Is Wind Power to Gas (P2G) Ready for Prime Time on the North American Grid?

AUTHOR

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Abstract--

This paper discusses the finances of power to gas (P2G) technology. The power is wind power, the gas is green methane (CH_4), the grids are the North American (NA) electric and natural gas (NG) grids. The paper discusses the two phases of a model wind power to gas plant (P2GP). First, wind power (electricity) from the grid is converted into hydrogen (H_2) gas using a H_2 electrolyzer (HE). Second, a Sabatier reactor (SR) is used to convert the green H_2 into green methane (CH_4). CH_4 is green natural gas (GNG). The GNG is then injected into the NA NG grid. The HE H_2 has to be converted into CH_4 because the NA NG grid cannot accept significant quantities of even green H_2. The model P2GP is a continuous flow plant. The presentation discusses both the HE and SR technologies. The goal of this paper is to determine whether P2G is a technology that is ready for prime time[1] on the North American grid.

To determine this, the author has developed a levelized cost of gas ($LCOG_{H2}$; $LCOG_{CH4}$) financial algorithm for a model wind P2GP. This algorithm is presented to the reader in an Excel[2] P2GP LCOG Financial Algorithm Workbook. The LC financial principles are discussed. This P2GP LCOG algorithm is used for sensitivity analysis and to confirm "published" P2G plant specifications (specs). The P2GP

[1] is currently commercially viable"
[2] a fully functioning Excel Workbook

LCOG Algorithm uses "project accounting" to compute a partial "LCOG" for both P2G plant phases: $LCOG_{H2}$-H_2 production-HE and $LCOG_{CH4}$-CH_4 production-SR. To compute the $LCOG_{H2}$, the algorithm's P2GP HE Phase requires 10 HE specifications (specs) [independent variables] and 20 dependent variables. Both the HE and the SR specs (metrics) and dependent variables are defined using a standard set of SI and US "English" energy units.

The author used the paper's P2GP LCOG Financial Algorithm and a "dataset" of compiled HE specs to do sensitivity analysis. He found that the low HE efficiency (η) and the high HE CapEx were sufficient[3] to not allow the model P2GP to operate commercially on the North America electric and NG grids. The HE $LCOG_{H2}$ was 91% greater than the US Henry Hub 05/19/20 spot price for NG [7]. The low SR η as well as the high SR CapEx would further preclude a P2GP from operating commercially on the NA electric and NG grids. The cost of capital[4] was not a factor. This is confirmed by the fact that currently there are no commercial P2GP operating (or planned) on the North American grid.

1. THIS PAPER WAS WRITTEN UNDER "SHELTER-IN-PLACE' ORDERS BY THE GOVERNORS OF THE STATES OF ILLINOIS AND COLORADO.

The author lives in Chicago, IL. He was in Georgetown, CO planning to ski when he heard about these two shelter-in-place orders. He followed both of these orders. He has continued to stay in Georgetown and to write this paper without his regular office files. The paper's Excel[2] P2GP LCOG Financial Algorithm Workbook currently only has the HE worksheet (WS). It does not have the SR WS nor the summary WS. Based on his current research, the author can present his conclusion without the SR worksheet. Because a "post shelter-in-place" version of this paper (and it's complete Excel P2GP LCOG Financial Algorithm Workbook) will include the SR phase, this paper discusses the SR technology. The author also plans to update certain of the 10 HE spec values and complete the paper's Reference List.

2. THE LCOG ALGORTHUM AND ITS EXCEL WORKBOOK

For the reader to follow the paper's narrative and to do rapid computations, the reader should download (@ https://tinyurl.com/StavyPapers2020) the 06/28/20 version of the paper's Excel P2GP

[3] even before computing the $LCOG_{CH4}$ using a SR to convert the H_2 into green CH_4
[4] the discount rate

LCOG Financial Algorithm Workbook. The current version of the paper's Workbook only has the HE WS. The complete Excel P2G LCOG Financial Algorithm Workbook[5] will have three worksheets (WS); WS #1, HE; WS # 2, SR and WS # 3, the Summary WS. Each WS will have notes to explain each of the phase's specs and each of the phase's dependent computed values. A printed copy of WS # 1, HE is on pages 12-14. Fig. 1 (page 17) is the Schematic of the model P2G plant. The P2GP LCOG Financial Algorithm uses "project accounting" to "fine tune" sensitivity studies. This also allows the user to do a separate sensitivity study for each (HE, SR) phase of the P2GP. For each P2GP phase, a separate partial LCOG is computed.

The paper discusses the HE $LCOG_{H2}$ algorithm by referring to the HE WS lines for the 10 HE specs and for the HE LCOG algorithm's 20 dependent computed values. An Acronym Glossary is on pages 15-16. Table # 1, The 10 HE Specs (Metrics) Are Defined, is on page 18. The References are on page 19. The post shelter-in-place version of this paper will also discuss the SR $LCOG_{CH4}$ WS by referring to the SR WS lines for the SR specs (independent variables) and for the SR $LCOG_{CH4}$ algorithm's dependent computed variables.

The paper's model P2GP is basic. The model P2GP is a continuous flow plant. One of the HE specs specifies how many hours a day the HE operates. The SR operates the same number of hours a day and at the same time. There is no storage of the wind electricity at the P2GP before powering the HE. There is no storage of the H_2 during the plant operation nor is there any plant storage of the CH_4 (SNG) before its injection into NA NG grid. The two phases operate continuously at the same time. A model P2GP can also be designed to have storage. If there were storage, the two phases would not have to operate at the same time. The paper's P2GP LCOG Algorithm only computes the LCOG (US$/mmBtu$_{NG}$; €/kWh$_{NG}$) for the continuous production of first the H_2 and then the CH_4.

For this paper, both "back of the envelope" simplicity and an accurate first approximation of the cost (US$/mmBtu$_{NG}$; €/kWh[6]) to produce green methane (GNG) from wind power 2 gas (P2G) technology are the two criteria for choosing a computational method. This paper's levelized cost (LC) algorithm meets both criteria. The goal of this paper is to present a LCOG algorithm based on generally accepted financial and engineering principles with a recognized uniform set of P2GP specs.

[5] hereafter referred to as the Excel WP2G LCOG Workbook
[6] In the Euro Zone, retail NG is priced in €/kWh

Putting the P2GP LCOG algorithm on an Excel workbook allows the author (reader) to quickly do a sensitivity analysis. By selecting different realistic values for the 10 HE specs, it became clear to the author that that there are two key specs that determine whether the P2G technology is ready for commercial development. These are the P2GP Round Trip efficiency (η) and the Total[7] P2GP CapEx.

The reader who has downloaded the HE WS of the paper's Excel[2] W2G LCOG Workbook can enter their own 10 HE spec values and check their results. While this paper discusses the 10 HE specs (metrics) and will, in the next version of this paper, also discuss the SG specs, there is no data base of P2G plant specs (HE or SR) for use by reader. Creating a database is not the primary goal of this paper EPRI has started to provide one such data base. [1] This author has the much more modest goal of first, presenting a recognized standard levelized cost (LC) methodology, (i.e. an accurate "back of the envelope" P2GP LCOG financial algorithm), second, using one case study to demonstrate to the reader how LCOG algorithm works and three, comparing the HE $LCOG_{H2}$ with the current US Henry Hub spot price for NG. The author was unable to locate any commercial P2GP on the North American gird. The paper does not have a case study to discuss how to compile a database of the 10 HE specs from current authoritative sources. Interested readers who want to learn how to compile a database of P2GP specs should review the Cabin Creek Pumped Storage Plant compilation case study that is found in the author's Wind Europe 2018 Paper [2].

2. STANDARD (SI) AND AMERICAN "ENGLISH" ENERGY UNITS

The paper defines P2GP specs and dependent variables using the standard SI and US "English" energy units for electricity, H_2, CH_4 and NG. The North American H_2 industry uses the kg_{H2} and Nm^3_{H2} (standard SI mass and volune units) for measuring the physical production and the pricing of industrial H_2. This paper adds MWh_{H2} and the US "English" energy unit; $mmBtu_{H2}$. The North American NG industry uses the $mmBtu_{NG}$ (the standard US "English" energy unit) for measuring the production and the pricing of NG. This paper adds $US\$/MWh_{NG}$ and for Euro zone readers, the $€/kWh_{NG}$. There are published authoritative standard conversion factors [3][8].

The key conversion factors in the P2GP LCOG algorithm are

[7] Total CapEx refers to the sum of the HE CapEx and the SR CapEx
[8] from both the EIA and the IEA

1 MWh_{ELECT} = 3.4120 $mmBtu_{ELECT}$ = 1 MWh_{H2} = 1 MWh_{NG} = 3.4120 $mmBtu_{NG}$

1 kWh_{ELECT} = 3.412 Btu_{ELECT} = 1 kWh_{H2} = 1 kWh_{NG} = 3.4120 Btu_{NG}

CH_4 ≡ NG ≡ SNG ≡ GNG

In the P2GP LCOG financial algorithm energy flow, first, the HE converts the MWh_{ELECT} into $mmBtu_{H2}$. Second, the $mmBtu_{H2}$ are converted by the SR into $mmBtu_{Ch4}$ which are then injected into the NA NG grid. This does not mean that the P2G plant is 100% efficient.

1. H_2 Production--$MWh_{ELECTin}$ from the NA electric grid go into the HE and $mmBtu_{H2out}$ come out of the HE and go into SR
2. CH_4 Production-- $mmBtu_{H2in}$ come into the SR and $mmBtu_{CH4out}$ come out of the SR and go onto the NA NG grid

3. THE TWO PHASES OF THE POWER TO GAS PLANT

This paper discusses the P2G technology focusing on the two phases of all P2GP; one, the production of the H_2, and two, the conversion of the H_2 into methane (CH_4).

In the paper's model P2GP, wind electricity powers a HE. While this technology is called P2G it is actually wind electricity[9] to gas. The HE uses the wind energy to separate H_20 into H_2 and O_2. The equation is:

$$2H_2O \rightarrow 2H_2 + O_2.$$

Currently there is no H_2 electrolyzer technology that is the most "financial mature" technology. The paper's $LCOG_{H2}$ algorithm measures the "financial maturity" of HE with different technologies. The most important P2GP LCOG Algorithm HE values are WS # 1 Line 1, HE efficiency (η), WS # 1 Line 3, HE Power In ($MW_{ELECTin}$) and WS # 1 Line 4, HE CapEx-US$/$MW_{ELECTin}$ (€/$MW_{ELECTin}$).

[9] electricity is kinetic energy while the H_2 (CH_4) gases are potential energy

In the paper's model P2GP, the H_2 is used as one of the feed stocks for a generic Sabatier reactor (SR). The other feed stock is CO_2, which to be environmentally sound, must be taken out of the atmosphere. In the Sabatier reactor, CO_2 reacts with the H_2 in the presence of catalysts to produce methane, water and heat. The SR equation is:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

The SR is used in the American space program to recycle the atmospheric CO_2 of manned space vehicles. Back on earth, and unlike the serial production of HE, wind turbines and PV panels, there is no commercial serial production of SR. The site-specific construction of a SR is possible but its CapEx is not currently commercially viable. The P2GP LCOG Algorithm measures the "financial maturity" of different SR. If SR were in commercial serial production, the most important P2GP LCOG Algorithm SR varables would be WS # 2 Line I, SR Capacity ($mmBtu_{CH4out}$; MWh_{CH4out}), WS # 2 Line 10, SR CapEx-US$/$mmBtu_{CH4out}$ (€/MHw_{CH4out}), and WS # 2 Line 11, SR efficiency (η).

4. THE HE WORKSHEET OF THE EXCEL P2G PLANT LCOG FINANCIAL WORKBOOK

The author stated above that the low HE efficiency (η) and the high HE CapEx are sufficient to not allow the model P2G plant to operate commercially on the North America electric and NG grids. The HE computed the $LCOG_{H2}$ to be US$21.60/mmBtu which is 91% greater than the 05/19/20 US Henry Hub NG spot price of US$1.85/mmBtu (€0.00551/kWh). The low SR η as well as the high SR CapEx would further preclude a P2GP from operating commercially on the NA electric and NG grids.

The paper will now go over the HE worksheet Line by Line to show how the $LCOG_{H2}$ is computed. This section also explains the levelized cost method. For readers who cannot download the Excel HE WS #1, it is printed on pages 12-14.

All the lines refer to are on HE WS #1. Below are the author's comments on the 10 P2G plant specs and on the computation of the 20 dependent variables used to compute the $LCOG_{H2}$.

1. Foreign Exchange

Line FX is the FX value (US$1.14610/€) on 05/22/20 [4] that is used to convert the US$ $LCOG_{H2}$ values into € zone values (€/kWh_{H2}; €/kWh_{NG}).

2. P2G Plant Specifications

Line 1, P2G Plant HE Efficiency is 70%. This is the base case spec (which is an optimistic value).

Line 2, P2G Plant hours/day operating is 20. This is the base case spec. Four hours are for maintenance of the model P2G plant. Other P2GP can operate on different schedules. During the 20 hours both the HE and the SR work in continuous series production.

Line 3, P2G Plant Power Input is 300 MWh_{ELECT}. HE are sized and priced by their power input. This is the base case spec.

Line A, the MWh_{ELECT} of wind electricity to be converted in H_2 is 6,000, which is the product of Line 2 times Line 3.

Line B, the daily H_2 produced is 4,200 MWh_{H2} which is the product of Line 1 times Line A.

Line CF is 3.4120 mmBtu/MWh. This the standard conversion factor [3][8] for converting MWh_{H2} into $mmBtu_{H2}$ This done because the spot price of NG at the US Henry Hub is quoted in US$/$mmBtu_{NG}$.

Line C, the daily P2G Plant HE H_2 produced is 14,330 mmBtu/day which is the product of Line B times Line CF.

Line D, the yearly P2G Plant HE H_2 produced is 5,230,000 mmBtu/yr which is the product of Line C times 365.

Line 4, P2G Plant HE CapEx, is US$573,000/$MW_{ELECT}$ (€500/kW_{ELECT})[10] of electric power input.

Line E, Total P2G Plant CapEx, is US$171,900,000. This is the product of Line 3 times Line 4.

[10] the published value of a prominent Norwegian manufacture was €500/kWh (US$573/kWh) [4]

3. Cost of the Wind Power that is First Being Converted into $mmBtu_{H2}$

Line 5, the cost of the wind electricity that is first being converted into H_2, is US$40/MWh (€34.90/MWh). This US$40.00/MWh (€34.90/MWh), is the author's estimate of a modern utility scale wind plant's LCOE[11].

Line F is the same cost of this wind electricity after it is converted from $US\$/MWh_{ELECT}$ into $US\$/mmBtu_{ELECT}$. Line F is $US\$11.7233/mmBtu_{ELECT}$ (€0.03490/kWh_{ELECT}) which is the quotient of Line 5 divided by Line CF.

4. After Efficiency (η) Loss Cost of the Wind Power That is Being Converted in $mmBtu_{H2}$

Line G is the after efficiency (η) loss cost of the wind power that is being converted into H_2 AELCOE-$US\$/mmBtu_{ELECT}$. The computed value of $US\$16.75/mmBtu_{H2}$ is quotient of Line F divided by Line 1.

Line H is the extra cost (AELCOE-COE) of the wind electricity because of the η loss. The computed value is $US\$5.02/mmBtu_{ELECT}$ which is Line F minus Line G.

Line I is the % increase in the cost of the wind power from the η loss when it is converted into H_2. The 43% increase in the cost is computed by dividing Line H by Line G.

5. P2G Plant HE CapEx, OpEx and the LC Method Explanation

Line 6 is the HE annual fixed O&M cost as a % of the total HE CapEx (Line E). 3% is the base case value.

Line J, the HE annual Fixed O&M cost is US$5,157,00/year. This is the product of Line 6 multiplied by Line E.

Line 7 is the HE variable O&M cost in $US\$/mmBtu_{H2}$. US$1.00 (€0.00298/kWh) is the base case value.

[11] it can also be a PV plant's LCOE [5]

Line 8 is the physical life of the HE. 20 years is the base case.

Line 9 is the Interest/ROE Rate or the cost of capital. The author's estimate is 8%. This is the cost (as a %) to invest the capital in the HE CapEx (Line E). The P2GP owner either provides the capital (equity) or borrows (debt) the capital to in order to own the HE of the P2G plant. This spec is also known as the return on assets (ROA) or as the internal rate of return (IRR). An P2G plant has a physical life (Line 8). During its physical life, as the P2GP operates by first converting the wind power to H_2 and then by converting the H_2 into CH_4, Line E, Total P2G Plant CapEx, must be recovered (depreciation) and the cost of capital (Line 9) for using the invested capital must be paid. If borrowed money is used to construct the P2GP, the cost of borrowing the money is called the lender's interest. If the P2G plant owner uses their own capital to construct the P2GP, the cost of using the owner's money is called the return on owner's equity (ROE). The cost of capital (Line 9) is a weighted average percent for both the lender's interest and for the owner's ROE. Let us hypothesize that the P2GP debt/owner's equity ratio is 1:1; the interest on the debt is 6% and the required ROE is 10%; then the weighted average Interest/ROE Rate is 8%.

Line K is the capital amortization factor-CAF. It is computed to be 0.08720. This is the end of year annual payment computed for a financial annuity having US$1.00 as the principal borrowed, a loan period of 20 years (Line 8) and an interest rate of 8% (Line 9).

Line L is the annual capital amortization (ACA) in US$/year. This computed to be US$14,987,025/yr (€13,076,542/yr). Line L is the product of Line E multiplied by Line K.

The levelized cost (LC) method uses a financial annuity to compute Line L. The ACA-US$/yr is one constant yearly payment for both the depreciation of Line B and for the payment of Interest/ROE (Line 9) over the physical life of the P2GP. This level (constant) capital amortization payment gives the method its name. The first year's payment is almost all Interest/ROE, while the last year's payment is almost all depreciation.

6. Computation of the LC of the H_2 Gas Used as a Feedstock to Produce CH_4 (GNG) in the SR-$LCOG_{H2}$-US$/$mmBtu_{H2}$

Line M is the annual capital amortization-ACA in US$/$mmBtu_{H2}$. The US$2.87/$mmBtu_{H2}$ is computed by dividing Line L by Line D.

Line N is the fixed O&M cost in US$/mmBtu$_{H2}$. US$0.99/mmBtu$_{H2}$ is computed by dividing Line J by Line D.

Line O is the variable O&M cost in US$/mmBtu$_{H2}$. The US$1.00 value is transferred from Line 7.

Line P is the after η loss cost of the wind electricity that is being converted in mmBtu$_{H2}$. The US$16.75 value is transferred from Line G.

Line Q is the HE LCOG$_{H2}$ to be used a feedstock to produce CH_4 in the SR-LCOG$_{CH4}$. Line Q is the sum of Lines M, N, O and P. The LCOG$_{H2}$ is in $21.60/mmBtu$_{H2}$. Line M is 13.3% of Line Q while Line P is 77.5%. Lines N and O together are only 9.2% of the HE LCOG$_{H2}$.

7. Difference Between the HE LCOG$_{H2}$ and the US Henry Hub Spot Price for NG-US$/mmBtu$_{H2}$

Line R is the HE LCOG$_{H2}$ transferred from Line Q above.

Line 10 is the US Henry Hub NG Spot price. US$1.85/mmBtu$_{NG}$ was the price on 05/19/20. [7]

Line S is how much the HE LCOG$_{H2}$ is greater (less) than the Henry Hub NG spot price on 05/19/20. The HE LCOG$_{H2}$ is US$19.74/mmBtu$_{H2}$ greater than the 05/19/20 Henry Hub price. Line S is Line R less Line 10.

Line T is the % that the HE LCOG$_{H2}$ is greater (less) than the Henry Hub NG spot price. 91% is Line S divided by Line R.

5. CONCLUSION RESTATED

Is wind P2G technology ready for prime time on the North American grid?

Based on the research that the author did to assemble the following facts, the author's answer is NO.

1. There are currently no commercial P2G Plants on the North American grid.

2. No specs for any commercial P2G Plant were found in an authoritative database.

3. The author complied 10 base case specs for just the HE phase of the model wind P2G Plant.

4. The HE $LCOG_{H2}$ produced was 91% greater than the 05/19/20 spot price of NG at the US Henry Hub. Both the H_2 and the NG were priced in US$/mmBtu.

5. Fact 4 alone precludes a P2G Plant from operating commercially on the North American grid.

6. The low SR η as well as the high SR CapEx would further preclude a P2G Plant from operating commercially on the North American electric and NG grids.

HE WORKSHEET # 1 OF THE EXCEL P2G PLANT LCOG FINANCIAL ALGORITHM WORKBOOK

line			H_2 Production		
1. Foreign Exchange			**a**	m/d/y	
FX	Enter	US$/€ exchange rate	$1.14610	05/22/20	COLOR CODE
2. P2G Plant HE Specifications					Entry
1	Enter	P2G Plant HE Efficiency-η-%	70%	Capacity Factor	Result
2	Enter	P2G Plant-hrs/day Operating	20	83%	Side Column Result
3	Enter	P2G Plant-HE Power Input-MW_{ELECT}	300.0		Transfer Result
A	Computed	Daily MWh_{ELECT} of Wind Electricity to be converted into H_2-MWh_{ELECT}/day	6,000		Check Value
B	Enter	Daily P2G Plant HE H_2 Produced-MWh_{H2}/day	4,200		In €
CF	Enter	Conversion factor-mmBtu/MWh	3.4120		Conversion Factor
C	convert MWh to mmBtu	Daily P2G Plant HE H_2 Produced-$mmBtu_{H2}$/day	14,330		
D	Computed	Yearly P2G Plant HE H_2 Energy Produced-$mmBtu_{H2}$/year	5,230,596	€/kW ↓	
4	Enter	P2G Plant HE CapEx-US$/$MW_{ELECT}$	$573,000	500 €	
E	Computed	Total P2G Plant HE CapEx-US$/P2G Plant HE	$171,900,000	€ 149,986,912	
3. Cost of the Wind Power to be Converted into $mmBtu_{H2}$				€/MWh↓	€/kWh↓
5	Enter	Cost of the Wind Power to be converted into H_2-COE_{ELECT}-US$/$MWh_{ELECT}$	$40.00	€ 34.90	€ 0.03490
F	converted to mmBtu	Cost of the Wind Power to be converted into H_2-COE_{ELECT}-US$/$mmBtu_{ELECT}$	$11.7233	**€ 0.03490**	
				€/kWh ↑	

4. After Efficiency (η) Loss Cost of the Wind Power to be Converted into $mmBtu_{H2}$

				€/kWh ↓
G	computed	After η Loss Cost of the Wind Power to be converted into H_2-$AELCOE_{ELECT}$-US$/$mmBtu_{ELECT}$	$16.75	€ 0.04986
H	computed	Extra Cost ($AELCOE_{ELECT}$-COE_{ELECT}) of the Wind Power-US$/$mmBtu_{ELECT}$	$5.02	€ 0.01496
I	computed	% Increase in the Cost of the Wind Power when converted into H_2	43%	43%

5. P2G Plant HE CapEx, OpEx and the LC Explanation

6	Enter	Annual Fixed O&M Cost-% Total HE CapEx, Line E	3.00%	€/yr↓	
J	Computed	Annual Fixed O&M Cost-US$/yr	$5,157,000	€ 4,499,607	
7	Enter	Variable O & M Cost-US$/$mmBtu_{H2}$	$1.00	€ 0.00298	←€/kWh
8	Enter	Physical Life of the HE-Years	20		
9	Enter	Interest/ROE Rate-%	6.0%		
K	Computed	Capital Amortization Factor-CAF	0.0872	€/yr↓	
L	Computed	Annual Capital Amortization-ACA-US$/yr	$14,987,025	€ 13,076,542	

6. Computation of the LC of the H_2 gas used as a feedstock to Produce CH_4 (GNG) in the SR-US$/$mmBtu_{H2}$-$LCOG_{H2}$

			US$/mmBtu↓	€/kWh ↓	%
M	Computed	Annual Capital Amortization-ACA-US$/$mmBtu_{H2}$	$2.87	€ 0.00853	13.3%
N	Computed	Fixed O&M Cost-US$/$mmBtu_{H2}$	$0.99	€ 0.00294	4.6%
O	Transferred from Line 7	Variable O&M Cost-from Line 7 above-US$/$mmBtu_{H2}$	$1.00	€ 0.00298	4.6%
P	Transferred from Line G	After η Loss Cost of the Wind Electricity to be converted into H_2-from Line G above-$AELCOE_{ELECT}$-US$/$mmBtu_{ELECT}$	$16.75	€ 0.04986	77.5%
Q	Computed	LC of the H_2 gas to be used as a feedstock to produce CH_4 in the SR-$LCOG_{H2}$-US$/$mmBtu_{H2}$	$21.60	€ 0.06430	100.0%

7. Difference between the HE $LCOG_{H2}$ and the Current Spot Price of NG at the US Henry Hub-US$/$mmBtu_{NG}$

				€/kWh ↓	
	Transferred from Line	LC of the H_2 gas to be used as a feed stock to produce CH_4 in the SR-$LCOG_{H2}$-			
R	Q	US$/$mmBtu_{H2}$	$21.60	€ 0.06430	Date ↓
10	Enter	US Henry Hub Spot NG Price-US$/$mmBtu_{NG}$	$1.85	€ 0.00551	05/19/20
S	Computed	The HE $LCOG_{H2}$ is greater (less) the Henry Hub NG Price-US$/$mmBtu_{NG}$	$19.75	€ 0.05879	
T	Computed	% that the HE $LCOG_{H2}$ is greater (-%) then US Henry Hub Spot (Future) NG Price	91%	91%	

Acronym Glossary

Acronym	Description
CH_4 =	methane
CO_2 =	carbon dioxide
EIA =	Energy Information Administration (US)
GNG =	Green natural gas
H_2 =	hydrogen
H_2O =	water
HE =	H_2 electrolyzer
IEA =	International Energy Agency (OECD)
kg_2 =	kilogram-H_2
LC =	levelized cost
LCOE =	levelized cost of energy
LCOS =	levelized cost of storage
mmBtu =	million British thermal units
MW =	megawatt
MWh =	megawatt hour
NA =	North American
NG =	natural gas
Nm^3 =	nominal cubic meter-H_2
O_2 =	oxygen

Acronym	Description
P2G =	power to gas
P2GP =	power to gas plant
ROA =	return on assets
ROE =	return on equity
SI =	Système International d'Unités
SR =	Sabatier reactor
WACC =	weighted average cost of capital
WS =	worksheet
η =	efficiency

FIGURE # 1, Schematic of the P2G Plant

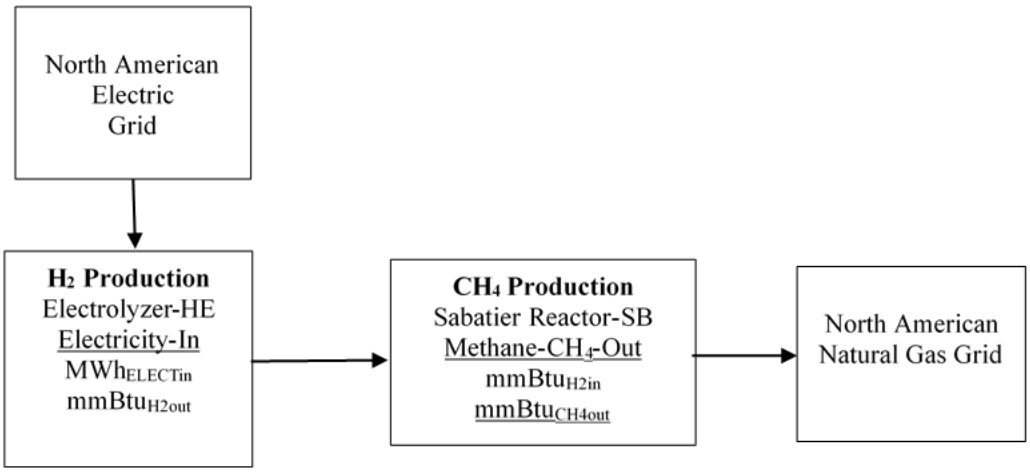

Table # 1, The 10 HE Specs are Defined

spec #	H_2 Production-HE
1	P2G Plant HE Efficiency-η
2	P2G Plant-hrs/day Operating
3	P2G Plant HE Power Input-US$/$MW_{ELECTin}$
4	P2G Plant HE CapEx-US$/$MW_{ELECTin}$
5	Cost of the Wind Power to be converted into H_2-COE-US$/$MWh_{ELECT}$
6	Annual Fixed O&M Cost-% Total HE CapEx, Line E
7	Variable O & M Cost-US$/$mmBtu_{H2}$
8	Physical Life of the P2G Plant-Years
9	HE Interest/ROE rate-%
10	US Henry Hub NG Spot Price-US$/$mmBtu_{NG}$

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