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Fuel Cell
---Advanced Power Generation for the 21st Century---

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Guest Forum
技術講演会

Fuel Cell ---Advanced Power Generation for the 21st Century---

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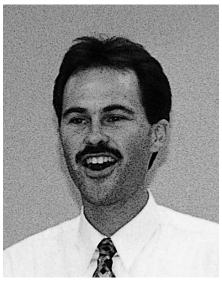

Dr. Jacob Brouwer

Dr. Brouwer is the Associate Director of the National Fuel Cell Research Center at the University of California, Irvine. He has been active in the energy field for over 12 years with extensive experience in the areas of pollutant emission reduction, advanced combustion technologies and fuel cells.

21世紀を目前にした今,燃料電池がクリーンで高効率なエネルギー源として再び熱い注目を浴びています。何故,燃料電池が注目をされているのだろうか？ どのような用途があるのだろうか？ そして,普及への道筋は？などなど---。このような疑問を持って,燃料電池および関連技術の総合的な研究開発を進める米国 立燃料電池研究センタ(NFCRC)の 副所長 Dr. Brouwerを堀場製作所にお招きし,燃料電池の最新の動向と今後の課題についてご講演いただきました。

クリーンカーをはじめとする様々の分野で燃料電池の実用化が間近に迫っていますが,一方で,解決しなければならない課題も少なくありません。より高性能で安定な電池そのもの開発はもちろんですが,同時に,パソコンや携帯電話,コージェネ発電や送電システムなどライフライン全体にわたり,それぞれの国状に応じた新たなインフラの構築が求められます。

NFCRCの創立以来のメンバーであるホリバは,得意の計測・分析技術をもって燃料電池の実用化に寄与したいと願っています。

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Fuel Cells —Advanced Power Generation for the 21st Century—

Many believe that fuel cells will be the next generation source of energy. Today I will speak about the reasons driving fuel cell research and the latest developments in the field.

<An energy source of quality and reliability>

There has been increasing concern about emissions from our energy production systems and their impact on the global environment. Urban air quality has been recognized for a long time as a problem of the industrial revolution. In the information age, power quality and power reliability are major driving forces for new energy production technology.

Energy efficiency and Building Efficiency of buildings have not been appropriately valued in the United States to-date, but, from the point of view of energy self-sufficiency, conservation and should be changed to sustainable energy they are quite important.

California, where the National Fuel Research Center (NFCRC) is located, has the environmental impetus to develop next generation energy sources because of its geography and climate. The regulations for automobile emissions are some of the strictest in the world because of the smog problem. Automobile makers are considering using fuel cells (FCs) in the next generation of vehicles sold in California. The time schedule for this is much shorter than could have been imagined 1 or 2 years ago.

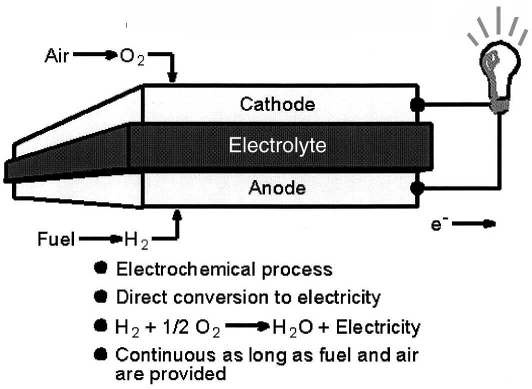
Another event that has recently occured in California is electric utility deregulation, which may open opportunities for distributed and dispersed power generation.

FCs are kind to the environment, efficient, and they are suited to distributed power generation. Significantly, California's South Coast Air Quality Management District has issued a blanket exemption for permitting FC installations in southern California. Further, when FCs are used in co-generation applications up to 90% of the fuel energy can be used.

<FC development and how FCs work>

FCs were discovered by Sir William Grove in 1839, but it wasn't until quite recently that they began to receive serious attention. In the 1960's PEMFC (Proton Exchange Membrane FC) and AFC (Alkaline FC) were used as the power source in the space program, and this is where they proved their high efficiency and reliability. PAFC (Phosphoric Acid FC) units were the first to be developed and commercialized for general use and have been installed all over the world in more than 200 stationary power plants and numerous transportation applications. Second generation FCs include MCFC (Molten Carbonate FC) and SOFC (Solid Oxide FC).

The development of FCs is picking up pace because of their consideration for use in transportation applications. A good way to understand why FCs are efficient is to look at how power is generated by traditional fossil fuel technologies. The fuel is first consumed in a combustion process generating heat (and pollutants), the heat is transferred via heat exchanger to raise steam, the steam is



Basics of a Fuel Cell

21世紀に備える優れた電力源　燃料電池

＜質と信頼性が追求されるエネルギー源＞

地球温暖化や大気汚染など, 人類が消費するエネルギーが気象に及ぼす影響が危惧される今日, 新たなエネルギー源を開拓する場合にまず, 考慮すべき課題はその質と安定供給への信頼性である。
NFCRCのあるカリフォルニアは, 地形的・気象的に光化学スモッグなどが発生しやすいため, 自動車排ガス規制は世界で一番きびしく,各自動車メーカーでは燃料電池車が次世代の乗り物として研究開発が急速に進んでいる。最近, カルフォルニア南部地域では発電や配電に関する規制緩和がなされ, 環境にやさしく, 高効率で, 分散型のFC発電設備設置への免税措置が講じられている。コージェネ方式を用いれば燃料のもつ全エネルギーの 90% もが利用可能になる。

＜ FC の開発と作動原理＞

FCは1839年William Groveにより発見され,1960年代にはプロトン交換型燃料電池(PEMFC)やアルカリ型燃料電池(AFC)が宇宙開発用の電力源として使われるようになり,高い効率と信頼性が証明された。その後,溶解炭酸塩型燃料電池(MCFC)や固体酸化物型燃料電池 (SOFC)など, さまざまなタイプのFCの研究開発が進み,特に輸送機分野への応用開発が進んでいる。

passed through a turbine to produce mechanical energy which is subsequently converted to electricity through a generator. With the FC fuel is converted to electricity in one step.

FCs work through a basic electro-chemical mechanism. An electrolyte is sandwiched between two electrodes. Air (or oxygen) and fuel (hydrogen) are passed over the electrodes, ions are transferred through the electrolyte and electricity is produced without the fuel and oxidant coming into direct contact. One cell only produces a low voltage, so to increase voltages to useful levels one connects several cells together in what are called FC stacks.

<Characteristics of FCs>

Next I want to talk about some problems that need to be overcome so that FCs can be used more widely.

Advances in FC technology have been remarkable, with lower cost designs, and technical advances and accomplishments in the various FC types. For FCs to be successful; however, the advancement of full FC systems including fuel processing and handling , power electronics , controls and other ancillary equipment is required. In fuel processing, for example, the hydrogen to be used as fuel can be made by electrolysis of water, or by passing fossil fuels such as methanol and natural gas through a reformer. Methanol is easily reformed and because it is a liquid, transportation and storage are simple.

Advances may also be required because of pollutant emission concerns which not only applies to the FC itself (its only emission is water), but to the fuel processing equipment which may emit other pollutants.

The next point to consider is power conversion, conditioning and control. FCs produce a direct current so for current end-use technologies the power needs to be converted to alternating current. Computers and other equipment already run on DC containing AC to DC transformers within each unit. With a FC one might consider operating equipment directly on DC to avoid the inefficiencies of converting the power twice. However, this would require a change in the design of these technologies (i.e., removing the power transformers). If power output could be standardized, FCs could be located in a building to supply power directly to the DC equipment, thereby increasing the overall efficiency of the FC system.

Theoretically FCs are not limited by the Carnot efficiency which provides the FC with inherent potential efficiency advantages over heat engines such as the internal combustion engine. In practice, the cost of most FC systems is a major hurdle. For instance, advanced gas turbine combined cycle plants can be installed at a capital cost of less than $500/kilowatt and produce electricity with greater than 50% efficiency. FCs can operate at higher efficiencies, but with much higher cost.

Other hurdles include infrastructure. For example, in the transportation sector there is a large fuel infrastructure in place, gas stations, etc., that is not directly useable by FCs at the moment. If the FC can be developed to enable it to use this infrastructure, widespread use in transportation applications would be more likely.

Another concern is the safety aspects of FCs. Some are concerned about the use of hydrogen as a fuel in FCs. Hydrogen is dangerous in certain mixtures with air, but in a practical comparison, a hydrogen leak would be less likely to cause an explosion than the LPG and gasoline that we use today. This is due to the high diffusivity and low density of hydrogen.

<Hybrids>

As you can see, FCs have many advantages, but I don’t believe that FCs will be our only source of power. Central utilities will continue to produce electricity using combustion (e.g., gas turbine combined cycle plants) and nuclear generating stations. In distributed and dispersed power applications I expect FCs to be used together with micro-turbines, photo-voltaics, wind energy, flywheels, ultra-capacitors, and hybrid FC-heat engine cycles.

FCは電気化学作用を動作原理としており,電解質をサンドイッチ状にはさんだ2枚の電極に空気(酸素)と燃料(水素)を供給することによって発電する。FC一個当たりの起電力が0.5Vと小さいため,実用上はいくつかを直列につないで使用する。

＜ＦＣの特徴＞

FC技術は目覚しく進歩したが,今後広く普及させるためには,燃料の製造や取扱い,パワーエレクトロニクス,制御,その他の周辺技術を含めたFC発電システム全体を発展させなければならない。
燃料用水素は水を電気分解したりメタノールや天然ガスなどを改質して作るが,中でも,メタノールは改質が容易で輸送や貯蔵の面からも有望である。但し,改質器から汚染物質が排出される可能性もある。

FCが発生する電力は直流のため,一般の電気機器へ供給するためにはDC→AC変換が必要となるが,この時のエネルギーロスが問題となる。もし,規格を統一し直流を直接利用できるようになれば,FC電力供給システム全体の効率は大幅に向上する。

FCの発電効率は,他の内燃のエンジンのようにカルノー・サイクルよる原理的な制約は受けないが,発電コストが最大の課題である。現在,ガスタービンでは$500/KW以下,効率50%以上が達成されているが,F Cではこれより高効率だがコストが障害となっている。ガソリンのような既存の燃料供給インフラを共用することができれば,FCの輸送機器分野へ展開は大きく前進するだろう。

水素がリークし爆発する危険性との指摘もあるが,水素の物性を考えると現在主流のLPGやガソリンよりもはるかに安全である。

By mixing different power generation technologies, one can optimize the performance and features best suited for each site including higher efficiency, power availability, use of renewable sources, and reliability. Examples of this include heat engine-electric hybrid systems, FC-heat engine hybrids, and solar-FC hybrids.

One concept that provides high fuel to electricity efficiencies in this context is the FC-heat engine hybrid. SOFCs, and other FCs, increase in efficiency at higher pressure. The FC-gas turbine concept involves pressurizing the FC by putting it between the compressor and the turbine of a gas turbine engine, replacing the combustor. A high temperature FC, such as an SOFC, can emit heat sufficient to drive the turbine and power the compressor. High-pressure operation of the FC increases its output and efficiency with enough thermal energy remaining in the FC exhaust to generate additional electricity through a generator. This type of system can produce electricity at remarkably high fuel-to-electricity efficiencies, theoretically approaching 80%.

<Applications for FCs>

Some of the applications being considered for FCs are power generation, transportation, processing and manufacturing, and consumer electronics.

Lets look at power generation first. The FC will likely not replace the current system of central generation, distribution and end user, but will be competitive at a much smaller scale. This scale is that often referred to as distributed or local power generation, which is amenable to co-generation and can include units with output as high as 10-50 MW. Distributed power generation will complement the current central generation system as it does, for example at the Irvine Hyatt which currently operates a 200kW PAFC plant for heat and electricity.

Many companies around the world, including most of the major automobile manufacturers are considering FCs for transportation applications, and their use is also being considered for aircraft and even bicycles.

In manufacturing and processing, chlor-alkali production uses proton exchange membrane technology, and reversible FCs can be used to produce hydrogen from water for food processing, petroleum refining and other applications. They are also being considered for use as uninterruptible power supplies (UPS).

FCs operated on hydrogen only have water as an emission, so they can be used to power consumer electronics instead of using batteries.

FCs could also be used in biological applications if a means of converting the energy in biological fluids using an FC could be identified. This means that small biological FCs could be put inside the body to power heart pacemakers, hearing aids and automated medication systems. Another idea is the possible replacement of expensive Nafion-based PEMFC electrolyte materials with a biologically produced membrane similar to that used by electric eels to produce their electric charge.

A place where FCs are already competitive is in remote applications such as satellites, high altitude aircraft, and space stations.

No one knows how the paradigm shift of electric power production will occur and how distributed power generation (DPG) will play a role, but if FCs are successful they will assist in making DPG a reality. In developing countries cellular phones are popular because they are economically feasible and wise since they avert the installation of expensive transmission wires. The desk top computers of today are the super computers of only a few years ago, decentralizing computing power in a manner that may forshadow the decentralization of electric power generation. In locations throughout the world where brown-outs are common or reliable electricity supply is not available because of bottlenecks in the utility grid the use of DPG can relieve these pressures and may provide an economically viable and environmentally sensitive approach for power generation using FCs.

＜ハイブリッド化＞

このようにFCには多くの利点があるが,私はFCが唯一のエネルギー源だとは考えていない。分散型の電力源としては,マイクロタービン,太陽電池,風力発電,フライフォイール,超大容量コンデンサ,ハイブリッド型熱エンジンなどがある。FCとヒートエンジンのハイブリッドなどは高効率発電の一つの例である。コンプレッサとガスタービンの間にSOFCを置いたハイブリッド型のシステムでは,発電効率が著しく上昇し,理論的には,燃料対電力の変換効率は80%にも達する。

＜応用例＞

様々な分野でFCの新しい用途が検討されている。

電力分野では既存の中央集中型の発電システムを補完するための小規模発電用である。NFCRCのあるIrvine Hyattでは,200KWのPAFCシステムが熱源・電力用として稼働中である。輸送分野では本命の自動車の他に,航空,自転車などの可能性もある。工場では,水の電気分解による水素の活用や,無断電源などがある。家庭用としては乾電池の代替もありえる。バイオ分野では,体内に埋め込むペースメーカーや補聴器などが研究されている。宇宙衛星,高度航空機などの分野ではすでに商業レベルで達している。

分散発電(DPG)の将来を予測することは難しいが,携帯電話やパソコンの普及が電力インフラの整備を上回っている発展途上国の方がDPGが実現される可能性は高い。

<Expansion in the developed and developing world>

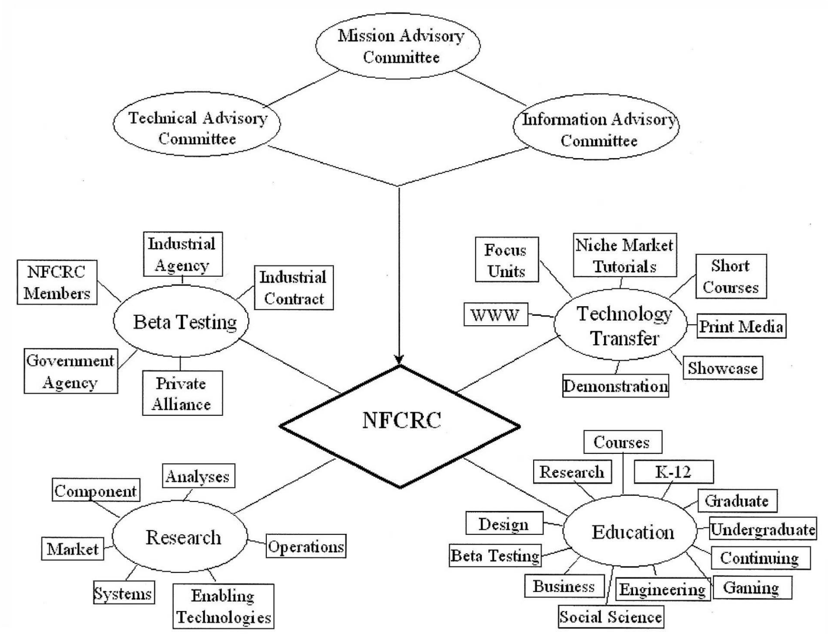
I'd like to address some differences in the use of FCs in the developed and developing world. I believe that in developing countries small modular FCs can be used to avoid large investments in infrastructure, and to build a distributed power generation system. This would be much like cellular phone technology which has been widely adopted in developing countries avoiding the investment and time delays associated with the installation of an expansive system of telephone wires. On the other hand, in developed countries where environmental regulations can be stronger, the high efficiency and low emissions of FCs make them a valid alternative. The cost of these technologies compared to the electric grid already present in these countries, however, may not lead to widespread use of FCs as distributed power generators. In space exploration FCs will continue to be used as well, where their cost is less important and their operating characteristics give FCs an advantage.

<The National Fuel Cell Research Center >

Finally I would like to introduce the NFCRC.

The NFCRC is the first total approach to fuel cell development and deployment. Its mission is to promote and support the genesis of fuel cell power generation by providing technological leadership with a vigorous program of research and beta testing, coupled with education and technology transfer to and from the marketplace. Together with its Affiliates and Members and the fuel cell community at large, the NFCRC envisions a future that meets the demands for energy generation while minimizing harmful environmental impacts with fuel cells as a major source of power.

The NFCRC is grateful for the leadership and support of Horiba, a Founding Member of the NFCRC, and looks forward to continued participation and collaboration with Horiba in the advancement of environmenally sensitive technologies.



＜先進国・途上国への展開＞

FCが普及する推進力は先進国と途上国とでは異なるだろう。途上国では,インフラ構築コストの少ない分散型発電システムとして,先進国では環境保全や宇宙開発への展開となるだろう。

＜NFCRCについて＞

NFCRCは,FCに関する研究,教育,技術移転など様々な機能を担う初めての国立のFC研究センタである。NFCRCの参加者と共に,環境への負荷を最小にするエネルギー源の実現を願っている。とくに,NFCRCの発起人であり有力メンバの一員であるホリバの活躍を多いに期待している。