Report of the

Alternative Sustainable Energy

Research Initiative

2010

Prof. David Cahen

Scientific Director

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Executive Summary

Prof. David Cahen, Scientific Director

The Alternative and sustainable Energy Research Initiative (AERI) began its fifth grant-giving cycle this fall. This is an intermediate milestone in our ten-to-twenty year vision for the Initiative; and a good moment in time to look back at what we have accomplished, and to look ahead at the enormous challenges yet before us.

AERI began in 2006 with a pledge and a challenge from Mr. Yossie Hollander, an Israeli business leader and alternative energy advocate. He asked Weizmann Institute scientists for an outline of the kinds of alternative energy projects they would propose if more flexible funding was available to pursue their ideas. The Alternative and sustainable Energy Research Initiative, together with the Mary and Tom Beck-Canadian Center for Alternative Energy Research, is built on that shared vision. It has become the primary vehicle for accelerating, coordinating and sharing alternative energy research at the Weizmann Institute of Science. Other major donors now include (in alphabetical order):

- Mr. and Mrs. George Brady (Canada)
- The Brazil-Israel Alternative Energy Fund (Brazilian Friends of the Weizmann Institute of Science)
- Mr. and Mrs. Andrew Lengyel (Canada)
- Lew and Pearl Litwin (Canada)
- Irving, Jack and Wilfred Posluns (Canada)
- Mr. Barrie Rose (Canada)
- Mr. and Mrs. Daniel S. Shapiro (UK)
- Mr. and Mrs. Robert Zaitlin (US)

One of the main purposes of AERI was to provide a pool of funds for trying out new ideas and for jump-starting research projects that were not yet ready for conventional grants. In that spirit, we have funded two pilot projects that formed the basis for fuller-fledged studies.

Prof. Ronny Neumann's experiments in carbon dioxide reduction became a joint project with Prof. David Milstein and Prof. Gershom Martin. It resulted in the discovery of a radically new approach to water-splitting hydrolysis. The Weizmann team divided classical hydrolysis into a sequence of reactions. Using a special ruthenium complex that Milstein's team designed in previous studies, they were able to liberate hydrogen and oxygen in consecutive heat- and light-driven steps. The ruthenium catalyst at the heart of their process 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 catalyst is not consumed in the reaction. Further scientific work is building on that discovery. [1]

Prof. Gary Hodes is pursuing new designs for high-voltage, nanoporous solar cells based on semiconductor absorbers sandwiched between two transparent, nanoporous materials. He has identified several factors, some of them unexpected, that impact the performance of these solar cells.

The three-year AERI-funded pilot project with the team of professors Ed Bayer, Gideon Schreiber and Dan Tawfik and their labs are now beginning to produce a second generation of "designer cellulosomes." Their research has moved on to stage where it can attract more traditional grants.

Another three-year pilot by Profs. Uri Pick and Avihai Danon was jump-started by AERI. Their genetic engineering of triglyceride levels in green algae for production of biodiesel fuels has also "graduated" to the point that it is pursing competitive grant funding from conventional sources.

In the same vein, Prof. Yitzhak Maron and Dr. Eyal Kroupp are continuing to pioneer diagnostics and controls for optimizing the "Z-pinch" approach to creating nuclear fusion. Their efforts were aided by two years of AERI funding.

Prof. Michael Hass is looking forward to another year of AERI funding for his far-sighted efforts to use the new Soreq Applied Research Accelerator Facility (SARAF) to do basic research in novel ways to reduce radioactive wastes in commercial nuclear technology. Much of his efforts in the past year have been in bringing the first phases of the

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[1] Milstein, et. al "Consecutive Thermal H_2 and Light-Induced O_2 Evolution from Water Promoted by a Metal Complex" *Science* 3 April 2009: Vol. 324 no. 5923 pp. 74-77

accelerator's research program into operation so that it can begin to explore some of his ideas for cleaner fuel cycles for fission reactors.

For the past two years, AERI has helped support the efforts of a new scientist recruited to the Weizmann Institute, Dr. Ron Milo. We are pleased to note that one of Dr. Milo's papers, ""Network Motifs: Simple Building Blocks of Complex Networks," published in the journal *Science* in 2002, has been singled out by Thomson Reuters Scientific and their ISI Web of Knowledge as one of the most-cited articles in his field for the decade from 2000 to 2009. Grants from AERI have helped his work in the "eco-metrics" of energy and carbon fixation. Dr. Milo is one of our second generation of systems biologists at the Weizmann Institute, having studied under Prof. Uri Alon for his Ph.D.

Finally, AERI has been active in working to encourage the next generation of clean energy researchers. We were proud that four of our students initiated and organized the Student Solar Conference 2010. SSC2010 was a four-day conference in April that brought together young scientists from nearly all the schools of higher learning in Israel (Weizmann, Tel Aviv University, Bar-Ilan, Ben Gurion, and Hebrew U). I have included a report of their meeting in this report as well.

The world of science has much catching up to do if we hope to wean the world to cleaner, carbon-neutral forms of energy. Our conviction remains that basic research into the fundamentals of energy, light, matter and materials, biology and chemistry is the best route to produce the hoped-for paradigm-shifting discoveries that will lead to a cleaner, "greener" energy future.

Thank you for your interest in alternative and sustainable energy and for your support for our research efforts.

AERI-Funded Projects 2009/2010 Cycle

- Alternative carbon fixation cycles for increased productivity and sustainable energy, Dr. Ron Milo
- Reconstitution of an active oxygenic photosystem by incorporating its natural components in sol-gel matrices, Dr. Dror Noy
- Self-propagating assemblies as buffer layers for inverted solar cells, Prof. Milko van der Boom

Continuing Projects:

- High voltage semiconductor-sensitized nanoporous cells, Prof. Gary Hodes
- Towards novel nuclear-energy schemes and radioactive waste transmutation, Prof. Michael Hass
- GeoNumbers – the useful earth and energy numbers database and EcoDollars: the environmental cost of products, Dr. Ron Milo
- Quantum-dot based luminescent concentrators for solar energy conversion, Dr. Dan Oron
- New concepts for the catalytic conversion of carbon dioxide for "C neutral" energy, Profs. Ronny Neumann, David Milstein, and Gershom (Jan M.L.) Martin

AERI-Funded Projects 2010/2011 Cycle

NEW

- "Enhancing biofuel production" Prof. Avi Levy, Department of Plant Sciences, coordinator of an 11-person, collaborative AERI project, incorporating two new grants:
    - "Lipidomics-based engineering of high-lipid content in marine algae through mimicking virus-host interactions" Dr. Assaf Vardi and Dr. Asaph Aharoni, Department of Plant Sciences
    - "Genetically engineered cyanobacteria for biomass and biodiesel generation under elevated temperature and CO_2 concentration," Prof. Avigdor Scherz, Department of Plant Sciences

CONTINUATION Grants[2]

- Catalytic reduction of carbon dioxide, Prof. Ronny Neumann
- High voltage semiconductor-sensitized nanoporous cells, Prof. Gary Hodes
- Novel nuclear-energy schemes and radioactive waste transmutation, Prof. Michael Hass
- GeoNumbers – the useful earth and energy numbers database and EcoDollars: the environmental cost of products, Dr. Ron Milo
- Reconstitution of an active oxygenic photosystem by incorporating its natural components in sol-gel matrices, Dr. Dror Noy
- Self-propagating assemblies as buffer layers for inverted solar cells, Prof. Milko E. van der Boom

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[2] NOTES:

Prof. Dan Oron did not submit a request for renewal of *Colloidal semiconductor quantum dots as intermediaries in photovoltaic solar cells* because he got an ERC (European Research Council) grant.

Dr. Ron Milo did not ask for a continuation request for his 2009/10 project on *Alternative Carbon Fixation Cycles for Increased Productivity and Sustainable Energy* because he got ERC funding for it.

Prof. David Milstein did not join the request of Ronny Neumann, because he got an ERC grant (on this topic)

Prof. Gershom Martin did not join the request of Ronny Neumann, because he took an extended leave of absence.

AERI Projects 2006 – 2011

AREA	Projects 2006-2007	Projects 2007-2008	Projects 2008-2009	Projects 2009 - 2010	Projects 2010 - 2011
CLEAN FUELS	Reduction of carbon dioxide. *Prof. Ronny Neumann* ***(pilot project)***	New concepts for the catalytic conversion of carbon dioxide →	*Profs. Ronny Neumann, David Milstein, Gershom (Jan M.L.) Martin*→	→	Catalytic Reduction of Carbon Dioxide - *Prof. Ronny Neumann*
	Chemical storage of electrical energy with carbon monoxide →	*Prof Igor Lubomirsky*	→	→	
SOLAR CELLS		Hybrid nanoparticle-organic systems *Profs. Rudich, Naaman, Hodes, Kronik, Dr. Rybtchinski,* ***(pilot project)***	High-voltage, nanoporous cells.	→ *Prof. Gary Hodes*	→ High voltage semiconductor-sensitized nanoporous cells, *Prof. Gary Hodes*
			Quantum-dot concentrators →	for solar energy conversion *Dr. Dan Oron*	Self-propagating assemblies for inverted solar cells – *Prof. Milko E. van der Boom*
BIOMASS AND BIOFUELS	Genetic engineering of triglycerides in →	green algae for production of biodiesel →	*Profs. Uri Pick, Avihai Danon*		"Enhancing Biofuel Production" *Prof. Avi Levy and 10 teams*
	Designer cellulosomes as a →	platform for processing biomass.→	*Profs. Ed Bayer, Gideon Schreiber, Dan Tawfik*		"Genetically engineered cyanobacteria for biomass *Prof. Avigdor Scherz,*
		Genetically engineered cyanobacteria for biomass	*Dr. Dror Noy, Prof. Avigdor Scherz* →	*Dr. Dror Noy*	Incorporating natural components in sol-gel matrices – *Dr. Dror Noy*
WASTE FREE NUCLEAR POWER		Control of the plasma density for optimizing energy conversion →	systems. *Dr. Eyal Kroupp, Prof. Yitzhak Maron*		
			Novel radioactive	waste → transmutation.	→ *Prof. Michael Hass*
METRICS			GeoNumbers	*Dr. Ron Milo* →	→ *Dr. Ron Milo*
				Alternative Carbon Fixation Cycles *Dr. Ron Milo*	

Dr. Dror Noy

Department of Plant Sciences

My laboratory studies the fundamental processes involved in photosynthetic solar energy conversion. Plants and other evolutionarily older photosynthetic organisms use light to create energy for all their metabolic needs. They are a source of inspiration for designing artificial devices for solar energy conversion and storage. Our group focuses on the flow of energy and electrons to and from the catalytic sites of photosynthetic enzyme complexes. We take a modular approach, looking at the process as a series of electro-chemical reactions between a number of catalytic beginning and ending points, The "endpoint" of each catalytic process provides the raw materials needed for the next step in the process. Our aim is to design new proteins that are capable of performing charge and energy transfers between the catalytic endpoints found in photosynthetic systems. We hope to be able to streamline the process and make many of the steps more efficient.

By applying state-of-the-art computational and empirical tools of protein *de novo* design, our lab constructs novel protein-cofactor complexes that simplify the natural energy and electron transfer proteins. In the next stage of the building process, we create an interface designed to couple the artificial proteins with their natural and/or catalytic partners. New designs are tested by a variety of analytical and spectroscopic methods, and the results are used for optimizing the previous designs in an iterative process.

This learning by design approach provides substantial insights into folding and assembly of protein-cofactor complexes, and the critical parameters affecting their function as energy- and electron-transfer relays. Most importantly, it can teach important lessons on how Nature achieves functional diversity by combining only a few basic modules into a variety of elaborate networks of long-distance inter- and intra-protein energy and electron-transfer reactions. In the future, these lessons may be used for designing and constructing custom-built networks of enzyme complexes to carry out chemical transformations of our choice, either in a non-biological context, or in a biological setting.

Achievements

In January 2007 I joined the Weizmann Institute's Plant Sciences department. There, I have established a lab whose strength lies in the unique combination of protein and pigment preparative techniques, analytical and spectroscopic methods, empirical and computational protein design, as well as the deep and thorough understanding of biological energy and electron transfer processes. Our recent achievements include:

Computational design and preparation of a new. non-natural oxidation/reduction (redox) protein. In this design, an iron-sulfur cluster – a ubiquitous natural redox center – is embedded within an artificial protein structure. Unlike natural iron-sulfur proteins in which the cluster is typically bound by an irregular loop, the artificial protein provides a regular helical scaffold for iron-sulfur cluster binding. This makes the design extendable into a multi-center redox protein in which iron-sulfur clusters are within electron tunneling distance from each other. Thus, the current design is a prototype for a protein-based electron transfer (ET) "wire" (Grzyb et al. BBA 2010). This is an important step in creating "modular" new protein systems.

Formulation of empirical guidelines for designing chlorophyll- (Chl) binding helical proteins based on a survey and analysis of Chl-binding proteins' crystal structures. This provides useful guidelines for designing *de novo* proteins with stronger and more specific Chl-binding sites. This opens the way for constructing artificial protein-Chl complexes that can serve as light-harvesting modules in bioinspired solar energy converters (Braun et al. Proteins – in press).

Incorporation of dimers (a structure formed from two sub-units) of water-soluble chlorophyll derivatives into *de novo* designed proteins. The system is unique in providing the simplest possible model for arranging interacting Chls within a protein medium. These dimers are the basic unit in photosynthetic light-harvesting complexes. By providing a controllable protein environment, this system is a useful tool for studying the mechanisms by which the protein environment regulates energy-and-electron-transfer (EET) within light harvesting pigments. Particularly, we can learn how natural photosynthetic complexes can actively and rapidly switch between light-harvesting and light energy dissipation modes to protect themselves against damage by high light intensities. This is an important question and a topic of hot debate in current photosynthesis research. (Cohen-Ofri et al. manuscript in preparation).

Encapsulation of the active photosystem II (PSII) into an inorganic sol-gel matrix. Photosystem II is the complex of twenty protein subunits and nearly 100 cofactors and other components that is the primary engine of photosynthesis in plants, algae and cyanobacteria. This is the first example of incorporating the natural water-splitting catalyst (PSII) into a biocompatible, transparent sol-gel matrix. It provides a basis for constructing an inorganic alternative to the photosynthetic membrane for embedding and coupling natural and artificial photocatalysts.

Design and preparation of a water-soluble analog of a transmembranal Chl-protein motif. This is the second example of converting a transmembranal protein into a water-soluble one while maintaining its functional characteristics. The only other example is the KcsA potassium channel analog made by the DeGrado lab (Slovic et al. *PNAS* 2004). Our design was more challenging than the KcsA design because our protein binds cofactors and is a partial motif in a larger protein complex rather than a whole protein. (Margalit et al. manuscript in preparation)

Design and preparation of a complex of allophycocyanin (APC), a natural light-harvesting protein, with *de novo*-designed Chl-binding proteins. The new design opens many possibilities for assembling simplified photosystem analogs combining natural and artificial functional protein modules. (Tennyson et al. manuscript in preparation)

Altogether, the emerging new structures and protein design methodologies mark significant progress in our ability to develop new protein scaffolds that control and organize redox cofactors and light-harvesting pigments. Already at these early stages of design, some structures provide simplified models of natural light-harvesting and charge separation systems.

Prospective

In the near future, my research will capitalize on these achievements and will evolve in the following directions:

- Extending the iron-sulfur protein design to include multiple cofactors and interfaces to natural redox proteins. The new designs will be tested and optimized first for efficient electron transfer (ET) through the protein-embedded, iron-sulfur redox chain, and finally as ET relays to or from natural biocatalytic redox centers.
- Designing novel Chl-binding proteins based on the lessons learned from the recent survey of natural structures, as well as previous designs. The primary goal is to achieve more control of Chl organization and binding to create simplified models and benchmarks for the elaborate Chl-array systems found in natural light-harvesting complexes.
- Coupling photosystem One (PSI) and PSII in a sol-gel matrix and creating a novel scaffold that will enable photosynthesis without the need of the photosynthetic membrane.

With improved protein designs and better control over cofactor organization and electronic structure I am striving to construct a genuine molecular hybrid system that integrates artificial redox proteins with natural photosynthetic enzymes. Demonstrating efficient ET or EET between de novo designed protein-cofactor complexes and a natural catalytic redox or light-harvesting partner will be a major breakthrough in understanding the operation principles of biological ET and EET networks and a step forward in the ability to manipulate them at the molecular level.

My recent achievements have put such hybrid systems within reach. For example:

a) de novo designed iron-sulfur proteins can be used to relay electrons from PSI to the catalytic centers of hydrogen evolving enzymes,

b) PSII can be coupled directly to PSI by using soluble electron carriers to shuttle electrons through the pores of sol-gel matrices,

c) natural phycobiliproteins such as APC can be attached to a de novo designed Chl-binding protein such that excitation energy is transferred efficiently from the natural light-harvesting module to the pigments embedded in the de novo designed proteins.

These directions are being actively pursued in my lab either independently or as collaborative projects with leading international groups.

I would like to thank donors to AERI for making a major investment in my laboratory and in research at the Weizmann Institute of Science. Your support has helped me launch an ambitious and innovative research program that examines the inner workings of photosynthesis and natural energy systems.

Recent Publications

- Paula Braun, Eran Goldberg, Christopher Negron, Mathias von Jan, Fei Xu, Vikas Nanda, Ronald L. Koder, and **Dror Noy "**Design Principles for Chlorophyll Binding Sites in Helical Proteins." *Proteins Struct. Funct. Bioinfo.* in press (2010).
- Iris Margalit, Joanna Grzyb, Ilit Cohen-Ofri, **Dror Noy** *"De novo* design of a minimal, water-soluble analog of photosynthetic light harvesting complexes" (manuscript in preparation)
- Ilit Cohen-Ofri, Joanna Grzyb, **Dror Noy**, "Excited state dynamics of zinc–bacteriochlorophyllide monomers and dimers within de novo designed proteins" (manuscript in preparation)
- Jebasingh Tennyson, Joanna Grzyb Ilit Cohen-Ofri, Liron David, Noam Adir, **Dror Noy**, "In vitro assembly of allophycocyanin antenna with a de novo designed chlorophyll-binding protein" (manuscript in preparation)

Dr. Ron Milo

Department of Plant Sciences

Systems biology is a new, holistic, quantitative approach to the study of biological systems. In general terms, it involves the development of analytic or computational models to propose specific testable hypotheses about a biological system, followed by experimental validation, which typically involves large-scale laboratory tests. My team and I use this approach to reveal how plant (and other organisms) systems operate, are regulated, and have evolved.

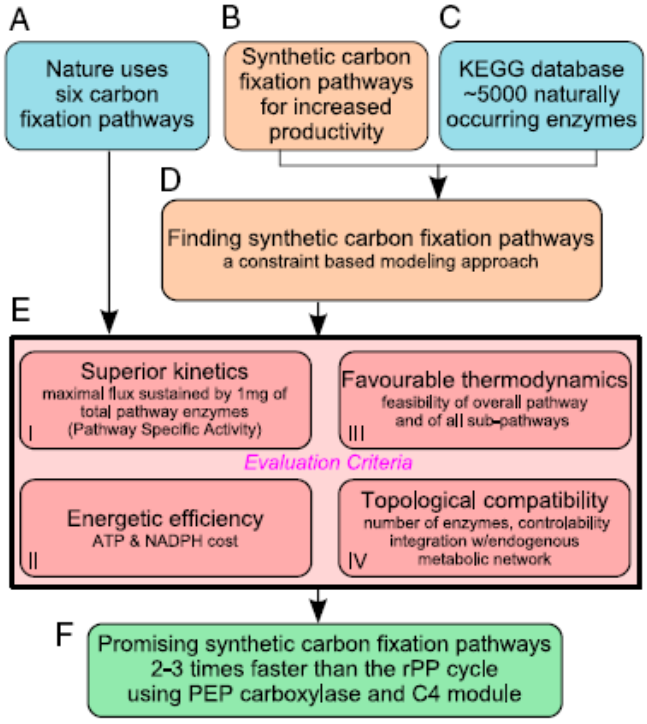
One of my major projects focuses on the efficiency of photosynthesis, the engine that drives our biosphere, the source of our food, and the dominant process determining atmospheric carbon dioxide (CO_2) concentrations. Our research involves breaking down photosynthesis into its simplest components and individual steps, and analyzing them using the tools of systems biology. Our goal is to find the bottlenecks and limiting factors in the process of converting photons of sunlight into molecules of stored sugars, used for food and fuel. We also seek to understand the constraints that shape the properties of photosynthesis and the limitations on the maximal productivity of plants and other photosynthetic organisms.

Another one of my lab's projects is GeoNumbers, an online database for energy and earth sciences researchers. Let me explain the project briefly. It is currently very frustrating and time-consuming for energy researchers to find reliable measurement data that include references and description of the methodology by which they were taken. The idea for GeoNumbers comes from BioNumbers, an Internet-based database of useful biological numbers that enables biology researchers to find, in less than one minute, any common biological number that can be important for their research. The energy research and earth sciences communities have a great need for easy access to such reliable numbers, especially in the field of alternative energy, hence GeoNumbers. I have solicited the help of a number of Weizmann Institute experts in various related fields in developing and building GeoNumbers and making it available to researchers worldwide. It is in these kinds of multidisciplinary projects that the strength of the Weizmann Institute really shines through.

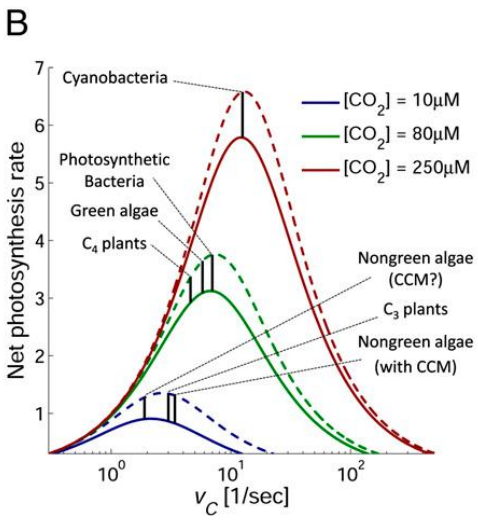
Alternative carbon fixation pathways

Carbon fixation is the process by which CO_2 is incorporated into organic compounds. In modern agriculture in which water, light, and nutrients can be abundant, carbon fixation could become a significant growth-limiting factor. Hence, increasing the carbon fixation rate is of major importance in the road toward sustainability in food and energy production. There have been recent attempts to improve the rate and specificity of Rubisco, the carboxylating enzyme operating in the Calvin–Benson cycle; however, they have achieved only limited success. Nature employs several alternative carbon fixation pathways, which prompted us to ask whether more efficient novel synthetic cycles could be devised.

Using the entire repertoire of approximately 5,000 metabolic enzymes known to occur in nature, we computationally identified alternative carbon fixation pathways that combine existing metabolic building blocks from various organisms. We compared the natural and synthetic pathways based on physicochemical criteria that include kinetics, energetics, and topology. Our study suggests that some of the proposed synthetic pathways could have significant quantitative advantages over their natural counterparts, such as the overall kinetic rate. One such cycle, which is predicted to be two to three times faster than the Calvin–Benson cycle, employs the most effective carboxylating enzyme, phosphoenolpyruvate carboxylase, using the core of the naturally evolved C4 cycle. Although implementing such alternative cycles presents daunting challenges related to expression levels, activity, stability, localization, and regulation, we believe our findings suggest exciting avenues of exploration in the grand challenge of enhancing food and renewable fuel production via metabolic engineering and synthetic biology.



Why is Rubisco relatively slow?



Rubisco (D-ribulose 1,5-bisphosphate carboxylase/oxygenase), probably the most abundant protein in the biosphere, performs an essential part in the process of carbon fixation through photosynthesis, thus facilitating life on earth. Rubisco is present in most photosynthetic anaerobic bacteria and cyanobacteria; as well as eukaryotes, such as algae and higher plants. However, the catalytic rate of Rubisco is remarkably slow. This enzyme is known to have both a low catalytic rate and a tendency to confuse its substrate, carbon dioxide, with oxygen. This apparent inefficiency is puzzling and raises questions regarding the roles of evolution versus biochemical constraints in shaping Rubisco.

With two physicists at the Weizmann Institute, Dr. Tsvi Tlusty and his Ph.D. student, Yonatan Savir; we examined these questions by analyzing the measured kinetic parameters of Rubisco from various organisms living in various environments (see example chart above). We used simple power/law correlations between kinetic parameters to analyze Rubisco's speed and efficiency. Our analysis suggests that the evolution of Rubisco is confined to an effectively "one-dimensional" landscape. Rubisco appears to be tuned to the intracellular environment in which it resides such that the net photosynthesis rate, within this essentially one-dimensional landscape, is nearly optimal. Our analysis indicates that the specificity of Rubisco is not the main determinant of its efficiency – but rather the trade-off between the carboxylation velocity and CO_2 affinity. As a result, the presence of oxygen has only a moderate effect on the optimal performance of Rubisco, which is determined mostly by the local CO_2 concentration. Our results indicate that Rubisco is close to optimality in the net photosynthesis rate and therefore cannot be significantly improved by point mutations. To improve the performance of Rubisco one may perhaps focus on improving the CO_2 concentrating mechanisms (CCM) that enable the accumulation of CO_2 at the carboxylation site rather than mutating the Rubisco itself. Nevertheless, the results do not preclude the possibility that a drastic change may result in a Rubisco that is subject to different constraints, which may perhaps allow better performance.

Eco Dollars

There is growing awareness of the need for efficiency in the consumption of natural resources. But, in spite of this interest, the true impacts and costs are not presented to the consumer or embodied in the price of the service or product. Often these costs are not known even to the scientists or engineers who are developing novel alternatives.

Quantifying these environmental costs is key to alleviating the tragedy of our global Commons.[3] In economics terms, it is defined as the internalization of external costs.[4] EcoDollars is intended to rebalance the social and environmental components with the economic one, leading to higher environmental sustainability[5] and eco-efficiency, from both the producer and the consumer.

Systems biology is an emerging field focusing on finding quantitative principles in the complex networks that constitute the cell and make the miracle of life. Systems biology shows promise in tackling questions previous unsolvable with conventional techniques of biology. The Weizmann Institute of Science is a leading world center in this subject, with a strong interactive and interdisciplinary community. We have been incorporating our systems biology expertise as a source for inspiration in tackling the challenge of measuring natural resources costs and efficiency.

A major obstacle in approaching the above questions in quantitative terms is the relative difficulty in collecting the relevant values from the vast literature. To that aim, we have been developing GeoNumbers based on the model of BioNumbers. We began BioNumbers three years ago after facing a similar challenge in the field of molecular biology. I created BioNumbers during my postdoctoral fellowship at Harvard University. BioNumbers contains full references and comments, and enables discussion on the methodology and its reliability. It is a wiki-like, community-based effort, accessed monthly by over 3,000 users and contributors from more than 50 countries. It is now further developed and managed at the Weizmann Institute in collaboration with Harvard University.

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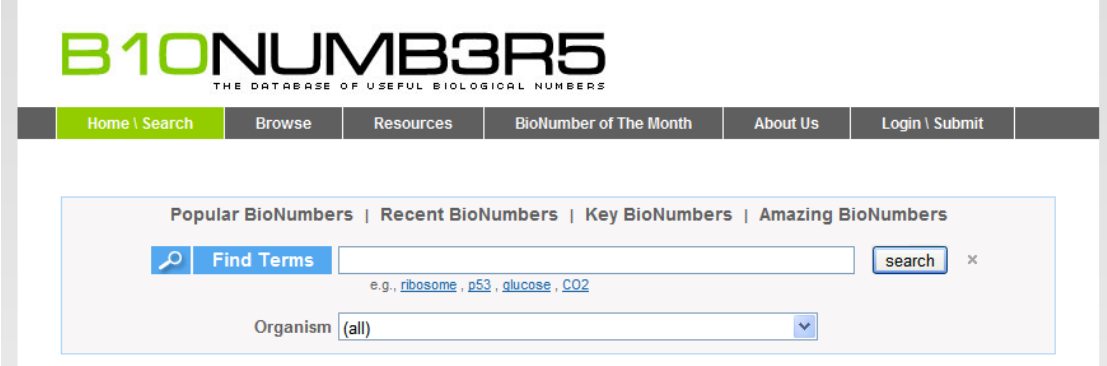
3 "The tragedy of the Commons" (1968), Garrett Hardin, *Science*, Vol. 162, No 3859, p. 1243-1248

4 "The Problem of Social Cost" (1960), H. R. Coase, *The Journal of Law and Economics,* volume 3, p. 1-44. "The Problem of Externality" (1979), Carl J. Dahlman, *Journal of Law and Economics,* Vol. 22, No. 1, p. 141-162.

5 "The EU ExternE project" (External costs of Energy), http://www.externe.info/

The Research

The food system is a dominant player in utilization of natural resources. The Green Revolution in the 1950s has dramatically increased productivity by about 3-fold, while turning agriculture into a form of production reliant on fossil fuels used in mechanized tools, pesticides, herbicides, fertilizers and transportation. In the US, about 17% of the total energy usage is invested in the food production system; and about half of all land and fresh water is diverted to food production.[6] The food system is a prime example how natural resources, population, and economy come together, requiring interdisciplinary perspectives and quantitative reasoning.



Based on the lessons and expertise obtained from developing BioNumbers (www.BioNumbers.org) and making it the leading database for quantitative data in molecular biology, we began developing GeoNumbers as an open access database of useful numbers in energy, environment and sustainability. We initiated efforts to engage experts in the respective fields to focus on the best literature sources for data extraction. The incorporation of information on different time and spatial scales (e.g. fast local cycles vs. global slow cycles, and cell-sized phenomena vs. global scale), in one portal of information, is invaluable for inference of feedbacks and dominant forces within complex interrelated networks, as in the concept of Panarchy.[7]

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6 "Sustainability of meat based and plant based diets and the environment" (2003), D. Pimentel and M. Pimentel, *American Journal of Clinical Nutrition*, with the industry, Vol. 78, No. 3, 660S-663S Food, energy, and society (2008), By D. Pimentel and M. Pimentel, third edition.

7 Panarchy: Understanding Transformations in Human and Natural Systems (2002) by Lance H. Gunderson (Editor), C. S. Holling

Food usage of land and energy resources

An interdisciplinary approach and understanding is required to resolve the growing conflicts of food and energy scarcity confronting humanity, as well as to address the deterioration of natural resources and its ramifications at the turn of the 21st century. Our research is one of many endeavors aimed at reducing humanity's ecological footprint and placing humanity back on the track of sustainability. We have been researching case studies using "toy" models that deal with issues of food usage of land and energy resources, and natural costs offsetting via tree planting (positive ecological footprints). Besides understanding the environmental impacts of a product or service, our endeavor has been concerned with ways of developing methods to "weigh," "normalize," and "sum" these burdens into tangible and scientific-sound scales, i.e. developing appropriate metrics for EcoDollars.

Recent Publications

- Savir Y, Noor E, **Milo R**, Tlusty T, "Cross-species analysis traces adaptation of Rubisco toward optimality in a low-dimensional landscape" *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA*, Volume: 107, Page: 3475-3480, 2010
- **Milo R**, Jorgensen P, Moran U, Weber G, Springer M, "BioNumbers-the database of key numbers in molecular and cell biology" *NUCLEIC ACIDS RESEARCH*, Volume: 38, Page: D750-D753, 2010
- Bar-Even A, Noor E, Lewis NE, **Milo R**, "Design and analysis of synthetic carbon fixation pathways" *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA*, Volume: 107, Page: 8889-8894, 2010
- Noor E, Eden E, **Milo R**, Alon U, "Central Carbon Metabolism as a Minimal Biochemical Walk between Precursors for Biomass and Energy" *MOLECULAR CELL*, Volume: 39, Page: 809-820, 2010

Prof. Milko E. van der Boom

Department of Organic Chemistry

Our lab focuses on the unique properties of a class of organic molecules that contain metal ions. We have learned how to arrange these metal complexes in single-molecule layers to form new types of micro-electronic devices such as solar cells, sensors, and even logic circuits. For instance, we created a tiny, highly accurate, reusable micro-sensor that can detect a few parts-per-million of water in a solution such as auto or aircraft fuel. Similar building blocks are being used to build new generation materials that may outperform the current silicon-based computer technology. Recent findings include the formation of organic materials that operate as logic gates, electronic circuits and flip-flops (the heart of Random Access Memory; RAM).

Organic solar cells

Solar cells made with organic materials offer a potentially efficient and low-cost way to convert sunlight to electrical power. Scientists have already demonstrated the proof-of-principle of such devices. However, the difficult processing conditions required and the limited efficiency of current organic solar cells hampers their commercialization.

I have launched a new line of research to completely redesign these experimental organic solar cells using thermally and photochemically robust organic materials that are easily available and processed. In fact, part of the cell would be self-assembling – using our functional organic molecules. These would attach and build themselves into a buffering layer between two components of the experimental organic solar cells. This new research direction has already resulted in the formation of new devices capable of efficiently converting solar light into electricity.

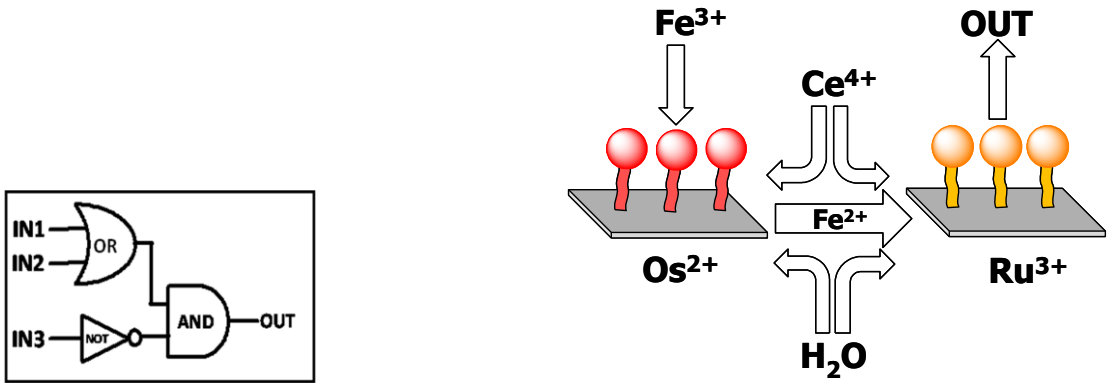
Organic logic

We are also experimenting with molecular electronics and the development of organic systems that “communicate" with each other. This could lead to systems based on organic compounds having the ability to perform logical operations and computations. Silicon chips have thousands of electronic logic gates etched on them. But metal complexes offer another way to build logic gates. Although electronic logic circuits have been highly successful, molecular logic gates have some potential advantages — not least that they can operate in much smaller spaces. Molecular logic gates use concentrations of specific chemicals as their

inputs and, as their outputs, the production of a particular chemical species, often accompanied by a color change or similarly easy-to-identify property. Our lab and others have demonstrated the advantages of building the active logical molecules onto a surface such as a glass plate. For example, smaller quantities of material are needed and the logic gates are easier to recover and reuse.

In a recent article, we demonstrated a logic gate of organic molecules containing the metals osmium (Os) and ruthenium (Ru), which they tethered to a glass surface to form layers one molecule thick (see illustration below). Such organized structures may be the key to the miniaturization of computer-like devices at an atomic scale, and are likely to be a centerpiece in post-silicon-age future generations of computers.

This groundbreaking research has been highlighted by the most prestigious scientific journals including *Angewandte Chemie*, *Nature*, *Nature Nanotechnology* and *Chemical and Engineering News*. Recent results include the demonstration of electrical addressable organic films that mimic the behavior of memory elements, flip-flops and logic circuits. The first computers were developed in the mid 20th century and were the size of a large room. We have now almost all the necessary components made from organic components in our hands to create novel computational devices.



Above: Tethered organic complexes containing osmium (Os) or ruthenium (Ru) on separate glass surfaces to form molecular logic gates, circuits, molecular memory elements and flip-flops.

Recent Publications

- Kaminker R, Motiei L, Gulino A, Fragalà I, Shimon L J W, Evmenenko G Dutta, P, Iron Mark A, **van der Boom M E**, "Stepwise Assembly of Coordination-Based Metal-Organic Networks" JOURNAL OF THE AMERICAN CHEMICAL SOCIETY Volume 132 Pages 14554-14561, 2010
- Motiei, L Yao, Y ,Choudhury, J, Yan, H, Marks, TJ, **van der Boom, M**. Facchetti, A. "Self-Propagating Molecular Assemblies as Interlayers for Efficient Inverted Bulk-Heterojunction Solar Cells" JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, Volume 132 Pages 12528-12530, 2010
- Choudhury J, Kaminker R, Motiei L, de Ruiter G, Morozov M, Lupo F, Gulino A, **van der Boom ME**, "Linear vs Exponential Formation of Molecular-Based Assemblies" JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, Volume: 132, Page: 9295-9297, 2010
- de Ruiter G, Motiei L, Choudhury J, Oded N, **van der Boom, ME**, "Electrically Addressable Multistate Volatile Memory with Flip-Flop and Flip-Flap-Flop Logic Circuits on a Solid Support" ANGEWANDTE CHEMIE-INT. ED., Volume: 49, Page: 4780-4783, 2010
- **van der Boom ME**, "Oxygen Atom "Cut and Paste" from Carbon Dioxide to a Fischer Carbene Complex" ANGEWANDTE CHEMIE-INT. ED., Volume: 48, Page: 28-30, 2009 Invited Highlight article.
- Motiei L, Lahav M, Gulino A, Iron MA, **van der Boom ME** "Electro-chemical Characteristics of a Self-Propagating Molecular-Based Assembly" JOURNAL OF PHYSICAL CHEMISTRY B DOI: 10.1021/jp910898f 2010 in press. Invited paper for the special issue honoring Prof. Michael R. Wasielewski.

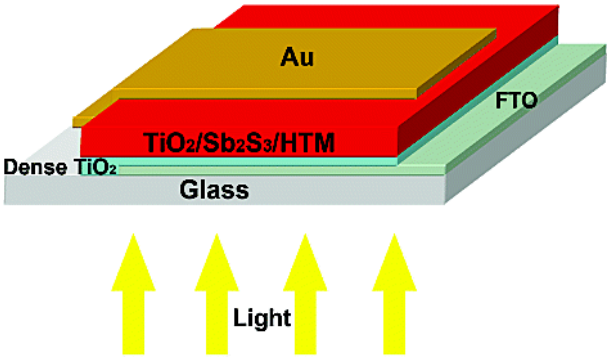
Prof. Gary Hodes

Department of Materials and Interfaces

Our group is working to maximize the efficiency of solar cells while exploring new ways to make them less expensive. We are currently exploring how to optimize two new types of Extremely Thin Absorber (ETA) solar cells: one based on nanoporous titanium oxide (TiO_2) made by spin coating; and another based on zinc oxide (ZnO) nanorods made by chemical bath deposition (CBD); both of them built on conducting glass sheets with particular emphasis on controlling the open circuit voltage of the cells.

ETA solar cells

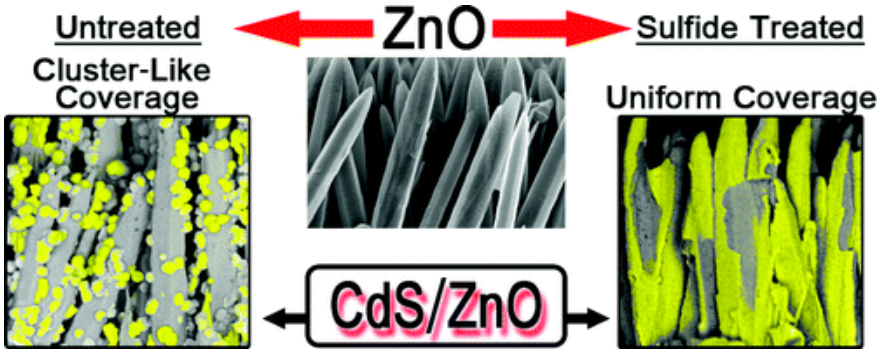
Solid-state nanocrystalline solar cells composed of Sb_2S_3 (antimony sulfide) deposited in a chemical-bath were used as a light-absorber layer deposited on nanoporous TiO_2 and spiro-MeOTAD as an organic hole-transporting material yielded a solar conversion efficiency of 5.2% at 0.1 sun illumination and a peak 88% of the incident monochromatic photon-to-current conversion efficiency. Use of the spiro-MeOTAD as hole conductor instead of the CusCN normnally used by us led to an increase in open circuit voltage of 50-100 mV.s



- Moon SJ, Itzhaik Y, Yum JH, Zakeeruddin SM, **Hodes G**, Gratzel M, "Sb_2S_3-Based Mesoscopic Solar Cell using an Organic Hole Conductor" JOURNAL OF PHYSICAL CHEMISTRY LETTERS, Volume: 1, Page: 1524-1527, 2010

Modification of ZnO nanorod films for ETA cells

ZnO nanorod films are increasingly used as an alternative to nanoporous TiO_2 as the electron conductor in semiconductor-sensitized nanoporous solar cells

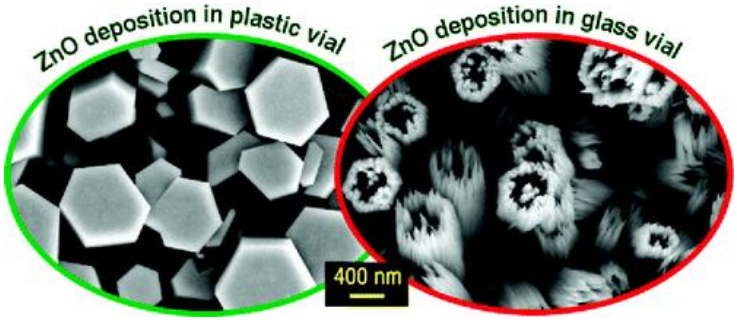


(SSSCs). Semiconductor light absorbers deposited onto ZnO by chemical bath deposition (CBD) tend to form poorly covering deposits of isolated clusters. We showed how a short solution pretreatment of the ZnO nanorod films with a sulfide solution, which forms a thin ZnS film at the ZnO surface, results in a very large improvement of the coverage and uniformity of the CBD semiconductor coatings. These composite films give large improvements in solar cell efficiency. Several factors can be responsible for this improvement: better coverage of the ZnO nanorods, less shorting between hole conductor and conducting substrate, and the formation of a ZnS buffer layer.

- Edri E, Rabinovich E, Niitsoo O, Cohen H, Bendikov T, **Hodes G**, "Uniform Coating of Light-Absorbing Semiconductors by Chemical Bath Deposition on Sulfide-Treated ZnO Nanorods" *JOURNAL OF PHYSICAL CHEMISTRY C*, Volume: 114, Page: 13092-13097, 2010

Effect of glass reaction vessel on zinc oxide deposition

Zinc oxide (ZnO) is probably the most studied material deposited as films by aqueous solution methods. Both neutral and alkaline solutions are commonly used, and deposition is often carried out in glass vessels. We showed that for depositions carried out under alkaline conditions, slow dissolution of the glass by the solution often results in formation of zinc silicates together with the ZnO. While this silicate formation is most clearly seen after long deposition times (many hours), it can be detected already within one hour. This small amount of silicate negatively affects the performance of solar cells made using the ZnO. We also described conditions where the zinc silicate deposits without formation of ZnO, providing a method of depositing such films. Finally, we note that the glass of a reaction vessel also can affect deposition of CdSe, pointing to a more general role of this normally neglected parameter.



- Kokotov M, Bar-Nachum S, Edri E, **Hodes G**, "Effect of Glass Dissolution on the Solution Deposition of ZnO Films and Its Exploitation for Deposition of Zn Silicates" *JOURNAL OF THE AMERICAN CHEMICAL SOCIETY*, Volume: 132, Page: 309-314, 2010

Prof. Michael Hass

Department of Particle Physics

Conventional nuclear reactors are based on the fission of the ^{235}U (1% of natural Uranium) and ^{239}Pu isotopes. If non fissile isotopes like ^{238}U or ^{232}Th could be used as nuclear fuel, there would be sufficient material to run reactors for hundreds of years. This is particularly important for the case of Thorium as this element is much more abundant compared to Uranium. Use of Thorium would also reduce greatly the problems associated with nuclear proliferation and waste management problems.

However, very strong sources of fast neutrons are needed for Thorium conversion on an industrial scale. One of the possibilities is to use fast neutrons escaping a core of conventional reactor. A few of such "breeding" reactors were built during the second half of the 20th century. The new generation of economically more competitive breeding reactors is being discussed. Another possibility is to use very strong accelerator-based neutron spallation source. The information on the breeding yields as function of parameters such as a given neutron energy spectrum, the composition of the irradiated material, the moderator material etc., is very important for the design of the breeder reactors or accelerator driven systems.

Our research work in the past year has been involved with the newly-constructed 40 MeV, superconducting SARAF accelerator at the Israeli SOREQ Research Center. We have been carrying out the associated research and development work towards production of intense light radioactive beams such as ^{6}He and ^{8}Li that are of interest to nuclear astrophysics as well as to neutrino physics. These projects are groundwork for the next phase of research at SARAF. The beam energy is planned to be boosted up to 40 MeV. The commissioning of this next phase is foreseen in a few years. High deuteron currents will allow one to obtain an intense source of energetic neutrons of the order of 1013 n/s and 1015 n/s for the first and second phase respectively. We plan to take advantage of this opportunity and launch an experimental program for measuring transmutation and thorium conversion yields for different isotopes of interests.

Dr. Dan Oron

Department of Physics of Complex Systems

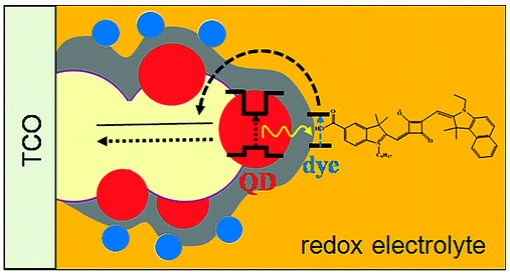


Figure 1. (a,b) Schematic presentation of a system. The system consists of a transparent conducting oxide (TCO) on which nanocrystalline (nc) TiO_2 (off-white big circles) is grown. QDs (red circles) bound to nc-TiO_2 via a MPA linker (not shown) and covered by a thin layer of amorphous TiO_2 (gray coating) to which dye molecules (small blue circles) are connected.

Third-generation solar cells based on organic dyes are a promising photovoltaic alternative to silicon. Yet conversion efficiencies and, more importantly, photostability, are still inferior to those based on inorganic materials. Researchers recently presented a new design for dye cells in which semiconductor nanocrystals ("quantum dots"), incorporated in the electrode, serve as light absorbers. This design combines the broad absorption spectrum and stability benefits of quantum dots with the improved electrical contact of organic dyes with the conducting substrate.

This design mimics the light reaction of photosynthesis, where light absorption and photochemistry are performed at different locations by different chemical entities. Here, the quantum dots serve as "antennas," funneling absorbed light to the charge separating dye molecules *via* nonradiative energy transfer. Since this design practically separates the processes of light absorption and charge carrier injection, scientists are able to optimize each of these separately. Preliminary photon-to-current efficiency measurements show a full coverage of the visible spectrum despite the use of a red absorbing dye, and high transfer efficiency of energy from the quantum dots to the dye, exceeding, in some cases, 70%. Time resolved luminescence measurements clearly relate this to resonance energy transfer from the quantum dots to the dye. The presented design introduces new degrees of freedom in the utilization of quantum dot sensitizers for photovoltaic cells. In particular, it opens the way toward the utilization of new materials as well as better usage of the solar spectrum via both up-conversion and multiple exciton generation.

- Buhbut S, Itzhakov S, Tauber E, Shalom M, Hod I, Geiger T, Garini Y, **Oron D**, Zaban A., "Built-in Quantum Dot Antennas in Dye-Sensitized Solar Cells" *ACS NANO*, Volume: 4, Page: 1293-1298, 2010. See also the editorial of this issue "Sustainability through Nanotechnology", highlighting this contribution.

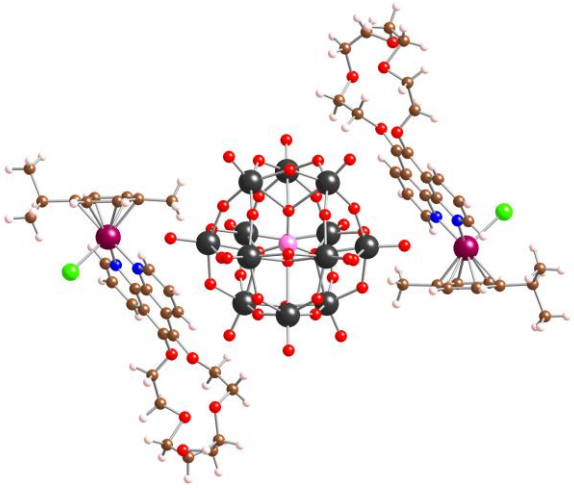
Prof. Ronny Neumann

Department of Organic Chemistry

The significant increase in the amount of CO_2 in the atmosphere and has mandated intensive efforts for efficient methods to convert CO_2 to organic molecules. Our ultimate aim is to reduce CO_2 to CO using solar energy because it represents a means to store solar energy as chemical energy. Thus, the caloric content of CO may be used directly, or CO may be further reacted to produce methanol or other compounds as a liquid fuel. Our group tested three novel ways to reduce CO_2 using light as the driving energy – a process called photoreduction.

Scientists have tried a wide range of transition-metal coordination compounds based on iron, cobalt, ruthenium, and rhenium as photo-catalysts. Our group recently reported success with a ruthenium-substituted polyoxometalate as a catalyst to reduce CO_2, using a variety of commonly available tertiary amines as reducing agents. It is the first example of CO_2 photoreduction with an inorganic, easily synthesized catalyst that is also stable against photodegradation. Further research will be directed to improving the efficiency of the photochemical system. We will try substituting sacrificial amines for hydrogen donors that can be regenerated.

We recently demonstrated using water as the reducing agent instead of amines. We have been able to use ultraviolet (UV) light to reduce carbon dioxide to carbon monoxide using water as a reducing agent. We prepared a new hybrid compound based on a ruthenium (II) bipyridine complex that works with a photoactive $PW_{12}O_{40}^{3-}$ polyoxometalate. Using this new compound in a titanium-silicate support allowed the photoreduction of CO_2 to CO with UV light. Similarly binding methylviologen to the $PW_{12}O_{40}^{3-}$ polyoxometalate also allowed the photoreduction of CO_2 to CO with UV light.



Crystal structure of 2 RuPhen-H3PW12O40. W-black; O-red; P-pink; C-brown; N-blue; Ru-purple; Cl-green.

The photoreduction of CO_2 with water as reducing agent represents an important avenue of research. The results we obtained are one order of magnitude better than those previously reported in the literature. Our next challenge will be to design such hybrid photocatalytic systems reactive also with visible light, not just UV.

Finally, we were able to demonstrate a third catalyst that was able to oxidize hydrogen and use it as the reducing agent. In the presence of a platinum compound, we were able to show that a Rhenium (I) phenanthroline-Polyoxometalate hybrid complex can oxidize H_2 to two protons and two electrons which in the presence of visible light can catalyze the photoreduction of CO_2 to CO with H_2 as the reducing agent instead of the universally used amines as sacrificial reducing agents.

Although the turnover frequency and quantum yield observed in the reduction of CO_2 with H_2 is lower than has been reported for previous rhenium catalyzed photoreduction of CO_2 with amines, we feel that the use of H_2 in such systems represents an advance. Furthermore, the hybrid complex enables CO_2 reduction with H_2 using visible light as opposed to other semiconductor catalysts, e.g. Ga_2O_3, MgO or TiO_2, that require UV irradiation. The concept of oxidation of H_2 by polyoxometalates and storage of the resulting electrons and protons on the polyoxometalate may also prove useful in a myriad of other photoreduction reactions that presently use amines as sacrificial reducing agents.

Publications

- Alexander M. Khenkin, Irena Efremenko, Lev Weiner , Gershom Martin, **Ronny Neumann** "Photochemical Reduction of Carbon Dioxide Catalyzed by a Ruthenium-Substituted Polyoxometalate" Chemistry, A European Journal, 2010, *16*, 1356-1364.
- Jessica Ettedgui, Yael Diskin-Posner, Lev Weiner and **Ronny Neumann** "Photoreduction of Carbon Dioxide to Carbon Monoxide with Hydrogen Catalyzed by a Rhenium (I) phenanthroline- Polyoxometalate Hybrid Complex." Journal of the American Chemical Society, in press.

Prof. David Milstein

Department of Organic Chemistry

Many of the classical synthetic reactions in chemistry, which are used by industry for the preparation of essential products such as pharmaceuticals, agrichemicals and new materials, produce large amounts of waste and utilize toxic reagents. This is harmful to the environment and poses health and economic concerns. In order to alleviate theses global problems, we are designing catalysts that can enable fundamentally new, environmentally benign processes. The design is based on special compounds which include a metal atom and organic groups (ligands) attached to it. The organic groups are designed to be able to cooperate with the metal center in the "activation" of chemical bonds, thereby allowing facile, selective bond-making and bond breaking of molecules, that may lead to unprecedented catalytic synthetic processes. In this way, we have designed in recent years catalysts based on the metal ruthenium which incorporate "pincer" type ligands, capable of opening and closing an "arm" (hemilabile pincers). These catalysts have led, for example, to a new, "green" way to form the amide bond, which is ubiquitous in chemical and biological systems, such as proteins, peptides and polymers. These reactions involve breaking bonds between oxygen-hydrogen and oxygen-carbon, and making new nitrogen-carbon bonds. This work, published in *Science* magazine, was cited among the significant scientific discoveries of the year 2007. During the last year, we have extended this approach to an important family of compound: ammonia and amines, which play a crucial role in many processes of the chemical industry. Employing a ruthenium pincer complex that we have designed, we have demonstrated a very facile way to reversibly activate the nitrogen-hydrogen bond of amines and ammonia, by a concerted action of the ligand and metal. The mechanism of this unique bond activation has been studied, and we are now planning to explore the potential of this system in the development of new, environmentally benign catalytic processes based on N-H bonds of amines and ammonia.

Recent Publications

- Gnanaprakasam B, Zhang J, **Milstein D,** "Direct Synthesis of Imines from Alcohols and Amines with Liberation of H-2" *ANGEWANDTE CHEMIE-INTERNATIONAL EDITION*, Volume: 49, Page: 1468-1471, 2010
- Kohl SW, Weiner L, Schwartsburd L, Konstantinovski L, Shimon LJW, Ben-David Y, Iron MA, **Milstein D**, "Consecutive Thermal H-2 and Light-Induced O-2 Evolution from Water Promoted by a Metal Complex" *SCIENCE*, Volume: 324, Page: 74-77, 2009

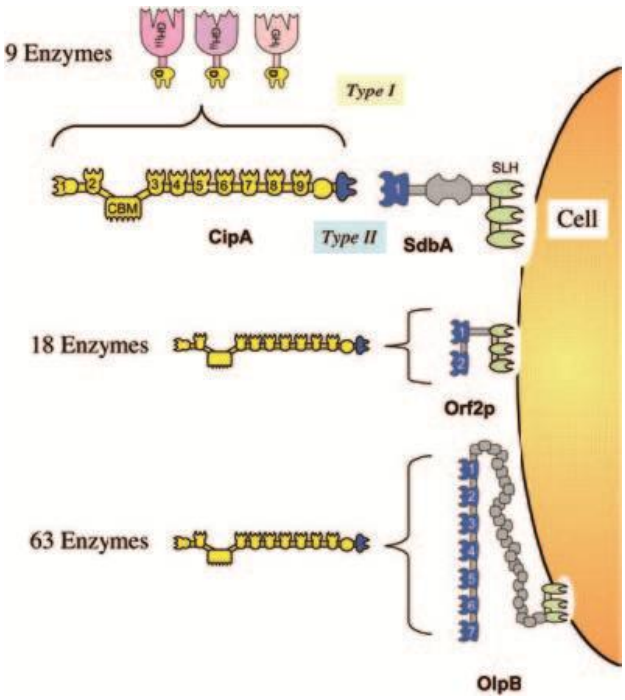
Designer Cellulosomes

Profs. Ed Bayer, Gideon Schreiber, Dan Tawfik

Department of Biological Chemistry

By the conclusion of their three-year AERI-funded pilot project, the team of professors Ed Bayer, Gideon Schreiber and Dan Tawfik and their labs were beginning to produce a second generation of "designer cellulosomes " in their efforts to find more efficient ways to quickly digest cellulose – the most abundant organic polymer on earth – but one that is difficult to break down into its natural sugars for biomass fuels.

Cellulosomes are all built on a multi-functional integrating subunit that is aptly called scaffoldin. This molecular scaffold links the various active components of the cellulosome together very much like Lego® toy building blocks. The modular design enables the various components to work together, and organizes the various subunits (e.g., the enzymes) into the complex. Two complementary classes of binding modules: a cohesin module on the scaffoldin; and a dockerin module on the enzyme; act as the connectors. Each cellulosome shares one or more cellulose-binding modules (CBMs) that "grab" the cellulose to be broken down and hold it for the cellulose digesting units, the cellulases, to work. The scientists find the Lego-like construction of these biologically active, interacting components a prime example of Nature "at play."



Their "first generation" re-engineered cellulosomes used cellulases from *Thermobifida fusca*; a common, heat-loving soil bacteria often found in active compost; as a model to explore the conversion from a free cellulase system to the cellulosomal mode. Three of the six *T. fusca* cellulases were converted by

Left: Schematic representation of the supramolecular Lego-like architecture of the Clostridium thermocellum, which can have up to 63 enzymes working on one scaffoldin.

replacing their cellulose-binding modules (CBMs) with a dockerin, and the resultant recombinant "cellulosomized" enzymes were incorporated into scaffolding proteins that contained cohesin(s) together with a CBM. The activities of the resultant "designer" cellulosomes were compared with an equivalent mixture of wild-type enzymes, and showed that some of their designs showed marked improvements in performance over the same mix of cellulases acting independently.

For their next generation designer cellulosome, they added a fourth *T. fusca* cellulase, (Cel5A) equipped with a dockerin. They are also examining the contribution of intervening linker segments of different lengths to see if the distance between the active cellulases made any improvements in the overall activity of simple one- and two-enzyme designer cellulosome complexes. The results demonstrated that the cellulose binding unit appeared to play a major role in the degradation of crystalline cellulosic substrates. They also found that a particular combination of two of their converted enzymes working together were particularly effective in digesting even the most recalcitrant cellulosic substrate (Avicel).

While they noted that the length of the linker between the catalytic module and the dockerin had little, if any, effect on the activity; they found that the positioning of the dockerins were critical. They noted that when the dockerins were placed in the manner consistent with their usual position (the C terminus) on most cellulosomal enzymes, this resulted in an enhanced synergistic response. All their engineered systems in these second generation tests out-performed the mixtures of wild-type enzymes. The ability to design and produce artificial cellulosomes of such precise composition provides a way to address such distinct aspects of cellulosome structure and function. These designer cellulosomes may also become the precursors for improved cellulase systems for future industrial conversion of cellulosic biomass to biofuels.

SSC2010: Solar Student Conference 2010

The Solar Student Conference is an annual, student-organized and guided conference designed to promote interaction between the participants from the entire spectrum of solar research activity. Prof. David Cahen, scientific director of the Alternative and sustainable Renewable Energy Research Initiative (AERI) says that the conference tries to encourage the creation of a future generation of scientists in the domain of solar energy, in order to return to Israel it's world leading position in solar energy research which was lost due to insufficient investment in solar energy. Today, there is a huge increase in demand for advanced studies in renewable energy. The problem is that there aren't enough research groups in that area, Prof. Cahen said.

In the four-day conference, young scientists from various Institutes of higher learning (Weizmann, Tel Aviv University, Bar-Ilan, Ben Gurion, and Hebrew U) gathered to deal with the problems of producing and storing solar energy. This is a high priority in Israel, a country that has insufficient sources of energy. Most of the lectures are given by the participating students, with plenty of time dedicated for discussions.

The conference was organized four students from the Weizmann Institute - Yigal Levin, Ran Vardimon, Elad Noor and Stella Itzhakov with the assistance of the Alternative sustainable and Renewable Energy Initiative at the Weizmann Institute. The conference enabled the participants to meet and get to know nearly all the students working in solar energy in the country, exchange ideas, ask questions and create future partnerships that will help them later in the scientific career, all in a relaxed atmosphere. A brief hands-on competition

challenged groups of students to deal with existing systems and small scale and see the difficulties and challenges that are facing these systems. The purpose of the contest was to see how to apply existing solutions to cope best by using cheap materials and simple field. Nine teams competed, and came up with a wide array of solutions from the simple materials provided. Armed with only the most basic materials - aluminum foil, cardboard, glue, thread, scissors measuring stream quality solar cell 8-Sergeant (Pythagoras company contribution), and given only two hours to build the system, the teams competed to see which combination would create best solar to the cell and produce the highest electrical current.

The winning group - Rachel Asa (University of Jerusalem) Gil Tucker (University of Jerusalem) and William Weisinger (Arava Institute) Yafit Yitzchaik (Weizmann Institute), offered a simple and effective application in parabolic dish which is widely used solar energy industry. SSC2010- photos courtesy of Elad Noor.

See http://www.weizmann.ac.il/conferences/SSC2010/ for complete information on SSC2010 held in Zikhron Yaakov from April 26th through 29th.

Keynote Lectures:

David Cahen, Weizmann Institute of Science - "Introduction to Photovoltaics"

Binyamin Koretz, BrightSource - "Solar Tower Technologies"

Dan Weinstock, Better Place - "The impact of large-scale EVs on the electricity grid: The smart charging grid solution"

Eliezer Gileadi, Tel Aviv University - "When the world will run out of oil: A rigorous way of considering alternative fuels"

Amit Mor, Eco Energy - "Renewable Energy - Creating the Conditions for a Thriving Solar Industry in Israel"

Moti Herskowitz, Ben Gurion University - "Alternative liquid fuels and other means for reducing oil consumption : Role of the Israeli Research Universities and Centers"

Stephen Lipson, **Technion -** "Fundamental physical limitations on collecting and converting solar energy"

Noam Ilan, Eilat-Eilot - "Development and Commercialization of Renewable Energy Technologies on the way to creating a thriving RE industry in Israel"

From the press: Interview with Prof. David Cahen (Tashtiot Portal in Hebrew)

http://www.tashtiot.co.il/2010/04/28/%d7%93%d7%95%d7%93-%d7%9b%d7%90%d7%94%d7%9f-%d7%9c%d7%9b%d7%95%d7%9f-%d7%95%d7%99%d7%a6%d7%9c%d7%9f/

Coverage of the student competition (Tashtiot Portal in Hebrew)

http://www.tashtiot.co.il/2010/04/30/%d7%aa%d7%97%d7%a8%d7%95%d7%aa-%d7%90%d7%a0%d7%a8%d7%92%d7%99%d7%94-%d7%a1%d7%95%d7%9c%d7%90%d7%a8%d7%99%d7%aa/

Location: Beit Daniel, Zikhron Ya'akov