TECHNOLOGY INTELLIGENCE

FIRST LOOK

An initial evaluation of emerging technology topics

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SUBJECT: Hydrogen Production by Plasma Processing of Municipal and Other Wastes

PURPOSE: Provide background and context on a technology for producing large quantities of renewable H_2 from waste materials

SUMMARY:

- Plasma processing of Municipal Solid Waste (MSW) in the US could supply 20%-40% of H_2 required to meet today's total Vehicle Miles Traveled *if the entire light-duty fleet were fuel cell vehicles*.
- Plasma processing of agricultural wastes could supply this much or more additional H_2.
- Plasma processing of all MSW in the US would increase electricity demand by up to 7%; at least some of this could be met by off-peak capacity.
- Siting plasma-processing units at existing landfills would provide local H_2 generation capacity proportional to population and close to demand, mitigating some H_2-economy infrastructure issues.
- A significant fraction of MSW (60-66%) comes from renewable sources.
- In addition to providing large quantities of H_2, plasma processing of MSW reduces landfill volume by 99% and mass by 89%, mitigating landfill problems.
- Plasma processing might represent a viable alternative to current disposal methods for GM's industrial waste (62,932 metric tons in 1998)
- The economics and detailed energy balance of H_2 production by plasma processing of MSW require further investigation.

IMPLICATIONS:

- If detailed economic and energy analyses are favorable, plasma processing of MSW could eventually provide an attractive source of meaningful quantities of H_2 for vehicle propulsion.

SOURCE ASSESSMENT: Discussions with Westinghouse Plasma Corporation and Startech Environmental Corporation, company websites, and independent analysis.

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Initial Assessment

Hydrogen Production by Plasma Processing of Municipal and Other Wastes

Introduction
In this report, we review and analyze the potential of using plasma processing (or plasma gasification) as a source of renewable H_2 created from *existing waste streams*. The following abbreviations will be used in this report:

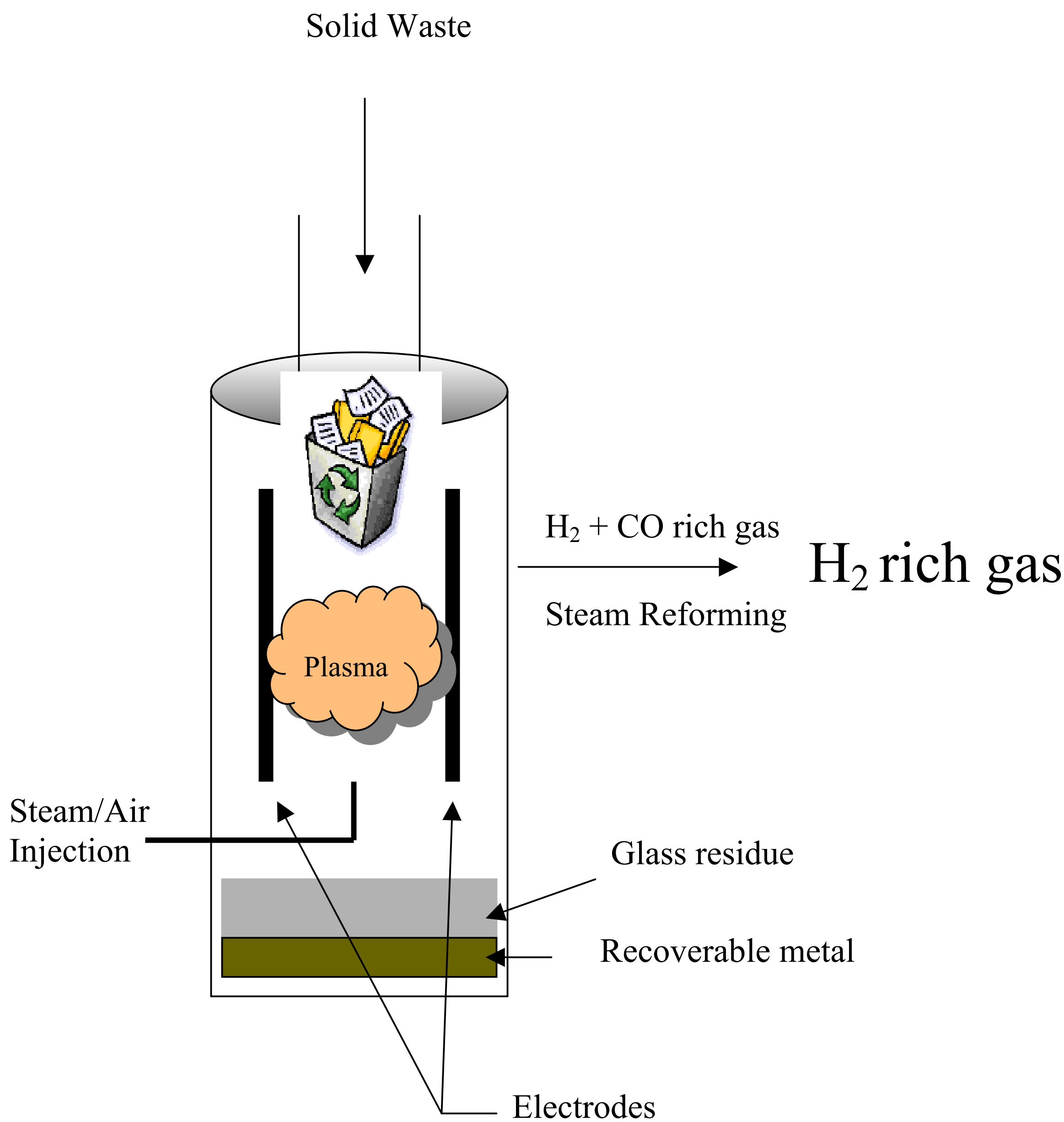
ASR – Automotive Shredder Residue
MSW – Municipal Solid Waste
SEC – Startech Environmental Corporation
VMT – Vehicle Miles Traveled
WPC – Westinghouse Plasma Corporation

Plasma Processing
Industrial plasma processing has been used for decades as a method to recycle scrap metal. For example, a plasma melt system has been in operation at GM's Defiance plant for approximately 13 years. More recently, plasma processing has been commercially developed to destroy hazardous waste (e.g., medical wastes, PCBs, etc.). Plasma processing of conventional municipal solid waste (MSW) is just starting to attract attention.

Plasma processors operate by generating an electrical arc between electrodes, often in an oxygen-free or oxygen-reduced atmosphere. **Figure 1** shows a simplified diagram of a plasma processing system. Under intense plasma conditions, complex solid feed materials are reduced to much simpler materials. Metallic materials condense to raw metals and can be recovered; other inorganic materials are reduced to inert solids (e.g., glasses) that can be safely landfilled or used as construction materials. Organic materials are converted to simple gaseous products: H_2, CO, CO_2, and CH_4.

Plasma processing of MSW typically reduces the waste volume by more than 99% and the waste mass by about 90%. The output gas stream volume is approximately 25 standard cubic feet (scf) of gas per pound of waste. Significantly, this gas stream has an energy content of approximately 260-290 BTU/scf[1]. The energy content of the output gas and the required plasma energy vary with the amount of water in the input stream. Startech Environmental Corporation (SEC) claims the energy of the output gas stream is approximately four times the electrical energy needed to operate the plasma processor[1]. Westinghouse Plasma Corporation (WPC) has provided separate numbers on energy and mass balance for one set of plasma processor operating conditions that show an even more favorable energy balance. **Table I** shows the makeup of the output gas mixture. WPC values were based upon a complete mass and energy balance. WPC reports that H_2 concentration in the output gas stream can be dramatically increased by increasing the

Figure 1. Plasma Processing of Waste



added water and plasma energy. In principle, the CO in the output gas stream can be converted to H_2 and CO_2 via steam reforming to yield an overall H_2 concentration in the range of 30 to 75%.

Table I. Plasma Conversion Gas from MSW

Gas	Volume Percentage of total (SEC)[1]	Volume Percentage of total (WPC)[2]
H_2	40 - 60%	9.4
CO	20 - 35%	23.9
CO_2	3 – 6%	2.1
N_2	5 - 15%	40.8
O_2	0 – 2%	
CH_4	0 – 3%	
H_2O		22.1
Other		1.7

MSW in the United States

The average person in the US generates approximately 4.5 pounds of MSW per day[3]. Overall the US population generates 4.64×10^{11} pounds/year of waste[4]. We have used these well-defined values to calculate the potential for MSW as a source of H_2. We provide separate estimates below based upon independent data provided by SEC and WPC.

Using the reported quantities of MSW with output gas information provided by SEC, we estimate that plasma processing could produce 2.29×10^{10} kg/year of H_2. Assuming fuel-cell vehicle fuel economy of 50 miles/kg-H_2, the total vehicle miles traveled (VMT) using this amount of H_2 would be 1.15×10^{12} miles annually. This represents 43% of the 2.69×10^{12} miles traveled in the US in 1999[6]. The estimated electricity required for this processing is 8.1×10^{11} MJ/year, approximately 7% of the CY2000 US electricity produced. These estimates assume that CO in the output gas stream is steam reformed to H_2 using waste heat from the plasma process.

Using the values provided by WPC, we estimate that plasma processing could produce 1.2×10^{10} kg/year of H_2. This represents 22% of the total H_2 needed to fuel a fuel-cell vehicle fleet for 1999's US VMT. The electrical energy needed to generate this H_2 is 1.21×10^{11} MJ/year, representing 1% of the US total electric production. (This calculation uses data from a WPC facility in Southeast Asia; the composition of MSW in Southeast Asia is not known.)

In both cases, the additional electric demand could be met, at least in part, with excess US electrical power capacity available during off-peak demand times if the penalty of underutilizing the capital investment of the plasma processors was acceptable (i.e., by restricting plasma processing operation to off-peak hours).

The composition of MSW as reported by the EPA is shown in **Table II**. In this table, renewables are defined as yard waste, wood, food waste, and paper. These represent approximately 66% of the total MSW generated in the US before recycling takes place. As such, these are renewable sources of H_2 and are themselves CO_2-neutral. Including the energy required by the plasma, there will be a CO_2 burden associated with the conversion of these materials to H_2. However, the overall lifecycle of converting the renewables in MSW to H_2 should have a dramatically lower CO_2 production rate than the production of H_2 from existing fossil fuel sources.

In the US, a fraction of MSW is typically separated and either composted or recycled, and therefore does not go into landfills. Of the 231.9 million tons of MSW generated in the US in 2000, 162 million tons were deposited in landfills. In a H_2 production scenario that relies upon plasma processing of MSW - in itself a form of recycling - the separation of yard waste, paper, and wood might be discontinued, representing a cost savings to municipalities that currently employ the additional effort and transport costs associated with this step. If we recalculate the amount of H_2 that could be generated from only the landfilled MSW, the percentage of current VMT that can be supplied from MSW is reduced to 30% using SEC's numbers and 16% using values from WPC. Electric energy requirements are also reduced proportionately.

Table II. Composition of MSW[5]

Material	Concentration (%) Pre- Recycling	Concentration (%) Post-recycling
Yard Waste[a]	12.8	7.4
Wood[a]	5.5	7.5
Food Waste[a]	11.2	15.6
Paper[a]	37.4	29.2
Plastic	10.7	14.4
Metal	7.8	7.2
Glass	5.5	6.1
Other	9.9	12.6
Total	100.0	100.0
[a]Renewables	66.1	58.2

Plasma systems could also be used to process other sources of waste, such as industrial wastes (both hazardous and non-hazardous) and medical waste, which are not included in the above calculations. These additional sources of waste would further contribute to the H_2 supply. The US EPA reports that 7.6×10^9 tons/year of industrial waste goes to landfill. However, the composition of this waste (and the amount of H_2 per ton of waste) differs from that of MSW.

Agricultural Wastes

Agricultural wastes could be used to supplement MSW in the production of H_2. We have chosen one source of agricultural waste as an example to estimate the potential for additional H_2 production.

The US generates roughly twice as much corn stover as MSW. It was projected that the US would plant 79 million acres of corn in 2002. Corn stover is generated at a rate of roughly 5.75 tons/acre, yielding an overall mass of 4.5×10^8 tons of stover. It is likely that, on a pound-per-pound basis, plasma gasification of corn stover would generate more H_2 than MSW because MSW contains metals and other inorganic materials. However, assuming that corn stover would generate equal quantities of H_2 as MSW, and assuming that only 75% of all corn stover is collected and processed, it would represent an additional source of H_2 equal to 1.6×10^{10} to 3.4×10^{10} kg (i.e., 2.28×10^{12} to 4.8×10^{12} MJ/year) using values from WPC and SEC, respectively. This represents an additional 30-63% of the total need for today's VMT.

GM Industrial Waste

GM processed 62,932 tons of industrial waste in 1998. Of this amount, 38% was landfilled, 32% recycled or re-used, 18% was incinerated, and 8% was treated for energy recovery. Typical industrial waste streams from GM include batteries, process solids and sludges, demolition waste, PCB equipment, and waste oils. Some of these waste streams might be candidates for plasma treatment for H_2 production and/or represent cost-reductions for hazardous waste disposal, thereby providing another synergistic opportunity for plasma processing technology.

Synergies With a Future H_2 Infrastructure

There are currently 155 operating oil refineries and 1,967 operating landfills in the US. Unlike the geographical distribution of oil refineries, landfills are roughly distributed to be proximal and proportional to population density. This is true because landfill space must be available to accommodate the generation of MSW, which is proportional to population. As such, the siting of plasma processors at existing landfill sites would provide H_2 generation capacity that is proportional to population density and local to population centers. This has the potential of dramatically reducing the requirements for construction of new infrastructure to support the distribution of H_2. To the extent that new infrastructure is not needed, this overcomes a major hurdle in the transition to a H_2 economy.

Economics of H_2 Generation Via Plasma Processing

WPC provided a detailed breakdown of costs for a $10M facility in Southeast Asia that is capable of processing 13.2 tons/hour MSW, as shown in **Table III.** Using these values, we calculate the operating costs of processing MSW to be $11/ton (after credits for the sale of recovered slag and metal) and $18/ton without consideration for these credits. Using WPC's capital costs amortized over 15 years at 10% interest and 100% plant utilization, the capital costs are $11/ton, yielding an overall cost for MSW processing of $22 to $30 per ton. These costs do not include credits for selling recovered energy. The national average tipping fee for MSW disposal in the US in 2002 was $34/ton.[7]

Based upon the values provided by WPC, we have also calculated the costs of producing H_2 from MSW, also shown in **Table III**. This table shows only the costs for H_2 produced directly by the plasma process. The table does not include the costs for additional H_2 that can be produced by steam reforming of CO (which is also produced directly from plasma processing of MSW) nor does it include the costs associated with purification of the H_2. Given these constraints, we estimate the H_2 production costs to be between $1.16 and $1.87/kg, depending upon the value assigned to the slag and metal co-products.

Table III. Costs for Plasma Processing of MSW

Item	Costs ($/ton of MSW)	Costs ($/kg H_2)
Coke	$5.02	$0.318
Flux	$0.32	$0.020
Labor	$3.78	$0.239
Electrodes	$1.36	$0.086
PGR Maint	$1.82	$0.115
Water	$0.14	$0.009
Plasma Elec	$4.94	$0.313
Misc Elec	$1.00	$0.063
Slag	-$2.12	-$0.134
Metal	-$5.29	-$0.335
Capital	$11.13	$0.704
Operating Costs	$10.97	$0.694
Operating Costs (without credits)	$18.37	$1.163
Total Costs	$22.09	$1.398
Total Costs (excluding credits)	$29.50	$1.867

Companies Involved in Plasma Processing

Several companies involved in developing systems for plasma processing of waste are listed in **Table IV**. In addition to these companies, there are others not on this list that focus more on treatment of other types of waste (e.g., PCBs, medical, etc.).

WPC (a spin-off of the old Westinghouse Electric Corporation) built the plasma arc metal melters at GM's Defiance plant. They have also built three plants in Japan for Hitachi Corporation, two for gasification of MSW and/or ASR[8]. WPC also designed a 300 ton/day energy facility for a customer in Europe that will utilize a feed stream consisting of a blend of MSW and industrial waste. In addition, WPC has also been developing plasma systems for the gasification of coal and the pyrolysis of natural gas to H_2.

Table IV. Companies Developing Systems for Plasma Processing of Waste

Company Name	Location
Westinghouse Plasma Corporation	Madison, PA
Startech Environmental Corporation	Wilton, CT
PEAT International, Incorporated	Northbrook, IL
Integrated Environmental Technologies, LLC	Richland, WA
Resorption Canada Limited	Gloucester, Ontario, Canada

Summary

Plasma gasification is an emerging technology for the disposal of many kinds of wastes. It shows promise as a significant source of renewable H_2 when used to process waste streams that are high in organic content, e.g. MSW and agricultural wastes. Preliminary analysis presented here suggests that a large fraction of total future H_2 needed for transport fuel could be met from MSW and/or agricultural wastes processed with this technology. If plasma processors were employed at existing landfills, the H_2 produced would be proximal and proportional to demand. An associated environmental benefit of the technology is the substantial reduction in landfill mass and volumes. Based upon the values provided by WPC, plasma gasification appears to provide an economical means for H_2 production.

Recommendations

Plasma gasification should be thoroughly investigated to better determine its potential as a H_2 source. This technology is also promising as a source of renewable electricity using either the pure H_2 in a PEM fuel cell or using the mixed syngas with other existing generation methodologies. In considering this technology as a potential source of H_2, careful engineering assessment of the energy balance will be required, with particular attention paid to the additional requirements for steam reforming and H_2 purification. This will likely require visiting one or two companies to work with their engineers to clarify some of the more complex assumptions and calculations needed. Most companies (with the exception of WPC) have insisted upon non-disclosure agreements (NDAs) before key information would be divulged. Signing NDAs or entering into some type of more formal collaborative agreement will probably be required to gather the data necessary for a more detailed assessment.

References

1) Discussion with David Lynch and Karl Hale of Startech Environmental Corp.
2) Discussion with and data provided by Dan Lazzara of Westinghouse Plasma Corporation.
3) EPA website: www.epa.gov/epaoswer/non-hw/muncpl/facts.htm
4) EPA website: www.epa.gov/epaoswer/non-hw/muncpl/report-00/exec-00.pdf
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