Economic Viability of a “Green” Ammonia Plant (GAP)

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OVERVIEW

This parametric analysis aims to answer the question about what would the price of gasoline need to be, in order to enable the economic viability of “clean” ammonia (NH3) production as a clean or green replacement fuel for engines, turbines or fuel cells. Economic viability or profitability of GAPs is defined here as part of a scenario in which (1) ammonia and gasoline energy are sold and bought at the same energy price, (2) achieving a compounded & annualized ROI (CAROI) for the producer of ammonia of near 6 % and a payback near 7 years, and producing ammonia by only using green electricity from geothermal, solar or wind sources, which may be available at low-cost (maybe curtailed) during off-peak times[1].

To run this analysis we adopted the “Green Energy Calculator” of the FON website[2], by having some of the “green plant” parameters represent those needed for the ammonia plant, without changing the Calculator algorithms. In this adaptation, the needed GAP energy is entered both as kW power input as well as a cost addition to the monthly Operation and Maintenance (O&M) charges, in-stead of the Minimum Monthly Charges (MMC) by the utility.

For the below-described ammonia plant and economic parameters (such as gasoline prices ranging from 4-7 $/gal), the GAP profitability could achieve the above targets with and without tax credits or some small gasoline price or taxation increase (5%), if the GAP cost were at or below 9 $/(gal NH3/year) range, the O&M costs were about 2 % of GAP capital cost / year and the green electricity inputs were available at 40 $/MWh.

The synthesis of jet-fuel from green electricity (e.g. by starting with “green” ammonia and adding energy and captured CO2 during its conversion to urea and to hydrocarbons) was also briefly explored. However, its profitability at the assumed energy conversion efficiencies near 5 % is negative, unless gasoline prices increase by 22-28 $/gal.

DISCUSSION

Among the main assumptions made and definitions used in this analysis were the following:

1. Crude oil and gasoline prices are assumed to escalate at 3 %/year, green energy prices only escalate at 1 – 1.5 %/year[1].
2. Curtailed geothermal electricity rates of 40-60 $/MWh are much lower than gasoline prices of 4 $/gal or than their lower heating value (LHV) equivalent of 124.2 $/MWh, which raises the possibility that building and operating GAPs, which would sell ammonia at the same or lower energy price than gasoline
3. Payback time is determined by using all net revenue of each year of operation to pay interest and principal of the GAP loan, and keeping up such payments in the following years until complete payback. This results in the minimum payback time, compared to fixing the loan re-payments at the level of the 1st-year’s profit, which generally would result in a longer payback period. (The Calculator offers both of these two options)
4. CAROI is equivalent to the yield in %/year of a compounding savings account, which would yield the same cumulative interest on top of the initial investment at the end of a time period equal to the GAP service life
5. The GAP’s installed capital cost is estimated to be between that of a low-cost corn-fermentation ethanol plant and a more sophisticated one using residual cellulosic feed-stocks, costing between 1 and 9 $/(gal/year), respectively[5].
6. The GAP ammonia (heating value) output rate is determined by the power input times the capacity factor, which in turn is the product of GAP “up-time” and energy conversion efficiency. The fact that the GAP power input is not free (contrary to the solar PV power) is taken into account by adding its cost to the monthly Energy and O&M line item, with its own annual escalation factor. The ammonia output rate is converted to gallons NH3/year by using a mid-range energy conversion efficiency between 9-11 MWh/ton NH3[6,7]. With an exemplary 110 MWh/day of energy input, the GAP would

produce (110/11) x (40/100) tons NH3/day x (2000/5) x 365/1,000,000 = 0.584 million gal NH3/y. This last figure is then used to estimate the installed GAP cost via item 5 above.

In adapting the inputs of the PV “plant” to those of a GAP we derived the following equivalencies. The exemplary values below may not be same as those used to obtain the parametric analysis results in Table 1:

PV Calculator Inputs	**GAP Calculator Inputs**	**Value**	**Calculator Input**
1. Peak generator output	GAP power input	110 MWh/day	4583 kW
2. Capacity or use factor	Energy-conversion eff.	50 %[4]	50 %
3. Generator product life	GAP service life	25 years	25 years
4. Loan interest	Cost of capital	5 %/year	5 %/year
5. Number comp’ding periods	Same	365 per year	365 per year
6. Fuel-based electricity cost	Gasol.cost displaced by GAP	4.00 $/gal	0.1242 $/kWh[3]
7. Electricity cost escalation	Gasoline cost escalation	3 %/year	3 %/year
8. Capital investment	GAP installed cost	9 $/(gal NH3/y)	9x0.623 M$=5,610,000 $*

*(110,000 kWh/day)(50/100)(3.6E6 J/kWh)/(1054 J/Btu)/(110,000 Btu/gal) = 0.623 Mgal/y

9. Max Fed. tax credit/refund	Max Fed. tax credit/refund	0	0
10. Max State tax credit/refund	Max State tax credit/refund	0	0
11. Crude oil cost	Same	80 $/barrel	80 $/barrel
12. Util. min. mo. charge (MMC)	Energy and O&M costs	211,824 $/mo	211,824 $/mo

These Energy and Operation & Maintenance (O&M) GAP costs are composed of:
1) Energy, for which in this example we use the 110 MWh/day of curtailed geo-thermal electricity costing 40 or 60 $/MWh[1]. W/the latter 60 $/MWh x 110 MWh/day x 30 days/mo = 330,000 $/mo,
2) Plus an approx. 1-3 % capital/year for GAP O&M, e.g. 0.2%/mo x 5.61 million $ = 11,220 $/mo
341,220 $/mo

12. Utility MMC escalation	Energy and O&M cost escal.	1.5 %/year[1]	1.5 %/year

The following comments may further clarify the function of the above inputs in light of the following

Calculator Outputs:	**Original Meaning**	**Meaning for GAP Analysis**
1.	Capital investment after subsidies in $	Same meaning
2.	Life cumulative utility MMC in $	GAP life cumulative energy and O&M costs
3.	Electric energy savings in kWh/year	Energy of gasoline displaced by ammonia
4.	Average electricity cost savings in $/year	Energy sales of green NH3 instead of gasoline
5.	Crude oil import savings in $/year	Same
6.	Average return on assets in %/year	Same
7.	Payback time in years: Minimum & fixed	Same
8.	Loan repayments in $/year: Maximum & fixed	Same
9.	Average, annual ROI in %/year	Levellized GAP ROI
10.	Total generator life ROI in %	Total GAP life ROI
11.	Total net cost savings in $	Total net GAP income from NH3 sales
12.	Compounded, annualized ROI in %/year	Same
13.	Normalized cost of system in $/W (peak)	Same, except watts are electricity input to GAP
14.	Normalized cost of system in $/W (average)	Same, except watts are electricity input to GAP
15.	Averaged output electricity cost in $/kWh	Averaged GAP ammonia-energy cost in $/kWh; to convert to $/GGE, multiply by 32.2 kWh/GGE

With the above inputs and outputs, the determination of plant economics has worked very well for us. There are two features that, if important, need additional careful consideration: a) The fact no plant realistically operates without some down-time for maintenance. We assumed zero down-time fraction above. One way to allow for more that zero downtime would be to increase the capital costs by a factor of 1/(1- down-time fraction); and b) The fact that curtailed, lowest-cost electricity may not be available at all times, so that either down-time fraction is increased or some energy storage (and capital cost) is added, a larger plant needs to be installed, a larger electricity cost needs to be budgeted, or some combination of all of these.

Table 1 lists a selection of results of the Calculator analysis runs for a GAP:

- Runs 1-13 are for GAPs, while Runs 14-17 are for Green Jet Fuel Plants (GJFP).
- Runs 1-4 show that GAP operation with input energy costs of 60 $/MWh require gasoline prices to rise by 35-75% (via inflation or taxation) in order for the GAPs to become profitable, with a payback period near 7 years[8] and a CAROI over 5 %/year, achievable without tax credits / refunds.
- Runs 5-7 show that if the electricity input cost could be reduced from 60 to 40 $/MWh, no change in GAPcosts or government subsidies, GAPs could become profitable with only 10-30 % increase in gasoline prices
- Runs 8 and 9, with either 30/0 or with 30/35 % Fed/State tax refunds, the GAPs can be profitable at today's gasoline prices
- Runs 10 to 13 show how decreases in plant costs increase the economic GAP performance, w/o any subsidies, at today's gasoline prices
- The above runs demonstrate how to use the freely-available Calculator for this type of economic analysis – but mindful that the choice of installed plant capital costs of 5-9 $/(gal/year) and O&M costs of 2 %/year, while reasonable, are speculative at this point and thus contribute to the uncertainty of the obtained results.
- Additional Runs 14 to 17 were made to see how difficult it would be to make a "green" jet-fuel synthesis plant profitable. Assuming an energy conversion efficiency of just 5 %, the results shows that gasoline (or jet-fuel) would need to increase by 22 to 28 $/gal, while keeping available electricity costs at today's level.

Table 2 shows the Calculator[2] data for Run # 8, with. The good and intuitively credible news is that the O&M costs, being 6-14x smaller than the green energy GAP energy input costs, have relatively little influence on the GAP economic viability outcome. Conversely, the green energy cost level is the key parameter, which controls GAP profitability

Assuming an energy conversion efficiency for a "green" air-source jet fuel plant (ASJFP, to convert air-sourced CO2 and water to jet fuel) of not 50 but 5% capacity/energy conversion efficiency and a corresponding increase in plant complexity and cost, the economic viability requires a much higher price of jet fuel, as indicated in the bottom half of Table 1.

CONCLUSIONS

The above parametric analysis demonstrated that the available web-calculator for PV "plant" economics can serve to also estimate the economics of green ammonia or jet fuel plants.
For the chosen (reasonable yet uncertain) GAP operating parameter values, we found economic GAP viability/profitability conditions both with and without GAP subsidies, for plant costs below 9 $/(gal/year) and below 3 $/W; for electricity costs at or below 0.04 $/kWh (40 $/MWh).
The good and intuitively credible news is that the plant O&M costs, being 7-14x smaller than the green energy GAP input costs, have relatively little influence on the GAP economic viability outcome. Conversely, the cost of green energy – be it from geothermal, solar, wind or ocean sources -- is the key parameter, which controls GAP profitability.

REFERENCES

[1] Mike Kaleikini, Plant Manager, Puna Geothermal Venture, Private Communication, 6 July 2010

[2] Ulrich Bonne (Kailua-Kona, HI), "Green Energy ROI and Electricity Cost Calculator," Friends of NELHA website, rev. 1 June 2010, http://www.energyfuturehawaii.org/learn-more/7-renewable-energy-a-energy-efficiency/199-green-energy-roi-and-electricity-cost-calculator.html [2]

[3] A 4 $/gal gasoline cost is equivalent to (4 $/gal)/(110,000 Btu/gal)/(1054 J/Btu)(3.6E6 J/kWh) = 0.1242 $/kWh

[4] Conservative 10-12 MWh/ton NH3 energy requirement, equiv to 60-50% plant energy conversion efficiency, in view of the 5.27 kWh/kg (4.78 MWh/ton) Lower Heating Value of ammonia

[5] U.Bonne (MinneFuel, LLC) et al, "Niche for Modular Cellulosic BioEnergy Plants," CPAC Summer Institute, University of Washington, Seattle, WA, 16 July 2008, rev. 19 July

[6] John H. Holbrook (Richland, WA) and Jason C. Ganley (Washington, DC), “Method and apparatus for anhydrous ammonia production," US Pat. Appl. 20080193360 A1, August 14, 2008
[7] N.Sammes, G.Restuccia (CO School of Mines, Golden, CO) and J. Ganley (NHThree LLC), "Ammonia Synthesis in a Modified IT Ammonia Synthesis in a Modified IT-SOFC System," SSAS, Iowa State University, 2008, http://www.energy.iastate.edu/Renewable/ammonia/ammonia/2008/Sammes_2008.pdf
[8] Guy Toyama, Private Communication, July 2010

Nomenclature and Acronyms

CAROI	Compounded and Annualized Return On Investment in %/year, equivalent to the total yield of a compounding savings account after the same number of years
FON	Friends of NELHA, with web at www.EnergyFutureHawaii.org
GAP	Green Ammonia Plant
GGE	Gallons Gasoline Equivalent, expressing volume units holding the energy content as a gallon of gasoline
HECO	Hawaii Electric Companies
HELCO	Hawaii Electricity & Light Company in Hawaii County
LHV	Lower Heating Value
MMC	Minimum Monthly Charge by utilities
NELHA	Natural Energy Laboratory of Hawaii Authority, in Hawaii County
NH3	Chemical formula for ammonia
NREL	National Renewable Energy Laboratory, in Golden, CO
O&M	Operation and Maintenance, incl. labor to run the plant, insurance, property taxes, etc
PGV	Puna Geothermal Venture in Hawaii County
PUC	Public Utility Commission

Table 1. Economics of Green Ammonia and Jet Fuel Plants vs. Gasoline & Green Energy Costs

Run #	------------------ Inputs-----------------------							--------------------- Outputs -----------------------					
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Gasoline Price		Capital Cost	Cost/Pwr Ratio	Capac. Factor	Green Energy	F/S T.C.	GAP CAROI	GAP Payb.	Gasoline Parity Tax		GAP NH3 Cost	Price Ratio
	$/gal	$/kWh	$/(gal/y)	$/W	%	$/MWh	%	%/year	Years	$/gal	%	$/kWh	-
1	4.0	0.124	9	2.917	50	60	none	< 0	> 25	0	0	>0.20	< 0.7
2	5.4	0.168	9	2.917	50	60	none	3.1	15.78	1.40	35	0.197	0.851
3	6.0	0.186	9	2.917	50	60	none	4.67	11.57	2.00	50	0.193	0.965
4	7.0	0.217	9	2.917	50	60	none	6.36	7.90	3.00	75	0.191	1.138
5	4.0	0.124	9	2.917	50	40	none	< 0	> 25	0	0	> 0.20	< 0.7
6	4.2	0.130	9	2.917	50	40	none	2.87	15.91	0.20	5	0.150	0.869
7	6.0	0.186	9	2.917	50	40	none	6.46	7.38	2.00	50	0.143	1.303
8	4.0	0.124	9	2.917	50	40	30/--	4.06	13.14	0	0	0.136	0.913
9	4.0	0.124	9	2.917	50	40	30/35	7.37	7.01	0	0	0.122	1.018
10	4.0	0.124	8	2.593	50	40	none	2.97	15.76	0	0	0.143	0.869
11	4.0	0.124	7	2.269	50	40	none	3.79	13.63	0	0	0.136	0.913
12	4.0	0.124	6	1.945	50	40	none	4.69	11.52	0	0	0.129	0.963
13	4.0	0.124	5	1.621	50	40	none	5.70	9.45	0	0	0.122	1.018
	------------------------------- Green Jet Fuel Plant (JFP) -----------------------------												
14	32.0	0.994	40	1.296	5	40	none	3.88	14.37	28.00	700	1.186	0.84
15	32.0	0.994	40	1.296	5	40	30/35	8.84	6.07	28.00	700	1.068	0.93
16	27.4	0.851	20	0.648	5	40	30/35	9.29	7.80	23.40	585	1.009	0.84
17	26.4	0.820	10	0.324	5	40	30/35	11.8	6.04	22.40	560	0.979	0.84

http://www.energyfuturehawaii.org/solarCalc.php 1 Oct. 2010

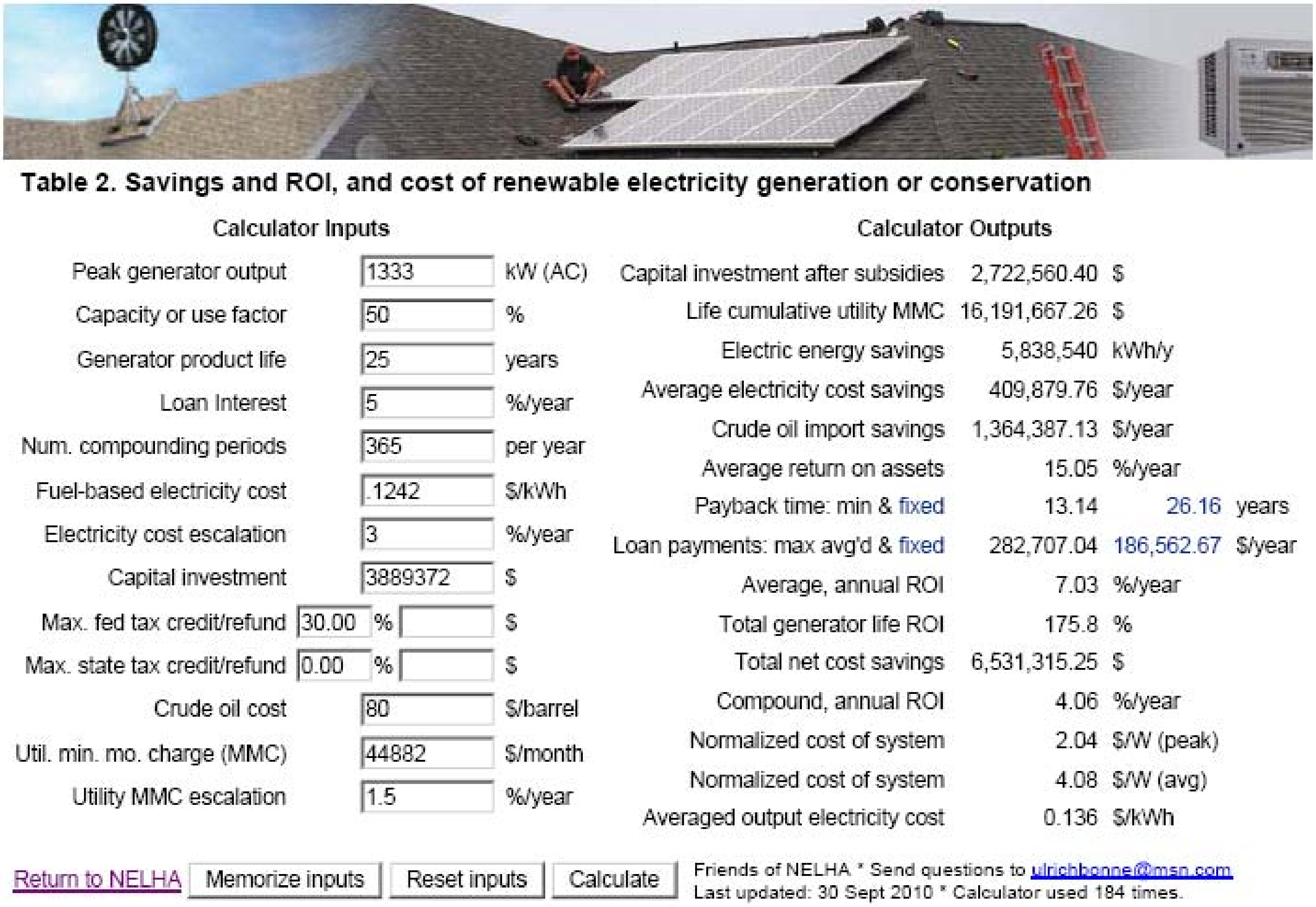

Table 2. Savings and ROI, and cost of renewable electricity generation or conservation

Calculator Inputs

Peak generator output	1333	kW (AC)
Capacity or use factor	50	%
Generator product life	25	years
Loan Interest	5	%/year
Num. compounding periods	365	per year
Fuel-based electricity cost	.1242	$/kWh
Electricity cost escalation	3	%/year
Capital investment	3889372	$
Max. fed tax credit/refund	30.00 %	$
Max. state tax credit/refund	0.00 %	$
Crude oil cost	80	$/barrel
Util. min. mo. charge (MMC)	44882	$/month
Utility MMC escalation	1.5	%/year

Calculator Outputs

Capital investment after subsidies	2,722,560.40	$		
Life cumulative utility MMC	16,191,667.26	$		
Electric energy savings	5,838,540	kWh/y		
Average electricity cost savings	409,879.76	$/year		
Crude oil import savings	1,364,387.13	$/year		
Average return on assets	15.05	%/year		
Payback time: min & fixed	13.14		26.16	years
Loan payments: max avg'd & fixed	282,707.04		186,562.67	$/year
Average, annual ROI	7.03	%/year		
Total generator life ROI	175.8	%		
Total net cost savings	6,531,315.25	$		
Compound, annual ROI	4.06	%/year		
Normalized cost of system	2.04	$/W (peak)		
Normalized cost of system	4.08	$/W (avg)		
Averaged output electricity cost	0.136	$/kWh		

Friends of NELHA * Send questions to ulrichbonne@msn.com
Last updated: 30 Sept 2010 * Calculator used 184 times.