Report of the Alternative Sustainable Energy Research Initiative 2009

Prof. David Cahen

Scientific Director

Table of Contents

Executive Summary

Prof. David Cahen, *Scientific Director*

The Alternative and Sustainable Energy Research Initiative (AERI) supports exploratory, long-term or bridging research into potential future ways towards developing sustainable, affordable energy sources, research that is unlikely to be supported (at all, or sufficiently) by usual sources. AERI aims to assure that alternative, sustainable energy research will be at the frontier of scientific exploration by Weizmann Institute scientists. For the past three years, AERI awarded grants for projects, ranging from very fundamental to more applied research towards clean fuels, solar cells, biofuels, and waste-free nuclear power. This report gives some highlights of that research. With unexpected speed, we can already point to several highlights in the areas of recapturing and recycling carbon dioxide by artificial or by natural photosynthesis and in water splitting, i.e., on potential new ways to create clean fuels.

A highpoint is Prof. David Milstein's remarkable discovery and unraveling of a new way to split water into oxygen and hydrogen, which made headlines after its April 2009 publication.

Prof. Igor Lubomirsky's group designed, developed and built an experimental model system to capture carbon dioxide using a bed of molten carbonate (which could be heated using solar power). They then use electrolysis to separate carbon monoxide (CO) from the heated mixture. The CO can be easily made into clean burning fuels using current technology.

AERI support is helping nanoscience researchers in their basic research into the harnessing nanomaterials for a new generation of solar cells.

Several projects explore ways to produce or use biomass for clean burning biofuels. To create a cheap biomass source that would not compete with food production, Profs. Avihai Danon and Uri Pick are testing and creating thousands of strains of algae, analyzing their metabolism and regulatory network, in their research for ways to produce new strains of algae that will be more efficient solar energy converters than existing strains.

Profs. Ed Bayer, Gideon Schreiber and Dan Tawfik have combined their efforts on biochemistry of cellulose, bio-informatics and enzyme libraries to create and test new combinations of enzymes, built into structures that exist in cellulose-degrading bacteria, to break down cellulose into simple sugars. Their efforts aim at turning abundant, non-edible agricultural and timber waste products into a source of energy.

Efforts in basic plant science by Dr. Dror Noy and Prof. Avigdor Scherz focus on finding ways to supercharge the photosynthetic capabilities of bacteria to generate chemical building blocks for clean fuels.

The Weizmann Institute plays a key role in developing diagnostic and testing tools to understand what happens when super-hot matter implodes in a nuclear fusion reaction. With some AERI support, Prof. Yitzhak Maron in the Plasma lab works with fusion researchers around the world in efforts to achieve safe, sustainable fusion reactions on a small scale.

In a recently AERI funded project Prof. Michal Hass researches the basic nuclear science "know how" that is critical for future cleaner and safer (4^{th} generation) nuclear reactors.

Already at this stage the number of young researcher-led AERI research projects, is significant (3 out of 9, including one who started his project as untenured, jr. researcher).

Finally, the presence and activities of AERI (which extend also into the realm of education) are important also to attract new researchers to the Weizmann Institute.

In addition to the directly funded research by the ten-year Alternative Sustainable Energy Research Initiative, the Weizmann Institute intends to build up an endowment to take over the job of sustaining support for alternative energy research in the future.

This is a productive and exciting time for alternative sustainable energy research worldwide and I am very proud that the Weizmann Institute of Science decided on and put into motion a unique approach to mobilize its human capital for this research effort. On behalf of all those involved and, even more so, on behalf of the future generations that will profit from what we do now, I would like to say "thank you" for your support and encouragement.

ARTIFICAL PHOTOSYNTHESIS

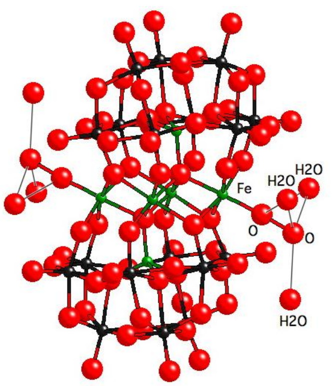
A New Catalyst

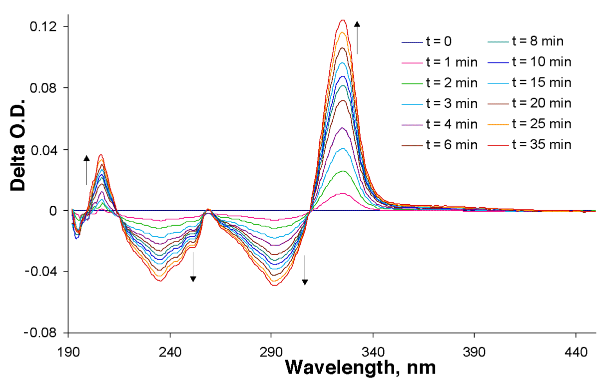
Prof. Ronny Neumann

Department of Organic Chemistry

Natural enzymes have developed methods to transport oxygen, using iron (in hemoglobin) and to activate oxygen for oxidation (monooxygenases). The steps in enzymatic activation include oxygen binding followed by formation of reactive peroxo species. There is great interest in carrying out such molecular oxygen activation in robust synthetic systems and in water. In order to realize this goal, Prof. Neumann's group has synthesized a robust water-soluble compound that does in fact lead to the formation of an activated oxygen species that has now been isolated for the first time (see diagram below).

The reaction of oxygen with a multi-iron substituted poly-oxometalate in water yielded an activated form of oxygen, termed "end-on" hydro-peroxo group, on the poly-oxometalate. This hydro-peroxo group was stabilized via hydrogen bonding with water and is unusual for its long oxygen-oxygen bond length and nearly linear iron-oxygen-oxygen bond angle. A method, called Electron Energy Loss Spectroscopy, was used to determine the compound's properties and allowed the observation of the activated compound during its formation. Further studies revealed the unique oxidation properties of this compound.





Above: A molecular model of the structure of the activated oxygen compound and the observation of its formation as determined by Prof. Neumann and colleagues, published in Angewandte Chemie ***47**, 9908-9912 (8 December 2008).*

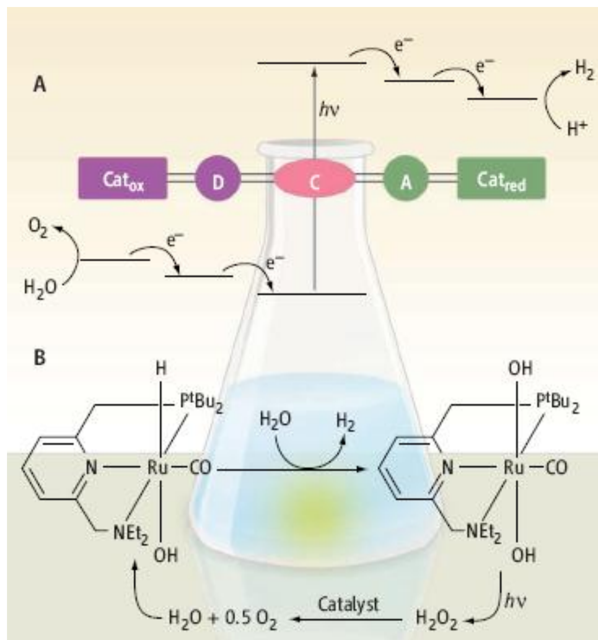
Splitting Water into Hydrogen and Oxygen

Prof. David Milstein and Dr. Stephan Kohl

Department of Organic Chemistry

Designing efficient systems for splitting water into hydrogen and oxygen, driven by sunlight, is an important challenge facing science today in the quest to use hydrogen as a step towards clean, sustainable fuel. But man-made systems that exist today are very inefficient and often require additional use of sacrificial chemical agents. In this context, it is important to establish new mechanisms by which water splitting can take place.

A unique approach developed by Prof. David Milstein and colleagues of the Weizmann Institute's Organic Chemistry Department, provides important steps in overcoming this challenge. During this work, the team demonstrated a new mode of bond generation between oxygen atoms and even defined the mechanism by which it takes place. This is important because generating dioxygen molecules by forming a bond between two oxygen atoms, originating from water molecules is one of the bottlenecks for splitting water. Their results have recently been published in *Science*.[1]



A: Conventional approaches to water splitting involve a catalyst and use of sacrificial electrons, represented in the energy state diagram.
B: The unique, three-step process described by Weizmann Institute researchers. Illustration from Science *Magazine, April 2009 article "Rethinking Water Splitting."*

The new approach that the Weizmann team has devised is divided into a sequence of reactions, which leads to the

1 Stephan W. Kohl, Lev Weiner, Leonid Schwartsburd, Leonid Konstantinovski, Linda J. W. Shimon, Yehoshoa Ben-David, Mark A. Iron, and David Milstein, " Consecutive Thermal H_2 and Light-Induced O_2 Evolution from Water Promoted by a Metal Complex" *Science* 3 April 2009 324: 74-7

liberation of hydrogen and oxygen in consecutive thermal- and light-driven steps, mediated by a unique ingredient – a special metal complex that Milstein's team designed in previous studies. Moreover, the one that they designed – a metal complex of the element ruthenium – is a "smart" complex in which the metal center and the organic part attached to it cooperate in the cleavage of the water molecule.

The team found that upon mixing this complex with water the bonds between the hydrogen and oxygen atoms break, with one hydrogen atom ending up binding to its organic part, while the remaining hydrogen and oxygen atoms (OH group) bind to its metal center.

This modified version of the complex provides the basis for the next stage of the process: the "heat stage." When the water solution is heated to 100˚C, hydrogen gas – a potential source for clean fuel – is released from the complex and another OH group is added to the metal center.

"But the most interesting part is the third 'light stage,'" says Milstein. "When we exposed this third complex to light at room temperature, not only was oxygen gas produced, but the metal complex also reverted back to its original state, which could be recycled for use in further reactions."

These results are even more remarkable considering that the generation of a bond between two oxygen atoms promoted by a man-made metal complex is a very rare event, and it has been unclear how it can take place. Yet Prof. Milstein and his team have also succeeded in identifying an unprecedented mechanism for such a process. Additional experiments have indicated that during the third stage, light provides the energy required to cause the two OH groups to get together to form hydrogen peroxide (H_2O_2), which quickly breaks up into oxygen and water. "Because hydrogen peroxide is considered a relatively unstable molecule, scientists have always disregarded this step, deeming it implausible; but we have shown otherwise," says Prof. Milstein. Moreover, the team has provided evidence showing that the bond between the two oxygen atoms is generated within a single molecule – not between oxygen atoms residing on separate molecules, as commonly believed – and it comes from a single metal center.

Discovery of an efficient artificial catalyst for the sunlight-driven splitting of water into oxygen and hydrogen is a major goal of renewable clean energy research. So far, Milstein's team has demonstrated a mechanism for the formation of hydrogen and oxygen from water, without the need for sacrificial chemical agents, through individual steps, using heat and light. They now plan to combine these stages to create an efficient catalytic system.

Storing Electrical Energy by Reducing CO_2 to Carbon Monoxide

Prof. Igor Lubomirsky

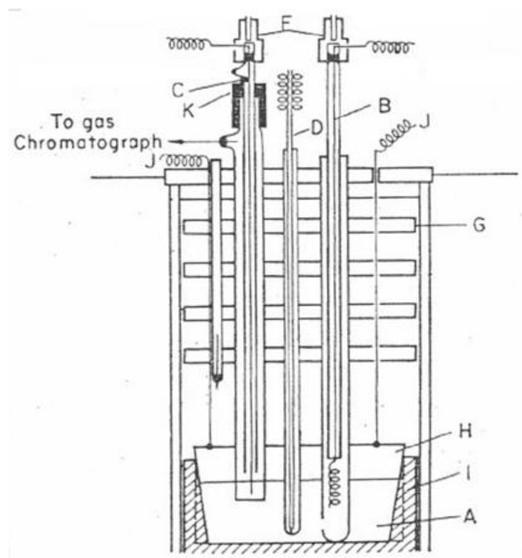
Department of Materials and Interfaces

Prof. Igor Lubomirsky in the Department of Materials and Interfaces investigates how to use solar energy to drive a waste-free system to capture atmospheric carbon dioxide and convert it into a storable fuel stock that can be used to produce clean fuels.

In research so far, Prof. Lubomirsky and his team designed and built an experimental setup that captures carbon dioxide by way of a molten carbonate that could be heated using concentrated solar power. They then use electrolysis (to use electricity that is generated in places, far from the electrical grid, by e.g., wind generators) to separate carbon monoxide (CO) from the heated mixture. Even though pure CO is poisonous, it can be stored and transported safely, and also easily converted into a number of clean burning fuels.

In the first stages of this research a promising carbonate "melt" and durable materials to contain the melt for long-term operations at the required temperature were identified. The next step was to begin selecting suitable electrode materials for the cathode and anode to carry out the electrolysis. The electrodes need to operate at high temperatures and for long periods of time without becoming coated or corroded by the carbonate.

Prof. Lubomirsky successfully solved the most important and difficult problems associated with the electrochemical production of CO from molten carbonates.



Above: Experimental set up for high temperature electrochemistry. A – Molten carbonate electrolyte. B – Reference electrode Pt wire. C – Working electrode (Cathode) Nickel or Graphite. D – Thermocouple type K. J – Counter electrode (Anode) Graphite. H – Alumina crucible. I – Ceramic crucible holder. G – Electric furnace.

They developed the electrodes, the electrolyte and the container for the electrolyte. Their working prototype has been tested for 100 hrs. of continuous operation without detectable degradation within a temperature range of 750-950 °C. The process does not use noble metals or other particularly expensive materials, and – most importantly – it seems promising in terms of sustainability.

The next phase of the project involves refining the system, scale up the experimental setup to use higher electrolysis currents, and carry out long-term stability tests.

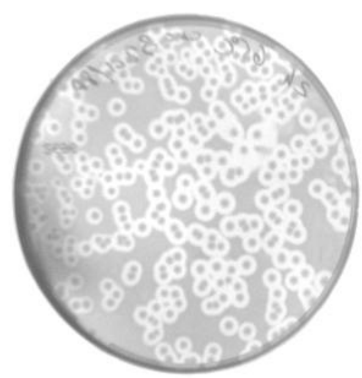
Designer Cellulosomes for Processing Biomass-to-biofuels

Profs. Ed Bayer, Gideon Schreiber, Dan Tawfik

Department of Biological Chemistry

For the past several years, a team of Weizmann Institute scientists has been working to create the world's first "designer cellulosomes" as a way to break down cellulose quickly and efficiently enough to be a viable way to produce biofuels. Cellulose is one of the most abundant plant products. It is high in biomass but tough to break down. an obvious result of evolution, because such toughness is what makes it one of the structural elements of plants. Still, because of its abundance, if we can find a way to turn cellulose – controllably – into the simple sugars that can form the basis for clean burning biofuels, which will be a major step towards affordable, sustainable biofuels. The aim of this far-sighted project is to take Nature's most efficient cellulose-digesting machines and make them faster and more robust.

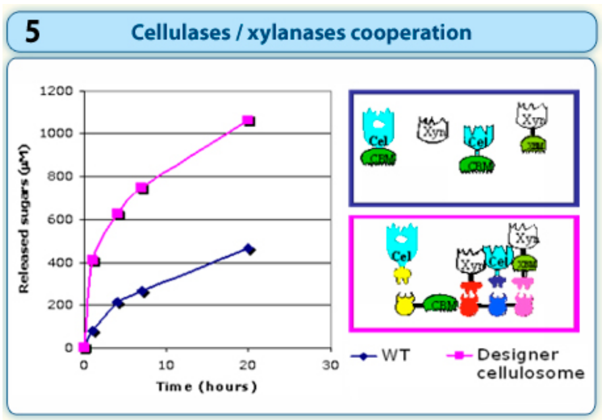
The interdisciplinary effort, led by Prof. Edward Bayer, builds on the discovery (by Bayer and colleagues) of cellulosomes, ensembles of enzymes that assist in digestion or degradation of cellulose, and aims at generating artificial designer cellulosomes for more efficient and safe degradation of cellulose to yield, ultimately, glucose, a sugar. Their designer cellulosome is to be constructed from a large number of different individual cellulose-degrading enzyme components, assembled by a specialized scaffolding framework of binding proteins.



An assay system developed for cellulase-producing E. coli cells. Cellulose derivatives are embedded in agar, and "halos" form around bacterial colonies that express an active endoglucanase enzyme.

They started by studying a large number of natural cellulose-degrading enzymes originating from many different organisms. Then they began combining the most promising of these enzymes into a multi-enzyme cellulosome complex in order to enhance their action and overcome the natural resistance of crystalline cellulose. Their recent studies have shown that the synergistic action of multi-enzyme complexes is most critical when degrading native forms of cellulose. The research team had to develop its own tests and procedures to measure the cellulose-digesting activity of dozens of enzymes. Then, they developed new ways to assemble these enzymes on a protein scaffold and measure their combined action.

They recently compared the activity of their first "designer cellulosomes" to a natural system, produced by the bacterium, *Thermobifida fusca*, and found that in some cases, the "designer cellulosomes" worked better than the mixture of natural enzymes. They are currently studying the assembly of other types of relevant enzymes produced by this bacterium into designer cellulosomes, in order to enhance degradation of the plant cell wall.



They were able to examine the proximity effect among the different types of enzymes on the degradation of natural substrates (as straw). They succeeded in demonstrating that the close proximity between specific combinations of enzymes resulted in enhanced degradation of the complex polymer (Figure at left).

The scientists concentrate on finding the best combinations of enzymes. They are also tapping Prof. Dan Tawfik's expertise in "directed evolution" to systematically create and screen a large number of mutant cellulose digesting enzymes and Prof. Gideon Schreiber's bio-informatics expertise to see if there are variations with even higher activity. By the end of this year they hope to test a cellulosome that is at least 5 times more active than the individual enzymes composing it, thus bringing them closer to their long-term goal of constructing designer cellulosomes for efficient conversion of cellulose to soluble sugars.

The project demonstrates the synergistic strength of the three research groups as well as the advantages of combining different enzymes in new ways. The project team now has two Ph.D. students and two postdoctoral fellows working with Prof. Bayer and Prof. Gideon Schreiber and Prof. Dan Tawfik.

Cyanobacteria as new platforms for clean energy

Prof. Avigdor Scherz

Dr. Droy Noy

Department of Plant Sciences

Photosynthetic bacteria and micro-algae are evolutionarily ancient organisms that have very efficient solar energy conversion (photosynthesis) machinery and some unique metabolic pathways for the production of hydrogen gas, which is considered a promising intermediate for clean fuels.

Dr. Noy's seeks to find simple ways to combine the components of photosynthesis into novel energy conversion systems. The building blocks for these new systems are protein structures, which serve as the scaffolds for combining various biochemical "parts" found in Nature. These natural "parts" include photosensitive pigments, chlorophylls, and bacterio-chlorophylls, various enzymes and their synthetic derivatives. Importantly, this strategy does not attempt to redesign the catalytic sites of natural enzymes or to design novel ones, which is a formidable challenge because of the complexity of enzymatic active sites. Instead, it focuses on controlling the pathways of energy and charge transfer between the catalytic centers – the working parts of the combined structures. Testing and assembling the right biochemical components could enable the researchers to create new combinations of biocatalysts that operate out of their natural context, an engineered type of natural photosynthesis.

Prof. Avigdor Scherz collaborates with Dr. Noy to prepare mutants of promising strains of heat-tolerant cyanobacteria that have fairly simple and direct photosystem pathways. They use novel mutants, developed in the lab of Prof. Scherz, of strains of hydrogen-producing cyanobacteria and algae that are heat-tolerant and photosynthetically active over a range of 15-45°C. This could allow their bioengineered solar energy conversion systems to operate in harsh and marginal growing conditions.

Control of the Plasma Density Distribution for Optimizing the Energy Conversion in Implosion Systems

Prof. Yitzhak Maron, Dr. Eyal Kroup

Department of Particle Physics

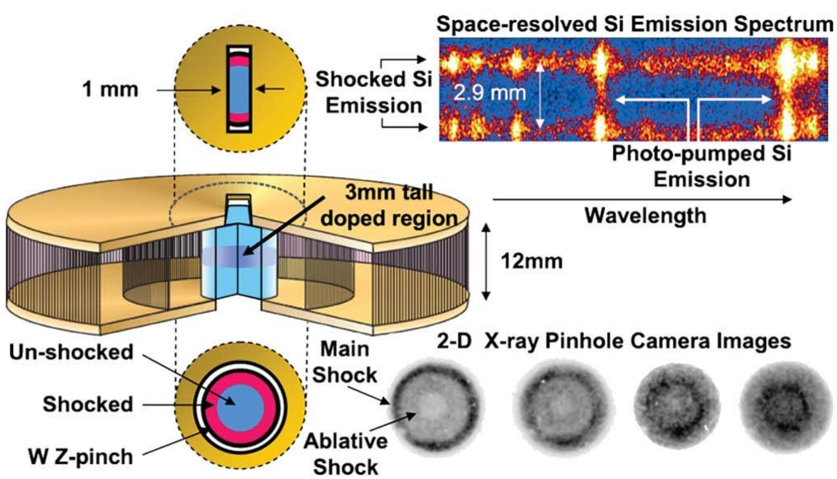
The plasma lab at the Weizmann Institute of Science is studying the fundamental physics of the very hot, very dense plasmas that are necessary to create nuclear fusion. The plasma lab works with the top nuclear fusion labs around the world, including the pulsed power fusion experimental program at Sandia National Laboratories (US). The lab's unique contributions to the science of understanding the complex dynamics of plasmas near the point of fusion are vital to the worldwide efforts to create sustainable nuclear fusion as a source of clean energy.

In pulsed-power fusion, a pulse of intense electrical energy is converted to X-ray energy, which then heats a fusion pellet to temperatures comparable to those on the sun. The intense X-ray energy burst is created in a hot, dense and short-lived plasma formed as a result of the conversion of magnetic energy, by implosion, to plasma kinetic energy. The Z-pinch technology being explored with Sandia has a cost per radiated x-ray joule that is a factor of 100 times lower than other technologies, which makes it a leading candidate for fusion energy.

The plasma laboratory at the Weizmann Institute specializes in the development of advanced diagnostics based on optical techniques in tandem with detailed atomic physics simulations for understanding the dynamics of these hot-dense plasmas. For example, a recent collaboration with the Freidrich-Schiller University in Jena (Germany) resulted in an important contribution to the field of X-ray spectroscopy within Z-pinch plasma studies. For the first time, scientists were able to measure and track the history of the ions' rapidly changing energies, as a function of its position along the pinch column, using a series of spectral images captured at increments of 1 nanosecond (1 billionth of a second), at a resolution of 0.1 mm, and at ultrahigh spectral resolution.

They showed that a significant portion of the electrical energy invested in the Z-pinch gas is stored in the form of "ion turbulent motion" that is not available for x-ray radiation. Understanding the processes that govern the energy conversion to ion turbulent motion will allow for optimizing the Z-pinch as an x-ray source. One of their goals is to decrease the turbulence in the plasma and create a more controlled implosion. It is noteworthy that obtaining this result was made possible using a recent breakthrough in developing new plasma diagnostic technique. The new technique developed by the plasma laboratory enables them to distinguish between the two forms of the ion kinetic energy, namely, between thermal and turbulent motions. Until recently, such diagnostics were considered to be nearly impossible.

The plasma group has discovered, and shared with the worldwide scientific community, new methods to measure the magnetic fields that are used to drive the implosion of matter that creates the plasma. They are also improving spectrographic instruments to measure and observe the visible, UV and X-ray light and radiation over time as the plasma heats up.



Above Diagram of an experimental apparatus used to capture space-resolved emission spectrum and x-ray pinhole images corresponding (from left to right) to times of 5.7, 5.0, 3.7, and 2.9 nanoseconds of an implosion created in a z-pinch device.

New (2009 cycle) projects

Quantum-dot based concentrators for solar energy conversion

Dr. Dan Oron

Department of Physics of Complex Systems

Dr. Dan Oren, a young physicist who joined the Department of Physics of Complex Systems in 2007, already has promising results for making nanocrystals that can harvest light into electrical energy in unconventional ways. In conventional photo cells, each photon (light particle) excites a single electron, which is, in turn, converted into electric current. In nanocrystal-based cells, it may be possible to open a new channel by which a single high-energy (blue, green) photon generates not one, but two excited electrons – leading to a higher current for a given solar light intensity. His novel design attempts to optimize the nanocrystal properties so as to favor this channel while reducing alternative mechanisms, which lead to dissipation into heat.

High-voltage semiconductor-sensitized nanoporous cells

Prof. Gary Hodes, *Department of Materials and Interfaces*

Recent advances made in very high efficiency tandem cells, where three cells, sensitive to different parts of the solar spectrum are built in series, have resulted in greater than 40% efficiency. However these cells are extremely expensive.

Nanoporous photovoltaic cells are based on a highly-porous substrate (invariably a metal oxide) on which a sensitizing layer (a dye or a semiconductor) is deposited. A specific subset of these cells is the Extremely Thin Absorber (ETA) cell, using a semiconductor sensitizer on the oxide and also a hole conductor to complete the circuit.

The purpose of this project is to investigate ETA cells (which are intrinsically cheap) with the intention of finding one which is selectively sensitive to the high energy part of the solar spectrum and can provide the high voltage part of a tandem cell. This will be done by:

(a) Identifying a materials combination that is capable of giving a high voltage and

(b) Engineering the different interfaces in the system to minimize the energy losses in the conversion process.

GeoNumbers – the useful earth and energy numbers database

Dr. Ron Milo

It is currently very frustrating and time-consuming to find reliable numbers in energy research that include references and description of the methodology by which they were measured. GeoNumbers will be based on the example of BioNumbers – a database of useful biological numbers that enables researcher in the biology community to find in less than one minute any common biological number that can be important for their research. GeoNumbers will contain full references and comments, and enable discussion on how the number was arrived at and how reliable it is. It is meant to develop into a community-based effort. The alternative energy research community has a strong need for easy access to reliable numbers. Dr. Milo proposes to harness the wide experience of experts in various fields working at the Weizmann Institute to help build GeoNumbers and make it available to the international community.

EcoDollars: the environmental cost of products

Dr. Ron Milo

Environmentally minded consumers want to contrast different items in terms of their cost to the environment, in terms of the way they impact sustainable life on earth. This is currently not feasible for the average consumer. Dr. Milo's vision is that every product will someday have a label stating a sustainability index, its overall cost in terms of resources such as energy, water, raw materials. These costs will be aggregated into an EcoDollar label paralleling the usual monetary price tag. Clear indication of the EcoDollar cost, which reflects the whole cost of offsetting the impact of the product on the environment, will give an incentive for companies to manufacture products in an increasingly environmentally friendly and sustainable way. This approach is in line with efforts to define the ecological footprint of consumption using life cycle analysis and input-output resource relationships.

Novel nuclear-energy fuel and radioactive waste transmutation

Prof. Michael Hass

Department of Particle Physics

The scientific and engineering community is working intensively on novel ideas for the design of safer and more efficient nuclear plants and on solutions of the long-standing problems in the nuclear power industry. AERI will be supporting exploratory R&D work that takes advantage of the unique possibilities offered by construction of a new, modern accelerator at the Soreq Research Center (located not far from Rehovot) that is run by the Israel Atomic Energy Commission. The Soreq Applied Research Accelerator Facility (SARAF), is presently being commissioned, and will introduce the Israeli nuclear physics community to the science of the "21st century," in the same way that the Koffler Accelerator introduced Israel to "20th Century" nuclear science, more than 30 years ago.

One idea is to explore the possibility of using Thorium (Th), a relatively abundant and non-fissionable element, for production of the fissile material. If non-fissile isotopes like ^{238}Uranium or ^{232}Th could be used as nuclear fuel, there would be sufficient material to run reactors for hundreds of years. Use of Thorium would also reduce greatly the problems associated with nuclear proliferation and waste management. Various schemes have been proposed to convert "fertile" ^{232}Thorium to fissile ^{233}Uranium (U) via capturing fast neutrons – the "breeder" reactor approach. However, intense sources of energetic neutrons are needed to achieve these goals. The SARAF accelerator will provide the researchers with such a source. Once "bred," the ^{233}U can be later recharged into the reactor core for further energy production. Basic research information is critically needed to design a new generation of economically more competitive breeding reactors.

Another line of active research seeks to use similar transmutation techniques to transform the radioactive "waste" of nuclear fission reactors. The main concern is transforming the long-lived waste products, with half-lives of the order of many thousand years, into isotopes with much shorter half-lives. Since current technology can not guarantee the integrity of a geological isolation of waste burial sites for such long periods, Hass seeks novel solutions to this problem so as not to burden future generations with potentially hazardous radioactive wastes. While waste transmutation on industrial scale is not feasible in the near future, any practical, experimental information regarding the transmutation process is of great importance for long-term solutions.

Such basic research and development efforts may help position the Weizmann Institute, and Israel in general, on the future map of international efforts towards the development and implementation of these cleaner nuclear fuel production and waste reduction scenarios.

AERI Projects 2006 – 2009

AREA	Projects 2006-2007	Projects 2007-2008	Projects 2008-2009
CLEAN FUELS	Reduction of carbon dioxide to hydrocarbons (alkanes/alcohols) by hydrogen. *Prof. Ronny Neumann (pilot project)*	New concepts for the catalytic conversion of carbon dioxide for "C- neutral" energy. *Profs. Ronny Neumann, David Milstein, Gershom (Jan M.L.) Martin*	
	Chemical storage of electrical energy with carbon monoxide as an intermediate product. *Prof Igor Lubomirsky*		
SOLAR CELLS		New type of hybrid nanoparticle-organic systems for solar energy conversion *Profs. Yinon Rudich, Boris Rybtchinski, Ron Naaman, Gary Hodes, Leeor Kronik (pilot project)*	High-voltage, semiconductor-sensitized nanoporous cells. *Prof. Gary Hodes*
			Quantum-dot based concentrators for solar energy conversion *Dr. Dan Oron*
BIOMASS AND BIOFUELS	Genetic engineering of triglycerides in green algae for production of biodiesel. *Profs. Uri Pick, Avihai Danon*		
	Designer cellulosomes as a platform for processing biomass. *Profs. Ed Bayer, Gideon Schreiber, Dan Tawfik*		
		Genetically engineered cyanobacteria; novel platforms for biomass and molecular hydrogen generation. *Dr. Dror Noy, Prof. Avigdor Scherz*	
WASTE FREE NUCLEAR POWER		Control of the plasma density distribution for optimizing the energy conversion in implosion systems. Dr. *Eyal Kroupp, Prof. Yitzhak Maron*	
			Towards novel radioactive waste transmutation. *Prof. Micha Hass*
METRICS			Geo-Numbers and Eco-Dollars *Dr. Ron Milo*