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# INTEGRATED, RENEWABLE HYDROGEN UTILITY SYSTEMS

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## Abstract

The objective of this project is to establish the means of deploying renewable, hydrogen, utility power systems in isolated locations. The method is to develop the design and analysis tools, build a test system and build a full prototype system, as pathfinders for taking advantage of the ability of hydrogen to store large amounts of intermittent energy in a dispatchable and cost effective way. The expected location of the prototype system is in Kotzebue, AK, because the village has a remote, yet growing wind farm, and realistic loads and environmental conditions. This project goes past the use of fuel cells, or internal combustion generator sets, and fossil fuels in utility applications, and leads towards the long term us of hydrogen as a storage buffer for utility energy. Systems integrated to do this are significantly more complex than the linear systems, which will use 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. Our objectives include developing and experimentally testing the best methods for optimized design and control of realistic integrated, renewable, hydrogen power systems.

## Introduction

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, the tools that will to analyze hydrogen storage systems will also analyze the cost and performance expectations of all the other potential energy storage systems. For any application, there can be an optimum method of energy storage. That optimum should be chosen on basis of cost and performance, and that criteria will most likely change for each storage medium as the cost and performance parameters for them evolve over time. The general format for these systems is depicted in Figure 1, with the options for components from source to load.

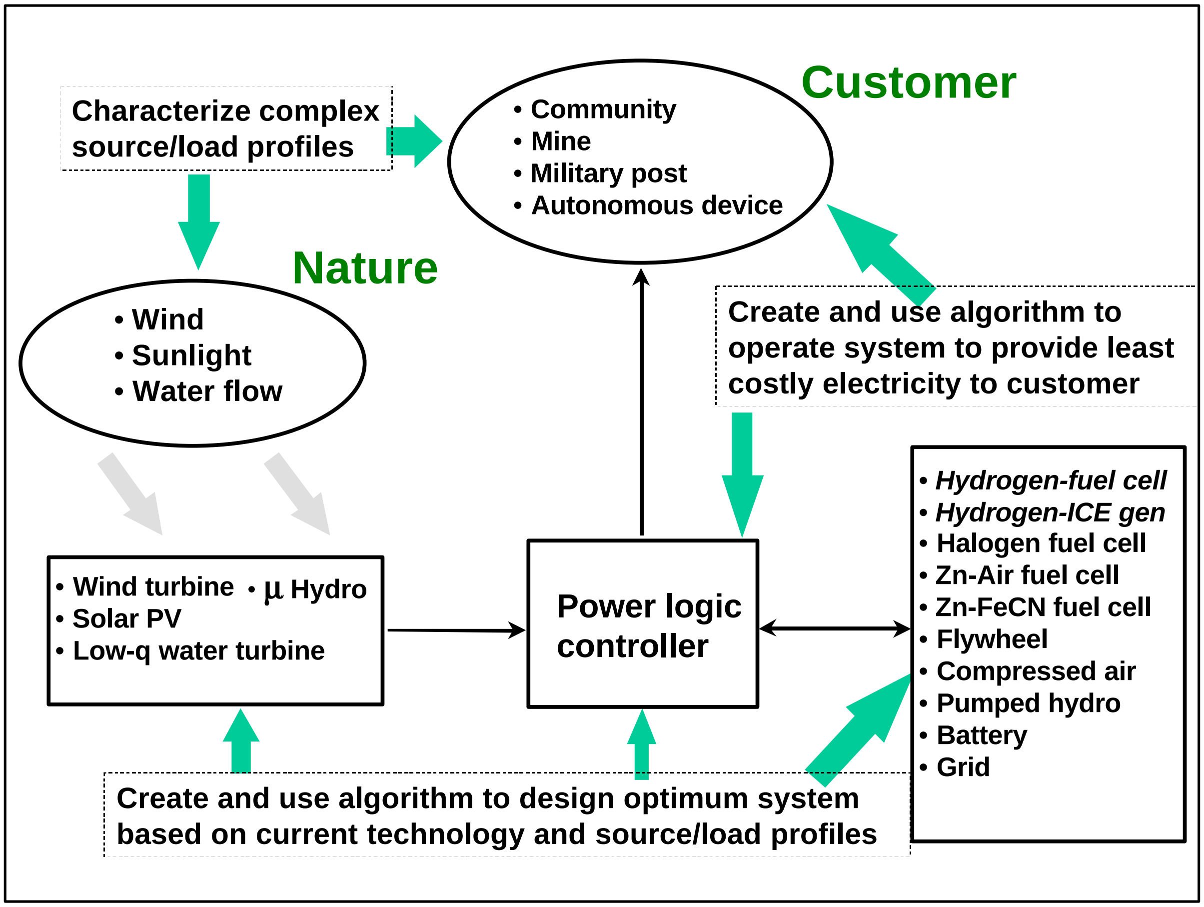


**Figure 1 - Source, Process, Storage and Load Options for Remote, Renewable Power Systems**

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 advanced technology, the use of hydrogen as a storage medium will have its earliest market in high-value applications, where electricity values are high, such as for premium power or in niche applications in isolated locations.

The 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 storage, 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 internal combustion engine generator or fuel cell. 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 to remote locations. A hydrogen system permits optimization of input and output power and 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, because can currently be significantly less expensive than a fuel cell. Optimized, ICE generator sets have been considered for several years as a transition power plant for the fuel cell. The can have similar efficiency and emission performance as a fuel cell, and can currently be significantly less expensive. However, there are still no manufacturers of ICE hydrogen generators, and the performance and cost of fuel cells is evolving rapidly. As a result, we expect that over the next decade the output power element for hydrogen systems will shift towards fuel cells almost exclusively.

## Project Description

This project is made up of two phases. This report summarizes the activities of the first phase. Phase One has three primary objectives:

1. To develop models that are specifically designed to optimize hydrogen storage systems for remote renewable applications. These models will also used to compare hydrogen systems with all other storage systems and to permit the rational ways to select the best system for a given application. The models will be used to optimize the system design for a specific application, and once designed, will be used to optimize the control of a system to provide the most reliable and lowest cost electricity to the customer. Models are yet to be developed for optimization of design and control of a hydrogen system. DRI is developing these models and relating them to current models for similar systems. DRI's models will be an integration of new work with appropriate, existing models for isolated power systems.

2. To design, purchase and construct a small scale, complete hydrogen renewable energy system. Such system would be designed and sized appropriately to test out any design and control models and methods in a realistic system. This will allow us to understand the implications of design, control and interface issues.

3. 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 second phase of this project.

## Status of Economic Evaluation/Systems Analysis

We needed a robust, simulation software system for this analysis activity. For the project, we must be able to model the behavior of the individual components of a system as well as their complex interactions. Any simulation platform software that we use must also be able to model electrolyzers, hydrogen storage and fuel cells directly. With this is our criteria, we chose TRNSYS as the system simulation software platform on which to base our models.

Before selecting TRNSYS, we considered other pre-existing, similar software packages such as HOMER, of 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. HYBRID2 can approximate the operation of our renewable hydrogen system and examine the behavior of individual components over time, but it currently models only wind, PV, diesel, and battery systems and is not capable of modeling electrolyzers, hydrogen storage, or fuel cells directly.

We have recently begun the full economic evaluation and systems analysis. Some examples will be shown later in this report. 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 system fuel cell. Operation of the standby power is not necessary, but as an option, it softens the engineering constraints on the full system.

## Small Scale, Complete Hydrogen Renewable Energy System

To test our, and other models, we have designed and purchased a complete small-scale, renewable, hydrogen, fuel cell development power system. This effort was done entirely on university funds. It includes 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 and a computer-based control system with analysis software. Because output power the system is sufficient to power the average home, we are naming this system a residential-scale, renewable fuel cell power system.

All of the components for this system were purchased in early FY 99, but construction of the system was delayed until June 1999 because of long delays in construction of the DRI Northern Nevada Science Center, which is the laboratory where this system will be used. The wind turbines have been installed on 80-foot tall towers and are operational. The rest of the system is expected to be completed in late July 1999. The wind turbines have an 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.

Separate, high-current power lines from each of the two solar arrays and each of the to wind turbines will run into the laboratory so that any combination of renewable resource can be connected to the power control system.

## Prototype System for a Remote Village in Alaska

DRI is exploring the opportunity to install a renewable hydrogen power system for practical use in Kotzebue, Alaska with the Kotzebue Electric Association (KEA). The concept of a remote hydrogen renewable power system in Alaska, and the motivation for such a system was developed in 1993 and is described in several documents. Some of the motivations are:

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 above \$700M.

The technologies necessary for an integrated renewable hydrogen power system are available, and close to the costs needed for full economic use in remote applications.

KEA has installed ten 65-kW wind turbines to offset then consumption of diesel fuel. Three have been operating for over a year, seven more were recently installed. Kotzebue exhibits the characteristics of numerous worldwide remote communities where integrated renewable energy is yet to be deployed. It has an operating and abundant renewable wind source. There is a well-staffed and trained workforce and physical resources in KEA. The Village of Kotzebue has at least one commercial load that has agreed to become isolated from the local grid to test our system under real conditions.

A team of representatives from DRI and DCH Technology met and worked with the Kotzebue Electric Association (KEA), local permitting authorities, and other Alaska entities. We have derived the plan to integrate a 20-kW hydrogen power system with the output of three 60-kW wind turbines and a local utility load. Initial design and options are done and are described in the following figures and tables.

The figures show two of several different examples of system designs for remote Alaska. In the first example, shown in Figure 2, the complete hydrogen storage power system is geographically located at the wind turbine site, which is approximately three miles from the village. Adjacent to the wind turbines, is the transmitter for the local commercial radio station KOTZ whose power requirements are approximately 14 kilowatts. 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 and proportional to the amount to wind driving the turbines at any time. This design would be the equivalent of a self contained, remote, renewable power system using hydrogen storage supplying a variable utility load.

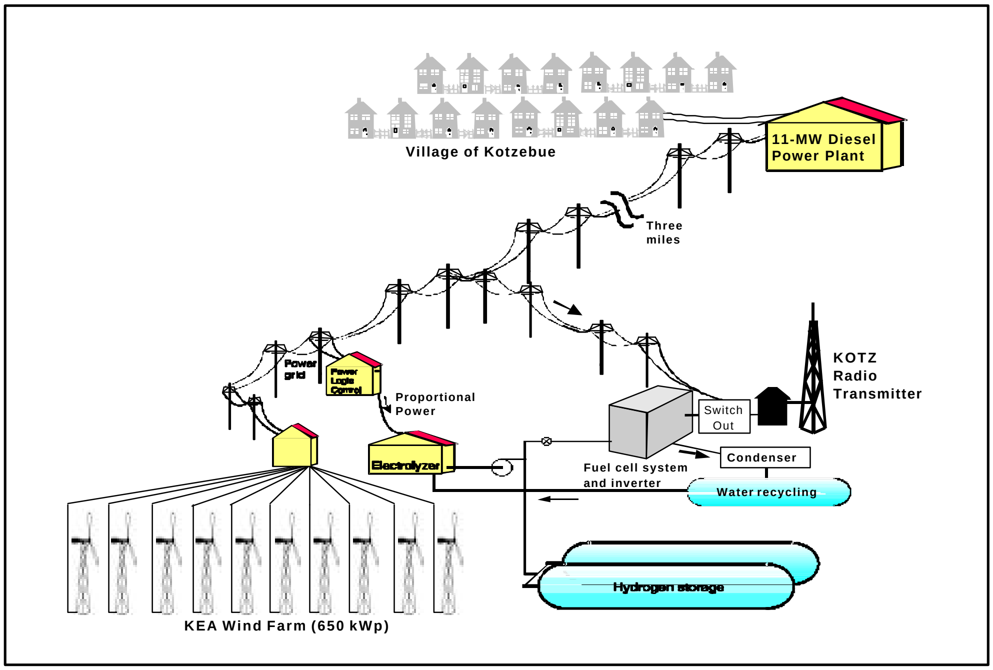


**Figure 2 – Isolated hydrogen, fuel cell power system for radio transmitter site**

In the second example, shown in figure 3, the hydrogen production and storage is located at the wind turbine site and a fuel cell is located in the village.  A small low-pressure gas line carries the hydrogen from the storage site fuel cell in the village.  This system uses the lower incremental infrastructure cost of a hydrogen gas line to transmit power from its production location to its point of use.

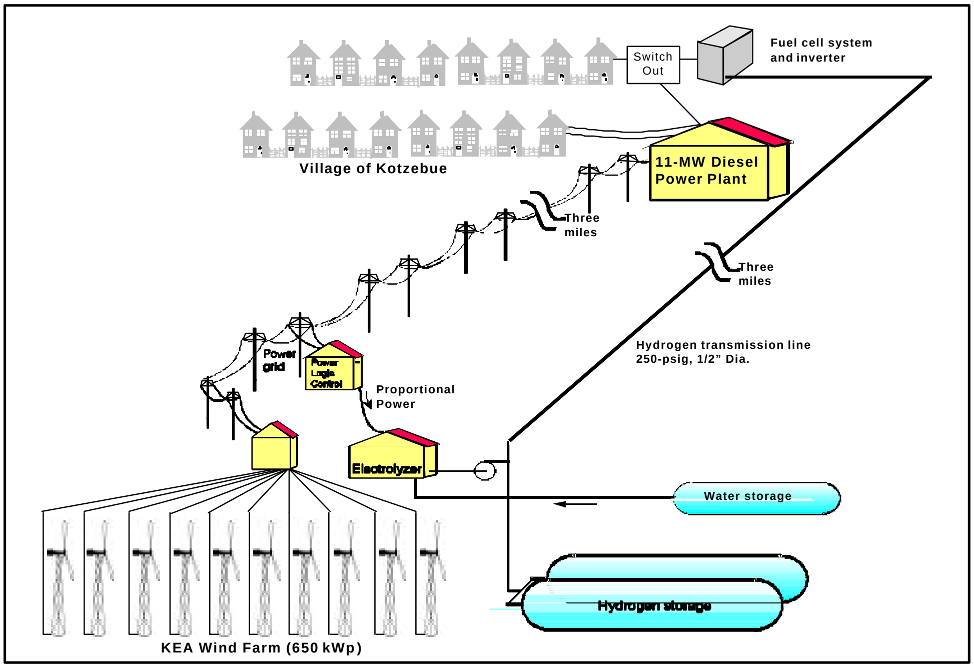


**Figure 3 – Renewable hydrogen, fuel cell power system with hydrogen transmission**

The use of a fossil fuel storage system, such as propane and a performer to soften be design requirements on the system is not employed in each year of these two examples.  Instead, in these KEA prototype systems, the use of a switchover to the main village diesel power grid will simulate the use of a standby fuel reservoir and a reformer attached to the fuel cell.

## Costing of System Options

Cost estimates for the installation of these two system configurations as well as other systems work performed and are shown on Tables 1 and 2.   Two significant variants that we show in Table 1 are the cost of the fuel cell and the amount of hydrogen storage capacity.  For a 20-kW fuel cell stack, we have found that for the same performance the price varies from manufacturer to manufacturer from $60,000 to $400,000.   The hydrogen storage system cost varied based on two things, a fuel cell efficiency variation between 40% and 50%, and a variation in storage time from 10 days to 88 days.

## Table 1 - Kotzebue Alaska Renewable Hydrogen Power System

| | | | | | |
|---|---|---|---|---|---|
| Electrolyzer (180 kW) | 410,000 | 410,000 | 410,000 | 410,000 | 410,000 |
| Fuel cell (20kW) | 60,000 | 400,000 | 200,000 | 60,000 | |
| Fuel cell BOP | 24,000 | | 24,000 | 24,000 | |
| Storage tank volume (gal) | 30,000 | | 30,000 | 60,000 | |
| Storage tank quantity | 2 | | 6 | 6 | |
| Total storage volume (gal) | 60,000 | | 180,000 | 360,000 | |
| Total storage tank cost | 59,200 | | 177,600 | 363,600 | |
| Controller and DAQ | 15,000 | | 15,000 | 15,000 | |
| Power electronics | 70,000 | | 70,000 | 70,000 | |
| Inverter | 18,000 | | 18,000 | 18,000 | |
| Compressor | 7,000 | | 7,000 | 7,000 | |
| Shipping electrolyzer | 2,000 | | 2,000 | 2,000 | |
| Shipping storage tanks | 3,000 | | 9,000 | 9,000 | |
| Shipping fuel cell | 800 | | 800 | 800 | |
| Shipping compressor | 600 | | 600 | 600 | |
| Site preparation | 12,000 | | 12,000 | 12,000 | |
| Fuel cell shed | 10,000 | | 10,000 | 10,000 | |
| Water processing equipment | 45,000 | | 45,000 | 45,000 | |
| Controllable resistive load (6 kW) | 7,000 | | 7,000 | 7,000 | |
| Switch out system at load | 8,000 | | 8,000 | 8,000 | |
| Storage batteries | 1,000 | | 1,000 | 1,000 | |
| H2 line to town | 12,000 | | 12,000 | 12,000 | |
| System final design w/Arctic engr | | 65,000 | 65,000 | | 65,000 |
| System safety and permitting | | 22,000 | 22,000 | | 22,000 |
| **System component subtotal** | | $1,191,600 | $1,116,000 | | $1,255,900 |
| **Project total** (less cost share) | $918,600 | | $1,183,000 | $1,229,000 | |
| **System performance** | | | | | |
| Fuel cell system efficiency | | 0.40 | 0.40 | | 0.50 |
| Average load power consumption (kW) | | 18.00 | 18.00 | | 18.00 |
| Longest possible storage time (days) | | 9.46 | 28.37 | | 88.65 |

There were several other option studied with significant differences in system cost. One of those

of Kivalina, Alaska. Kivalina has a 120-kW average load, and is currently powered by diesel generators. Recently the village of Kivalina elected to move the entire village and power system

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. In this case, since there are no pre-existing

the entire town can be powered with wind energy and a hydrogen fuel cell with the system cost that adds approximately 20% to the cost of the move of the village.

**Table 2 - Kivalina Alaska Renewable Hydrogen Power System**

| | | |
|---|---|---|
| Wind farm | 4,000,000 | 4,000,000 |
| Electrolyzer (1080 kW) | 2,460,000 | 2,460,000 |
| Fuel cell (200kW) | 600,000 | 1,000,000 |
| Fuel cell BOP | 75,000 | 75,000 |
| Storage tank volume (gal) | 30,000 | 30,000 |
| Storage tank quantity | 20 | 20 |
| Total storage volume (gal) | 600,000 | 600,000 |
| Total storage tank cost | 592,000 | 592,000 |
| Controller and DAQ | 125,000 | 125,000 |
| Power electronics | 170,000 | 170,000 |
| Inverter | 180,000 | 180,000 |
| Compressor | 17,000 | 17,000 |
| Shipping electrolyzer | 2,000 | 2,000 |
| Shipping storage tanks | 30,000 | 30,000 |
| Shipping fuel cell | 2,000 | 2,000 |
| Shipping compressor | 600 | 600 |
| Site preparation | 100,000 | 100,000 |
| Fuel cell shed | 10,000 | 10,000 |
| Water processing equipment | 85,000 | 85,000 |
| Controllable resistive load (6 kW) | 15,000 | 15,000 |
| Switch out system at load | 8,000 | 8,000 |
| Storage batteries | 10,000 | 10,000 |
| H2 line to town | | |
| System final design, incl. Arctic engr | 165,000 | 165,000 |
| System safety and permitting | 55,000 | 55,000 |
| **System component subtotal** | $8,701,600 | $9,101,600 |
| **Project total Includes labor, travel (less cost share)** | $9,796,600 | $10,196,600 |
| **System performance** | | |
| Fuel cell system efficiency | 0.50 | 0.50 |
| Average load power consumption (kW) | 120.00 | 120.00 |
| Longest possible storage time (days) | 17.73 | 17.73 |

## Summary

Existing models for 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. Early estimates in system design and cost show that it is reasonable to consider hydrogen and fuel cell or internal combustion power systems for remote communities in Alaska and elsewhere.

A complete residential scale system has been purchased and is currently being installed 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.

## Acknowledgements

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We are verty thankful for the cost-shared efforts and technical support of Stuart Energy Systems, DCH Technology and Kotzebue Electric Association.

## Figures



## Tables