Plasma Torch Process for Hydrogen Production at Small Distributed Stations

George H. Miley[*], William C. Gough[**], Xiaoling Yang, Joshi Shrestha and Hugo Leon

University of Illinois, Urbana-Champaign Campus
Department of Nuclear, Plasma and Radiological Engineering, Urbana IL, USA
[*]Corresponding author: ghmiley@illinois.edu
[**]Emeritus CEO FMBR, 442 Knoll Drive, Los Altos, CA 94024, USA

ABSTRACT

Hot plasmas offer an efficient method to carry out a number of advanced industrial processes such as water process, hydrogen production, and materials recycle. Here we discuss use of a unique Inertial Electrostatic Confinement (IEC) plasma jet for these processes. In the case of hydrogen production, water is completely dissociated in the ultra hot jet plasma and then the ions mass is separated along with recovery of their excess energy, yielding pure gas products and electricity. For waste processing, the ultra hot plasma treatment produces syn-gases, coke and electrical products. The IEC plasma jet unit and its use for industrial processing are described here. While initial small distributed units would use electrical input, future large plants are envisioned to use a fusion powered unit.

Keywords: plasma processing, hydrogen production, plasma hydrogen production, plasma jet, Inertial Electrostatic Confinement.

1 INTRODUCTION

The electrically driven plasma torch for materials processing and hydrogen production proposed here is motivated by a longer term version of a fusion driven unit. Indeed, nuclear sources, both fission and fusion, have been proposed for electrical generation and can also be applied for high temperature electrolysis or thermo-chemical decomposition [1, 2]. However, in view of the extremely hot plasma in a fusion reactor, better processing efficiencies appear possible if the plasma can be used directly for hydrogen production rather than degrading the plasma kinetic energy to heat. Such an approach is considered here. It relies on the identification of a fusion concept that can both offer a compact design and allow plasma to be extracted out of the main fusion chamber into a process region. Fusion reactor designs under consideration today are typically based on Tokamak magnetic confinement. However, that leads to very large and expensive systems. For small compact fusion plants, an alternate confinement system that reduces the reliance on large external magnetic field coils is required. Among the possible approaches, the Inertial Electrostatic Confinement (IEC) fusion device is inherently small, simple to construct and can achieve an order of magnitude higher temperature than possible with other plasma devices such as arcs (Figure 1). In addition, as part of prior studies of it's use as a space thruster, a method to extract the plasma from the IEC in the form of a flowing plasma jet has been developed. This jet provides an effective way to flow the hot plasma into a chamber where material vaporization or water dissociation can be performed. In view of these attractive features, an IEC fusion torch concept for hydrogen production and waste treatment recycling was recently proposed [3, 4]. This concept follows from the original fusion torch concept for material recycling [5], but posses more unique features through incorporating use of an IEC for plasma generation. In addition to processing applications, the IEC has other far reaching implications, e.g. it has also been proposed as a vital component in the future power mix needed for a sustainable global society.

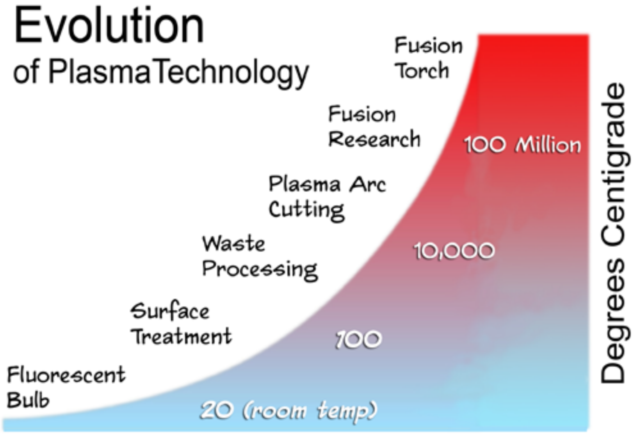

Figure 1: The fusion torch and research devices such as the electrically drive IEC plasma are orders of magnitude hotter than arc type plasmas currently used for waste processing.

2 PLAMSA TORCH CONCEPT

The IEC-fusion-torch system proposed in Ref. 3 uses the hydrogen-boron (p-B^{11}) fusion fuel cycle. When burned, unlike D-T fusion which releases 80% of its energy in neutrons, p-B^{11} yields 3 energetic alpha (helium ion) particles. This fuel is ideal since neutron activation and tritium contamination of the materials are avoided. However, burning it requires much hotter plasmas and better confinement that is possible with the Tokomak concept [6]. Fortunately, research now shows that p-B^{11} fusion is possible in the IEC configuration [4]. The IEC is well-suited for this demanding task due to its characteristic non-Maxwellian plasma and potential trap physics which make sustainment of recirculating high energy ion beams. In addition, as already noted, the hot plasma can be conveniently coupled out via a jet-like electrostatic "divertor" into the processing region.

Indeed, the required ion temperature conditions for burning p-B^{11} have already been achieved in experimental IECs at several labs [6]. However, the confinement time and the stability of its non-Maxwellian plasma must be maintained at higher power levels. This appears possible with a carefully controlled ion-injected type IEC, and this approach is currently under study at several IEC labs, including the University of Illinois [Figure 2]. There are now a half dozen small but active p-B^{11} research programs in the United States.

The use of p-B^{11} fusion has many practical advantages for industrial processes. In addition to minimal involvement of radioactive substances, the fuels required are readily available. Hydrogen for the reaction would be extracted as a small side stream from the main hydrogen production in the plant. The Boron required is abundant and ubiquitous. For fusion, the isotope B^{11} is needed, and fortunately this isotope represents 80% of natural boron. Most people are familiar with household use of Borax and boric acid; but the biggest industrial use of borates is in the glass industry. Last year's world's output of boron was equivalent to the production of about 84 quad of fusion energy of which over 20 quads is the U.S. share, compared to the total U.S. energy consumption of 100 quads.

3 MATERIALS PROCESSING

The concept of injecting, vaporizing and ionizing materials in hot plasmas has been widely studied for some years and the physics and engineering of this process is well understood. The remaining challenge is to do this on a large scale with multiple materials.

The use of a plasma process for ionizing materials is well suited for subsequent separation into basic elements. Various electromagnetic processes similar to large scale mass spectrometers can be conveniently applied to the flowing plasma containing the ions. Following disclosure of the torch concept in Ref. 4, researchers have reported at least nine different separation processes may be compatible with the fusion torch.

In addition to materials processing, the IEC torch can also be used for water dissociation to produce hydrogen [4]. In this process, water is completely ionized in the high temperature flowing plasma. The ions are then separated out and ultimately recombined into hydrogen and oxygen using a modified electrostatic direct collection section inserted into the diverted plasma column [4, 6]. In the process, the excess energy carried by the ions is electromagnetically converted into electrical output, greatly improving the overall plant efficiency. The other unburned fusion fuel species and reaction products ("alphas particles", i.e. helium) are also divided into separate streams and their excess kinetic energy is also directly converted to electricity by the electrostatic converter. This approach potentially offers several key advantages over high temperature electrolysis. Very pure hydrogen and oxygen are obtained with high conversion efficiency. Also, excess (waste) energy involved in the ionization process is directly converted to electricity at a high efficiency, allowing a hybrid hydrogen-electrical plant.

4 NEAR-TERM ELECTRICALLY-DRIVEN IEC JET PLASMA FOR WASTE PROCESSING AND HYDROGEN PRODUCTION

To this point, we have assumed use of a p-B^{11} power source for large p-B^{11} fusion torch plant to implement a full hydrogen society. In order to rapidly move ahead on a near term basis, we now propose use of a non-fusing electrically driven IEC for the torch. Such a unit would have the same basic IEC geometry, but would require purchase of electricity to power it. This makes it possible to use present laboratory type IECs as the basis for scaling up to commercial units. While the economics of such a unit would not be nearly as attractive as a p-B^{11} plant, preliminary estimates indicate that such units would still be economically competitive with plasma arc processes already in use at several sites for treatment of city wastes [8].

Electrically driven units would be restricted in size to < 100 MW due to power demands, but this would still provide a network of small distributed H_2 production units. An added advantage is that experience gained from the electrically-driven units would hasten development of p-B^{11} plants since many of the technological issues carry over.

In the following, we discuss a next step bench scale device to build up the database needed for design of commercial scale small hydrogen stations and also waste processing plants.

5 BENCH SCALE DEVICE CONSTRUCTION

A step-wise development plan starts with small bench scale studies and culminates a full size plant. The bench scale experimental device is illustrated in Figure 2, along with an exhaust plasma channel where water is injected into the plasma stream. The resulting ions flow into and are separated by a quadrapole mass analyzer. For this initial proof-of-principle demonstration, the IEC is run in an electrically-driven mode rather than using a fusion reactor as will ultimately be done in the full scale hydrogen plant.

The physics behind this experiment can be briefly described, as follows. The spherical grid in Figure 3 is surrounded by a vacuum vessel. Gas injected into this vessel builds up to 10s of Torr pressure after which a –50 kV potential is applied to the grid. A plasma discharge develops between the grid and the chamber wall. Ions from the discharge are extracted by the biased grid and accelerated through the grid openings. Due to spherical focusing the ions are directed toward the center of the vessel where the increased volumetric charge density creates a small region (“core”) of high positive potential. Ions passing (scattering) through the center region continue to the opposite side until they reach the potential surface they were originally born on. At that point, their kinetic energy has been converted to potential energy, and they reverse directions repeating this motion, further building up the central core density and potential, ultimately developing a “virtual” anode around the central plasma “core” [7]. This virtual anode accelerates electrons through the center core region in a manner analogous to the original ion motion.

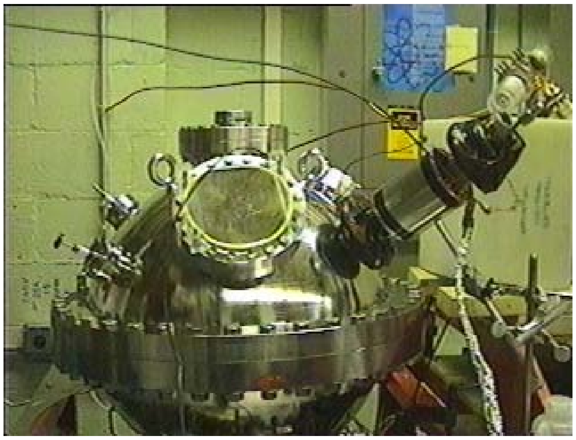

Figure 2: Photo of an ion injected IEC experiment

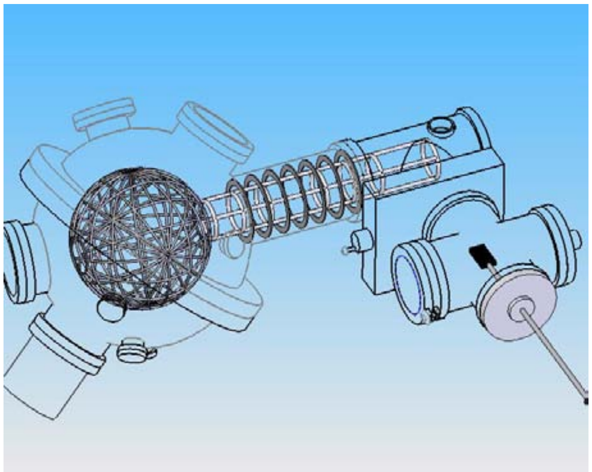

Figure 3: Design of 2-kW experimental IEC plasma jet unit. A material sample (shown withdrawn) is inserted in the jet plasma. Off-gases exit through tubing at the top of the interaction region.

In this case, however, the electrons create a negative potential in the center, which traps transient ions, causing the center core plasma density to increase yet higher. This unique formation of “virtual” electrodes and potential wells was first discovered by Philo Farnsworth, inventor of electronic television. Such devices have frequently been termed the Farnsworth “Fusor” [7]. Miley and co-workers have extended these concepts to grid designs that create ion beams passing through grid holes (termed the “star mode”) which are employed in the plasma torch version. This mode of operation has the important advantage that ion bombardment of the grid and associated sputtering are drastically reduced. They also found that increasing the size of one of the grids allows extraction of a plasma “jet” from the central IEC core plasma. This jet forms a flowing plasma channel where the water is injected and ionized [Figure 3]. In summary, the bench test of Figure 2 is intended to demonstrate the efficient ionization and separation of hydrogen and oxygen injected into the flowing plasma.

A current ion injected IEC experimental device is shown in Figure 3. This unit is combined with the jet extraction grid to form the torch showed in Fig. 2. A next step in the R&D would add an electrostatic energy conversion and mass separator section to demonstrate the efficient separation of elements and recovery of excess energy. The database obtained would allow the construction of a demonstration electrically-driven IEC hydrogen station.

6 CONCLUSION

The development of an electrically-driven IEC plasma torch hydrogen station is proposed as a logical first step towards a future p-B^{11} IEC fusion hydrogen economy. The IEC plasma torch hydrogen station appears to have attractive features compared to other competing technology. It offers higher efficiencies than direct electrolysis units. Other industrial plasma processing generally employ various arc processes [8]. In contrast, the IEC plasma jet opens the way to much higher temperatures and larger process volume. Also, the incorporation of electrostatic mass analysis and energy recovery in the exhaust channel introduces the possibility of new processes, such as hydrogen production and materials recycle. Construction of a pilot plant unit to study and verify these processes is identified as the next step before full scale implementation of the electrically-driven IEC plasma torch technology. Such units appear well suited for use in small distributed H_2 "filling stations".

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