Making Ammonia Fuel From Alaska's Abundant Stranded Renewable Energy

Ammonia Fuel Conference
Detroit, MI
27 September 10

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MUST Run the World on Renewables – plus Nuclear ?
MUST Run the World on Renewables – plus Nuclear?

- Climate Change
- Demand growth
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
  - Sunshine
  - Tides
  - Meteors and dust
- Spend our capital?
“Americans can be counted on to always do the right thing – but only after they have tried everything else.”

Winston Churchill

The dog caught the car.

Dan Reicher
Proposed ANS* Gas Pipeline

“ALCAN” Alaska Highway Route

TransCanada Pipelines

* Alaska North Slope
Economics of Existing and Potential Energy Projects in Alaska

<table>
<thead>
<tr>
<th>Types of Energy</th>
<th>Proposed Capacity</th>
<th>Cost of Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>Greater than 1,000 MW</td>
<td>$0.00/kWh - $0.10/kWh</td>
</tr>
<tr>
<td>Hydro</td>
<td>100 MW - 1,000 MW</td>
<td>$0.10/kWh - $0.20/kWh</td>
</tr>
<tr>
<td>Geothermal</td>
<td>10 MW - 100 MW</td>
<td>$0.20/kWh - $0.30/kWh</td>
</tr>
<tr>
<td>Wind</td>
<td>1 MW - 10 MW</td>
<td>$0.30/kWh - $0.40/kWh</td>
</tr>
<tr>
<td></td>
<td>less than 1MW</td>
<td>$0.40/kWh and greater</td>
</tr>
</tbody>
</table>

(Sizes vary by capacity, color varies by cost, and shape varies by type of energy)

Source: MAFA 2009

Legend:
- Proposed Transmission Line
- Existing Transmission Line
- Roads
Tidal Current Energy

Many good sites in Alaska
109 TWh/yr

Puget Sound, WA
8 sites
4 TWh/yr

Golden Gate, San Francisco, CA
<2 TWh/yr

Maine 7 Sites
0.4 TWh/yr

Muskeget Channel
Massachusetts
0.1 TWh/yr

US TOTALS
Primary Energy = 115 Twh/yr
Average Power = 13,000 MW
Making Ammonia Fuel From Alaska's Vast Stranded Renewable Energy Resources

44,000 miles coastline
Making Ammonia Fuel From Alaska’s Vast Stranded Renewable Energy Resources
Making Ammonia Fuel From Alaska's Vast Stranded Renewable Energy Resources
“Enhanced”, “Engineered” Geothermal Mt. Spurr, Alaska

Hot dry rock: flash injected water to steam
Geothermal: hot water, surface recharge
Alaska

- 650,000 pop
- Railbelt:
  - 60% pop
  - Only “grid”
- 200 “villages”
- 100+ with good RE
- Energy islands
- 44,000 miles coast > all other states
- Other Renewables Unknown:
  - Solar
  - Instream kinetic (rivers)
  - Biomass
Alaska Business Opportunities: RE – NH3 “Green” Ammonia

Monetizing Alaska’s vast RE

1. Export from GW-scale RE: Increase cash IN
2. Village energy “independence”
   – Indigenous renewables; diverse
   – Seasonal, diurnal variability
   – Storage as NH3: pressurized tanks
   – Reduce cash OUT
Alaska Business Opportunities: Business is About Cash Flow

- Maximize cash IN
- Minimize cash OUT
- Short, long term NCF, IRR, NPV
- Enterprises:
  - State, Communities
  - People of Alaska
  - Capital Investors
“There’s a better way to do it... Find it”
Comparing the world’s energy resources

Where should we invest for the long-haul??

SOLAR

World energy use

©Richard Perez, et al.

*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear “use-them, lose-them” resources. World energy use is annual.
Our Spaceship Earth
one island in one ocean ... from space
Map by K. O’Hashi, Nippon Steel
Alaska in the future global energy economy

Liquid Ammonia Fuel
Why Ammonia?

Fertilizer and Fuel

Only liquid fuel embracing:

- Energy cycle inherently pollution free
  - Potentially all RE-source: elec + water + Nitrogen
  - Cost competitive with hydrocarbon fuels?
- Carbon-free: clean burn or conversion; no CO₂
  - Excellent hydrogen carrier; easily “cracked” to H₂
  - Reasonably high energy density
- Decades of global use, infrastructure
  - Practical to handle, store, and transport
  - End-use in ICE, Combustion Turbine, fuel cell
  - Safety: self-odorizing; safety regs; hazard
Anhydrous Ammonia  \( \text{NH}_3 \)

\( \text{N} \)  Nitrogen

\( \text{H} \)  Hydrogen

Molecular weight = ~ 17

18% \( \text{H} \) by weight: “other hydrogen”

\( \text{NH}_3 + \text{O}_2 = \text{N}_2 + \text{H}_2\text{O} \)
Ammonia
534 kg  H2
EACH

Hydrogen gas
350 kg  H2
Streetcar
New Orleans
1871
“Ammoniacal Gas Engine”
Ammonia fueled – Norway 1933

Ammonia fuel tank
Belgium, 1943
Ammonia Fueled Bus: Thousands of Problem-free Miles
X-15 rocket plane: NH$_3$ + LOX fuel

Mach 6.7 on 3 Oct 67

199 missions between 1959 and 1968
Ammonia + Gasoline Powered

- Idle: gasoline
- Full power: 80% ammonia

Summer ’07 Detroit → San Francisco
'08: 1,000 hours, ICE, 6 cyl, 100 hp
75% ammonia, 25% propane

Irrigation pump
Central Valley, CA
Oct '09 Ammonia Fueled V-8 with Hydrogen Injection: Reformed from NH₃ Hydrogen Engine Center, Algona, IA
Ammonia Fuel Uses

• Internal Combustion Engine (ICE)
  – Diesel: \(\text{NH}_3\) gas mixed with intake air
  – Spark-ignition: \(70\%+\ \text{NH}_3\) plus –
    gasoline, ethanol, propane, NG, hydrogen
  – \(\text{NOx} \sim \frac{1}{4}\) gasoline engines

• Combustion Turbines

• Direct Ammonia Fuel Cells:
  – Combined heat + power (CHP)
  – No \(\text{NOx}\)

• Reform ("crack") to liberate hydrogen for fuel cells:
  \(2\text{NH}_3 \rightarrow 3\text{H}_2 + \text{N}_2\)
Ammonia Properties

- C-free fuel: unique physical, chemical properties
- Carbon-free energy cycle, system
- #2 global industrial chemical trade
- 95%+ from stranded natural gas
  - ~ $1.00 / MMbtu
  - Trinidad, Australia, Quatar, Algeria, Russia
  - Other from coal gasification → hydrogen + Haber-Bosch
- Liquid at >125 psi at room temperature
- ~ Half energy density gasoline or diesel, volume or weight
- Easily “cracked” to H₂ + N₂ at end-use
- Low flammability, flame spread
Ammonia Properties

• Forms:
  – “Anhydrous” NH₃: useful as fuel
  – Urea: (2) NH₃ + CO₂
  – Ammonium nitrate: NH₄NO₃
  – UAN: aqueous urea + ammonium nitrate

• Decades infrastructure + safety record
  ~14 MMt / year in USA, mostly fertilizer
  – Inhalation hazard; detected @ 5 ppm
  – OSHA, NIOSH regs + exposure limits
  – Toxic to aquatic life
MONTHS: GH2, NH3
Hydrogen Cavern

6,400 kWh / Mt
3,790 kWh / m^3

NH₃

Metal-Air Batteries
(Not rechargeable electrically)

NaS Battery
Li-ion Battery

H₂

Weight energy density kWh / ton
Volume energy density kWh / m^3

Output Energy Density
(Input Energy Density x Efficiency)

Lighter

ESA
WWW.ELECTRICITYSTORAGE.ORG

Fly Wheels
E.C. Capacitors
Flow Batteries
Zinc-Air Batteries
Lead-Acid Batteries
Ni-Cd"
“Atmospheric”
Liquid Ammonia
Storage Tank
(corn belt)

30,000 Tons
190 GWh
$ 15 M turnkey
$ 80 / MWh
$ 0.08 / kWh

'09 ARPA-E “Grids” Goal: $100 / kWh
“Firm” Energy Essential

- Rural Alaska, Islands, Humanity
- Every hour, every year
- Dispatchable
- Strategically: indigenous, secure
- Market price: worth more
- Bankable large projects
- Risk avoidance:
  - Rapid climate change
  - Death
Alaska Business Opportunities: 
*
RE – NH3 = “Green” Ammonia
*

1. Export GW-scale RE: Increase cash **IN**
2. Energy “independence”: Reduce cash **OUT**
   - Villages, communities
   - Indigenous renewables; diverse
   - Seasonal, diurnal variability
   - Storage as NH3 in pressurized tanks
   - “Firm” energy
Expect N-Fertilizer Consumption to Rise: World Food Supply

40% of humanity requires Haber-Bosch synthetic N-fertilizers
Anhydrous Ammonia (NH3) wholesale price,
NOLA (New Orleans, LA)
Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

Figure III: Ammonia Prices (Average, New Orleans)

Source: Green Markets
Anhydrous Ammonia NH₃
Diammonium Phosphate

Wholesale at terminal

May 10
$447

New Orleans Landed $ 425
Corn Belt Wholesale $ 447
Corn Belt Farmer $ 560
95% Global Ammonia Synthesis Plant
Natural Gas
1 – 3,000 tpd
Haber-Bosch process
Haber-Bosch Process
1909 – 1913 BASF
• NH₃ synthesis
• Coal gasification → H₂
• WWI explosives
• 40% humanity: N fertilizer

Haber-Bosch Reactor
1921
Ludwigshafen, Germany
Inside the Black Box:
Steam Reforming (SMR) + Haber-Bosch

3 \( \text{CH}_4 \) + 6 \( \text{H}_2\text{O} \) + 4 \( \text{N}_2 \) \( \rightarrow \) 3 \( \text{CO}_2 \) + 8 \( \text{NH}_3 \)

Energy consumption \( \sim 33 \text{ MMBtu} \) (9,500 kWh) per ton \( \text{NH}_3 \)

Tons \( \text{CO}_2 \) per ton \( \text{NH}_3 \) = 1.8
Burrup Peninsula, NW Australia, Natural Gas to Ammonia Plant

- 760,000 Mt / year
- $US 650 million capital cost '06

The Competition

Natural gas input

80,000 Mt
liquid storage
-33°C

To wharf
Ammonia Tanker
Burrup Peninsula
Western Australia
Ammonia or LPG Tanker

9,000 – 35,000 Mt

Refrigerated
USA imports ~70% of NH3

Liquid ammonia pipeline

Valero LP Operations: NuStar

NOLA
Ammonia Storage Terminal
Mississippi River
Winona, MN
USA NH3 Infrastructure

- ~ 3,000 miles pipelines
  - ~ 250 psi liquid
  - Smaller diameter than NG or hydrogen
- ~ 4.5 MMt large “atmospheric” tank storage
- Mild steel construction
  - Low cost
  - No corrosion or embrittlement
Global Ammonia = 140 million Mt / year

- #2 chemical
- 200 plants, nat gas + coal
- ~ 500 Million Bbl oil
- ~ 2% oil
- ~ 0.5% energy

14 million Mt / yr USA; 60% imported; corn ethanol
Cost: Ammonia from Stranded Natural Gas (NG)

- Burrup, Australia Plant: 750,000 Mt / year
- $650M capital @ 15% capital recovery factor (CRF)
- 34 MMBtu NG / Mt NH₃
- NG cost $1.20 / MMBtu long-term
- Tanker shipping to New Orleans, LA (NOLA) $50 / Mt
- CO₂ emission 1.8 Mt / Mt NH₃

<table>
<thead>
<tr>
<th></th>
<th>C-tax 0</th>
<th>C-tax $50 / Mt CO₂</th>
<th>C-tax $100 / Mt CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>98</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>NG</td>
<td>41</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Shipping</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>C-tax</td>
<td>0</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>Plant O&amp;M</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total NOLA / Mt</td>
<td><strong>$191</strong></td>
<td><strong>$281</strong></td>
<td><strong>$371</strong></td>
</tr>
</tbody>
</table>
1. Increase Cash IN:
   Export AK GW-scale RE as “Green” Ammonia

• Can RE compete with “brown”? 
• What would C-tax need to be? 
• What would global NG price need to be?
Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)
2. Decrease Cash OUT: Village “Energy Independence” via RE Generation + Storage

- Energy Islands
- What’s Annual Average Cost of Energy (COE) ?
- Competitive ?
- What degree of “energy independence” ?
- Is SSAS required ?
Village-scale
3 Mt / day Mini-NH3 Plant
Natural Gas Fueled Haber-Bosch

Natural Gas
Village-scale
3 Mt / day Mini-NH3 Plant
RE Electricity Haber-Bosch
"Village" SSAS Renewables – Ammonia Integrated System

Renewable Electricity Sources

Air

Air Separation Plant

N₂

H₂O

SSAS reactor

Liquid Ammonia Transmission Pipeline

Liquid Ammonia Tank Storage

Generators (ICE, CT, FC)

AC grid Wholesale

End users Retail

ATV, Snowmobile, Outboard Fuel

Space Heat
Liquid Ammonia Tank Storage

Cost per Gallon: 250 psi Ammonia Tanks

Tank cost per gallon

Tank capacity, gallons

Largest highway-transportable
**RE Ammonia Transmission + Storage Scenario**

- **Wind Generators**
- **Electrolyzers**
- **Air Separation Plant**
  - Air
  - Electricity
  - N₂
- **Haber-Bosch Ammonia Synthesis**
  - H₂
  - H₂O
- **Liquid Ammonia Transmission Pipeline**
- **Liquid Ammonia Tank Storage**
- **Generators**
  - ICE, CT, FC
- **End users**
  - Wholesale
  - Retail
- **Cars, Buses, Trucks, Trains**
- **Aircraft Fuel**
Wind – to – Ammonia Potential, NW Iowa
Ammonia from hydrogen from zero-cost off-peak hydro
Inside the Black Box: HB Plus Electrolysis

\[
3 \text{H}_2\text{O} \rightarrow 3 \text{H}_2 + \frac{3}{2} \text{O}_2 \\
3 \text{H}_2 + \text{N}_2 \rightarrow 2 \text{NH}_3
\]

Energy consumption \(~12,000\ 	ext{kWh per ton NH}_3\)
RE Ammonia Transmission + Storage Scenario

Solid State Ammonia Synthesis (SSAS)

Wind Generators

Electrolyzers

Haber-Bosch Ammonia Synthesis

Air Separation Plant

Electricity

Air

N₂

H₂

H₂O

Liquid Ammonia Tank Storage

Liquid Ammonia Transmission Pipeline

AC grid Wholesale

Generators ICE, CT, FC

End users Retail

Cars, Buses, Trucks, Trains

Aircraft Fuel
Inside the Black Box: Solid State Ammonia Synthesis

\[ 6 \text{H}_2\text{O} + 2 \text{N}_2 \rightarrow 3 \text{O}_2 + 4 \text{NH}_3 \]

Energy consumption 7,000 – 8,000 kWh per ton \( \text{NH}_3 \)

Benchtop

Proof-of-concept
Solid State Ammonia Synthesis (SSAS)
NHTThree LLC patent
Why SSAS?

- Electrolysis + Haber-Bosch too costly
  - From RE electricity
  - Capital components at low capacity factor (CF)
  - Energy conversion losses
- Proton conducting ceramics (PCC) now
- Solid oxide fuel cell (SOFC) success
- Need stranded RE transmission
- Need RE storage
Solid State Ammonia Synthesis (SSAS)

• Goals:
  – Renewables-source ammonia (NH3)
  – Compete with natural gas source NH3
• High energy conversion efficiency
  – ~50% better than electrolysis → hydrogen + H-B
  – No hydrogen production
• Electricity + water + nitrogen → ammonia
• ~ 50% lower capital cost
• SSAS reactor: SOFC * in reverse

* SOFC: Solid oxide Fuel Cell
SSAS vs H-B NH3 Synthesis

Solid State Ammonia Synthesis vs Haber – Bosch

Renewable-source electricity input

- H-B per MW input
  - Capital $1.5 M
  - 2 tons / day output

- SSAS per MW input
  - Capital $650 K
  - 3.2 tons / day output
Adak, Alaska
Aleutian Islands
Class 7 Wind: Capacity Factor (CF) >45% ?
**“Green” Ammonia (NH₃) Output**

> 2,000 MW Adak Wind-to-ammonia Plant  
> $5 B total capital @ $2,500 / kW  
> 45% Capacity Factor (CF)

Windplant Annual Energy Production

<table>
<thead>
<tr>
<th>As electricity:</th>
<th>21,600</th>
<th>MWh / day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7,884,000</td>
<td>MWh / year</td>
</tr>
</tbody>
</table>

Convert to NH₃ by:

<table>
<thead>
<tr>
<th>Electrolysis + H-B</th>
<th>SSAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 12 MWh / Mt</td>
<td>@ 7.5 MWh / Mt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mt (tons) / year</th>
<th>657,000</th>
<th>1,050,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales @ $300 / Mt</td>
<td>$197 M</td>
<td>$315 M</td>
</tr>
<tr>
<td>(plant gate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple ROI</td>
<td>4%</td>
<td>6%</td>
</tr>
</tbody>
</table>
Liquid Anhydrous Ammonia (NH₃) -33 C, 1 atmosphere
“Green” Ammonia (NH3) Output
- 2,000 MW Adak Wind- to- ammonia plant
- $5 B total capital @ $2,500 / kW
- 45% Capacity Factor (CF)
- 15% Capital Recovery Factor (CRF)

Windplant Annual Energy Production
As electricity: 7,884,000 MWh / year

<table>
<thead>
<tr>
<th>Electrolysis</th>
<th>+ H-B</th>
<th>SSAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales: Mt (tons) / year</td>
<td>657,000</td>
<td>1,050,000</td>
</tr>
<tr>
<td>Total Cost of Sales:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital @ 15% CRF</td>
<td>$750M</td>
<td>$750M</td>
</tr>
<tr>
<td>Plant O&amp;M @ $0.03 / kWh</td>
<td>24M</td>
<td>24M</td>
</tr>
<tr>
<td>Input energy</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$774M</td>
<td>$774M</td>
</tr>
<tr>
<td>Cost / Mt NH3</td>
<td>$1,178</td>
<td>$737</td>
</tr>
<tr>
<td>Shipping @ $50 / Mt</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Total NOLA / Mt</td>
<td>$1,228</td>
<td>$787</td>
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</tbody>
</table>
## “Green” Ammonia (NH3) Output

- **2,000 MW Adak Wind-to-ammonia plant**
- **$5 B total capital @ $2,500 / kW**
- **45% Capacity Factor (CF)**
- **12% Capital Recovery Factor (CRF)**

### Windplant Annual Energy Production

As electricity: 7,884,000 MWh / year

<table>
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<th>SSAS</th>
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<tr>
<td>Total Cost of Sales:</td>
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<td></td>
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<tr>
<td>Capital @ 12% CRF</td>
<td>$600M</td>
<td>$600M</td>
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<tr>
<td>Plant O&amp;M @ $0.03 / kWh</td>
<td>24M</td>
<td>24M</td>
</tr>
<tr>
<td>Input energy</td>
<td>0</td>
<td>0</td>
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<tr>
<td>TOTAL</td>
<td>$624M</td>
<td>$624M</td>
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<tr>
<td>Cost / Mt NH3</td>
<td><strong>$ 949</strong></td>
<td><strong>$ 594</strong></td>
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<tr>
<td>Shipping @ $50 / Mt</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Total NOLA / Mt</td>
<td><strong>$ 999</strong></td>
<td><strong>$ 644</strong></td>
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Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)
Grant Applications for SSAS: Solid State Ammonia Synthesis

Dr. Majumdar, ARPA-E
Anchorage, AK
17 Aug 10

Bill Leighty, Director
The Leighty Foundation
Juneau, AK
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907-586-1426 206-719-5554 cell
SSAS R+D+Demo Concept

- $4 – 5 M total program
- Simulate Alaska community energy island
- SSAS offer RE-source internal energy independence?
  - Discover, demonstrate tech & econ advantages
  - Conversions efficiency; byproduct heat used
  - Economic: capital, O&M costs
- R&D plus demo pilot plant:
  - NHThree LLC patented IP
  - PCC tube mfg pilot plant
**SSAS R+D+Demo Concept**

- Deploy at UAS Tech Center, Juneau
- Operate in two modes on AEL&P grid:
  - Hydroelectricity-to-NH3
  - NH3-to-AEL&P grid
- SCADA data collect, analyze
- Modify system hardware + software
- Relocate to smaller community
- Implications for export of large-scale, stranded AK RE
TDX Power, Inc., St. Paul Island
Candidate SSAS Pilot Plant Advanced Test Site
AEL&P (Juneau) R+D+Demo
SSAS Renewables – Ammonia
Integrated System
AEA “Renewable Energy Grant” app: NO
**RE – SSAS pilot plant**

![Diagram of SSAS pilot plant]

**Figure 1.** Complete, containerized SSAS renewable energy conversion and storage system pilot plant

**SSAS Pilot Plant for Denali Commission EETG**
Rev: 6 Sep 09  W. Leighty
Alaska Applied Sciences, Inc.  PROPRIETARY

SSAS: Solid State Ammonia Synthesis

~25 - 50 Inputs

SCADA system

HDD

Network

sensor, transducer: to SCADA
SSAS Grant Applications

- ’08 AELP via AK HB152 (RE demos)
- ’09 NHThree LLC via ARPA-E
- ’09 AASI via Denali Commiss EETG
- ’10 Coffman + NHThree LLC via ARPA-E
'08 AEL&P Grant Application: Renewable Energy, AEA, HB152

- Alaska Electric Light & Power (AEL&P) Juneau
- R+D+Demonstration of SSAS system
- $800K, round one, HB152 grants
- Advance SSAS from lab scale: tech + econ feasible
- Statewide application:
  - “Energy Islands”
  - “Energy Independence”
  - Village survival: imported energy cost, delivery
  - Scaleup: export NH3, tanker
- Demonstrate in major AK city, first: Juneau
- Redeployed to remote community
- Not funded by AEA: no R&D
Sept ’09 AASI Grant Application: Denali Commission (Alaska) EETG (Emerging Energy Technology Grant program)

• Alaska Applied Sciences, Inc., Juneau (AASI)
• $800K: SSAS R+D+Demonstration (same as AEL+P)
• Not funded by Denali:
  – Timing mismatch
  – NHThree LLC prime subcontractor: single-source
  – NHThree LLC ARPA-E application pending: mfg plant
• Statewide application:
  – “Energy Islands”
  – “Energy Independence”
  – Village survival: imported energy cost, delivery
• Demonstrate in major AK city, first: Juneau
• Close loop to AEL+P hydro grid
• Redeploy to village if successful
• Eight support letters
Denali Commission Summary

- R&D plus pilot plant: NHThree LLC
- Simulate Alaska community energy island
- SSAS offer RE-source internal energy independence?
  - Discover, demonstrate
  - Technical: conversions efficiency; byproduct heat used?
  - Economic: capital, O&M costs?
- Deploy at UAS Tech Center, Juneau
- Operate in two modes on AEL&P grid:
  - Hydroelectricity-to-NH3
  - NH3-to-AEL&P grid
- SCADA data collect, analyze
- Modify system hardware + software
- Relocate to smaller community?
- Final report; conference papers; wide distribution
- Implications for export of large-scale, stranded AK RE?
SSAS Commercialization:  
*R + D + Demonstration*  
*Funding Required by NHTthree LLC*

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Plant for PCC tubes</td>
<td>$ 2.5 M</td>
</tr>
<tr>
<td>Portable Pilot Plant: RE $\rightarrow$ NH3 $\rightarrow$ RE</td>
<td>1.0 M</td>
</tr>
<tr>
<td>Portable Pilot Plant transport, install, ops</td>
<td>.5 M</td>
</tr>
<tr>
<td>R+D + Management</td>
<td>1.0 M</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 5.0 M</strong></td>
</tr>
</tbody>
</table>
SSAS Commercialization:  
*R + D + Demonstration*  
Potential Funding Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska SB220 “EETG”</td>
<td>$ 1 M</td>
</tr>
<tr>
<td>Iowa Power Fund</td>
<td>1 M</td>
</tr>
<tr>
<td>ARPA-E “unsolicited”</td>
<td>1 M</td>
</tr>
<tr>
<td>Farm Bill Sec 9003 Approp</td>
<td>1 M</td>
</tr>
<tr>
<td>Foundations</td>
<td>?</td>
</tr>
<tr>
<td>Private equity</td>
<td>1 M</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 5 M</strong></td>
</tr>
</tbody>
</table>
Alaska Business Opportunities: RE – NH3 “Green” Ammonia

Monetizing Alaska’s vast RE

1. Export from GW-scale RE: Increase cash IN
2. Village energy “independence”
   – Indigenous renewables; diverse
   – Seasonal, diurnal variability
   – Storage as NH3: pressurized tanks
   – Reduce cash OUT
Alaska’s Immediate Opportunity: SSAS

- Village energy “independence” - degree
  - Diverse, indigenous RE sources
  - Convert % to NH₃
  - Storage as NH₃ in steel tanks: annually-firm
  - Deliver energy services: CHP, heat, transport,
  - Competitive price: $6-8 / gallon diesel + heat fuel
- SSAS R&D and Demonstration
  - NHThree LLC owns SSAS IP patent
  - PCC tube mfg pilot plant
  - RE – SSAS pilot plant → AK village(s)
Alaska’s Immediate Opportunity: SSAS

- Funding Collaboration: State of AK, Denali, Fed, Industry
  - $4-5M total R&D&Demo
  - EETG funds
    - SB220 State $2.5M
    - Denali Commission $2.5M
    - USDA: ’08 Farm Bill Sec 9003 “RE Fertilizer Research”
- Set stage for GW-scale NH₃ export via SSAS
  - Diverse RE
  - Capital cost; CF; lower cost of energy (COE)?
- Barriers
  - EPA: Ammonia not a fuel
  - DOE: Currently not interested; “toxic”; electricity transmis
  - Industry: too risky, no fuel market, hazardous
NH3 plant gate costs, per metric ton, estimate ~130 MMt / year global

- Stranded NG → SMR → H-B $ 200
- Wind → electrolysis → H-B 1,000
- Wind → SSAS 600
MUST Run the World on Renewables – plus Nuclear?

• Climate Change
• Demand growth
• Depletion of Oil and Gas
• Oil spills and pollution
• Only 200 years of Coal left
• Only Source of Income:
  ▪ Sunshine
  ▪ Tides
  ▪ Meteors and dust
• Spend our capital?

What would it take...
Joel Makower
Comparing the world’s energy resources

Where should we invest for the long-haul??

*SOLAR

World energy use

©Richard Perez, et al.

*Yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear “use-them, lose-them” resources. World energy use is annual.
“Americans can be counted on to always do the right thing – but only after they have tried everything else.”

Winston Churchill

The dog caught the car.

Dan Reicher
Making Ammonia Fuel From Alaska's Abundant Stranded Renewable Energy

Ammonia Fuel Conference
Detroit, MI
27 September 10

Bill Leighty, Director
The Leighty Foundation
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Brian Hirsch, Alaska Office, NREL
Anchorage, AK
Brian.Hirsch@nrel.gov

DVD’s available
SUMMARY: Dr. Majumdar, ARPA-E

• ARPA-E FOA applications
  – NHTThree LLC FIRST ROUND
  – Coffman + NHTHree LLC GRIDS
  – Hydrogen Discoveries, Inc GRIDS
  – Alaska Applied Sciences, Inc. GRIDS

• AK laboratory: innovation + save $
  – 220 villages: islands, most have RE
  – Anhydrous ammonia (NH3) storage, fuel:
    “independence”, survival

• Handoff: print, DVD, CD
END presentation

Following slides are supplementary
ARPA-E help

- “Broad Funding Announcement” current?
- Workshop on RE systems; global context
- Reconsider NH3 and GH2 proposals
- SSAS: Denali Commission ’09 proposal
- Ammonia a fuel: DOE list
- Send rep to 7th Ammonia Fuel Conference 27-28 Sept, Detroit
“Run world on renewables” problems:

1. Transmission
2. Firming, dispatchable storage
3. Electricity grid integration
4. Curtailed RE generation
“Green” Ammonia (NH₃) Output

> 2,000 MW Adak Wind-to-ammonia plant
> $5 B total capital @ $2,500 / kW
> 45% Capacity Factor (CF)
> 12% Capital Recovery Factor (CRF)

Windplant Annual Energy Production
As electricity: 7,884,000 MWh / year

Electrolysis

+ H-B     SSAS

Sales: Mt (tons) / year  657,000  1,050,000

Total Cost of Sales:
Capital @ 12% CRF    $600M  $600M
Plant O&M @ $0.03 / kWh  24M  24M

Input energy  0  0

TOTAL  $624M  $624M

Cost / Mt NH₃
$949  $594

Shipping @ $50 / Mt  50  50

Total NOLA / Mt  $999  $644
Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)
ARPA-E help

• Collaborative funding SSAS R&D&Demo:
  – $4 – 5M total
  – AK: SB220 “EETG”
  – AK: Denali Commission “EETG”
  – IA: Iowa Power Fund, OEI, State
  – ’08 Farm Bill Sec 9003 “RE fertilizer research”
  – ARPA-E “unsolicited”
Other Alaska GW-scale Stranded RE

- Higher capacity factor (CF) $\rightarrow 100\%$
- Lower cost of energy (COE)
- Tanker transport affordable

  - Geothermal
  - Wave, tidal
  - Instream kinetic
  - Solar
  - Biomass