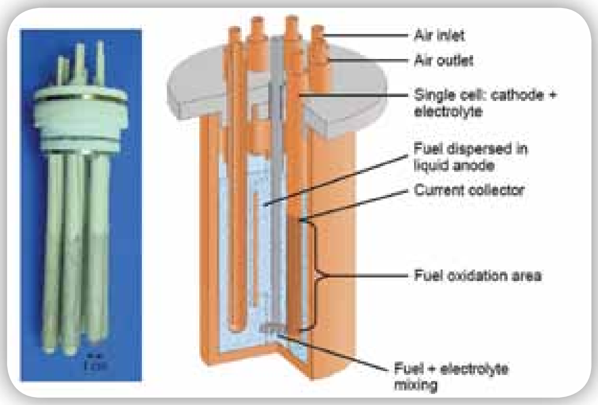
SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Coal Power Without Combustion

Sustainable energy independence in the United States depends largely on the ability to continue to make electricity from coal—by far the country's most plentiful fuel. Clean coal combustion technologies now in development, such as integrated gasification–combined-cycle (IGCC) and oxyfuel combustion systems, are expected to help secure a place for coal in the next generation of power plants. But another innovative approach may offer a simpler option for the long run: direct electrochemical conversion of carbon into dc power via fuel cells.



EPRI has evaluated SRI's tubular cell design for utility-scale direct carbon fuel application, along with designs from Contained Energy and CellTech Power. (Courtesy of SRI International)

Direct carbon fuel cells (DCFCs) have been under investigation for several years but have received less attention than fuel cells based on hydrogen and natural gas. The technological and financial risks associated with the development of DCFCs are significantly higher than those associated with their gas-fed counterparts, but the benefits could be substantial. With their potential for highly efficient, modular, clean coal conversion, DCFCs offer compelling possibilities for addressing national energy needs in a manner consistent with environmental constraints.

Potential DCFC Benefits

Efficiency is a key advantage, and in theory cell efficiencies could approach 80%. Researchers believe that when fed with a processed, devolatilized coal stock, a DCFC generation system could achieve efficiencies of 50–60%, compared with 27–43% for conventional coal systems with CO_2 capture. Efficiencies for hybrid DCFC configurations could be even higher.

The process is remarkably clean. If pure carbon is used as the feedstock, the only gas generated at the fuel cell anode is CO_2 (in equilibrium with CO), making the fuel cell exhaust stream ideally suited for subsequent sequestration. In practice, coal would require processing to minimize impurities, which could compromise fuel cell life and durability.

IGCC and oxyfuel combustion technologies also can be configured to produce concentrated CO_2 streams. But these processes are quite complex, requiring an expensive, energy-intensive air separation unit to supply high-purity oxygen. Smaller, simpler DCFC units could have much lower CO_2 separation and storage costs and reduced parasitic power requirements.

Like other fuel cell technologies, the basic DCFC energy conversion equipment is modular, which allows systems to be built in relatively modest increments (tens of megawatts). As a result, DCFC capacity could be added incrementally and provide both electric and thermal energy services in efficient and flexible distributed generation systems.

Refining Technical Assessments

Further experiments and technical analyses are needed to determine whether DCFC technology can compete economically and match the reliability of other coal-based generation options. Particular focus is needed on fuel processing requirements and system durability. Analyses indicate that the fuel cell's stack life must exceed 60,000 hours to achieve an economically acceptable levelized cost of electricity while minimizing operation and maintenance costs.

Capital costs for DCFC systems are expected to be quite high compared with conventional generation. But considering the high efficiency, environmental benefits, relatively inexpensive fuel, and extremely simple operation, the overall economics could still be competitive, permitting higher "allowable" installed costs. As with all coal-based technologies, the economics will depend substantially on how carbon emissions are valued under future climate regulations.

EPRI convened a workshop in 2006 with seven leading DCFC developers to review and assess research and potential utility applications. The assessment (EPRI document 1013362) showed that the technology is still in an early stage of research and development and that each of the technology platforms examined has its unique challenges, limitations, and development hurdles. A subsequent study (EPRI document 1016170) provided more detailed analysis and experimental testing of DCFC components and developed conceptual system designs for utility-scale (100-megawatt) plants based on the three leading DCFC platforms.

Continued research and development is warranted to advance the science of DCFCs toward practical utility applications. Early applications may use biomass as a feedstock before coal-based systems are adopted.

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New Coatings Promise Efficiency Gains for Photovoltaic Solar Cells

Elements with such unlikely names as erbium and ytterbium may help so-called third-generation photovoltaic (PV) technologies to at least double the efficiency of today's best commercial solar cells. First-generation flat-plate PVs still dominate the market, but their thin wafers of crystalline silicon are only 10–20% efficient in converting sunlight to electricity and are expensive to manufacture. Second-generation thin-film modules offer lower manufacturing costs and higher production flexibility but are far less efficient than crystalline wafer cells and have limited prospects for efficiency gains.

In 2007 EPRI, EDF, and the French National Center for Scientific Research (CNRS) joined to support a consortium of 20 international laboratories and universities in their work to identify, fabricate, and demonstrate materials and structures that could produce commercial PVs with conversion efficiencies exceeding 40%.

First- and Second-Generation Limitations

In PV cells, electricity is produced when absorption of a photon releases an electron in the cell's "p" layer (where most of the mobile charges are positive), and the electron is able to move across a junction to the cell's "n" layer (where most of the mobile charges are negative). The ability of photons to release the electron is constrained by an amount of energy known as the bandgap. First- and second-generation cells are able to take full advantage of only a small portion of the photons hitting the cell. Photons with energies less than the bandgap—most of those in the infrared range, for example—are not absorbed and not transformed into electricity. Also, the more energetic photons yield only the bandgap amount of useful energy when they are absorbed, meaning that most of the energy from these photons is wasted.

A third-generation approach called multilevel absorption uses materials that allow the PV cell to tap lower-energy photons. These materials operate as a sort of energy ladder by which absorption of low-energy photons can excite electrons across the bandgap. Research shows that this "up-conversion" of photon energies may be achieved by applying microphotonic coatings to the backs of conventional crystalline PV cells.

Promise in Rare-Earth Coatings?

The coatings are doped with rare-earth elements such as erbium and ytterbium. Incoming infrared light not converted into electricity by the conventional PV material is absorbed by erbium ions in the oxide coating. The photon energy absorbed by multiple erbium ions is transferred to individual ytterbium ions, bringing them to a highly excited state. The ytterbium ions then re-radiate the energy as visible light, which is reflected back through the PV cell for absorption and electricity generation.

Microphotonic coatings applied to the backs of conventional crystalline silicon PV cells could substantially increase their conversion efficiencies.

Researchers have succeeded in converting 17% of the photon energy within a narrow portion of the infrared band into visible light, an efficiency that far exceeds previous results. However, this result was achieved under favorable laboratory conditions, using highly concentrated light. Still, results indicate that a 1% relative increase in efficiency of crystalline silicon is feasible, and prospects for a 5–10% gain are being examined.

Much additional progress will be required before microphotonic coatings become available in commercial devices. Current research focuses on optimizing the up-conversion efficiency of today's best materials, exploring new materials, and combining materials to enhance up-conversion across a wider spectral range and under normal outdoor light. Development and testing of a proof-of-concept device are expected to begin in 2011, and commercial PV modules incorporating up-conversion technology appear possible within a decade.

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