Turning Electricity into Gas

Rotterdam Mainport University of Applied Sciences (RMU)

Topic: Turning electricity into gas

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Management Review

In this project 'turning electricity into green gas', research has been conducted as to how electricity can be converted into natural gas and be used as fuel for the auxiliaries and main engines on-board vessels. This application results in reduction of air pollution caused by these vessels. To comply with the Tier III regulations, which are mandatory for entering certain areas in the world, solutions have to be found to reduce NO_x and SO_x emissions by ships.

The *problem definition* of this project is:
Seagoing vessels cause emissions of NO_x and SO_x.

The objective is to produce natural gas by using electricity to reduce emission of NO_x and SO_x of seagoing vessels.

The *main question* is: 'How can electricity be converted into natural gas and be used as fuel for the auxiliaries and main engines on-board vessels, to reduce air pollution caused by these vessels?'

The *sub questions* are:

- What is methanation
- What is electrolyses?
- How is LNG produced by using these processes?
- How is the technology of converting electricity into natural gas used at this moment?
- What is the efficiency of the converted gas?
- How can electricity be generated by natural sources on board of vessels?
- How can this technology be implemented in existing vessels?

To answer these questions a qualitative research method has been done to support our Desk research which applies to the problem analysis, theories, models and literature. After that a field research has been perdormed. In this last research, expert companies have been approached to get actual solutions and experiences with the use of this system.

Conclusion: From our desk-research it has been found that it is possible for a vessel to sail on 'green-gas' that has been obtained from electricity produces on board by wind or solar energy by using methanation and electrolysis. Because of this, the vessel will comply with the regulations of the tier III.

Recommendations: The amount of 'green-gas' that is produced on the vessel can be used to drive the main engine and auxiliary engines. As a result of the latter, there will be no use of fossil fuel in the harbour which means that there will be no harmful emissions.

1. Contents

2. Preface

The project 'Turning electricity into green gas' is part of de 2nd year of the Maritime Officer Bachelor at the Rotterdam Mainport University of applied sciences.

In this project 'turning electricity into green gas', research has been conducted as to how electricity can be converted into natural gas and be used as fuel for the auxiliaries and main engines on-board vessels. This application results in reduction of air pollution caused by these vessels. To comply with the Tier III regulations, which are mandatory for entering certain areas in the world, solutions have to be found to reduce NO_x and SO_x emissions by ships.

The project team consists of: Jeroen Spermon, Jordan Post, Marc Schröder, Rens Nagtegaal and Ron van Wamelen.
For the project, all tasks were divided among these members. Once a week, during a scheduled meeting, progress and results were discussed and agreements made for the next period. During the process we were accompanied by Mr van Kluijven and Mr Snoeijer. By using their expertise, this project could be completed successfully.

In the next chapters, the results of the research are presented.

3. Introduction

The *problem definition* of this project is:
Seagoing vessels cause emissions of NO_x and SO_x.

The objective is to produce natural gas by using electricity to reduce emission of NO_x and SO_x of seagoing vessels.

The *main question* is: 'How can electricity be converted into natural gas and be used as fuel for the auxiliaries and main engines on-board vessels, to reduce air pollution caused by these vessels?'

The *sub questions* are:

- What is methanation?
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- How is LNG produced by using these processes?
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- How can this technology be implemented in existing vessels?

Because of the scope of this project the following subjects will not be included in the conducted research.

- The exact cost of refitting a ship necessary for using our technology.
- Calculation of down-times/installation times due to the proposed conversions.
- Determination of education needed for operational use of the proposed systems.
- Exact cost for implementation in any existing fleet.

4. Sub questions

4.1. Methanation

To generate methane (CH_4) it is possible to use the physical-chemical process: methanation. In the process carbon-monoxide (CO) or carbon dioxide (CO_2) and hydrogen (H_2) go through a catalyst. When the components have been through the catalyst it has been formed into methane and water (H_2O). The water can return to the electrolysis system. Because it is less expensive to store methane than electricity, the methane is stored in big tanks so it can be used later on.

4.1.1. Chemical process of methanation

Mole is a unit which can be used in calculations of chemical processes. One mole is about 6,022 14*10^{23}. So to get to know how much grams of hydrogen is needed to get a certain amount of methane, the reaction process is converted into Mole. This is the easiest way because the periodic table says how much grams is equal to one Mole. See below:

CO_2	+	4 H_2	=	CH_4	+	2 H_2O		CO_2=	44.01 g/mole
1 mole	+	4 mole	=	1 mole	+	2 mole		H_2=	2.02 g/mole
								CH_4=	16.04 g/mole
44.01 g	+	8.08 g	=	16.04 g	+	36.04 g		H_2O=	18.02 g/mole

The molecular mass can be found in the periodic table of elements. In the process above, it can be seen that 44.01 gram of carbon dioxide and 8.08 grams of hydrogen is needed to produce 16.04 grams of methane.

If 1 kilogram of methane is needed to run an engine you would need:

2744.0 grams of CO_2
503.7 grams of H_2

4.2. Electrolysis

Electrolysis is a chemical reaction to separate an element by electricity. For example using a direct current in water (H_2O), this H_2O will separate into the elements hydrogen (H_2) and oxygen (O_2) . This technique was invented and has been used since around 1800.

4.2.1. Principle

To start up the process the following items are necessary:

- an electrical power source
- two electrodes of inert metal
- pure water
- electrolyte
- Hoffman voltameter

At the right a schematic example is shown how to use the setup. At the left side (cathode, -), hydrogen will be generated. At the other side (anode, +), oxygen will be generated.
The electrolyte, mostly a salt like potassiumhydroxide (KOH) or sodiumchloride (NaCL), is added for conduction. Pure water will not conduct any current and by using for example sea water the process could cause contamination on the electrodes which will have a negative result at the process.
Further calculations on the efficiency of electrolysis are discussed in the next chapter, as well as conventional electrolysis and industrial electrolysis.

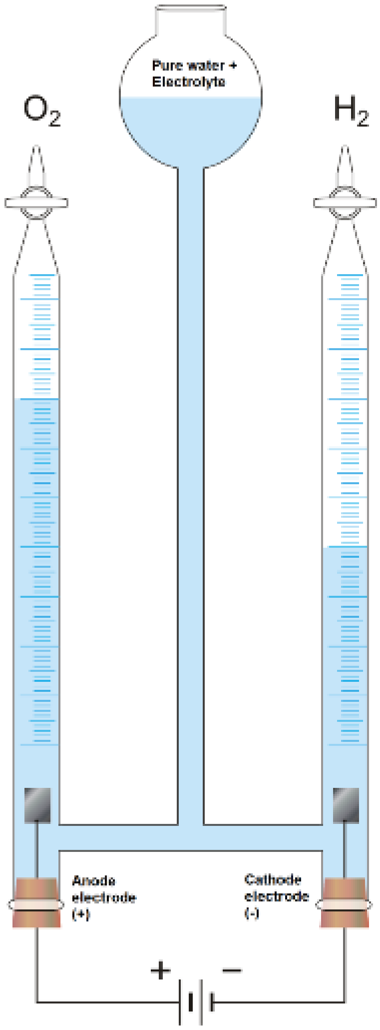

Figure 1: Use of Hoffman voltamet

4.2.2. Conventional Electrolysis

Conventional electrolysis is, in principle, still the same as in the year 1800 and works with the Hoffman voltameter as shown in the previous chapter.
During electrolysis the following process takes place: $2\,H_2O \xrightarrow{elektrolyse} 2H_2 + O_2$
Every 2 water molecules get split into 2 hydrogen molecules and 1 oxygen molecule.
Mole ratio water: hydrogen = 1:1

With the use of the electrolysis law of Faraday the following can be determined.

The law of Faraday:

$$n = \frac{I \cdot t}{z \cdot F}$$

Legend:

n = Quantity of substance in the mole
I = Current in Ampere
t = Time in seconds
z = number of electrons per particle converted to substance
F = Constance of Faraday = 96485.3 coulomb/mole

When the formula is converted to determine the current, it results in the following:

$$I = \frac{n \cdot z \cdot F}{t}$$

The following values are entered:

n = 1 mole
z = 2 electrons
t = 1 hour = 3600 seconds

By using these values, the power can be calculated.

The conversion of 1 mole of water (18 grams) to 1 mole of hydrogen (2 grams) takes 0.268 kWh

So to create 1 Kg of H_2 the Total power consumption will be 132.95 kWh/K

4.2.3. Industrial electrolysis

Industrial electrolysis is used in plants to produce bigger amounts of hydrogen. This process can be monitored better, and is more efficient A producer of industrial electrolyzers is Hydrogenics.

By using an Industrial electrolyzer the power consumption will be 4.9 kWh/Nm^3 H_2 at full load according to the datasheet of Hydrogenics.
So with 1 kWh it produces 0.204 Nm^3 hydrogen
To convert this 0.204 Nm^3 to a flow in m^3 the following formula will be used.

$$q_a = q_n \cdot \frac{P_n}{P_a} \cdot \frac{T_a}{T_n}$$

Legend:

q_a = flow in m^3/h
q_n = flow in nm^3/h
P_n = normal pressure in mbar
P_a = working pressure in mbar
T_a = working temperature in kelvin
T_n = normal temperature in kelvin

The output is dependents on two variables, the operating pressure of the electrolyzer and the ambient temperature.
Because of this variables the worst (25 bar at 5 degrees) and the best (10 bar at 40 degrees) will be calculated.

At 25 bar at 5 degrees this results in

0.0084 m^3 of H_2 at normal conditions weighs 0.0076 kg.
This process consumes 132.06 kWh/kg H_2

At 10 bar at 40 degrees this results in

0.0237 m^3 of H_2 at normal conditions weighs 0.0213kg
This process consumes 46.82kwh/kg H_2

MODEL	HySTAT®-10-10	HySTAT®-15-10	HySTAT®-10-25
Operating Pressure	10 barg		25 barg
Max. Nominal Hydrogen Flow	10 Nm³/h	15 Nm³/h	10 Nm³/h
Hydrogen Flow range	40 - 100% (25 -100% as an option)		
Hydrogen Purity (before HPS)	99,9%; H_2O saturated, O_2 < 1,000 ppm		
Hydrogen Purity (after HPS)	99,998% (99,999% as an option); O_2 < 2ppm; N_2 < 12ppm; Atm. Dew point: -60°C or -76°F (-75°C or -103°F as an option)		
Nr. of cell stacks	1		
Estimated AC power consumption (all included)	4,9 kWh/Nm³ at full load		
Voltage	3 x 400 VAC ± 3% (3 x 480 or 575 VAC ± 3% as an option)		
Frequency	50 Hz ± 3% (60 Hz ± 3% as an option)		
Installed power	100 KVA	120 KVA	100 KVA
Max. cooling water t° (electrolyte)	40°C	40°C	30°C
Design flow cooling water (electrolyte)	2 m³/h		
Max. cooling water t° (gas cooling)	15°C		
Design flow cooling water (gas cooling)	0,15 m³/h		
Demineralized water consumption	< 1 liter/Nm³ H2		
Electrolyte	H_2O + 30% wt. KOH		
Approx. Electrolyte Quantity	300 L		
Installation Area	Indoor, in dedicated building		
Ambient Temperature Range	+5°C to +40°C		
Dimensions Process Part (LxWxH)**	1,7m x 1,85m x 2,6m		
Dimensions Power Rack (LxWxH)	0,9m x 0,9m x 2,3m		
Dimensions Control Panel (LxWxH)	1,0m x 0,5m x 2,1m		
Approx. empty Weight Process Part	1.350 kg	1.500 kg	1.400 kg
Weight Power Rack	750 kg		
Weight Control Panel	400 kg		

Figure 2: technical specifications Hydrogenics

4.3. Efficiency

To define the amount of electric energy required for 1 kW of propulsion by a methane-gas fueled engine, a calculation has to be made.

Energy contained within fuel, is defined as the specific calorific value of this fuel. This is the amount of heat produced by the complete combustion of 1 gram of the fuel.

Calorific Values of gasses and MDO in kJ/kg

Hydrogen	130000
Methane (CH_4)	39820
MDO	44800

(Ref: Biomass Energy Data Book)

4.3.1. Energy balances and calculations

Engine Manufacturers quote fuel consumption figures in g/kWh. Typical figures for a modern engine are between 165 and 170g/kWh. This gives an indication of the efficiency of an engine.

Because the specific fuel consumption would vary depending on its calorific value (the lower the value, the more fuel must be burnt to produce a certain amount of power), engine manufacturers base their figures on a calorific value of 42700 kJ/kg.

When using this calorific value, for 1 Kwh thrust, 7259 kJ is needed.

Methane has a calorific value of 39820 kJ/kg

For 1 Kwh of engine thrust, 1.07 x 170 g of Methane is needed.

This results in a Methane consumption of 182.3 g/kWh.

As determined in the Electrolysis and Methanation chapter:

1 kilogram of methane is made with

23.58	kWh:
2744	grams CO_2
503.7	grams H_2

To produce 182.3 grams of methane, 4.3 Kwh electrical power is needed.

Conclusion:

For 1 kWh of Thrust, 4.3kWh of electrical power is necessary.

When using Hydrogen as fuel directly, this efficiency doubles.

39kWh solar/ 29.4kWh wind equals 68.4 Kwh can produce 2.9kg Methane

729kg Methane is needed for 1 hour travelling with 4000kW engine

4.4. Green Electrical Energy Sources

In this chapter the efficiency of both, wind and solar energy will be discussed. Because wind and radiance of the sun are unreliable energy sources and vessels sail everywhere on earth, the global average of the available energy is used in the below calculations.

4.4.1. Wind energy

Wind energy can be used to create electricity shore based/seabed or on a vessel. Both situations are discussed.
The Netherlands at this moment have two wind parks at sea. These are the Offshore Windpark Egmond aan Zee and the wind turbine-park Prinses Amalia. The Offshore Windpark Egmond aan Zee is situated at 15 kilometers off the Egmond aan Zee coast and produces 108 megawatts. The wind turbine park Prinsess Amalia is at 23 kilometers from the IJmuiden coastline and produces 120 megawatts. The biggest shore based windturbine is the Samsung S7.0-171. This turbine produces 7 MW with a rated windspeed of 11.5 m/s.
Several parks are currently under construction and plans are made for additional parks.

4.4.2. Available power

The available power from the wind is called the Wind Power Density. This is the amount of watt per square meter wind. This is influenced by the density of the air, the surface of the wind turbine and the wind velocity. The Wind Power Density is higher above 50 meters and above the sea. Most turbines inland or offshore are therefore placed above 50 meters. On a vessel this will be more difficult but vessels have the advantage of being able to use the increased Wind Power Density of wind at sea. Therefore it can use smaller wind turbines. The following graph shows the average global wind speeds at 80 meter.

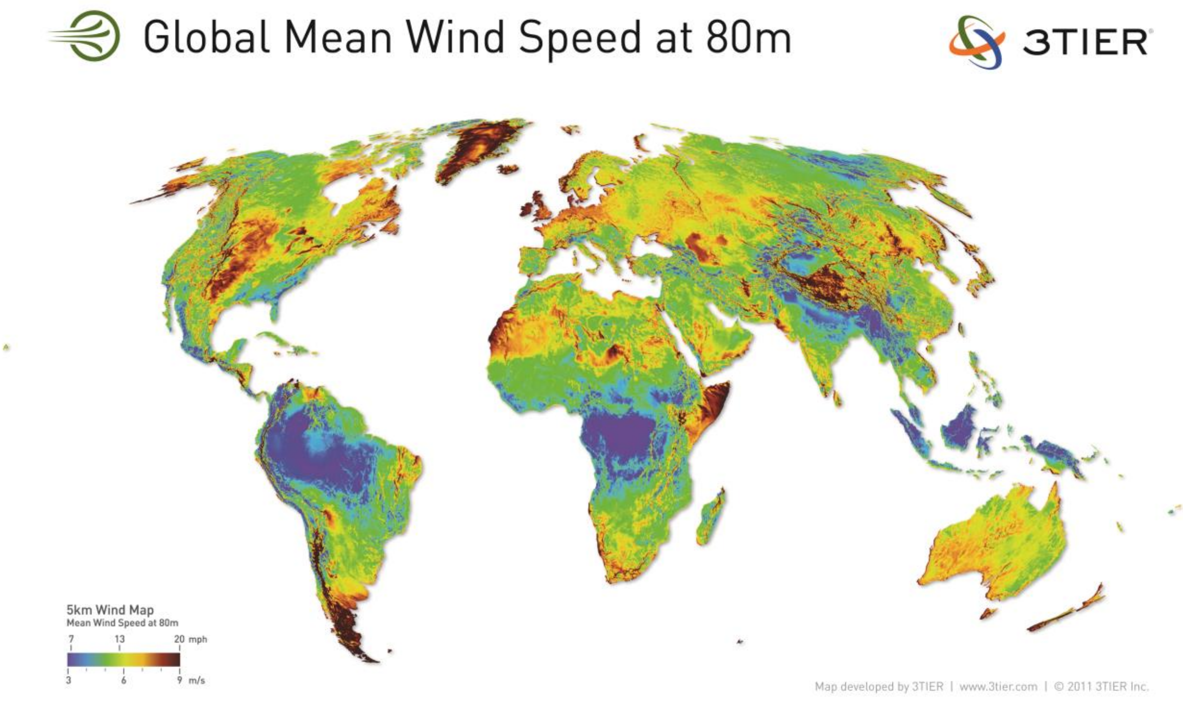

Figure 3

According to the Betz' Law the maximum achievable efficiency from the Wind Power Density is 59% because the wind needs to exit the wind turbine as it enters. The current best commercial wind turbines can use about 75% of the limit.

4.4.2. Solar energy

Solar energy can also be used as an energy source for electrolysis. Some vessels already have solar panels to generate electricity. The generated electricity of solar panels is influenced by the sunlight. A solar panel produces the most energy in direct sunlight on a cool day. Warm weather can lower the efficiency because the heated components increase the electrical resistance.

4.4.3. Available power

The available power for solar energy is the radiation of the sun. However, the sun will radiate more energy to the earth’s surface around the equator and less energy with the increasing latitude. Also the weather can drastically reduce the amount of irradiation. The following graph shows the average global irradiation in the world. The global average irradiation of the sun on the earth’s surface is 164 watts per square meter

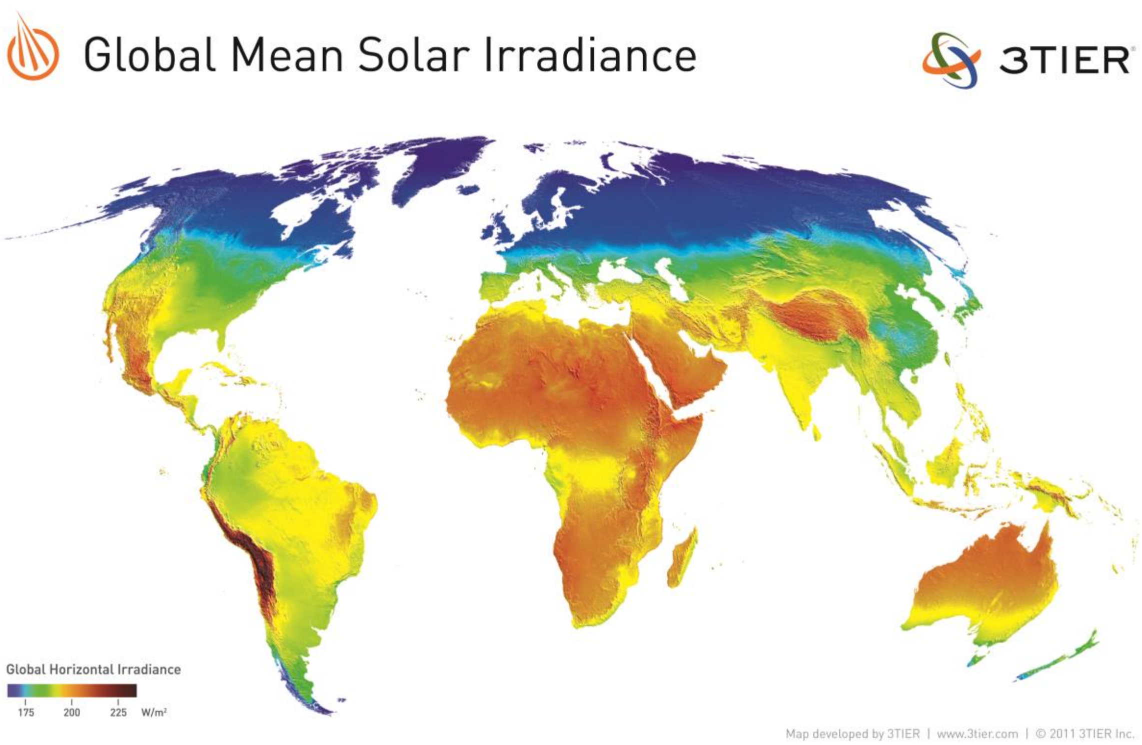

Figure 4

The energy from solar panels is measured during the Standard Test Conditions (STC) and is expressed in Watt peak (Wp). These test conditions include a temperature of 25 degrees celsius and a radiation of 1000 Watt per square meter. In real conditions the radiation verifies because of the weather, but is the strongest around the equator.

The current efficiency of commercial solar panels is about 17% at most. However, new technologies are under development. The solar panels using GaAs look promising with an efficiency of 32,5% in the lab. Additionally, GaAs technology has the benefit of a high resistance against high temperatures.

4.4.4. Comparison

Wind and solar energy have both their benefits and drawbacks.
To produce 1 kWh by using solar panels with GaAs technology, an efficiency of 32.5% and the average global radiance, a surface of 19 square meters completely covered with solar panels is required, with the commercial solar panels with an efficiency of 17% this will be a surface of 36 square meters.

To illustrate the possibilities for onboard 'green' energy production we have researched the possibilities for the MS BAHREIN. This vessel of 165 meters has 4 hatches with a combined surface of 774 square meters.

If these hatches are covered with solar panels (GaAs) 39 kWh will be produced. This will be 20 kWh with regular solar panels. Of course, larger vessel can be equipped with much more panels and will therefore produce more electricity.

The windturbine AIRCON 10 is a promising looking, small windturbine that could be placed onboard vessels, it produces 9.8 kW at a nominal windspeed of 11.0 m/s. The turbine will produce electricity in windspeeds from 2.5 m/s up to 35 m/s. Three of these can be placed onboard the Bahrein, which results in 29.4 kW. The weight of the hub has to be accounted for in stability calculations. Airdraft will be increased as a negative effect.

4.5. Obtaining CO_2

The CO_2 needed to produce Natural Gas can be extracted from exhaust gases. The best way to do this, is by absorbing the CO_2 from exhaust gas and extract it thereafter by releasing it from its absorber.

The company Union Engineering has Low Pressure CO_2 Extraction Plants especially designed for combustion engines running on Heavy Fuel Oil. A marine vessel produces approximately 3359 grams CO_2 by burning 1000 grams of HFO in its engine. The said extraction unit can recover 85-90% of the CO_2 present in the exhaust gas. This results in 2855 grams extracted CO_2 gas. The CO_2 will have a purity of 99.0% and is stored in an insulated CO_2 storage tank.

5. Conclusion

From our desk-research it has been found that it is possible for a vessel to sail on 'green-gas' that has been obtained by using methanation and electrolysis. Because of this, the vessel will comply with the regulations of the tier III.
Next to this desk-research, field-research has been performed. For this, an expert company has been approached to obtain additional information. This information proved to be of limited use to confirm the conclusions from the desk-research.

To obtain 1000 grams of methane, 2744.0 grams of CO_2 and 503.7 grams of hydrogen is needed. Because methane has a low calorific value, 182.3 grams is needed to produce 1 kilowatt-hour of engine thrust. To obtain this amount of energy, 4.3 kilowatt-hour of electricity is required. This form of energy can be obtained by using windmills and solar panels.

If the vessel could sail directly on hydrogen, the efficiency will double.
With 39.0 kilowatt-hour of solar energy and 29.4 kilowatt-hour of wind energy, 2.9 kilogram of methane can be produced per hour in ideal conditions.

To sail a vessel, equipped with a 4000 kilowatt engine, a surface of 774m^2 of solar panels and 3 Aircon 10 wind generators for one hour, 729.0 kilogram methane is needed.
To produce this amount of methane the vessel has to sail approximately 10 days to generate enough electrical power.

6. Recommendations

From this research it can be concluded that it is possible to sail a vessel on ‘green-gas’ that has been obtained with the use of methanation and electrolyzes. By this the vessel will comply with the regulations of the tier III law that will be in force in 2016.

By using the surpluses of electricity on land it is possible that this ‘green-gas’ will be produced there. This amount of gas can be stored on the vessel and can be used in the tier III areas.

The amount of ‘green-gas’ that is produced on the vessel can be used to drive the main engine and auxiliary engines. As a result of the latter, there will be no use of fossil fuel in the harbour which means that there will be no harmful emissions.

A major increment in efficiency can be acquired when using the produced hydrogen directly as fuel.

7. Resources

Illustrations:

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8. Appendix 1: interview with subject matter expert

The only nearby subject matter expert was available in the Netherlands. Germany has currently a working installation in Falkenhagen, eastern Germany, but could not be contacted. Several attempts have been accomplished.

In despite of having just one interviewee, the answers are considered as reliable, because they fully correspond with the previous performed desk-research.

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The questionnaire supplemented with questions and answers by the expert:

1 Wat is grootste schaal waarop thans (wellicht in proefopstelling) methaangas wordt geproduceerd?

Die is in principe onbeperkt. De waterstof wordt geproduceerd in kleine units (1-10 m3/h), die eenvoudig in cascade kunnen worden geschakeld. De methanisering is prima op te schalen, mits er natuurlijk voldoende kooldioxide voor handen is.

2 Wat is het volume van dergelijke installaties?

Ik denk dat een installatie tot 10 m3/h H_2 of CH_4 prima in heen 5 ft zeecontainer is te bouwen. De benodigde additionele veiligheidsmaatregelen zijn vaak beperkend voor de minimale afmeting.

3 Wat zijn de praktische *energie* rendementen voor beide productieprocessen (elektrolyse t.b.v. waterstofproductie, mechanisatie t.b.v. methaanproductie)?

Op dit moment nog niet top: laten we zeggen resp. 60 en 90%

4 Zijn er op korte termijn verbeteringen te verwachten op het gebied van rendement betreffende dit proces?

Zie onder

5 Worden energieoverschotten gebruikt, of wordt energie opgewekt voor het Power2Gas principe?

Zie onder

6 Wat zijn volgens u de voordelen van power to gas en welke knelpunten ziet u?

Opslagmogelijkheden te over; zeker in Nederland, waar het gasnet wijd vertakt ligt. Wel gaat de energie over van elektriciteit naar gas (of een andere energiedrager, bijv. methanol, etheen, etc.) Je hebt dus met meerdere stakeholders (partijen) van doen. Elektriciteit is het feestje van Tennet, die van gas ligt bij Gasunie. Dergelijke partijen hebben altijd autonoom hun beheer en onderhoud kunnen doen, nu zullen ze moeten gaan afstemmen en een deel van de business bij een andere neerleggen. Dit blijkt toch een grote cultuuromslag.

7 Wat is het verwachte rendement van het totale proces? Ik heb gelezen dat het tussen de 30-40 % is, is dit genoeg en zou dit verhoogd kunnen worden?

Dat zijn de hele oude systemen. Vooral de productie van H2 is niet erg hoog. De innovatie van betere h2 productie systemen heeft de afgelopen decennia stil gelegen, omdat er geen/weinig vraag was. Met de huidige vraag, zullen de ontwikkelingen ook we op gang komen. Ik zie veel belovende alternatieven langs komen.

Laten we eerst eens inzetten op 60-70%. Dat is nog niet hoog, maar dat waren de eerste zonnepanelen ook niet. Als we toen niet hadden doorgezet, had er nu niets op de daken gelegen! Tevens zal P2G nooit als eerste optie worden ingezet:

1: geproduceerde duurzame elektriciteit (nuttig) gebruiken
2: energiebesparingen/smart toepassingen (afstemming vraag en aanbod)
3: H2-toepassing
4: synthetisch aardgas

Naarmate de mogelijkheden minder worden, zullen de kosten voor de transporteur hoger worden. Met andere woorden voordat je bij P2G bent aangekomen, heb je al van alles gedaan om het in de huidige infra in te passen. Dat gaat schijnbaar niet lukken en daardoor kom je met negatieve prijzen te zitten: je moet letterlijk van je energie af! In een dergelijke situatie is elk procentje, dat P2G aan rendement heeft dan ook winst.

8 Hoe komen we aan de benodigde CO2? Vangen we die op uit uitlaatgassen en zo ja, hoe?

Mijn droom is om het uit de lucht te halen, maar gezien de lage concentratie (0,04%) houdt dit in dat we wel heel veel lucht moeten door leiden voor een beetje CO2. CO2 kun je gewoon kopen via de reguliere handel. Met certificaten kun je het groen laten verklaren. Een andere optie is terugwinning uit (liefst stationaire) emissiebronnen. In de rookgassen van een ketel zit ca. 10% CO2, tevens kun je het water ook hergebruiken. Als je naar aardgasvervanging wilt, zal je of H2 of CO2 in voorraad moeten hebben. Meestal kiest men voor CO2 (niet brandbaar), zodat -zodra de H2-productie start- er direct CH4 kan worden geproduceerd.

9 Het gas komt terecht in het gasnetwerk, hoe zit het met opslag (in tanks?) van dit gas?

Gewoon maken en vervolgens op de juiste kwaliteit brengen. De specificaties zijn hetzelfde als voor groengas/biogas en aardgas van de NAM. Opslag is dan ook niet nodig of je moet er andere plannen mee hebben (denk aan CNG voor de tankstations)

10 Na alle stappen in dit proces, worden de kosten van 1 kWh dan niet te hoog? Komen hier bijvoorbeeld subsidies voor?

Ik denk dat er juist helemaal geen subsidies nodig zullen zijn! De netwerkbeheerders kunnen dit prima zelf oppakken en de kosten socialiseren (in de transporttarieven opnemen). Zie mijn antwoord bij 2

11 Ik ga ervan uit dat dit een CO2 neutrale oplossing is, klopt dit ook? En zo nee, waarom niet?

In principe wel. Al het CO2 wordt immers omgezet naar CH4 (of een andere C energiedrager) Kleine eigen energieverbruiken heb je natuurlijk wel….

12 Ik zou graag een proefopstelling bezoeken, is die er in Nederland en is dat toegankelijk voor bezoekers?

Ik ben bezig het eerste P2G-systeem in Nederland bij ons op locatie te bouwen en testen. Deze gaat –zodra de vergunningen rond zijn en de aannemer zijn werk heeft gedaan- naar Rozenburg (R'dam) en zal daar ca. 5 jaren worden beproefd. Je bent van harte welkom om eens naar Groningen te komen om de units te aanschouwen.

13 Er staat al een grote opstelling in Duitsland, hoe zijn de ervaringen daar? Hoe is het rendement?

Volgens mij is hij nog maar net operationeel. We zullen dan ook even moeten wachten op de verbruiken/rendementen. Vaak is het echter appels met peren vergelijken, omdat iedereen dit op een andere manier doet. De één neemt wel het eigen verbruik mee en de ander niet, etc.