CAET Alternative Energy Symposium 2008 Abstracts

Fuel Cell

Hydration Dynamics in a Closed-Loop PEMFC

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The subject of water management is a key issue in the design and operation of Polymer Electrolyte Membrane Fuel Cells (PEMFC). In this paper we present a dynamic model central to understanding the water management and flooding issue.

First we consider membrane hydration and show how the interplay between electro-osmotic drag and back-diffusion determines ionic conductivity. Then we illustrate how over-hydration causes liquid water to be ejected from the membrane and to the Gas Diffusion Layer (GDL), where it will block the transfer of oxygen to the reaction sites. This dynamic model is then analyzed from a closed-loop perspective.

Performance of High Temperature Proton Exchange Membrane (PEM) 4 and 24 Cell Fuel Cells Stacks

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The rising prices of energy of over the last five years have fueled the demand for competitive alternate energy technologies (e.g., fuel cell, solar cell, wind turbine, geothermal, and bio-fuel) to mitigate the risks of severe dependence on international oil.

This paper will introduce various types of fuel cell technologies (e.g., direct carbon, alkaline, phosphoric acid, molten carbonate, solid oxide, proton exchange membrane and regenerative/electrolysis) to explain the reasons for the growth of these emerging technologies over the next decade. Finding commercial markets for mature fuel cell products can be very challenging for most domestic suppliers. Demographic and market research data have suggested that entry barriers can be due to the lack of infrastructure (e.g., ease-of-access to the reactants) to support the auxiliary power units.

The authors will report on findings of market research and entry strategies used to overcome some of the barriers facing mature fuel cell products. The authors will present findings (i.e., tests' results) of the HTPEM stacks. This paper will compare and contrast the performance of the 4 and 24 cells stacks via supporting data. Finally, the authors will explain the future of auxiliary power units (i.e., fuel cells products) in domestic commercial markets and the need for continued collaboration with universities and partners.

Full Cell Technology: Concise Module Introducing Students to Electrocatalysis

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A fourteen-week course was designed to expose students to a variety of fuel cell technology areas. The course was filled with intensive lectures, demonstrations, multi-media presentations, hand-on laboratories and field trips. The course was divided into three modules: overview of fuel cell technology and polymer electrolyte membranes; fundamentals of electrocatalysis; and fuel cell thermodynamics and diagnostics.

This work presents the five-week electrocatalyst module. The integrated approach combines the fundamentals of electrochemistry and catalysis with electrocatalysis. The other two modules will be discussed in different presentations.

Integrating Fuel Cell Concepts into Undergraduate College Science

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Bringing such evolving technology as fuel cell into the general curriculum can be challenging for educators at the undergraduate level. We describe an approach used at the Chicago State University to deliver the concepts involved in fuel cell technology to the chemistry and physics classroom. The approach includes using traditional lectures, field trips to fuel cell industries, and lab activities to enhance student learning in a hands-on manner.

The course was divided into three parts. This first section concentrated on the overview of alternative energy, introduction to fuel cell, and fuel cell chemistry. The other two sections will be discussed by my colleagues in different presentations.

Sulfonated Dendritic Polymer Membranes for Fuel Cell

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The fuel cell technology is an alternative energy/power for the future. The performance of a proton exchange membrane fuel cell is dependent upon the ability of the membrane to transport protons from the anode to the cathode. The current technology uses expensive perfluorinated sulfonated polymer like Nafion with limitations.

In this work a new hyperbranched sulfonated polysulfonate was prepared for possible application as a membrane material. Due to its inherent structure and the presence of sulfonic acid groups on the outer part of the polymer it is expected to provide efficient proton transport. The monomer 2-hydroxy-4-methyl-benzene-1,3-disulfonyldichloride (HDDC) was synthesized by reacting m-cresol in large excess of chlorosulfonic acid at room temperature. The monomer was polymerized via self-condensation in a biphasic system. The polymer was hydrolyzed to free sulfonic acid to obtain water-soluble product. Insoluble hyperbranched polymer was obtained by reacting with 4,4'-dihydroxybiphenyl prior to hydrolysis. The polymer melted at around 215-225 °C.

Palladium-based Bimetallic Nanoparticles for Cathode Electrocatalysis in Polymer Electrolyte Membrane Fuel Cell

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Palladium-copper (Pd-Cu) alloy nanoparticles were prepared by a single-phase colloidal protocol and supported on carbon black materials. The nanoparticles, while capped with a monolayer shell consisting of a mixture of oleylamine and oleic acid, exhibited an average diameter of 3 nm. The metal composition found in the nanoparticles matched the amount and ratio of metal precursors used for the synthesis. The nanoparticles were supported on carbon black and the resulting catalyst was thermally activated by removing the organic monolayer shell under controlled temperatures and atmospheres. The electrocatalytic oxygen reduction reaction (ORR) activities were characterized using the thin film rotating disk electrode technique.

Our results have important implication to the design of low cost, active, and durable electrocatalysts for polymer electrolyte fuel cells (PEFCs).

Novel PEMFC Using Aligned Carbon Nanotubes as Electrodes in MEA

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Proton exchange membrane fuel cells (PEMFC) are under extensive development as hydrogen-fueled power generation devices due to inherent advantages such as high efficiency, low noise, low emissions, and low operating temperature. A PEMFC is comprised of a membrane-electrode assembly (MEA), gas diffusion layers (GDL), and bipolar plates. The MEA is the key element of the fuel cell consisting of an anode, a cathode, and a membrane electrolyte. At present, the electrode catalyst materials are primarily platinum supported on amorphous carbon. Since platinum is a precious metal with limited supply, enhancing its utilization efficiency and reducing the usage will result in significant reduction in PEMFC cost. The current technologies of making MEAs are ink-based processes. Wilson and Gottesfeld [1] described a method of forming thin film catalyst layers for the MEA by preparing inks containing the amorphous carbon supported precious metal and a solubilized form of the polymer electrolyte, followed by applying the ink to a decal and transferring the dried ink to the polymer membrane by hot-pressing. The disadvantage of this technique is that only a portion of the catalyst is utilized because of insufficient access of the sites exposed to the reactants, the carbon support network (electron path), and electrolyte network (proton path) [2-4].

With the recent development of nanotechnology and the demand in fuel cell performance improvements, carbon nanotubes (CNTs) have drawn a great deal of attention as novel catalyst supports for PEMFCs. The desirable attributes of CNTs are their unique geometric shape, high surface area, stability in the fuel cell environment and excellent mechanical and electrical properties [5-7].

At Argonne National Laboratory, we developed a process to synthesize and functionalize various kinds of aligned carbon nanotubes (aligned CNTs) with the electrocatalytic active sites for oxygen reduction. Furthermore, we developed a new process for fabricating nano-structured MEAs using aligned CNTs as the electrode materials. The new design can potentially eliminate the need for PEMFC components, such as GDL, and improve catalyst utilization. In this paper, we will present our recent progress in preparing aligned CNT-based MEAs and the results of single cell testing.

Bio-Fuel

Catalysts in Production of Biodiesel: A Review

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Transesterification of vegetable oil for production of biodiesel can be enhanced by using catalyst. Due to variation in fatty acid composition of oil employed in the production of biodiesel, different types of catalysts are employed.

A review of catalysts in production of biodiesel will be presented and advantage and disadvantage of using each type of catalyst will be discussed.

Effect of Cottonseed Oil Methyl Ester on Direct Injection Diesel Engine Performance Exhaust Emissions

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Diesel engines are the most efficient prime movers. To provide a feasible solution to the twin issues of fossil fuel depletion and environmental degradation, it becomes necessary to develop alternative fuels with properties comparable to petroleum based fuels. Among various possible bio-fuel options, Vegetable oil promises greener substitutes for fossil fuels. In addition, they are biodegradable, non-toxic and have a potential to significantly reduce the emissions of sulphur oxides, poly aromatic hydrocarbons (PAH), smoke and particulate matter (PM). However, the engine operational and durability problems in adopting straight oils (raw) are reported, owing to high viscosity and low volatility.

This paper investigates the viability of usage of Cotton Seed Methyl Ester (CSME) as a bio fuel in a CI engines without any amendment either in injection pressure or ignition advance. The experiments were conducted using various blends of CSME with mineral diesel to study the performance and emission characteristics in a 10 hp, single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine. The acquired data were analyzed for various parameters such as Thermal efficiency, Brake Specific Fuel Consumption (BSFC), CO, CO2, HC emissions. The performance and emission characteristics of engine on operation with CSME blends were found close to diesel. In gist, adoption of CSME promises to be an alternative fuel for diesel engines.

Solar

Solar Cell Literature Review of Emerging Technologies and Manufacturing Best Practices for a Pilot Manufacturing Plant

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Energy prices have significantly increased over the last three years due to environmental forces of change (i.e., regulation, competition, labor, socio-economic factors, financial factors, and globalization).

This paper will report on some of the global energy drivers (e.g., rising US oil consumption, declining global oil extraction rate, rising price per barrel of oil) fueling the increase in energy costs that have created an increase demand for alternate energy technologies (e.g., solar cells, fuel cells, wind and bio-fuel).

This researcher will compare and contrast various types of emerging solar cells technologies (e.g., polymer thin films, ink jet printing, triple junction thin film amorphous photovoltaic, nano-crystalline) to gain an in-depth understanding of best-of-breed applications suitable for a pilot manufacturing plant. Also, the author will demonstrate how selection criteria (e.g., scalability, affordability, durability, flexibility, longevity, and adaptability) can be used to select the Best-of-Breed solar cell technology for a pilot manufacturing plant. This researcher will explain various Best-in-Class manufacturing methodologies that could be deployed in a pilot manufacturing plant. In addition, mature market research strategies and manufacturing best practices will be explored. Finally, this author will compare and contrast emerging technologies and best practices used to manufacture flexible and fixed solar cell products in a typical pilot plant.

Using Scanning Electrochemical Microscopy to Investigate Electron-Transfer Processes in Dye Sensitized Solar Cells

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Interest in dye sensitized solar cells (DSC) has grown recently, owing to their flexibility and customizability. The presence of a liquid electrolyte in contact with a photosensitized titanium thin film increases the complexity of DSCs relative to their silicon-based solid-state counterparts. Improvements in DSC technology will require new techniques to characterize and study electron-transfer reactions that occur at the solid/liquid interfaces found in this type of solar cell.

This talk will focus on the use of electrochemistry, in particular scanning electrochemical microscopy (SECM) as a viable tool to quantitatively characterize electron-transfer reactions relevant to DSC. Here, we report on our research with titanium dioxide films that have been stained with an anthocyanin dye, and their subsequent characterization with SECM. We will discuss the advantages and disadvantages of several data collection modes for this purpose.

Solar Electrification in Two Rural Communities in Chagres National Park, Panama

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The seventy-person community of Santo Domingo is located in Chagres National Park in Panama. When the park was established in 1985, there were about 30 small communities within its border, and now the communities within it are subject to many regulations which affect their way of life, making it more difficult for them to sustain themselves. Santo Domingo is isolated and far from other communities; a 10 km dirt road separates it from the nearest sizable town. The community's economy is based on subsistence farming and cattle ranching. The community of Santa Librada, about a half-day's travel away from Santo Domingo and also inside the park, is demographically similar and deals with similar issues.

One difficult aspect of life in the park is the lack of access to electricity. In order to provide electricity and basic amenities (such as lights, television, and radio) for Santo Domingo, the Northwestern University chapter of Engineers for a Sustainable World (ESW-NU) has visited the community several times to implement solar energy-related projects. ESW-NU has also implemented similar projects in Santa Librada.

ESW-NU has worked on several photovoltaic solar energy projects in Chagres National Park. One involved designing and building solar-powered charging stations for electric fences, which are used by ranchers to protect their cattle from jaguars. The charging stations were also used to provide electricity for the ranchers' houses. The second project involved creating a centralized solar panel system at each community's school and church. In Santo Domingo, the systems provide electricity for lights and a computer, installed later in the project so that community members could acquire computer literacy, as well as for the recharging of family batteries. Santa Librada's community systems power lights and a refrigerator to preserve food for the school children. The newest project involves electrification of seventeen individual houses in Santo Domingo. This will improve the quality of life by providing greater access to electricity for household lighting and appliances. The project will also benefit both the environment and human safety by reducing chemical pollution from batteries. Implementation of the project will begin in August 2008.

The results of the projects include not only concrete, immediate benefits such as largely eliminating the need for kerosene lamps, but also long-term consequences such as the community members' potential economic asset of having technical solar expertise.

Throughout the projects, the ESW-NU team has worked to make the projects socially, economically, and technically sustainable. This paper will include a discussion of the concept of sustainable development and how the team pursued that goal.

Computational Investigation of the Effect of Oxidation State on Conformational Ensembles: Applications to Possible Molecular Wires for Solar Energy Devices

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Biological systems rely on heme-proteins to carry out a number of basic functions essential for survival. One class of heme-proteins, C-type cytochromes, found in a variety of bacteria, plants, and animals were studied as possible building blocks for solar energy devices because of their ability to initiate electron transfer (ET). The c7 protein was chosen because (1) experimental

scattering data are available and (2) it has three heme sites making the effect of oxidizing or reducing the iron in the center of the site larger than for proteins with single hemes. To assess their suitability for ET devices, their solution conformation must be determined. Experimental solution-phase x-ray scattering studies have found that the c7 type cytochrome, extracted from the Geobacter genome and expressed in Escherichia coli, has identifiably different solution-state conformations in the reduced and oxidized form.

The current work seeks to determine what conformational changes produce the experimentally observed differences in the scattering spectra. A starting structure obtained from crystal structural data (Protein Data Bank entry 1os6) was subjected to nanosecond scale constant pressure and temperature molecular dynamics simulations in a 50x50x50 Angstrom cube of water using the Chemistry of Harvard Molecular Modeling (CHARMM) program. The calculations reproduced the observed scattering differences between the oxidized and reduced states. The role of several lysine residues and the n-terminus group in the electrostatically driven conformational change upon oxidation were investigated. These results demonstrate that molecular dynamics (MD) combined with x-ray scattering is an effective way to assess ensemble conformations.

Concentrated Solar Power: Technology and Economic Study

Kourosh Sedghisigarchi and Asad Davari
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This paper presents a feasibility study of generating electrical power and/or thermal energy from concentrated solar energy, commonly termed concentrated solar power (CSP).

First, different CSP technologies are described and compared. Costs involved in building large scale power plant based on CSP technology are discussed as well as small scale systems. For this purpose, reliability, environmental benefits and maintenance costs are studied.

Finally, penetration of concentrated solar energy as a future high efficiency green power source is explained.

Net Metering for Homeowners Using Solar Energy

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The objective is to estimate the energy saving and cost for a typical West Virginia homeowner if he/she had an appropriately sized solar array and engaged in *Net metering*. With net metering, excess electricity produced from your photovoltaic system can be returned to the local utility. This electricity is "sold" to the utility or credited to your account.

In this paper, a comprehensive survey will be done for the net metering issues which are net meeting initiatives, barriers, implementation mechanism, utility costs and benefits, customer uptake, impact of tax and incentives, safety benefits, cost and revenues.

Wind

Wind Turbine Generators – A Comparison of Machine Technologies

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What is meant by an asynchronous generator; or a doubly-fed induction generator? How do the machines that are utilized in wind turbines differ from conventional generators at a typical thermal power plant? What are the electrical behaviors for different machines.

A brief introduction to the electro-mechanical conversion process will be presented for several common wind energy conversion systems. This will include a comparison of the machine topologies, and the behavior of the various types of machines.

Attendees will benefit by gaining a better understanding of machines types--this is paricularly important as wind becomes a bigger player in the operation of the grid given the almost universal use of only one type of machine in thermal and hydro generation.

Integrated Wind Technologies in the Built Environment

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Innovative Design Solutions are based on a Holistic Systems Thinking. As part of our complex global climate, wind is a natural energy source that occurs as a consequence of global and regional temperature differentials caused by solar radiation. Wind power provides an alternative energy source, it is clean, not limited to ground or other vanishing resources and naturally available.

In our developed world, buildings account for about 50% of the energy consumption, another estimated 25% are consumed by transportation and the remaining 25% by the industry. In order to provide clean and renewable energy it is required to investigate energy generation and conservation in all areas of consumption. Designers should therefore share the responsibility to not only shape our environment but consider its long term sustainable performance.

A transfer of design principles between architect and specialists from other disciplines can help to develop innovative sustainable solutions within an integrated model. This interdisciplinary approach challenges engineering and science, scrutinizes limitations, and trusts that innovative solutions can be achieved. As faculty at the Syracuse University School of Architecture and Syracuse Center of Excellence Research Fellow I am collaborating with Professor Thong Dang from the Syracuse University School of Mechanical and Aerospace Engineering. Our Design Research on the integration of innovative wind technologies can hereby not only investigate environmentally friendly manufacturing and construction modes but can also lead to the development of new design typologies.

As a designer I am adamant about the design quality of the developed product. An aesthetically pleasing solution can drastically increase consumer acceptance while providing environmentally friendly performance. The current trend of additive design is unsatisfactory in the realm of design and efficiency. In my design work and university research I have investigated sustainable solutions in various scales, ranging from Product and Architectural Design to the award winning competition design proposal for America's first off-shore wind farm in Nantucket Bay at Cape Cod.

The presentation is intended to explain the relationship between design and technological enhancement for the integration of wind technologies into the Built Environment based on case studies in various scales.

Sustainable and Renewable Energy

Research Investigations and Advances on Hydrogen Production from Coal, Biomass and Other Solid Fuels

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Although hydrogen is the most abundant element in the universe, it does not occur naturally in large quantities or in high concentrations on Earth. Hydrogen must be produced from other compounds such as fossil fuels (natural gas, coal, heavy oils and oil sands), biomass, or water and is therefore considered an energy carrier like electricity. Based on the available supply of fossil fuels, coal has a longer role in providing the energy needed for sustainable development and human comfort. The use of coal along with other solid fuels, such as biomass, municipal solid waste and industrial residue have increased in recent years, in combined cycle power plants as well as in the production of hydrogen fuel. The gasification of carbonaceous, hydrogencontaining fuels is an effective method of thermal hydrogen production and is considered to be a key technology in the transition to a hydrogen economy. The effectiveness of hydrogen production from coal based on gasification highlights the technical challenges to the separation of hydrogen from syngas.

The current work discusses the research investigations and recent advances in possible solutions available for hydrogen production from solid fuels. The challenges for each solution and possible remedies are highlighted based on the reviews of some of the available alternatives. Comparison is provided with existing hydrogen production methods based on fuel utilization, conversion efficiency and cost of production for eventual improvement of the hydrogen production technology. Proposal for system approach to increase hydrogen production from different solid fuels with various conversion processes put together in one location is discussed briefly with benefits and challenges.

Emerging Green Energy Sources for Reducing Our Dependency on Fossil Fuels

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As Americans, we generate more than 85% of the energy we consume by combusting fossil fuels, e.g., petroleum, natural gas, and coal. Historically, the relative abundance and ease of recovery of these fuels has provided us with low-cost energy. However, with the increasing worldwide demand for energy leading to higher costs, dwindling petroleum reserves, and growing environmental concerns related to the combustion of fossil fuels, there is a growing awareness of the need to develop alternative energy sources to complement and, perhaps ultimately, replace fossil fuels. There are considerable R&D efforts underway to develop renewable energy sources, often referred to as "green energies," such as biomass, wind, solar, geothermal, hydroelectric, and ocean waves. Currently, renewable energy accounts for less than 7% of the energy we consume annually, with hydroelectric and biomass (combustion of wood and wood residues for combined heat and power generation) being the primary sources.
Recently, there has been growing interest in utilizing biomass to produce liquid transportation fuels such as ethanol, and wind and solar energies to generate electricity. This paper provides an overview of these efforts and includes a discussion of how much of the U.S. energy demand these renewable energy sources can potentially provide in the next 25 years.

The Role of Sustainable Energy Systems and Energy Management Measures on Global Warming

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The demand for energy is growing worldwide and this has to be met with in an environmentally friendly manner. The greenhouse gas emissions from the industrial sector and transportation systems contribute significantly to global warming. There is a need not only to develop efficient energy technologies, but also the need to conserve them efficiently. There is a growing interest to develop renewable energy sources such as wind, solar, biomass on one side and on the other side to develop efficient and sustainable energy technologies to utilize coal, oil and gas. Cogeneration is also receiving a great deal of attention worldwide to meet part of the energy demand due to its overall high energy utilization efficiency and reduced pollutants and greenhouse gas emissions. Given the current global situation, there is no single energy source, which can meet the requirement. In the present paper the role various sustainable energy systems and energy management measures are discussed.

Why Should Used Tires Be Considered as a Renewable Energy Source?

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Renewable Energy Definition
U.S. EPA definition - Energy obtained from sources that are essentially inexhaustible, unlike, for example, fossil fuels, of which there is a finite supply. Renewable sources of energy include wood, waste, geothermal, wind, photovoltaic, solar thermal energy, and any other sources that are naturally or continually replenished. By definition of the U.S. government DOE renewable energy means a non-depletable source of energy.

The U.S. Environmental Protection Agency estimates that for every single human being in the United States one scrap tire is generated annually (inexhaustible, continually replenished, non-depletable).

With these facts and definitions, it would be inexcusable for legislators, scientists, educators and other citizens in our country to assume that scrap tires are not a renewable source of energy. In the U.S. an incredible number of scrap tires exist on the ground or in landfills and this number is rapidly growing. This year alone over 300 million used or scrap tire will be generated in the U.S., and since 1950 over 16 billion scrap tires have been generated.

Instead of addressing the problems created by scrap tires the populous of the U.S. has turned a blind eye to the fact that they are a health hazard and that they are not going away unless we use technology to solve the problem and create useful products using this source of energy.

Conversion to Energy

There are a number of ways to convert scrap tires to useful energy. The simplest of course is tires to electric energy. If we just assume using the tires that are currently generated, it would equate to enough electric energy to supply 19 million residences, for a day.

Further uses for scrap tires would be to employ Pyrolysis, which creates a number of beneficial products. The first is carbon black that is used in paint mastics, the second is oil that could be reprocessed into diesel fuel, and the third is syn-gas which could be injected into the natural gas pipe lines and finally steel from the belting.

Fact scrap tires are renewable and if they had the same incentives as other renewables the U.S. would come closer to energy independence. This paper will further discuss the benefits of the Pyrolysis of tires.

A Prototype of an Energy Scavenging Power Supply for Small Sensor Systems

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The goal of this project was to design a rugged, reliable, and maintenance-free way of providing energy to a small sensor system. This device harvests energy from the environment around its immediate location and temporarily stores that energy. Due to the stand alone nature of the sensing system, the power supply needed to have a relatively long lifetime of 20 years or more. It must also provide power under a larger variety of operational scenarios.

The technical solution to the problem employs a thermoelectric device, a piezoelectric ceramic, and a photovoltaic cell to generate a current which will charge a capacitor. The sensor then draws its power from the capacitor as needed. Each power scavenging component is independent of the others and therefore increases the environmental scenarios the system will operate in.

The finished product fits in a 1.97”x2.53”x1.66” box, weighs 160 grams, and can withstand a variety of extreme environmental conditions over its projected lifespan of 20 years. After approximately 13 minutes of collecting energy from typically available sources, enough energy will have been collected and stored to power the sensor system for over two hours with no additional energy input. Availability of even minor sources of additional energy should allow the sensor to operate indefinitely.

A Conceptual Process Design and H2A Cost Analysis for the Hybrid Cu-Cl Thermochemical Cycle for Hydrogen Production

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The hybrid copper-chlorine (Cu-Cl) cycle is one of the most promising thermochemical cycles for hydrogen production using nuclear or solar heat. The advantage of the hybrid Cu-Cl cycle relative to other cycles is the relatively lower temperature heat (550ºC) source required. Several types of nuclear reactors can be used as a heat source such as the supercritical water reactor being developed in Canada, CANDU Mark 2, the lead cooled reactor, or the high temperature gas reactor. Solar heat can be provided using the commercially proven tower technology.

The Cu-Cl cycle consists of the three major reactions shown in Table 1. The electrolysis reaction *(1)* in which cupric chloride ($CuCl_2$) is produced at the anode and H_2 at the cathode is carried out electrochemically. The $CuCl_2$(a) from *(1)* is hydrolyzed to copper oxychloride (Cu_2OCl_2) according to the hydrolysis reaction *(2)*. Molten cuprous chloride (CuCl) is then produced from the decomposition reaction *(3)*.

Table 1. Reactions in the Copper-Chlorine Cycle

Reaction	Conditions
(1) $CuCl(a) + HCl(a) + 2H_2O \rightarrow CuCl_2 \cdot 2H_2O(a) + ½\ H_2(g)$	100ºC, 24 bar
(2) $2\ CuCl_2(s) + H_2O(g) \rightarrow Cu_2OCl_2(s) + 2HCl(g)$	400ºC, 1 bar
(3) $Cu_2OCl_2(s) \rightarrow ½\ O_2(g) + 2CuCl(s)$	540ºC, 1 bar

All reactions have been experimentally demonstrated. The early experiments indicated technical challenges in the hydrolysis (2) and electrolysis reactions (1). The two thermal reactions, the hydrolysis of CuCl2 (2) and the decomposition of Cu2OCl2 (3) have been proven at ANL. In bench scale experiments, all of the oxygen was recovered at 530ºC from reaction (3). The electrolytic reaction (1) was demonstrated at the Atomic Energy of Canada, Ltd. (AECL) at Chalk River recently. Meeting the performance (500 mA/cm2 at 0.5V) and cost ($2500/m2) targets is the primary challenge for the electrolysis reaction.

We consider the hydrolysis reaction to be the most challenging reaction because of two factors: (i) a competing reaction of CuCl2 and (ii) the need for excess water. The competing reaction is the thermal decomposition of CuCl2:
(4) 2CuCl2 (s) ⇔ 2CuCl (s) + Cl2 (g).

Because CuCl is a product of the subsequent reaction, this competing reaction is not a showstopper, provided the Cl2 can be scavenged and its amount formed is minimal. The need for excess steam was demonstrated both experimentally and theoretically. This preliminary work clearly defined some of the challenges facing the development effort. The decision to proceed with further development was justified by the results of recently completed efficiency calculations and H2A cost analysis, which are discussed below. We also present a brief summary of our experimental work in which we address the challenges identified in the hydrolysis reaction.

Comparative Study of Different Combined Cycle Configurations Based on Thermodynamic Simulation

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Thermodynamic analysis has been carried out for a combined power cycle with variations in configurations of topping and bottoming cycles. In this work attention has been focused to find the optimum configuration for single pressure (SP), dual pressure (DP) and triple pressure (TP) heat recovery steam generator (HRSG) which is added to simple or intercooler-reheat (IC-RH) gas cycle to get maximum exergy efficiency from combined cycle. Deaerator, an essential open feed water heater in steam bottoming cycle is located to improve the efficiency and remove the dissolved gasses in water. The low pressure (LP) and intermediate pressures (IP) in HRSG are evaluated from the local exhaust gas temperatures to get the minimum possible temperature difference between fluids instead of a usual fixation. From this work, the optimum pressure ratios for air compressor and steam reheater have been examined for the configurations in topping and bottoming cycles. The results showed that the high combined cycle efficiency can be achieved with the combination of simple gas cycle and TP HRSG at lower values of pressure ratios compared to the IC-RH gas cycles. The exergetic losses in cycle components are compared for the configurations of gas and steam cycles.