Village Wind Diesel Hydrogen Report

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The cost of energy in hub and satellite villages has long been a major contributor to the cost of living in rural Alaska. Wind energy currently displaces a portion of the diesel fuel used for power generation in 5 Alaskan villages; Kotzebue, Selawick, Tooksook Bay, Wales and Saint Paul Island. Numerous other villages are being considered as potential sites for integration of wind generation into the diesel electric system.

Wind diesel electric systems are showing promise as sources of long term flat priced electricity for village power needs. Since the price of wind doesn't change the cost of the wind generated component of electricity is not subject to fuel price volatility. As with any renewable energy the upfront capital cost is higher than diesel engines.

Wind diesel alone however, does not address the broader energy needs of rural communities. Fuels such as gasoline, diesel and heating oil have to be transported to the village. This report explores the potential of using wind to produce hydrogen for transportation and heating fuels at a small, 400 person and large, 4000 person village.

Similar to fossil fuel, hydrogen is not an original source of energy and is often called an energy carrier. Just as fossil fuels store the sun's energy, hydrogen stores energy from other sources. In the case of wind-derived hydrogen, it could be used to store wind energy and used later as a fuel.

Hydrogen is the most abundant element in the universe. On earth it occurs in combination with other elements. Water, H_2O, is the most plentiful combination. Hydrogen alone is expressed as H_2 since its molecule occurs in pairs. Hydrogen can be separated from natural gas, $CH_{4,}$ in a steam reformer. Steam reformation is widely employed for generating hydrogen used in the pharmaceutical industry, food production, heavy industrial uses and to improve and enhance petroleum fuels.

Hydrogen can also be separated from water using electric current in a process called electrolysis. There are several electrolysis systems currently available on the market. Some systems are designed for production of high-grade hydrogen for scientific research and as a cooling medium in power plants. Although not widely used for the production of energy, there are manufacturers building electrolysis based hydrogen generators for vehicle fueling. Two companies, Hydrogenics and Proton Energy, both Canadian companies, are mentioned in the reference section of this report. One of these systems, the HySTAT Energy Station ™, by Hydrogenics Corporation, is designed to produce hydrogen on a large enough scale to supply a village.

The HySTAT Energy Station ™ is a modular system. Depending on the fuel needs of the village, hydrogen modules can be added until sufficient production capacity is installed to meet local needs. Fuel for vehicles would be distributed, (sold) at the local fueling station. Heating fuels would be transported by a village tanker truck to tanks located near homes and businesses similar to the heating fuel tanks now used.

Hydrogen can be stored as a gas under pressure or liquefied. In liquid form the energy density is much higher however at least 25% more energy is required to liquefy it. The only reason to liquefy hydrogen would for long term storage or long distance transportation. Leaving the hydrogen in gaseous form and compressing it to 5000 psi increases the energy carrying capability of fuel tanks on vehicles and avoids the need to liquefy the product.

Hydrogen Storage would be required for a village and be based on the size of the village and the local wind regime. In other words, the more fuel needed the more storage may be required. As an example, the HySTAT Energy Station ™ includes storage modules that can be matched to village needs. For purposes of this report minimum storage, a single module about 2 days storage, was assumed.

Electrolysis requires relatively high quality water. The HySTAT Energy Station ™ does not include a water treatment system but the manufacturer does mention the need for demineralized water in the product literature. Demineralizers are widely used in the power industry to ready water for use in boilers. The technology is readily available in the market place and was not researched in the preparation of this report. However, one of the investigators has experience with power plant water treatment systems and has included water treatment in the O&M costs of the hydrogen generation system.

Transport of the hydrogen within the village would be carried out using a tanker truck equipped with valves and controls for delivering hydrogen on a periodic basis such as once a week or twice each month depending on the heating needs of the particular home or business customer.

Hydrogen produced in the village would not be transported far, typically only within the village itself. It may be possible to export hydrogen to markets outside Alaska. However, to transport long distances would require the hydrogen be liquefied. Liquefying hydrogen requires more electrical energy and was not considered for this report. Villages located in high wind regimes and with ocean access could benefit from the production and export of hydrogen to outside markets in the future.

Both BP and Shell have business units focused on the development of hydrogen technologies. These efforts center on the development of larger scale technologies for global energy markets. However, as the technologies continue to develop it is likely more end use consumer equipment will become available for village applications.

Special Handling Notes

Just as with the handling of fossil fuels, hydrogen requires care. Hydrogen gas is very light and will escape easily. To avoid excessive loss of hydrogen fuel special valves and filler couplings will be required for vehicle fuel and storage tanks. Individuals will need to be mindful of these characteristics to reduce hazards and optimize fuel usage.

Hydrogen handling will require special training as well. The hydrogen flame is light blue and often not visible to the human eye. Radiant heat of the hydrogen flame is low compared with that of burning fossil fuel. Individuals handling the fuel will need to be trained in the use of hydrogen detectors and flame sensors. Hydrogen that does escape poses no environmental threat.

As a transportation fuel, hydrogen works well, keeping in mind its characteristics as a light molecule and with low energy content per volume. The fuel burns cleanly and internal combustion engines can be optimized by the manufacturer to operate on hydrogen. When burned it produces water vapor. Therefore, as a heating fuel, accommodation for this characteristic must be made. Vents and exhausts would need to be designed to shunt condensed water away from buildings.

While not the subject of this report domestic water needs in homes and village businesses remain a source of concern. It is worth noting the water vapor resulting from the burning of hydrogen could be collected and used to meet household needs. The hydrogen delivery truck would then be delivering both heating fuel and water in the same trip.

Hydrogen Equivalents

Hydrogen is the smallest and lightest molecule of all known elements. By weight it is the most energy intensive however by volume it has only about a third of the energy content of fossil fuels. For instance, a standard cubic foot of natural gas contains approximately 1000 BTUs while a scf of hydrogen contains 319 BTUs. In order to obtain the energy equivalent of 5 gallons of gasoline a hydrogen tank 72" long and 13" in diameter pressurized to 5000 psi would be required. [Interview with Jerry Jones of Collier Technologies, 12/21/05]. Collier Technologies converts new engines to operate on propane or hydrogen. The company worked with the Desert Research Institute to develop the technology, obtained patents and markets new engines in the 5 – 30 kw range. For instance, the 5 kw (11hp) normally aspirated engines start and operate on hydrogen at a 34% thermal efficiency. A typical gasoline engine is approximately 28% thermally efficient.

Early adoption of hydrogen fuel for small vehicles such as snow machines, four wheelers and our board engines will require trade offs. For instance, a snow machine would require an extra fuel tank if the owner wanted the same travel distance 5 gallons of gasoline provides. The owner may otherwise wish to fuel his or her machine more often to save room and weight of the extra tank.

Schematic Diagram Explanation

See Village Wind Diesel Hydrogen System Schematic

The schematic shows a village with a conventional diesel power plant supplying the electric system. The wind turbines operate in parallel with the diesel power plant. Power is supplied to homes and businesses via electric lines. The wind generated electricity replaces a share of the diesel fuel required to power the village electrical needs and is operated by the local electric company.

A portion of the wind turbine electric output powers an electrolyser to produce hydrogen from water. The hydrogen is used to power standard 4 cycle internal combustion engines such as 4 wheelers, snow machines and outboards as well as meet space heating needs. Hydrogen will burn cleanly in a normally aspirated internal combustion engine when air and spark timing are adjusted for the fuel. In the village, hydrogen is delivered by truck to homes and businesses and used for space and water heating needs. The storage tank next to the fueling station stores hydrogen generated by the electrolyser and supplies the tanker truck for village deliveries and vehicle fuel. Each heated building would have a hydrogen storage tank to store pressurized hydrogen. A pipe from the tank carries hydrogen to a space heater, furnace or water heater where the hydrogen is burned to produce heat for the home or business.

The portion of the wind turbine electric output dedicated to produce hydrogen powers an electrolyser. Electrolysis is the process of separating the oxygen and hydrogen in water using electricity. The oxygen from the process is pure and may find some uses in the village for welding but would most likely be vented harmlessly to the atmosphere. When the wind is not blowing hydrogen is not being produced. Diesel fuel is never used to produce hydrogen.

Hydrogen generated by the electrolyser is stored in a tank next to the fuel station. Gasoline and diesel are sold at the station for users of those fuels. Hydrogen is sold to those with hydrogen fueled vehicles.

The small village, 400 people, would require 4 of the HySTAT Energy Station ™ systems. The large village, 4000 people, would require 38 of the HySTAT Energy Station™ systems. There is some economy of scale for the large village however the upfront capital requirements are substantial. Please see cost estimates for small and large villages found in the accompanying spreadsheets.

Hydrogen Safety

The U.S. Department of Energy EERE lists the following as the primary safety issues for the use of hydrogen as fuel source.

- **Hydrogen can be handled safely when guidelines are observed and the user has an understanding of its behavior.** Like all fuels, hydrogen is an energetic substance which must be handled appropriately; it is this energetic quality that makes fuels useful. Hydrogen is considered to be as safe as other commonly used fuels, although its characteristics are different (just as gasoline differs from natural gas).
- **Hydrogen is lighter than air and diffuses rapidly.** Hydrogen has a rapid diffusivity (3.8 times faster than natural gas), which means that when released, it dilutes quickly into a non-flammable concentration. Hydrogen rises two times faster than helium and six times faster than natural gas at a speed of almost 45 mph (20m/s). As the lightest element in the universe, confining hydrogen is very difficult. Industry takes these properties into account when designing structures where hydrogen will be used. The designs help hydrogen escape up and away from the user in case of an unexpected release.
- **Hydrogen is odorless, colorless, and tasteless,** so most human senses won't help to detect a leak. For these and other reasons, industry often uses hydrogen sensors to help detect hydrogen leaks and has maintained a high safety record using them for decades. By comparison, natural gas is also odorless, colorless, and tasteless, but industry adds a sulfur-containing odorant to make it detectable by people. Currently, no known odorants can be used with hydrogen since they contaminate fuel cells (a popular application for hydrogen). Today, researchers are investigating other methods that might be used for hydrogen detection like tracers and advanced sensors.
- **Hydrogen flames have low radiant heat.** A hydrogen fire has significantly less radiant heat compared to a hydrocarbon fire. Since the flame emits low levels of heat near the flame (the flame itself is just as hot), the risk of secondary fires is lower.
- **An explosion cannot occur in a tank or any contained location that contains only hydrogen.** An oxidizer, such as oxygen, must be present. There is little likelihood that hydrogen will explode in open air, due to its tendency to rise quickly. Hydrogen does burn very quickly, however, sometimes making a loud noise that is mistaken for an explosion.
- **Asphyxiation.** With the exception of oxygen, any gas can cause asphyxiation. In most scenarios, hydrogen's buoyancy and diffusivity make hydrogen unlikely to be confined where asphyxiation might occur.
- **Toxicity.** Hydrogen is non-toxic and non-poisonous. It will not contaminate groundwater (it's a gas under normal atmospheric conditions), nor will a release of hydrogen contribute to atmospheric pollution.
- **Hydrogen Codes and Standards.** Codes and standards help dictate safe building and installation practices. Today, hydrogen components must follow strict guidelines and undergo third party testing for safety and structural integrity.

http://www.eere.energy.gov/hydrogenandfuelcells/education/safety.html

The Hindenburg Myth

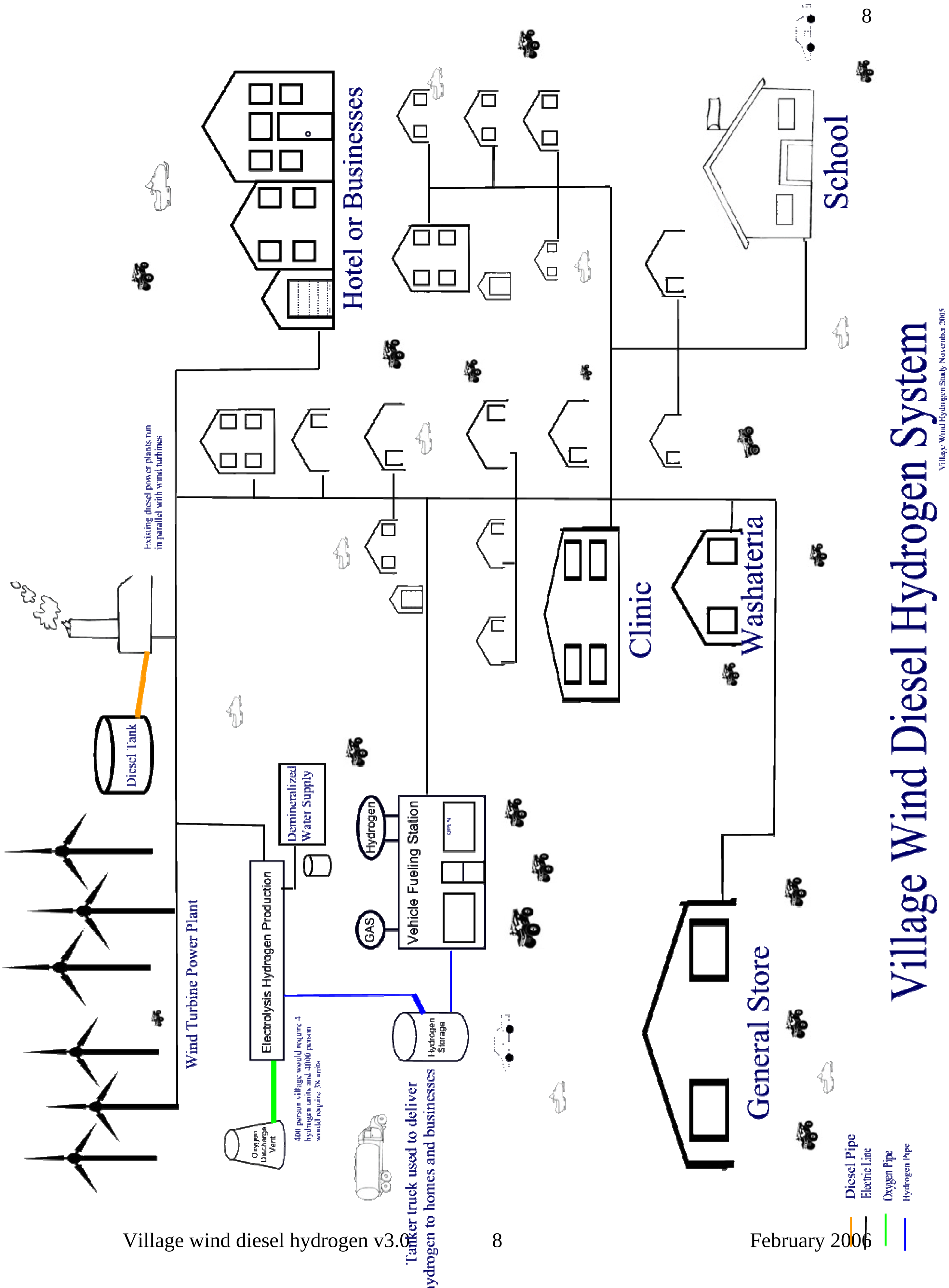
People still associate hydrogen safety with the terrible crash of the Hindenburg more than 65 years ago. Yet the catastrophic fire aboard the Hindenburg was the result of the aluminum based material used on the dirigible's skin – a material akin to solid rocket fuel! Today's safety regulations do not permit this to occur. It should be noted that because dissipates quickly, no Hindenburg fatality was the result of a burn from hydrogen.
http://www.usfcc.com/about/Hydrogen%20Basics.pdf, website of the US Fuel Cell Council, retrieved 12/28/05

Future Research and Development: Pilot Project

Technologies to produce electricity from wind exist and are currently in use in Alaska. Technologies to produce hydrogen from water are available in the market place. There are some manufacturers producing internal combustion engines from the factory built to operate on gaseous fuels that are readily tuned to fire on hydrogen. There are no known commercially available; space heater, furnaces or boilers available from manufacturers for residential, commercial building space or water heaters. There are manufactures of industrial hydrogen fueled furnaces which are not intended for space heating but for waste incineration.

Prior to deployment of hydrogen fuel production at a village, a pilot project should be undertaken. The purpose of the pilot project would be to produce hydrogen fuel from wind and use it in various IC engines and space heating equipment. The project would be used as a test bed to mature the technologies sufficiently prior to deployment in a rural application.

A collaborative of stakeholders would need to be formed consisting of, native village energy experts, local electric and fuel utilities, state and federal government representatives and oil company hydrogen experts. The purpose of the collaborative would be to develop the scope of work for a pilot project leading to the development of practical hydrogen fueled machines for village Alaska.



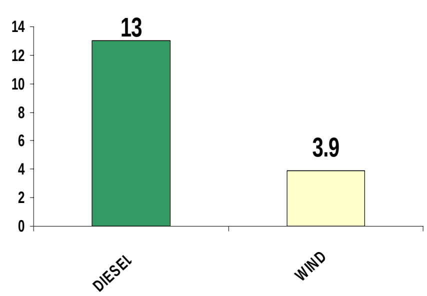
Village Wind Diesel Hydrogen System
Village Wind Hydrogen Study November 2005
Hotel or Businesses
School
Clinic
Washateria
General Store
Existing diesel power plants run in parallel with wind turbines
Diesel Tank
Wind Turbine Power Plant
Electrolysis Hydrogen Production
Demineralized Water Supply
Hydrogen
GAS
Vehicle Fueling Station
Hydrogen Storage
Oxygen Discharge Vent
400 person village would require 4 hydrogen units and 4000 person would require 38 units
Tanker truck used to deliver hydrogen to homes and businesses
Diesel Pipe
Electric Line
Oxygen Pipe
Hydrogen Pipe

Cost of Wind-Derived Hydrogen
Equivalent values were calculated on a BTU basis.
Assumes grant funding of wind system

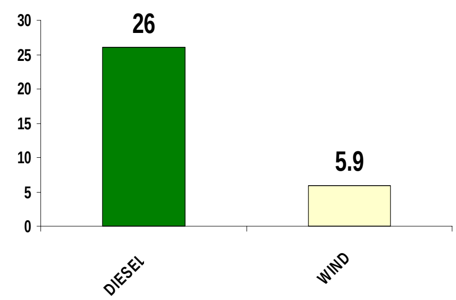
	small village	large village
cost of hydrogen to displace diesel	$4.69 / gal	$3.59 / gal
cost of hydrogen to displace gasoline	$3.89 / gal	$2.96 / gal

Assumptions including capital costs, grants and O&M costs are included in the Excel workbook named **wind hydrogen product costs rev3.xls** which has been transmitted with this report.

<u>Comparative cost of generated power</u>
Assumes grant funding of wind system



Hub Village
Cents per Kw



Satellite Village
Cents per Kw

Excerpted from March 2004 Denali Commission liaison to BP Wind trip report
Calculated values are for generation only and assume the following:
Wind generation capital is 75% grant funded
Remaining 25% is loan funded at 8%
28% capacity factor

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