and integration engineering involve the hardware and software needed to optimize the operation of the system.

Competitive Technologies

The competitive options to renewable hydrogen for stand-alone energy systems are:

Conventional Diesel

- Strengths: Proven, works anywhere.
Strong cost advantages if area has limited renewable energy resources.
- Weaknesses: Non-sustainable.
Lost economic opportunity if oil is imported.
Environmental impact due to spills and emissions.

Renewable Electric Using Battery Storage

- Strengths: Improved efficiency and simplicity in smaller units (< 1 kW) results in lower cost, smaller electricity generator.
- Weaknesses: Not practical on larger scales due to cost of battery maintenance.
Not practical when the quiescent periods of a renewable exceed a few tens of hours because of the inability to simultaneously optimize power in/out and energy storage.
Reduced performance at temperature extremes.

Hydrogen Bromide (HBr)

- Strengths:
- Improved efficiency and simplicity in smaller units (< 1 kW) results in lower cost, smaller electricity generator.
- Weaknesses:
- Unproven technology.
 - Need to store two toxic chemicals (Br and HBr) plus hydrogen.
 - High toxicity of bromine (0.1ppm) and hydrogen bromide (3ppm).
 - Additional capital and operating costs due to increased safety requirements and operating procedures.
 - Additional permitting costs and challenges.
 - Uses bromine as the oxidizer of hydrogen instead of atmospherically-abundant oxygen, and HBr as the stored product instead of water.

Sourcing

Equipment needed to build renewable hydrogen energy systems will be sourced from a wide number of qualified suppliers. The RHECG will establish strict requirements with equipment suppliers to make sure that equipment specifications are met. Strict equipment evolution and testing procedures will be adopted, and, in some cases, joint technical development will be pursued.

Market Analysis

Industry Assessment

RHECG will achieve its goals by offering a new and unique product to the market. By being the first to demonstrate a “stand-alone” renewable hydrogen energy system in a community energy application, RHECG will position itself as a technology leader in this area. The emerging center for hydrogen energy technologies at DRI can become a nucleus for companies developing components for these and similar systems. Strategic partnerships will be struck with key suppliers. The renewable energy and fuel cell industries will be in an excellent position to finance such partnerships as they are in a rapid growth phase, with shipment of wind energy systems expected to increase at an average rate of 25% per year for the next five years, and with major transportation and utility fuel cell markets opening over the next five years. As the penetration of wind energy into the market increases, the need for energy storage will become more apparent.

The use of renewables to offset fuel consumption is already being adopted, making economic sense where the wind resource is strong and transportation fuel costs approach \$2 per gallon. As the cost of diesel fuel increases and the cost of wind energy decreases, there will be growing pressure to increase penetration of wind energy into the grid. Penetrations as high as 50% have been demonstrated at some locations. Higher rates of penetration will improve the economics of introducing hydrogen and fuel cell systems.

Market Analysis

The initial market for these systems will be small power utility demonstrations (e.g., Kotzebue, AK) and renewable energy systems for scientific research stations (e.g., White Mountain Research Station, CA or Antarctica). RHECG is ideally positioned to market the systems because of DRI's extensive research network around the world and its collaboration with Northern Power Systems, a provider of remote power systems worldwide (including wind, solar, and fueled power plants in Antarctica). These initial niche markets will provide a testing ground to confirm the concept and test component technologies. After five years of successful operation in these applications, renewable hydrogen systems are expected to have established credibility in the electric power industry.

Market Plan

Implementation

By bringing products to market first, RHECG will establish a leading position within this technology area. Power utilities are very cautious and reluctant to replace systems of known reliability for new systems with unknown performance history. Typically it takes five years for products to qualify in the power sector (i.e., the operation of the system must be demonstrated for at least five years before it is implemented in a production capacity).

As a consequence, an extended demonstration phase is planned in which a small model system (10-100 kW) will be used to gain experience in the utility market. In addition, systems for research stations and exploration camps will be developed and sold. The use of hydrogen in these specialized applications with highly trained people will establish a valuable experience base for the use of hydrogen as an energy carrier. These early demonstrations will also generate precedence for codes and standards for design and construction of these systems. DRI, through its worldwide environmental research network, has excellent channels into this market.

Marketing Strategy

The marketing strategy is to establish a "first in the marketplace" position. Successful, well-publicized demonstration of the concept will attract new business partners and possible projects. In the first demonstration projects, the RHECG will act as the prime contractor and designer/supplier of these systems. Initially, the best projects based on lowest risk and highest strategic value will be selected. Later, using the analysis developed for design and project feasibility, new projects with the most potential value will be identified, and the potential customer will be appraised of the benefits.

Sales Strategy

Initial sales, during the five-year "proof of concept" period, will be to electrical utilities in the form of small demonstration systems of a standard size (10-100 kW). A limited number of systems will be sold during this first phase to ensure that the systems are well supported in the field. In addition, smaller systems (1kW – 10 kW) will be sold to scientific research stations.

After the technology enters broad commercialization in the electrical utility sector, it is envisaged that RHECG will play a leading role in providing engineering services for system design and feasibility, as well as software for supervisory control systems. Since the skills to operate these systems will need to be developed, training of local operators will also be required and can be supported by remote data communication.

Strategic Alliances

Key to RHECG's business plan is striking strategic alliances with key component suppliers for the wind turbines, electrolytic fuel appliances, power electronics, and fuel cells. Some development of these technologies will be needed for the successful integration of these components into systems. Undertaken as joint development programs with the suppliers, RHECG will add valuable design enhancements to these components and will gain preferred marketing rights and in some cases exclusive rights in certain markets.

Following recruitment of capable suppliers, RHECG will work with key power utilities such as the Kotzebue Electric Association to establish first demonstration sites. The first demonstrations will provide a valuable learning experience for future implementations. The pioneers will act as trainers and implementers in future systems, broadening the base of ability for supply of these

systems. As the systems move through commercialization, regional training centers will be established with local universities, colleges and trade schools. Certificates of training will also be developed.

Throughout the design and demonstration phase, support of the Department of Energy, state governments, and funding agencies for environmental research will be critical. Long-term commercialization in remote regions throughout the world will benefit from World Bank economic and environmental initiatives that will provide financing for these projects.

Service

Ongoing service for the systems will be provided by local service organizations. RHECG will set up models for these organizations and, along with key suppliers, will develop the training materials required for the transfer of expertise into these remote communities. Initially, DRI will serve as a training center; but as the materials are developed, they will be distributed to regional training centers

Organization

RHECG is in an excellent position to staff its organization. The company has the ability to draw on the research capabilities of DRI as well as the technical expertise of the other partners. Administrative support can initially be supplied by DRI and paid from project expenses on a project by project basis. As the level of RHECG's activities increase, there will be a need to locate outside DRI

Key positions:

- Chief Executive Officer: group leader responsible for general direction, strategies, and partnerships.
- Director of Marketing and Business Development: responsible for sales and marketing , development of sales force
- Technical Program Manager: responsible for technical direction, securing intellectual property.
- Individual project leaders : responsible for individual projects.
- Admin: responsible for payrolls, payables/receivables, budgeting and financial reporting.

Financing

As this is initially a consulting group, the first capital requirements are low and the organization can be grown on a "project by project" basis. Start-up expenses and seed capital to provide initial facilities and set-up will be provided by financing from component suppliers and industry partners.

Initial Implementation

The current technology development and demonstration program is pre-commercial. The schedule and milestones for the program is as follows:

Table 1. Implementation schedule of project and initial business phases

Phase	Completion	Goal
Phase 1 : Proof of Concept Demonstration	1999	Collect data, refine design models
Phase 2: Controls Development	2000	Develop and implement control strategy
Phase 3: Pilot Process	2001	System and component testing, refine design for scale-up
Phase 4: Demonstration	2002	Install first remote community power system

Financial Forecast

Phase I : Alpha Test: Proof of Concept Demonstrations

During the alpha test phase of technology development, DRI project activities will be cofunded by the continuation of support from the DOE Renewable Hydrogen Utility Program. The cost share for this project will be contributed by component suppliers and other research grants. The systems under alpha test in Reno, Nevada and Kotzebue, Alaska will be used as a proving ground to carry out technical marketing of wind hydrogen technology. During this period, the team of project partners will identify the business structure for commercializing the products of this project and establish RHECG based on that structure. During the formation of RHECG, participating parties will begin the identification and pursuit of market opportunities, employing the concepts developed under the Integrated Renewable Hydrogen/Utility Systems Project. During this time, the final business plan will be developed, defining the revenue-generating elements among specific intellectual property, consulting services, and sales and deployment of full or partial systems.

Phase II: Beta Test System Prototyping and Demonstration

During this phase, a limited number of demonstration systems will be established at select utility sites. This five-year period (shown in Table 2) will provide test data to determine reliability for system acceptance. At the same time, systems will be sold to identified niche markets (e.g., remote scientific research centers, repeater stations, small military applications, and exploration camps). It is anticipated that the systems will be in the 100kw range.

Table 2. Phase 2 - Beta Test System Prototyping and Demonstration

	Year 1	Year 2	Year 3	Year 4	Year 5
Units Sold	1	1	2	3	5
Total Units	1	2	4	7	12
Unit Cost	\$ 5,909,742.00	\$ 4,727,793.60	\$ 3,545,845.20	\$ 2,954,871.00	\$ 2,718,364.00
Sales Revenue	\$ 6,264,326.52	\$ 5,011,461.22	\$ 7,517,191.82	\$ 9,396,489.78	\$ 14,407,329.20
Less: CoGS	\$ 5,909,742.00	\$ 4,727,793.60	\$ 7,091,690.40	\$ 8,864,613.00	\$ 13,591,820.00
Gross Margin	\$ 354,584.52	\$ 283,667.62	\$ 425,501.42	\$ 531,876.78	\$ 815,509.20
Less: Salaries	\$ 240,000.00	\$ 262,500.00	\$ 408,750.00	\$ 510,000.00	\$ 787,500.00
Net Income	\$ 114,584.52	\$ 21,167.62	\$ 16,751.42	\$ 21,876.78	\$ 28,009.20

Barriers Encountered in Completely Meeting Project Goals and Results

As originally planned, the project was to lead to an installation of a renewable hydrogen power system in Alaska employing a 50 kW PEM fuel cell stack from our industry partner, International Fuel Cells (IFC). The value of this fuel cell constituted a significant cost share in Phase 2 (in excess of \$600,000, depending on how the stack was valued). Unfortunately, shortly after the contract was awarded, IFC instituted a new corporate policy of avoiding government funding that could encumber their intellectual property. They subsequently withdrew from our partnership, and the IFC PEM stack was no longer available for use in this project. As a result, a search and cost study of fuel cell stacks and systems was implemented in Phase 1. The results are discussed in this report.

The loss of a fuel cell provider as a partner resulted in the opportunity to survey the industry and understand the variations in cost, performance, and, more importantly, the expected evolution of these two fuel cell characteristics throughout the industry and across several fuel cell technologies. As a result, we have found an order of magnitude range in current costs for similar products and have recognized technologies other than PEM that can potentially provide greater long-term economic opportunity in this marketplace. We have acquired a fuel cell for the DRI RRHFUS and identified several excellent choices for replacement of the IFC stack for the Phase 2 system.

Additionally, we developed a clearer understanding of the level of strategic and market opportunities for hydrogen-specific ICE generators in light of the rapidly evolving fuel cell industry. This can aid in understanding the relevance and benefit of developing of this technology as fuel cells continue to evolve.

The State of Nevada, through the University Applied Research Initiative, provided funding for a complete, renewable, hydrogen utility system as an experimental resource to support the goals of this project. The system was designed and components purchased in July 1998, with plans to begin installation at the Northern Nevada Science Center (NNSC) in November 1998. The NNSC completion was delayed until May 1999, delaying completion of the renewable hydrogen system until October 1999.

The system is now installed and performing as expected. We are getting useful information on the real capacity factor for wind power in the northern Nevada, important new information for the State energy planning efforts. Additionally, exposure from the system's presence has generated positive public exposure for renewable solar and wind power, hydrogen energy systems, and fuel cells as an economic opportunity. Members of the university system, the renewable energy community, and the private sector have demonstrated a strong interest in all aspects of the research being carried out with the RRHFUS. The system is fully capable of providing important data on integrated, renewable energy performance under controlled scenarios, and on specific component performance.

Conclusions

Existing models for analysis of remote power systems were studied, and the modeling package TRNSYS was purchased. It is being modified for use with remote, hydrogen, fuel cell power systems. Other first-order modeling has shown a reduction of approximately 30% for renewable and electrolysis power when the control system permits simultaneous direction of power to storage and the load, as opposed to all the power being routed through storage. The peak power from the renewable and the peak power to the electrolyzer are the same. The peak power from the fuel cell or ICE generator is the same as the load peak.

An important refinement will result from the addition of mesoscale climate modeling, providing a known confidence integral for wind or cloud forecasting and softening the system engineering requirements. The system engineering requirements can also be softened and costs reduced by the addition of standby fuel or power. This can be a separate diesel generator, or fuel supply and reformer connected to the system fuel cell. Operation of the standby power is not necessary; but, as an option, it softens the engineering constraints on the full system.

A complete residential-scale, hydrogen, fuel cell system (RRHFUS) has been purchased and is currently operating at the DRI Northern Nevada Science Center location in Reno, Nevada. This system will be used to test models and control systems for future isolated renewable power systems. The system provides a unique opportunity for a wide range of experiments in integrated, renewable power system operation and can test system designs as well as individual component performances. The data from RRHFUS will help in designing and operating future distributed power systems.

Early system designs and cost estimates show that it is reasonable to consider hydrogen and fuel cell or internal combustion power systems for remote communities in Alaska and elsewhere. There is a significant economy of scale in installing larger systems and the expected cost

reductions over the next decade will make renewable hydrogen systems competitive in many markets worldwide. Today there are competitive opportunities for renewable hydrogen systems of a scale greater than 125 kW in remote locations with wind capacity factors greater than 0.30.

Modeling of renewable hydrogen systems has shown that they technically can be accomplished and that they are economically viable under certain circumstances today and that viability should expand rapidly as the component technologies come down in cost. The synergies among the independent evolution of the component technologies are evident in the expected growth in the marketplace for the systems developed under this project.

DRI has begun exploring the opportunity to install a renewable hydrogen power system for practical use in Kotzebue, Alaska. This effort has been in conjunction with the Kotzebue Electric Association (KEA). A plan has been developed for the installation of a prototype system in conjunction with an already operating wind turbine array. In meeting with the Kotzebue Electric Association and local permitting authorities, the possibility of local barriers to building a system in the village was minimized. KEA also helped in identifying a willing customer for the power from a hydrogen power system, while agreeing to disconnect them from the local diesel-powered grid.

The initial capital cost for the proposed site is high because of the small average load of 16 kW. Four different sites were considered, two at 125 kW, one at 3300 kW and the 16 kW system at the radio transmitter.

In the long term, new methods of wind turbine excitation are going to be needed to permit turbines to operate independent from a power grid. This will help in increasing the market for wind turbines as well as total wind remote power systems

Acknowledgements

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Attachment 1. Tables for expected system capital cost scenarios for Alaska

Table A1- 1. Kotzebue KOTZ radio transmitter 16 kW average load

Kotzebue Alaska Renewable Hydrogen Power System for KOTZ radio transmitter				
	Today low storage	Mid-term	Far-term	Today high storage
Load average power (kW)	16	16	16	16
Load peak power (kW)	20	20	20	20
Fuel cell stack peak power (kW)	20	20	20	20
Fuel cell stack cost per kWp	6,000	500	100	6,000
Renewable capacity factor	0.35	0.35	0.35	0.35
Fuel cell average efficiency	0.40	0.45	0.58	0.40
Electrolyzer system average efficiency	0.69	0.71	0.75	0.69
Peak power renewable required (kW)	108	93	68	108
Electrolyzer peak power (kW)	108	93	68	108
Electrolyzer system cost per kW	2,500	750	250	2,500
Electrolyzer system cost	269,151	69,752	17,077	269,151
Fuel cell BOP cost per kW	1,000	200	100	1,000
Fuel cell cost	120,000	10,000	2,000	120,000
Fuel cell BOP cost	20,000	4,000	2,000	20,000
Storage tank volume (gal)	60,000	60,000	60,000	60,000
Storage tank quantity	3	3	3	9
Total storage volume (gal)	180,000	180,000	180,000	540,000
Single storage tank cost	52,100	35,000	20,000	52,100
Fittings	2,350	1,600	2,350	2,350
Saddles	2,150	1,500	2,150	2,150
Total storage tank cost	169,800	114,300	73,500	509,400
Controller and DAQ	15,000	10,000	8,000	15,000
Power electronics cost/kWp to load	700	500	300	700
Power electronics total cost	14,000	10,000	6,000	14,000
Compressor	10,000	7,000	5,000	10,000
Shipping electrolyzer	2,000	2,000	1,500	2,000
Shipping storage tanks	4,500	4,500	4,500	13,500
Shipping fuel cell	3,800	3,800	3,800	3,800
Shipping compressor	600	600	600	600
Site preparation	75,000	75,000	75,000	75,000
Fuel cell, electrolyzer housing	8,000	8,000	8,000	8,000
Water processing equipment	45,000	35,000	30,000	45,000
Switch out system at load	8,000	8,000	8,000	8,000
Storage batteries	1,000	1,000	1,000	1,000
System final design w/Arctic engr	65,000	65,000	65,000	65,000
System safety and permitting	15,000	15,000	15,000	15,000
Renewable power required (kWp)	108	93	68	108
Renewable installed cost per kWp	0	0	0	0
Renewable installed cost total	0	0	0	0
System component subtotal	\$846,551	\$443,452	\$326,277	\$1,195,151
Capital cost (\$/Wp)	42.33	22.17	16.31	59.76
System performance				
Fuel cell system efficiency	0.276	0.320	0.435	0.276
Average load power consumption (kW)	16.00	16.00	16.00	16.00
Longest possible storage time (days)	22.02	25.49	34.71	66.06

Table A1- 2. Kivalina Village 125 kW average load

Kivalina Alaska Renewable Hydrogen Power System			
	Today	Near-term	Near-term
Load average power (kW)	125	125	125
Load peak power (kW)	200	200	200
Fuel cell stack peak power (kW)	200	200	200
Fuel cell stack cost per kWp	6,000	500	100
Renewable capacity factor	0.45	0.45	0.45
Fuel cell average efficiency	0.40	0.45	0.58
Electrolyzer system average efficiency	0.69	0.71	0.75
Peak power renewable required (kW)	554	478	351
Electrolyzer peak power (kW)	554	478	351
Electrolyzer system cost per kW	2,500	750	250
Electrolyzer system cost	1,383,857	358,633	87,803
Fuel cell BOP cost per kW	500	200	100
Fuel cell cost	1,200,000	100,000	20,000
Fuel cell BOP cost	100,000	40,000	20,000
Storage tank volume (gal)	60,000	60,000	60,000
Storage tank quantity	25	25	25
Total storage volume (gal)	1,500,000	1,500,000	1,500,000
Single storage tank cost	52,100	35,000	20,000
Fittings	2,350	1,600	2,350
Saddles	2,150	1,500	2,150
Total storage tank cost	1,415,000	952,500	612,500
Controller and DAQ	15,000	10,000	8,000
Power electronics cost/kWp to load	700	500	300
Power electronics total cost	140,000	100,000	60,000
Compressor	10,000	7,000	5,000
Shipping electrolyzer	2,000	2,000	1,500
Shipping storage tanks	37,500	37,500	37,500
Shipping fuel cell	10,000	10,000	10,000
Shipping compressor	600	600	600
Site preparation	275,000	275,000	275,000
Fuel cell, electrolyzer housing	10,000	10,000	10,000
Water processing equipment	45,000	35,000	30,000
Switch out system at load	8,000	8,000	0
Storage batteries	10,000	10,000	10,000
System final design w/Arctic engr	125,000	125,000	125,000
System safety and permitting	15,000	15,000	15,000
Renewable power required (kWp)	554	478	351
Renewable installed cost per kWp	2,000	1,300	750
Renewable installed cost total	1,107,085	621,631	263,410
System component subtotal	\$5,909,742	\$2,718,364	\$1,591,613
Capital cost (\$/Wp)	29.55	13.59	7.96
System performance			
Fuel cell system efficiency	0.276	0.320	0.435
Average load power consumption (kW)	125.00	125.00	125.00
Longest possible storage time (days)	23.49	27.19	37.02

Table A1- 3. St. George Village 125 kW average load

St. George Alaska Renewable Hydrogen Power System			
	Today	Near-term	Far-term
Load average power (kW)	125	125	125
Load peak power (kW)	200	200	200
Fuel cell stack peak power (kW)	200	200	200
Fuel cell stack cost per kWp	6,000	500	100
Renewable capacity factor	0.45	0.45	0.45
Fuel cell average efficiency	0.40	0.45	0.58
Electrolyzer system average efficiency	0.69	0.71	0.75
Peak power renewable required (kW)	554	478	351
Electrolyzer peak power (kW)	554	478	351
Electrolyzer system cost per kW	2,500	750	250
Electrolyzer system cost	1,383,857	358,633	87,803
Fuel cell BOP cost per kW	500	200	100
Fuel cell cost	1,200,000	100,000	20,000
Fuel cell BOP cost	100,000	40,000	20,000
Storage tank volume (gal)	60,000	60,000	60,000
Storage tank quantity	15	15	15
Total storage volume (gal)	900,000	900,000	900,000
Single storage tank cost	52,100	35,000	20,000
Fittings	2,350	1,600	2,350
Saddles	2,150	1,500	2,150
Total storage tank cost	849,000	571,500	367,500
Controller and DAQ	15,000	10,000	8,000
Power electronics cost/kWp to load	700	500	300
Power electronics total cost	140,000	100,000	60,000
Compressor	10,000	7,000	5,000
Shipping electrolyzer	2,000	2,000	1,500
Shipping storage tanks	22,500	22,500	22,500
Shipping fuel cell	10,000	10,000	10,000
Shipping compressor	600	600	600
Site preparation	275,000	275,000	275,000
Fuel cell, electrolyzer housing	10,000	10,000	10,000
Water processing equipment	45,000	35,000	30,000
Switch out system at load	8,000	8,000	0
Storage batteries	10,000	10,000	10,000
System final design w/Arctic engr	125,000	125,000	125,000
System safety and permitting	15,000	15,000	15,000
Renewable power required (kWp)	554	478	351
Renewable installed cost per kWp	2,000	1,300	750
Renewable installed cost total	1,107,085	621,631	263,410
System component subtotal	\$5,328,742	\$2,322,364	\$1,331,613
Capital cost (\$/Wp)	26.64	11.61	6.66
System performance			
Fuel cell system efficiency	0.276	0.320	0.435
Average load power consumption (kW)	125.00	125.00	125.00
Longest possible storage time (days)	14.09	16.31	22.21

Table A1- 4. Kotzebue Village 3300 kW average load

Kotzebue Village, Alaska Renewable Hydrogen Power System			
	Today	Near-term	Far-term
Load average power (kW)	3,300	3,300	3,300
Load peak power (kW)	6,000	6,000	6,000
Fuel cell stack peak power (kW)	6,000	6,000	6,000
Fuel cell stack cost per kWp	6,000	500	100
Renewable capacity factor	0.35	0.35	0.35
Fuel cell average efficiency	0.40	0.45	0.65
Electrolyzer system average efficiency	0.69	0.71	0.75
Peak power renewable required (kW)	22,205	19,182	12,571
Electrolyzer peak power (kW)	22,205	19,182	12,571
Electrolyzer system cost per kW	2,500	750	250
Electrolyzer system cost	55,512,422	14,386,318	3,142,857
Fuel cell BOP cost per kW	500	200	100
Fuel cell cost	36,000,000	3,000,000	600,000
Fuel cell BOP cost	3,000,000	1,200,000	600,000
Storage tank volume (gal)	100,000	100,000	100,000
Storage tank quantity	100	100	100
Total storage volume (gal)	10,000,000	10,000,000	10,000,000
Single storage tank cost	62,100	45,000	20,000
Fittings	2,350	1,600	2,350
Saddles	2,150	1,500	2,150
Total storage tank cost	6,660,000	4,810,000	2,450,000
Controller and DAQ	25,000	18,000	10,000
Power electronics cost/kWp to load	700	500	300
Power electronics total cost	4,200,000	3,000,000	1,800,000
Compressor	25,000	20,000	15,000
Shipping electrolyzer	15,000	10,000	8,000
Shipping storage tanks	150,000	150,000	100,000
Shipping fuel cell	75,000	75,000	75,000
Shipping compressor	600	600	600
Site preparation	75,000	75,000	75,000
Fuel cell, electrolyzer housing	15,000	15,000	15,000
Water processing equipment	85,000	70,000	60,000
Switch out system at load	120,000	120,000	
Storage batteries	50,000	50,000	25,000
System final design w/Arctic engr	125,000	110,000	100,000
System safety and permitting	15,000	15,000	15,000
Renewable power required (kWp)	22,205	19,182	12,571
Renewable installed cost per kWp	2,000	1,300	750
Renewable installed cost total	44,409,938	24,936,284	9,428,571
System component subtotal	\$150,558,660	\$52,061,702	\$18,520,329
Capital cost (\$/Wp)	25.09	8.68	3.09
System performance			
Fuel cell system efficiency	0.276	0.320	0.488
Average load power consumption (kW)	3,300.00	3,300.00	3,300.00
Longest possible storage time (days)	5.93	6.87	10.48

Attachment 2

Evaluation of Wind-Hydrogen Generating Plant For Northern Telecommunications Application

Introduction

Hydrogen production via electrolysis provides a simple way of storing electrical energy which can be used with an intermittent renewable energy source such as wind. Combined with a fuel cell the process becomes an emission-free continuous energy supply.

The common oil-based fuel and energy sources used in the North present major problems in terms of operating costs and environmental degradation. Renewable energy sources reduce or eliminate the transportation of fuel and the land/air pollution presented by spent fossil fuel. However, since renewable energy is often intermittent in availability, a means of energy storage is required.

The most common storage means for electric based energy sources is battery. Batteries provide efficient short-term storage and fast delivery of energy. For small systems they are the most cost effective. For large systems (more than 1 kW) requiring long storage times especially in adverse environmental conditions, batteries are not practical and hydrogen potentially offers a better alternative. Its long-term storage efficiency is good at all temperatures, and it takes up less real estate and is less expensive than batteries.

Hydrogen also has the distinct added value of being a fuel for heating or transportation. Therefore, an entire energy economy can be formed on hydrogen alone using the best forms of source energy available.

Electrolyser and Stuart Energy have been developing renewable-based hydrogen generating plants since the early 1990's. A 450 W PV system has been operating at Stuart's Toronto plant since 1991. In 1996, a 40 kW PV hydrogen plant was commissioned in Los Angeles for vehicle re-fuelling. It was the first of its kind and size anywhere. In 1997, the first 1.5 kW wind-PV hydrogen plant began operation north of Toronto.

In 1999, Stuart commissioned a 5 kW wind-PV hydrogen plant at the Desert Research Institute in Reno, Nevada. This system represents the current state of the art in renewable hydrogen systems providing reliable, low maintenance, unattended production of high purity hydrogen fuel.

The next phase in the project involving Desert Research Institute is to design a wind-hydrogen plant with fuel cell to deliver power for a 10 kW (peak) telecommunications load in the remote north. This report is a pre-feasibility analysis to identify the best system configuration and basic economics.

Methodology for Specification of Wind Hydrogen System

The key issue in specifying the system is determining the size of the components of the energy system that are needed to meet energy demands. In general the size of the fuel cell is determined by the peak load, assuming that peak loads can occur during times of no energy production. To the size of the base load generator is added capacity needed for reliability. Given the higher cost of fuel cells, the back up power generation system could be provided by a hydrogen fueled motor generator set. To size other components the system must be modeled using representative, preferably historical, wind data and component performance characteristics. A computer program simulates system operation to determine the amount of storage required, the size of the electrolyzer and the number of wind turbines. Specifying the components the economics of the system can be determined.

Simulation Program

The main simulation program requires wind and load data profiles as “duration curves” for the site, the power-wind speed curve for the wind generator, and required efficiency figures for the system components. See Table 1 for a printout of the required inputs and parameters. The program steps through a system simulation in one hour increments over a month, and keeps track of all energy balances including wind generation, fuel cell generation, energy dumped, and energy not delivered (loss of load). See Table 2 for a typical output run.

Subprograms are used to produce wind duration curves from atmospheric station data, wind and load “pseudo data” from the respective duration curves, and alternative wind energy output for cross-checking.

Table A2 - 1 – Input Parameters for Simulation Program

- IS THERE A WIND GENERATOR, YES(1) OR NO(2)?
- NAME OF WIND GENERATOR POWER CURVE FILE:
- NAME OF WIND DATA FILE:
- WIND SPEED-UP FACTOR:
- NAME OF LOAD POWER DATA FILE:
- AVERAGE LOAD (kW):
- HYDROGEN CONVERSION EFFICIENCY (C.F./kWh):
- HYDROGEN GENERATOR SET EFFICIENCY (kWh/C.F.):
- INVERTER EFFICIENCY (AS DECIMAL):
- BATTERY EFFICIENCY (AS DECIMAL):
- USEFUL BATTERY CAPACITY (FRACTION OF FULL CAPACITY):
- HYDROGEN STORAGE CAPACITY (C.F.):
- MAX. BATTERY CHARGING POWER (kW):
- BATTERY FULL CAPACITY (kWh):
- NUMBER OF WIND GENERATORS:
- COMPRESSOR AVERAGE LOAD RATIO (AS DECIMAL):

Table A2 - 2 – Outputs from Simulation Program

- WIND GENERATED ENERGY (kWh) = 9251.
- BATTERY LEVEL (kWh) = 12.4
- HYDROGEN STORAGE LEVEL (C.F.) = 24593.
- HYDROGEN GEN. SET GENERATED ENERGY (kWh) = 1708.
- GENERATOR SET STARTS = 104
- GENERATOR SET RUN HOURS = 256
- DUMP ENERGY (kWh) = 91.8
- ENERGY NOT DELIVERED (kWh) = 162.7
- LOAD ENERGY (kWh) = 4369.
- INVERTER RATING (kW) = 10.

The simulation software assumes the following configuration and control strategy:

- a) The wind generator main power bus (DC) connects directly to the hydrogen plant representing the main load to the wind generators.
- b) The hydrogen plant compressor operates only if there is sufficient power available on the main power bus.
- c) A battery bank is charged from the main bus and takes first priority in utilizing incoming power.
- d) The hydrogen produced is compressed into storage tanks.
- e) The customer load is served from an inverter. The inverter normally draws power from the battery bank; however if the batteries are low, the fuel cell draws hydrogen from storage to operate the inverter.

To optimize energy efficiency, the simulation utilizes the high efficiency battery link whenever possible, and uses the lower efficiency hydrogen-fuel cell link when the batteries are depleted. It will be seen in the next section how some battery storage is beneficial for the efficiency and economics of the total generating package. The economics of using battery are site and load specific in that batteries make sense, only in areas which are relatively accessible for battery maintenance and with average loads less than 50 kW.

Kotzebue Case Study

The wind-hydrogen plant is to provide electric power to a telecommunications load with a peak power rating of 10 kW. A typical stochastic load profile taken from a remote northern community has been assumed. The load profile is scaled to represent a load with a peak of 10 kW and an average of 6 kW based on energy delivered.

The wind data used is from Cambridge Bay (latitude 69 deg., longitude 105 deg.), North West Territories. A wind duration curve was derived from bin type wind data for the location (see Figure A2 - 1). The mean wind speed for the site is about 14.5 MPH.

The following fixed system efficiencies are assumed:

Hydrogen plant conversion rate – 8.1 cu.ft. of H₂/KWh input power
Fuel cell conversion rate - 0.04 kWh output power/cu.ft. of H₂
Inverter efficiency – 0.9
Battery efficiency – 0.9
Battery useful capacity – 0.7
Compression & Aux. Power load ratio – 0.1

Two wind system configurations are considered in the analyses. There are existing Atlantic Orient 50 kW wind generators (Model AOC 15/50) on site. These machines are normally grid-connect machines, however some manufacturers such as Atlantic Orient have been testing stand-alone systems that couple an AC wind generator to a load without the assistance of an electric grid. The practicality of this type of configuration for our application would have to be studied in detail, however we will consider this option in the simulation (see Figure A2 - 2 for power curve).

The second wind system configuration is the well-tested one of self excited wind turbines serving a stand-alone load. The particular turbines considered in the analysis are Bergey Excel 10 kW (see Figure A2 - 3 for power curve).

For each wind system configuration two storage configurations were considered: 1) Zero battery storage, and 2) Mixed H₂ and battery storage.

Various simulations are performed with the software until an optimized solution is achieved. The main criteria are to minimize battery and hydrogen storage but ensure that Energy Not Delivered (loss of load) is less than 1% of the Load Energy. On initialization, the hydrogen tanks are assumed full. Therefore, for steady state continuity, the tanks must again be full after the simulation. There is always a limit on how hard a battery can be charged, and it is assumed in the simulation that the average charging power is limited to 1/6 of the battery capacity.

Simulation 1 – AOC 15/50 Wind Generator, No Battery Storage:

No. Of Wind Generators – 1
Size of Electrolyser – 60 kW
Hydrogen Storage – 43,500 cu.ft.
Battery Capacity – 0 kWh
Maximum Battery Charging Power – 0 kW
Load Energy Required – 4,369 kWh/month
Wind Generated Energy – 14,759 kWh/month
Fuel Cell Energy to Load – 4,328 kWh/month
Dumped Wind Energy – 0 kWh/month
Energy Not Delivered – 41 kWh/month

Simulation 2 – AOC 15/50 Wind Generator with H₂ & Battery Storage:

No. Of Wind Generators – 1
Size of Electrolyser – 60 kW

Hydrogen Storage – 25,000 cu.ft.
Battery Capacity – 42 kWh
Maximum Battery Charging Power – 7 kW
Load Energy Required – 4,369 kWh/month
Wind Generated Energy – 14,759 kWh/month
Fuel Cell Energy to Load – 1,859 kWh/month
Dumped Wind Energy – 4,556 kWh/month
Energy Not Delivered – 26 kWh/month

Simulation 3 – Bergey Excel Wind Generator, No Battery Storage:

No. Of Wind Generators – 7
Size of Electrolyser – 70 kW
Hydrogen Storage – 31,500 cu.ft.
Battery Capacity – 0 kWh
Maximum Battery Charging Power – 0 kW
Load Energy Required – 4,369 kWh/month
Wind Generated Energy – 16,190 kWh/month
Fuel Cell Energy to Load – 4,342 kWh/month
Dumped Wind Energy – 1,226 kWh/month
Energy Not Delivered – 27 kWh/month

Simulation 4 – Bergey Excel Wind Generator with H2 & Battery Storage:

No. Of Wind Generators – 4
Size of Electrolyser – 40 kW
Hydrogen Storage – 23,500 cu.ft.
Battery Capacity – 54 kWh
Maximum Battery Charging Power – 9 kW
Load Energy Required – 4,369 kWh/month
Wind Generated Energy – 9,251 kWh/month
Fuel Cell Energy to Load – 1,415 kWh/month
Dumped Wind Energy – 474 kWh/month
Energy Not Delivered – 41 kWh/month

The following design and cost assumptions are used in the calculation of simple economics for the simulation runs above.

- 1) The hydrogen plant must be sized to accept the full output of the wind generators. Stuart's five year projection is to achieve a low pressure hydrogen plant (installed) for this size (60 kW) of \$1,400/kW.
- 2) The lowest cost hydrogen storage is low pressure (200 PSI) at about \$1.10/cu.ft.
- 3) The cost of battery storage is about \$200/kWH, and the charger and special battery housing are assumed to be about \$8,500.
- 4) The cost of the fuel cell is about \$3,000/kW. The fuel cell must deliver 10 kW.
- 5) The cost of the inverter is about \$700/kW US. The inverter must deliver 10 kW.
- 6) The environmental container that will house all equipment except the hydrogen storage is part of the hydrogen generator cost.

- 7) The Atlantic Orient wind generator is assumed to cost \$1,000/kW US. It's peak rating is 60 kW. The modifications to make it operate "stand- alone" are assumed to be \$10,000. (Cost of synchronous condenser) The Bergey Excel wind generator costs about \$28,000 US.
- 8) The O & M cost plus capital return factor is assumed to be 20% of the total system capital cost.
- 9) Simple cost of energy is calculated as yearly O & M cost plus required capital return divided by the yearly energy to the load.

Figure A2 - 1 Wind Duration Curve for Cambridge Bay

Figure A2 - 2. AOC 15/50 Power Curve

Figure A2 - 3. Bergey Excel Power Curve

The following table summarizes the economic results for the four simulation cases considered.

Table 3: Simulation	1	2	3	4
H2 Plant Cost	\$84,000	\$84,000	\$98,000	\$56,000
Wind Gens. Cost	\$70,000	\$70,000	\$196,000	\$112,000
H2 Storage Cost	\$48,000	\$28,000	\$35,000	\$26,000
Batt. Storage Cost	\$0	\$17,000	\$0	\$19,000
Fuel Cell Cost	\$30,000	\$30,000	\$30,000	\$30,000
Inverter Cost	\$7,000	\$7,000	\$7,000	\$7,000
Total Capital Cost	\$239,000	\$236,000	\$366,000	\$250,000
Cost per kW (pk)	\$23,900	\$23,600	\$36,600	\$25,000
Operating Cost/yr.	\$47,800	\$47,200	\$73,200	\$50,000
Energy to Load/yr. (kWh)	52,400	52,400	52,400	52,400
Cost of Energy(\$/kWh)	0.92	0.90	1.40	0.96

On the basis of this analysis the cost of power to supply a 10 kW load under these conditions will be of the order of \$1.00 per kWh which is not unreasonable given the size of the load, and compares favorably with diesel generators in this size range. Earlier analysis simulating a village power system showed that assuming the same wind profile and a higher energy demand, a 1 MW average load as opposed to 6 kW, the economy of scale seen in lower component costs, use of cogenerated heat and reduced operating maintenance costs reduces power costs to less than 40 cents per kWh. ⁽¹⁾

Results and Conclusions

Table 3 above presents some interesting results.

Battery storage is not necessarily required with the single AOC 15/50 wind generator since the output is more than enough to serve the load through the hydrogen-fuel cell cycle. However, adding battery storage does not affect the cost of energy in the short term, but would significantly improve the system reliability by offering a redundant power supply. Also, the system with battery storage offers significant "dumped" energy. If this dump energy can be utilized to provide resistive heating or generate more hydrogen for alternative fuel uses, then the net cost of energy is lowered.

The advantage of battery storage is very evident in the Bergey Excel cases. Here, we are able to more closely match supply and load by using multiple small wind machines. By adding some battery storage, we are able to lower the wind system capacity and therefore the size of the hydrogen plant.

The analysis indicates that there appears to be opportunity, even at today's component costs, for renewable hydrogen electric generators as an alternative to conventional generators in medium to high wind areas of Alaska where energy costs exceed \$1.00/kWh for small loads (1-50 kW) and \$.50/kWh for larger loads (1 MW+). More detailed analysis using actual site wind and load data,

considering more equipment choices, and using accurate cost data and economic modeling, would be required as part of a design-build exercise.

Recommendations

This study should provide the required information to make a decision as to whether to proceed further with a feasibility and design phase leading to an actual installation.

The implementation of a design-build project should therefore include:

- 1) Design Study – Specify components
 - a) Use site wind and load data
 - b) Study more equipment options
 - c) Acquire better cost data including installation costs
- 2) System Acquisition
 - Finalize system design
 - Prepare requests for proposals
 - Select component suppliers
 - Prepare budget and review with players
 - Acquire system components
- 3) System Installation
 - Prepare installation schedule
 - Do site preparation
 - Supervise acquisition and installation of equipment
 - Test and commission
- 4) System Monitoring
 - Set up data acquisition and remote monitoring of system
 - Set up program for collecting and interpreting data
 - Set up response mechanism for dealing with system problems or faults causing shutdowns.

We would suggest three approaches to system configuration for consideration.

- 1) Connect the renewable hydrogen electric generator (RHEG) to the existing wind farm grid. Simulate the output (in real time) of one of the Atlantic Orient wind machines as input to the RHEG. This is the least cost approach to operating the system under real conditions.
- 2) Configure an Atlantic Orient wind generator as “stand-alone” and connect to the RHEG. Atlantic Orient would need to be involved in the system design.
- 3) Provide the complete system as configured in Simulation 4 (DC wind generators and RHEG with battery storage).

References:

(1) Fairlie, M., Stewert, B., Scott, P., Van Camp, J. “Renewable Hydrogen for Remote Power Applications”, CHA Annual Meeting, June 1997.

Attachment 3. September 21, 1998 Status report

To: Neil Rossmeissl DOE, Hydrogen Program Office

From: Glenn Rambach DRI, Reno

Total pages: 9

Status of the Project

Integrated renewable/hydrogen utility system

DOE solicitation number DE-Ps-36-97GO10227

September 21, 1998

PI: Glenn Rambach

Desert Research Institute

Reno, NV 89506

This project has three main tasks for the fourth quarter of FY 98.

- Design, procure and build a a residential-scale system in Reno.
- Program management, system safety, design and cost of a Kotzebue renewable hydrogen power system.
- Modeling and methods for system design and control.

We are on track with the project deliverables and budget and have created an improved state of affairs for the possibility of using hydrogen and fuel cells with renewable energy in a pilot system, as well as in general use. The use of our funds from the State of Nevada as cost share have been very effective for the critical element of providing a flexible system for safely validating all remote, renewable power concepts.

Introduction

DRI is leading the first phase of a multi task effort to advance the state of technology for deployment of renewable systems using fuel cells in remote applications worldwide. During this phase a small, 2 kilowatt test system is being constructed at DRI this Reno location to test the design and control system algorithms, and to provide a test bed for components to be used in early small renewable energy systems. This will be a complete renewable, hydrogen, fuel cell utility system, including two small wind turbines, several kilowatts of photovoltaics, an electrolyzer, hydrogen storage, a fuel cell and a control and data acquisition system.

A major element of this first phase will be the planning, assessment and design of a practical system to be deployed in association with the Kotzebue Electric Association. Once the design is complete, it is planned that the full system will be constructed in the second phase of this project. DRI and members of the DRI team have studied, and published on, the issue of remote wind hydrogen fuel cell projects in Alaska for at least four years. We are encouraged by the realistic possibilities at Kotzebue, as will be described below.

Additionally, we will develop the decision-making tools to help in understanding the developing market place for renewable, hydrogen, fuel cell utility systems. We will also develop the design and operating algorithms to optimize the design of any system and its performance once it is deployed.

We are partnered with an electrolyzer company, Stuart Energy Systems, a hydrogen systems and safety company, DCH Technologies, and an electric power provider in remote Alaska, the Kotzebue Electric Association (KEA). In mid June, participants from DRI and DCH visited KEA to study the possible options for designing and deploying a renewable, hydrogen utility system in the region. We met with Brad Reeve, the director of the Kotzebue Electric Association and Craig Thompson, their primary power engineer. We studied the possible load options within the community, in nearby communities and possibilities near the wind turbine site. We met with members of the community and potential power customers that may participate in this project. We also met with the city fire chief to discuss safety issues relevant to the power system the components and the use of hydrogen. During the visit it became evident that there is indeed a likely opportunity to design and install a wind powered system to connect the intermittent wind turbines to a steady load and use hydrogen and a fuel cell for the storage loop. The Kotzebue Electric Association is a well run, forward thinking electric association that has a good business history and a successful record exploring advanced concepts and realizing their benefits. They have the in-house resources to handle new systems such as the three Atlantic Orient wind turbines that were installed in their system last year. They will be installing seven more wind turbines this autumn, bringing their peak wind capacity to 600 kilowatts.

Residential-scale renewable fuel cell system

One of the key products of this project will be a residential-scale system employing a combination of wind power, solar power, a fuel cell and an electrolyzer. These components will be integrated in a complete hydrogen, renewable power system in Reno, to serve as a test facility for isolated power systems incorporating energy storage. We will provide the control system hardware and software along with a data acquisition system to test the system performance and implications of variations in the design and control system algorithms.

The preliminary design of the DRI residential-scale remote power system was accomplished in June. In early July the design passed a preliminary design review and the primary components, and long lead time items were purchased. The site for the system has been selected and is currently being prepared, and an electrical engineering contractor has been retained for the basic installation of the facility.

The input-energy components for this system will include 2.1 kW of solar photovoltaic, mounted on passive tractors, and two 1.5 kW DC wind turbines. This will power a 5 kW unipolar electrolyzer. The hydrogen will be stored in a 100 psi pressure vessel capable of storing 600 SCF.

The fuel cell is a 2 kW PEM stack that operates at 48 VDC. All these DC components, along with a set of batteries for peak shaving will be connected to a common DC bus.

The system load will be simulated in using a 5 kW, computer-controlled, resistive load. As a system then, we will be able to generate relationships among the wind turbine output, solar output, environmental conditions, fuel cell and electrolysis conditions and any predetermined load profile.

Delivery of all the main components: the fuel cell stack, electrolyzer, wind turbines, solar

photovoltaics, programmable load and control and data acquisition systems is expected in October.

Integrated renewable hydrogen energy system for Kotzebue, Alaska

Original and ongoing discussions with the Kotzebue Electric Association (KEA) centered on potential siting of a wind, hydrogen, fuel cell system and considered several locations. Two of those locations were in communities in the Kotzebue area, about 80 to 150 air miles from the village of Kotzebue. Several other locations were considered within the Kotzebue village. Later in this project, DRI will provide an assessment of all reasonable sites and villages in Alaska and the potential for deploying a renewable, hydrogen power system. That assessment will be based on the combined technical, economic, and social criteria that initiated the concept of renewable, hydrogen power systems in Alaska in 1993.

In June, project participants from DRI and DCH Technology met in Kotzebue Alaska with the Kotzebue Electric Association and other stakeholders in the village, to discuss the possibilities for constructing a hydrogen, wind energy system and options for its siting and design. Our host and primary contact was Brad Reeve, general manager of KEA. We also met with Craig Thompson of Thompson Engineering, the electrical engineering contractor to KEA. The discussions began with an introduction of participants in the project and a description of the overall concept. Later discussions included the options for design and siting of the system, and safety and permitting issues.

The three villages currently under consideration are Wales, Kivalina and Kotzebue, all of which are serviced by the technical staff at KEA.

Wales

This village has a population of approximately 120 people with an average load of approximately 65 kilowatts and a peak of approximately 125 kilowatts. This is a good load for either the 200 kW PAFC or 250 kW PEM hydrogen fuel cell systems currently available. The only current power source in Wales this a diesel generator. However, two new 50 kilowatt AOC wind generators will be installed this autumn to offset some of the diesel fuel requirement. The annual average wind power class estimated for Wales by the United States Wind Resource Atlas is approximately class 4 to 6.

Wales is an attractive location because the wind capacity factor is high, and the load is small enough that the entire village could be powered by an integrated hydrogen system. However, approximately 13 additional wind turbines would be required and, the village's remoteness, 150 miles SW of Kotzebue, makes it difficult to service the power system by KEA personnel, and response times are relatively long. As a result, Wales is not the optimum community to test a first-of-a-kind power system upon which entire community relies. It would however be an excellent candidate for a second-generation test of a complete system.

Kivalina

This village has a population of approximately 175 people with an average load of approximately 125 kilowatts, and a peak of approximately 190 kilowatts. The current source of power is from diesel generators. The annual average wind power class estimated for Kivalina is approximately

class 5 to 6. There are no current plans for wind turbines in Kivalina. However, the city recently voted to move the village inland from their current location on a barrier island. It is expected that the cost of this move will be approximately \$50-60 million dollars. It may be possible to include the necessary wind turbines and hydrogen system in the move, in which case a renewable system would constitute a fraction of the total village relocation cost.

Estimates for the wind turbines would be approximately \$2-5 million. A phosphoric acid fuel cell would cost approximately two million dollars. (However, since the cycle time of the PAFC is approximately 8 hours, its operation would not be optimum with an interruptible renewable energy system). The remaining electrolyzer, hydrogen storage, balance of plant, installation and permitting would be approximately \$5 million dollars. So if the complete system were to be included in the move of the village of Kivalina the additional cost could conservatively be approximately \$10 million dollars. It is likely that any move of the village of Kivalina would not occur for several years, during which time the cost and availability of the key components of such a large-scale system should improve dramatically. Therefore, this may be a likely large-scale candidate for hydrogen renewable energy systems that can follow along the success of a smaller-scale validation in Kotzebue.

Kotzebue

This village has a population of approximately 3500 people with a peak electrical load approximately 3500 kilowatts. KEA currently has 11MW of diesel generating capacity with six generators. In 1997, they installed 3 AOC 50-kilowatt wind turbines, and will install 7 additional wind turbines during the summer and fall of 1998. The annual average wind power in the area is estimated for Kotzebue is approximately class 4 to 5.

The main community of Kotzebue is approximately 1.5-mile long and .75 miles wide. The diesel power plant, and its 1.2 million gallon supply of diesel fuel are located within the town proper. The wind turbines are approximately 1.5 miles south of town on a large open tundra field. KEA has extended a 7-kV line, part of the local power grid, to the wind site. The turbines have induction generators requiring 60 Hz excitation from the diesel-powered grid. At the wind turbine site, a transformer steps down the 7 kV to 480 V, equal to the wind turbine output voltage when they are synchronized. The same transformer boosts the wind turbine's 480 VAC to 7-kV.

Our preliminary discussions on siting a project in Kotzebue centered on two primary issues. First, we considered siting project within the village proper, where there are numerous opportunities to separate out a small load from the grid which would be consistent with small fuel cells that would be available for project such as this. A site within the village, however would only have power available to it from the 7-kV grid, which is not specifically the wind power, but rather the combined power from the wind turbines and central diesel generator plant.

Second, we considered siting the project adjacent to the wind turbines, away from the village. Here we could use the 480 volts directly from the wind turbines, which would be available only when the wind turbines are producing power. While this would be most attractive siting, by using power directly from wind turbines, the remoteness of this location, relative to the village and its loads posed some strategic problems prior to our visit.

The original plans for the DRI Renewable Hydrogen Utility Project was to carry out an 18 month market assessment, model development, safety analysis and systems design for renewable hydrogen utility systems in general, and produce a specific design for the Kotzebue village. One of the primary products of this first visit to Kotzebue is a much clearer understanding of the near-term possibility for installing a well designed, reliable hydrogen, fuel cell system associated with the wind turbines. The prime motivator for this is the presence of an ideal 15-kilowatt load that is adjacent to the wind turbine installation.

While KEA "wheels" the wind turbine power to the grid approximately two miles away, the local 15-kilowatt load is only a few hundred yards from the wind turbine distribution center. This load is a 10-kilowatt local public radio transmitter for the KOTZ radio station in the village. Mr. Reeve of Kotzebue Electric Association arranged a meeting with the DRI team members and the manager of the radio station. We discussed the possibility of solely powering the transmitter from wind turbines using a hydrogen fuel cell system for energy storage. KEA had discussed possible options or benefits such as discounting the electricity rate for the transmitter. The station manager is willing to provide the transmitter site as a load for our project.

The transmitter is a continuous load of approximately 13.8 kW. Its proximity to the wind turbines, the access for maintenance, the constant load requiring leveling from an intermittent resource makes this transmitter an ideal location for a realistic, remote hydrogen renewable fuel cell utility installation.

DRI and members of the DRI team are encouraged by the realistic possibilities at Kotzebue. The wind capacity factor is very good. The candidate for the load provides a valuable local service, and can be reliably backed up with the grid in the event of any system problems. In this way we can provide a truly remote system, yet still have a reliable and safe back up if problems should occur.

The location near the wind turbines provides an opportunity to operate a renewable hydrogen fuel cell system in a remote arctic environment, while still having good access to operation and maintenance resources. KEA is well equipped and staffed with experienced personnel to successfully participate in the installation of a system such as this and to be responsible for operation and maintenance of a power system of this complexity.

Preliminary system design

We have the load profile of the transmitter site and are currently assessing the annual wind profile to finalize a design for a system to power the station transmitter. Our first design anticipates storing hydrogen at 225 psi with capacity for running the full load for ten days. Commercial pressure vessels rated for hydrogen service at 250 psi, in an arctic environment have been identified.

In the current design, the hydrogen production for the system would probably require a peak of 100 to 150 kW of wind electricity. The fuel cell, of course would only need to be 15 kilowatts, the maximum load of the transmitter. In our discussions with Stuart Energy Systems, we learned that there are no barriers to providing an electrolyzer of that size with a compressor to deliver the hydrogen into the pressure vessels.

Recently, DRI has learned that a major potential industrial partner is interested in providing 15 kW PEM fuel cell power system and related services to enable a project like this to be realized. We have been considering the types of designs that would be possible at the Kotzebue transmitter site, and recognized that the biggest limiting factor to a hydrogen utility system is the unavailability of a 15 kW fuel cell at a reasonable cost. A PEM fuel cell made available to this project in this way creates a situation that makes it very possible to design and build a real renewable power system providing real dispatchable electricity to a useful and functioning load. This will clearly show how and where hydrogen can be beneficially used worldwide with renewable power systems, improving the penetration of renewables in the world.

The control system and power electronics for this system and its components is relatively straightforward even though it has to be custom designed and made.

An important lesson learned as a result of the visit to Kotzebue was how we would perform the water management for the electrolyzer and the fuel cell. Water is not currently available at the transmitter site and we are considering designing a closed water system with minimal makeup water transported from the village to the site. We have been working on this concept with Stuart Energy Systems, and it appears to be a reasonable approach towards the issue. A water management system of this type will prove to be very important in future deployments of remote hydrogen systems in many parts of the United States and the rest of the world.

Currently the wind turbines, when the wind is blowing, operate synchronously with the grid, providing 480 VAC into a 3-phase transformer that boosts it to 7 kV. The 7 kV gets put in to the trunk line that is connected to the city's main grid service at, also 7 kV. At the transmitter site there is a transformer to step down the 7 kV to 480 volts to power the transmitter

During the visit, Mr. Reeve arranged for the DRI and DCH visitors to meet with Ron Munson, the fire chief for Kotzebue. We introduced the idea of the project with Mr. Munson and explained a number of the different possible design scenarios. We described the type of pressure-vessel storage for hydrogen, and the lack of well-known codes and standards for hydrogen. Kotzebue has a very well equipped fire department with well-trained personnel, there are a lot of residential and business size propane tanks throughout the village. Mr. Munson was very positive towards the possible system design, and believes that there will be no permitting issues for us siting pressurized hydrogen cylinders either in the village or at the transmitter site.

David Haberman, of DCH Technology had explained that the Kotzebue Fire Department would receive:

- Training on how to respond to an emergency related to hydrogen and hardware in such a project,
- A portable hydrogen detector, and
- A system monitoring connection to the hydrogen energy project so they can assess the condition from a computer in the fire station.

Representatives of DRI and DCH also traveled to the University of Alaska Fairbanks to meet with Ron Johnson and Deben Das of the Mechanical Engineering Department. We have been

discussing common interests and designs for remote hydrogen systems with representatives of UAF since 1994. During this visit we discussed the potential for sharing responsibility for the arctic engineering that may be necessary to complete a hydrogen, fuel cell project in Kotzebue. Professors Johnson and Das both agreed that collaboration among DRI, UAF and DCH will be important for the success of our mutual projects of interest.

Computer model of the generic stationary hydrogen energy system

This will be the basis for a design model that will aid in optimizing the final design of a renewable, isolated power system where energy storage is used, primarily in the form of hydrogen and electrochemical systems. The inputs to the model will be:

- The control strategy for a system
- A table of performance and cost specifications for all component of options
- The potential load profile (It may be possible to describe the load using methods other than a time series. For example a power spectrum with a characteristic mean and standard deviation might be used.)
- the renewable resource profile
- Relevant financing information (including financing and cost of electricity models)

The outputs from a model will be:

- The operation of the system components over time
- The cost of electricity
- The reliability factor of the electricity delivery

The computer model will not be used in isolation. Rather it is intended as a core function of the design and control optimization algorithms that are described below.

Other computer models do exist that can handle some of the input and output functions described above. Various existing computer models were evaluated based on written descriptions of their performance. TRNSYS modeling software was selected and purchased. It is meant to be used for modeling dynamic processes and has prebuilt modules for electrolyzers solar PV and other components. A FORTRAN compiler was also purchased to support TRNSYS.

The design optimization model

This optimization model is intended for use as an engineering design tool. The user will input certain parameters (described below), and the model will determine the best system design.

The system model, described above, will be a core function of this optimization model. The optimization model will vary component parameters and then call the system model as a function and then send it the components as a parameter.

Unlike the system model, a particular parameter can serve as either an input or an output parameter in the optimization model. For example, the user might want to specify that the reliability of the system be 100% (i.e. the system will always provide to the load the necessary amount of electricity) and the optimization model will determine the system design that will provide the lowest cost of electricity under those conditions. In another example, the user can specify a maximum capital that is available, and the optimization model will determine the

maximum reliability that can be implemented.

The expected parameters (input or output) will include: reliability, cost of electricity, capital cost, footprint (land area used), noise level, etc.

Control optimization algorithms

This model will determine the best way to manage the system components. It will also call the system model as a core function. The algorithms that it determines as optimal would be used by the power logic controller to control the system energy and power resources. This model will be verified by using the residential-scale system.

World Hydrogen Conference and Lake Tahoe Fuel Cell Conference

In June, a presentation was made on the criteria for remote hydrogen power systems at the twelfth world hydrogen conference, in Buenos Aires, Argentina. The paper received much interest and led to discussions on near term projects and extensions of the concept. At that conference some preliminary discussions were carried out on the relevance of similar power systems for the Patagonia region of Argentina. Patagonia exhibits several of the primary characteristics necessary for the early adoption of these power systems. There is a very high capacity factor wind regime there, and numerous villages that are remote from each other, and any centralization are in need of high value electrical power.

We also gave a presentation on our work in remote, hydrogen, fuel cell systems at the Lake Tahoe Fuel Cell Conference, hosted by DRI and the W. Alton Jones Foundation in July. This was the basis for ongoing discussions of worldwide use of fuel cells in the developing world. Productive sessions on enabling the future of such systems included members of the World Bank, Richard Bradshaw of DOE, Ballard Power Systems, International Fuel Cells, SOFCO, and the Global Environmental Fund.

Summary

The residential-scale hydrogen, renewable energy system, to be built in Reno, was designed and the major components have been purchased. All the components and the support building are expected to arrive in October. Site preparation and electrical engineering is underway. Operation of the system is expected to begin in January. This is the first system employing solar and wind power, with a hydrogen, fuel cell storage system, and will be capable of testing future plans for numerous integrated, renewable power systems. It will also help in expediting development work on similar systems in Alaska.

A trip to Kotzebue by key members of the DRI team had several positive results:

- Several sites and hydrogen system options were considered, including three possible communities.
- An agreement by KEA to support the project and install and operate the system we all agree upon, to power the local public radio station solely on wind power, buffered with a hydrogen, fuel cell storage system.
- An agreement with the Kotzebue Fire Chief that they are satisfied with the design concept and see no problems currently with permitting a project in the village or at the transmitter site.

- All of the key issues are well in hand, leading to the immediate ability to design and install a complete renewable hydrogen storage system at a preferred location, identified after the site visit as the Kotzebue public radio transmitter site.
- The potential for acquiring a 15 kW PEM fuel cell power system and related services for this project is one of the key reasons why a successful project can be considered at this time.
- Additionally, the other main, large scale components, such as the electrolyzer, compressor, storage tanks and power logic control system are all readily available.
- With the combination of intellectual resources available to the team, there appear to be no barriers to successfully designing buildings and deploying a functioning system at this time.
- The heavy construction, building siting, power line management, arctic engineering support, operation and maintenance for a project such as this is well within the capabilities of the Kotzebue Electric Association.

The efforts to do the system modeling, design modeling and control system algorithms have been initiated and all are on schedule, and support software has been purchased.

Attachment 4

4A. Energy Research and Development at DRI: Important for the U.S. and the World

The Desert Research Institute (DRI), a science and technology research and development element of the University and Community College System of Nevada (UCCSN), is engaged in a multidisciplinary energy program. The objectives that drive the DRI energy activities follow a long range strategy to assure the successful transition to a fully sustainable energy economy. These motivations stem from the recognized potential for technology to positively address the significant risks associated with our current fossil fuel-based energy economy. The risk to the future U.S. economy from dramatic increases in the reliance on foreign oil supplies (67% by 2020) is serious. Today, at 50%, oil imports represent more than one third of the U.S. trade deficit. The continued increase in the influence of foreign oil on the U.S. economy will not turn around without a conscientious effort to develop alternative energy technologies to the point of being competitive with fossil sources. Additionally, the economic drivers on energy development in Europe and Asia are very different than in the United States. For example, the pump price of gasoline in many other countries represents its true cost of approximately \$4 to \$5 per gallon. With the addition of some very serious environmental problems, industries and governments in Europe and Asia have shown more motivation than in the U.S. to develop new, marketable energy technologies. When it becomes necessary for the U.S. to employ these new technologies, our options may be reduced to importing them from the nations that sought to develop them first. Over all, this could represent trillions of dollars per year throughout most of the next century.

The energy future envisioned by DRI is founded on realistic science, engineering and economic principles, and is intended to avoid the potential of sudden economic crises caused by the imbalanced geopolitical distribution of fossil energy resources around the world. The increased use of renewable energy sources such as wind, solar, geothermal, microhydro and biomass moves us towards a complete reliance on local energy resources. Wind energy had grown annually by more than 40% worldwide over the past 7 years. The advances in related technology and integration of advanced energy systems expected from efforts derived from our strategy will accelerate the commercialization of these new, clean and economically viable energy sources. Today, the populations of China and India add up to more than 2 billion people, and they currently consume about 0.8 barrels of oil (bbl) per year per person (energy equivalent), while in the United States the per capita consumption is about 24 bbl/year, and the world average is about 4 bbl/year. Energy growth drives the development in any country. In considering the example of only China and India moving towards the world average of energy consumption, as they must, the result will mean that about one third of the world's population will increase their energy use by over 500%. The high sulfur coal available to these regions is now the best energy option to fuel their economic growth, but more than doubling global energy consumption on the foundation of coal or any other fossil fuel or non-renewable source would impose an unacceptable insult to the world's environment, and create a serious increase in economic instability from the increased regional reliance on international energy trading.

The long range results from our research and development will help to assure four critical conditions:

Economic stability thorough the avoidance of disruptions to the lifeblood of our economy, our energy supply.

Economic competitiveness through early development of exportable energy technologies.

Energy security through the assurance of reliable, indigenous energy supplies, and

Environmental stewardship through the establishment of long-term, clean, global energy economy.

DRI has been developing energy system concepts based on foundation of the complex interrelationships among economics, technology, policy, environment and energy resources. Our objective is to help accelerate a logical introduction of, and transition to, sustainable transportation and utility energy systems.

History shows us that every technology that experiences widespread use was introduced into a high value niche market first. From there, economies of scale and other drivers expand the market and drive further development, in turn expanding markets. All of which is always subject to traditional “valley of death syndrome” issues in new business and technology development. With this as a basis, we employ a critical, comparative assessment of all technology elements to determine the a rational expectation for the future technical performance and

costs for all technology options. The result is a roadmap from the market introduction point through the expected market growth path. An example of this method of coupled technology and economic strategy is shown graphically in the adjacent figure for market entry opportunities for fuel cells. This maps the market for any power plant by graphing the size of a power plant versus the cost for any application. This graph shows the demonstrated acceptable cost for power plants at various sizes for many applications. Markets more to the right in the adjacent figure are easier to enter, mainly because they have a higher acceptable cost, and will provide customers who are willing to pay a higher price for the early, higher cost production runs of a new power technology. Other considerations for early markets are the size of the power plant (smaller is easier to produce early), the engineering challenges for any application, and the production quantities expected early in a market. As shown, the automobile power plant is by far the most challenging market to address. The expected costs are the lowest, and the engineering challenges and early production expectations are the most daunting. With this approach, we are planning on introducing fuel cells in applications more towards the right in this plot. At DRI, we currently

have two electric vehicles, a scooter and a utility transporter (shown) that we are planning modify with fuel cell power plants to demonstrate that fuel cells are technically capable of permitting electric vehicles to perform as well as their gasoline counterparts. This will also demonstrate that the fuel cell adds to an electric vehicle the driving range and refueling convenience that is comparable to gasoline and diesel fuel.

With this strategy, we have also constructed a fully renewable utility power facility at DRI. It employs two wind turbines, two solar photovoltaic arrays, a fuel cell and a hydrogen production and storage system. This is being used to learn how to optimize future renewable energy systems so they may permit fully autonomous power production without a need to rely on a fossil powered grid connection. Then wind or solar power systems can be deployed in remote communities where the value of power is high and provide indigenous power without the need for a diesel fuel supply currently required by almost all remote locations. An example is shown in the figure.

Other DRI activities directed towards the integrated plan for long term energy development include a new fuel cell design for reducing production cost, a plan to improve the assessment of wind power availability by measurement and modeling and a new, lower cost method of producing hydrogen from sunlight.

For more information, contact Glenn D. Rambach, (775) 674-7043, glennr@dri.edu, DRI Energy and Environmental Engineering Center, Reno, NV. Additional information is also on our web site <http://www.dri.edu/EEEC/Energy>.

4B. - Renewable, Hydrogen-Based Energy for Isolated Communities Worldwide

The use of fossil fuels constitutes our greatest source of air pollution and causes most of the anthropogenic greenhouse gas production. Importation of foreign oil results in more than 1/3 of the U.S. balance of trade deficit (\$52B/year), and requires more than \$50B/year to protect and maintain a stable, foreign supply.

Over the past two decades many of the technologies needed for a sustainable energy economy have evolved considerably, and are at the brink of large-scale commercialization. Renewable technologies such as wind and solar have proven to be technically viable sources of power. Wind power production costs are competitive with conventional sources, while solar power is expected to be competitive within a decade. There are certain markets where the value of electricity is several times higher than the electricity price in large power grid markets. For example, dozens of communities in Alaska pay \$.25 - .75/kWh for diesel-powered electricity, where the national average is less than \$.10/kWh. Many of these regions have abundant, quality wind resources. These high-value power markets are where renewable technologies are making their commercial entry.

Increased use of renewables in these markets will accelerate economy-of-scale cost reductions, and broaden the market base. About 1/3 of the world's six-billion population has yet to benefit from the use of utility electricity, and it is prudent to foster the use of renewables in developing regions.

An application of renewable power DRI is pursuing is in remote regions, where intermittent renewable power systems integrated with adequate energy storage will provide a steady supply of electricity to a community, and be competitive with fossil power alternatives. The energy storage component will provide power to the load when the renewable source is quiescent. Several examples of energy storage methods are: batteries, hydrogen-fuel cell systems, hydrogen-engine-generators, flywheels, pumped hydroelectric and compressed air. Where compressed air and pumped hydroelectric are not practical, the hydrogen systems currently show the most promise.

The components necessary to demonstrate a renewable hydrogen power system for a remote community are available, but have yet to be integrated in this way. A system design would require the renewable power source to be sized to produce base-load electricity, and supply enough additional power for hydrogen production as the energy storage medium. The maximum storage capacity is simply a function of the average load and the maximum credible renewable quiescent period. Kotzebue Electric in the community of Kotzebue, Alaska currently has three AOC 66-kW wind turbines, and is planning for more 10 - 12 more. The nature of the wind resource, the wind turbine installation and the load profile make this an excellent location for early deployment of a hydrogen storage system that can be integrated into the local infrastructure. The power system waste heat can also be integrated into the water or space heating load to increase efficiency, and still provide renewable energy on demand.

Wind, hydrogen, fuel-cell isolated power system

There are two key benefits that would result from the implementation of such a prototypical, uninterruptable renewable power system demonstration:

- 1) A generic design optimization algorithm that matches an arbitrary renewable energy source profile with an arbitrary community load profile with the right amount and type of storage. This can be generalized for any energy storage process and medium, and
- 2) A generic control system optimization algorithm that provides electricity to the customer at the lowest cost, and highest quality and reliability, based on temporally varying source and load conditions. The control system, as well as the overall power system design will strongly benefit from advanced, mesoscale meteorological forecasting, which will aid in optimizing the system and will drive down the capital and operating costs.

In addition to utility electricity, isolated communities have a requirement for vehicle transportation. As hydrogen powered vehicles enter the niche marketplace, they can be introduced into these enclosed communities in a fleet-like manner. Fleet introduction of hydrogen-powered vehicles in niche applications is a favorable way to bring them into the general marketplace, and in isolated communities, the hydrogen production and storage elements can be increased incrementally to allow renewable hydrogen to provide both utility electricity and transportation.

REFERENCES

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