The Ammonia Economy
Global Potential and Possible Pathways

NH3FUEL CONFERENCE
DES MOINES, IA
SEPTEMBER, 2014

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The Prize – 21st Century

(With Apologies to Daniel Yergin)

A zero carbon fuel

That can be used for transportation and power generation

That is scalable from global chemical to global energy proportions

That is an inherently clean fuel with regard to traditional pollutants and CO_2

That has a century long history of large scale handling and use

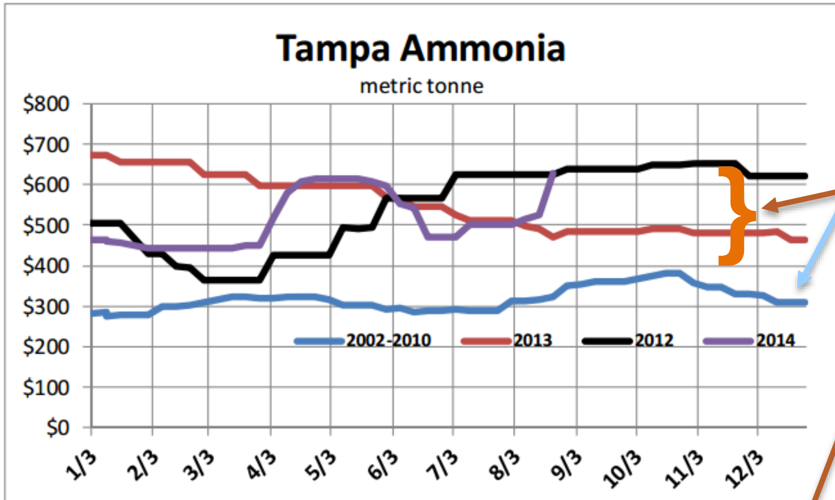
That is competitive in energy pricing to current fuels

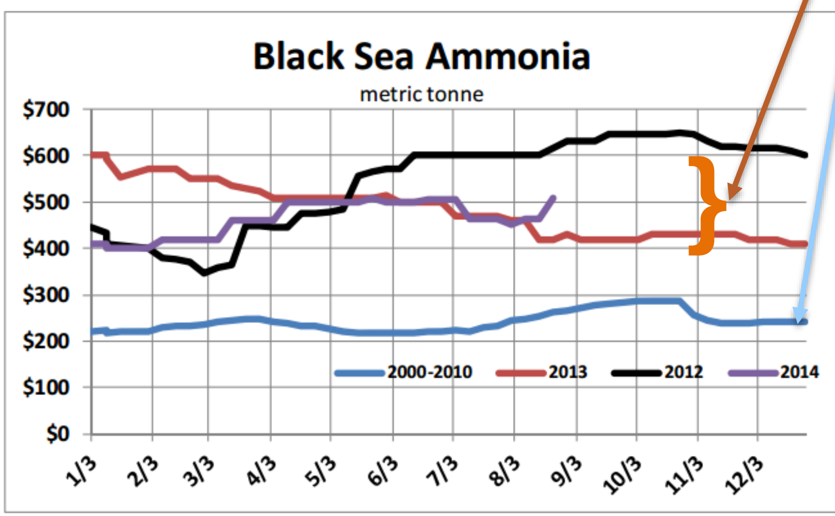
That holds promise for low or no carbon production (through CCS on standard technology or advanced technology for renewables or nuclear)

That *appears to be* within easy reach through optimization of production, use and safety regulations

CLEAN AIR TASK FORCE

Price History - Ammonia Industry



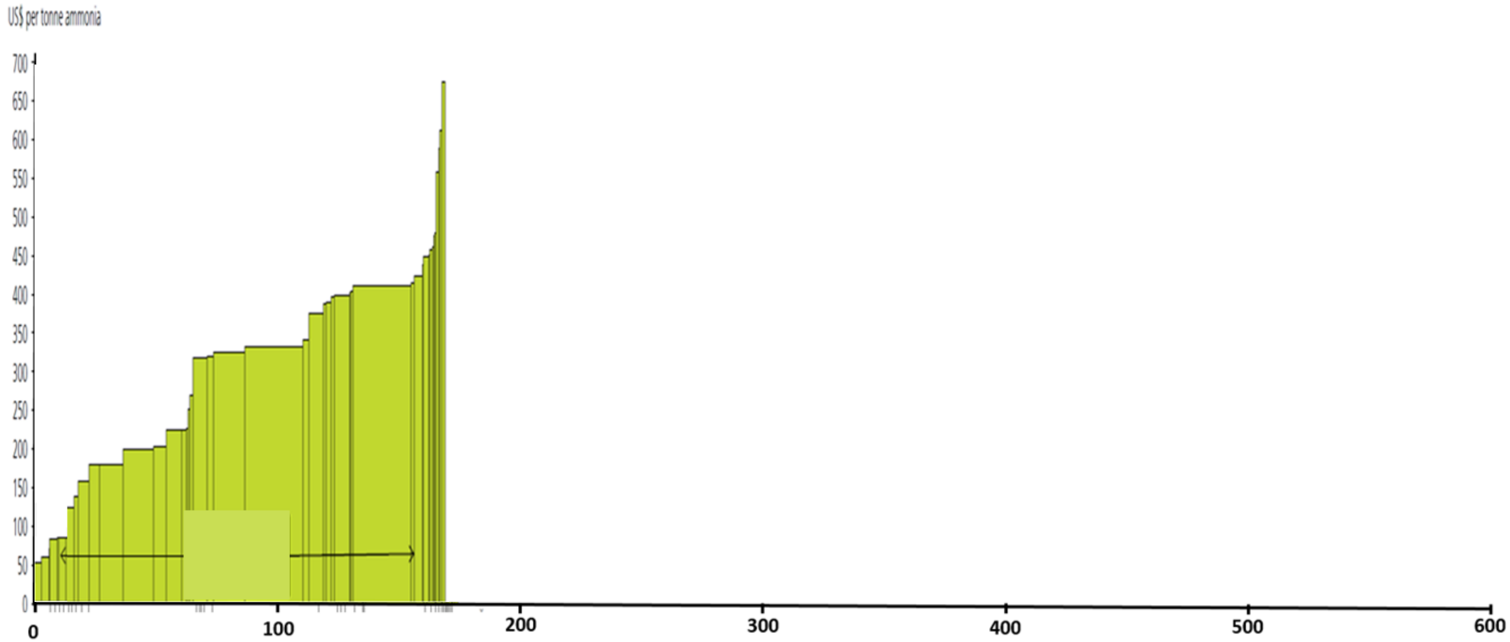


- **2002 – 2010 - $200 - $350**
- **US Mainland about $100 higher**
- **2012 – 2014 - $350 - $ 650**

http://farmfutures.com/mdfm/Faress1/author/252/2014/8/WFertR081914.pdf

CLEANAIR TASK FORCE

General Cost Structure of Ammonia Industry



Greenfield annual capital charge - 10% of $1000 per tonne of annual capacity

Debottleneck or multi-plant site- 10% of $500 per tonne of annual capacity

HIGH Transport and Storage – Intercont Ship, Trans Cont Rail

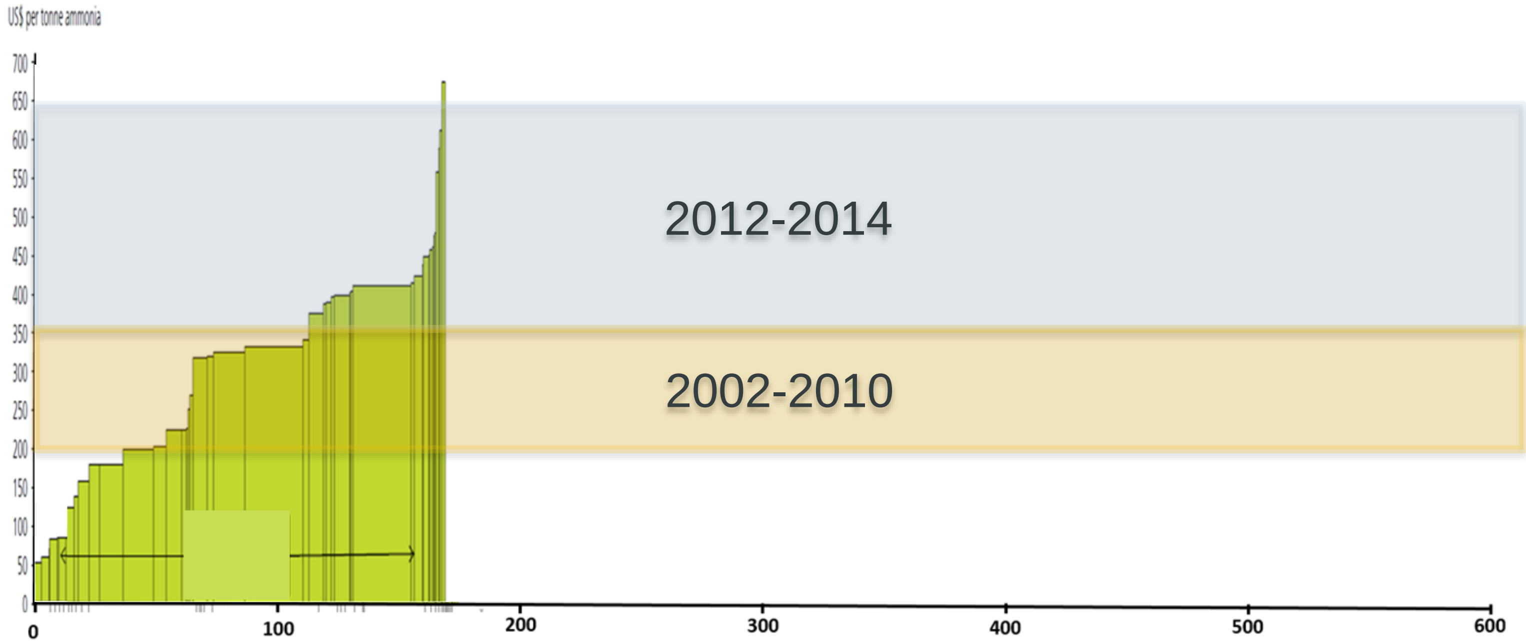
MEDIUM Transport and Storage – Barge, Regional Sea, Medium Truck/Rail

LOW Transport and Storage – Pipeline, Dedicated Regional Sea

HIGH Marketing and Back Office – Sales into global market

LOW Marketing and Back Office – Dedicated, contractual offtake to fuel

Historical Price Ranges



Greenfield annual capital charge - 10% of $1000 per tonne of annual capacity

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HIGH Transport and Storage – Intercont Ship, Trans Cont Rail

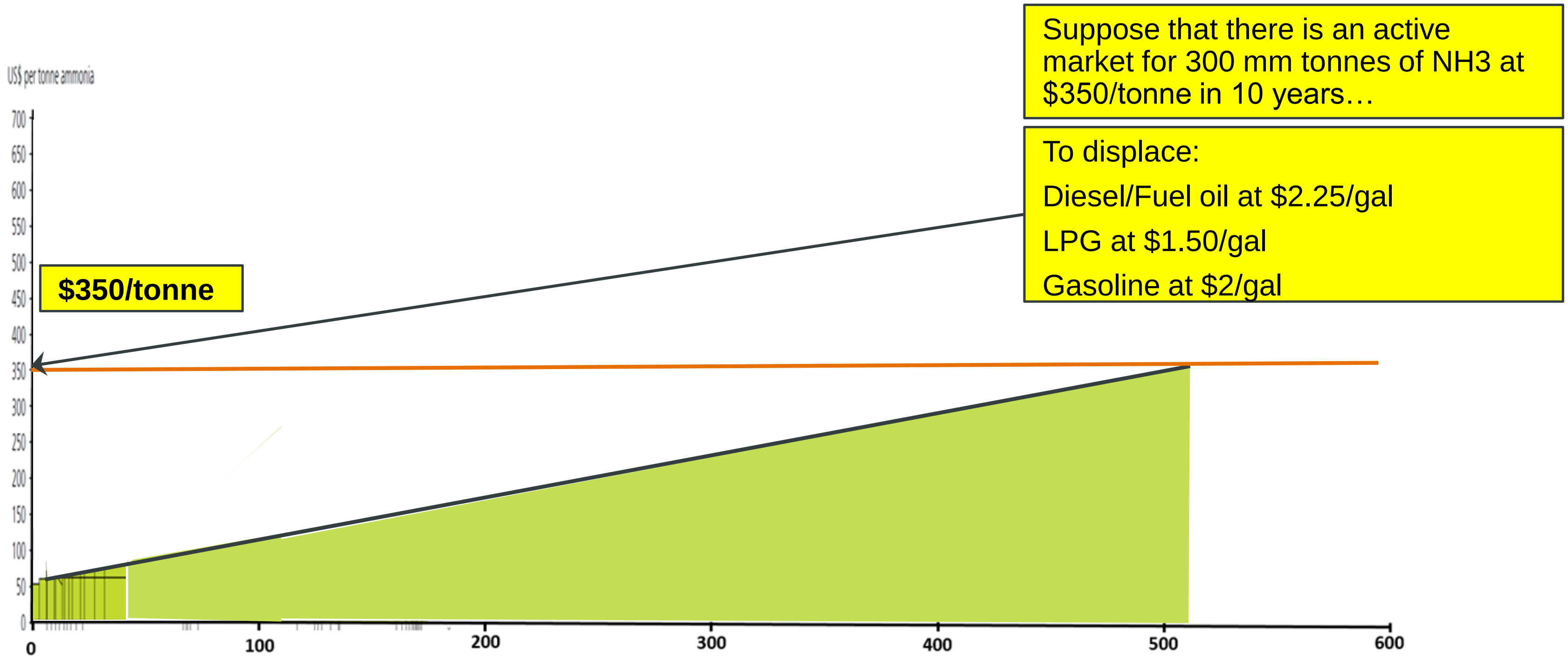
MEDIUM Transport and Storage – Barge, Regional Sea, Medium Truck/Rail

LOW Transport and Storage – Pipeline, Dedicated Regional Sea

HIGH Marketing and Back Office – Sales into global market

LOW Marketing and Back Office – Dedicated, contractual offtake to fuel

What Happens with a Growing Fuels Market?



- Will there be ammonia to supply such a market?

Hawaii distillate, resid and coal import (125 T BTU)

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	5.86E+06
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	124,987,434
MMBTU gas required for NH3	32.0	187,616,000
TCF natural gas required for NH3	2.94E-08	0.172
Tonnes water produced from NH3	1.58E+00	9,263,540
# Global ammonia industry	6.67E-09	0.039
# of World Scale NH3 Plants	1.25E-06	7.33
Number of 60,000 cbm vessels	2.44E-05	143
Number of 80 tonne railcar deliveries	0.0125	73,288
# of 1 MM TPA NH3 pipeline	1.00E-06	5.9
MWh from 45% efficient power plants	2.81E+00	16,475,030
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	188.0
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.40
Tonnes LNG equivalent	0.41	2,403,830
Metric Tonnes coal equiv	1.04	6,097,520
Tonnes oil equivalent (TOE)	0.500	2,931,500
Tonnes resid equiv	0.530	3,107,390
Gal LPG equiv	234	1,371,942,000
Gal Gasoline equiv	172	1,008,436,000
Gal Ethanol equiv	253	1,483,339,000

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal
$350	$30.00	$4.00	$4.00	$4.00	$50	$5.00
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$639	$688	$936	$624	$52	$1,265
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)
2800	2800	2200	2800	2200	2200	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal
$0.125	$0.228	$0.313	$0.334	$0.284	$0.024	$0.452

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33

CASE NOTES

HAWAII distillate, resid and coal import (125 T BTU)

Gas price - $40 per mmbtu

Power - $350 per mwh (about 80% from coal, resid and fuel oil)

This could be displaced by 6 mmt nh3 (about 7.5 ammonia plants)

About 150 cargo ship deliveries per year.3

Fuel cost for ammonia per year - $2.0 bb. Fuel cost for power ('free' heat from CHP) - **$125 per MWH.**

Scenario Model

- **Inputs are tonnes NH3 and unit costs of fuels.**
- **Outputs are parameters of the scenario and relative economics.**

- Example parameters –
- # of ammonia plants
- # of railcars and ship cargoes
- MWh of power
- Tonnes of oil, coal, lng equivalent
- Tonnes of clean water from NH3 combustion

- Comparative costs for equivalent BTU's from various fuels

CLEAN AIR TASK FORCE

LNG 2012 Total Trade - 325 BCM

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	600,000,000
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	12,790,800,000
MMBTU gas required for NH3	32.0	19,200,000,000
TCF natural gas required for NH3	2.94E-08	17.640
Tonnes water produced from NH3	1.58E+00	948,000,000
# Global ammonia industry	6.67E-09	4.000
# of World Scale NH3 Plants	1.25E-06	750.00000
Number of 60,000 cbm vessels	2.44E-05	14,620
Number of 80 tonne railcar deliveries	0.0125	7,500,000
# of 1 MM TPA NH3 pipeline	1.00E-06	600.0
MWh from 45% efficient power plants	2.81E+00	1,686,000,000
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	19,235.7
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	41.23
Tonnes LNG equivalent	0.41	246,000,000
Metric Tonnes coal equiv	1.04	624,000,000
Tonnes oil equivalent (TOE)	0.500	300,000,000
Tonnes resid equiv	0.530	318,000,000
Gal [illegible] equiv	234	140,400,000,000
Gal Gasoline equiv	172	103,200,000,000
Gal Ethanol equiv	253	151,800,000,000
Price NH3	$500	
Total NH3 cost $		300,000,000,000
Fuel cost for power, $/kwh from NH3	$ 0.179	
Price NATURAL GAS	$23.00	
Total Natural Gas cost $		$ 293,940,000,000
Fuel cost for power for power, $/kwh from gas	$ 0.175	
Price GASOLINE	$2.90	
Total Gasoline cost $		$ 299,280,000,000
Fuel cost for power, $/kwh from gasoline	$ 0.227	
Price LPG	$2.15	
Total LPG cost $		$ 301,860,000,000
Fuel cost for power, $/kwh from LPG	$ 0.180	
Price DIESEL	$3.20	
Total Diesel cost $		$ 299,520,000,000
Fuel cost for power, $/kwh from diesel	$ 0.227	
Price COAL	$100	
Total Coal cost $		$ 62,400,000,000
Fuel cost for power, $/kwh from coal	$ 0.047	
Price ETHANOL	$4.00	
Total Ethanol cost $		$ 607,200,000,000
Fuel cost for power, $/kwh from ethanol	$ 0.361	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	330

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$500	$23.00	$2.90	$2.15	$3.20	$100	$4.00	$300	$420
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$500	$490	$499	$503	$499	$104	$1,012	$294	$298
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.179	$0.175	$0.227	$0.180	$0.227	$0.047	$0.361	$0.105	$0.107

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

325 bcm (*.90 mmtoe/bcm) equiv to about 300 mm toe

This is equivalent to 600 MM TPA ammonia (4 X current ammonia industry)

Global LNG

LNG Global trade 2012 was equivalent to 600 MM TPA Ammonia

This is equivalent to 4 X current global ammonia business.

This is a proxy of low cost, large scale natural gas available with capability for industrial construction around the world for commercial use.

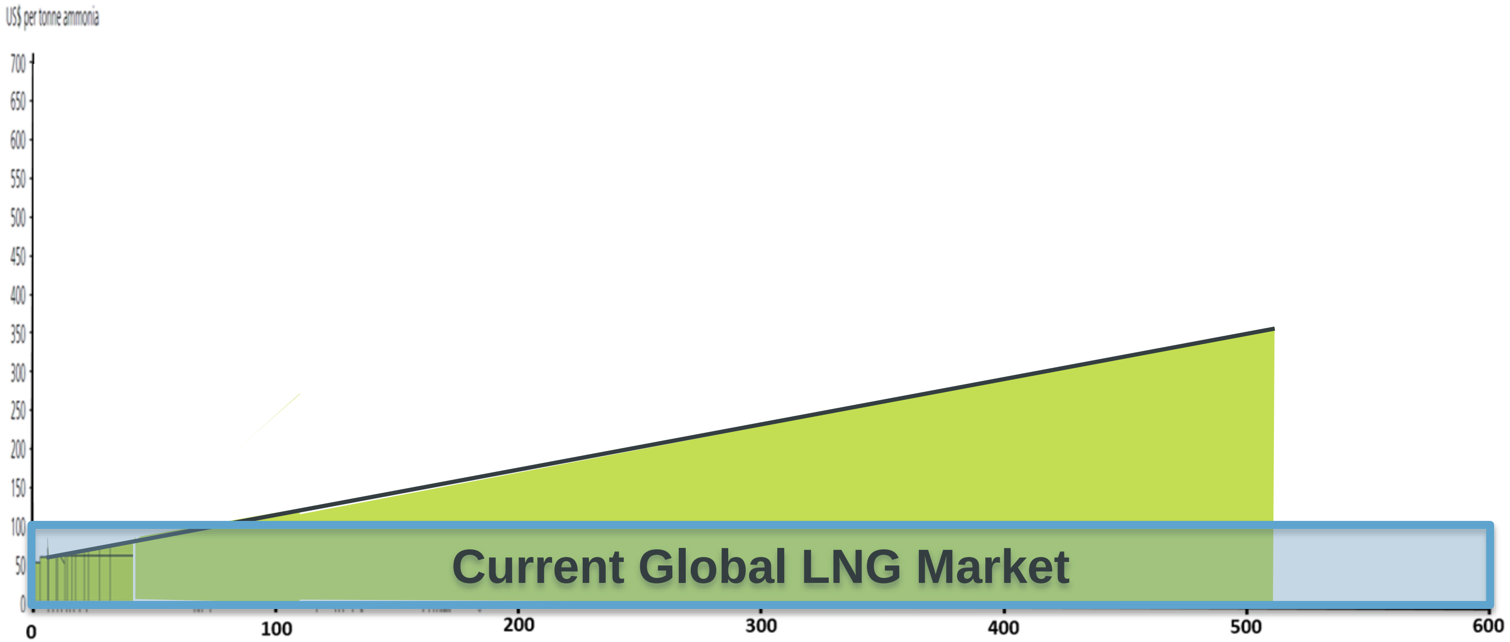
LNG market does not include:

Medium sized resources (< a few TCF)

Difficult access to deep port (e.g., Alaska)

Political barriers (e.g., US shale gas)

What Happens with a Growing Fuels Market?



- There is low cost, commercializable natural gas available for low cost ammonia (especially considering the growing amounts of gas not available for LNG).

Alaska LNG Project

Alaska has massive store of low cost gas from decades of gas re-injection.

There is a $60-$70 BB, 6 year project proposed for building a gas pipeline to Anchorage and LNG export to Asia.

10% of the proposed gas would feed 5-6 North Slope ammonia plants.

This can be done in parallel with gas pipeline project, but is much more flexible and quicker payback.

10% of ALASKA LNG project (10% of 60 BB$ - 19 mtpa (900 bcf/yr))

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	4,609,757
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU contained in NH3	21.32	98,270,799
MMBTU gas required for NH3	32.0	147,512,223
TCF natural gas required for NH3	2.94E-08	0.14
Tonnes water produced from NH3	1.58E+00	7,283,416
# Global ammonia industry	6.67E-09	0.03
# of World Scale NH3 Plants	1.25E-06	5.76
Number of 60,000 cbm vessels	2.44E-05	112
Number of 80 tonne railcar deliveries	0.0125	57,621.96
# of 1 MM TPA NH3 pipeline	1.00E-06	4.61
MWh from 45% efficient power plants	2.81E+00	12,953,417
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	147.79
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.32
Tonnes LNG equivalent	0.41	1,890,000
Metric Tonnes coal equiv	1.04	4,794,147
Tonnes oil equivalent (TOE)	0.500	2,304,878
Tonnes resid equiv	0.530	2,443,171
Gal LPG equiv	234	1,078,683,132
Gal Gasoline equiv	172	792,878,200
Gal Ethanol equiv	253	1,166,268,515
Price NH3	$350	
Total NH3 cost $		$ 1,613,414,941
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$25.00	
Total Natural Gas cost $		$ 2,454,695,590
Fuel cost for power for power, $/kwh from gas	$ 0.190	
Price GASOLINE	$4.50	
Total Gasoline cost $		$ 3,567,951,899
Fuel cost for power, $/kwh from gasoline	$ 0.352	
Price LPG	$3.50	
Total LPG cost $		$ 3,775,390,963
Fuel cost for power, $/kwh from LPG	$ 0.293	
Price DIESEL	$4.00	

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal
$350	$25.00	$4.50	$3.50	$4.00	$125	$4.50
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$533	$774	$819	$624	$130	$1,139
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)
2800	2800	2200	2800	2200	2200	2800
Fuel cost for power, $/kw from NH3	Fuel cost for power for power, $/kw from gas	Fuel cost for power, $/kw from gasoline	Fuel cost for power, $/kw from LPG	Fuel cost for power, $/kw from diesel	Fuel cost for power, $/kw from coal	Fuel cost for power, $/kw from coal
$0.125	$0.190	$0.352	$0.293	$0.284	$0.059	$0.407

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33

CASE NOTES

Alaska has massive reserves of gas on the North Slope following years of re-injection for EOR. There is no exploration or drilling cost required for this gas, but there is no current way to deliver it to market. The leading candidate now is a $50-$60 BB project to build a pipeline to Anchorage and a LNG export terminal. In addition to taxes, revenues and employment, the development and monetization of this gas is critical to Alaska's future viability. Oil production is declining to the point that operation of the Trans Alaska pipeline is increasingly difficult. Anchorage, Fairbanks and many internal towns have very high and increasing energy costs. Most run on imported diesel. Anchorage is running low on it's local gas field.

The gas pipeline/LNG option is facing many barriers. It is very uncertain what the LNG market will be 8-10 years from now (after $60 BB is on the ground). This is not a commercial risk. It is a 'bet the state' risk.

Ammonia production on the North Slope (with very cheap gas, probably strong support from government and industry players and ample engineering infrastructure) for delivery to Alaskan cities and towns (and eventually Asia) could become a very attractive proposition.

- It doesn't require mega-investment to prove the markets or even to build the first plant.
- The investment is incremental ($1 BB at a time with 3 yrs to revenue, rather than $50 BB with at least 8 yrs to revenue.) Further investment is based on success and market development. If market is bigger than originally envisioned, 'debottlenecking' is simple – build another ammonia train.
- The market risk is much smaller (ammonia is a valuable, fungible commodity that is easily shipped to buyers in a deep market).
- It is much more flexible in market distribution (e.g., reduced internal AK demand in summer sends product to Asia seasonally). It can be delivered to all towns, cities, facilities in Alaska at any scale required (for power, heat and transportation fuel (gasoline/diesel very expensive in Alaska).
- It can be stored easily for winters.
- It is ideal for CHP. Heating fuel is very dear in Alaska's climate isolated from finished fuel products. District heating and small scale, clean power gen are very valuable in this environment.
- It is not as vulnerable to earthquakes, sabotage or high pressure pipeline failure as a gas pipeline.

THIS MODEL REFLECTS AMMONIA PRODUCTION EQUIVALENT TO 10% OF THE PLANNED CAPACITY OF THE LNG/PIPELINE PROJECT.

This reflects a right-sized scenario as an alternative to the gas pipeline.

We can expect that construction of ammonia plants would be considerably more expensive than in Texas or Louisiana. Especially for the first few (getting the labor force up there and trained, logistics, etc). But this is actually a less capital intensive project than the pipeline (and it stays in one place). If the ammonia (and methanol/MTG) industry develops on the North Slope the HR/engineering infrastructure will have a steady stream of projects for years to come.

Under these circumstances, we can expect that capex for construction, operation and logistics to trend down toward today's costs (even as those costs fall further). In Alaska, higher capex and operating costs will be offset by very low finding and lifting costs for the gas (much as the world is very willing to operate in very harsh and expensive environments to produce oil).

CLEAN AIR TASK FORCE

65% of 25% of global nuclear converted to ammonia, 410 twh

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	65,600,000
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	1,398,460,800
MMBTU gas required for NH3	32.0	2,099,200,000
TCF natural gas required for NH3	2.94E-08	1.929
Tonnes water produced from NH3	1.58E+00	103,648,000
# Global ammonia industry	6.67E-09	0.437
# of World Scale NH3 Plants	1.25E-06	82.00
Number of 60,000 cbm vessels	2.44E-05	1,598
Number of 80 tonne railcar deliveries	0.0125	820,000
# of 1 MM TPA NH3 pipeline	1.00E-06	65.6
MWh from 45% efficient power plants	2.81E+00	184,336,000
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	2,103.1
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	4.51
Tonnes LNG equivalent	0.41	26,896,000
Metric Tonnes coal equiv	1.04	68,224,000
Tonnes oil equivalent (TOE)	0.500	32,800,000
Tonnes resid equiv	0.530	34,768,000
Gal LPG equiv	234	15,350,400,000
Gal Gasoline equiv	172	11,283,200,000
Gal Ethanol equiv	253	16,596,800,000
Price NH3	$350	
Total NH3 cost $		22,960,000,000
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$15.00	
Total Natural Gas cost $		$ 20,959,200,000
Fuel cost for power for power, $/kwh from gas	$ 0.114	
Price GASOLINE	$3.00	
Total Gasoline cost $		$ 33,849,600,000
Fuel cost for power, $/kwh from gasoline	$ 0.235	
Price LPG	$2.00	
Total LPG cost $		$ 30,700,800,000
Fuel cost for power, $/kwh from LPG	$ 0.167	
Price DIESEL	$3.80	
Total Diesel cost $		$ 38,887,680,000
Fuel cost for power, $/kwh from diesel	$ 0.269	
Price COAL	$50	
Total Coal cost $		$ 3,411,200,000
Fuel cost for power, $/kwh from coal	$ 0.024	
Price ETHANOL	$3.00	
Total Ethanol cost $		$ 49,790,400,000
Fuel cost for power, $/kwh from ethanol	$ 0.271	
MegaTonnes CO2 saved with [illegible] vs GAS	5.50E-07	36

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$350	$15.00	$3.00	$2.00	$3.80	$50	$3.00	$200	$290
0	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$320	$516	$468	$593	$52	$759	$196	$206
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.125	$0.114	$0.235	$0.167	$0.269	$0.024	$0.271	$0.070	$0.074

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

Global nuclear power – 2500 twh (equivalent to 8.5 Quad at 100%, about 21 Quad heat at 40%)

Levelling Base Load for existing nuclear.

Assume typical 1 GW nuclear plant producing power at incremental operating cost of $0.02 per kwh (? Is this a reasonable number, it might actually be high). Assume 100% utilization for simplicity (scale down to 95% later if necessary)

The theory of this case is that the plant can devote 25% of its output 24/7 to ammonia production (once the infrastructure for local production of ammonia power is in place.) During peak hours, the ammonia power production (sized to 25% of baseload (250 MW)) could supplement the 750 MW from the plant. During peak summer months, the ammonia production could be scaled back to provide up to 125% of the original 1 GW.

As infrastructure builds, this could theoretically grow to 100% ammonia production from the nuclear plant.

The case is 25% of current nuclear converted via Electrogen/FAM. This is 625 twh. If we assume that 65% (?, efficiency of power converted to ammonia BTUs) (410 twh of this energy is converted to ammonia (21.7 mmbtu per tonne).

This is 65 MM tonnes ammonia.

The requirement of 5000 gpd Electrogen/FAM modules is about 15000. The initial capex estimated from Electrogen is $275K per unit. We can expect that large scale manufacture and learning curve to come down to $200K (and probably further). At $200K, this would be about $3BB capex. At $0.02 per kwh and sales price of $350/tonne, the capital will be paid off within 2-3 years. It should be noted that $3 BB is a very small investment for upgrading the worlds' nuclear fleet to 25% flexibility on diurnal peak shaving and increasing effective peak capacity by 25%. And at these assumed ammonia price, it is a very profitable investment.

The other cost associated with this infrastructure is power/CHP devices to convert the ammonia to useable energy. We will use a 'theoretical' MHI ammonia MegaNinja as a prototype (nominally sized as 1.5 MW – 10 MW, power efficiency at 45%, additional heat available from CHP/absorptive AC at 30%). We will assume capex at $800/kw ($8 MM for 10 MW machine). This scenario requires 2100 10 MW machines (about $17 BB).

At 45%/30% efficiency, these units will produce 185 Twh of power and 125 Twh eq (.42 Q, 420 mm mmbtu) of heat/AC. At a cost of $350 per tonne ammonia, the total cost of 65 mm tonnes of ammonia in this scenario is $22.8 BB. If we value the heat at $3/mmbtu (conservative), the fuel cost for power is about $0.12 per kwh.

This power is available on standby with 5 minute startup and initially installed at the highest value sites (office buildings, highrise dwellings, retail, food (refrigeration), light manufacturing, banks, hospitals,etc) that can best utilize uninterruptible power and CHP (absorptive AC, medium pressure steam, water/space heating, etc).

One of the main attributes of this strategy is that it is incremental. The ammonia production element can be started at small scale (e.g., 5000 tpd) and can initially serve ammonia fertilizer markets as well as dedicated offtake to energy. The energy market can also be started at small scale (e.g., 1.5 MW for high value CHP or dedicated uninterruptible power) and it can be supplemented or backed up with commercially available ammonia. The real beauty is that this market can grow regionally around existing nuclear plants. It can (and will) grow organically according to purely economic drivers allowing entrepreneurs and power customers (and grid management/regulators) to develop their own cost/risk/benefit energy profile at the same time they are growing zero carbon and efficient energy use.

Global Nuclear

Nuclear power plants do not follow load (they operate full tilt 24/7). In general, the power overnight is not highly valued and seeks big markets at low prices.

If 25% of global nuclear were to be converted to ammonia at 65% efficiency, this would be equivalent to 65 MM TPA ammonia (about 45% of current global production.)

This requires commercialization of low capital electrolytic production technology.

There are several additional advantages:

Production of fuel for regional grid stabilization (e.g., renewables)

Locally controlled DG/CHP with NH3

Arbitrage of NH3/power by the nuclear plant.

Overview of Sources (for future development)

- Alaska North Slope
- US Southwest/Fracking in general
- Middle East / North Africa (lowest cost ammonia currently, lots of headroom)
- Canada Hydroelectric (10's of GW of low cost power on contract)
- Iceland (practically unlimited geothermal at 3.7 cents/kwh)
- Big Wind (depends on low capex electrolysis tech, allows local grid stabilization)
- Off Peak Nuclear (depends on low capex electrolysis tech, allows local grid stabilization)

CLEANAIR TASK FORCE

Where Are the Markets?

10% 2012 New England gas demand 250 bcf

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	11,727,179
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	250,000,000
MMBTU gas required for NH3	32.0	375,269,725
TCF natural gas required for NH3	2.94E-08	0.345
Tonnes water produced from NH3	1.58E+00	18,528,943
# Global ammonia industry	6.67E-09	0.078
# of World Scale NH3 Plants	1.25E-06	14.66
Number of 60,000 cbm vessels	2.44E-05	286
Number of 80 tonne railcar deliveries	0.0125	146,590
# of 1 MM TPA NH3 pipeline	1.00E-06	11.7
MWh from 45% efficient power plants	2.81E+00	32,953,373
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	376.0
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.81
Tonnes LNG equivalent	0.41	4,808,143
Metric Tonnes coal equiv	1.04	12,196,266
Tonnes oil equivalent (TOE)	0.500	5,863,589
Tonnes resid equiv	0.530	6,215,405
Gal LPG equiv	234	2,744,159,865
Gal Gasoline equiv	172	2,017,074,772
Gal Ethanol equiv	253	2,966,976,264
Price NH3	$350	
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$12.00	
Total Natural Gas cost $		$ 2,997,466,929
Fuel cost for power for power, $/kwh from gas	$ 0.091	
Price GASOLINE	$4.00	
Total Gasoline cost $		$ 8,068,299,090
Fuel cost for power, $/kwh from gasoline	$ 0.313	
Price LPG	$3.50	
Total LPG cost $		$ 9,604,559,527
Fuel cost for power, $/kwh from LPG	$ 0.293	
Price DIESEL	$4.00	
Total Diesel cost $		$ 7,317,759,640
Fuel cost for power, $/kwh from diesel	$ 0.284	
Price COAL	$100	
Total Coal cost $		$ 1,219,626,607
Fuel cost for power, $/kwh from coal	$ 0.047	
Price ETHANOL	$4.00	
Total Ethanol cost $		$ 11,867,905,057
Fuel cost for power, $/kwh from ethanol	$ 0.361	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	6

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$350	$12.00	$4.00	$3.50	$4.00	$100	$4.00	$300	$420
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$256	$688	$819	$624	$104	$1,012	$294	$298
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.125	$0.091	$0.313	$0.293	$0.284	$0.047	$0.361	$0.105	$0.107

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

New England gas and fuel infrastructure is increasingly inadequate, risk-prone and costly to the economy.

Gas supply through pipeline and LNG cannot supply winter needs and storage is not adequate to arbitrage costs through the year.

Gas prices annually cycle $10 per mmbtu (see ref tab). NY 10-20 Vermont 15-25.

Liquid fuels have sustainably risen over the last 5 yrs. – LPG $3.5/gal and heating oil $4/gal. These fuels are also constrained by supply.

Annual consumption of gas (as a proxy) is 2500 bcf. Modelling displacing 10% of gas as an energy security, environmental, cost saving and DG/CHP measure.

This is equivalent to 14 ammonia plants (maybe $12 BB) vs. 80% of a world scale LNG plant.

It is also equivalent to about 2800 FAM units (about $1 BB if FAMs priced at $350 K). These FAM units could be supplied by very low cost stranded Canadian hydropower (totally green power at prices below current/foreseeable gas and heating oil prices.)

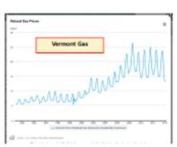
For flatline price through the year, annual energy cost is $4.1 BB ammonia, $4.5 BB gas, $9.6 BB LPG, $7.3 BB fuel oil.

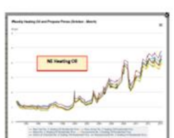
Ammonia is:

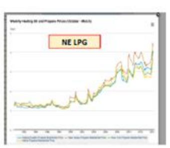
- Storable for times of the year that gas prices are high
  (no fuel use when power not needed in local service with power available within minutes on demand). Greatly increasing efficient utilization of BTUs
- Stand by fuel and generating capacity for extra cold winters and hot summers. Local depots for large (strategic reserve) storage of ammonia are much cheaper and distributable than gas storage. These strategic reserves cover risks and arbitrage for summer power and winter heating. They can be supplied based on swings in the market.

This scenario is incremental in execution. Starts with small, high value implementations with government/corporate support. Subsidies should not be required. With early demonstration and marketing, the market will grow (or not) according to competitiveness and risk management/arbitrage opportunities. We can expect support and assistance from utilities.

The other options that are already on the table for these issues (e.g., gas pipelines, gas storage) are expensive, one time, multiyear investments, multi billion $ projects with no exit ramp. And tie the market to a limited number of suppliers.







New England Gas Demand

New England and Mid Atlantic running short of gas and fuel oil for power and heating. Polar vortex put great pressure on power production last winter. Problem is getting worse with shutdown of coal plants.

It is very difficult and expensive to bring more gas into the region. 10% of current gas to the region is equivalent about 12 MM TPA ammonia (about 14 NH3 plants).

Fuel oil prices are routinely about $4/gal now (about 80% more expensive than ammonia at $350/tonne).

Ammonia can be used for distributed generation and combined heat/power around the region (energy security, urban deployment, grid stability)

CLEANAIR TASK FORCE

Hawaii distillate, resid and coal import (125 T BTU)

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	5.86E+06
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	124,987,434
MMBTU gas required for NH3	32.0	187,616,000
TCF natural gas required for NH3	2.94E-08	0.172
Tonnes water produced from NH3	1.58E+00	9,263,540
# Global ammonia industry	6.67E-09	0.039
# of World Scale NH3 Plants	1.25E-06	7.33
Number of 60,000 cbm vessels	2.44E-05	143
Number of 80 tonne railcar deliveries	0.0125	73,288
# of 1 MM TPA NH3 pipeline	1.00E-06	5.9
MWh from 45% efficient power plants	2.81E+00	16,475,030
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	188.0
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.40
Tonnes LNG equivalent	0.41	2,403,830
Metric Tonnes coal equiv	1.04	6,097,520
Tonnes oil equivalent (TOE)	0.500	2,931,500
Tonnes resid equiv	0.530	3,107,390
Gal LPG equiv	234	1,371,942,000
Gal Gasoline equiv	172	1,008,436,000
Gal Ethanol equiv	253	1,483,339,000
Price NH3	$350	
Total NH3 cost $		2,052,050,000
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$30.00	
Total Natural Gas cost $		$ 3,746,457,000
Fuel cost for power for power, $/kwh from gas	$ 0.228	
Price GASOLINE	$4.00	
Total Gasoline cost $		$ 4,033,744,000
Fuel cost for power, $/kwh from gasoline	$ 0.313	
Price LPG	$4.00	
Total LPG cost $		$ 5,487,768,000
Fuel cost for power, $/kwh from LPG	$ 0.334	
Price DIESEL	$4.00	
Total Diesel cost $		$ 3,658,512,000
Fuel cost for power, $/kwh from diesel	$ 0.284	
Price COAL	$50	
Total Coal cost $		$ 304,876,000
Fuel cost for power, $/kwh from coal	$ 0.024	
Price ETHANOL	$5.00	
Total Ethanol cost $		$ 7,416,695,000
Fuel cost for power, $/kwh from ethanol	$ 0.452	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	3

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$350	$30.00	$4.00	$4.00	$4.00	$50	$5.00	$200	$290
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$639	$688	$936	$624	$52	$1,265	$196	$206
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.125	$0.228	$0.313	$0.334	$0.284	$0.024	$0.452	$0.070	$0.074

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

HAWAII distillate, resid and coal import (125 T BTU)

Gas price - $40 per mmbtu

Power - $350 per mwh (about 80% from coal, resid and fuel oil)

This could be displaced by 6 mmt nh3 (about 7.5 ammonia plants)

About 150 cargo ship deliveries per year.3

Fuel cost for ammonia per year - $2.0 bb. Fuel cost for power ('free' heat from CHP) - **$125 per MWH.**

Fuel cost for gas per year - $3.7 bb. Fuel cost for power ('free' heat from CHP) - $228 per MWH.

Fuel cost for diesel per year - $3.6 bb. Fuel cost for power ('free' heat from CHP) - **$284per MWH.**

Fuel cost for coal per year - $0.3 bb. Fuel cost for power ('free' heat from CHP) - $30 per MWH.

Fuel price not the whole story.

Ammonia much easier to distribute and store than coal or gas.

Ammonia much cleaner to burn and use than coal, resid or fuel oil.

Ammonia can be deployed for power gen at 40%+ efficiency at scales between 250 kw and 50 M. At a capex of $600- $800 per kw. With turn on/off in a few minutes. Coal and gas cannot.

Small scale, clean combustion (500 kw – 200 MW) greatly facilitates CHP (heating, absorptive AC, hot water). Raising efficiency to 70-80% and displacing other heating fuels (perhaps 50% additional to electricity.

Ammonia at $250 - $350 per tonne is available from $2-$4 gas around the world for this entire market once the demand is established. That existing demand for fuel oil, LPG, LNG has established much higher prices.

Hawaii resid/distillate

Most of Hawaii's electricity is generated from heavy hydrocarbons. This is expensive (HI power more than 3X cost of mainland) and environmentally destructive, 35-40 cents/kwh). Hawaii is working very hard to reduce hydrocarbon reliance (small scale LNG, renewables energy efficiency).

There is great scope for this since power is so expensive. But the cheapest way is through ammonia.

Displacing all of HI resid, fuel oil and coal about equivalent to 6 MMTPA NH3 (about 7 plants or 140 cargo ship deliveries.) Ammonia at $350/tonne has a fuel cost of 13 cents / kwh (not counting credit for CHP from ammonia diesel gen sets).

Hawaii Alternatives Goals

Hawaii's goal is to have capacity for 4 MM MWh from Solar, wind and efficiency by 2020.

This is equivalent to 1.6 MM TPA ammonia. And likely much more expensive.

Hawaii Renewable, Distributed Generation, Efficiency by 2020 - 4 MM MWh

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	1,600,000
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	34,108,800
MMBTU gas required for NH3	32.0	51,200,000
TCF natural gas required for NH3	2.94E-08	0.047
Tonnes water produced from NH3	1.58E+00	2,528,000
# Global ammonia industry	6.67E-09	0.011
# of World Scale NH3 Plants	1.25E-06	2.00000
Number of 60,000 cbm vessels	2.44E-05	39
Number of 80 tonne railcar deliveries	0.0125	20,000
# of 1 MM TPA NH3 pipeline	1.00E-06	1.6
MWh from 45% efficient power plants	2.81E+00	4,496,000
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	51.295
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.11
Tonnes LNG equivalent	0.41	656,000
Metric Tonnes coal equiv	1.04	1,664,000
Tonnes oil equivalent (TOE)	0.500	800,000
Tonnes resid equiv	0.530	848,000
Gal LPG equiv	234	374,400,000
Gal Gasoline equiv	172	275,200,000
Gal Ethanol equiv	253	404,800,000
Price NH3	$500	
Total NH3 cost $		800,000,000
Fuel cost for power, $/kwh from NH3	$ 0.179	
Price NATURAL GAS	$23.00	
Total Natural Gas cost $		$ 783,840,000
Fuel cost for power for power, $/kwh from gas	$ 0.175	
Price GASOLINE	$2.90	
Total Gasoline cost $		$ 798,080,000
Fuel cost for power, $/kwh from gasoline	$ 0.227	
Price LPG	$2.15	
Total LPG cost $		$ 804,960,000
Fuel cost for power, $/kwh from LPG	$ 0.180	
Price DIESEL	$3.20	
Total Diesel cost $		$ 798,720,000
Fuel cost for power, $/kwh from diesel	$ 0.227	
Price COAL	$100	
Total Coal cost $		$ 166,400,000
Fuel cost for power, $/kwh from coal	$ 0.047	
Price ETHANOL	$4.00	
Total Ethanol cost $		$ 1,619,200,000
Fuel cost for power, $/kwh from ethanol	$ 0.361	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	1

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$500	$23.00	$2.90	$2.15	$3.20	$100	$4.00	$300	$420
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$500	$490	$499	$503	$499	$104	$1,012	$294	$298
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from ethanol	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.179	$0.175	$0.227	$0.180	$0.227	$0.047	$0.361	$0.105	$0.107

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

4 MM Mwh is about 440 MW running 100%
To generate 4 mm MWh at 40% efficiency equivalent to 1.6 MM Tonnes per year of ammonia (taking no account of CHP)
Fuel cost for power (no credit for CHP and flexibility in dispatch) at $500/tonne is $180 per MWh
This can be delivered by 40 cargo loads
It would be about 500 1MW diesel gen sets deployed in various configurations around the islands.

On 2 of the major islands, electricity rates are over 40 cents/kwh. Even on Oahu, they are 30.

Exhibit 6: Impact of Energy Efficiency, Distributed Generation, and Renewable Energy

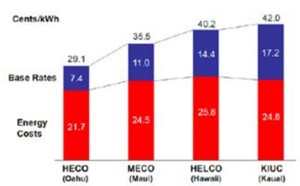
Source	2012 Actual (MWh/year)	Added 2013-2015 (MWh/year)	Cumulative Added 2013-2020 (MWh/year)	Total by 2020 (MWh/year)
Energy Efficiency Savings	793,600	581,400	1,556,400	2,350,000
Distributed Generation	189,563	401,572	762,466	952,029
Utility-Scale Renewables	1,134,389	793,143	1,461,223	2,595,612
Total	2,117,552	1,776,115	3,780,089	5,897,641

Source: PUC Docket No. 2010-0037; PUC Report to the 2014 Legislature on Hawaii's EEPS, December 2013; HECO RPS Status Report for the year ending December 31, 2012; KIUC RPS Status Report for the year ending December 31, 2012; State Energy Office Renewable Energy Projects Directory; *2013 Integrated Resource Planning Report*, Hawaiian Electric Companies, August 2013; Hawaii Public Utilities Commission Document Management System (DMS); Regulatory agency postings and notices; ICF Analysis.

About 440 MW
about 4 mm MWh

By 2020, the State of Hawaii is expected to have reduced electricity demand by 2,350,000 MWh/year and will likely be producing 952,029 MWh/year in customer generated electricity and another 2,595,612 MWh/year in utility-scale renewable generation. The total impact of these trends will be to reduce annual demand for fossil-fuel-based electricity generation by a total of 3,780,089 MWh/year between 2013-2020.

Average Electric Rate Level by County: 2011



	HECO (Oahu)	MECO (Maui)	HELCO (Hawaii)	KIUC (Kauai)
Customers	297,000	68,000	81,000	30,000
Sales (GWh)	7,242	1,181	1,104	435
Capacity (MW)	1,786	290	287	122
Avg Use/Customer (kWh)	23,564	17,369	13,771	11,505
Distribution Lines (Miles)	2,294	1,500	3,212	701

CLEANAIR TASK FORCE

1/8 of midwest propane demand and IL annual purchase of NH3 (1 MM tonnes)

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	1,000,000
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	21,318,000
MMBTU gas required for NH3	32.0	32,000,000
TCF natural gas required for NH3	2.94E-08	0.029
Tonnes water produced from NH3	1.58E+00	1,580,000
# Global ammonia industry	6.67E-09	0.007
# of World Scale NH3 Plants	1.25E-06	1.25
Number of 60,000 cbm vessels	2.44E-05	24
Number of 80 tonne railcar deliveries	0.0125	12,500
# of 1 MM TPA NH3 pipeline	1.00E-06	1.0
MWh from 45% efficient power plants	2.81E+00	2,810,000
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	32.1
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.07
Tonnes LNG equivalent	0.41	410,000
Metric Tonnes coal equiv	1.04	1,040,000
Tonnes oil equivalent (TOE)	0.500	500,000
Tonnes resid equiv	0.530	530,000
Gal LPG equiv	234	234,000,000
Gal Gasoline equiv	172	172,000,000
Gal Ethanol equiv	253	253,000,000
Price NH3	$350	
Total NH3 cost $		350,000,000
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$12.00	
Total Natural Gas cost $		$ 255,600,000
Fuel cost for power for power, $/kwh from gas	$ 0.091	
Price GASOLINE	$4.00	
Total Gasoline cost $		$ 688,000,000
Fuel cost for power, $/kwh from gasoline	$ 0.313	
Price LPG	$3.50	
Total LPG cost $		$ 819,000,000
Fuel cost for power, $/kwh from LPG	$ 0.293	
Price DIESEL	$4.00	
Total Diesel cost $		$ 624,000,000
Fuel cost for power, $/kwh from diesel	$ 0.284	
Price COAL	$100	
Total Coal cost $		$ 104,000,000
Fuel cost for power, $/kwh from coal	$ 0.047	
Price ETHANOL	$4.00	
Total Ethanol cost $		$ 1,012,000,000
Fuel cost for power, $/kwh from ethanol	$ 0.361	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	1

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$350	$12.00	$4.00	$3.50	$4.00	$100	$4.00	$300	$420
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$256	$688	$819	$624	$104	$1,012	$294	$298
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.125	$0.091	$0.313	$0.293	$0.284	$0.047	$0.361	$0.105	$0.107

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

Midwest Fertilizer, Heat and Electricity

The Midwestern states ran dangerously low of LPG for heat and farm use this winter with emergency measures required. Even with growing availability of propane from shale oil and gas, the infrastructure for delivery and storage of propane was strained by high demand for drying extra wet crops followed by record cold.

Prices rose to $4-5 per gallon (normally around $2). And a lot of people got really cold and mad.

I've modelled ammonia equivalent to 12.5% of Midwest propane demand (also equivalent to Illinois demand for ammonia fertilizer). If 12.5% of LPG demand were stored at ammonia facilities at the end of harvesting and the start of winter (when these facilities are operating low because they are most full before and during planting season), this could be a substantial cushion for managing the costs and risks of LPG shortages. This is equivalent to 230 MM gal LPG (replaced by 1 MM tonnes ammonia). The total cost of that ammonia at $350/tonne is $350 MM. The cost of the equivalent BTUs of LPG at $2/gal is $468 MM and at $4/gal is $936 MM. There clearly is large financial incentive even without the consideration of risk management.

If Sturman engine 1.0 MW units (40' trailers with Sturman fitted control systems) were sited on farms and neighborhoods, they would produce well-conditioned power for local use and utility offtake at 45% efficiency. The units are also ideally suited for CHP (total efficiency up to 75% or so) which can be used for district heating and, very importantly, crop drying.

One other huge advantage is countercyclical infrastructure use. The ammonia infrastructure is weighted toward winter and spring (for planting) and the LPG infrastructure is weighted toward summer and fall (for crop drying and winter heating). The ammonia producers will be happy to have profitable smoothing of their storage and distribution.

MidWest LPG Demand

The Midwestern states ran dangerously low of LPG for heat and farm use this winter with emergency measures required. Even with growing availability of propane from shale oil and gas, the infrastructure for delivery and storage of propane was strained by high demand for drying extra wet crops followed by record cold.

Prices rose to $4-5 per gallon (normally around $2). And a lot of people got really cold and mad.

1/8 of MidWest LPG demand is 1 MM TPA NH3. Even at $500 per tonne, ammonia BTUs are 20% cheaper than $4/gal LPG.

If ammonia diesel gens were sited on farms and neighborhoods, they would produce well-conditioned power for local use and utility offtake at 45% efficiency. The units are also ideally suited for CHP (total efficiency up to 75% or so) which can be used for district heating and, very importantly, crop drying.

One other huge advantage is countercyclical infrastructure use. The ammonia infrastructure is weighted toward winter and spring (for planting) and the LPG infrastructure is weighted toward summer and fall (for crop drying and winter heating). The ammonia producers might be happy to have profitable smoothing of their storage and distribution.

CLEAN AIR TASK FORCE

Displace 20% of Class 1 Rail Diesel (700 mm gals)

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	4,487,179
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	95,657,692
MMBTU gas required for NH3	32.0	143,589,744
TCF natural gas required for NH3	2.94E-08	0.132
Tonnes water produced from NH3	1.58E+00	7,089,744
# Global ammonia industry	6.67E-09	0.030
# of World Scale NH3 Plants	1.25E-06	5.60897
Number of 60,000 cbm vessels	2.44E-05	109
Number of 80 tonne railcar deliveries	0.0125	56,090
# of 1 MM TPA NH3 pipeline	1.00E-06	4.5
MWh from 45% efficient power plants	2.81E+00	12,608,974
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	143.9
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.31
Tonnes LNG equivalent	0.41	1,839,744
Metric Tonnes coal equiv	1.04	4,666,667
Tonnes oil equivalent (TOE)	0.500	2,243,590
Tonnes resid equiv	0.530	2,378,205
Gal LPG equiv	234	1,050,000,000
Gal Gasoline equiv	172	771,794,872
Gal Diesel equiv	156	700,000,000
Price NH3	$500	
Total NH3 cost $		2,243,589,744
Fuel cost for power, $/kwh from NH3	$ 0.179	
Price NATURAL GAS	$10.00	
Total Natural Gas cost $		$ 955,769,231
Fuel cost for power for power, $/kwh from gas	$ 0.076	
Price GASOLINE	$4.00	
Total Gasoline cost $		$ 3,087,179,487
Fuel cost for power, $/kwh from gasoline	$ 0.313	
Price LPG	$4.00	
Total LPG cost $		$ 4,200,000,000
Fuel cost for power, $/kwh from LPG	$ 0.334	
Price DIESEL	$4.00	
Total Diesel cost $		$ 2,800,000,000
Fuel cost for power, $/kwh from diesel	$ 0.284	
Price COAL	$100	
Total Coal cost $		$ 466,666,667
Fuel cost for power, $/kwh from coal	$ 0.047	
Price ETHANOL	$4.00	
Total Ethanol cost $		$ 4,541,025,641
Fuel cost for power, $/kwh from ethanol	$ 0.361	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	2

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$500	$10.00	$4.00	$4.00	$4.00	$100	$4.00	$300	$420
Tonnes NH3 for 21.3 MMBTU	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$500	$213	$688	$936	$624	$104	$1,012	$294	$298
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.179	$0.076	$0.313	$0.334	$0.284	$0.047	$0.361	$0.105	$0.107

AMMONIA, NO CCS	AMMONIA w/ HARVEST	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
T CO2 per 21.3 mmbtu,only production, no CCS	T CO2 per 21.3 mmbtu,only production, CO2 harvest	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE	T CO2 per 21.3 mmbtu, NOT COUNTING LIFECYCLE
1.93	0.68	1.23	1.65	1.48	1.68	2.42	0.33	1.80	1.80

CASE NOTES

Displacing 20% via blending (or pure ammonia) potentially saves a great deal of money

$500/tonne ammonia 20% cheaper than $4/gal diesel

This could also substantially assist on emissions (NOx, HC, PM). Pure ammonia eliminates these emissions (with, at worst, simple SCR). Ammonia blends dilutes emissions and, likely,substantially reduces HC/PM with optimization of engines (requires some research).

Much simpler to implement than LNG rail (distribution, handling, flexibility for operations/arbitrage, fuel sourcing). For example, diesel/LNG blending is not practical. Fuel switching on the same locomotive not practical.

Railroad (displace diesel)

Diesel fuel is the major operating expense of long haul rail and is being challenged by increasingly stringent environmental regulations.

Displacing 20% via blending (or pure ammonia) requires about 4.5 MM TPA NH3 and potentially saves a great deal of money. $500/tonne ammonia 20% cheaper than $4/gal diesel

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Global Markets - Overview

- Alaska (displace diesel across the state, supply Anchorage, alternate export market for Alaska gas)
- Hawaii (displace diesel, resid and gasoline across the islands)
- Northeast/MidAtlantic (energy security, grid stability, displace fuel oil)
- Midwest (energy security, grid stability, displace fuel oil/LPG)
- Caribbean (displace diesel, resid and gasoline across the islands)
- Japan (alternative to expensive LNG and coal, replacing nuclear)
- Indonesia (displace diesel, resid and gasoline across the islands)
- China (clean cities, rural access, much easier than gas)
- Europe (energy security, CHP, DG, fertilizer/fuel)
- Africa, South America (ammonia diesel gen, clean cities, rural access)

CLEAN AIR TASK FORCE

NEIGHBORHOOD ENERGY STATION (LIKE A GAS STATION) Dispensing 1.75 MM Gals Per Year Of Ammonia

MODEL RESULTS

USER INPUTS ALLOWED IN GREEN CELLS	ALL VALUES EQUIV 1 MT NH3	ALL VALUES CORRESPOND TO CASE PARAMETERS
REQUIRED INPUT or CALCULATE Tonnes NH3 for your scenario in D4	1.00	4,060
OPTIONAL USER-DEFINED VARIABLE. ENTER VARIABLE NAME IN THIS CELL. ENTER (1 T NH3 BASIS) IN C5. ITERATE D4 TO ACHIEVE DESIRED QUANTITY IN D5		0.00
MMBTU (or 1000 CF gas equiv) contained in NH3	21.32	86,558
MMBTU gas required for NH3	32.0	129,930
TCF natural gas required for NH3	2.94E-08	0.000
Tonnes water produced from NH3	1.58E+00	6,415
# Global ammonia industry	6.67E-09	0.000
# of World Scale NH3 Plants	1.25E-06	0.01
Number of 60,000 cbm vessels	2.44E-05	0
Number of 80 tonne railcar deliveries	0.0125	51
# of 1 MM TPA NH3 pipeline	1.00E-06	0.0
MWh from 45% efficient power plants	2.81E+00	11,410
# of 10 MW plants that can be run for 1 year, 45%	3.21E-05	0.1
Equivalent # of 6 mtpa LNG train (BTU basis)	6.87E-08	0.00
Tonnes LNG equivalent	0.41	1,665
Metric Tonnes coal equiv	1.04	4,223
Tonnes oil equivalent (TOE)	0.500	2,030
Tonnes resid equiv	0.530	2,152
Gal LPG equiv	234	950,116
Gal Gasoline equiv	172	698,376
Gal Ethanol equiv	253	1,027,262
Gal Ethanol equiv	253	1,027,262
Price NH3	$350	
Total NH3 cost $		1,421,114
Fuel cost for power, $/kwh from NH3	$ 0.125	
Price NATURAL GAS	$15.00	
Total Natural Gas cost $		$ 1,297,274
Fuel cost for power for power, $/kwh from gas	$ 0.114	
Price GASOLINE	$3.00	
Total Gasoline cost $		$ 2,095,128
Fuel cost for power, $/kwh from gasoline	$ 0.235	
Price LPG	$2.00	
Total LPG cost $		$ 1,900,232
Fuel cost for power, $/kwh from LPG	$ 0.167	
Price DIESEL	$3.80	
Total Diesel cost $		$ 2,406,961
Fuel cost for power, $/kwh from diesel	$ 0.269	
Price COAL	$50	
Total Coal cost $		$ 211,137
Fuel cost for power, $/kwh from coal	$ 0.024	
Price ETHANOL	$3.00	
Total Ethanol cost $		$ 3,081,787
Fuel cost for power, $/kwh from ethanol	$ 0.271	
MegaTonnes CO2 saved with NH3 with harvest vs GAS	5.50E-07	0

COST, THERMO AND CO2 MATRIX

AMMONIA	NATURAL GAS	GASOLINE	LPG	DIESEL	COAL	ETHANOL	METHANOL	DME
INPUT Price of NH3 delivered to site, $ per tonne	INPUT Price of gas delivered to site, $ / mmbtu	INPUT Price of gasoline delivered to site, $ / gal	INPUT Price of LPG delivered to site, $ / gal	INPUT Price of diesel delivered to site, $ / gal	INPUT Price of coal delivered to site, $ / tonne	INPUT Price of ethanol delivered to site, $ / gal	INPUT Price of methanol delivered to site, $ / tonne	INPUT Price of DME delivered to site, $ / tonne
$350	$15.00	$3.00	$2.00	$3.80	$50	$3.00	$200	$290
0	MMBTU gas for 21.3 MMBTU	Gal gasoline for 21.3 MMBTU	Gal LPG for 21.3 MMBTU	Gal diesel for 21.3 MMBTU	Tonnes coal for 21.3 MMBTU	Gal ethanol for 21.3 MMBTU	Tonnes methanol for 21.3 MMBTU	Tonnes DME for 21.3 MMBTU
1.0	21.3	172	234	156	1.0	253	0.982	0.71
NH3 Fuel Cost (for 21.3 mmbtu) - This Scenario	Gas Fuel Cost (for 21.3 mmbtu) - This Scenario	Gasoline Fuel Cost (for 21.3 mmbtu) - This Scenario	LPG Fuel Cost (for 21.3 mmbtu) - This Scenario	Diesel Fuel Cost (for 21.3 mmbtu) - This Scenario	Coal Fuel Cost (for 21.3 mmbtu) - This Scenario	Ethanol Fuel Cost (for 21.3 mmbtu) - This Scenario	Methanol Fuel Cost (for 21.3 mmbtu) - This Scenario	DME Fuel Cost (for 21.3 mmbtu) - This Scenario
$350	$320	$516	$468	$593	$52	$759	$196	$206
kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 35% efficiency (coal like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3 like)	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3	kwh from 21.3 mmbtu at 45% efficiency (gas/nh3
2800	2800	2200	2800	2200	2200	2800	2800	2800
Fuel cost for power, $/kwh from NH3	Fuel cost for power for power, $/kwh from gas	Fuel cost for power, $/kwh from gasoline	Fuel cost for power, $/kwh from LPG	Fuel cost for power, $/kwh from diesel	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from coal	Fuel cost for power, $/kwh from methanol	Fuel cost for power, $/kwh from DME
$0.125	$0.114	$0.235	$0.167	$0.269	$0.024	$0.271	$0.070	$0.074

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CASE NOTES

Local Energy Station Dispensing 1.75 Mm Gals Per Year Of Ammonia

A typical high volume gasoline station can easily dispense 1.5 MM gallons of multiple grades of gasoline/diesel in a year. This case examines a 'neighborhood' ammonia energy station of approximately the same scale that could provide power and heat to the neighborhood (or condo or office building) in an urban environment. This station would house a diesel genset/CHP unit running on ammonia. The prototype for this is the MHI MegaNinja gas-driven genset (delivered on 40' trailer, 1.5 MW generator operating at 42.5% efficiency, designed for combined heat/power taking efficiency up to 75% for medium pressure steam/space and water heating and adsorptive air conditioning.)

The general complexity of these stations would be less than a gasoline station (single grade, dispensed almost entirely to the generators instead of retail interface with hundreds of transactions to untrained public per day). But tank volume, general regulatory requirements and fuel delivery logistics would be similar.

The average weekly volume would be about 35,000 gallons. We can 'design' for 40,000 gal/week peak usage. A typical tank size for

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Very rough project costs would be about $1.2 MM for ammonia MegaNinja, $0.1 MM for underground tank, connections and land. Roughly $1.5-$2 MM.

With these delivery assumptions (1.75 MM gal ammonia/year), a 1.5 MW Meganinja can be supplied 85% of the time (.13/.15). The unit would be available 100% of the time (minus maintenance) and could be run at the cost of more frequent ammonia deliveries. We can model this as

A CHP unit that is integrated into the local electrical grid, sells excess power into the grid and buys power from the grid when power is offered at below cost/value of local power and heat supply. For example, buying low cost base load power at night from utility based on TOD pricing and operating during the day to ease peak power demand on the utility's peakers)

Runs 85% of the time routinely (providing 1.5 MW for 7450 hrs for 11,200,000 kwh and 26,000 mmbtu of CHP heat (calculated as 30% of the mmbtu's in the 1.75 mm gal of ammonia)). We will assume conservatively that 15,000 mmbtu of that heat would be effectively used or sold.

At $300/tonne, 1.75 mm tonnes of ammonia costs $1.2 MM

If we assume New England/Middle Atlantic urban environments, then $0.14 per kwh and $14 per MMBTU are conservative prices for residential customers (especially conservative in the winter). Sales (or avoided costs of gas/power purchases) of the power and CHP heat from 85% operation at these prices would yield $1.57 MM for power and $0.21 MM for heat for a total of $1.78 MM.

At $300/tonne ammonia, the fuel cost for power (even rejecting all the CHP heat) is $0.107 per kwh. So, for the additional 15% of the year that kwh are valued at higher than $0.11 per kwh, the generator can be operated for additional profit. For example, in New England/Middle Atlantic region, retail electricity prices are uniformly above $0.16 per kwh. So, if we are running a 1500 kw unit for 15% of a year (1300 hrs), we are selling 2,000,000 kwh at a margin of $0.05 (bringing in $100,000 extra revenue).

Overview on very rough numbers running the business blind (i.e, selling at average prices, managing CHP heat and extra power sales loosely)
Fuel cost at $300/tonne - $1,200,000
Revenues from 85% base operations (contracted at conservative prices) - $1,780,000
Opportunistic sales of power for other 15% of generating capacity – $100,000
Operating margin of $680,000 to cover capex/opex/profit.

Upside potential on these revenues.

Capacity payments from PJM RPM (market to pay for guaranteed capacity in PJM grid). In New York, this is about $200 per MW (paid whether the unit is running or not). This is $73,000 per year.

Potential payments from reliability premiums from the grid (this power is much more reliable than grid provided power (no risk from gas deliverability, downed power lines, frozen equipment, price spikes from hot summer afternoons, etc).

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CLEANAIR TASK FORCE

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- Well positioned availability of reliable power can be very valuable during high stress in the grid (prices have spiked above $1000/MWh and $100 per mmbtu on several occasions over the last few years). This value can be captured via market/auction transactions on advanced grid markets like RPM or through opportunistic transactions in real time.

- Upside revenue potential for similar projects in other regions of the world. Examples:
- Island economies that must generate their power from fuel oil (Hawaii, Caribbean, Indonesia). Fuel oil is $30-$40 per mmbtu. It is dirty and must be located away from populations (and especially resorts). That also makes it very difficult to capture and utilize the 1/3 of the btu's from CHP that clean ammonia engines can provide. These units can provide clean power at less than half the cost and, on top of that, very efficient heat and air conditioning (absorptive chilling).

- Medium scale distribution/retail (frozen/refrigerated foods), light industry and agriculture utilizing refrigeration, medium pressure steam or drying (e.g., crops) that place high value on the associated heat)

- Regions that place high value on pure water (exhaust from ammonia MegaNinja is water and nitrogen. Pure water can be captured at the cost of condensing the water.) Combustion of 1.75 MM gallons of ammonia generates about 1.7 MM gallons of water.

- They will be very attractive to sites willing and able to pay large premiums for locally controlled, uninterruptible power (financial/business centers, server farms, hospitals.
- military/government installations, large research facilities/research universities)

- Regions that are imposing a cost on CO_2 emissions (e.g., California) can reduce or eliminate those costs.
-

- This is potentially a very positive development for utilities, local/regional government (e.g., PJM and RPM) for:
- Predictable standby reserve available on 5 minute call-up (with right incentives and minimally sophisticated ‘smart grid’ controls) (much cheaper and much more flexible than spinning reserve CCGT that is only used as gas prices are rising above $40/mmbtu)
- Distributed and potentially very substantial regional fuel reserve for mid-winter, late summer, regional security (much cheaper (pseudo-‘free’) than natural gas storage and much more flexible)
- This is potentially a very positive development for property managers and energy customers
- More predictable/controllable pricing through contract and/or arbitrage at regional or urban level with ammonia producers/gas monetizers. And significantly lower than market prices over the last five years.
- Lots of headroom for optimization for profits. Project design for medium pressure steam, space heating, hot water heating, drying operations (e.g., crops), heat driven chillers (air conditioning, refrigeration for food distribution and retailing)
- This is potentially a very positive development for urban governments
- Distributed, secure energy storage for reliable power within the city
- Very clean power generation (zero carbon as well as zero traditional pollutants)
- Initial infrastructure for ammonia fuel for buses, delivery trucks, taxis, govt vehicles etc for superclean transport in cities (much cheaper than CNG or electric, much, much cheaper than hydrogen)

CLEAN AIR TASK FORCE

How Does This All Get Started?

- **Market demonstration at 1-10 MW scale (diesel gen, refit, new optimized, blends)**
- **Tech/market demo at 25-50 MW scale (repowering coal/fuel oil boilers)**
- **Engage ammonia producers/investors**
  - **New build guaranteed offtake (some fraction of production)**
  - **Eventually, utility plants with guaranteed returns for fuel take or pay (with perhaps shared profits for joint sales into market after satisfaction of energy market contractual requirements)**
  - **Market, regulatory, technology demo support from self selected producers**
  - **Plant technology/engineering firms (KBR, Uhde, MHI, etc) that will benefit from increased building**
- **Low cost, high CO2 value areas for low carbon, low cost fuels**
- **Accelerate demo/commercialization of power to NH3 technologies**
  - **Compile list of potentially interested investors, green funding, etc for incipient technologies for investments in the range of $5-$20 MM for FEED, critical demoes or initial deployment in regions for low cost "stranded" power (i.e., Canada, Iceland)**
  - **Competition for proposals for ammonia from power, perhaps with funding from such entities (NH3Fual Association as clearinghouse??)**

- **Future Search with engaged stakeholders sponsored by CATF**