The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-SuA

Automotive Energy

Moderator: J. Hobbs, American Institute of Physics

3:00pm **IPF-SuA1 Technology, Economics, and Policy of Hydrogen and Fuel Cells**, ***D. Dresselhaus***, Massachusetts Institute of Technology **INVITED**

The history of alternative transportation fuels is largely a history of failures. None has overcome the institutional, financial, and technological inertia of gasoline and diesel. Only ethanol made from corn is gaining market share in the US - thanks to large federal and state subsidies and a federal mandate. What are the prospects of alternative low-carbon fuels, especially biofuels, electricity and hydrogen? Is California's low carbon fuel standard a model for orchestrating the transiton to alternative fuels? Is hydrogen different? Might hydrogen and fuel cells succeed on a grand scale, where others have not? If so, how might this unfold? What role do hybrid vehicles play in this process? This presentation will address the technology, economics, and policy of hydrogen and fuel cells, and will explore possible and likely outcomes.

3:40pm **IPF-SuA3 Frontiers, Opportunities and Challenges for a Hydrogen Economy**, ***J.A. Turner***, National Renewable Energy Laboratory **INVITED**

Energy is one of the most important issues facing our world today; in fact, in today's society energy is as important as food and water. Humankind finds itself faced the challenge of how to continue to power society, particularly in the face of the rapidly growing economies of emerging nations like India and China, and yet answer questions of sustainability, energy security, geopolitics and global environment. One of the major issues facing America and most other countries in the world is how to supply a transportation fuel, an energy carrier to replace gasoline. Hydrogen as an energy carrier, primarily derived from water, can address issues of sustainability, environmental emissions and energy security. The "Hydrogen Economy" then is the production of hydrogen, its distribution and utilization as an energy carrier. While the vision of a hydrogen economy has been around for over 130 years, the most recent push to use hydrogen as an energy carrier came as part of a US Presidential Initiative, announced in the 2003 State of the Union Address. It is important that we consider hydrogen in tandem with other technologies as an alternative to the once-abundant hydrocarbon resources on which our society depends. This talk will introduce sustainable energy systems, including fuel cell technology and discuss the vision, the barriers and possible pathways for the production and implementation of hydrogen into the energy infrastructure.

4:20pm **IPF-SuA5 The (Re) Electrification of the Automobile**, ***M.A. Tamor***, Ford Research and Advanced Engineering **INVITED**

It is easily forgotten that a century ago electric vehicles had a dominant market share over steam and internal combustion automobiles. While quiet, clean and reliable, the EV was challenged by range and performance limitations, and eventually done in by the electric self-starter …. one of the first electrified features! Driven in large part by the quest for improved fuel efficiency and emissions – and accelerated by design opportunities and attractive customer features – the re-electrification of motor vehicle is now progressing rapidly. Electrified functions range from the mundane, such as power steering and engine coolant pumps, through a spectrum of hybrid powertrain concepts and on to a resurgent interest in all-electric vehicles. Each incremental function and additional load increases the demand for efficient and cost-effective energy storage and is driving new, sometimes divergent, battery requirements. The hybrid electric vehicles available today are all what might be called "power hybrids" that have been optimized to achieve impressive fuel efficiency with minimum battery energy capacity – and so minimum battery weight and cost. Driven by commercialization of HEVs, rapid progress on batteries and power electronic systems paves the way to two revolutions in the motor vehicles: First, is the proposal to shift a significant fraction of propulsion energy from petroleum fuel to electricity by "plugging in." The "plug-in" HEV is an "energy hybrid" that by definition requires a much larger battery, and creates a new connection that allows motor vehicles to exploit the efficiency and diversity of the electric grid. While not overwhelmingly attractive in the present economy of still-cheap oil and fossil fuel-generated electricity, the plug-in hybrid could prove critical to closing the gap between a limited supply of renewable fuel and ever-growing transportation needs. Second, with no rigid connections between the various powertrain elements, the series HEV – "power" or "energy" - enables re-engineering of the motor vehicle including its shape, structure, materials and manufacturing. In short, the re-electrification of the automobile is enabled by progress in battery technology, but itself may enable revolutions in the nature and the economics of personal transportation.

5:00pm **IPF-SuA7 General Motors' Perspective on New Transportation Technologies**, ***J. Bereisa***, General Motors Corporation **INVITED**

Will review the rationale behind and the progress made in fuel cell cars and the hydrogen economy and specifically highlight technical progress achieved in fuel cell vehicles, remaining challenges and issues related to creating the hydrogen refueling infrastructure.

The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-MoM

Energy Efficiency

Moderator: J. Hobbs, American Institute of Physics

8:00am **IPF-MoM1 Solar Photovoltaics: At the Tipping Point**, ***L. Kazmerski***, National Renewable Energy Laboratory **INVITED**

The prospects of current and coming solar-photovoltaic (PV) technologies are envisioned, arguing this solar-electricity source is at a tipping point in the complex worldwide energy outlook. The co-requirements for policy and technology investments are strongly supported. The emphasis of this presentation is on R&D advances (cell, materials, and module options), with indications of the limitations and strengths of crystalline (Si and GaAs) and thin-film (a-Si:H, Si, Cu(In,Ga)(Se,S)$_2$, CdTe). The contributions and technological pathways for now and near-term technologies (silicon, III-Vs, and thin films) and status and forecasts for next-generation PV (organics, nanotechnologies, non-conventional junction approaches) are evaluated. Recent advances in concentrators, new directions for thin films, and materials/device technology issues are discussed in terms of technology evolution and progress. Insights to technical and other investments needed to tip photovoltaics to its next level of contribution as a significant clean-energy partner in the world energy portfolio. The need for R&D accelerating the now and imminent (evolutionary) technologies balanced with work in mid-term (disruptive) approaches is highlighted. Moreover, technology progress and ownership for next generation solar PV mandates a balanced investment in research on revolutionary (long-term) technologies (quantum dots, multi-multijunctions, intermediate-band concepts, nanotubes, bio-inspired, thermophotonics, . . .) having high-risk, but extremely high performance and cost returns for our next generations of energy consumers. This presentation provides insights (some irreverent, some entertaining) into how this technology has developed---and where we can expect to be by this mid-21st century.

8:40am **IPF-MoM3 The Physics of Terrestrial Concentrator Solar Cells with Over 40% Efficiency**, ***R.R. King***, *D.C. Law, K.M. Edmondson, C.M. Fetzer, G.S. Kinsey, H. Yoon, D.D. Krut, J.H. Ermer, R.A. Sherif, N.H. Karam*, Spectrolab, Inc. **INVITED**

Solar cell efficiency is one of the most enabling device parameters for widespread implementation of solar electricity generation on Earth, since high efficiency dramatically reduces not only the cell area needed to generate a given power, but also the cost of all area-related components in a photovoltaic system. The efficiency of a solar cell with a single energy band gap E_g in unconcentrated sunlight is quite limited by fundamental considerations, such as thermalization of photogenerated electrons and holes, non-absorption of low energy photons, and the limited quasi-Fermi level splitting at one sun. Multijunction concentrator cells are able to overcome these fundamental efficiency limits, and as a result have attracted much attention recently for cost-effective terrestrial photovoltaics. If the subcell bandgaps for the multijunction solar cell are chosen from metamorphic semiconductors that are lattice-mismatched to the growth substrate, theoretical efficiencies can be raised even higher than for lattice-matched designs. Advances in the design of metamorphic subcells to reduce carrier recombination and increase voltage, wide-bandgap tunnel junctions, metamorphic buffers to transition to the lattice constant of the active subcells, concentrator cell anti-reflection coating and grid design, and integration into current-matched 3-junction cells have resulted in new heights in solar cell performance. A metamorphic $Ga_{0.44}In_{0.56}P$/ $Ga_{0.92}In_{0.08}As$/ Ge 3-junction solar cell has reached a record 40.7% efficiency at 240 suns, under the standard reporting spectrum for terrestrial concentrator cells (AM1.5 direct, low-AOD, 24.0 W/cm^2, 25°C). This metamorphic 3-junction device is the first solar cell to reach over 40% in efficiency, and has the highest solar conversion efficiency for any type of photovoltaic cell to date. Experimental lattice-matched 3-junction cells have now also achieved over 40% efficiency, with 40.1% measured at 135 suns. The multijunction structure of these cells and their operation at concentration allow efficiencies substantially above the Shockley-Queisser limit[1] of 30% for a single-band-gap device at one sun, and above the theoretical limit of 37% for single-band-gap cells at 1000 suns,[2] to now be achieved in practice.

[1]W. Shockley and H. J. Queisser, J. Appl. Phys., 32, 510 (1961).
[2]C. H. Henry, J. Appl. Phys., 51, 4494 (1980).

9:20am **IPF-MoM5 Thermoelectrics and Waste Heat Recovery**, ***L.E. Bell***, BSST LLC **INVITED**

Thermoelectric (TE) devices are reversible, solid-state heat engines. When a temperature difference is applied across a TE array, electric power is produced; and when electric power is applied, a portion of the array cools (sinks thermal power) and another portion heats (produces thermal power). Increased needs to lower energy costs and reduce green house gas emissions have renewed interest in the technology. TE applications have been limited most importantly by lower conversion efficiency, but also by the cost of the materials and systems. Recent advances in performance through the development of more efficient thermodynamic cycles, laboratory demonstrations of improved materials, and the availability of more comprehensive design tools, have increased interest in the application of the technology for power generation uses. The recent recognition of the need to reduce CO_2 emissions has renewed interest in TE technology with respect to waste heat harvesting from vehicle exhaust. Since the 1960's, TEs have been employed in critical military and space applications where their demonstrated ruggedness and maintenance-free operation has outweighed energy conversion efficiency limitations. Target applications are small to midsize (up to 40 kW) sources of exhaust waste heat and include: vehicle exhaust residential, commercial, and industrial fuel-fired heating systems; diesel powered electric generators; and other similar applications. TE technology is evolving to the point where systems with conversion efficiencies of 6% to possibly 20% are being investigated. Prospects for successful implementation of TE technology for waste heat recovery to reduce CO_2 and other green house gas emissions are discussed for a range of business sectors for which the technology appears attractive. Examples of current approaches to implementation are given, along with estimates for critical system characteristics including projected size, weight, efficiency, and rough costs. Important current programs funded by various U.S. and foreign government agencies are described and their level of technical and commercial readiness are assessed.

10:20am **IPF-MoM8 Current Status of Solid State Lighting**, ***S. Nakamura***, University of California, Santa Barbara **INVITED**

The light emitting diode (LED) takes electrical energy and converts it to bright bluelight. The light generation is very energy efficient (60%), which is much better than normal incandescent bulb (5%). The light is generated inside of a crystal of gallium nitride (GaN), and it only requires a 3-volt battery. The efficiency of white LEDs that use blue LEDs will become higher, almost close to 100% (currently 150 lm/W). Then, all of the conventional lighting, such as incandescent bulbs (10 lm/W), fluorescent lamps (70 lm/W), and others, would be replaced with the white LEDs in order to save energy and resources. Also, these white LEDs would be operated by a battery powered by a solar cell in the daytime. So, it means that this lighting would be operated with clean energy thanks to its high efficiency and low voltage operation. In the developing countries, there is no electricity and no light at night. However, white LEDs operated with a small battery powered by a solar cell in the daytime could be used as a light source in those developing countries.

11:00am **IPF-MoM10 Emerging Energy Policy on Capitol Hill**, ***M. Kenderdine***, GTI **INVITED**

The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-MoA

Nuclear Energy

Moderator: J. Hobbs, American Institute of Physics

2:00pm **IPF-MoA1 Status of Fusion Power**, ***R.J. Hawryluk***, Princeton Plasma Physics Laboratory **INVITED**

Fusion is an attractive long-term form of nuclear energy. Experiments on magnetically confined plasmas in the 1990's demonstrated not only the ability to confine plasmas with the temperatures required for a fusion reactor but also produced significant fusion power (up to 10.7 MW in the Tokamak Fusion Test Reactor and 16.1 MW in the Joint European Undertaking for <1sec) using deuterium-tritium fuels. This major step, together with results from a worldwide research effort, has provided confidence in the design of the International Thermonuclear Experimental Reactor (ITER) to produce 500MW (thermal) of fusion power for 400 sec. ITER is an international experiment whose partners are the European Union, India, Japan, the People's Republic of China, the Republic of Korea, the Russian Federation and United States. ITER aims to demonstrate the scientific and technical feasibility of fusion power and will be constructed in Cadarache, France. For the first time, the fusion reactions will provide the majority of the heating for the plasma with an energy gain >10. The design of ITER has identified important scientific and technology issues, which are currently being addressed in facilities around the world. However for a fusion demonstration power plant, further progress on the underlying science and technology is required to achieve ~2500 MW (thermal) continuously with a gain >25 in a device whose size is comparable to ITER. This requires addressing issues associated with plasma boundary due to the higher power and plasma stability due to the need to sustain even higher pressure plasmas at the magnetic field of ITER. Furthermore, efficient continuous operation requires minimizing the external power for controlling the plasma. Experiments on the three main approaches to magnetically confining a plasma, the advanced tokamak, the spherical tokamak, and the stellerator, in parallel with the design and construction of ITER, are exploring innovative solutions required for a demonstration power plant. The advanced tokamak relies on active instability control and a combination of external current drive to increase the fusion power and achieve continuous operation. The spherical tokamak achieves higher fusion power at a given size and magnetic field by decreasing the ratio of the plasma major radius to minor radius. The stellarator is passively stable and does not require external power to drive the plasma current continuously. This research is supported by the U.S. Department of Energy under Contract Number DE-AC02-76CH03073.

2:40pm **IPF-MoA3 The Role of High Temperature Gas Reactors in the Future Development of Nuclear Power**, ***E.M. Campbell***, *F. Venneri*, *A.S. Shenoy*, *C.J. Hamilton*, General Atomics **INVITED**

Given the increased worldwide demand for energy, the desire for energy security and the need to reduce anthropenic influence on the earth's climate, it appears certain that there will be a significant increase in the role of nuclear power. While the early expansion of nuclear power will be dominated by light water reactors with modern safety features and improved economics, advanced Generation IV reactors such as high temperature gas reactors will become increasingly important following the demonstration of commercial scale prototypes in the next decade. High temperature gas reactors have many attractive features arising from the use of inert helium gas as a coolant, graphite as a moderator and fuel encapsulated in a robust TRISO ceramic coating. These features enable the reactors to be passively safe — they employ no safety features with an emergency core coolant reservoir — while not sacrificing attractive economics, and at the same time producing output temperatures in excess of 900ºC. Such temperatures allow for flexibility in siting (even in regions with little or no water availability), and the efficient production of electricity as well as numerous process heat applications such as the large scale production of hydrogen and economic desalination. These latter applications which to date have not used a "nuclear heat source" will become increasingly important in the future and are made possible only by these Generation IV reactors. The fuel form in these reactors enables a wide range of fission fuels to be deployed including uranium, thorium, and actinides including those from spent fuel, allows for extremely deep burn, and provides increased barriers for proliferation. In this presentation the role of gas reactors in an expanding nuclear market will be discussed. Their unique features will be presented including passive safety, economics, modularity, fuel and siting flexibility, applications and symbiosis with other reactors such as fast sodium reactors. An attractive scenario for the large scale deployment of these reactors which addresses fuel availability and waste will also be included.

*Work supported by General Atomics internal funding.

3:40pm **IPF-MoA6 Sustainable Nuclear Energy Production and Nuclear Waste Management**, ***M. Peters***, Argonne National Laboratory **INVITED**

The world energy demand is increasing at a rapid pace. In order to satisfy the demand and protect the environment for future generations, future energy sources must evolve from the current dominance of fossil fuels to a more balanced, sustainable approach to energy production. The future approach must be based on abundant, clean, and economical energy sources. Therefore, because of the growing worldwide demand for energy and need to minimize greenhouse gas emissions, there is a vital and urgent need to establish safe, clean, and secure energy sources for the future. Nuclear energy is already a reliable, abundant, and carbon-free source of electricity for the U.S. and the world. In addition to future electricity production, nuclear energy could be a critical resource for "fueling" the transportation sector (e.g., process heat for hydrogen and synthetic fuels production; electricity for plug-in hybrid and electric vehicles) and for desalinated water. Nuclear energy must experience significant growth to achieve the goals of our future energy system. The most significant technical challenge that must be addressed to allow the necessary expansion is safe, secure, and sustainable nuclear waste management. The nuclear fuel cycle is a key concept when discussing a sustainable future for nuclear energy. The nuclear fuel cycle is a cradle-to-grave concept starting from uranium mining to fuel fabrication to energy production to nuclear waste management. At first order, there are two approaches to the nuclear fuel cycle. An open (or once-through) fuel cycle, as currently planned by the United States, involves treating spent nuclear fuel (SNF) as waste with ultimate disposition in a geologic repository. In contrast, a closed (or recycle) fuel cycle, as currently planned by other countries (e.g., France, Russia, Japan), involves treating SNF as a resource whereby separations and recycling of transuranics (TRU's) in reactors work with geologic disposal. Open fuel cycles require multiple geologic repositories whereas closed fuel cycles can reduce the volume and toxicity of waste, conserve uranium resources, and provide additional energy. Nuclear waste management and lack of a closed fuel cycle are principal impediments to the future viability of the nuclear energy option. In the advanced, closed fuel cycles that are currently being developed in France, Russia, Japan, the United States, China, and India, SNF would be sent to a reprocessing plant where its major constituents are separated into several streams: a TRU stream, to be recycled, and several other streams, including a "clean" uranium waste stream (note that this uranium could be recycled as part of future nuclear fuels), and waste streams containing the fission products. The TRU's are fabricated as fresh nuclear fuel, to be irradiated again in a fission reactor, ideally a fast-neutron system. Approximately 30% of the TRU's are fissioned each time the fuel is irradiated in a low conversion-ratio fast reactor. The remaining 70% stay in the cycle until they are fully fissioned. Even a closed fuel cycle requires a geologic repository to dispose of long-lived fission products and potentially very small amounts of TRU's, the latter being from minor separations process losses. The volume and toxicity of waste requiring geologic disposal is reduced significantly in a closed fuel cycle; however, the doses from the encased radionuclides still require long-term isolation in durable waste forms in geologic repositories. Engineering and technology development will improve the reliability and cost effectiveness of nuclear energy and closed fuel cycle approaches. However, the rapid expansion of nuclear energy technologies required to satisfy the needs of the future will require breakthroughs that will only be possible through a coupling of applied and basic science and engineering. In particular, advanced modeling and simulation tools and approaches integrated with engineering and facilities design will be the avenue for using basic science insights to further the prospects for sustainable nuclear energy and nuclear waste management.

4:20pm **IPF-MoA8 Nuclear Energy Policy**, ***D. Hill***, Idaho National Laboratory **INVITED**

The U.S., through the National Energy Policy and the landmark legislation, Energy Policy Act of 2005, has adopted policies that support a diverse clean energy portfolio, including expanded use of nuclear energy. The nuclear industry is pursuing the business and licensing cases for building at current count, more than thirty new plants over the next decade. Government is sharing the risk that first movers of these new plants will face by cost-sharing the license preparation effort, by sponsoring production tax credits for the first 6,000 MW of new nuclear generating capacity, and through loan guarantees for the low emissions technologies. Additionally, last year, the Bush Administration proposed the Global Nuclear Energy Partnership, a multinational initiative that focuses on developing the technologies and infrastructure that will be needed to support anticipated global expansion of nuclear energy. A key element, advanced recycling of spent nuclear fuel, would address the waste burden associated with the once-through fuel cycle that relies extensively on surface storage and eventually, deep geologic disposal of spent nuclear fuel. Recycling would recover and reuse materials contained in spent fuel by separating them from the waste products without producing plutonium. This paper examines nuclear energy policy in the U.S., outlook for nuclear energy in the U.S. and the world, reasons to move toward a closed fuel cycle and U.S. and international progress on development of advanced fuel cycle technology.

The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-TuM

Energy for Low Carbon Input

Moderator: J. Hobbs, American Institute of Physics

8:00am **IPF-TuM1 The Prospects for Low-Cost Photovoltaic Electricity**, ***D.E. Carlson***, BP Solar **INVITED**

In the last decade the photovoltaic (PV) industry has grown at an annual rate of about 35%. While PV modules made in the 1960s sold for hundreds of dollars per Watt, prices are now in the range of $3-$4 per Watt, and this corresponds to levelized electricity costs of about 20-25 cents/kWh for large commercial systems. Silicon technology has dominated the industry since its inception and about 91% of all solar cells sold in 2006 were based on crystalline silicon. However, there are a number of other technologies under development involving materials such as amorphous silicon, microcrystalline silicon, cadmium telluride, copper-indium-gallium-diselenide, gallium arsenide (and related compounds), dye-sensitized titanium oxide, nanocomposite materials and organic molecules and polymers. The U.S. Department of Energy has set a goal of attaining levelized electricity costs of 6 to 8 cents/kWh for commercial PV systems as part of the Solar America Initiative, and this will require not only a reduction in the cost of the PV modules, but also in the cost of inverters, support structures, wiring and installation. Continued improvements in solar cell conversion efficiency will help to reduce costs. While the efficiency of crystalline silicon PV modules is generally in the range of 12 to 15% today, the module conversion efficiency should increase to about 17 to 20% by 2015. In the laboratory efficiencies as high as 24.7% have been demonstrated for single crystal silicon solar cells. The efficiencies associated with other PV technologies also continues to improve, and thin film copper-indium-gallium-diselenide solar cells have been fabricated with conversion efficiencies as high as 19.5% in the laboratory. Efficiencies as high as 40.7% have been demonstrated for a triple-junction cell operating under concentrated sunlight. There are also a number of new potentially disruptive PV technologies that could lead to significantly higher efficiencies in the next few decades, and new types of solar cells may be developed using novel multijunction structures, intermediate-band semiconductors, multiple-carrier generation, collection of hot carriers, etc. that could lead to conversion efficiencies in excess of 50%. If the growth rate of the last several years continues, then PV module prices could fall below $1 per Watt by 2030, and PV could be supply about 10% of the world's electricity in the 2030-2035 timeframe.

8:40am **IPF-TuM3 Constraining Carbon to Confront Climate Change**, ***R. Bierbaum***, University of Michigan **INVITED**

Article 2 of the Framework Convention on Climate Change calls for stabilizing concentrations of greenhouse gases in the atmosphere at levels that prevent *dangerous anthropogenic interference with the climate system* and in a time frame to *allow ecosystems to adapt naturally to climate change*. Increasingly, expert assessments are calling for limiting the global average temperature increase to 2-2.5oC above pre-industrial levels and atmospheric concentrations below 550 ppm CO2-equivalent to meet these goals. Given that the earth is already committed to 1.4oC today and emissions are growing rapidly, domestic and international policy responses must be immediate, significant and sustained. The size of this task and the potential roles of various technologies and policies to achieve these goals will be described. A roadmap to confront climate change will need to include the following elements: accelerating the implementation of win-win solutions; developing a new global framework for mitigation; identifying strategies to adapt to ongoing and future changes in climate; creating and rebuilding cities to be climate resilient; increasing investments and cooperation in energy technology innovation; and forging partnerships across governments, corporations, the financial community and private organizations.

9:20am **IPF-TuM5 Offshore Sustainable Electricity Supply Systems: The POSEIDON Vision**, ***D. de Jager***, Econcern B.V., The Netherlands **INVITED**

Seas and oceans cover over 70% of the earth's surface. They already play a crucial role in the global energy supply: a considerable part of our oil and natural gas is extracted off shore, and will be in the future. But at sea, also large potentials of renewable energy sources can be harvested, like wind, wave, tidal and osmotic energy. By offering space, abundant energy resources, and the opportunity for geological sequestration of carbon dioxide, the seas offer a huge opportunity to meet the world's growing energy demand in a sustainable way. The POSEIDON vision is a seaway to harvest these energy resources and to create a sustainable electricity supply system. The heart of the concept is the construction of an off shore electricity transmission grid. This grid connects major onshore demand regions with each other, and with off shore fossil and renewable electricity production and storage technologies. In combination with geological sequestration of carbon dioxide (including enhanced oil or gas recovery), a carbon free electricity supply could be attained. The POSEIDON vision emphasizes the importance of an integrated system approach. Production, conversion and transformation, transmission and distribution, storage and final energy demand are not separate elements, but must be considered from a system perspective. Also changes over time should be taken into account. POSEDION builds on current infrastructure, ensures access to sources, balances load and demand, and enables the incorporation of new emerging off shore technologies. By combining these technologies and marine resources, the seas offer the opportunities to build a truly sustainable energy system: cheap, reliable and sustainable. POSEIDON is an initiative of Econcern, the sustainable energy solution provider. Europe is seen as an excellent region to prove the concept. The North Sea region will be discussed as an example, as well as the key technologies that are expected to form the basis of this concept: off shore wind and wave energy, high-voltage electricity transmission technologies, and zero emission power plants. Developing POSEIDON-like systems asks for venturous project developers and other companies, inventive policy and decision makers, and creative researchers. They all can contribute to building this new, truly sustainable perspective.

10:40am **IPF-TuM9 Science & Technology Barriers to Economic Ethanol Biorefineries**, ***M. Himmel***, NREL **INVITED**

Lignocellulosic biomass has long been recognized as a potential low-cost source of mixed sugars for fermentation to fuel ethanol. Several technologies have been developed over the past 80 years that allow this conversion process to occur, often in wartime context, yet the clear objective now is to make this process cost competitive in today's markets. Replacing 30% of U.S. 2004 finished motor gasoline demand (or about 60 billion gallons) with ethanol by 2030 will require a significant increase in ethanol production over today's corn starch-based industry. This process is technically feasible for corn stover and wheat straw today using biochemical conversion technology that includes pretreatment, enzymatic hydrolysis, and fermentation. However, the process remains fundamentally inefficient and is therefore risky to commercialize. Cellulosic ethanol production via biochemical conversion can provide fuel at prices commensurate with historical gasoline prices (<$1.00/gallon) only by taking full advantage of critical scientific breakthroughs in feedstock production and biomass conversion science. Indeed, in order to ensure a successful transition from existing to 2030 technologies, investing in knowledge-based solutions to critical barriers is essential.

11:20am **IPF-TuM11 Carbon Sequestration to Mitigate Climate Change - A Geological Perspective**, ***R.C. Burruss***, US Geological Survey **INVITED**

The fraction of global carbon emissions that must be eliminated to impact climate change is huge, about 70% of present emissions over many years (100's to 1000's of gigatonnes of CO_2) to stabilize atmospheric CO_2 at about 500 ppm. Such reductions require all means of carbon management, including geological and biological sequestration; shift from fossil fuel to renewable biomass; electricity from solar, wind, and nuclear power; and improved efficiency of generation and use. The IPCC Special Report on Carbon Capture and Storage (2005) estimates that storage of CO_2 in geological formations (geological sequestration) could eliminate about 50% of emissions. The potential role of enhanced carbon storage in biomass and soils (biological sequestration) is difficult to evaluate due to the complex dynamics of greenhouse gases in the global biosphere. Geological sequestration involves injection of supercritical CO_2 into porous and permeable rock formations at depths of 1 to 3 km beneath low permeability seals. Storage formations include oil and gas reservoirs, saline aquifers, coal beds, and organic-rich shale. Over 30 years of experience with CO_2 injection in oil fields for enhanced oil recovery demonstrate that injection and storage of CO_2 is possible with existing technology. Geological sequestration projects currently deployed in Norway, Canada, and Algeria, collectively store 3 megatonnes (MT) CO_2/year. For perspective, a 1000 MW coal-fired power plant emits about 4 MT CO_2/yr and the largest CO_2 separation plant captures 4 MT CO_2/yr. Clearly, CO_2 capture and storage to eliminate a significant fraction of atmospheric emissions will require deployment of new energy systems at an enormous scale. Although the basic principles of geological sequestration are well known and reservoir engineering for CO_2 injection is understood, significant research remains. A particular concern is identification of storage sites with adequate capacity for commercial projects (CO_2 storage from a 1000 MW power plant for 50 years requires a volume equivalent to a 2-3 billion barrel oil field). Other concerns include detailed knowledge of the integrity of sealing formations, and the rates of reaction of CO_2 with dissolved components in formation water, host rocks, and organic matter. This information is needed to assess the permanence of CO_2 storage and the potential environmental impacts of leakage.

The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-TuA

Frontiers in Physics

Moderator: J. Hobbs, American Institute of Physics

2:00pm **IPF-TuA2 Probing the Intrinsic Magnetism of the Electron (and Measuring the Fine Structure Constant)**, ***G. Gabrielse***, Harvard University **INVITED**

A single electron is suspended by itself for months at a time. The electron and apparatus together form an artificial, home-made atom whose energy levels we probe using quantum jump spectroscopy. Much as measurements of the magnetism of the earth reveal something about the inner structure of the earth, measurements of the electron's intrinsic magnetism tells about the inner structure of the simplest of elementary particles. For the first time since 1987 the electron's magnetic moment is measured with a higher accuracy. The new measurement, together with quantum electrodynamics theory, determines the important fine structure constant about ten times more precisely than does any rival method. Many interesting techniques are employed, including the inhibition of spontaneous emission and the a single-particle self-excited oscillator, some of which are now applicable in MRI imaging and for ICR analysis of pharmaceuticals.

2:40pm **IPF-TuA4 Nanopores & Systems Biology**, ***J.J. Kasianowicz***, *J.W.F. Robertson*, National Institute of Standards and Technology, *O.V. Krasilnikov*, UFPE, Recife, Brazil, *V.M. Stanford*, National Institute of Standards and Technology **INVITED**

Proteins that form nanometer-scale pores in cell membranes are the basis of many biological processes including nerve activity and cell-cell communication. Research over the past two decades demonstrated that they could also be used for the selective detection and characterization of molecules (e.g., proteins, anthrax toxins, and DNA). More recently, a single nanopore was used as the transducer for a novel aqueous-based mass spectrometry technique. The ability to detect and discriminate between molecules with nanopores should provide useful analytical systems for health care applications.

4:00pm **IPF-TuA8 Circuits with Light at the Nanoscale**, ***N. Engheta***, University of Pennsylvania **INVITED**

For many years, the familiar notion of lumped circuit elements has been extensively and successfully used in microelectronics. This concept has allowed "modularization" of various functions at the circuit level, and thus has been proven to be a powerful tool in design, innovation, and discovery of new functionalities in the radio frequencies (RF) and microwaves. Can the concept of lumped circuit elements, and the mathematical machinery of circuit theory, be extended into the nanometer scale and into the optical domain? In other words, can we envision nanostructures that may act as a "module" representing a lumped circuit element, such as a nanoinductor, a nanocapacitor, a nanoresistor, and a nanodiode, etc. that will work with light, instead of electricity? Utilizing the notion of metamaterials and plasmonic materials with unusual values for material parameters such as negative or near-zero parameters, we have developed the concept of lumped circuit elements at the higher frequency regimes, such as terahertz (THz), infrared (IR), and optical domains. With this approach, nanoelements such as nanoinductors, nanocapacitors, nanoresistors, and nanodiodes can indeed be envisioned at optical frequencies by properly arranging plasmonic and nonplasmonic nanostructures as a tapestry of nanoparticles. This new circuit paradigm, which we coin "meta-nanocircuits" inspired by metaplasmonics, provides us with the possibility of tailoring and manipulating optical electric fields with desired patterns in sub-wavelength regions, and thus allows the mathematical tools of circuit theory to be used in the THz, IR and optical frequencies. This will open doors to many innovations in future optical nanoelectronics and nanosystems, and may likely lead to a new paradigm for information processing, detection, and storage, in the nanometer scales. In our theoretical and computational works, we have shown how more general circuits with various transfer functions can be considered by using blocks of nanostructures, providing new ways of designing nano-scale optical lumped components and devices such as filters, switches, etc. at optical wavelengths. Such meta-nanocircuits may one day be also interfaced with biological circuits, leading to the possibility of hybrid nano-bio circuits. In this talk, I will present an overview of some of our theoretical results and computational simulations on this concept of metactronics - metamaterial electronics.

4:40pm **IPF-TuA10 Understanding the Near Earth Object Population**, ***W.F. Bottke***, Southwest Research Institute **INVITED**

Near Earth Objects (NEOs) are asteroids and comets on orbits that allow them to approach and, in some cases, strike the Earth. This population is comprised of bodies ranging in size from dust-sized fragments to objects tens of km in diameter. It is now recognized that the impact of diameter $D > 0.1$ km NEOs represent a small but non-negligible hazard to human life and infrastructure. Interestingly, however, the potential threat represented by these bodies may also be one of easier ones to mitigate against, provided adequate resources are allocated to identify all of the NEOs of relevant size. Using our knowledge of the collisional and dynamical mechanisms that transport asteroids and comets from their source regions all the way to NEO space, we now have a working model of the steady-state orbital, size, and albedo distributions of the NEO population. This model does an excellent job of reproducing observations from various NEO surveys (e.g., LINEAR). We predict the existence of approximately 1000 NEOs that are roughly 1 km in size. The mean impact interval for these objects with the Earth is 0.5 My, with most impactors being asteroids rather than comets. We also find that the Earth should undergo a 1000 megaton (MT) collision every 64,000 years. Only a tiny fraction of the 300 m diameter bodies capable of producing these kinds of blasts have been discovered to date. These predicted impact rates are in good agreement with the terrestrial and lunar crater record and have been confirmed by recent work. Our NEO model has recently been used to predict the future rate of NEO discoveries using current and next-generation survey technology. We find that 90% of the potentially hazardous (diameter $D > 140$ m) NEOs could be found within 20 years or so using new ground- or space-based surveys. The cost of these systems vary, but much can be accomplished for a budgetary equivalent to a NASA Discovery-class mission ($200-$400 million). Our understanding of the processes that produce NEOs has also led to new insights into how the terrestrial impact flux has changed over time. We can now show that large breakup events in the inner portion of the main asteroid belt may trigger so-called asteroid showers, events that can dramatically increase the impact flux on Earth for prolonged periods (e.g., in some cases for as long as 100 My). In fact, one particular breakup event occurring within the last 200 My may have had important implications for our understanding of mass extinction events and life on Earth.

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