Ammonia Neighborhood Energy Stations
Opportunities, Markets, Issues

Dr. Steve Wittrig
Senior Advisor, Advanced Energy Systems
Clean Air Task Force (www.catf.us)
tswittrig@gmail.com

Assumptions

- **Stationary IC engines running on ammonia, designed and run for zero emissions including low NOX (not requiring NOX control) (prototype – Sturman engine)**
  - **Installed cost - $700 / kw, up to 1.5 MW**
  - **45% power efficiency; +40% useable energy for heat/AC in CCHP**
- **Ammonia at $250/tonne, Zero Carbon Ammonia at $350/tonne**
- **Rectifier/Inverter Power Electronics Microgrid Controller - $100 /kw**
- **24/7, 99% available, ultraclean, high quality power sold at $150 per mWh**
- **Onsite, ultraclean heat/MP steam/AC sold as byproduct at $6/MMBTU**

Neighborhood Energy Station

- 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 or village or light industrial or retail complex).
- This station would house a diesel genset/CHP unit running on ammonia. The prototype for this is a 1.5 MW generator operating at 45% efficiency, designed for combined heat/power taking efficiency up to 85% 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 (hardpiped) to the genset(s) instead of retail interface with hundreds of transactions to untrained public per day).
- A typical tank size for ammonia distributors is 30,000 gallons. Underground, chilled tank for safety, security and ease of temp/pressure maintenance.
- Fuel delivery logistics would be similar (11,500 gal tank trucks (typical size ammonia trucks)).
- Very rough project costs - $1.0 MM for ammonia IC genset(s), $0.15 MM for microgrid controller, $0.15 MM for underground tank and land. Roughly $1.5 - $2 MM.

Neighborhood Energy Station Base Operations

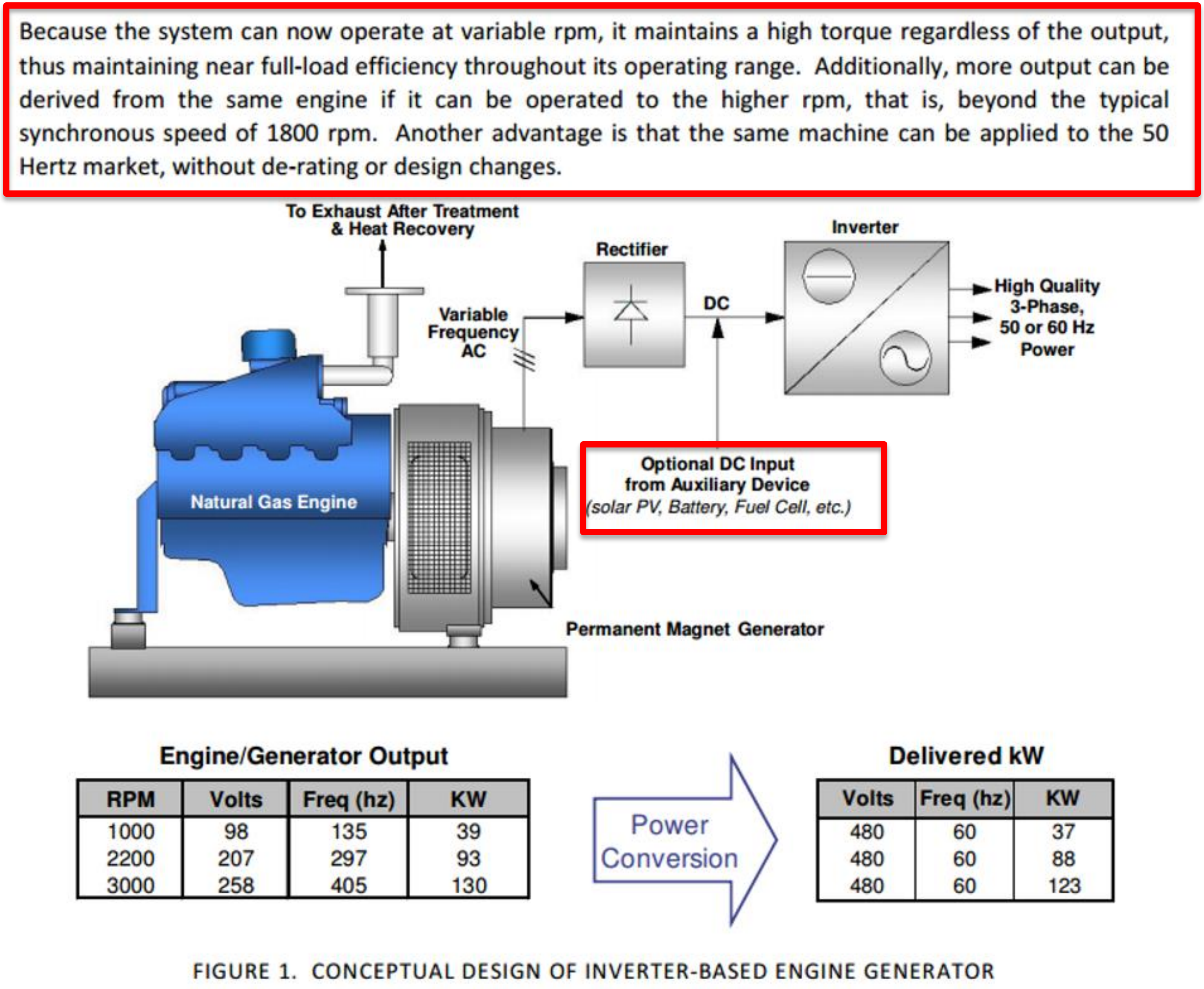
- With 3 truck deliveries per week (1.75 MM gal ammonia/year), a 1.5 MW engine can be supplied 85% of the time. The unit would be available 100% of the time (minus maintenance) and could be run at the cost of more frequent ammonia deliveries. At $250/tonne, 1.75 mm gallons of ammonia costs $1.0 MM. At $350/tonne for zero carbon ammonia, the cost is $1.4 MM

- Running 85% of the time (7450 hrs/yr) produces 11,400 mWh and 35,000 MMBTU of CHP heat (40% of the MMBTU's in the 1.75 mm gal of ammonia)). We will assume conservatively that 17,500 MMBTU of that heat would be effectively used or sold.

- Power revenue – 11,400 * $150 = $1.7 MM per year
- Heat revenue (at 50% sales) – 17,500 * $6 = $0.1 MM per year
- Margin $1.8MM - $1.0 MM = $0.8 MM
- Margin $1.8MM - $1.4 MM = $0.4 MM (for zero carbon power)

- Baseline operation, conservative prices, 85% operation, 50% sales of heat = $0.4 - $0.8 per year on $1.5 - $2.0 MM investment.

Rectifier/Inverter Power Electronics Microgrid Controller



Because the system can now operate at variable rpm, it maintains a high torque regardless of the output, thus maintaining near full-load efficiency throughout its operating range. Additionally, more output can be derived from the same engine if it can be operated to the higher rpm, that is, beyond the typical synchronous speed of 1800 rpm. Another advantage is that the same machine can be applied to the 50 Hertz market, without de-rating or design changes.

Engine/Generator Output

RPM	Volts	Freq (hz)	KW
1000	98	135	39
2200	207	297	93
3000	258	405	130

Delivered kW

Volts	Freq (hz)	KW
480	60	37
480	60	88
480	60	123

FIGURE 1. CONCEPTUAL DESIGN OF INVERTER-BASED ENGINE GENERATOR

http://bpe-ne.com/wp-content/uploads/2012/07/top10-reasons-to-choose-inverter-based-engine-chp.pdf

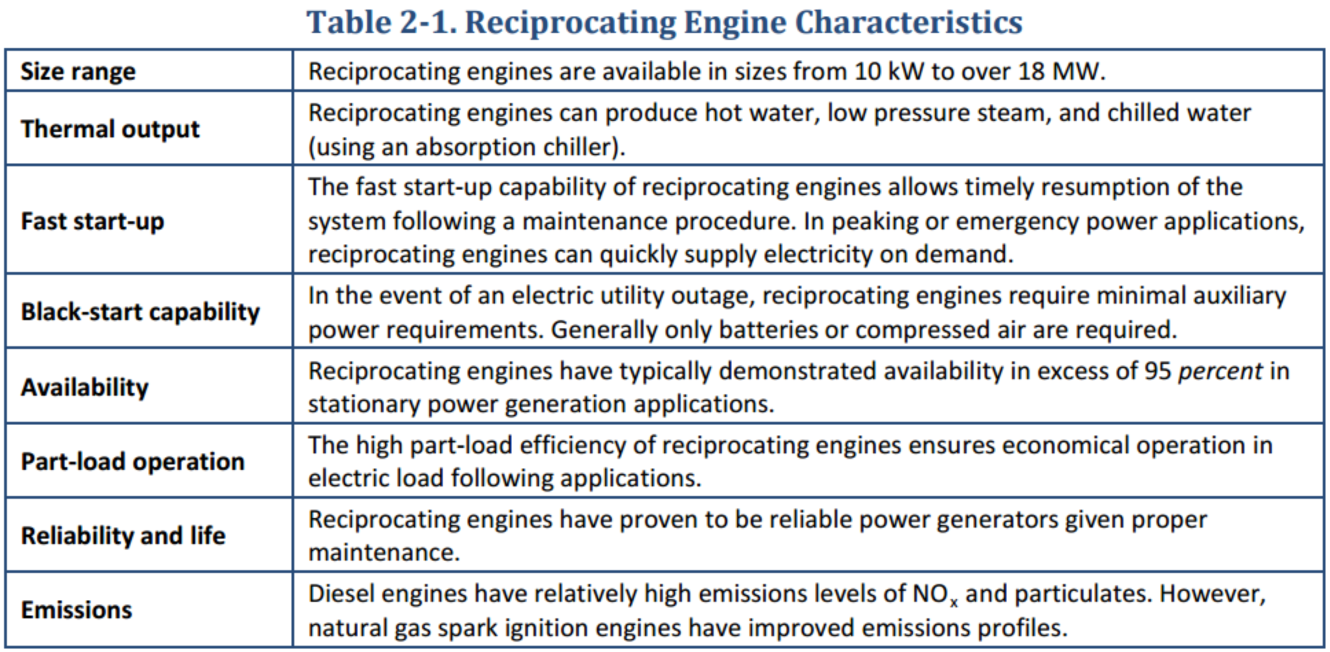
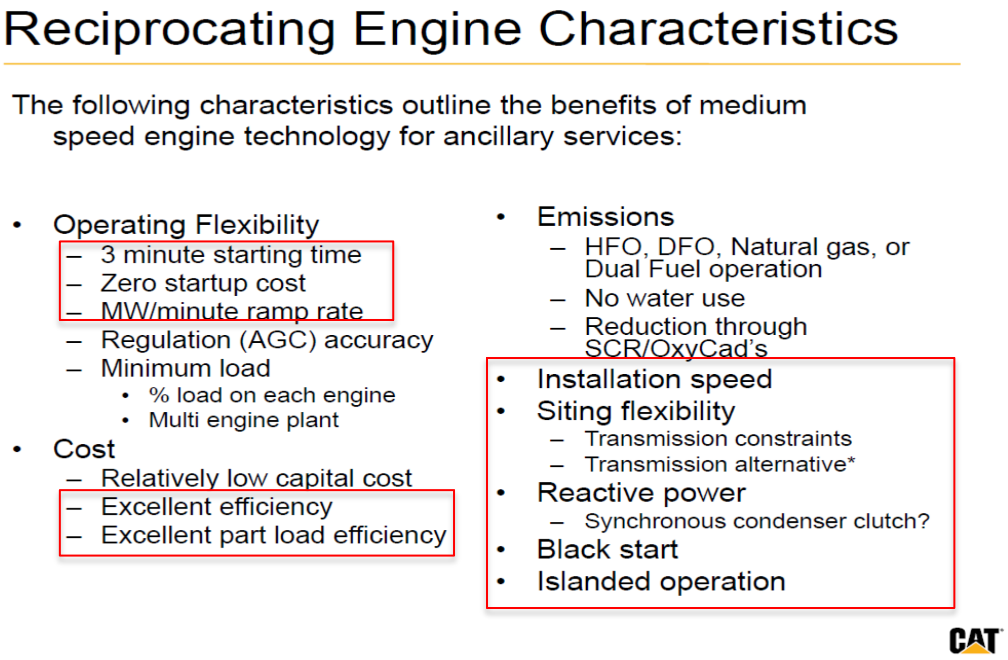


Table 2-1. Reciprocating Engine Characteristics

Size range	Reciprocating engines are available in sizes from 10 kW to over 18 MW.
Thermal output	Reciprocating engines can produce hot water, low pressure steam, and chilled water (using an absorption chiller).
Fast start-up	The fast start-up capability of reciprocating engines allows timely resumption of the system following a maintenance procedure. In peaking or emergency power applications, reciprocating engines can quickly supply electricity on demand.
Black-start capability	In the event of an electric utility outage, reciprocating engines require minimal auxiliary power requirements. Generally only batteries or compressed air are required.
Availability	Reciprocating engines have typically demonstrated availability in excess of 95 *percent* in stationary power generation applications.
Part-load operation	The high part-load efficiency of reciprocating engines ensures economical operation in electric load following applications.
Reliability and life	Reciprocating engines have proven to be reliable power generators given proper maintenance.
Emissions	Diesel engines have relatively high emissions levels of NO_x and particulates. However, natural gas spark ignition engines have improved emissions profiles.



Reciprocating Engine Characteristics

The following characteristics outline the benefits of medium speed engine technology for ancillary services:

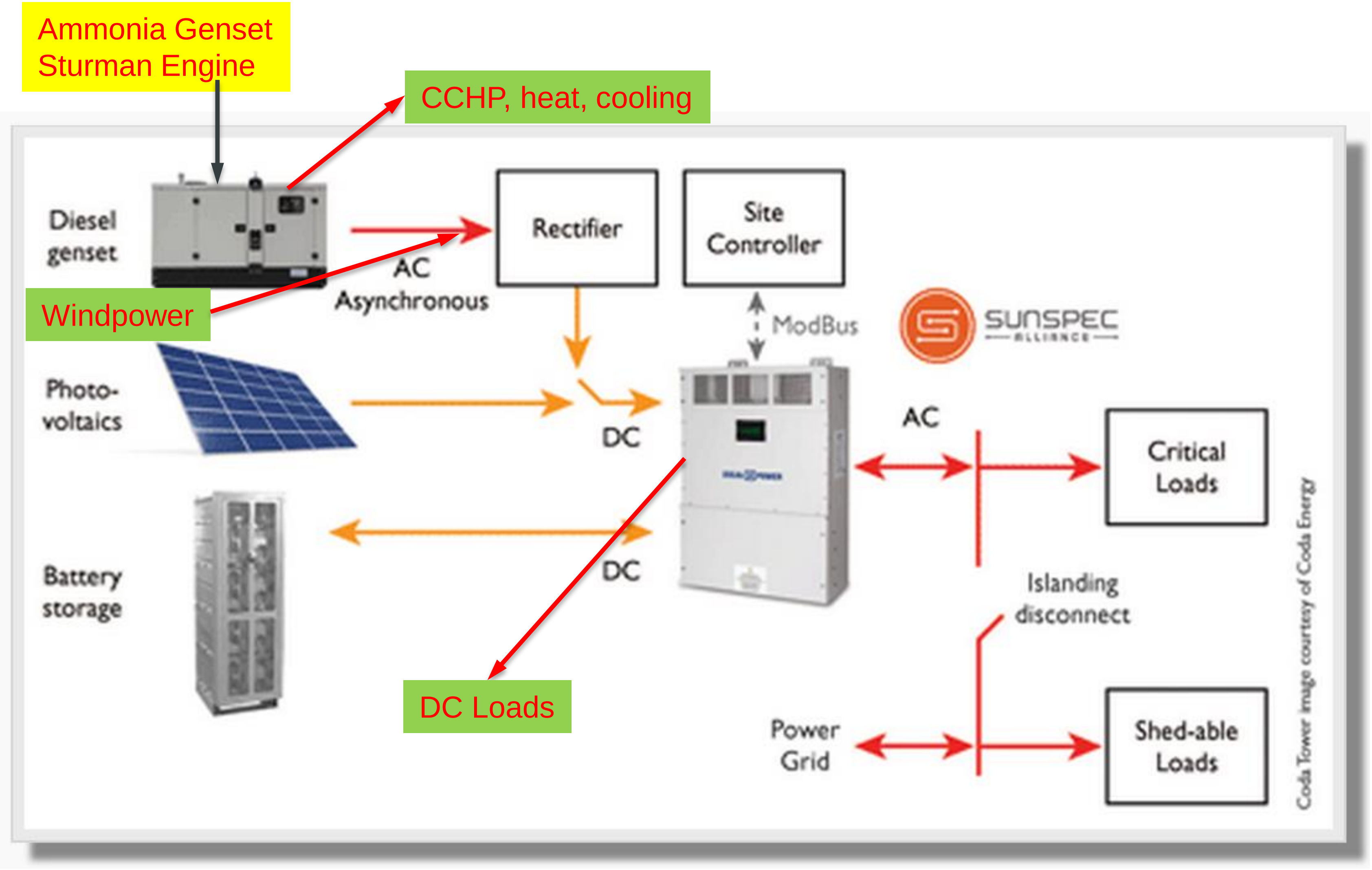
- Operating Flexibility
  - 3 minute starting time
  - Zero startup cost
  - MW/minute ramp rate
  - Regulation (AGC) accuracy
  - Minimum load
    - % load on each engine
    - Multi engine plant
- Cost
  - Relatively low capital cost
  - Excellent efficiency
  - Excellent part load efficiency
- Emissions
  - HFO, DFO, Natural gas, or Dual Fuel operation
  - No water use
  - Reduction through SCR/OxyCad's
- Installation speed
- Siting flexibility
  - Transmission constraints
  - Transmission alternative*
- Reactive power
  - Synchronous condenser clutch?
- Black start
- Islanded operation

chp technology doe ic engines.pdf

ancillary services presentation caterpillar ic engines.pdf

A Comprehensive Study on Microgrid Technology 2015.pdf

Neighborhood Energy Station – Ideal Power



Ammonia Genset
Sturman Engine

CCHP, heat, cooling

Windpower

DC Loads

http://www.idealpower.com/hybrid.aspx

Neighborhood Energy Station - Microgrid

- Easily accommodate local ***variable*** renewable solar or wind by cutting back genset (with immediate local load following). Feed DC solar directly prior to inverter. Feed variable frequency wind power into rectifier.
- Pass through solar/wind or ammonia power and ancillary services to the grid. 24/7 availability of peaking power (125% of genset rating typical), frequency regulation, voltage support, black start.
- Provide predictable, centrally addressable 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)
- Provide 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). 30,000 gallon underground tank of ammonia provides about 200 MWh of electricity (45%) and 600 MMBTU of CHP heat (40%), Over 5 days of continuous operation.
- Locally addressable loads via microgrid controller and locally optimized agreements on load priority, demand shedding (e.g., house by house incentives on high thermostat setting when grid power sales are very lucrative).
- Easily integrated systems for local DC loads

Compare to Battery Storage

- 30,000 gal underground tank (similar to gas station) stores about 200 MWh and 600 MMBTU CHP heat.
- About $100,000 capital cost.
- Cost of Li-ion battery storage - $500 /kWh – (2 mWh storage = $1.0 MM)
- Batteries 10X higher cost for 1% of energy storage (This does not even account for battery replacement every 10 years and no byproduct heat)
- Dispatch available at full power (1.5 MW) for 5.5 days
- Much longer life (genset versus batteries)
- Gensets require more maintenance
- Recharge of 5 days capacity takes about 15 minutes with scheduled deliveries
- Zero carbon 'recharge' from ammonia delivery (does not use local excess power to manage local peaks/valleys). Accesses lowest cost excess power in region.

Compare to Natural Gas Genset

- No need for gas supply
- No new pipelines required (multi hundred million $ projects, 5 year projects from negotiation thru gas flow, political/public opposition)
- Purchase fuel from multiple sources rather than prices set by pipeline operations
- Reduced exposure to single source price volatility
- Not subject to pipeline/compressor failure (accident, earthquake, terrorism)
- Very low cost local storage of energy (5.5 days of operation without refill) compared to expensive cavern storage backed up by LNG
- No CO2 emissions
- Low/No NOX
- Can be operated in urban or suburban areas

- *Access to $1.50 - $2.00 / MMBTU Stranded Gas for $250/tonne contracted ammonia*

Compare to Transmission/Distribution Infrastructure

- One 80 tonne rail car – 225 mWh and 700 mmbtu coproduct heat
- Deliver anywhere in 500 mile radius for $40/tonne ($3200/railcar)
- For power – 1.5¢ / kWh delivered (with no credit taken for heat)

- No transmission/conversion losses on lines and transformers
- Stored power dispatched as needed
- Flexibility by region/customer, by season, by unanticipated demand
- Responds to regional growth and economic activity

- Inter regional pipelines are much cheaper and safer than gasoline, crude oil or gas pipelines (liquid (pumps, not compressors), less explosive, less environmental risk from spill, no GHG (e.g., CH4), one component (cleaner, more predictable, simpler maintenance))
- Move utility scale power from remote areas with low cost, clean power to large markets (desert solar, Wyoming/Texas wind, Marcellus gas, Alaska gas, Iceland geothermal, Canada hydroelectric)

Neighborhood Energy Station (Upside Revenue Potential)

- Sell 15% of power capacity to high value peaks, 2000 mWh * $250/mWh = $0.5 MM
- Island economies that must generate their power from fuel oil (Hawaii, Caribbean, Alaska, Indonesia). Fuel oil is $30-$40 per mmbtu.
- 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 Sturman engine 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 CO2 emissions can reduce or eliminate those costs. Clean Power Plan. State Plans.
- Grid ancillary services. Load following, Peak power, Voltage/frequency regulation, Locational value, Black start

For the Future, Basis for Other Systems

- Initial infrastructure for ammonia IC engines for buses, delivery trucks, taxis, government vehicles etc for superclean transport in cities (much cheaper than CNG or electric, or hydrogen).
- Clusters of microgrids in cities for larger scale integration into district heating, cooling, demand management and integration of renewables.
- Consolidate delivery infrastructure for urban clusters. Low cost pipeline networks to deliver ammonia to microgrids throughout a region from central depots. Reduces truck traffic, labor, transfer/collision risk. Improves inventory flexibility and supply chain efficiency.
- Incremental targeted investment in clean energy production that produces its own revenue (unlike large generation plants on spinning reserve, pipelines or HVDC). Very good size for financing by utilities or municipalities (or for partnerships with co-ops or third party turnkey or service providers). Opportunity to break the impasse between utility and local investment and control in grid/power modernization and management of grid balancing with renewables.
- A base for on site production of H2 for Fuel Cell Vehicles.

Backup Slides

Reciprocating Engine Benchmarks

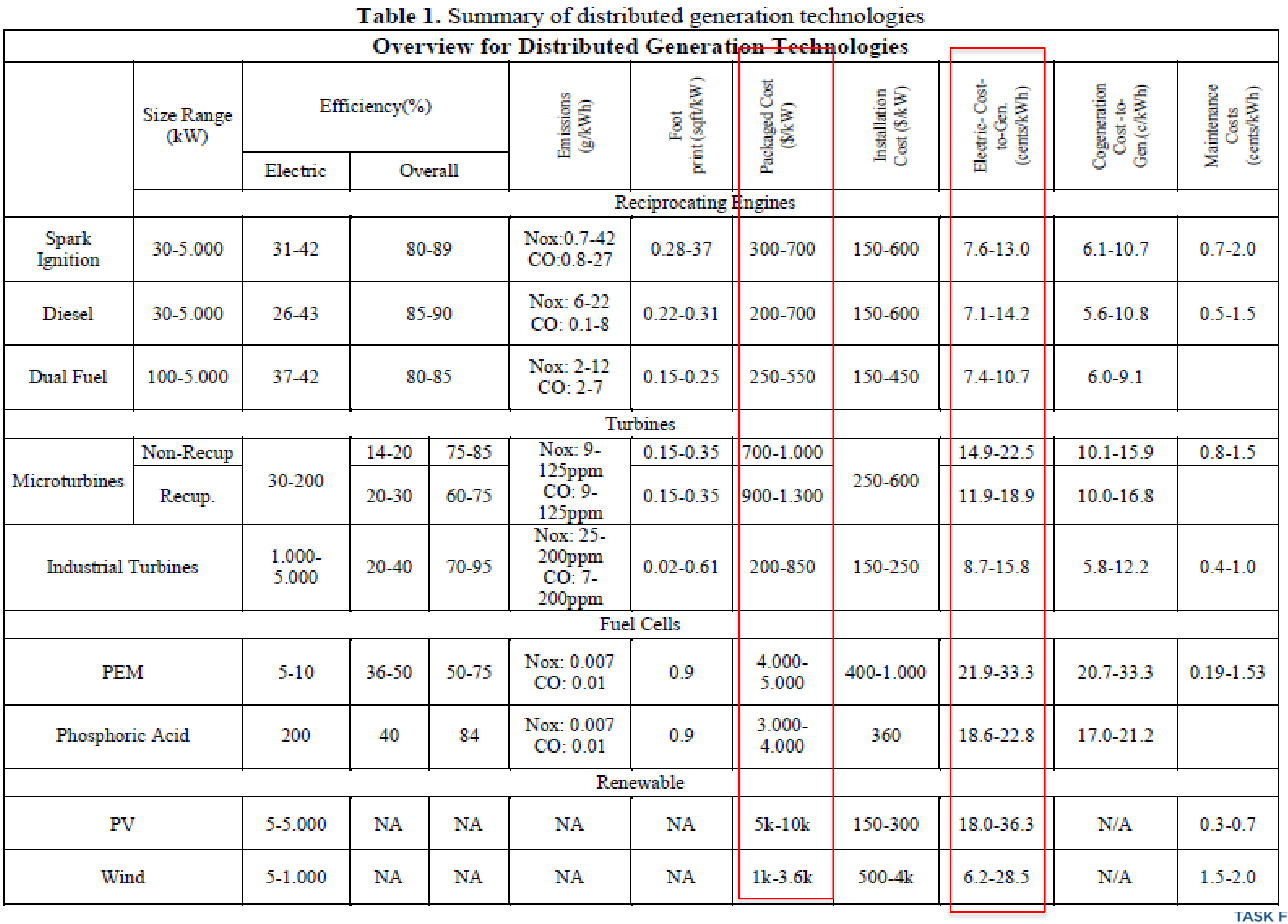
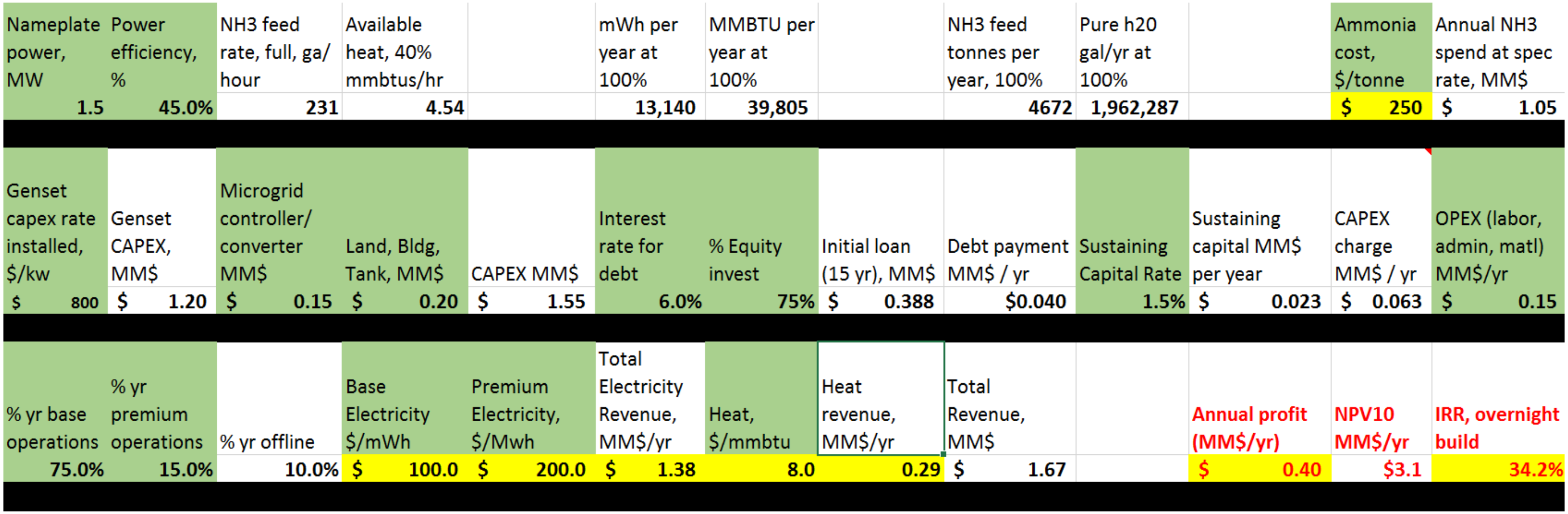


Table 1. Summary of distributed generation technologies

Overview for Distributed Generation Technologies											
		Size Range (kW)	Efficiency(%)		Emissions (g/kWh)	Foot print (sqft/kW)	Packaged Cost ($/kW)	Installation Cost ($/kW)	Electric-Cost-to-Gen. (cents/kWh)	Cogeneration Cost-to-Gen.(c/kWh)	Maintenance Costs (cents/kWh)
			Electric	Overall							
	Reciprocating Engines										
Spark Ignition		30-5.000	31-42	80-89	Nox:0.7-42 CO:0.8-27	0.28-37	300-700	150-600	7.6-13.0	6.1-10.7	0.7-2.0
Diesel		30-5.000	26-43	85-90	Nox: 6-22 CO: 0.1-8	0.22-0.31	200-700	150-600	7.1-14.2	5.6-10.8	0.5-1.5
Dual Fuel		100-5.000	37-42	80-85	Nox: 2-12 CO: 2-7	0.15-0.25	250-550	150-450	7.4-10.7	6.0-9.1	
Turbines											
Microturbines	Non-Recup	30-200	14-20	75-85	Nox: 9-125ppm CO: 9-125ppm	0.15-0.35	700-1.000	250-600	14.9-22.5	10.1-15.9	0.8-1.5
	Recup.		20-30	60-75		0.15-0.35	900-1.300		11.9-18.9	10.0-16.8	
Industrial Turbines		1.000-5.000	20-40	70-95	Nox: 25-200ppm CO: 7-200ppm	0.02-0.61	200-850	150-250	8.7-15.8	5.8-12.2	0.4-1.0
Fuel Cells											
PEM		5-10	36-50	50-75	Nox: 0.007 CO: 0.01	0.9	4.000-5.000	400-1.000	21.9-33.3	20.7-33.3	0.19-1.53
Phosphoric Acid		200	40	84	Nox: 0.007 CO: 0.01	0.9	3.000-4.000	360	18.6-22.8	17.0-21.2	
Renewable											
PV		5-5.000	NA	NA	NA	NA	5k-10k	150-300	18.0-36.3	N/A	0.3-0.7
Wind		5-1.000	NA	NA	NA	NA	1k-3.6k	500-4k	6.2-28.5	N/A	1.5-2.0

A Comprehensive Study on Microgrid Technology 2015.pdf

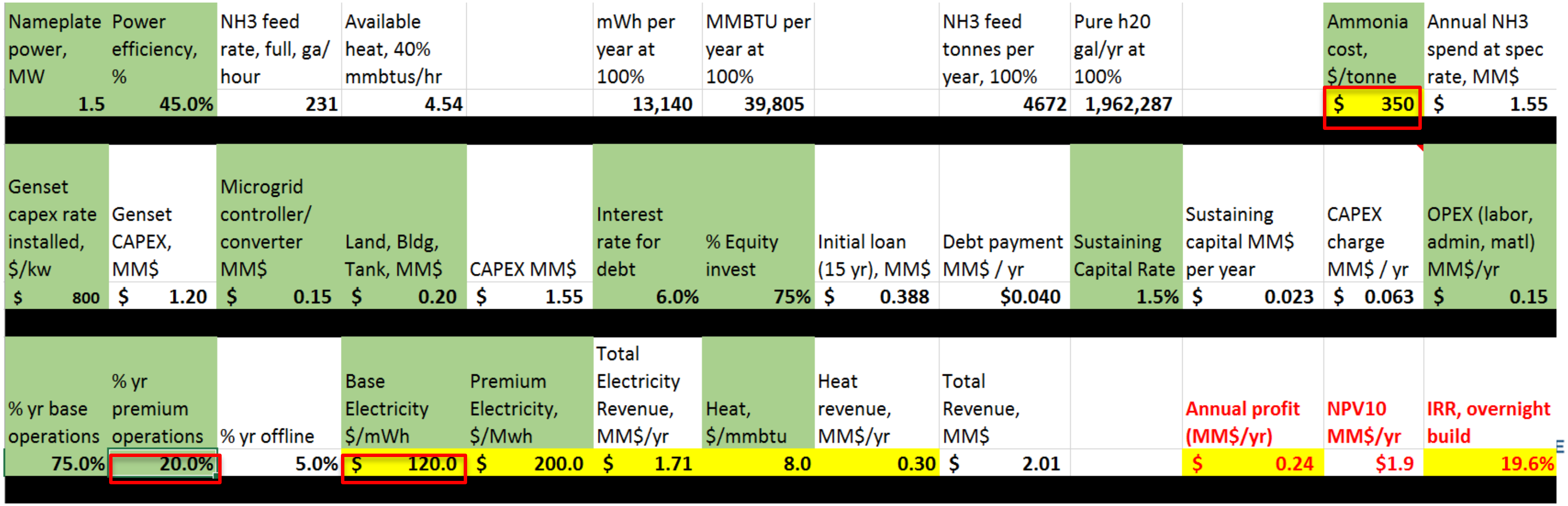
Neighborhood Energy Station Economics Model



Nameplate power, MW	Power efficiency, %	NH3 feed rate, full, ga/hour	Available heat, 40% mmbtus/hr		mWh per year at 100%	MMBTU per year at 100%		NH3 feed tonnes per year, 100%	Pure h20 gal/yr at 100%		Ammonia cost, $/tonne	Annual NH3 spend at spec rate, MM$
1.5	45.0%	231	4.54		13,140	39,805		4672	1,962,287		$ 250	$ 1.05

Genset capex rate installed, $/kw	Genset CAPEX, MM$	Microgrid controller/converter MM$	Land, Bldg, Tank, MM$	CAPEX MM$	Interest rate for debt	% Equity invest	Initial loan (15 yr), MM$	Debt payment MM$ / yr	Sustaining Capital Rate	Sustaining capital MM$ per year	CAPEX charge MM$ / yr	OPEX (labor, admin, matl) MM$/yr
$ 800	$ 1.20	$ 0.15	$ 0.20	$ 1.55	6.0%	75%	$ 0.388	$0.040	1.5%	$ 0.023	$ 0.063	$ 0.15

% yr base operations	% yr premium operations	% yr offline	Base Electricity $/mWh	Premium Electricity, $/Mwh	Total Electricity Revenue, MM$/yr	Heat, $/mmbtu	Heat revenue, MM$/yr	Total Revenue, MM$		Annual profit (MM$/yr)	NPV10 MM$/yr	IRR, overnight build
75.0%	15.0%	10.0%	$ 100.0	$ 200.0	$ 1.38	8.0	0.29	$ 1.67		$ 0.40	$3.1	34.2%



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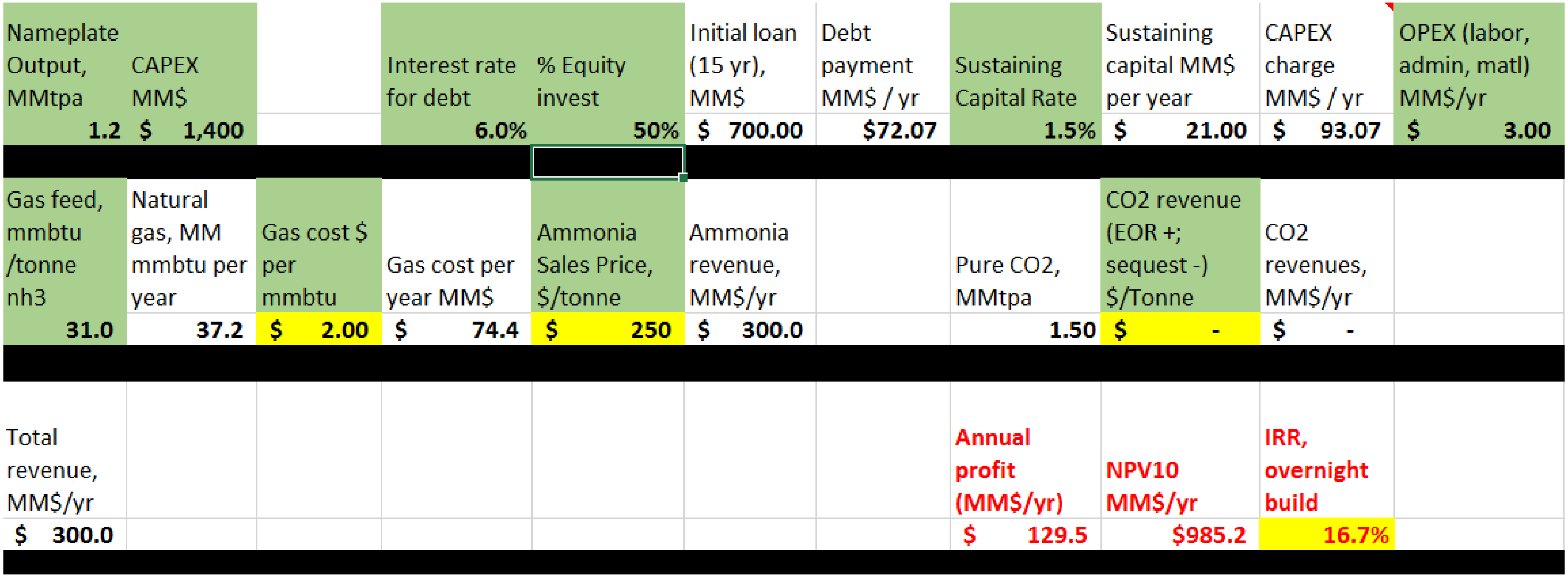
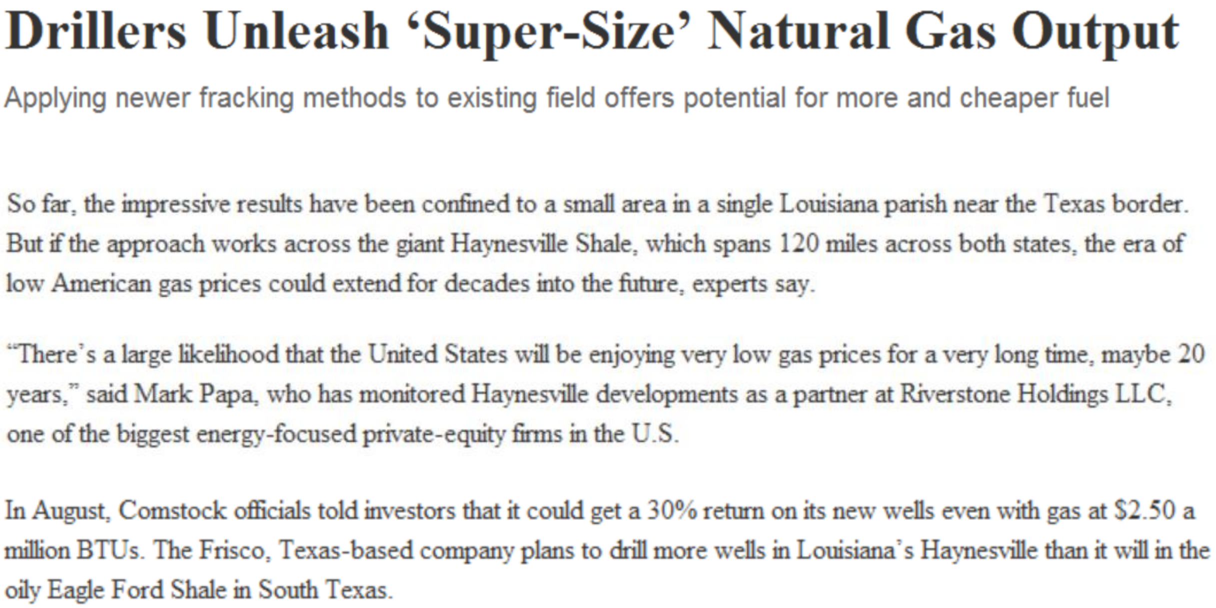
75.0%	20.0%	5.0%	$ 120.0	$ 200.0	$ 1.71	8.0	0.30	$ 2.01		$ 0.24	$1.9	19.6%

Indicative Economics NH3 Plant



Nameplate Output, MMtpa	CAPEX MM$		Interest rate for debt	% Equity invest	Initial loan (15 yr), MM$	Debt payment MM$ / yr	Sustaining Capital Rate	Sustaining capital MM$ per year	CAPEX charge MM$ / yr	OPEX (labor, admin, matl) MM$/yr
1.2	**$ 1,400**		**6.0%**	**50%**	**$ 700.00**	**$72.07**	**1.5%**	**$ 21.00**	**$ 93.07**	**$ 3.00**
Gas feed, mmbtu /tonne nh3	Natural gas, MM mmbtu per year	Gas cost $ per mmbtu	Gas cost per year MM$	Ammonia Sales Price, $/tonne	Ammonia revenue, MM$/yr		Pure CO2, MMtpa	CO2 revenue (EOR +; sequest -) $/Tonne	CO2 revenues, MM$/yr	
31.0	**37.2**	**$ 2.00**	**$ 74.4**	**$ 250**	**$ 300.0**		**1.50**	**$ -**	**$ -**	
Total revenue, MM$/yr							**Annual profit (MM$/yr)**	**NPV10 MM$/yr**	**IRR, overnight build**	
$ 300.0							**$ 129.5**	**$985.2**	**16.7%**	

http://www.wsj.com/articles/drillers-get-super-size-natural-gas-output-1441127955



Drillers Unleash ‘Super-Size’ Natural Gas Output

Applying newer fracking methods to existing field offers potential for more and cheaper fuel

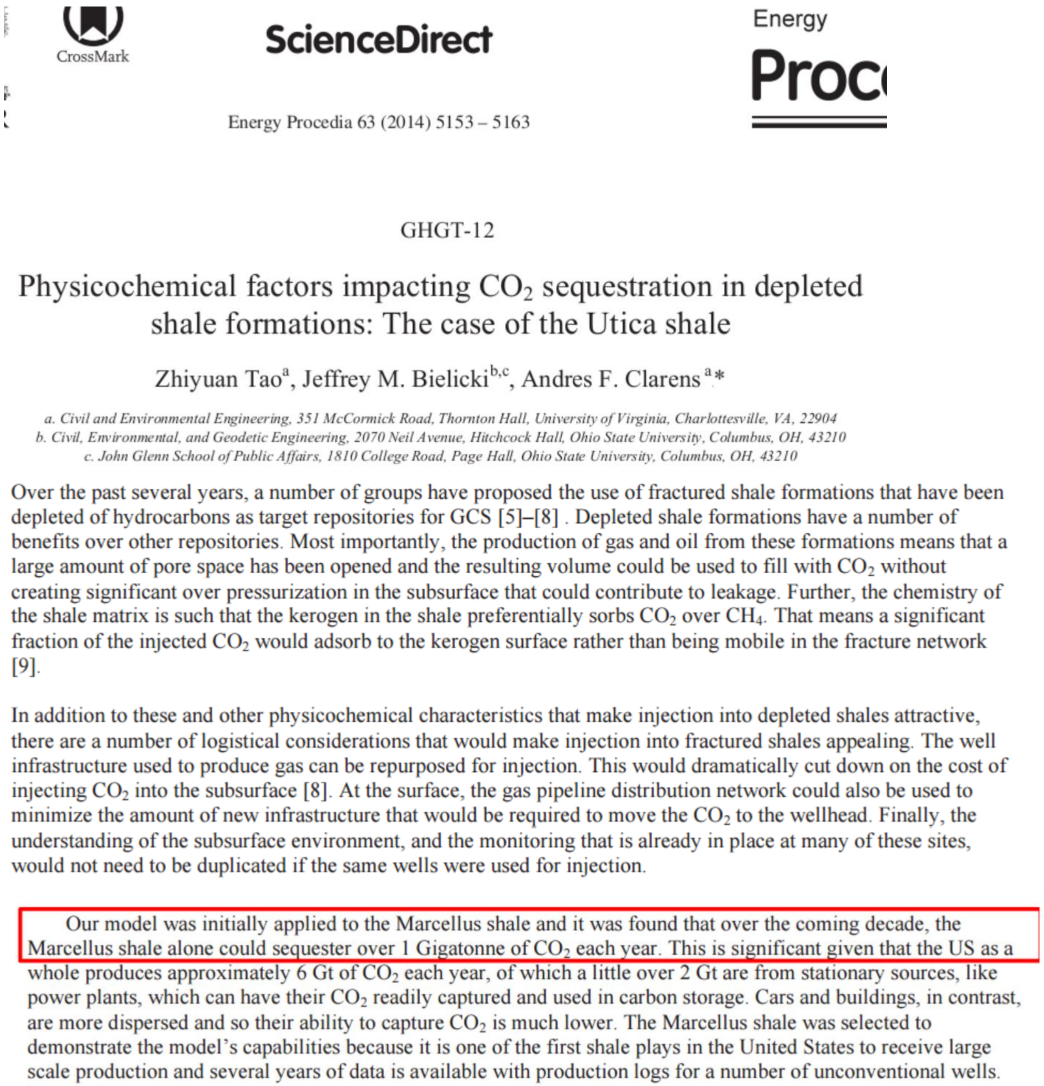
So far, the impressive results have been confined to a small area in a single Louisiana parish near the Texas border. But if the approach works across the giant Haynesville Shale, which spans 120 miles across both states, the era of low American gas prices could extend for decades into the future, experts say.

“There’s a large likelihood that the United States will be enjoying very low gas prices for a very long time, maybe 20 years,” said Mark Papa, who has monitored Haynesville developments as a partner at Riverstone Holdings LLC, one of the biggest energy-focused private-equity firms in the U.S.

In August, Comstock officials told investors that it could get a 30% return on its new wells even with gas at $2.50 a million BTUs. The Frisco, Texas-based company plans to drill more wells in Louisiana’s Haynesville than it will in the oily Eagle Ford Shale in South Texas.

30% return with $2.50 gas. Guaranteed offtake at $300 per tonne approximately 10% IRR (without CO2 sales). No need for pipeline or market risk.

http://ac.els-cdn.com/S1876610214023601/1-s2.0-S1876610214023601-main.pdf?_tid=4d916e58-51e5-11e5-9954-00000aacb361&acdnat=1441248279_2c9af880201e68dff70b73f374ca07c0



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GHGT-12

Physicochemical factors impacting CO_2 sequestration in depleted shale formations: The case of the Utica shale

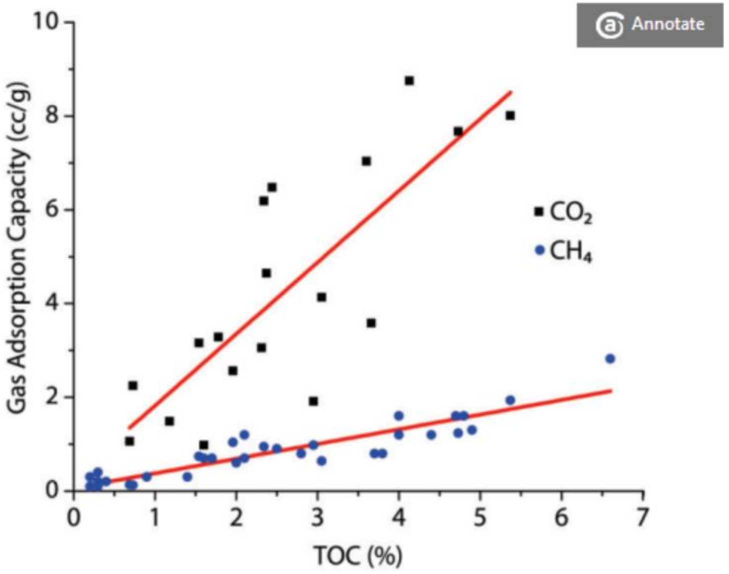
Zhiyuan Tao[a], Jeffrey M. Bielicki[b,c], Andres F. Clarens[a]*

a. Civil and Environmental Engineering, 351 McCormick Road, Thornton Hall, University of Virginia, Charlottesville, VA, 22904
b. Civil, Environmental, and Geodetic Engineering, 2070 Neil Avenue, Hitchcock Hall, Ohio State University, Columbus, OH, 43210
c. John Glenn School of Public Affairs, 1810 College Road, Page Hall, Ohio State University, Columbus, OH, 43210

Over the past several years, a number of groups have proposed the use of fractured shale formations that have been depleted of hydrocarbons as target repositories for GCS [5]–[8] . Depleted shale formations have a number of benefits over other repositories. Most importantly, the production of gas and oil from these formations means that a large amount of pore space has been opened and the resulting volume could be used to fill with CO_2 without creating significant over pressurization in the subsurface that could contribute to leakage. Further, the chemistry of the shale matrix is such that the kerogen in the shale preferentially sorbs CO_2 over CH_4. That means a significant fraction of the injected CO_2 would adsorb to the kerogen surface rather than being mobile in the fracture network [9].

In addition to these and other physicochemical characteristics that make injection into depleted shales attractive, there are a number of logistical considerations that would make injection into fractured shales appealing. The well infrastructure used to produce gas can be repurposed for injection. This would dramatically cut down on the cost of injecting CO_2 into the subsurface [8]. At the surface, the gas pipeline distribution network could also be used to minimize the amount of new infrastructure that would be required to move the CO_2 to the wellhead. Finally, the understanding of the subsurface environment, and the monitoring that is already in place at many of these sites, would not need to be duplicated if the same wells were used for injection.

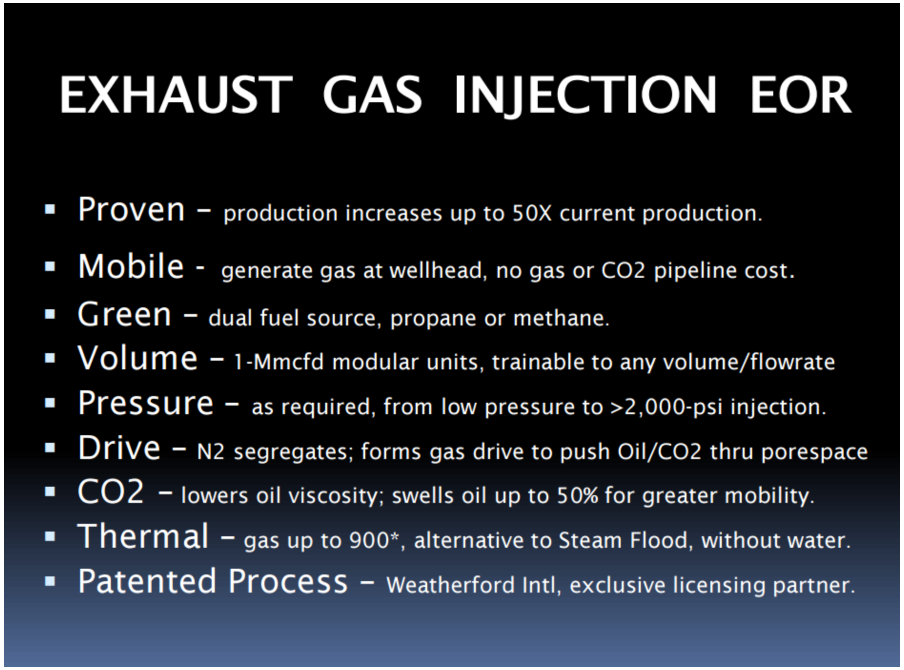
Our model was initially applied to the Marcellus shale and it was found that over the coming decade, the Marcellus shale alone could sequester over 1 Gigatonne of CO_2 each year. This is significant given that the US as a whole produces approximately 6 Gt of CO_2 each year, of which a little over 2 Gt are from stationary sources, like power plants, which can have their CO_2 readily captured and used in carbon storage. Cars and buildings, in contrast, are more dispersed and so their ability to capture CO_2 is much lower. The Marcellus shale was selected to demonstrate the model's capabilities because it is one of the first shale plays in the United States to receive large scale production and several years of data is available with production logs for a number of unconventional wells.



Enough room for free co2 output from 1,000,000 800 ktpa nh3 plants

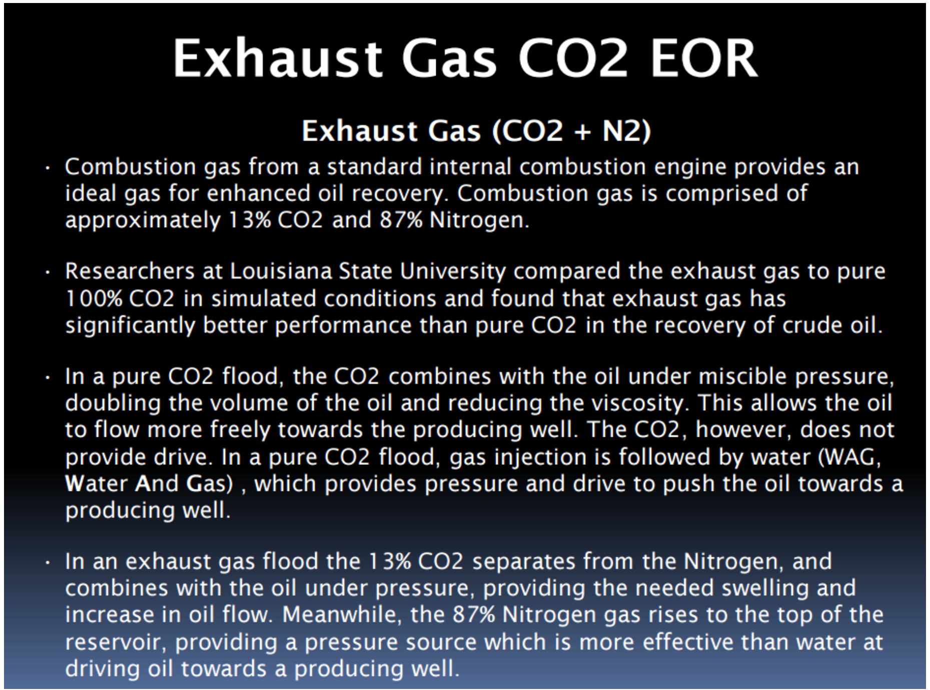
CLEANAIR TASK FORCE

http://fossilbayenergy.com/wp-content/uploads/2015/01/Oil-EOR-Services-Document.pdf



EXHAUST GAS INJECTION EOR

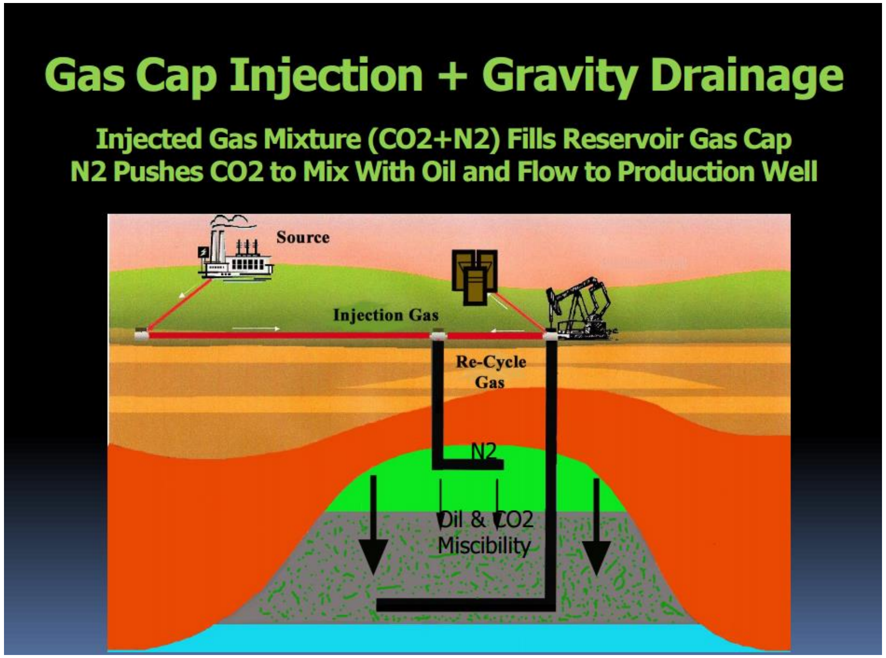
- Proven – production increases up to 50X current production.
- Mobile - generate gas at wellhead, no gas or CO2 pipeline cost.
- Green – dual fuel source, propane or methane.
- Volume – 1-Mmcfd modular units, trainable to any volume/flowrate
- Pressure – as required, from low pressure to >2,000-psi injection.
- Drive – N2 segregates; forms gas drive to push Oil/CO2 thru porespace
- CO2 – lowers oil viscosity; swells oil up to 50% for greater mobility.
- Thermal – gas up to 900*, alternative to Steam Flood, without water.
- Patented Process – Weatherford Intl, exclusive licensing partner.



Exhaust Gas CO2 EOR

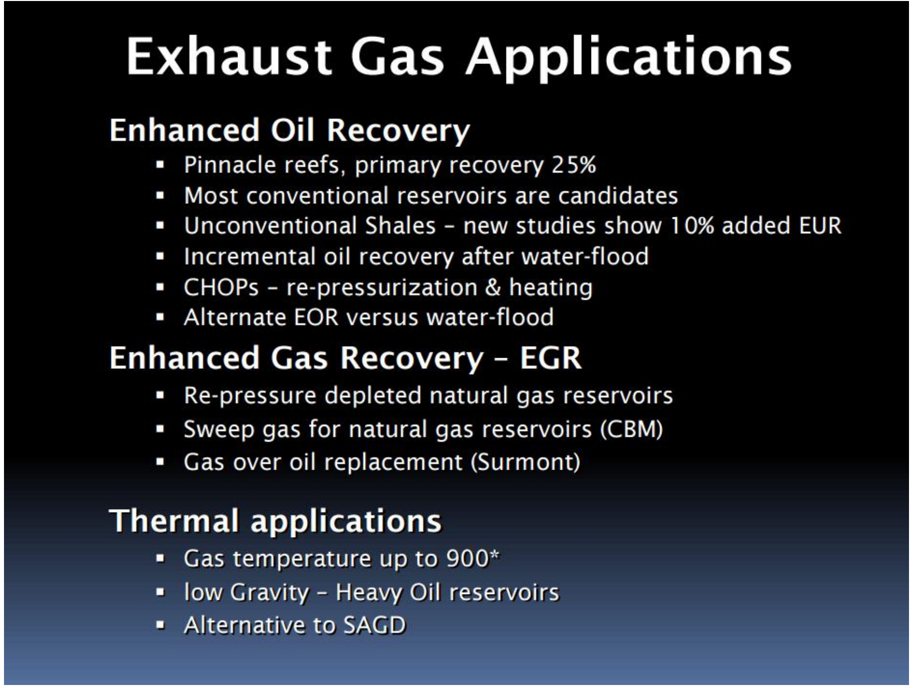
Exhaust Gas (CO2 + N2)

- Combustion gas from a standard internal combustion engine provides an ideal gas for enhanced oil recovery. Combustion gas is comprised of approximately 13% CO2 and 87% Nitrogen.
- Researchers at Louisiana State University compared the exhaust gas to pure 100% CO2 in simulated conditions and found that exhaust gas has significantly better performance than pure CO2 in the recovery of crude oil.
- In a pure CO2 flood, the CO2 combines with the oil under miscible pressure, doubling the volume of the oil and reducing the viscosity. This allows the oil to flow more freely towards the producing well. The CO2, however, does not provide drive. In a pure CO2 flood, gas injection is followed by water (WAG, **W**ater **A**nd **G**as) , which provides pressure and drive to push the oil towards a producing well.
- In an exhaust gas flood the 13% CO2 separates from the Nitrogen, and combines with the oil under pressure, providing the needed swelling and increase in oil flow. Meanwhile, the 87% Nitrogen gas rises to the top of the reservoir, providing a pressure source which is more effective than water at driving oil towards a producing well.



Gas Cap Injection + Gravity Drainage

Injected Gas Mixture (CO2+N2) Fills Reservoir Gas Cap
N2 Pushes CO2 to Mix With Oil and Flow to Production Well



Exhaust Gas Applications

Enhanced Oil Recovery

- Pinnacle reefs, primary recovery 25%
- Most conventional reservoirs are candidates
- Unconventional Shales – new studies show 10% added EUR
- Incremental oil recovery after water-flood
- CHOPs – re-pressurization & heating
- Alternate EOR versus water-flood

Enhanced Gas Recovery – EGR

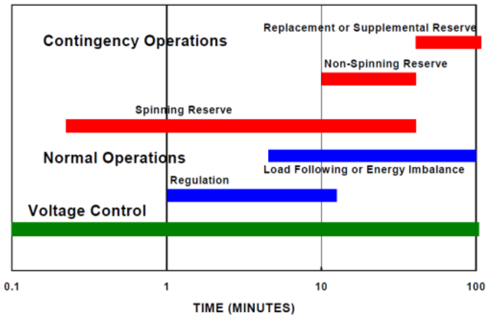
- Re-pressure depleted natural gas reservoirs
- Sweep gas for natural gas reservoirs (CBM)
- Gas over oil replacement (Surmont)

Thermal applications

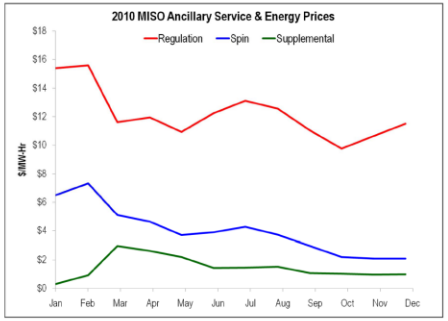
- Gas temperature up to 900*
- low Gravity – Heavy Oil reservoirs
- Alternative to SAGD

ancillary services presentation caterpillar ic engines.pdf

Time Scales for Ancillary Services



Pricing Example



CAT

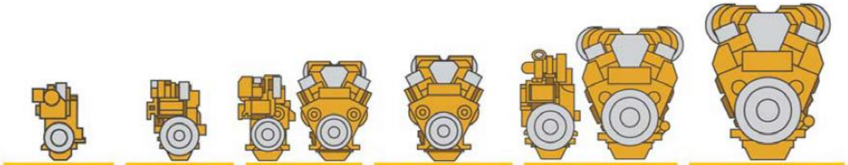
Reciprocating Engine Characteristics

The following characteristics outline the benefits of medium speed engine technology for ancillary services:

- Operating Flexibility
  - 3 minute starting time
  - Zero startup cost
  - MW/minute ramp rate
  - Regulation (AGC) accuracy
  - Minimum load
    - % load on each engine
    - Multi engine plant
- Cost
  - Relatively low capital cost
  - Excellent efficiency
  - Excellent part load efficiency
- Emissions
  - HFO, DFO, Natural gas, or Dual Fuel operation
  - No water use
  - Reduction through SCR/OxyCad's
- Installation speed
- Siting flexibility
  - Transmission constraints
  - Transmission alternative*
- Reactive power
  - Synchronous condenser clutch?
- Black start
- Islanded operation

CAT

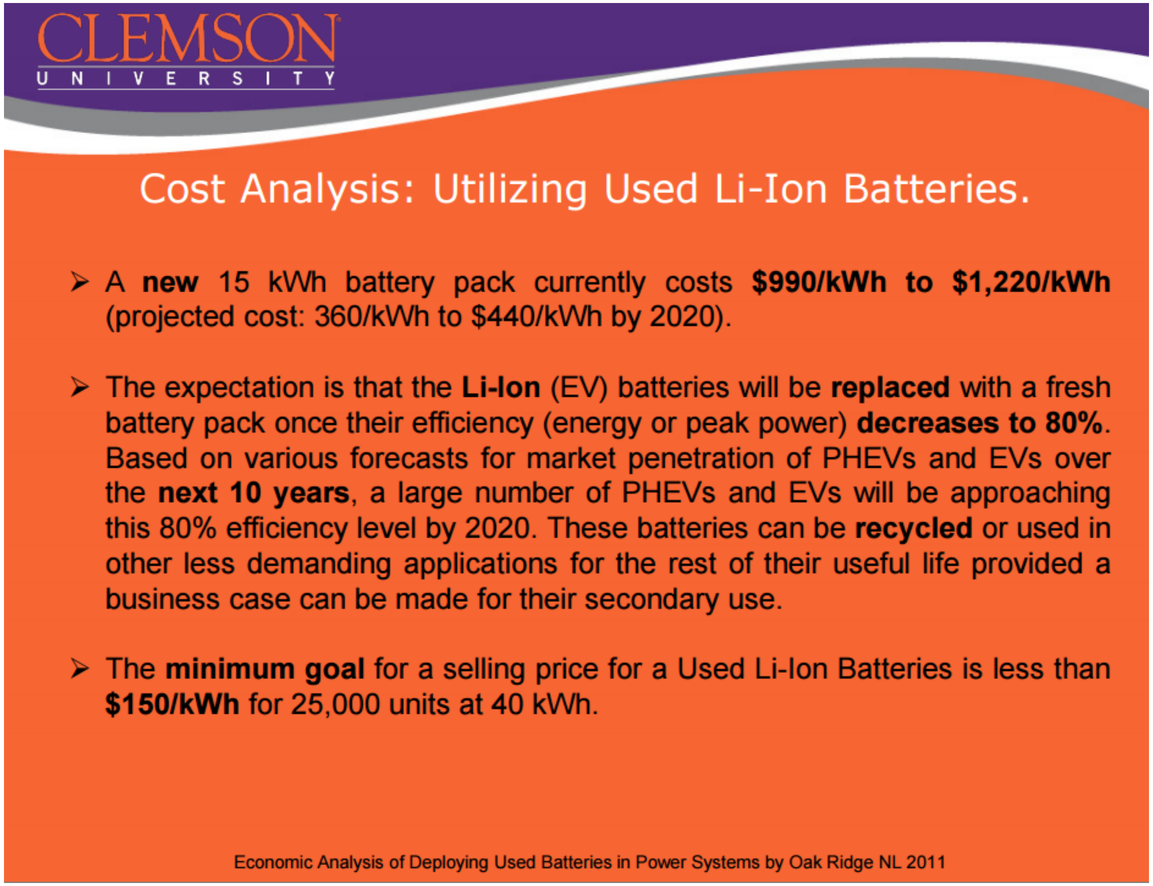
Products for Ancillary Services



CM20	CM25	CM32	GCM34	CM43	CM46DF
1,094 - 1,642 kWe	1,776 - 2,592 kWe	2,880 - 7,800 kWe	7,800 - 9,750 kWe	5,238 - 14,040 kWe	10,530 - 14,040 kWe

CLEANAIR TASK FORCE

http://www.nrel.gov/electricity/transmission/pdfs/second_grid_sim_zagoras.pdf



CLEMSON UNIVERSITY

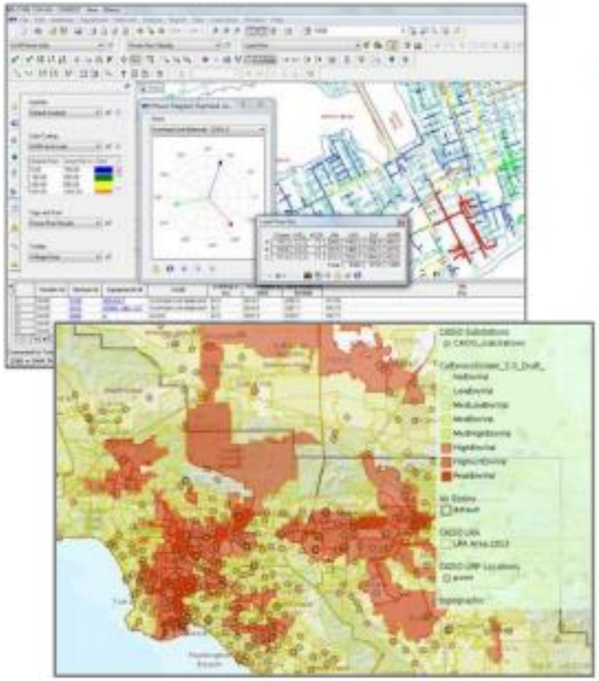
Cost Analysis: Utilizing Used Li-Ion Batteries.

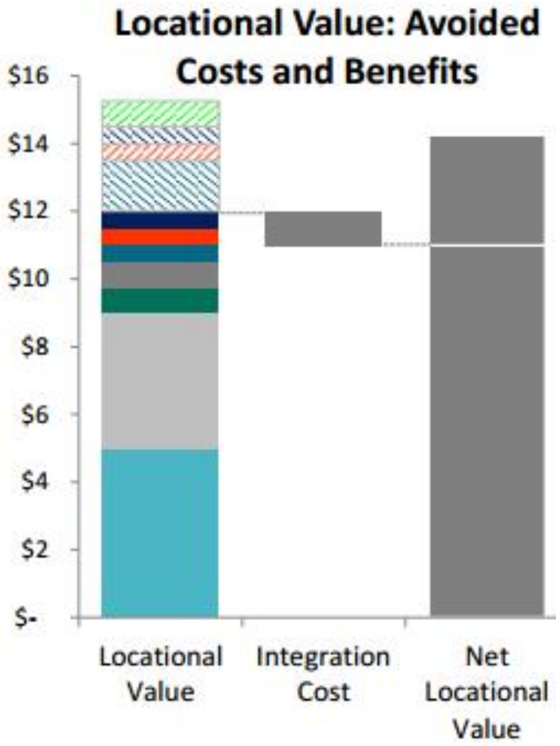
- A **new** 15 kWh battery pack currently costs **$990/kWh to $1,220/kWh** (projected cost: 360/kWh to $440/kWh by 2020).
- The expectation is that the **Li-Ion** (EV) batteries will be **replaced** with a fresh battery pack once their efficiency (energy or peak power) **decreases to 80%**. Based on various forecasts for market penetration of PHEVs and EVs over the **next 10 years**, a large number of PHEVs and EVs will be approaching this 80% efficiency level by 2020. These batteries can be **recycled** or used in other less demanding applications for the rest of their useful life provided a business case can be made for their secondary use.
- The **minimum goal** for a selling price for a Used Li-Ion Batteries is less than **$150/kWh** for 25,000 units at 40 kWh.

Economic Analysis of Deploying Used Batteries in Power Systems by Oak Ridge NL 2011

Ammonia Energy Station can be installed at highest locational value
Highest leverage to stabilize grid, relieve congestion and defer infrastructure investment

For Each DPA & Substations/Feeders → **Annual Dist. Planning & Integration Capacity Analyses** → **Biennial DRP Locational Value Analysis**





http://resnick.caltech.edu/docs/MTS_V2.pdf

Utility Level Storage to Stabilize Grid

Utility Storage Market Drivers:

- Wind and Solar Integration
- Energy Arbitrage
- Frequency Regulation & Ancillary Services
- Infrastructure Upgrade Deferral
- Locational Capacity

Different battery technologies will supply this market

120kW – 500kW
Bonneville Power Authority, WA

Ideal Power is forming alliances with leading battery suppliers

LG Chem

AQUION ENERGY

eos ENERGY STORAGE

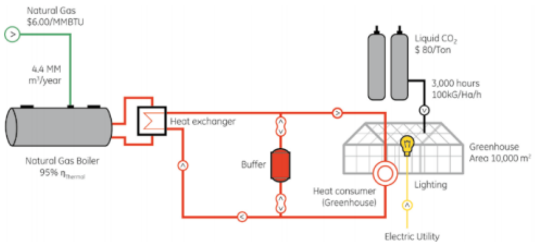
powin ENERGY

IDEAL POWER

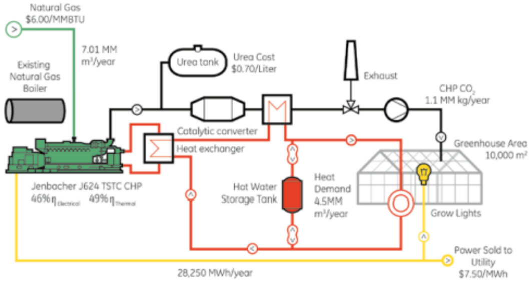
http://www.evernote.com/l/ALbpbSDydxdBU50aQaAN7yugZqO3SDOKX54/

The economic benefits of the CHP solution for greenhouses can be seen at a 25-acre (10-hectare) tomato greenhouse in the U.S. when compared to an installation with natural gas-fired boilers. The greenhouse illustrated here has installed a Jenbacher J624 gas engine with two-stage turbocharging and an output of 4.35 MW. It runs 6,600 hours per year and has heat coverage of 73.5 percent.

Before

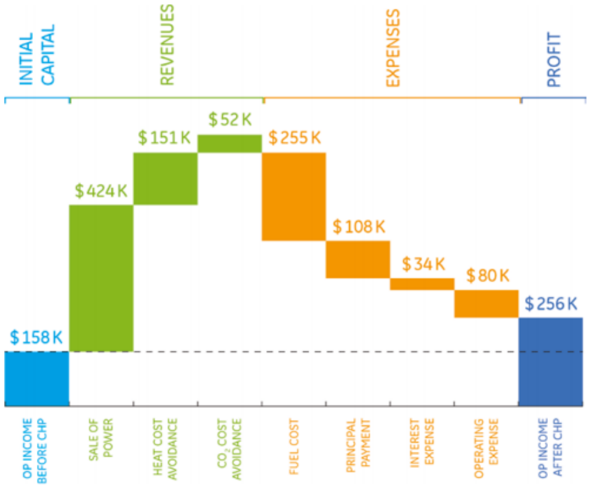


After

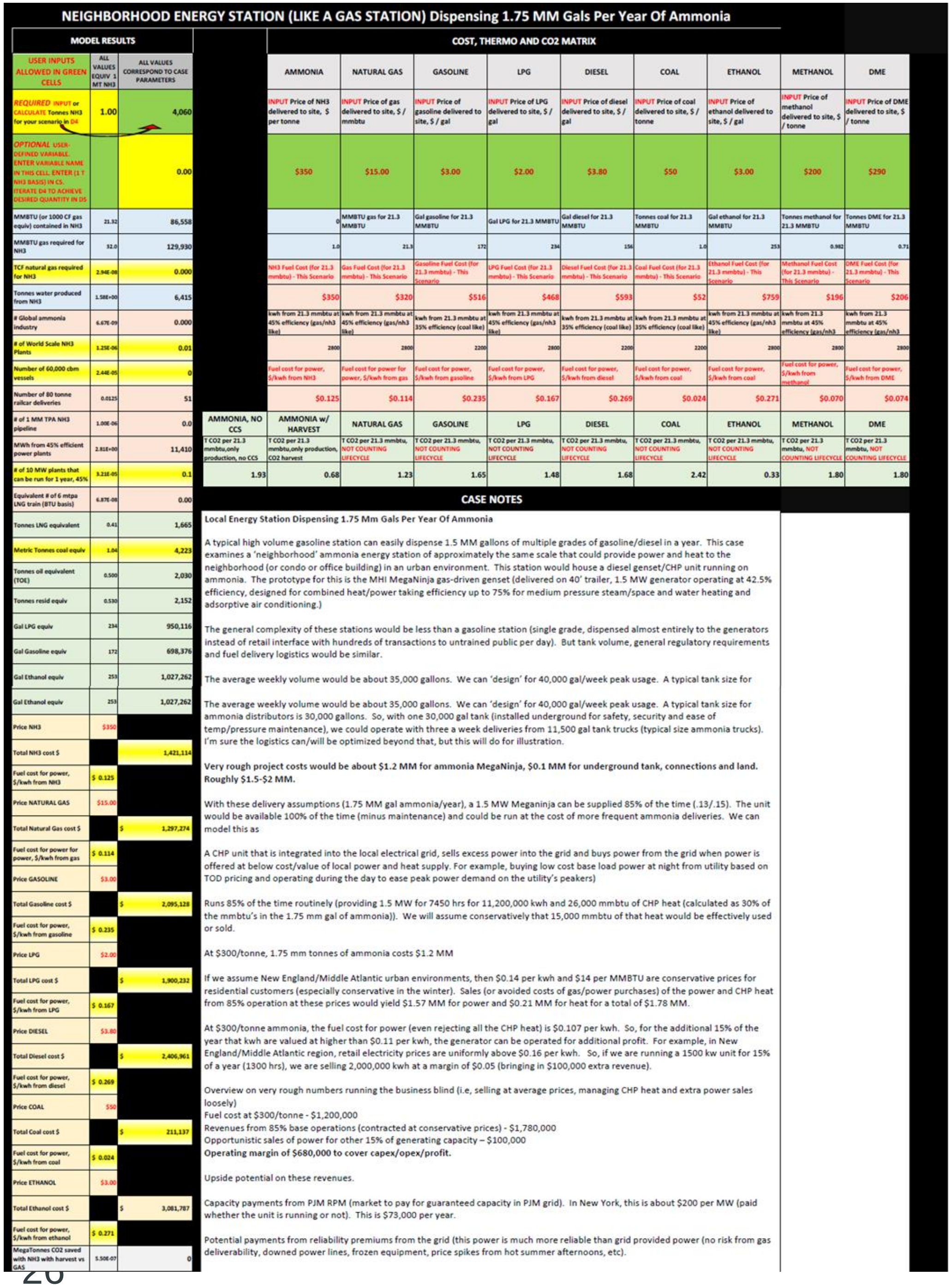


The breakdown

- Operating income increased by 62 percent through sales of excess power
- Installed system cost was $7 million, 80 percent of which was debt-financed at a 6 percent interest rate for 10 years
- Pre-tax payback is projected at 4.7 years



Profits shown are based on a 25-acre (10-hectare) tomato greenhouse in the U.S.



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

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

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

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 ammonia distributors is 30,000 gallons. So, with one 30,000 gal tank (installed underground for safety, security and ease of temp/pressure maintenance), we could operate with three a week deliveries from 11,500 gal tank trucks (typical size ammonia trucks). I'm sure the logistics can/will be optimized beyond that, but this will do for illustration.

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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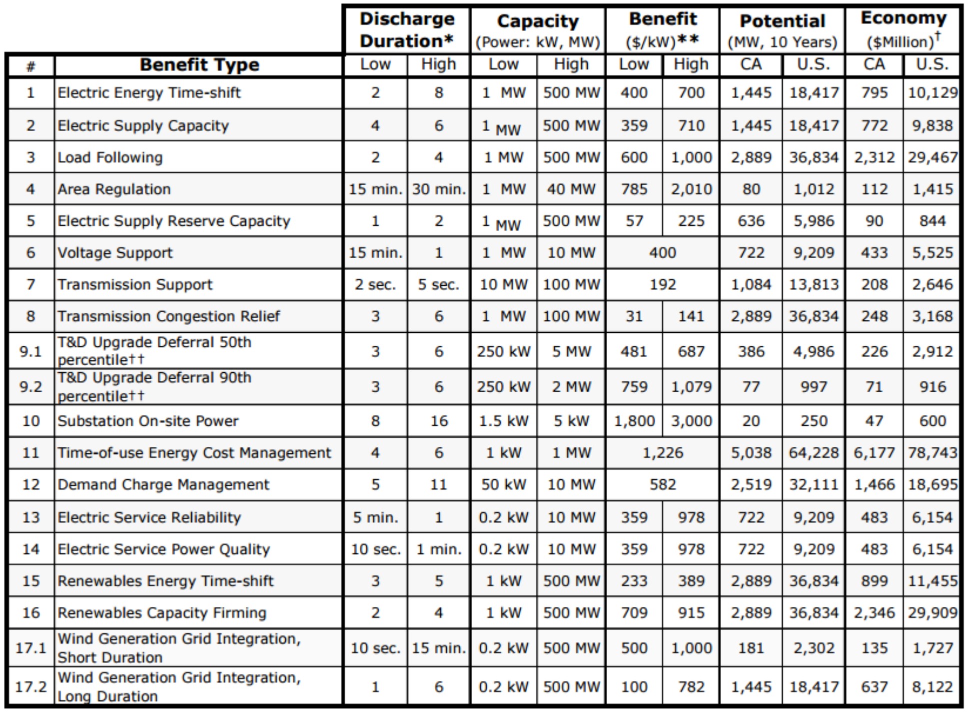
SANDIA REPORT
SAND2010-0815
Unlimited Release
Printed February 2010

Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide

A Study for the DOE Energy Storage Systems Program

http://www.evernote.com/l/ALZ2w0gbaIpPEbFE2K6NunYhMqI9ivtNNdw/

Table ES-1. Summary of Key Assumptions and Results



		Discharge Duration*		Capacity (Power: kW, MW)		Benefit ($/kW)**		Potential (MW, 10 Years)		Economy ($Million)†	
#	Benefit Type	Low	High	Low	High	Low	High	CA	U.S.	CA	U.S.
1	Electric Energy Time-shift	2	8	1 MW	500 MW	400	700	1,445	18,417	795	10,129
2	Electric Supply Capacity	4	6	1 MW	500 MW	359	710	1,445	18,417	772	9,838
3	Load Following	2	4	1 MW	500 MW	600	1,000	2,889	36,834	2,312	29,467
4	Area Regulation	15 min.	30 min.	1 MW	40 MW	785	2,010	80	1,012	112	1,415
5	Electric Supply Reserve Capacity	1	2	1 MW	500 MW	57	225	636	5,986	90	844
6	Voltage Support	15 min.	1	1 MW	10 MW	400		722	9,209	433	5,525
7	Transmission Support	2 sec.	5 sec.	10 MW	100 MW	192		1,084	13,813	208	2,646
8	Transmission Congestion Relief	3	6	1 MW	100 MW	31	141	2,889	36,834	248	3,168
9.1	T&D Upgrade Deferral 50th percentile††	3	6	250 kW	5 MW	481	687	386	4,986	226	2,912
9.2	T&D Upgrade Deferral 90th percentile††	3	6	250 kW	2 MW	759	1,079	77	997	71	916
10	Substation On-site Power	8	16	1.5 kW	5 kW	1,800	3,000	20	250	47	600
11	Time-of-use Energy Cost Management	4	6	1 kW	1 MW	1,226		5,038	64,228	6,177	78,743
12	Demand Charge Management	5	11	50 kW	10 MW	582		2,519	32,111	1,466	18,695
13	Electric Service Reliability	5 min.	1	0.2 kW	10 MW	359	978	722	9,209	483	6,154
14	Electric Service Power Quality	10 sec.	1 min.	0.2 kW	10 MW	359	978	722	9,209	483	6,154
15	Renewables Energy Time-shift	3	5	1 kW	500 MW	233	389	2,889	36,834	899	11,455
16	Renewables Capacity Firming	2	4	1 kW	500 MW	709	915	2,889	36,834	2,346	29,909
17.1	Wind Generation Grid Integration, Short Duration	10 sec.	15 min.	0.2 kW	500 MW	500	1,000	181	2,302	135	1,727
17.2	Wind Generation Grid Integration, Long Duration	1	6	0.2 kW	500 MW	100	782	1,445	18,417	637	8,122

*Hours unless indicated otherwise. min. = minutes. sec. = seconds.

**Lifecycle, 10 years, 2.5% escalation, 10.0% discount rate.

†Based on potential (MW, 10 years) times average of low and high benefit ($/kW).

†† Benefit for *one year*. However, storage could be used at more than one location at different times for similar benefits.

Downtown Chicago keeps cool with ammonia chillers

02 February 2012

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forward via community | Tweet | Share

Beneath the streets of downtown Chicago a network of pipes distributing chilled water forms part of one of the world's largest interconnected district cooling systems. Ammonia chillers, ice tanks and river water chillers provide cooling for building air conditioning, removing on peak grid stress. The system will take centre stage in June 2012 when IDEA holds their annual conference in Chicago.

Thermal Chicago's district cooling system serves around a hundred buildings and upwards of 45 million square feet (4 million m^2) of space. The company's customers include commercial and industrial facilities, office towers, condominiums, apartment buildings, theatres, hotels, data centres, retail centres and schools.

Chicago's district cooling system

In 1995, the first source of chilled water came online, called plant one, or P1, located at junction of State and Adams. At the time the nascent district cooling system only had 11 customers. The following year the largest plant, P2, came online. It contains the world's largest ice tank that can deliver 125,000 tonne-hours of cooling to the system and holds two million gallons (7 millions litres) of chilled water.

In the basement of the Blue Cross/Blue Shield of Illinois headquarters on Randolph Street you can find P3, housing three large ice tanks and an ammonia chilling plant. The ammonia chillers and ice tanks replaced a previous 30,000 ton R22 plant, with P3 able to stay online during entire renovation, which started in 2008 and finished in 2010.

Chicago's district cooling network is one of the largest in the world

Related articles

How ammonia district cooling can be joined with desalination
12 December 2011

http://www.ammonia21.com/articles/2077/downtown_chicago_keeps_cool_with_ammonia_chillers

About natural refrigerants

As a general differentiation, “natural refrigerants” are substances that exist naturally in the environment, while “non-natural refrigerants” or “synthetic refrigerants” are man-made chemicals. The most commonly used natural refrigerants today are ammonia (NH_3, R717) carbon dioxide (CO_2, R744), and hydrocarbons (HCs), such as propane (R290), isobutane (R600a) and propylene, also know as propene (R1270).

The precision of the term “natural refrigerants” is sometimes debated, given that, to be used as refrigerants, ammonia, carbon dioxide, and hydrocarbons also undergo an industrial purification and manufacturing process. However, today there is a well established distinction between substances whose chemical properties and safety aspects have been studied in their entirety and fluorinated gases, which, given their chemical complexity and comparatively short period of usage, have confirmed and/or unknown negative effects on ozone depletion, global warming and ecological safety, and therefore, are subject to continued debate.

The most commonly used natural refrigerants today are ammonia (NH_3, R717), carbon dioxide (CO_2, R744) and hydrocarbons (HCs), such as propane (R290), isobutane (R600a) and propylene, also know as propene (R1270).

Mixtures of ammonia and dimethyl ether (R723) have been developed, as well as various hydrocarbon blends with optimized performance and safety properties (isobutane/propane, R441 etc.). Water as a refrigerant has been used especially in absorption and adsorption chillers. The use of air is less common, but has been developed for deep-freezing applications.

Ammonia (ODP= 0; GWP= 0)

Ammonia (chemical symbol NH_3, refrigerant designation R717) is a colorless gas at atmospheric pressure. With zero ozone depletion and global warming potential, as well as a short atmospheric lifetime, it does not form any by-products or decomposition products with negative environmental impact. It is compatible with some, but not all, commonly used refrigeration system lubricants. In particular, it is not suited for use with polyol ester (POE) and poly vinyl ether (PVE) lubricants, and it only has limited applications with poly alkylene glycol (PAG) lubricants.

Despite its undisputed energy efficiency benefits, the use of ammonia is restricted in certain applications and geographic regions, due to its toxicity. As a result, R717 is effectively prohibited from use inside occupied spaces but can be used in unoccupied areas or outside.

However, many advances have been made in recent years to minimize risks for human health, particularly for ammonia installations in populated areas. These advances include using ammonia in conjunction with other refrigerants, such as in secondary systems, in order to reduce and isolate an ammonia charge, using advanced safety equipment, deploying containment casings, or using ammonia absorption systems.

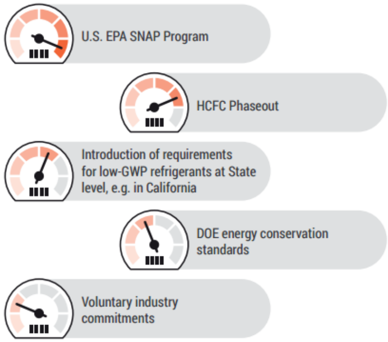
It is important to note that ammonia has a strong odor, making leaks easy to detect.

http://www.evernote.com/l/ALa9jFViPJVCo7m5QA2-oD9pWZWjyBxw9KU/

But even in the midst of limitations, since the last GUIDE, the list of positives has only expanded and the list of negatives attributed to natural refrigerants has diminished. An increased focus on safety has been mitigating concerns over flammability and toxicity, especially in the use of ammonia, which has been subject to increased scrutiny and fines from the EPA in order to reduce incidents and improve confidence.

The increased uptake in natural refrigerant-based systems is also lowering prices across all applications and there is hope of simplified solutions for both industrial and commercial applications, with packaged solutions becoming increasingly prevalent. Energy efficiency is also being increasingly linked with natural refrigerants, and solutions for warm-ambient climates, especially in commercial refrigeration, are being developed and tested extensively.

All of these positive impacts have meant that natural refrigerants in the three key applications –light commercial, commercial and industrial refrigeration– have all seen growth in the triple digits since 2013, with much untapped potential to be explored during the next five years if the market is able to assimilate itself quick enough to absorb and process the extra demand.



Several policy measures working together to accelerate uptake of natural refrigerants

At ATMOsphere America 2015, participants assessed through live polling a variety of policy measures in the U.S. in terms of their impact on accelerating the introduction of natural refrigerants through live polling. The EPA SNAP Program and the HCFC phase out are deemed to have the highest impact on accelerating the uptake of natural refrigerants, while voluntary industry initiatives are not believed to have a strong impact throughout the industry. But the advancements by Refrigerants, Naturally! and other companies can not be ignored.

CLEANAIR
TASK FORCE

Low Carbon Ammonia (And Front End For CCS)

- **Ammonia plants emit pure (sequestration-ready) CO_2. Approximately 2/3 is pure. With current technology, the rest is flue gas from the reformer.**
- **There are active markets to purchase CO_2 for enhanced oil recovery.**
- **Ammonia plants built close to EOR fields can sell their waste CO_2 to be sequestered in oil fields after use. EOR technologies exist for complete CO2 sequestration at low incremental cost. (co-injection with N2)**
- **This co-product value can reduce production cost for eventual fuel use.**
- **These operations will also supply a great deal of experience and technology for carbon capture and for CO_2 transportation and sequestration.**

- **This will serve as a bridge while “green ammonia” technologies from renewables, hydro and nuclear energy are optimized for a decarbonized ammonia energy system for power and for liquid fuel for transportation.**