Hydrogen from Municipal Waste to power the Public Transport system

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Abstract

Anaerobic Digestion has been widely use as an effective technology to handle the Municipal and Agricultural Organic Waste. Some countries would utilize the evolved biogas to generate electricity and subsequently feed into the electric grid however, the flare off is still the major way since the most countries' Feed-in-Tariff infrastructure could not support. Therefore, a method of upgrading the biogas for higher value use is proposed by us, in which the biogas is captured and turned into Hydrogen and Carbon Nanotubes by catalytic reaction. Such Hydrogen can bee seen as one of the cleanest renewable energy and could significantly contribute in mitigating the global climate change problem as it gives zero GHG emission. In the consideration of the CO_2 emission, the energy density and the long term cost effect, the use of Hydrogen is privileged over biogas. Hydrogen could be used in Fuel Cell to power urban transit bus and thus we could anticipate a sustainable green transportation system could be developed under the continuous supply of Hydrogen from our wastes.

Keywords: Hydrogen, Anaerobic Digestion, Fuel cell, Carbon Nanotubes (CNF), Greenhouse Gas Emission, Municipal Waste (MSW), Waste remediation, Renewable energy

1. Introduction

Confronting the brutal fact of rising global population, a competition on natural resources like water and the production of waste are also challenges for human beings. To effective handling large capacity of Municipal Waste (MSW) daily, Anaerobic Digestion has been widely use to convert the Organic compositions into biogas. The evolved biogas could be used to generate electricity and subsequently feed into the electric grid, however the electricity generated from the biogas could only provide usually <1% of domestic consumption and therefore leads this concept become less attractive.

Recently Plug-in Hybrid Electric Vehicles (PHEV) or Electric Vehicle (EV) have been addressed by the public as they could highly reduce the dependency on gasoline and diesel, however, despite the technology barrier of the battery, the long recharging time is a hindrance for public to accept. Therefore, Hydrogen based Fuel Cell vehicle (FCV) is another option and is highlighted to be the future in Automotives. Hydrogen is clean and could significantly contribute in mitigating the global climate change problem and it gives zero GHG emission. Furthermore, refuel of FCV is easy and it takes shorter time as EV does since the operating mechanism is similar to gasoline fueled vehicle in stations. Therefore, a concept in turning the MSW to hydrogen and subsequently power the urban transport system is proposed, so that Waste to Energy become more sustainable by better use of energy and the higher energy efficiency.

2. Materials and Methods

2.1 From MSW to biogas

According to the published statistic, the production of MSW per capita a day in modern city in 2009 was approximately 1.3kg.[1] In the consideration of logistics and economics feasibilities, we targeted a daily MSW handling capacity within 50km, and it would account for 450 tons MSW per day. Among the MSW, over 50% is Organic including the food and kitchen waste, and among which, 2/3 is putrescibles and it accounts for 40%.[1] For those putrescibles, they could be subjected to anaerobic digestion to breakdown the Organics.

Table 1 MSW composition in modern city in 2009

composition	%
Glass	3.6
Metal	1.9
Paper	23
Plastic	19
Putrescibles	41.4
Textile	2.8
Others	8.3

Anaerobic Digestion is a biological process of breaking down organic matters in the absence of oxygen.[2] Biogas is given out as one of the product and it originates from biogenic materials. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. Those organic materials include biomass, manure, sewage, municipal waste. The composition of biogas varies depending upon the origin of the anaerobic digestion process. [2] Below shows the typical biogas composition based on Anaerobic Digestion.

Table 2 Biogas composition

composition	element	%
Methane	CH_4	50-70
Carbon Dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen Sulfide	H_sS	0-3
Oxygen	O_2	0-2

2.2 Catalytic splitting of biogas

By using a thermal catalytic process, transition metal catalyst is used to capture carbon from carbon hydride gas and grow in filament structure with high crystallinity, the good morphological structure we call Carbon Nanofiber (CNF). The feedstock could be biogas from anaerobic digestion on MSW and therefore we could expect hydrogen gas at the end of the reaction. This process is different from Kvaerner Process which is a common method for the production of hydrogen from hydrocarbons (C_nH_m) nowadays, in which the hydrocarbons are separated into carbon (mostly carbon black) and hydrogen in a plasma burner.[3] Although the biggest advantage the hydrocarbon is transformed almost 100% into pure carbon and hydrogen, the temperature however initiated at around 1,600 ^{o}C would be too high. Compared to our reaction, the catalytic temperature of the hydrocarbon gas initiated at 350^{o}C and the conversion efficiency could reach 90%. The diameter of the graphite filaments and/or whiskers grown can be controlled by the size of the catalyst particles and so allows targetable nano morphologies of the captured carbon. This key aspect related to the chemistry of vapour to liquid to solid whisker growth in the CVD reaction and they have been the core topics in our team over the last decade and subject to international patents.[4]-[10]

$$C_nH_{2m} + (Me + Support) + Energy \rightarrow (C_n \times Me + Support) + mH_2$$

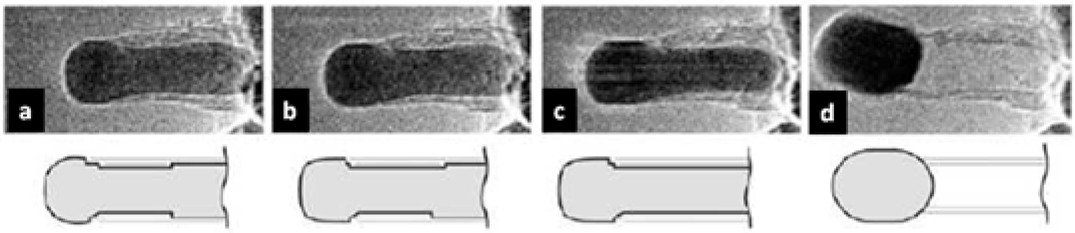

Figure 1 In-situ growth of Carbon Nanofiber over catalyst

2,3 From MSW to Hydrogen

By feeding 450 tons of MSW into the Anaerobic Digester a day would leads to a production of 5,000 tons of biogas per annum. Since the volumetric composition of methane in biogas is 60vol% and eventually a 3,000tpa of methane gas is produced. By further catalytic split the methane gas, we could estimate a production of 600 tons Hydrogen and 1,800 tons of Carbon Nanofibers per annum.

2.4 Our installations

In Austria, a reactor is operated in a $1.5m^3/h$ of methane splitting and compositing CNF into thermoplastics.[11] The thermoplastic has been being deveoped successfully into customer specific high value applications going into commercialization. Recently, we have successfully executed feasibilities for proprietory scale-up concept with BioEnergy2020+ and University of Technology Vienna, having further demonstrated a multiple of the current prototype's catalyst productivity.


Figure 2 Our catalytic reactor in Austria: C-Polymer (AUT); annual H_2 production: 2 tons/a

3. Results and Discussion

3.1 Hydrogen

As proposed, we intend to use Hydrogen as clean and renewable fuel in the public transport by Fuel Cell. In a typical Proton Exchange Membrane Fuel Cell (PEMFC), hydrogen and oxygen combine in a catalyzed electrochemical reaction to produce an electric current, heat and water. According to the state-of-art and the automotive applications PEMFC, the efficiency has reached 50%.[12]

In the existing Automotives market, EV and PHEV are available for motorcycle, sedan and coaches.[13]-[15] If we consider a coach bus runs 250km in the operation of air conditioning as an illustrative example, the table below shows the performance comparison.[16]-[21]:

Table 3 Comparison of EV and FCV

Bus specification			
Dimensions	12m(L)x2.53m(W)x3.25m(H)		
GVW	18,000kg		
Capacity	80 (35seating + 45 Standing)		
		EV	**FCV**
Power	Capacity	240kWh	200kW
	Weight	2,400kg	200kg
	Cost	US$132,000	US$50,000
Fuel		Electricity	Hydrogen
	Capacity	-	18kg
	Charging	10 hours	10 mins

For the battery power bus, it is equipped with a 240kWh $LiFePO_4$ battery while the Fuel Cell Hybrid bus is equipped with a 200kW Fuel Cell and a battery for range extension. The FC cost herein was based on a low production volume cost and therefore leads the cost comparable to the battery required, however if the Fuel Cell is produced in large volume, i.e. 500,000 units per year, according to the U.S. Department of Energy's Hydrogen posture plan, they are targeting the PEMFC cost at USD30-45/kW and deliver a minimum of 5,000 hours of service, compared to the cost at USD275/kW (50kW) in 2002 and USD110/kW (80kW) in 2006.[22] Therefore, the production cost for Fuel Cell is actually declining and is feasible for high volume production. By considering the same drive range, apparently the gross weight of Fuel Cell based bus is lighter than the Battery-type by 90%, or about 2,000kg! The reduced load on board could carry at least 30 passengers and therefore could create more efficiency economic value by the same drive. While compare with the charging of fuels, Hydrogen refilling is much quicker and it indeed operates as the same mechanism as gasoline. By using the existing pipelines and gas stations, we do not expect extra huge investments on reconditioning and equipment.

According to our postulations, we anticipate 600 tons per annum Hydrogen production from a daily MSW capacity of 450 tons. As such, 600 tpa Hydrogen could support a fleet of 100 coaches or urban transit buses, each with a drive range of 250km a day.

In 2007, Canada spent over almost $200 million Canadian for environmental projects in linking Vancouver and Whistler, host city and alpine venue of the 2010 Winter Olympics. . A total of 7 hydrogen refilling stations were opened in the area and 20 hydrogen-powered fuel cell buses provided transport for the people in and around.[23]-[25] In addition, in California in 2010, approximately 300 vehicles have driven over 3.5 million miles, filling up at 24 filling stations throughout the state. Based on a successful foundation, California has an initiative in investing US$180 million to grow the Hydrogen infrastructure with nearly 46 gas stations and deciding to build 50,000 fuel cell vehicle fleet and 60 transit buses by 2015.[26]-[27]

3.2 Carbon Nanotubes

Due to the discovery of carbon nanofibers in early 80s and the subsequent intense development in 90s, great interests have been aroused by Scientists and Engineers. Because of the great mechanical, thermal and electrical properties of carbon nanofiber, a variety of researches have been proposed ranging from everyday items like textile, electronics and sports gear.[28]-[42]

3.2.1 Thermoplastic

Our expertises in Austria are specialized in compositing of the CNF into plastics and have achieved superior performance. We designed to realize the "electrically conductive insulator" broadening the use of plastics in applications where just metal can be utilized without using sophisticated processing temperature. We offer a wide range of polymer-based, dust free nanofiber masterbatches and compounds, based on common thermoplastics, developed and optimized for existing and future high tech solutions. Due to the very good price to performance relation these materials qualify for standard commodity application as well. Depending on the type of application, the optimized level of surface conductivity and mechanical properties of the final product, 3% to 8% by weight of CNF is recommended. CNF's additionally afford polymers with higher temperature stability, improved thermal properties, and outstanding surface quality. The masterbatches and compounds offer uniform surface resistivity within the conductivity range. Also, CNF does not detach from the polymer host material and therefore retains the desired properties through all the life-time of the finished products.[11]

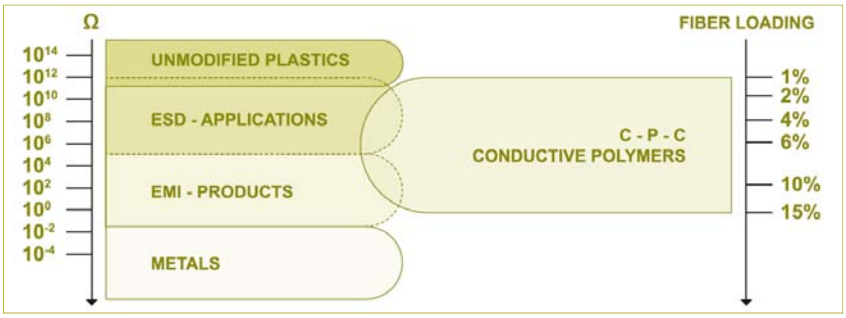

Figure 3 Possible application of carbon nanofibers

3.2.2 Further harvest to Hydrogen

Although the prospects of CNF are enormous in long term, the development into sufficient applications for thermoplastic composites may require some times to markets. Currently the material was only available in the order of 1.000tpa in most part from installations of 100 – 300tpa each, typically operated in batch mode. Today, the global CNF production is on the order of 1,000 tons per year at a market price of €50/kg. Based on our postulation, an annual CNF production could reach 1,800 tons per year per each according MSW treatment station, which is already 2 times of the global market production. Therefore, another option might be to use the CNF yield for further reaction to harvest the availability of Hydrogen. As illustrated below, CNF could be subjected to Boudouard reaction of CO_2 to give carbon monoxide. Afterwards the CO water shift reaction could generate 40% more of Hydrogen, or 400 tons more per year. Including the original generated, a total sum of 1,000 tons of Hydrogen could be generated. Alternatively, the generation of CO could actually react with the originally generated Hydrogen via the Fischer Tropsch Reaction to produce gasolines. For the feasible application of Hydrogen, it could either be Clean Fuel via Fuel Cell, synthesis of Methanol or synthesis of ammonia via chemical synthesis. In the application of Fuel Cell buses, 1,000 tpa of Hydrogen could power ~160 buses.

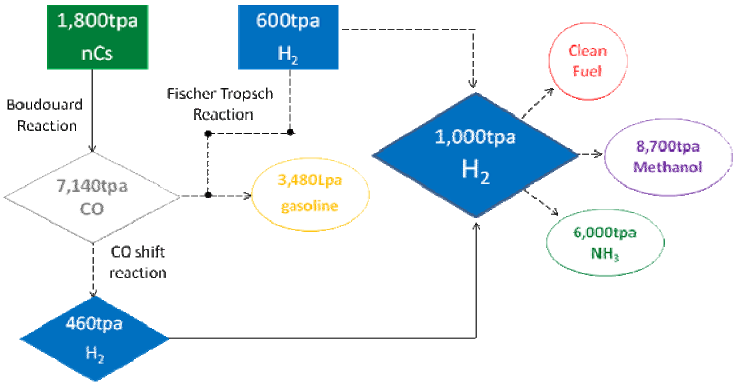

Figure 4 Chemically engineer of CNF to Hydrogen

3.3 Environmental impact

Hydrogen has been produced and used for industrial purposes for over one hundred years. Of the world's total hydrogen production of approximately 45 million tons, over 90% comes from fossil raw materials. [43]-[44] Global hydrogen usage is expected to surpass 50 million tons by 2004 and is expected to exceed 79 million tons by 2016.[43]-[44] Fossil fuel reforming is a method of producing hydrogen or other useful products from fossil fuels such as natural gas. This is achieved in a processing device called a reformer which reacts steam at high temperature with the fossil fuel. The steam methane reformer is widely used in industry to make hydrogen.

During the conversion of the fossil fuel into hydrogen, carbon is released into the atmosphere, typically as carbon dioxide. As a result, fuel cell systems using reformed fossil fuels would emit substantial amounts of carbon dioxide, so would not make much contribution to reducing carbon dioxide emissions, as is expected to be necessary to tackle global warming.

Steam-reforming: $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$

Compare to our thermal catalytic cracking of methane gas into solid carbon and hydrogen gas, obviously we have no CO_2 emission and at the same time, we do not need huge amount of water to reform. Indeed, scarcity of water is one of the human challenges in 20th century.

Catalytic cracking: $C_nH_{2m} + (Me + Support) + Energy \rightarrow (C_n{\times}Me + Support) + mH_2$

By compare with the same ton of hydrogen production (1 ton), as shown below, steam-reforming requires 9 tons of H_2O in preparation whilst thermal catalytic crackings requires none. Besides the consideration of water usage, crackings produce solid carbon as by-product and this would provide add-value for the whole process. If we perform the cracking with circulation, the unreacted methane gas will recirculate in loop, the burned off gas will be reduced by 75%! If we compare the CO_2, obviously we can see that thermal catalytic cracking can highly reduce the CO_2 emission. Providing this figure, if we produce 45 million tons of H_2 for application by SMR, we could estimate the annual production indeed consume 410 million tons of water for reaction and produce 406 million of CO_2! In contrast, our proposed catalytic cracking with circulation, approximately 340 million tons of CO_2 would be reduced, and counts for 1.2% global reduction in global anthropogenic CO_2 emission, i.e. 29,380 million tons.

Table 4 Comparison between steam-reforming and catalytic cracking

	feedstock (ton)		**product (ton)**		**burned off (ton)**	**emission (ton)**	
	NG/methane	H_2O	H_2	C		CO_2(gas)	CO_2(liquid)
Reforming	3.44	9.11	1	0	3.26	9.03	4.22

Cracking w/o circulation	7.76	0	1	3.8	2.97	6.88	0
Cracking with circulation	4.87	0	1	3.17	0.7	1.42	0

In 2009, International Energy Agency (IEA) predicts and identified a technology roadmap on the Light Duty Vehicles (LDV) evolution. The HFCV will ramp up from annual sales of a few thousand by 2015, to several million by 2030 and eventually to 60 million by 2050, which accounts for 37% of the global LDV sale. This is an ambitious but plausible scenario that assumes strong policies and clear policy frameworks, including provision of adequate infrastructure and incentives.[45]

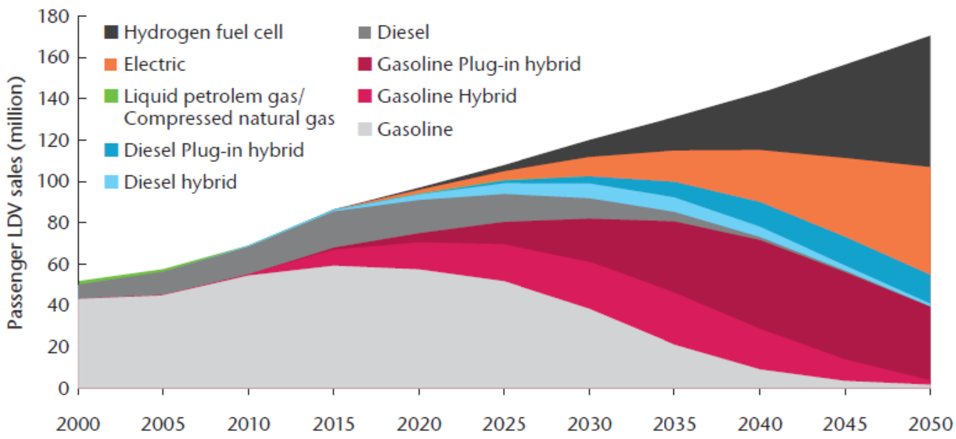

Figure 5 Annual LDV sales by technology type – Blue Map Scenario

4. Summary and Conclusion

The increasing global population would produce more and more waste in the future, an efficient and value-added process should be executed to turn Waste to Energy as soon as possible. We introduce a concept in collecting the biogas from MSW and subsequently upgrade thereafter into Hydrogen by thermal catalytic splitting. Based on our postulation model, a community with 350,000 capita could already generate 450 tons of Municipal Wastes a day and eventually could deliver 600 tons of Hydrogen and 1,800 tons of Carbon Nanotubes per annum. In the public transport system, 600 tons of Hydrogen could power nearly 100 Fuel Cell Urban Transit Buses, which runs 250km a day. If the generated CNF is used to further harvest the Hydrogen, ~1,000 tons of Hydrogen could be generated to power approximately 160 buses.

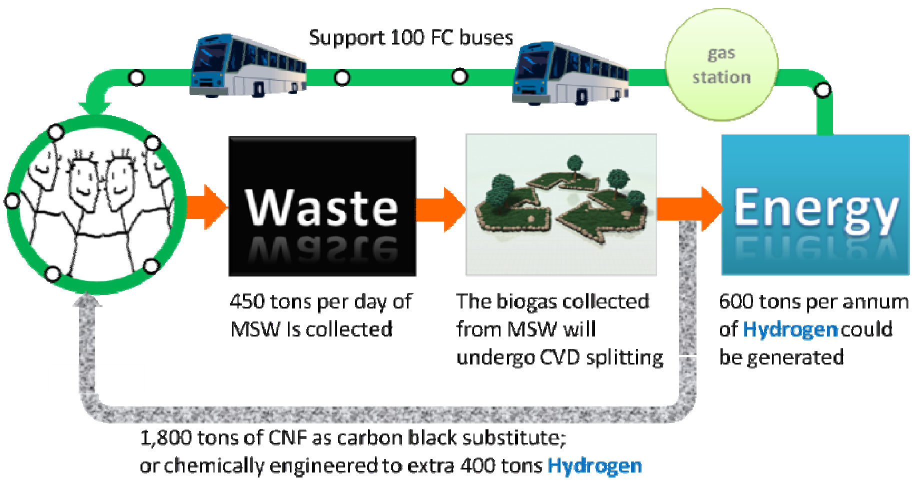

Figure 6 The concept of Waste to Energy

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