Highly Efficient Hydrogen Generation via Water Electrolysis Using Nanometal Electrodes

Submitted 15 September 2006

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Energy supplies in the 21st century will be challenged as fossil fuel reserves decline, human consumption increases, and greenhouse gasses accumulate to further damage the atmosphere. These challenges will be met by innovative solutions to enable the hydrogen economy; to replace petrochemical fuels with hydrogen for use in fuel cells and internal combustion engines. One of the most difficult challenges is to produce hydrogen at a cost competitive with current fuel pricing (fossil or natural gas). QuantumSphere Inc. (QSI) has developed a disruptive technology to increase the efficiency of water electrolysis, utilizing its capability to manufacture high surface area nanometal particles (3-50 nm) by a scalable process. QSI has developed a unique electrode structure for alkaline water electrolysis by capitalizing on the enhanced surface area and catalytic reactivity of its nanometal catalysts. To date, QSI has already met the US Department of Energy (DoE) 2010 technical target of 75% hydrogen generation efficiency while eliminating the need for platinum precious metal catalysts which further reduces electrolyzer cost.

I. INTRODUCTION

A volume of references speak to the supply and demand challenges of fossil-based fuels, including the decline in the discovery rate of major new oil deposits, the growing rate of energy consumption in the developing world, and the geopolitical ramifications of unstable foreign oil sources. Likewise, there is mounting scientific evidence of impending devastating global climactic changes caused by the release of greenhouse gases which are produced as a byproduct of fossil fuel combustion. The need to develop economically viable clean-energy sources is one of the critical challenges of our time. The efficient production and use of hydrogen as an energy storage medium is a key element in developing clean fossil fuel alternatives. This paper will review the current state of the art for hydrogen production and emphasize the ground-breaking development QSI has made in producing pure hydrogen from water.

Roughly 98% of the current hydrogen generated worldwide is prepared by steam reformation where steam is used to produce hydrogen from methane, typically derived from natural gas. To date, it is the most cost-effective method of hydrogen production. However, natural gas is not a renewable form of fuel and will only increase global emissions of carbon dioxide unless a highly efficient method of sequestration is developed. Conversely, electrolysis uses energy to dissociate hydrogen and oxygen from water:

$$\mathbf{H_2O \rightarrow H_2 + \tfrac{1}{2}O_2 \qquad E_o = 1.229\ V}$$

This event will occur on any conductive surface. When the proper amount of energy is applied, however, certain materials such as high surface area metals are more efficient and consume less energy to produce a given amount of hydrogen. The precious metal platinum has shown great activity for water electrolysis, attaining over 50% efficiency. Using electrodes composed of QSI nanometals, QSI has achieved up to 80% efficiency at lower current flow rates (100 mA/cm^2) and approximately 60% efficiency at higher rates (1000 mA/cm^2). Over the next year, QSI believes it will achieve or exceed the DoE 2010 target of 75% efficiency at rates beyond 1000 mA/cm^2 through further optimization.

A common parameter describing the economics of hydrogen production is often reported as "$/gge" which relates the cost to generate the hydrogen for an equivalent amount of energy contained in a gallon of gasoline; thus a "Gallon of Gas Equivalent" ($/gge). The cost of electricity is a significant variable in this calculation for electrolysis methods and one of continuous change. Many researchers express energy efficiency as a percentage calculated from the energy contained in the resulting hydrogen divided by the energy it takes to make that hydrogen. This is a more directly comparable unit of electrolysis efficiency, since it is independent of assumptions regarding electricity and delivery costs. For consistency, this paper will express hydrogen generation in terms of percent efficiency.

II. RESULTS

QSI uses its high surface area metallic nanoparticles as liquid and gas diffusion electrodes for water electrolysis by compression and sintering into porous plates. They have an expanded metal surface facing away from the electrolyte for strength and current collection. **Figure 1** shows a scanning electron micrograph of a porous electrode (nanoparticles on a metal particle substrate) and a transmission electron micrograph of the individual nanoparticles. These electrodes have tortuous pathways within them to expose orders of magnitude larger surface area to reacting water and to also allow the escape of the gaseous products. Electrolyte flows through the electrode to sweep away the bubbles as they form. The reference electrode is a zinc wire and the electrolyte is eutectic KOH (33% aqueous). Sweeps are accomplished using Solartron SI1287/SI1230 paired electrometers. **Table 1** summarizes the measured data in tabular form at specific operating currents, comparing QSI electrodes versus typical electrodes. These porous electrodes are being evaluated both in house and by a third party (DoppStein Enterprises [DSE] of Marietta, GA). The data shows high reproducibility.

Figure 1. a) Picture of QSI porous electrode used in electrolysis b) SEM image of surface of electrode, and c) TEM image of 5 nm QSI nanoparticles.

a) Porous Electrode *b) Surface of Electrode (nanoparticles on a support)* *c) 10 nm particles in electrode*

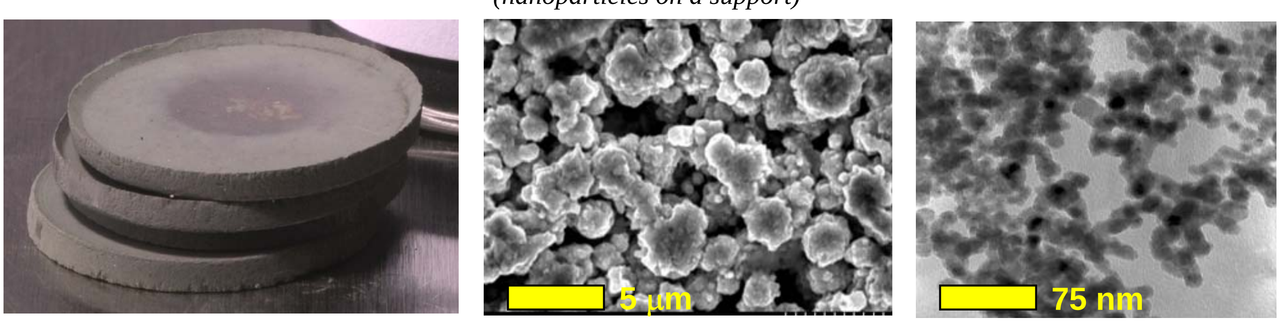
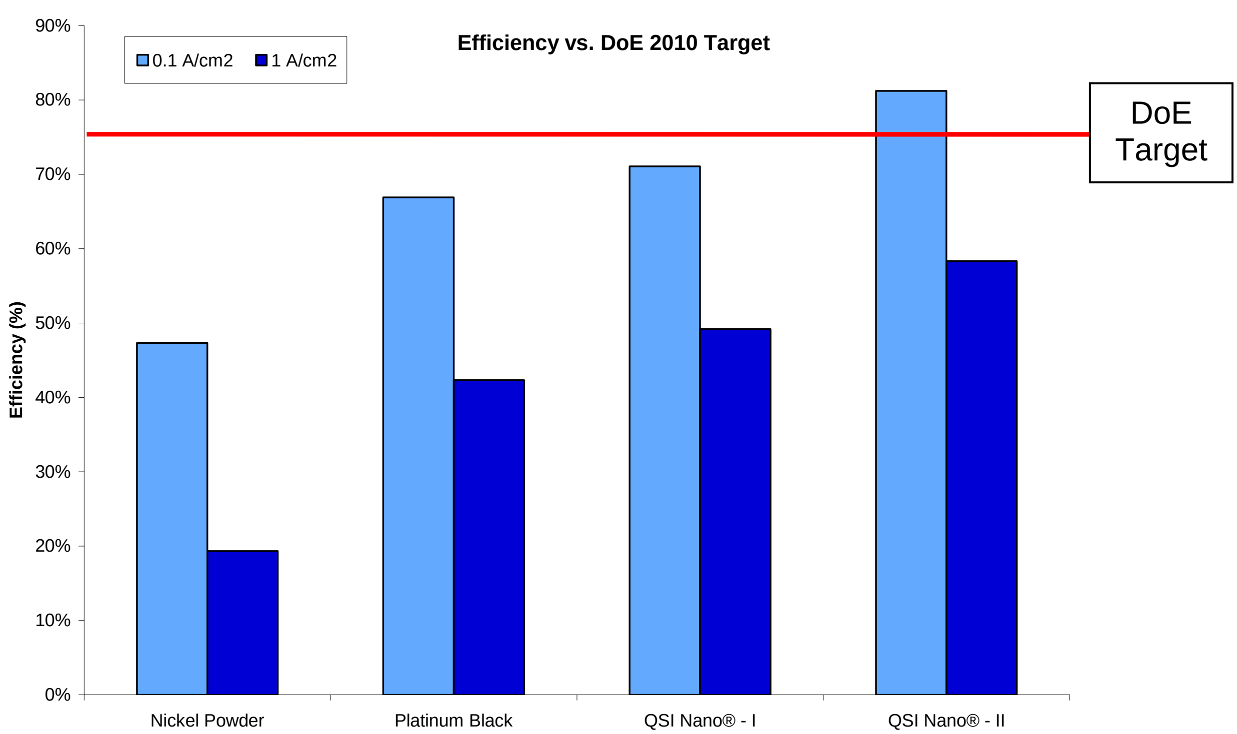


Table 1: Conversion efficiency for several electrodes. Electrodes prepared from high surface area nanometals demonstrate the best performance (QSI Nano® I and II).

Electrode Type	Conversion Efficiency 0.1 A/cm^2	Conversion Efficiency 1 A/cm^2
Nickel Powder	46%	19%
Platinum Black	67%	42%
QSI-Nano® -I	**71%**	**49%**
QSI-Nano® -II	**81%**	**58%**
DoE 2010 Target	75%	75%

Figure 2 represents the same data as a direct comparison to the 2010 DoE efficiency target. Despite that this new class of electrode is in early stage development, the efficiency target of 75% is exceeded in the low current case and is almost met in the high current case. For further details of the experimental design and electrochemical data, please contact QuantumSphere.

Figure 2. Efficiency of QSI Nano®-Electrodes versus DoE 2010 target.



III. Summary

QuantumSphere has developed novel alkaline water electrolysis electrodes that utilize high surface nanometals which are manufactured in-house. As of September, these electrodes have successfully met the DoE 2010 efficiency target up to roughly 300 mA/cm^2 and are only improving. We are confident that we will substantially surpass the DoE 2010 efficiency goal at current density this year, as the above results are only initial findings and results should improve dramatically as the nanometals and alloys are optimized for the electrode composition.

IV. Next Steps

- Optimize nanocatalyst composition and peripheral equipment to exceed efficiency of single electrolysis cell by 75% at current densities exceeding 1 A/cm^2
- Fabricate an optimized multi-cell alkaline hydrolysis stack
- Select and initiate discussions with an industrial or governmental development partner to realize a commercial electrolyzer by 2008-09

About QSI

QuantumSphere is a leading manufacturer of nanoscale metals and alloys for applications in renewable energy, electronics, aerospace, defense and other markets demanding advanced materials. The Company's proprietary technology enables the production of ultra-pure, highly uniform nanometals and alloys under 50nm in high volume at commercial prices to unlock a large number of new applications and sources of revenue for firms around the world. The Company has also created an extensive intellectual property portfolio around its process capabilities and end-use commercial applications. From R&D to ROI, the company is leveraging its leading market position to manufacture and ship high-performance catalyst materials and electrode devices for clean-energy applications such as batteries, micro fuel cells for portable power, photovoltaics (solar cells) and hydrogen generation, among others. QuantumSphere accomplishes this without compromising its commitment to the environment and the community.

About DSE

DoppStein Enterprises Inc. (DSE) is an R&D laboratory located in Marietta, Georgia, working in renewable energy related fields including metal-air fuel cells, direct methanol fuel cells, and hydrogen production through water electrolysis. The President and Chief Scientist is Robert Dopp who is one of the foremost authorities on Zinc Air technology with 36 related patents bearing his name. As consultants to the fuel cell and battery industries, DSE offers a wide range of expertise and depth of knowledge in commercial systems. As an independent third party expert, DSE has validated and optimized electrodes for hydrogen, fuel cell and battery applications using cutting edge catalysts based on QSI-Nano™ metals and alloys. This joint project of DSE/QSI encompasses hydrogen generation through more efficient water electrolysis using QSI's advanced nano catalysts.

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