Solid State Ammonia Synthesis (SSAS) Pilot Plant Demonstration System for Renewable Energy (RE) Firming Storage, Transmission, and Export

Alaska Applied Sciences, Inc.
William C. Leighty
Box 20993, Juneau, AK 99802
907-586-1426
cell 206-719-5554
wleighty@earthlink.net

Alaska Business License # 126487

Partners:

NHThree LLC, Richland, WA
Dr. John H. Holbrook, CEO
1161 Viewmoor Ct., Richland, WA 99352
john.holbrook@charter.net 509-396-2082

University of Alaska Southeast (UAS)
Richard A. (Rick) Caulfield, PhD
Provost & Dean of Graduate Studies and Research
11120 Glacier Highway, Juneau, AK 99801
racaulfield@uas.alaska.edu 907-796-6486

Alaska Electric Light and Power Company (AEL&P)
Scott Willis, VP
5601 Tonsgard Court, Juneau, AK 99801
Scott.Willis@aelp.com 907-463-6396

Alaska Power and Telephone Company (APT)
Bob Grimm, CEO
P.O. Box 3222, Port Townsend, WA 98368
Physical Address: 193 Otto Street, Port Townsend, WA 98368
bob.g@aptalaska.com 360.385.1733

Principal contractor candidate: NHThree LLC

Total project cost:	EETF grant	$ 750,000
	Applicant match, cash and in-kind	$ 250,000
	Total	$ 1,000,000

Previous applications:

- 2011 EETF
- 2009 Denali Commission Application, Emerging Energy Technology Grant
  Applicant: Alaska Applied Sciences, Inc. (AASI)
  Title: Solid State Ammonia Synthesis (SSAS) Pilot Plant for RE Firming Storage
  Project number: apparently none assigned; not funded

Project Summary: Renewable energy (RE) transmission and storage: this project will "test an emerging energy technology", advancing solid state ammonia synthesis (SSAS) from patented laboratory device to a proof-of-concept, pre-commercialization, pilot plant demonstration system, for stranded RE: TRL 3-4 to TRL 5-6. This project satisfies the four criteria in 4.3 Prioritization.

Fig 1. This system, after acceptance testing at contractor, candidate patent holder NHThree LLC, will be shipped to Juneau and at least one other Alaska location to test and verify performance, durability, and compatibility. Goal is demonstrating potential scaleup to achieve $200K per metric ton (Mt) anhydrous ammonia (NH_3) per day capital cost, 7.5 kWh / kg conversion (75% efficiency (HHV)), with low non-energy O&M cost, whereby RE can be stored as liquid NH_3 , a carbon-free hydrogen-based fuel, at both small and large scale, in common, propane-grade steel tanks at 10 bar. Deployment of SSAS energy conversion, storage, transmission, and end-use systems throughout Alaska allow:

1. Significant year-round energy independence for isolated communities with abundant RE;
2. Annual-scale firming of energy seasonally-variable RE resources (including Susitna);
3. Supplying RE-source NH_3 fuel for land and water surface transportation in Alaska;
4. Intra-Alaska transmission of RE-source energy without building new electricity transmission;
5. Export of Alaska's diverse, large-scale, stranded RE as liquid NH_3 via tankers to world markets.

JEDC's (Juneau Economic Develop Council) Southeast Cluster Initiative embraces all these features. The draft SE IRP declares the SE electricity intertie system uneconomic, increasing our incentive to find alternative(s) for gathering, transmission, firming storage of SE AK's diverse, stranded, RE resources.

As fossil fuels become more costly and restricted in supply, and as rapid climate change proceeds, Alaska could (a) operate its internal energy economy entirely on affordable, firm, dispatchable, indigenous, RE, nearly free of greenhouse gas (GHG) emissions and (b) export surplus, stranded RE as carbon-free NH_3 fuel. These two desirable strategies are not likely via electricity systems.

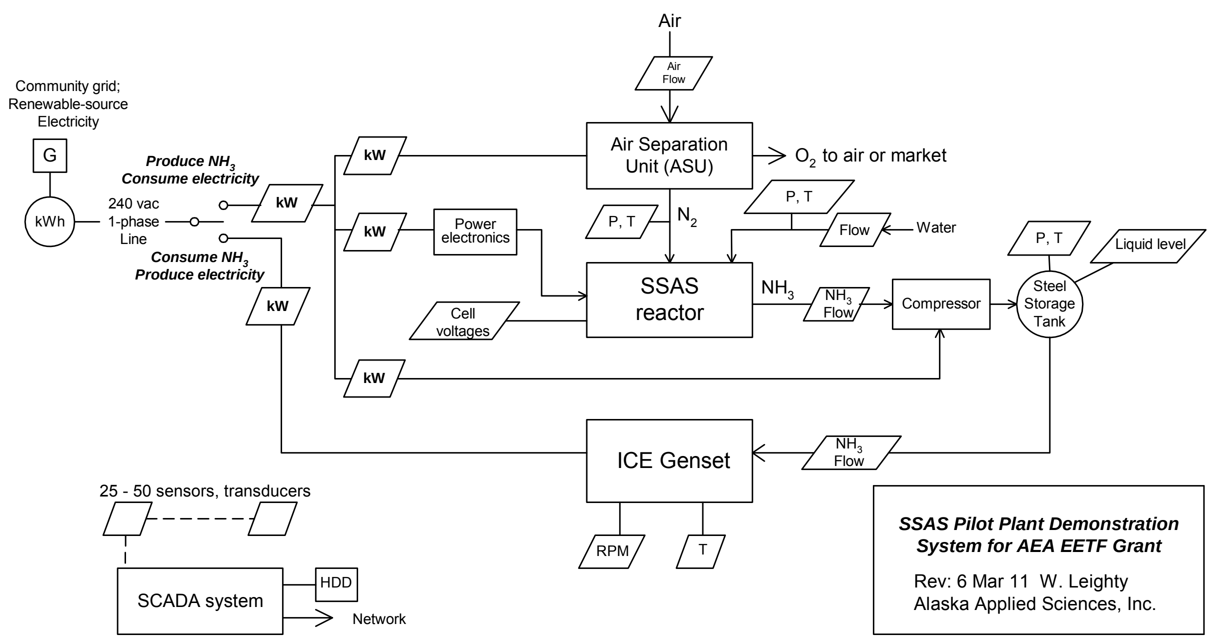

Figure 1. Proposed SSAS proof-of-concept pilot plant demonstration system: complete, instrumented, self-contained, transportable. Closed-loop capable. NH3 synthesis, storage, and regeneration.

This project is a complete, proof-of-concept, demonstration pilot plant, a self-contained, transportable, SSAS NH_3 synthesis, storage, and regeneration system, of 1 - 5 kWe input, which may be connected to an electricity grid or to a variety of RE generation devices to demonstrate the closed-loop operation needed for "energy island" communities. System energy conversion efficiency, durability, and other performance measures will allow scaling estimates for Alaska-wide and world-wide SSAS technical usefulness and profitability. Liquid NH_3 energy storage is at much lower capital cost than hydrogen or any competing form of electricity storage.

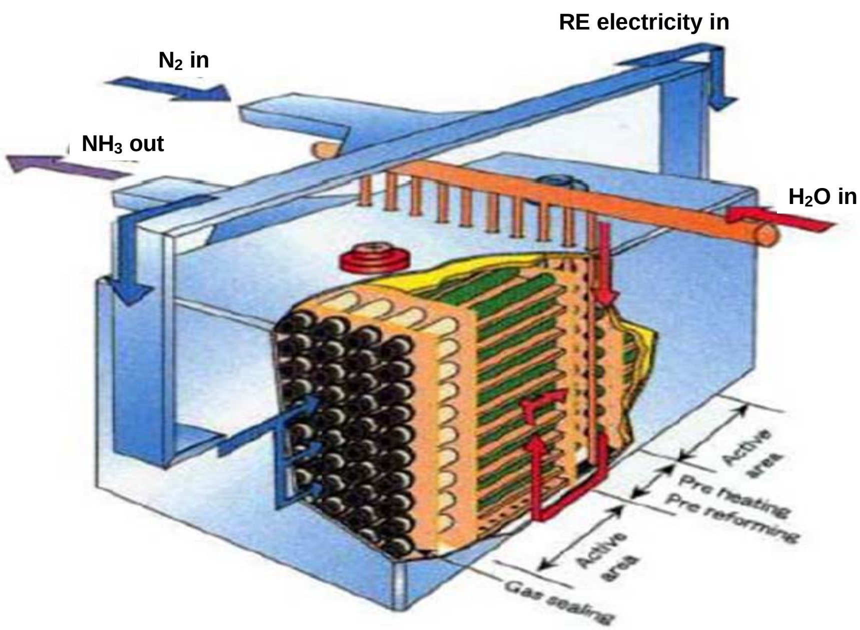

Figure 2. SSAS reactor [Fig. 4] construction of PCC tubes: gas management, RE electricity in, NH3 out

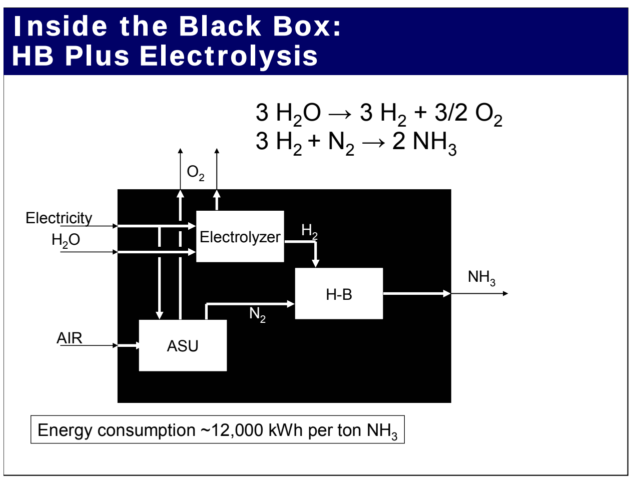

Figure 3. Haber-Bosch NH_3 synthesis from RE

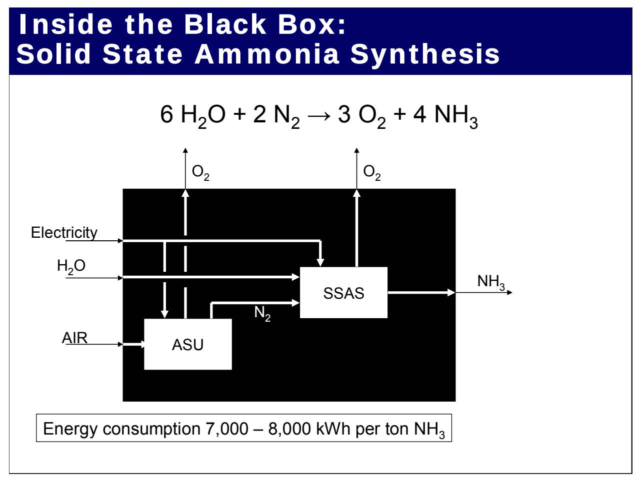

Figure 4. SSAS requires no electrolyzer

Technology readiness: SSAS was demonstrated in proton conducting ceramic (PCC) devices at Howard University and at Colorado School of Mines (CSM) in 2007-9: TRL 3-4. US Patent application was filed 10 Feb 07; US Patent 7,811,442 was granted 12 Oct 10, assigned to NHThree LLC (Richland, WA). Now SSAS needs to be demonstrated in a scale-model reactor composed of 20 – 100 PCC tubes, with gas management, packaging, and electric interface that will be necessary for commercial-scale (10 – 1,000 kW modules, scalable to any size) SSAS systems. Satisfactory performance and durability testing on the first reactor advances SSAS to proof-of-concept TRL 5-6. Goal is demonstrating potential scaleup to achieve $200K per metric ton (Mt) anhydrous ammonia (NH_3) per day capital cost, 7.5 kWh / kg conversion (75% efficiency (HHV)). Packaging the reactor in a complete SSAS energy conversion, storage, and electricity regeneration system (ICE genset is available), deployed at Alaska sites, will achieve TRL 6. No SSAS work has yet been done in Alaska. Some engineering, systems integration, and manufacturing could be done in Alaska.

Commercial production of SSAS components and systems will depend primarily on market acceptance of RE-source NH3 fuel. Production of current-carrying PCC tubes for solid oxide fuel cell (SOFC) is well-established; proton-conducting PCC tubes for SSAS are similar. The power electronics industry is mature. NH_3 - fueled ICE gensets and direct-ammonia fuel cells have been demonstrated. New engineering, but no new fundamental science, is needed. Thus, commercial availability in a limited size range (kWe input; kg to Mt NH_3 per day output), within 2-3 years, with adequate market pull, is feasible and likely. See Ref 1: nascent ammonia as fuel.

Technology Validation and Research Methodology: The SSAS demonstration pilot plant demonstration system will be fully instrumented with a SCADA system, by which the performance of every system component will be tracked over time, by which data energy conversion efficiency and component durability will be measured. Capital cost estimates will not be accurate at this small reactor scale, with PCC tubes made by hand, and with low-power electronics reactor interface.

Project Schedule: Reporting for all project phases will be monthly, driven by milestones which represent potential go / no-go decisions. Duration of the Alaska deployment and demonstration phase will depend on pilot plant longevity, communities' desire to host it, and funds available for its relocation, probably over a 1-2 year period. SCADA data collection and monthly O&M reports will continue at each deployment. The initial Juneau deployment(s) would probably be 1-3 months.

Site Suitability: Design, fabrication, and acceptance testing of the pilot plant demonstration system will be by our sole-source contractor, probably NHThree LLC, at facilities and subcontractors of their choice, principally or entirely in the Lower 48. Our contract, with NHThree LLC or other, will include any necessary "site control" features. The Alaska deployments will be temporary, for which permits will probably not be needed. First test and demo site will be at the AASI facility in Juneau; if successful, we will attempt subsequent Juneau deployments at one or more of: UAS Tech Center; AEL&P; IPEC; USCG 17th District HQ. We would obtain "site control" agreements as required, for each deployment beyond AASI. We were invited to site an identical system at the UAS Tech Center, as we proposed for the Denali Commission Emerging Energy Technology Grant program in '09. Juneau's utility, AEL&P, had agreed to assist in the closed loop operation mode. We would refresh those agreements for this project. We have made no site control arrangements for subsequent Alaska deployments; we could do so.

SSAS system nameplate rating would be 1-5 kWe input, single-phase; 3-15 kg NH_3 per day; 50 gallon NH_3 storage. Juneau's AEL&P grid provides RE input. The USCG has installed a 3.5 kW wind generator at the Juneau Station dock, to which we could offer connecting the SSAS system for a high-impedance, unregulated source input test. We would hire a Juneau-resident electronic controls contractor to help with SCADA design and operation contingencies not embraced in system design and acceptance testing.

Budget and Project Finance: Over 90% of project cash funding from all sources will flow to AASI's prime contractor for design, fabrication, and testing of the SSAS pilot plant demonstration system. AASI will provide project management and electrical interface design assistance as in-kind contribution. The contractor will provide both in-kind and cash from their investors, as specified on Grant Budget Form. EETF funding may attract other investor funding to enhance the scope and success of this project, during its term. NHThree LLC is the leading contractor candidate and approves this budget and plan.

Markets: See 1-5 in Technical Synopsis, above. Converting Alaska's diverse stranded RE, at village to global export scales, to liquid NH_3 fuel, could at once solve the transmission, annual-scale firming storage, and supply integration problems of these abundant energy resources, which typically suffer time-varying output at scales of seconds to seasons. AVEC, IPEC, and other community utilities could install SSAS systems, fed by new RE generation assets appropriate for the community RE resources, with common steel tanks capable of storing enough liquid NH_3 fuel for a large fraction of, or all of, the community's annual internal energy consumption. Very large steel tanks in the Corn Belt now store the chemical energy in liquid NH_3 for ~ $0.10 / kWh capital cost; Alaska community-size might cost ten times as much – still far below the cost of batteries, CAES, or other electricity storage schemes. Thus, RE-source NH_3 fuel is a valuable transmission and firming storage medium and strategy for AK.

Extant diesel gensets can be modified to run on NH_3 fuel or a diesel-NH_3 fuel blend. Or, the gensets can be replaced with new ones optimized for NH_3 fuel or blends. In CHP service, both gensets and direct-ammonia fuel cells offer high total energy recovery from NH_3 fuel. Emissions from both are C-free, primarily N_2 and H_2O. The

SSAS synthesis plant is theoretically ~80% efficient (HHV), but low capacity factor (CF) when driven by most RE generators represents a significant stranded capital asset.

Transmission and storage of Southeast Alaska's stranded hydro, tidal, and wave energy may be economically superior to exporting the energy via new electricity line(s) to BC, Canada. (Ref. 4)

The Railbelt needs to secure its total energy needs, not just electricity, from RE. The seasonally-variable output of large RE projects such as Susitna can be economically stored as NH_3 fuel for an annually-firm supply of transportation, space-heating, and CHP fuel, pipelined underground to city-gate markets for distribution. NH_3 fuel is probably economically superior to gaseous hydrogen (GH2) fuel for Alaska's internal and export markets, because of NH_3 fuel's higher energy density by volume, with consequent lower transmission, delivery, and energy storage costs, without hydrogen corrosion danger.

NH_3 fuel will not replace the electricity grid, but could account for most of new RE transmission and energy storage capacity, statewide. Most Alaska communities, large and small, could benefit from SSAS transmission and storage systems, if this project demonstrates technical and economic feasibility for likely commercial scaleup. Alaska's pioneering may spawn new local industries, as in a SE cluster.

Hydrogen (H_2) and anhydrous ammonia (NH_3) are the only practical carbon-free fuels. See Ref 1-3. NH_3 is both an N-fertilizer and a C-free fuel. It is the second-highest-volume industrial chemical in global trade; over 98% is made from coal and stranded natural gas via Haber-Bosch (HB) synthesis, with 1.8 Mt of CO_2 waste released to Earth's atmosphere per Mt NH_3 produced. SSAS should be able to to synthesize NH_3 from electricity, water, and atmospheric N more efficiently, at lower capital cost, than via the only available alternative, electrolysis + HB. Figs 3 - 4. RE-source electricity will produce C-emission-free NH_3. Future C-taxes will improve competitiveness of Alaska's RE-source "green" NH_3 on world N-fertilizer and nascent NH_3 fuel markets. The internal combustion engine (ICE), combustion turbine, and direct ammonia fuel cell operate efficiently on NH_3 fuel. [5]

The unpriced benefits to Alaskans, and beyond, are reducing GHG emissions to prevent a fraction of future rapid global climate change plus energy security via firm, indigenous, RE resources. SSAS technology success in this project can be commercialized within 5 years, given an NH3 fuel market.

Project Team Capabilities:

William C. Leighty, BS Electrical Engineering '66, MBA '71, Stanford. Principal, Alaska Applied Sciences, Inc. Co-author of 20 papers on alternatives to electricity for transmission and firming storage for diverse, stranded, renewable energy resources. *Nota bene*: The Leighty Foundation (TLF) has no connection to this application for funding; the References and above website are for technical insight only.

Dr. John H. Holbrook, BS, MS, PhD Materials Science, University of Cincinnati, Stanford. 30 years at Sandia, Battelle Columbus, and Pacific Northwest National Labs. Executive Director, Ammonia Fuel Network. Principal, NHThree LLC, formed to commercialize Solid State Ammonia Synthesis (SSAS).

Dr. Jason C. Ganley, Associate Professor of Chemical Engineering, Howard University. BS, MS, PhD Chemical Engineering, University of Missouri Rolla, University of Illinois at Urbana-Champaign. Research: Alternative fuels: anhydrous ammonia as a fuel cell and combustion fuel, synthesis of biodiesel from waste oils, high-temp solid electrolytes for fuel cells, oxide- and proton-conducting ceramic electrolyte synthesis and test for fuel cells.

By signature on this application, I certify that we are complying and will comply with the amount of matching funds being offered. Signed: ____

REFERENCES

1. Eight Ammonia Fuel conferences, Iowa State University: http://www.energy.iastate.edu/renewable/ammonia/ammonia.htm
2. REAP Business of Clean Energy conference, Anchorage, 18 June 10: http://www.leightyfoundation.org/files/REAP-Business-18Jun10-PodiumDraft-18JunPM.pdf
3. ASME Power conference papers:
http://www.leightyfoundation.org/files/ASME-Power-2010-Chicago.pdf
http://www.leightyfoundation.org/files/ASME-Power-2011-Denver-Jul-FINAL-13May11.pdf
4. SE AK IRP draft: http://www.akenergyauthority.org/southeastIRP.html
5. http://www.sciencedirect.com/science/article/pii/S0360319911022968