

ALASKA VILLAGE SURVIVAL: AFFORDABLE ENERGY INDEPENDENCE VIA RENEWABLES FIRMED AS HYDROGEN STORAGE IN LIQUID ANHYDROUS AMMONIA

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1. Introduction

Alaska village survival is threatened by the high cost of imported fuels for heating, electricity generation, and vehicles. During Winter 2007-8, the price per gallon of heating oil and diesel generation fuel exceeded \$8 in many villages. Many villagers were forced to move to Anchorage or Fairbanks. Although indigenous renewable energy (RE) resources may be adequate to supply a community's total annual energy needs, the innate intermittent and seasonal output of the renewables – except geothermal, where available, which may be considered “baseload” -- requires large-scale, low-cost energy storage to provide an annually-firm energy supply. Anhydrous ammonia, NH_3 , is the most attractive, carbon-free fuel for this purpose at Alaska village scale, because of its 17.8% mass hydrogen content and its high energy density as a low-pressure liquid, suitable for storage in inexpensive mild steel tanks.

In November '08, the Alaska Energy Authority (AEA) received a grant application from Alaska Electric Light & Power (AEL&P) for state Renewable Energy Program funds, to demonstrate an RE conversion and storage system, based on a novel Solid State Ammonia Synthesis (SSAS) technique, which might provide a technically and economically attractive path to village energy sustainability via annually-firm energy storage in mild steel surface NH_3 tanks. SSAS converts electric energy, water, and atmospheric nitrogen to NH_3 at high efficiency; indigenous renewable-source electricity is the key driver and resource. In February '09, AEA chose not to recommend funding this project, probably because it is primarily a research project, while the program's intent is building RE production facilities.

The stored NH_3 may easily be reformed to hydrogen fuel, with the nitrogen (N_2) byproduct returned to Earth's atmosphere. Or, the NH_3 fuel may be combusted directly in modified internal combustion engines (ICE's), combustion turbines (CT's), and space heaters at high efficiency. Or, it may be converted to electricity in direct-ammonia fuel cells. Figure 8 shows an NH_3 fueled ICE on long-term test.

For example, the 37 MWh of energy in 1 ton of hydrogen would be stored in about 6.5 tons of NH_3 , which would require approximately a 10,000 liter steel tank, which would cost about \$25 – 50K installed in an Alaska village. No gaseous hydrogen (GH_2) would be stored, avoiding low-energy-density, high-pressure GH_2 storage with the associated hydrogen embrittlement potential for steel components.

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Ammonia as a hydrogen storage medium may be a promising complement to gaseous or liquid hydrogen storage, especially at the large energy quantities required for an annually-firm RE supply. A successful Alaska demonstration, preceded by the requisite SSAS research and development, could pave the way to large-scale hydrogen storage, transmission, and delivery, as NH₃, in many North America and world markets. In the USA Corn Belt, the NH₃ pipelines and storage tanks are already in place.

2. Alaska: Energy Economy, Villages, Legislation

Alaska has no electricity (grid) connection to other North America electric energy systems. The “railbelt”, Anchorage and Fairbanks and the communities along the Alaska Railroad connecting them, are an isolated electricity transmission “grid”, Alaska’s largest energy “island”. This, and all other Alaska villages, towns, and cities, are energy islands. Except for hydro generation prevailing in Southeast Alaska (SE), electricity generation, heating, and transportation fuels are primarily imported petroleum products. Indigenous firewood space heating is common in some communities. Several coal-fired generating plants serve the railbelt grid.

A few communities supply a small fraction of their electricity from wind generation or other renewables; Kotzebue is perhaps the best example.¹ The non-profit Renewable Energy Alaska Project expertly encourages increasing renewable energy production from all resources.²

“ Power Cost Equalization (PCE) is the program designed to (1) extend power assistance to rural Alaska as a response to the development of other power around the state and (2) make power more affordable to rural Alaskans...

“ Because power costs in many rural communities are approaching the \$1.00 [per kilowatt-hour] range ... many rural families would simply not be able to afford to buy the electricity needed for even the basic services that we take for granted.”³

In FY 07, the State of Alaska, via its Alaska Energy Authority⁴, distributed \$25.4 million among 78,500 people in 183 villages and small towns, via the PCE program.⁵ FY08 cost is higher. The State would like to reduce this program’s cost.

Each Alaska community wishing energy independence via indigenous renewable energy resources must:

1. Assess its “internal” energy economy (initially excluding the “external” energy required to support the community, which is not supplied by the local economy – primarily fuel for aircraft and barges). This energy audit should yield community total annual energy consumption from all energy sources.
2. Assess its available, indigenous, renewable energy resources to find:
 - a. How much RE is available;
 - b. What total annual community energy demand would cost to harvest (generate) from the several RE sources;

- c. How much gross energy storage is required to provide firm energy year-round, for all energy needs, from these RE resources.
3. Determine costs for converting its energy-consuming equipment, from the electric generating plant to outboard, snowmachine, and ATV engines, to operate on NH₃ fuel.
4. Decide where to site its NH₃ storage tank or tank farm, preferably at a distance downwind of the community, so that any large accidental NH₃ leak would not endanger inhabitants.

3. NH₃ as a Hydrogen Energy Carrier and Storage Medium

a. NH₃ as a transmission and storage medium: Except for geothermal, RE sources are unfortunately time-varying in output, at time scales of seconds to seasons. The RE generation assets thus operate at an inherently-low capacity factor (CF) of typically 30-40%, inflicting this low CF on all downstream system components and preventing delivery of annually-firm energy to consumers. Several studies show that NH₃ may be a promising strategy and technology for gathering, transmission, firming storage, and distribution of diverse, GW-scale, stranded renewables.^{6, 7}

b. Properties of NH₃ :

- 17.8% mass hydrogen content; 1 ton contains ~ 6.5 MWh as hydrogen
- A carbon-free fuel; a carbon-free energy carrier if made from non-carbon-emitting energy sources or processes;
- A pumpable liquid at ambient temperatures at 150 psi;
- Can be readily reformed to produce hydrogen (~85% efficiency);
- Low pressure, low-cost storage and transport in trucks and pipelines;
- Not flammable except under extreme conditions of high compression and high ignition energy typically found only in specially-designed ICE's and CT's;
- Non-corrosive, non-embrittling to steel, although copper, brass, and bronze fittings must not be used;
- Liquid NH₃ has about half the volumetric energy content of gasoline: Table 1;
- Safety: ammonia is regulated as an inhalation hazard. Transport is regulated by the US DOT; no exotic equipment or vessel is required. Storage is regulated by the EPA and state agencies. Ammonia is delivered routinely to the end user in a variety of ways, including pipeline, barge, train, and tanker truck. At the end user's location, ammonia is typically stored in 250 psi-rated carbon steel tanks, which are much like propane tanks. Although ammonia is toxic in high concentration, its offensive odor improves leak detection safety.

c. Cost of energy storage as NH₃ : See Figures 1 – 3. In the Lower 48 States, large “atmospheric” refrigerated tanks can store energy for < \$100 / MWh capital cost. Such large tanks, transported to and installed in Alaska villages, might more than

double this cost. Perhaps not many Alaska communities would need such large storage. Figure 1 shows costs for smaller, pressurized liquid storage. Total energy storage cost would include capital and O&M costs and energy conversion losses for renewable-source electricity to NH₃ fuel, and energy recovery from the fuel.

	Liquid Anhydrous Ammonia	Liquid Hydrogen	10 Ksi Hydrogen Gas	Gasoline
Percent H ₂ by mass	18	100	100	16
Energy Density—Gravimetric (MJ/kg)	21	110	110	42
Energy Density—Volumetric (MJ/L)	14.0	7.6	6.5	34.0

Table 1. Energy content comparisons of ammonia with hydrogen and gasoline, without adjustment for the energy required for compression and liquefaction of hydrogen or ammonia.⁸

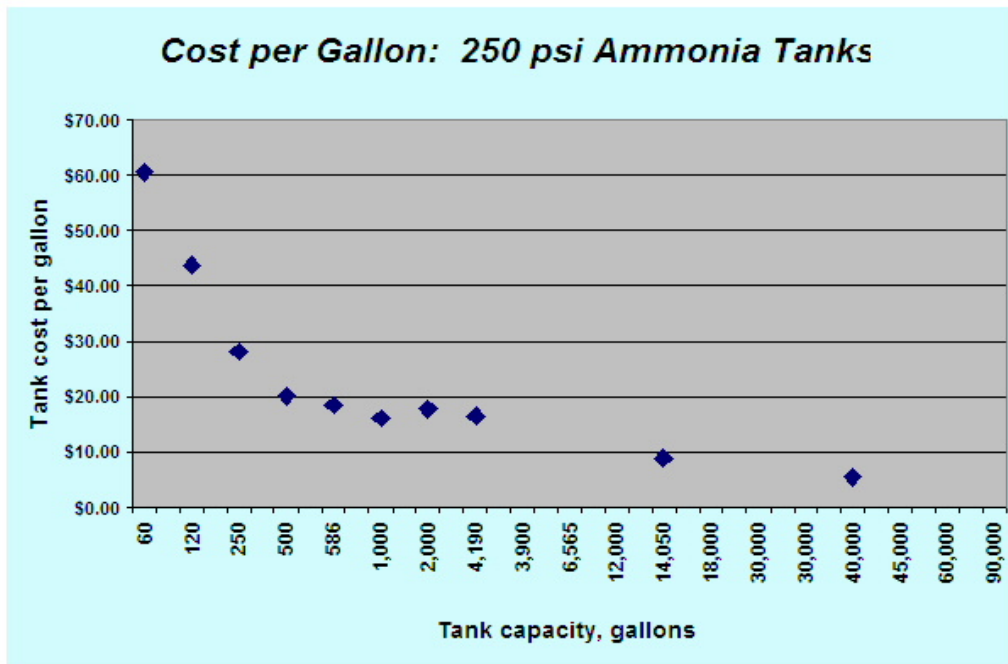


Figure 1. Village-scale mild steel (carbon steel) storage tanks, FOB California. Transport to, and installation in, Alaska villages could more than double the cost.



Figure 2. Energy storage: (above) Agricultural fertilizer liquid NH₃ “nurse tank”: capacity 1,450 gallons @ 265 psi = 620 kg hydrogen. Capital cost \$9.5K
 (below) Gaseous hydrogen tube trailer: capacity 5,800 gallons @ 3,200 psi = 350 kg hydrogen. Capital cost \$750K

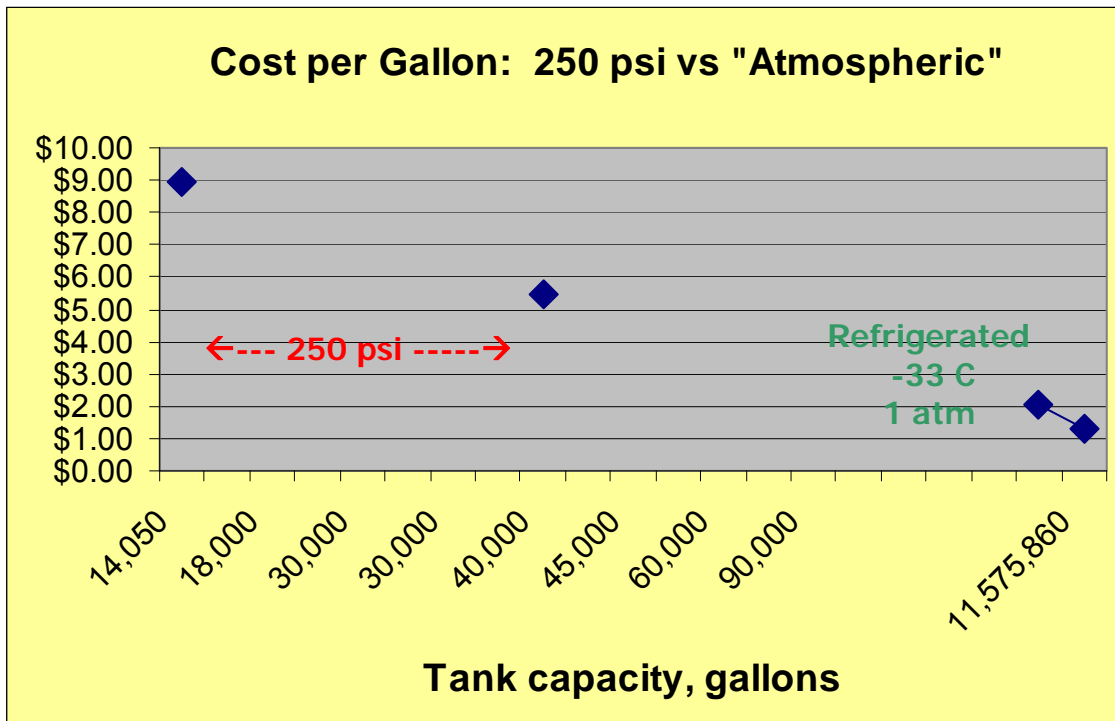


Figure 3. “Atmospheric” refrigerated tanks at -33 C and 1 atmosphere are optimum for GWh-scale ammonia energy storage. Both size ranges are liquid storage.

4. NH₃ Synthesis via Electricity from Renewable Energy Resources

a. Figure 4. Electrolysis followed by Haber-Bosch reactor. The Haber-Bosch process has prevailed for over a hundred years. Hydrogen must be supplied from electrolysis of water by electricity from RE, or other sources. Worldwide ammonia consumption is ~ 130 million tons per year; almost all is produced from hydrogen made from natural gas (methane, CH₄, via steam methane reforming (SMR) with the CO₂ waste product released to Earth’s atmosphere).

b. Figures 5, 6. Solid State Ammonia Synthesis (SSAS) is an invention patented by NHThree, LLC, which converts electricity, water, and nitrogen directly to ammonia in SSAS reactors without producing hydrogen as an intermediate feedstock.⁹ The electrolyzers are eliminated; the ASU remains. SSAS is a lab-scale device, not yet commercialized, offering potentially lower capital costs and higher conversion efficiency for renewable-source electricity to NH₃, in a simpler system than Haber-Bosch. SSAS appears more suited to remote, Alaska energy “island” villages.

c. Water and nitrogen sources. In most Alaska villages, fresh water supply is adequate for NH₃ synthesis feedstock. Atmospheric nitrogen, N₂, must probably be supplied by an on-site, electrically-driven air separation unit (ASU): a significant piece of capital equipment probably operating at low capacity factor (CF). ASU is a mature technology.

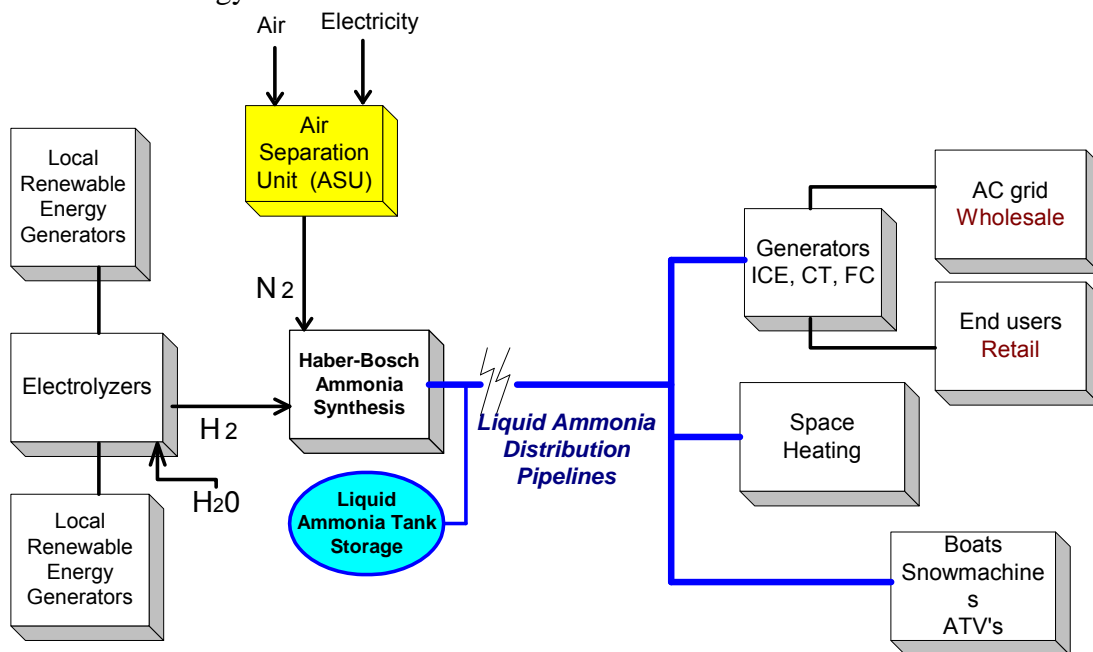


Figure 4. Haber-Bosch ammonia synthesis from electric energy requires electrolyzers and an ASU, at any production scale. Haber-Bosch NH₃ synthesis has dominated production for a century, producing almost all world NH₃ consumption of ~ 130 million tons from natural gas via SMR of methane, with waste CO₂ released to Earth’s atmosphere. RE-source hydrogen, H₂, eliminates waste CO₂.

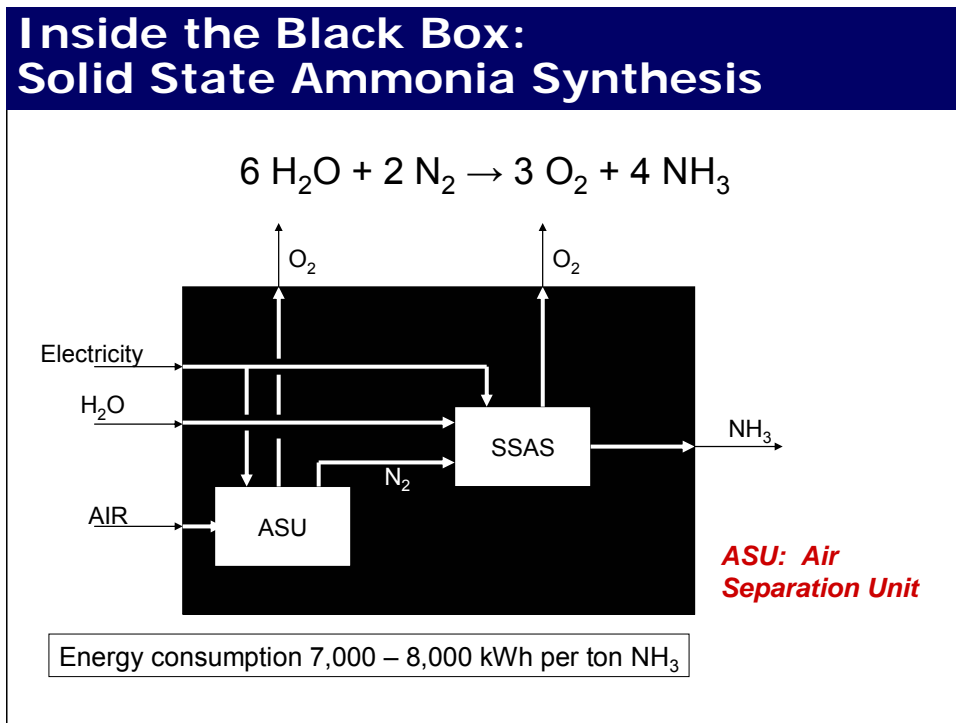


Figure 5. SSAS ammonia synthesis eliminates electrolysis, but requires an ASU. RE-source electricity eliminates the CO₂ waste product.

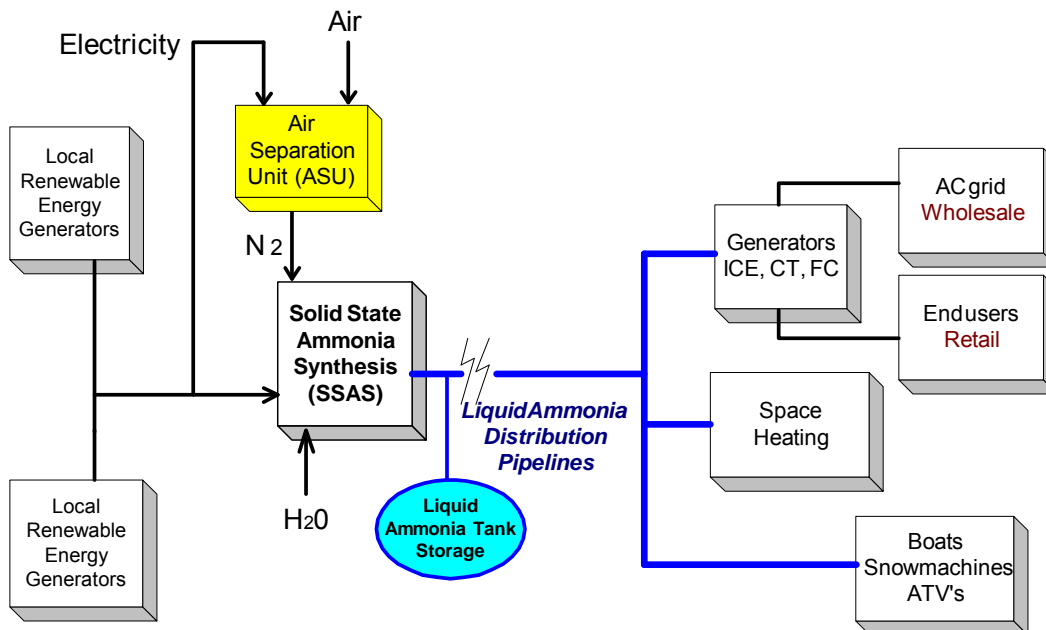


Figure 6. SSAS ammonia synthesis eliminates electrolyzers, but requires ASU. RE-source electricity eliminates the CO₂ waste product.

5. Alaska Electric Light & Power (AEL&P) Grant Application

In November '08, AEL&P, Juneau's electric utility, submitted a grant application for \$800,000 funding via the new Alaska Renewable Energy Fund program¹⁰, for a research and development and demonstration (R&D&D) program:

- Hydroelectricity from the AEL&P grid drives an SSAS reactor to synthesize NH₃ from water and atmospheric nitrogen (N₂); N₂ source unspecified;
- Liquid NH₃ is stored at ~200 psi at ambient temperature in a mild steel tank;
- An internal combustion engine (ICE) driven generator, built optimized for gaseous NH₃ fuel, converts NH₃ to electricity, returned to the AEL&P grid;
- This system models a village-scale system for storing enough NH₃ to provide enough "firm" renewable-source energy to supply all village internal energy needs every hour of every year;
- A successful system could be moved from AEL&P to a village for further test.

The AEL&P grant application states:¹¹

High-efficiency solid state ammonia synthesis (SSAS) will be advanced from laboratory to proof-of-concept and pre-commercialization pilot-plant stage. One or more SSAS modules will be built, capable of synthesizing anhydrous ammonia (NH₃) at ~10 kWe input from renewable-source electric energy, fresh water, and atmospheric nitrogen. The NH₃ will be stored in a pressurized steel tank, and will fuel an internal-combustion-engine (ICE) generating set delivering to the utility electricity grid.

A complete system will be located in Juneau at the Alaska Electric Light & Power (AEL&P) site. Hydroelectric energy will be converted, at ~ 10 kW scale, to NH₃, stored as a liquid at 250 psi in steel tanks, and regenerated to electric energy in an ammonia-fueled internal combustion energy (ICE) generating set and returned to the electricity grid. This system will model a village-scale system that could store enough surplus renewable-source energy, as liquid NH₃ in surface tanks, to supply the village's total year-round energy needs as firm energy, assuming enough local renewable energy production capacity is in place to generate this total energy.

The goal is village and other "energy island" energy independence via renewable-source energy and annual-scale firming storage, replacing all diesel electricity generation and oil heating. Deploying the project initially at AEL&P allows hydro energy input and lower project technical risk via Juneau's benign climate and favorable transportation access; the project may later be relocated to a smaller community for further evaluation and test.

The AEL&P project benefits would be:

1. A pilot-scale demonstration of how renewable electricity generation from diverse local sources may supply a major share, or all, of a village or small community

“energy island” annual energy consumption – of electricity and of heating and vehicle fuels -- with annual-scale firming via energy storage as NH₃ fuel. The average annual “village” cost of energy will depend on:

- *The cost per kWh of renewable-source generation at the village, assuming renewable sources are available and energetic, for high capacity factor generation;*
- *The amortized capital cost of conversion and annual-scale-firming storage components, plus O&M costs / kWh.*

The total annual average cost of energy (COE) at the village may or may not be lower than recent market prices for fossil fuel, but this COE will be predictable, after O&M cost is determined by experience, because fuel cost is zero. This pilot-scale system capacity of about 10 kWe input, producing about 32 kg of NH₃ fuel per day, will be about 1% of the scale needed for a typical Alaska village of 200 people.

2. Surplus stranded renewable energy, such as Southeast Alaska hydro which is now “spilled” at some plants, can be monetized by conversion to liquid NH₃ for export and sale as C-emissions-free fuel, for heating, for vehicles, boats, construction machinery, and for combined-heat-and-power (CHP) on-site electricity generation. This might apply to off-peak wind and other renewables: Fire Island (Anchorage area) wind, for example. This helps service renewable energy generation plant debt.

3. Monetizing surplus stranded renewable energy would lower the retail energy price for the generating facility customers, and for the NH₃ fuel consumers.

4. Community income flow to outside fuel suppliers will be greatly reduced, and potentially eliminated.

5. Community jobs will be created to construct and maintain the new RE systems.

6. In case AEL&P system demand exceeds hydro supply, even with Lake Dorothy I and II (Juneau area) increases, ratepayer cost might be reduced from that of diesel generation by instead using NH₃ fuel produced from Southeast Alaska surplus and stranded renewable resources.

6. Bulk Energy Storage Schemes

Figure 7 compares the several schemes and technologies currently considered as “electricity” storage, with gaseous hydrogen (GH₂) and liquid NH₃, which appear “off the chart”. No “electricity” storage option can affordably store enough energy to “firm” RE, at annual scale, other than geothermal which may be considered “baseload” supply, but have important applications in electricity transmission and distribution stability, power quality, and for the nascent “smart grid”. GH₂ and NH₃ are promising for GW-scale transmission and annual-scale firming of diverse, stranded renewables.

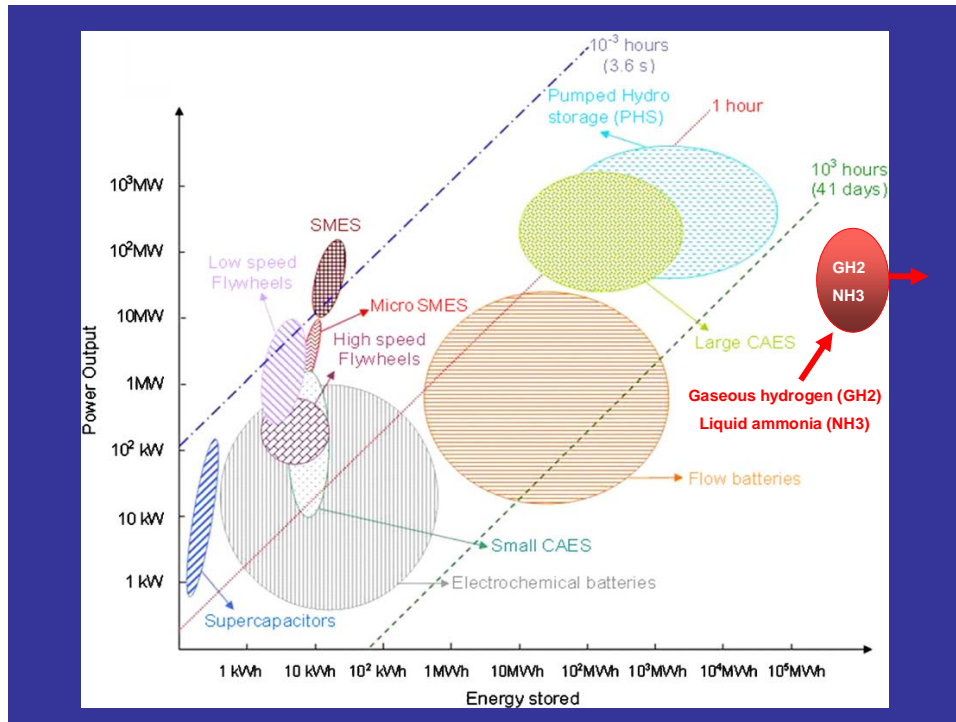


Figure 7. Energy storage scheme and technology comparison.

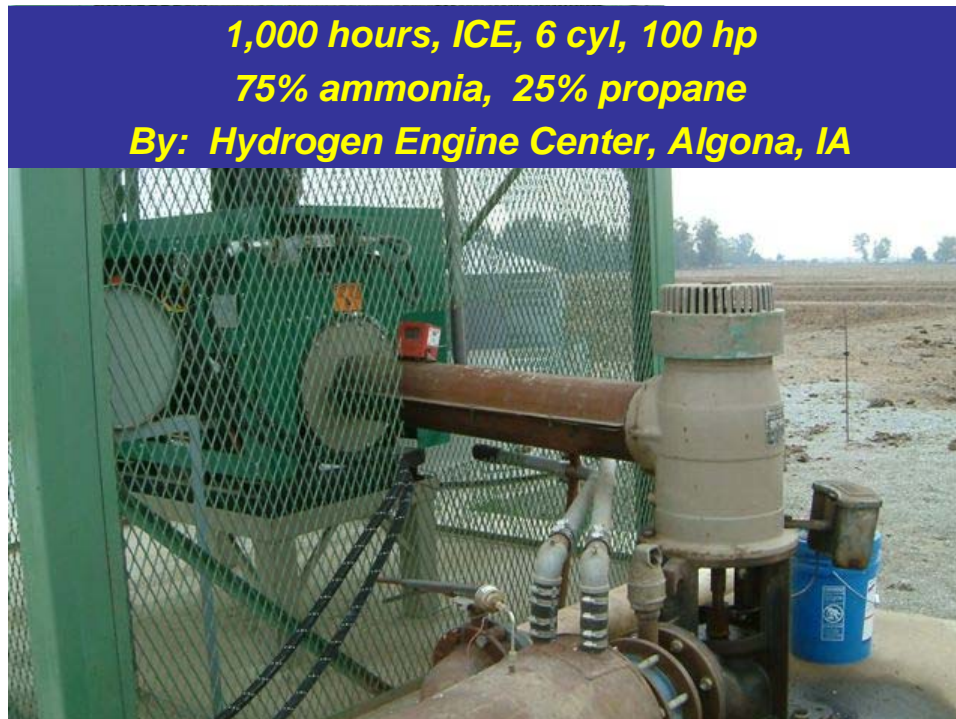


Figure 8. Ammonia-fueled internal combustion engine (ICE) operating an irrigation pump in Central Valley, California, on long-term test. 30:1 compression ratio; ~ 50% total efficiency. This ICE, or larger versions, could drive Alaska village electric generators. This ICE is not in production.

7. Conclusion

Alaska's high energy prices, isolation from the continental electricity grid, and abundant indigenous RE in many communities presents a good opportunity to explore the technical and economic feasibility of anhydrous ammonia, NH_3 , as a hydrogen-rich energy storage medium by which to supply firm energy, at annual scale, to achieve partial or total independence from imported fossil fuels for the Alaska community's "internal" energy economy.

A successful Alaska demonstration, preceded by the requisite SSAS research and development, could pave the way to large-scale hydrogen storage, transmission, and delivery, as NH_3 , in many North America and world markets. In the USA Corn Belt, the NH_3 pipelines and storage tanks are already in place.

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 - ¹⁰ http://www.akenergyauthority.org/RE_Fund.html
 - ¹¹ AEL&P grant application available from: Scott.Willis@aelp.com, 907-780-2222