Economic Analysis of an Integrated Wind-Hydrogen Energy System for a Small Alaska Community

Final Technical Report

Tasks 4,5,6 under the Project:
A Compilation and Review of
Proposed Alaska Development Projects

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Abstract

Wind-hydrogen systems provide one way to store intermittent wind energy as hydrogen. We explored the hypothesis that an integrated wind-hydrogen system supplying electricity, heat, and transportation fuel could serve the needs of an isolated (off-grid) Alaska community at a lower cost than a collection of separate systems. Analysis indicates that: 1) Combustible Hydrogen could be produced with current technologies for direct use as a transportation fuel for about $15/gallon-equivalent; 2) The capital cost of the wind energy rather than the capital cost of electrolyzers dominates this high cost; and 3) There do not appear to be diseconomies of small scale for current electrolyzers serving a a village of 400 people.

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Introduction

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 the scale of a small, 400 person village. An ISER economist teamed up with a utility engineer to consider whether an *integrated* wind-hydrogen energy system serving essentially *all* of the energy needs of a 400-person community in remote rural Alaska would be technically feasible and economically attractive in the medium-term (year 2020-2025).

Executive Summary

This summary covers the UAA-ISER portion of the overall scope of a project titled "A Compilation and Review of Proposed Alaska Development Projects", namely, Tasks 4,5, and 6. There are two main objectives: 1) Create a village-scale energy model that could be used to assess possible alternative technology systems and/or primary fuel inputs. 2) Demonstrate the model by specifying, costing, and evaluating a nonconventional wind-hydrogen energy system for small communities.

The principal results are: 1) It is technically feasible to produce and store hydrogen on a small scale. 2) It seems technically feasible to burn hydrogen directly in small internal combustion engines prevalent in rural Alaska, but these applications have not been demonstrated. 3) The capital costs of adding a hydrogen production, storage, and distribution system to an exising wind-diesel system are extremely high. 4) Most of these capital costs are due to wind production rather than to hydrogen production.

Our analysis demonstrates that a hydrogen production system is technically feasible for a small Alaska community of 400 people, using equipment that is commercially available today. However the capital cost of such a system would be quite high – about $14.00 per gallon displaced, or about $117,000 per person served.

These preliminary conclusions have two implications for policy and for future R&D. First, it appears that the *operating* cost of a hydrogen system would be low enough to be

affordable by users. Hence, a policy decision to subsidize capital costs would be "sustainable" after the capital was installed. Second, since the majority of the capital cost is for wind generation capacity, it appears that continued R&D on wind systems will have a significant positive impact on the cost of an integrated system. In other words, the capital cost of electrolyzers is *not* the chief hurdle to be overcome if hydrogen systems are to become economically viable.

A logical next step toward a viable integrated wind-hydrogen energy system is a pilot project that replicates Alaska conditions and tests the technical feasibility of direct-burn hydrogen systems, especially for small vehicles.

Experimental Methods

We constructed two spreadsheet models to facilitate the analysis. The first is the Alaska Village Energy Model (AVEM1.xls). This model integrates data and information from various sources to estimate total village energy demand for electricity, space heating, and transportation. The second is the Wind-Hydrogen Production Cost Model (WHPC3.xls).

Village Energy Demand Assumptions

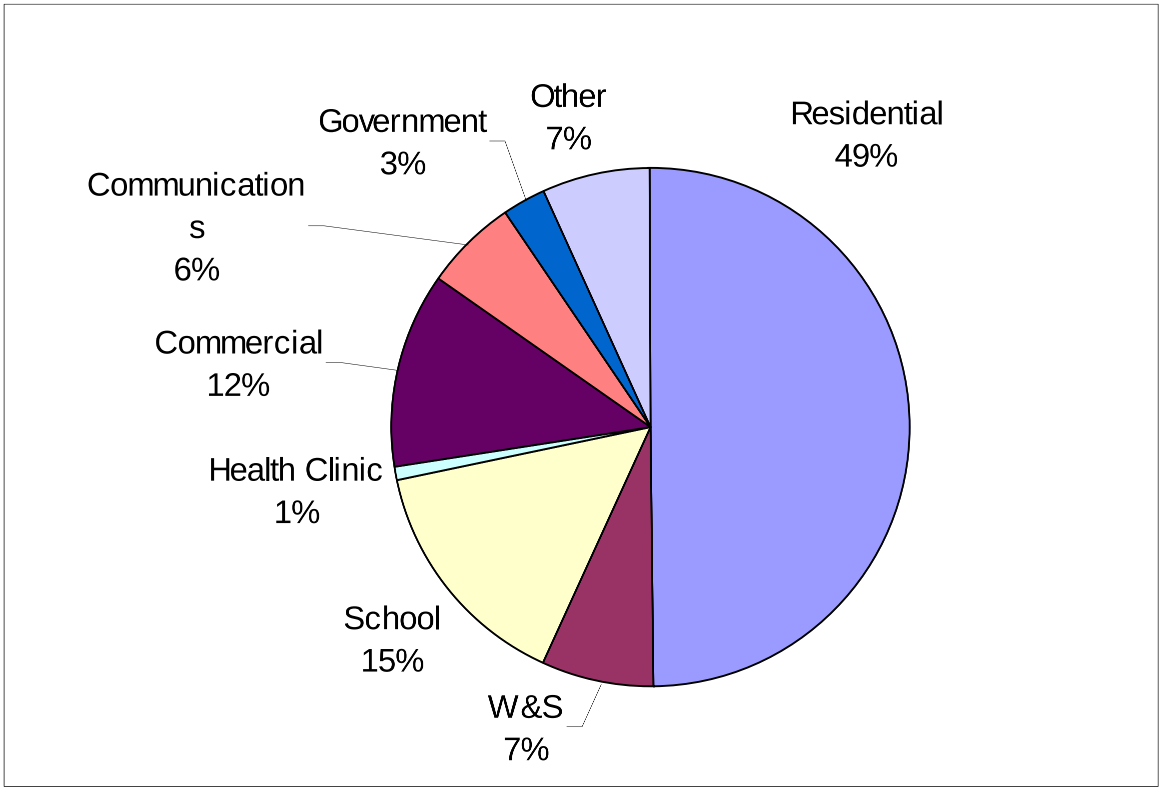
Using the AVEM model, we first specified the following characteristics of a prototype 400-person village:

- 400 people
- 130 households
- 2 small businesses
- 1 large commercial building (AC store)
- 1 community center
- 2 government buildings
- Sub-regional health clinic
- Advanced flush-haul sanitation, washeteria with Sauna

Electricity. Our model incorporates the algorithms of the Alaska Village Electric Load Calulator.[1] Using the above assumptions the estimated load for applications requiring electricity is 3,347 kWh per person per year.

[1] Devine, M.; Baring-Gould, E. I. (2004). Alaska Village Electric Load Calculator. 31 pp.; NREL Report No. TP-500-36824.

Figure 1. Electric Load for Prototype 400 Person Community
Average load = 3,337 kWh per person



note: W&S = water and sewer

Space Heat. We developed a "net heat" estimate by combining data from the AKWARM database, State of Alaska BEES energy standards, and additional engineering calculations. Our prototype house was 1,250 square feet in a climate equal to that of Kotzebue.

Table 1. Residential Space and Water Heat Demand

Residential space heat:		
number of houses	130	
net BTU per house (at baseboard)	64	million Btu per house measured at the baseboard
total net heat:	8,320	million Btu heat at baseboard

Residential water heat:		
number of houses	130	
net heat per house	22	million Btu per house net heat into the water
total net heat	2,860	million Btu heat at baseboard

Tables 2 and 3 summarize our estimates of space and water heat energy demand for nonresidential buildings.

Table 2. School and Commercial/Govt Buildings Space and Water Heat Demand

School space and water heat

square feet	25,000			
gal/ square foot (rural energy plan)	1.2	gal/Ft2	per rural energy plan	
gallons of fuel	30,000			
efficiency of boilers/heaters	75%			
Btu/gallon	138,000			
net heat supplied to school	3,105	million Btu heat (includes hot water heat)		

Commercial/govt space and water heat

square feet					
# of Small Businesses	2		assume	1,000	Ft2 each
# of Large Commercial:	1		assume	4,000	Ft2 each
# of Community Buildings:	1		assume	2,000	Ft2 each
# of Government Offices:	2		assume	1,000	Ft2 each
Total square feet				10,000	
gallons per square foot		1.2	avg of high(washeteria) and low (community h		
gallons of fuel		12,000			
efficiency of boilers		75%			
Btu/gallon		138,000			
net heat supplied to comm/govt		1,242	million Btu heat (includes hot water heat)		

Table 3. Transportation Vehicle Demand

Large vehicles (diesel)

Galena data:		40,000	gallons		
(city and school)		900	people		
		44.4	gallons/person		
for 400 people city and school:		17,778			
# personal automobiles/trucks	0.5	per household	equals:	65	vehicles
gal per auto/truck		200			
for 400 people, personal:		13,000			
Rounded, large vehicle fuel demand:		31,000	gallons diesel/yr		
		138,000	btu/gal		
total Btus, large vehicles:		4,278	million btu input energy into engines		

Small vehicles (gasoline):

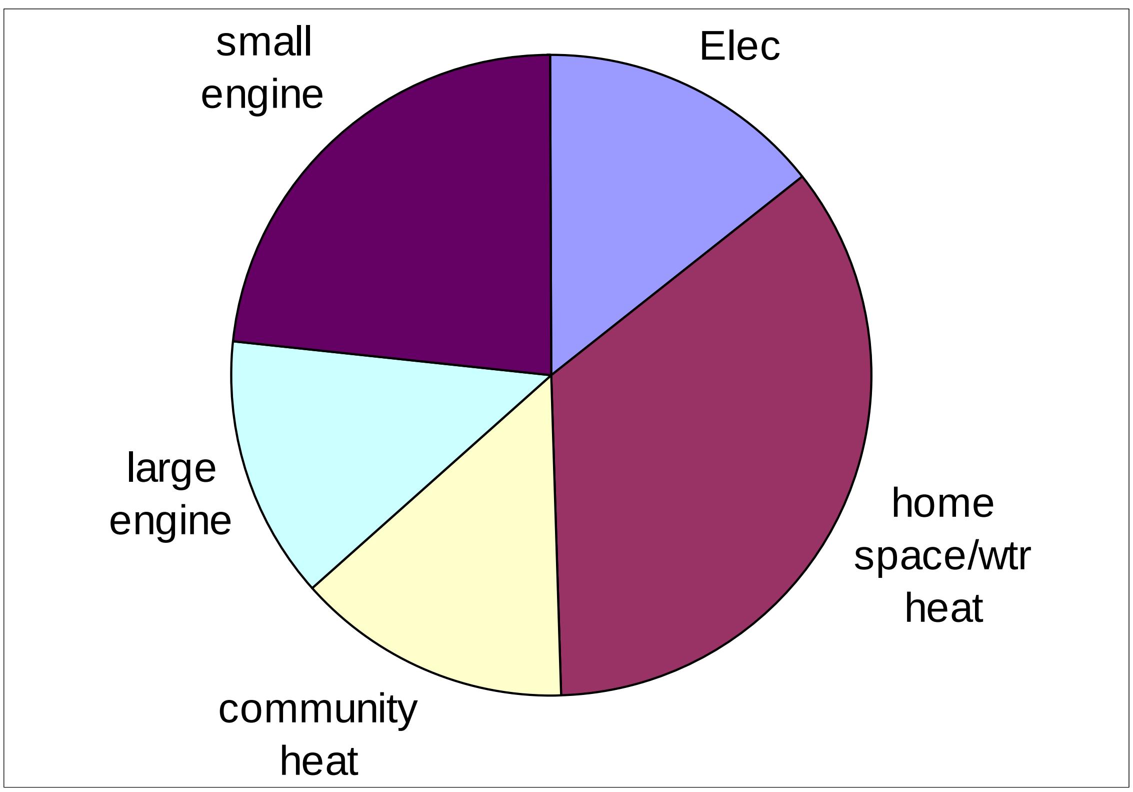
# of 4-wheelers	1	per household	equals:	130
# snowmachines	1.5	per household	equals:	195
# outboards /skiffs	0.1	per household	equals:	13
gallons per 4-wheeler per yr		200		
gallons per snowmachine per yr		200		
gallons per outboard per yr		[not considered in this analysis]		
Total gallons:		65,000		
gasoline Btu/gal		114,100		
Total Btus, small vehicles		7,417	million btu input energy to engines	

Total Village end use energy demand is estimated to be 32.2 billion Btu as shown in Table 4. Approximately 357,000 gallons of fuel are needed to serve this demand after accounting for inefficiencies of energy conversion. In the economic analysis we focus on the 246,000 gallons of fuel – for uses other than electricity generation -- that would need to be displaced by hydrogen.

Table 4. Summary of End-use Energy Demand and Fuel Usage

Summary tally of "end-use" energy demand for 400 person village:				
Electicity, measured at cust. Meter	4,556	million Btu	1,334,869 kWh	
Residential space and water heat, net heat at baseboard or into water	11,180	million Btu		
School and commercial net heat at baseboard or int	4,347	million Btu		
Large/diesel vehicles, fuel input to engine	4,278	million Btu		
Small/gasoline vehicles, fuel input to engine	7,800	million Btu		
Total	32,161	million Btu		
Subtotal excluding electricity	27,605	million Btu		
Rough estimate of fuel demands to meet these needs			**per HH**	**per person**
electricity @ 12 kWh sold/gal diesel	111,239	gal diesel	856	278
Residential space and water heat@ 75% efficiency	108,019	gal oil	831	270
School and comm. Heat and water heat	42,000	gal oil	323	105
Large/diesel vehicles	31,000	gal diesel	238	78
Small/gasoline vehicles	65,000	gal gasoline	500	163
Total	357,258	gal		
Subtotal excluding electricity	**246,019**			

Figure 2. Summary of Village End-use Energy Demand
Total = 32.2 billion Btu



Hydrogen Production and Storage

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 5,000 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 Concerns for Hydrogen

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 Safety

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 hydrogen dissipates quickly, no Hindenburg fatality was the result of a burn from hydrogen.[2]

The U.S. Department of Energy EERE[3] 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.

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[2] http://www.usfcc.com/about/Hydrogen%20Basics.pdf. website of the US Fuel Cell Council, retrieved 12/28/05

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

- **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.

Hydrogen Energy Equivalents and Required Storage Tanks

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 5,000 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.

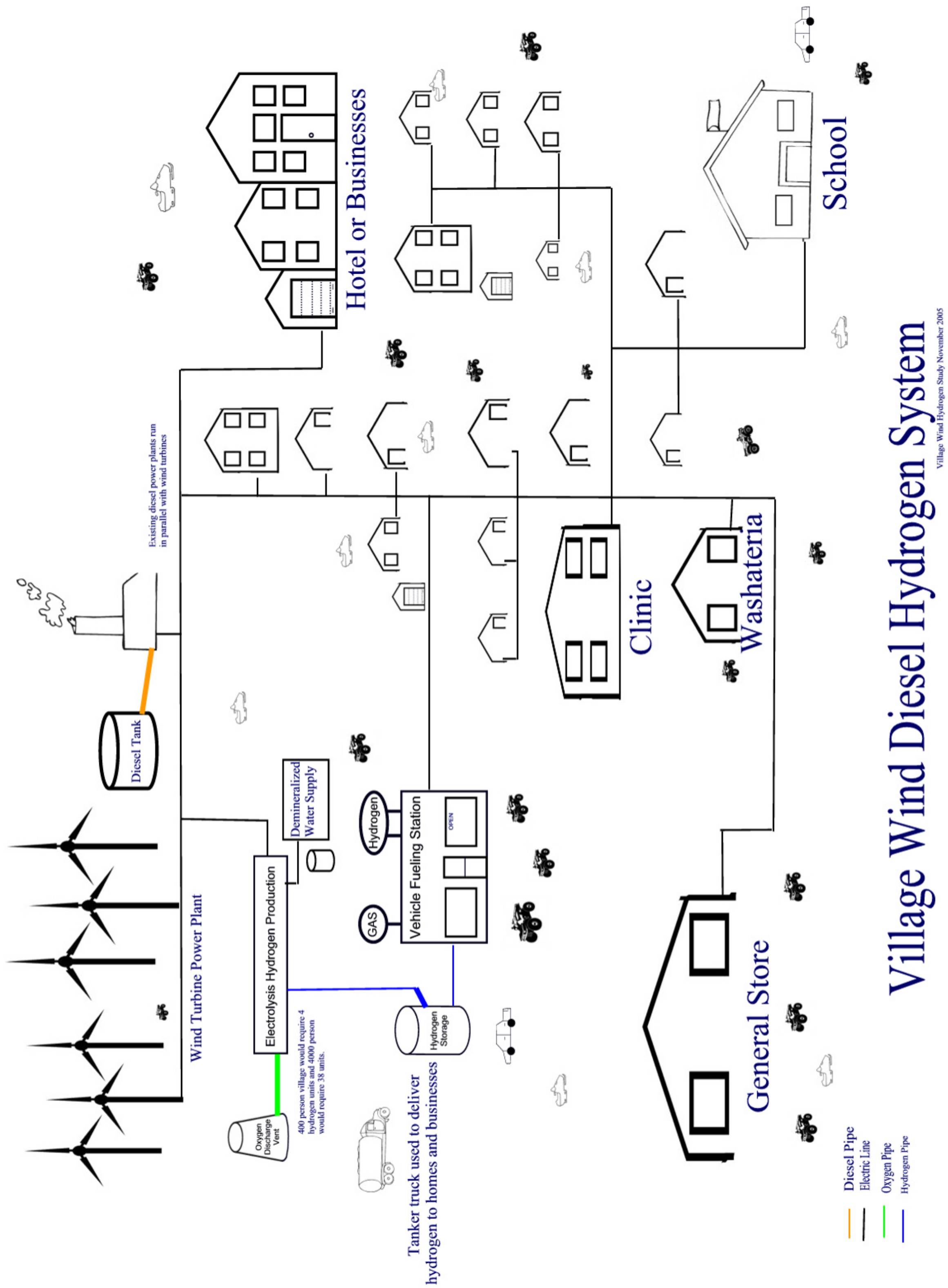
Early adoption of hydrogen fuel for small vehicles such as snow machines, four wheelers and our board engines will require trade offs. For instance, a snow machine would require an extra fuel tank if the owner wanted the same travel distance that five gallons of gasoline provides. The owner may otherwise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

Integrated Wind-Diesel-Hydrogen System

The schematic on the following page 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.

Figure 3. Wind-Diesel-Hydrogen Schematic



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.

Economic Analysis Assumptions

This analysis determines the incremental cost of adding a hydrogen system capable of serving the 27.6 billion net Btu demand for the small (400-person) village uses other than electricity. These are space heat, water heat, and vehicles.

To serve the total demand of 27.6 billion net Btu for uses other than electricity, shown above in Table 4, we estimate that 10 of the HySTAT Energy Station™ systems would be needed. (A large village, of 4000 people, would require 38 of the HySTAT Energy Station™ systems.) These estimates are quite approximate, based on a station output of 2,280 scf/hr.

The incremental wind generation capital is based on a 28% capacity factor and an installed capital cost of $4,500/kW. The assumed financing terms are 5% real interest over 30 years. No grant funding is assumed. Incremental wind system O&M is assumed to be $.02/kWh.

Results and Discussion

Capital Cost

Table 5 shows that estimated incremental capital costs for the hydrogen components of the system would be about $47 million, which equates to about $118,000 per person served.

Table 5. Incremental Capital Cost for Hydrogen System

Small Village Hydrogen Cost Model		
Hydrogen Requirements		
15,527	net million Btu	Space and water heat baseboard demand
75%	space and water heat combustion efficiency	
20,703	gross million Btu	space and water heat fuel input
4,278	gross million Btu	Large engine transportation fuel input
7,800	gross million Btu	Small engine transportation fuel input
32,781	million Btu	Total fuel input
319	Btu/scf	
102,760,711	scf/yr	hydrogen requirement
Hydrogen Incremental Capital Cost		
2,280	scf/hr	Hystat output
10	Number of HyStat units	
1,718,750	$	capital cost per Hystat system
17,187,500	$	Hydrogen electrolysis capital cost
0.126	kWh/scf	Hystat power requirement for electrolysis
12,947,850	kWh/yr	electic power for production
1.25	factor	adjust for additional power for compression
16,184,812	kWh/yr	total electricity input to hydrogen system
0.28	capacity factor	wind system actual/rated output
6,594	kW	required wind capacity
4,500	$/kW	cost of wind capacity
29,672,946	$	Incremental wind system capital cost
46,860,446	$	Total incremental capital for Hydrogen

O&M Cost

Incremental O&M costs are equal to about $436,000 per year. Of this, about $112,000 per year, is for O&M on the hydrogen production system. We have increased the manufacturer's unit cost estimates by 50% to account fo Arctic conditions. The remainder,about $324,000 per year, is O&M on additional wind-generation equipment.

Table 6. Incremental O&M cost for Hydrogen System

Hydrogen Incremental O&M		
6,813	$/unit/yr	annual O&M per Hystat unit
50%	add-on factor	aditional O&M for Arctic conditions
102,188	$/yr	annual O&M for Hystat units
1,000	$/yr	estimated water treatment per Hystat
10,000	$/yr	annual water treatment
112,188	$/yr	Total incremental O&M for hydrogen production
0.02	$/kWh	incremental wind electricity O&M
323,696	$/yr	incremental wind electricity O&M
435,884	$/yr	Total incremental O&M for Hydrogen System

Levelized Total Cost

The levelized total cost of the hydrogen system is about $3.5 million per year. The vast majority of this cost is capital, most of this capital cost is for additional wind capacity. Table 7 shows the levelized total cost and its components. Hydrogen from wind for use in direct fuel end uses would cost about $14 per gallon of diesel or gasoline displaced. The vast majority of that cost – almost $13 per gallon – would be up-front capital equipment. Ongoing operating costs appear to be under $2.00 per displaced gallon.

Table 7. Levelized Total Cost for Hydrogen System

Levelized Hydrogen Total Cost

5%		real discount rate
30	yr	lifetime of financing
3,048,339	$/yr	levelized capital
112,188	$/yr	O&M on hydrogen production
323,696	$/yr	
3,160,527	$/yr	Levelized total cost for Hydrogen
246,019	gal/yr	displaced fuel
12.85	$/gal	Levelized total cost of displaced fuel

Components of Levelized Hydrogen Total Cost

$/yr	$/gal displaced	% of total	
1,118,072	4.54	32%	capital -- hydrogen production
1,930,268	7.85	55%	capital -- wind capacity
112,188	0.46	3%	O&M -- hydrogen production
323,696	1.32	9%	O&M -- wind electricity production
3,484,223	**14.16**	100%	**Grand Total cost of displaced fuel**

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.

Conclusion

Our analysis demonstrates that a hydrogen production system is technically feasible for a small Alaska community of 400 people, using equipment that is commercially available today. However the capital cost of such a system would be quite high – about $12.50 per gallon displaced, or about $117,000 per person served.

These preliminary conclusions have two implications for policy and for future R&D. First, it appears that the *operating* cost of a hydrogen system would be low enough to be affordable by users. Hence, a policy decision to subsidize capital costs would be “sustainable” after the capital was installed. Second, since the majority of the capital cost is for wind generation capacity, it appears that continued R&D on wind systems will have a significant positive impact on the cost of an integrated system. In other words, the capital cost of electrolyzers is *not* the chief hurdle to be overcome if hydrogen systems are to become economically viable.

A logical next step toward a viable integrated wind-hydrogen energy system is a pilot project that replicates Alaska conditions and tests the technical feasibility of direct-burn hydrogen systems, especially for small vehicles.

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Appendix: Associated Excel Workbooks

Two Excel workbooks are associated with this report. At the time of writing (December 2008), they have been placed on the ISER Web site along with this report. The report can be found by searching the ISER publications database using the term “hydrogen.” The worksheets are:

AVEM1.xls	Village Energy Demand Model
WHPC3.xls	Wind-Hydrogen production cost model