U.S. – Israeli Workshop on Nanotechnology for Water Purification

Hilton Garden Inn Arlington/Courthouse Plaza

Arlington, Virginia USA

March 13-15, 2006

Sponsors and Organizers:

To Our Distinguished Workshop Participants:

Welcome to Arlington, Virginia and the first US-Israeli Workshop on Nanotechnology for Water Purification.

We have invited researchers from a spectrum of academic disciplines to discuss the state of the science, to assess where we are making progress and where we are stuck, to assess talents and abilities to break through the sticking points, and to look forward, identify and prioritize the opportunities for nanotechnology to impact critical areas of water purification.

In preparing for this event, we have arrived at a few essential facts that we would like to share; to help set the stage for the discussions ahead:

> *Water infrastructure is the largest essential investment facing mankind for the foreseeable future.*
>
> *Water utilities plan for infrastructure lifetimes of 50 to 100 years, yet infrastructure dating back hundreds of years is still depended on today.*
>
> *Compared to our progress in telecommunications after a short 100 years, water treatment brings some 2,000 years of human knowledge to ensure safe, dependable and secure water.*

We are all aware of the marvelous potential that nanotechnologies hold for water treatment. Let's also take a moment to turn this potential 'on its head': water research will truly make nanotech a discipline that enhances the quality of life in our world!

In the short time that we are together here, we challenge you not only to listen, but also to contribute your voice, your knowledge and your wisdom, and to envision and articulate a roadmap that we will use together to transform our research into the vital technologies needed to sustain our society.

Thank you for attending,

Rich Sustich	*Bob Rosenbaum*
WaterCAMPWS, US	*INNI, Israel*

U.S. – Israeli Workshop on Nanotechnology for Water Purification

Hilton Garden Inn Arlington/Courthouse Plaza

March 13-15, 2006

AGENDA

WORKSHOP DAY 1

Plenary Session
Opening

8:00 a.m. – 8:30 a.m. Welcome and Opening Remarks

Mihail Roco, National Science Foundation and National Nanotechnology Initiative

Mark Shannon, Professor and Director, Center of Advanced Materials for Purification of Water with Systems (WaterCAMPWS), University of Illinois at Urbana-Champaign (UIUC)

Rafi Semiat, Professor and Director, Stephen and Nancy Grand Water Research Institute, Technion - Israel Institute of Technology

State of the Science I – Environmental Monitoring for Water Purification – Contaminant Identification and Sensing
Chair: Yi-Lu, Department of Chemistry, UIUC, WaterCAMPWS

8:35 a.m. "The 7th Sense: Bionic Fiber-Optic Biosensors," Dr. Robert Marks, Department of Biotechnology Engineering, Ben-Gurion University of the Negev

9:00 a.m. "New Methods for On-Line Analysis of Particulates in Water," Israel Schechter, Professor, Department of Chemistry, Technion Israel Institute of Technology

9:25 a.m. "DNA Biosensors for Trace Contaminants in Water," Yi-Lu, Department of Chemistry, UIUC

9:50 a.m. "Detection of Aqueous Contaminants Using the Near Infrared Band-Gap Fluorescence of Single-Walled Nanotubes," Michael Strano, Department of Chemical and Biomolecular Engineering, UIUC

10:15 a.m. **Break**

State of the Science II – Membranes and Membrane Processes
Chair: Ovadia Lev, Professor, Laboratory of Environmental Chemistry, The Casali Institute of Applied Chemistry, The Hebrew University of Jerusalem

10:30 a.m. Membrane Surface Nano-Structuring: Selectivity Enhancement, Fouling Reduction and Mineral Scale Formation," Yoram Cohen, Professor, Chemical and Biomolecular Engineering Department; Director, Water Technology Research Center, University of California, Los Angeles

10:55 a.m. "Highly Conductive Nano-Domain Based Ion Exchange Membranes," Yoram Oren, Professor and Head, Department of Desalination and Water Treatment, Ben-Gurion University of the Negev

11:20 a.m. "High-Flux, Anti-Fouling Polymer Membranes from Self-Assembling Graft Copolymers," Ann Mayes, Toyota Professor of Materials Science and Engineering, Massachusetts Institute of Technology

11:45 a.m. "Relationships Between Material Parameters of Nanofiltration Membranes and the Resultant Membrane Performance," Dr. Charles Linder, Department of Desalination and Water Treatment, Ben-Gurion University of the Negev

12:10 p.m. "Nanometric Indicators for Water Filtration and Membrane Integrity," Ovadia Lev, Professor, Laboratory of Environmental Chemistry, The Casali Institute of Applied Chemistry, Faculty of Science, The Hebrew University of Jerusalem

12:35 p.m. **Lunch (On Your Own)**

State of the Science III – Contaminant Removal
Chair: Charles Werth, Civil and Environmental Engineering Department, UIUC, Water-CAMPWS

1:35 p.m. "Nanostructured Mn-Ce Mixed Oxide Catalyst for Purification of Industrial Wastewater," Miron Landau, Professor, Department of Chemical Engineering, Ben-Gurion University of the Negev

2:00 p.m. "Impact of Natural Water Solutes on Nitrate Reduction by Alumina-Supported Pd-Cu Catalysts," (Chaplin, Shapley, Werth, et al), Charles Werth, Civil and Environmental Engineering Department, UIUC

2:25 p.m. "Process Development of Catalytic Water Denitrification: Catalyst Optimization, Reactor Design and Quantum Chemical Computations," Moshe Sheintuch, Professor, Department of Chemical Engineering, Technion Israel Institute of Technology

2:50 p.m. "Nanotechnologies for Desalination and Arsenic Removal," Thomas Mayer, Sandia National Laboratories

State of the Science IV (a) – Biofouling and Disinfection
Chair: Jian-Ku Shang, Material Science Department, UIUC, WaterCAMPWS

3:15 p.m. "Biofouling Build-Up on Dense Membranes in Pressure-Driven Separation Processes for Wastewater Treatment," Carlos Dosoretz, Professor, Faculty of Civil and Environmental Engineering, Technion Israel Institute of Technology

3:40 p.m. **Break**

State of the Science IV (b) – Biofouling and Disinfection
Chair: Jian-Ku Shang, Material Science Department, UIUC, WaterCAMPWS

3:55 p.m. "Relating Organic Fouling of Reverse Osmosis Membranes to Intermolecular Adhesion Forces," Menachem Elimelech, Roberto C. Goizueta Professor of Environmental and Chemical Engineering, Yale University

4:20 p.m. "Assuring Adequate Disinfection of Drinking Water," Ovadia Lev, Professor, Laboratory of Environmental Chemistry, The Casali Institute of Applied Chemistry, Faculty of Science, The Hebrew University of Jerusalem

4:55 p.m. "Antimicrobial Nanomaterials for Water Disinfection Based on Visible-Light Photocatalysts," Jian-Ku Shang, Material Science Department, UIUC

5:20 p.m. **Poster and Networking Session**

5:50 p.m. **Day's Wrap-Up**

6:00 p.m. **Adjourn**

8:00 p.m. **Group Dinner (Sponsored)**

Keynote: "Desalination in Israel," Rafi Semiat, Professor and Director, Stephen and Nancy Grand Water Research Institute, Technion - Israel Institute of Technology

WORKSHOP DAY 2

Plenary Session

8:00 a.m. Welcome Remarks & Announcements

Water Security and Infrastructure Resilience

8:05 a.m. "On-Chip Canaries: Whole-Cell Early Warning Sentinels," Shimshon Belkin, Professor, Institute of Life Sciences, The Hebrew University of Jerusalem

8:30 a.m. "Emerging Challenges in Water Security and Infrastructure Resilience," Michael Royer, Physical Scientist, Urban Watershed Management Branch, WSWRD, National Risk Management Research Laboratory, USEPA

8:55 a.m. Instructions for Breakout Sessions

9:05 a.m. **Breakout Sessions**

Group A – Environmental Monitoring
Group B – Membranes and Membrane Processes
Group C – Contaminant Removal
Group D – Biofouling and Disinfection

10:30 a.m. **Break**

10:50 a.m. **Breakout Sessions continue**

12:15 p.m. **Lunch (On your own)**

1:15 p.m. **Breakout Sessions continue**

Plenary Session
Initial Reports from Breakout Sessions, Discussion of Collaboration Opportunities

3:35 p.m. Group A – Environmental Monitoring
3:55 p.m. Group B – Membranes and Membrane Processes
4:15 p.m. Group C – Contaminant Removal
4:35 p.m. Group D – Biofouling and Disinfection

5:00 p.m. **Day's Wrap Up – Mark Shannon**

5:15 p.m. **Adjourn**

6:00 p.m. **Possible Group Dinner**

WORKSHOP DAY 3

8:00 a.m. **Informal Breakfast**

9:30 a.m. **Distribute Initial Summary and Proposed Collaboration Roadmap**

10:45 a.m. **Closing Remarks**
Rafi Semiat / Mark Shannon

11:00 a.m. **Adjourn**

Presentation Abstracts

On-Chip Canaries: Whole-Cell Early Warning Sentinels

Shimshon Belkin

Institute of Life Sciences, The Hebrew University of Jerusalem, Israel

At the heart of every biosensor is a biological entity, the purpose of which is to react with the target analyte(s) and generate a readily quantifiable signal. Traditional biosensors are based on the unique specificity of enzymes to their substrates, antibodies to antigens or that of nucleic acids to their complementary sequences. In recent years we have promoted the use of a different concept, that of whole cell biosensors: natural or genetically engineered live cells that sensitively report on the presence of either pre-determined classes of chemicals, or on the general toxicity of the sample.

While some of the specificity characterizing molecule-based biosensors may be lost, it is more than compensated for by the fact that by using live cells we are able to detect, by very simple means, very complex series of reactions that can exist only in an intact, functioning cell. Only a sensor of this type can report on the “well being” of a system, on the toxicity of a sample, the genotoxicity of a chemical or the bioavailability of a pollutant. No molecular recognition or chemical analysis can provide this type of information.

In recent years we have genetically “tailored” microbial cells to respond to different classes of compounds, including toxicants that normally affect mammalian systems only. However, in order to turn such cells into “real” biosensors, they need to be immobilized onto a solid platform and coupled into a signal transduction apparatus. We have adopted several strategies to address this complex challenge, some of which will be described. One of the systems is based on integrating the genetically engineered reporter cells into a disposable biochip, which will be inserted into a “toxicity analyzer”. The instrument will be equipped with micro-fluidics components for water sampling, with optical systems for signal generation and imaging, and with the necessary electronics for data processing, analysis and communication. Two independent implementations are envisaged: a miniaturized portable instrument for spot checks and a larger stationary device for on-line monitoring of water safety.

Impact of Natural Water Solutes on Nitrate Reduction by Alumina-Supported Pd-Cu Catalysts

Brian P. Chaplin*, John R. Shapley[+], and Charles J. Werth*

***Department of Civil and Environmental Engineering, [+]Department of Chemistry, Center of Advanced Materials for Purification of Water with Systems, University of Illinois at Urbana-Champaign, USA**

Catalytic nitrate reduction was evaluated for the purpose of drinking water treatment using a Pd-Cu/-Alumina catalyst. Through a series of batch experiments, it was determined that sulfite, sulfide, humic acid, and elevated chloride greatly inhibited nitrate reduction. Partial regeneration of catalysts fouled by sulfite was achieved by using a dilute hypochlorite solution, but Cu dissolution occurred during the regeneration process. Groundwater samples, before and after pretreatment with powder activated carbon (PAC), were also evaluated. Dissolved constituents in the natural groundwater sample resulted in almost complete inhibition of nitrate. However, removal of a fraction of dissolved organic matter from the groundwater using PAC resulted in increased nitrate reduction. Elemental analyses of catalysts exposed to the natural groundwater suggest that mineral precipitation may also contribute to catalyst fouling.

Membrane Surface Nano-Structuring: Selectivity Enhancement, Fouling Reduction and Mineral Scale Formation

Yoram Cohen

Chemical and Biomolecular Engineering Department; Director, Water Technology Research Center, University of California at Los Angeles, USA

Developments of polymeric and ceramic membranes, primarily over the last two decades, have advanced the use of ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO) and pervaporation applications in water treatment, industrial separation processes, and pollution prevention applications. Chemical and colloidal fouling as well as mineral salt scaling of membranes are major problems that can severely limit membrane effectiveness and lead to increased process costs. In order to develop robust and efficient membranes, it is crucial to understand and quantify membrane surface impact on selectivity, fouling resistance as well as thermal and solvent stability.

A promising approach to increasing membrane performance, while mitigating fouling, is the structuring of membrane surfaces at the nano- and molecular levels. Of special interest are tethered polymer-modified (TPM) surfaces that consist of a single molecular layer of terminally-and covalently anchored polymer chains. Such membranes, when based on a stable membrane support, can function even when the tethered polymer phase is swollen by the permeate or feed streams. In order to tailor-design such TPM surfaces, kinetic models of surface graft polymerization were developed to enable optimization of surface chain density and size with respect to the desired membrane application. The application of TPM surfaces to create selective pervaporation membranes will be presented to demonstrate the role of surface chain spacing and size relative to the membrane pore. Examples of fouling-resistant NF/UF membranes with TPM surfaces will also be discussed for protein filtration and treatment of oil-in-water microemulsions. In these latter applications, grafted chain deformation can affect membrane permeability and solute rejection as illustrated by computational models and permeability studies. Finally, the problem of membrane scaling by surface crystallization of mineral salts and the potential impact of surface structure will also be addressed in view of growing interest in high recovery membrane desalting of brackish water.

Biofouling Build-Up on Dense Membranes in Pressure-Driven Separation Processes for Wastewater Treatment

Carlos G. Dosoretz

Department of Environmental, Water & Agricultural Engineering, Faculty of Civil and Environmental Engineering, Technion-IIT, Israel

Biofouling is a major impediment in reverse osmosis (RO) and nanofiltration (NF) cross-flow processes. Microorganisms are present in nearly all water systems. Due to the cross-flow component, feedwater microorganisms are transported to the membrane surface where they adsorb, forming a fouling layer -biofilm. Once attached, the microorganisms grow and multiply at the expense of feedwater' nutrients, forming a biofouling layer which reduces permeate fluxes and damages the membrane and increases operation costs. Membrane fouling restricts their widespread application in both municipal and industrial wastewater treatment because it reduces productivity and increases maintenance and operating costs.

Much research and development is taking place to investigate, model, and control membrane-fouling processes. However, due of the complexity of the biofouling matrix, which is highly heterogeneous and includes living microorganisms, no solution is still available. Our research is focused on in situ biofouling monitoring and amelioration of biofouling build-up on dense membranes in pressure driven-separation processes.

The nature of fully developed biofouling layers was studied in experiments performed with secondary effluents as feedwater without application of biocides. Biofouling, composed of bacteria and extracellular polymers, appeared to be the predominant form of fouling and the size and composition of biofilm population seem to be convergent to finite number. Bacterial counts in biofilm accounted for approximately 10^7 CFU/cm^2 regardless of the feed applied.

Dominant microbial populations identified by sequence homology (DNA extraction-PCR-DGGE analysis) corresponded phylogenetically to *Flavobacterium* sp, *Pseudomonas*, *Ralstonia, Cytophaga* regardless of the conditions applied. Microscopic observations (SEM) revealed presence of protozoa as well. Depth of mature biofilm measured by double staining-CLSM reached 20-30 µm during the tests. Biofilm development begins in few hours and after 8 hours a thin film (approx. 400 nm as detected by AFM), composed of the "concentration polarization layer" and a few bacteria are evident. Fully developed biofilms were found on the membranes after less than 3 days. FTIR spectra of the organic matter which accumulated on the membrane show the presence of proteins and high level of aliphatic and polysaccharide residues, typical components of EPS. Intensive chemical and/or enzymatic cleaning restore permeability but fail to completely remove biofilm debris.

With current membrane polymers, no simple solution to the biofilm formation problem is presently available. If biofouling is detected early, efficient countermeasures can be applied.

Relating Organic Fouling of Reverse Osmosis Membranes to Intermolecular Adhesion Forces

Menachem Elimelech

Department of Chemical Engineering, Environmental Engineering Program, Yale University, USA

Organic fouling of reverse osmosis (RO) membranes and its relation to foulant-foulant intermolecular adhesion forces has been investigated. Alginate and Suwannee River natural organic matter were used as model organic foulants. Atomic force microscopy was utilized to determine the adhesion force between bulk organic foulants and foulants deposited on the membrane surface under various solution chemistries. The measured adhesion force was related to the RO fouling rate determined from fouling experiments under solution chemistries similar to those used in the AFM measurements. A remarkable correlation was obtained between the measured adhesion force and the fouling rate under the solution chemistries investigated. Fouling was more severe at solution chemistries that resulted in larger adhesion forces: lower pH, higher ionic strength, presence of calcium ions (but not magnesium ions), and higher mass ratio of alginate to Suwannee River natural organic matter. The significant adhesion force measured with alginate in the presence of calcium ions indicated the formation of a crossed-linked alginate gel layer during fouling through intermolecular bridging among alginate molecules.

Nanostructured Mn-Ce Mixed Oxide Catalyst for Purification of Industrial Wastewater

M.V. Landau[a*], M. Abecassis-Wolfovich[a], A. Brenner[b], M. Herskowitz[a]

[a] **The Blechner Center for Industrial Catalysis and Process Development, Chemical Engineering Department, Ben-Gurion University of the Negev, Beer-Sheva, Israel**

[b] **Biotechnology and Environmental Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel**

Manganese – Cerium oxide catalysts are known as most efficient in catalytic wet oxidation (CWO) of organic pollutants in industrial wastewater. CWO of pollutants to nontoxic and biodegradable products requires relatively high temperature (>150ºC) and pressure (>10 bar). Complete oxidation to carbon dioxide and water is normally achieved at significantly higher temperatures. Structure and texture of catalysts are critical for performance of manganese-cerium oxide system. A new nanocasting strategy for preparation of novel catalytic materials has just been presented using ordered mesoporous silica (OMS) such as MCM-48 and SBA-15 as removable matrices. Furthermore, nanowires of manganese oxide and cerium oxide were also prepared separately inside SBA-15. However, the oxides surface area was similar or lower than that prepared by regular precipitation technique.

A method applying a sol-gel processing inside SBA-15 nanotubular mesopores to prepare 1-3 nm biphasic CeO_2-Mn_2O_3 nanocasted composites is reported in this presentation. The Ce- and Mn-oxide phases, over a range of Ce/Mn ratios, were prepared by co-gelation of Mn- and Ce-hydroxides inside nanotubular pores of meso-structured SBA-15. Thus, a homogeneous amorphous monolayer was formed followed by crystallization of the oxide phases at >950 K and final removal of the silica matrix. The nanocasted material retained the integrity and shape of the parent silica matrix. The packing mode of the nanocrystaline oxides, and consequently the interphase contact surface that determines the efficiency of the Ce-oxide action as a promoter in catalytic redox cycle, was controlled by the final drying conditions, yielding surface area of 50-350 m^2/g.

Several catalysts prepared by this method were characterized using HR-TEM, XRD, XPS, TPR-TPO and BET. They were tested in CWO of 2,4,6-trichlorophenol (TCP) (100 ppm), acetic acid and aniline using a trickle-bed reactor at 80 to 140ºC, 10 bar of oxygen and 3 min residence time. TCP conversion ranged from 84% at 80ºC to 100% at 120ºC with a catalyst having optimal atomic ratio Ce/Mn=0.55. Based on TOC measurements, all TCP converted was transformed to CO_2. Such high combustion activity has never been reported. The catalyst was stable for more than 200h. Mn/Ce catalyst prepared by standard method did not display combustion activity. Similar results were obtained in CWO of other pollutants.

Nanometric Indicators for Water Filtration and Membrane Integrity

Ovadia Lev[1], Jenny Gun[1], and Vitaly Gitis[2]

[1] The Laboratory of Environmental Chemistry, The Institute of Chemistry, The Hebrew University of Jerusalem, Israel
[2] Department of Environmental Engineering, The Ben Gurion University of the Negev, Israel

The drinking water industry relies increasingly on membrane treatment for the removal of chemical pollutants and pathogenic microorganisms. There is a growing need for a reliable method for direct evaluation of the integrity of membrane systems. Current integrity tests are not sensitive to detect small integrity breaches in the active layer of ultrafiltration (and to some extent also of microfiltration) membranes. The current lecture describes the development of two new nanoscale probes, fluorescent-dye labeled MS2 bacteriophages and gold nanoparticles, for seeded tests. The probes fulfill the primary requirements of membrane integrity tests: safety, which implies that the probes should not pose a health risk of any sort; sensitivity and low limit of detection since the probes should assure 4-5 logs viral removal; resolution, which implies that the technique should differentiate between holes of a specified target size and smaller ones; low background and interferences, which implies the natural background level of the probe material in the feed prior to the application of the probe should be extremely low; simple detection, which will facilitate on-site analysis; and low cost which will allow daily application.

Such inspection should be conducted on a daily basis, on-line, and without interfering with the routine operation of the treatment plant. Here we present our approach for the direct evaluation of drinking water membrane filtration systems. The approach is based on the introduction of a monodispersion of signal amplified reporting nanoparticles into the feed stream. A set of specific nanoprobe rulers of precise and accurate size were synthesized and investigated. Determination of the specific nanoprobe level in the filtrate will allow direct quantification of the corresponding viral, bacterial and parasite removal efficiency. The method will provide quick warning for membrane breaches, loss of integrity and wear. A similar approach has been used for the evaluation of deep bed filtration, revealing valuable mechanistic insight.

Assuring Adequate Disinfection of Drinking Water

Ovadia Lev and Jenny Gun

The Laboratory of Environmental Chemistry, The Casali Institute of Applied Chemistry, The Institute of Chemistry, The Hebrew University of Jerusalem, Israel

Taste, odor and color indicators for drinking water quality have been in use since biblical times, but in the mid-nineteenth century it was proven that they provide insufficient protection against microbial outbreaks. Coliforms, the most widely used indicators for the microbial quality of water, were introduced on the eve of the nineteenth century to provide warning against fecal contamination of drinking water systems. However in the last three decades it became clear that neither the lack of coliforms nor the absence of any other microbial indicator microorganism provides sufficient protection against gastrointestinal diseases. Moreover despite the rapid progress in analytical chemistry and biochemistry it became clear that even the most sophisticated analytical technique fails to provide assurance for the high level of safety that is now required of drinking water. Thus regulating agencies have to resort to an alternative mode of regulation - detailed specification of treatment techniques and increased reliance on engineering indicators – in order to guarantee safe drinking water quality. In the lecture we shall review the current treatment indicators that can assure adequate water disinfection with an emphasis on ozone disinfection. The reactivity of water dissolved ozone poses an additional challenge to water regulators.

Relationships Between Material Parameters of Nanofiltration Membranes and the Resultant Membrane Performance

C. Linder, Y. Oren

Zuckerberg Institute for Water Research, Ben Gurion University, Beer-Sheva, Israel

Nanofiltration membranes are becoming increasingly important in many applications of water treatment such as the processing of municipal waste streams for unlimited agricultural use. The membranes that are currently available do not have properties that can produce the required water quality at a rate and operational cost that is currently attractive. This situation is in part due to the lack of selective transport mechanism which would allow the transport of calcium and magnesium ions concomitant with significant rejection of mono valent sodium salts and very high rejections to organic solutes. The needs for such salt selectivity are to minimize membrane fouling by calcium carbonate or sulfate salts which limit the recovery ratio, the requirement of desalination (i.e., removal of sodium chloride) and the need for keeping Na to Ca ratio in a proper level for agricultural purposes. In this work, we describe our work in developing chemically stable NF membrane for reliable cost effective tertiary treatment of wastewater with high recovery. By manipulation of the nano structure the goal is to achieve a relatively high Ca-Mg permeability as compared to NaCl. This lecture will describe membranes made with systematic changes in the parameters of the selective barrier with respect to fixed charge density, sign, and hydrophobicity/hydrophilicity and characterized with respect to the retention of low molecular weight organics such as sucrose and single salt solutions of NaCl, CaCl2 and Na2SO4 and mixtures of the same salts.

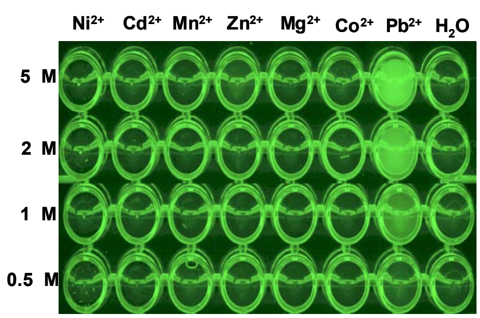
Sucrose rejections vs. flux of different membranes showed the expected inverse relationship between flux and rejection. Membranes with 98+% rejections to sucrose with Lp's above 4 l/m2/hr-bar were prepared having above 70% rejection to NaCl and less than 40% rejection to CaCl2 in single solution. In mixtures, however the CaCl2 rejection vs. NaCl was reversed. A membrane structure performance relationship will be presented describing the difference in membrane performance of solutions of single salt and salt mixtures.

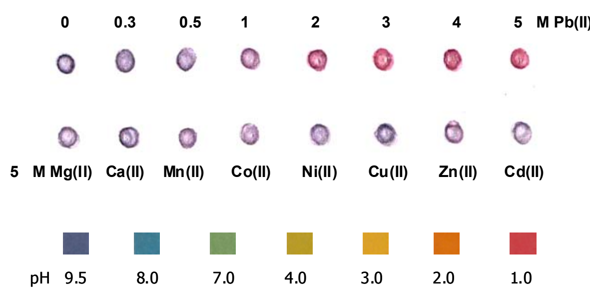
DNA Biosensors for Trace Contaminants in Water

Yi Lu

Department of Chemistry, Biochemistry and Department of Materials Science and Engineering, Beckman Institute for Advanced Science and Technology, Center of Advanced Materials for Purification of Water with Systems, University of Illinois at Urbana-Champaign, USA

Trace contaminants in water is a serious problem in number places around the world. Detection and quantification of those contaminants plays critical roles in solving the problem: knowing the identity and quantity of the contaminants allows design of effective removal strategies while it can also test and assure the quality after a successful removal strategy is applied. Designing sensors for trace contaminants is an effective way of achieving such a goal as it allows on-site, real-time detection at low concentration and with high spatial resolution. Despite recent progresses, designing sensors based on a single class of molecules for a broad range of analytes with high sensitivity and selectivity remains a significant challenge. We have been able to use a combinatorial method called in vitro selection to obtain DNAzymes (DNA with enzymatic activities, also called catalytic DNA) that can bind analyte of choice strongly and specifically (1) By labeling the resulting DNAzymes with fluorophore/quencher or gold nanoparticles, we have developed new classes of fluorescent and colorimetric sensors for both metal ions (such as lead) and organic molecules (2-7). A fluorescent sensor for Pb^{2+} has a detection limit of 0.2 ppb, below the level of 15 ppb for drinking water. A novel approach of using an inactive variant of DNAzymes to tune the detection range of the sensors is also demonstrated. Recent progress will be presented.





1. Jing Li et al. *Nucleic Acids Res*. 28, 481-488 (2000); 2. Jing Li and Yi Lu, *J. Am. Chem. Soc.* 122, 10466-10467 (2000); 3. Juewen Liu and Yi Lu, *J. Am. Chem. Soc.* 125, 6642-6643 (2003); 4. Juewen Liu and Yi Lu, *Anal. Chem.* 76, 1627-32 (2004). 5. Juewen Liu and Yi Lu, *J. Am. Chem. Soc*. 126, 12298-12305 (2004); 6. Juewen Liu and Yi Lu, *J. Am. Chem. Soc*. 127, 12677 - 12683 (2005); 7. Juewen Liu and Yi Lu, *Angew. Chem., Int. Ed.* 45, 90-94 (2006).

The 7th Sense: Bionic Fiber-Optic Biosensors

R. S. Marks

Department for Biotechnology Engineering and the National Institute for Biotechnology in the Negev, Ben-Gurion University of the Negev, Beer-Sheva, Israel

We are continually challenged with old and new threats. Our five senses developed through evolution and the 6th sense, non-measurable, but generally believed as existing, cannot help us monitor for most dangers that are either cellular or molecular. So, throughout history, we developed diagnostic tools, which served us well. Today, we are supplementing classic methods with rapid diagnostics using either biosensor (the 7th sense) or biochip technologies. The economic drivers are our increasing concern with our health, biodefense and old age. We will discuss our developments in this area, which have led us to develop the vision for a BioPen, the first Lab-in-a-Pen.

The development of chemiluminescent fiber-optic immunosensors to antibodies from Hepatitis C[1], West Nile[2], and Ebola viruses, cholera toxin[3] and Ovarian cancer using either silane or electropolymerization on ITO-coated fiber-optics

The development of bioluminescent fiber-optic whole-cell bioreporter biosensors to gentoxicants[4], heavy metals[5] and endocrine disrupting compounds.

The development of a chemiluminescent phagocyte-based fiber-optic sensor[6]

The development of nanofluidics[7] for biochip modules

---

[1] Konry, T., A. Novoa, Y. Shemer-Avni, N. Hanuka, S. Cosnier, A. Lepellec and R.S. **Marks** (2005) Optical immunosensor based on a poly(pyrrole-benzophenone) film for the detection of antibodies to viral antigen. Analytical Chemistry. 77 (6) 1771-1779.

[2] Herrmann, S. B. Leshem, S. Landes, B. Rager-Zisman and R.S. **Marks** (2004) Chemiluminescent optical fiber immunosensor for the detection of anti-West Nile virus IgG. Talanta. 66: 6-14.

[3] Leshem, B., G. Sarfati, A. Novoa, I. Breslav and R.S. **Marks** (2004) Photochemical attachment of biomolecules onto fiber-optics for construction of a chemiluminescence immunosensor. Luminescence. 19: 69-77 & Konry, T., A. Novoa, S. Cosnier and R.S. **Marks** (2003) Development of an 'electroptrode' immunosensor: Indium-tin-oxide-coated optical fiber tips conjugated with an electropolymerized thin film with conjugated cholera toxin B subunit. Analytical Chemistry. 75: 2633-2639 & **Marks**, R.S., E. Basis, A. Bychenko and M.M. Levine (1997) Chemiluminescent optical fiber immunosensor for detecting cholera antitoxin. Optical Engineering. 36 (12) 3258-3264

[4] Polyak, B., S. Geresh and R.S. **Marks** (2004) Synthesis and characterization of a biotin-alginate conjugate and its application in a biosensor construction. Biomacromolecules. 5: 389-396 & Pedahzur, R., B. Polyak, R.S. **Marks** and S. Belkin (2004) Water toxicity detection by a panel of stress responsive luminescent bacteria. Journal of Applied Toxicology. 24: 343-348 & Polyak, B., E. Bassis, A. Novodvorets, S. Belkin and R.S. **Marks** (2000) Bioluminescent whole-cell optical fiber sensor to genotoxicants: system optimization. Sensors and Actuators. B 3656: 1-9 & Polyak, B., E. Bassis, A. Novodvorets, S. Belkin and R.S. **Marks** (2000) Optical fiber bioluminescent whole-cell microbial biosensors to genotoxicants. Water Science and Technology. 42 (1-2) 305-311

[5] Hakkila, K., T. Green, P. Leskinen, A. Ivask, R. S. **Marks** and M. Virta (2004) Detection of bioavailable heavy metals in EILATox-Oregon samples using whole-cell Luminescent bacterial sensors in suspension or immobilized onto fiber-optic tips. Journal of Applied Toxicology. 24: 333-342

[6] Magrisso, M., O. Etzion, G. Pilch, A. Novodvoretz, G. Perez-Avraham, F. Schlaeffer and R.S. **Marks** (2005) Fiber-optic biosensor to assess circulating phagocyte activity by chemiluminescence. Biosensors & Bioelectronics. In Press.

[7] Ionescu, R.E., R.S. **Marks** and L. Gheber (2005) Manufacturing of nano-channels with controlled dimensions using protease nanolithography. Nanoletters. 5 (5) 821-827 & Ionescu, R., R. S. **Marks** and L. Gheber (2003) Nanolithography Using Protease Etching of Protein Surfaces. Nano Letters. 3 (12) 1639-1642 & Taha, Hesham, R.S. **Marks**, L.A. Gheber, I. Rousso, J. Newman, C. Sukenik and A. Lewis (2003) Protein printing with an atomic force sensing nanofountainpen. Applied Physics Letters. 83 (5) 1041-1043.

Nanotechnologies for Desalination and Arsenic Removal

Thomas M. Mayer

Sandia National Laboratories, USA

The water treatment program at Sandia National Laboratories aims to increase the availability of fresh water through cost-effective developments in desalination and trace contaminant removal technologies, particularly for treatment of brackish ground water. In this talk we review a number of efforts initiated by Sandia to address these problems. We especially aim to take advantage of the extensive nano-materials synthesis, characterization, and modeling capabilities of the laboratories. An extensive evaluation of As adsorption media is taking place to meet the new US drinking water standard of 5 mg/l, including development of new nano-engineered adsorption media with increased capacity. The bulk of our efforts are in innovative desalination technologies, focusing on reducing energy consumption in membrane processes and minimizing waste streams associated with desalination processes. Long-range R&D programs include development of high-efficiency biomimetic membranes for RO that mimic the function of natural aquaporin, which promise order-of-magnitude improvements in membrane efficiency. Extensive modeling of aquaporin function allows us to identify the essential ingredients that we will construct in a nanoporous inorganic membrane, chemically functionalized to provide efficient water transport and salt exclusion in nm-scale pores. Nanostructured ion exchange membranes using phase separated block copolymers with high conductivity ion channels promise much higher efficiency electrodialysis processes for desalination and wastewater treatment. Using these high efficiency membranes, an innovative hybrid RO-electrodialysis system is being evaluated to remove sparingly soluble calcium salts from an RO concentrate stream, allowing recycling of the concentrate and additional water recovery. New concepts in membrane module construction using optimized fluid dynamics designs are being examined to make the best use of these high efficiency membranes.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the US Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

High Flux, Anti-Fouling Polymer Membranes from Self-Assembling Graft Copolymers

Anne M. Mayes

Department of Materials Science and Engineering, Massachusetts Institute of Technology, USA

Water filtration technologies employing polymer membranes commonly suffer from fouling associated with their hydrophobic or charged surface chemistries. Submerged membrane bioreactors (MBRs) offer a particularly challenging environment for porous ultrafiltration (UF) membranes due to high concentrations of dissolved or suspended biological molecules and microorganisms, which can plug pores leading to rapid flux decline. To address fouling and flux limitations, polymer filtration membranes incorporating amphiphilic graft copolymers have been developed consisting of a poly(vinylidene fluoride) (PVDF) backbone and polyoxyethylene methacrylate (POEM) side chains, PVDF-g-POEM. These materials molecularly self-assemble into bicontinuous nanoscale domains of semicrystalline PVDF, providing structural integrity, and poly(ethylene oxide) (PEO), providing selective transport channels of well-defined size and anti-fouling character. PVDF ultrafiltration membranes coated with PVDF-g-POEM exhibit fluxes higher than commercial thin film composite NF membranes and show excellent resistance to fouling by model biomolecule-containing solutions (proteins, polysaccharides and NOM) and oily microemulsions in high concentrations (1000-40,000 ppm). These membranes offer further prospects for fractionation/recovery of valuable constituents from wastewater through their molecular sieving capability.

Highly Conductive Nano-Domain Based Ion Exchange Membranes

Yoram Oren, C. Linder, V. Freger, Y. Mirsky, V. Shapiro, O. Kedem

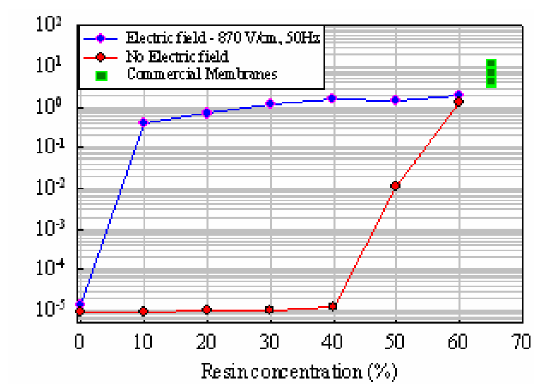
Laboratory for Desalination and Water Treatment Research, Zukerberg Institute for Water Sciences, Ben Gurion University, Israel

We explore a novel way for preparing highly oriented and hence, improved heterogeneous ion exchange membranes.

Today, heterogeneous ion exchange membranes are widely used in electrodialysis (ED). They are also being intensively studied for potential use in power sources such as DM fuel cells, in which they could serve as alternatives to the Nafion membrane.

According to the method, ion exchange membrane models are prepared by mixing ion exchange resin particles, a non-conductive liquid polymer precursor and a cross-linker. The mixture is exposed to a low- frequency AC electric field of 200 to 1300V/cm, while curing. Under these conditions the particles are polarized due to different bulk permitivities of the particles and the surrounding medium (Maxwell-Wagner polarization) and to distortion of the electric double layer inside the particle. As a result, they are ordered in chains connecting the two membrane surfaces.

Above a concentration threshold of 10-20 w% of the particles, the oriented membranes are as much as106 times more conductive than membranes prepared in the absence of the electric field (shown at right). The specific conductivities of the two types of membrane become close only when the concentration of the particle in the non-oriented membranes reaches values as high as 50- 60%. In addition water content is smaller than the corresponding non-oriented membranes.



Acquiring high conductivities with a much smaller concentration of particles will lower the swelling rate, reduce membrane costs, and improve the mechanical stability of the membrane. These properties are essential for successful ED.

In addition, oriented membranes have a great potential for improving the properties of fuel cells, since proton conductivity may be retained with a much smaller concentration of conductive channels, thereby giving a larger weight to the inert matrix, which may be impermeable to the fuel.

The behavior of the ordered membranes with respect to conductivity, swelling rate, transport properties (I/V curves) and approaching to nano-size ion exchange particles, as compared to non-ordered membranes will be discussed.

Emerging Challenges in Water Security and Infrastructure Resilience

Michael D. Royer

National Risk Management Research Laboratory, United States Environmental Protection Agency, USA

This presentation will provide an overview of the Water Sentinel program and of the research challenges and opportunities presented by deteriorating water infrastructure.

The overall goal of the WaterSentinel Initiative is to design and demonstrate an effective system for timely detection and appropriate response to drinking water contamination threats and incidents through a pilot program that will have broad application to the nation's drinking water utilities. WaterSentinel demonstrates the concept so that drinking water utilities of all sizes and characteristics can adopt and implement an effective contamination warning system. Although the conceptual design is subject to review and modification, the current WaterSentinel approach to detecting contamination involves: monitoring of water quality parameters; direct monitoring and laboratory analysis of high priority chemical, biological, and radiological contaminants; integration of water system data with existing public health surveillance systems; and active surveillance of customer complaints.

The United States' water and wastewater infrastructure is large (i.e., 16,000 publicly owned treatment works, 59,000 community water supplies, 600,000 miles of sewer, 1,000,000 miles of drinking water distribution piping), complex and expensive. The reliable and efficient functioning of America's potable water and wastewater infrastructure provides massive benefits to public health, the environment, industry, homeland security, and the economy. An inordinately large fraction of the U.S. water infrastructure will need to be renewed over the next 20 to 40 years, which poses a range of economic, technical, and public health challenges. EPA's overall strategy for promoting sustainable water infrastructure in the 21st Century will be briefly described. Research opportunities and challenges regarding innovative water mains inspection and condition assessment technologies will be discussed. Opportunities and challenges regarding innovation in other areas, such as materials, rehabilitation technologies, and system design will also be briefly addressed.

Desalination in Israel

Raphael Semiat

Rabin Desalination Laboratory (RDL), The Grand Water Research Institute (GWRI), The Wolfson Chemical Engineering Department, Technion, IIT, Israel

Clean water is essential for human well-being and survival, agriculture, industry and the environment. When water is consumed containing harmful contaminants or in insufficient quantities, human conditions can deteriorate through malnutrition, sickness, disease, miscarriage and death. Inadequate water usage for agriculture may lead to insufficient production and low-quality crops, causing hunger, poverty and death.

The water supply in most industrial countries is largely safe and adequate, however many nations and regions are facing severe shortages of clean water due to extended droughts, increased water demand as a result of population growth, more stringent health-based regulations, and competing demands from a variety of water consumers. Based on UNESCO estimations, 10,000 people are dying daily due to water-related diseases.

Average water consumption in Israel over the past 12 years has exceeded the natural supply by 400 million m^3/year – around 60% of urban, or 25% of the total consumption. About two thirds of the wastewater is treated on a secondary level, which is suitable for irrigation of some crops under severe regulations. The balance of sewage water is not treated adequately and finds its way to the aquifers and the sea, polluting the soil and the aquifers. Neighboring countries suffer from the same problems and require similar amounts of daily water consumption. Predictions for the future anticipate higher capacities and improved water quality.

Desalination techniques, like MED and VC have been developed in Israel, however, the reverse osmosis (RO) membrane technique is considered the most promising for brackish and seawater desalination. This is one of the key techniques in overcoming the water problem, yet the cost is still too high for many regions in the world and in the Middle East. The Israeli Government has decided to proceed in large program that will solve the acute problem in Israel. Such a program can also help our neighboring countries. Our task, as researchers is to find better solutions that will reduce the cost of produced water, while improving their quality and reduce environmental problems. Some highlights of the RDL research work will be presented.

New Methods for On-Line Analysis of Particulates in Water

Israel Schechter

Faculty of Chemistry and GWRI, Technion – IIT, Israel

We address the issue of monitoring water-borne hazardous particulates. Several new analytical techniques are suggested and evaluated. These include Laser Induced Breakdown Spectroscopy (LIBS), Polymeric film sensors coupled to chemical imaging instruments, and direct fluorescence fluctuation spectrometry.

The LIBS technique provides on-line elemental fingerprinting of water-borne particulates. It can detect particulates of ca 20 nm diameter, and up to macroscopic solid particles. The polymeric films are capable of sampling both dissolved and insoluble particulates. In regard to the particulates, quantitative chemical analysis can be performed, using new chemical imaging techniques. For example, the application of Fourier Transform Spectral Imaging Microscopy (FT-SIM) allows for quantitative analysis of some organic pollutants in water. While traditional chemical analysis suffers from known matrix effects (due to persistent humic substances and clay compounds), the polymeric film sensors are much less sensitive to matrix effects.

Direct quantification of organic particulates using fluorescence fluctuation analysis is also discussed, as well as some future methods, which are still under preliminary examination.

Antimicrobial Materials for Water Disinfection Based on Visible-light Active Photocatalysts

P. G. Wu[1], R. C. Xie[1], J. Imlay[2], and J. K. Shang[1]

[1]Department of Material Science, [2]Department of Microbiology, Center of Advanced Materials for Purification of Water with Systems, University of Illinois at Urbana-Champaign, USA

Quaternary oxides based on Ti, O, and N were synthesized by sol gel and solvothermal methods and tested for bacterial killing under visible light. The oxides were made into discrete nanoparticles, thin coatings, and mesoporous fibers. Bacterial testing indicated that the photocatalysts provided rapid killing of gram-negative bacteria, gram-positive bacteria, and spores. Scanning electron microscopy imaging of the bacteria showed that the photocatalytic oxidation caused disconfiguration of and membrane damage in the bacteria. Transmission electron microscopy revealed the removal of the outer layer of the bacteria and missing parts in the cell membrane. The damage in the cell membrane led to compositional changes inside the cell.

Process Development of Catalytic Water Denitrification: Catalyst Optimization, Reactor Design and Quantum Chemical Computations

Moshe Sheintuch, Irena Efremenko and Uri Matatov-Meytal

Department of Chemical Engineering, Technion, ITT, Israel

A continuous process for catalytic hydrogenations for nitrates and nitrites abatement from drinking water has been developed in our lab. We describe the process development procedure, which included the following steps, in order to explain the advantages of shortcomings of a catalytic water treatment process: (i) Catalysts selection and optimization- a bimetallic Pd/Cu was found to be most active and most selective (to nitrogen vs. ammonia); (ii) Support selection and optimization- various cloth supports, including an activated carbon cloth (ACC) were tested for their activity and convenience of operation; (iii) Catalyst preparation procedures - catalysts prepared by selective deposition of Cu on Pd/ACC led to better activity than catalysts prepared by co-impregnation or ion exchange methods.; (iv) reaction kinetics and product selectivity were studied in a batch and continuous units and were modeled; (iv) pH, temperature and tap (vs. distilled) water effects were characterized: (v) Catalyst longevity and especially its slow dissolution is characterized; (vi) Initial economic evaluations were conducted.

We use quantum chemical modeling to qualitatively understand some of the observations and optimization: (i) The computations explain that the dispersity of Pd catalysts supported on ACC is much higher than that on silica, which explains its better activity, due to the larger surface area and higher density of adsorption sites; (ii) Interaction of Cu atoms with both supports is stronger than that of Pd; adsorbed Cu atoms show higher ability to form monometallic than bimetallic bonds and that should result in poor mixing of the metal upon co-impregnation as was observed experimentally; (iii) Cu atoms in bimetallic Pd-Cu particles admit a significant positive charge; the experimentally measures solubility of metal atoms correlates with their calculated charges.

Detection of Aqueous Containments using the Near Infrared Band-Gap Fluorescence of Single-Walled Carbon Nanotubes

Michael S. Strano

Department of Chemical and Biomolecular Engineering, University of Illinois at Urbana-Champaign, USA

Molecular detection using near-infrared light between 0.9 and 1.3 eV has important environmental and biomedical applications because of greater light penetration into scattering media and reduced auto-fluorescent background from biological contaminants. Single Walled Carbon Nanotubes (SWNT) have a tunable near-infrared emission that we have demonstrated to be sensitive to changes in their local dielectric function but remain stable to permanent photobleaching. We report the synthesis and demonstration of several types of solution-phase, near-infrared sensors by functionalizing carbon nanotubes with ligands designed to modulate the fluorescence in response to selective molecular binding. Applications in environmental monitoring will be reviewed. In one model system, by adsorbing glucose oxidase and ferricyanide ions to the surface of carbon nanotubes, a flux-based -D-glucose sensor is created. Reaction of glucose at the enzyme ultimately injects charge into the nanotube and modulates the fluorescence via two distinct mechanisms of signal transduction—fluorescence quenching and charge transfer. The scheme extends easily to a wide range of enzymatic platforms. We also demonstrate a separate and parallel optical detection modality via specific DNA sequences including single nucleotide polymorphism on the surface of solution suspended single-walled carbon nanotubes. Hybridization of a 24-mer oligonucleotide sequence with its complement produces a hypsochromic shift of 2 meV, with a detection sensitivity of 6 nM. In another system, the transition of DNA secondary structure from the native B to the Z conformation is shown to modulate the dielectric environment of the single walled carbon nanotube (SWNT) around which it is adsorbed. The SWNT band gap near infrared fluorescence emission energy decreases up to 16 meV for a 30-mer oligonucleotide when the system is exposed to counter-ions that screen the charged backbone. The transition is thermodynamically identical for DNA on and off the nanotube, except that the propagation length of the former is shorter by one-sixth. These changes can be observed in strongly scattering or absorbing media, and we demonstrate optical detection of Hg^{2+} in whole blood, dye colored water, tissue, and from localized complexes within living mammalian cells. Lastly, potential directions relating to new classes of sensors for environmental monitoring will be discussed. The results demonstrate new opportunities for nanoparticle optical sensors that operate in strongly absorbing media of relevance to medicine, biology and environmental remediation.

Breakout Session Guidelines

Overview of Breakout Sessions

This document discusses the desired outcomes of the breakout sessions, the roles and responsibilities of the chairs/facilitators, panel members, and notetakers in achieving those outcomes, proposed questions to guide the discussions, ground rules for effective discourse, and an annotated version of the agenda.

Each breakout room will have a laptop computer, flip chart and related supplies.

Desired Outcomes of the Breakout Session

The breakout sessions are designed as an opportunity for participants to play a role in achieving the following workshop objectives:

1. To assess the current state of nanotechnology applications for water purification through presentation of current research in the areas of (a) desalination and water reclamation/reuse, (b) detection and removal of trace contaminants of concern, and (c) disinfection for human consumption.
2. To identify gaps in (a) the scientific understanding and characterization of materials and aqueous interactions at the nanoscale, (b) the ability to synthesize nanomaterials and systems with specific, desirable characteristics, (c) the understanding and minimization of fouling in nanotechnology applications in the aqueous environment.
3. To identify current and future opportunities for nanotechnology to enhance the resilience of existing water purification and distribution infrastructure to natural and anthropogenic catastrophes, including acts of terrorism.
4. To assess and prioritize the identified gaps (2 above) and opportunities (3 above) according to their relative impact on potential progress in water purification.
5. To inventory the capabilities of workshop participants to address identified gaps and opportunities.
6. To identify and initiate partnership opportunities among participants to effectively address the gaps and opportunities.

The desired outcomes for each of the breakout sessions are:

1. A list of knowledge and ability gaps, prioritized according their relative impact on potential progress in water purification.
2. An inventory of session participant's capabilities to address the identified knowledge and ability gaps.
3. The identification of at least four distinct partnership opportunities that will be put forward for further development among all workshop participants.

Each breakout session will present a 20-minute report in plenary that summarizes the gap analysis, the inventory of research capabilities and the potential partnerships among session participants. The breakout reports are intended to facilitate larger collaboration discussion across among all workshop participants.

The gap analysis, research capabilities, and partnership opportunities will be compiled into a workshop report that will be disseminated and presented to the sponsoring agencies and organizations as well as to other interested parties. Copies of the final report will be sent to all workshop participants and posted to a virtual workshop (to be developed by the WaterCAMPWS and the INNI) to facilitate ongoing collaboration among workshop participants.

Structure of the Breakout Sessions

Workshop participants will be assigned to concurrent breakout sessions. Each session will develop a report for presentation to the full workshop. Each session should attempt to address the key questions identified in advance (see below).

A chair/facilitator for each breakout session has been identified in advance of the workshop. Each session chair/facilitator will need to select a notetaker and a presenter to report the session's findings in the plenary session. Each participant is encouraged to participate full in the discussions.

Roles and Responsibilities

Below are the general responsibilities of the chair/facilitator and notetaker in each breakout session.

During the Breakout Session:

Session Chair/Facilitator:
The chair/facilitator's role is to assist the participants in achieving the desired outcomes, with a specific focus on drawing out key research gaps and collaboration opportunities for a document that will be incorporated into the conference report.

- Provide a brief overview of the session
- Facilitate the breakout session deliberations
- Answer questions or provide guidance as appropriate
- Lead the group to develop a list of research gaps, participant research capabilities and collaboration opportunities

Notetaker
It is often useful to designate two notetakers – one to capture detailed notes of the discussion (on computer or paper) and one to capture recommendations on a flit chart.

- Take detailed notes throughout the breakout session
- Capture participants' discussion during the session, focusing on main points and, if possible, who is saying what
- For example: "Dr. X reported a need for visualization techniques to understand molecular orientation at a membrane surface. Dr. Y agreed that this was a critical research need and that her research group is focusing on this issue but needs assistance in using Z method for this purpose." "Dr. X and Dr. Y agree to

explore and/or develop a collaborative effort to use Z method for visualizing molecular orientation at a membrane surface."
- Assist the chair/facilitator in preparing an electronic or legible document with the list of recommendations, based on the group's relative priorities
- Ensure that the document is delivered to the workshop organizers for inclusion in the final workshop report

Ground Rules and Guidelines for Discussion

All participants should follow these guidelines:
- One person speaks at a time
- Respect time limits
- Focus on task at hand/avoid sidebar conversations
- Expect, respect and accept different interests, perspectives and opinions
- Participate actively – share information, ideas and concerns

Chairs/facilitators should attempt to:
- Assist the group in achieving its goals
- Efficiently move deliberations along
- Keep group focused on task
- Seek active involvement and broad input, and ensure that all have opportunity to speak
- Develop a sense of ownership in the product
- Ensure time restraints are observed and commitments met
- Summarize status of discussions, check for confirmation, verify next steps

RECOMMENDED BREAKOUT SESSION AGENDA

As soon as plenary session concludes, all session participants proceed to designated breakout session rooms. **Begin promptly to ensure adequate time for discussion.**

10 minutes	▪ Welcome (Chair) ▪ Participant introductions (each participant should **briefly** identify himself/herself and their organization) ▪ Ask for any questions regarding ground rules, roles, session agenda
Morning Session	▪ Identify gaps in (a) the scientific understanding and characterization of materials and aqueous interactions at the nanoscale, (b) the ability to synthesize nanomaterials and systems with specific, desirable characteristics, (c) the understanding and minimization of fouling in nanotechnology applications in the aqueous environment. ▪ Identify current and future opportunities for nanotechnology to enhance the resilience of existing

	water purification and distribution infrastructure to natural and anthropogenic catastrophes, including acts of terrorism. ▪ Assess and prioritize the identified gaps and opportunities according to their relative impact on potential progress in water purification.
Afternoon Session	▪ Inventory the capabilities of workshop participants to address identified gaps and opportunities. ▪ Identify and partnership opportunities among participants to effectively address the gaps and opportunities.

POTENTIAL QUESTIONS FOR BREAKOUT SESSIONS

Below are potential questions that might be useful for framing discussions during the breakout sessions.

Knowledge Gaps, Research Needs / Researcher Capabilities, Collaboration Opportunities

- What are the critical gaps in our ability to understand and characterize materials and aqueous interactions at the nanoscale?
- What new understanding and investigative techniques will be needed to address these gaps?
- What are the knowledge gaps and synthesis limitations that impair our ability to readily synthesize nanomaterials and systems with specific, desirable properties?
- What are the prospects of and research needs for substantively enhancing nanomaterials synthesis capabilities?
- In what manner are session participants addressing the gaps and needs, and what additional capabilities do they need to bring their work to fruition?
- What opportunities can be identified for session participants to collaborate with each other (and with other identified researchers) to enhance each others' work?

Water Security and Infrastructure Challenges, Collaboration Opportunities

In addition to the knowledge gaps and research needs questions above, the following potential questions are intended to focus on the unique needs of protecting water purification systems and infrastructure from catastrophic impacts.

- What are the most credible threats to water purification systems and infrastructure from natural and anthropogenic catastrophes?
- What are the potential and probable impacts of the most credible threats?
- What are the most likely impacts on water purification systems and infrastructure from inadequate maintenance and aging?
- What capabilities are needed to reliably detect system and infrastructure impacts from both catastrophic incidents and aging?

- What capabilities are needed to promptly notify and protect affected populations from impacts?
- What capabilities are needed to effectively mitigate impacts and restore system and infrastructure performance?
- In what manner might nanotechnology enhance detection, protection and mitigation capabilities in systems and infrastructure?
- In what manner might nanotechnology enhance the resilience of systems and infrastructure to threats and aging?

Workshop Participants

Workshop Participants

Last Name	First Name	Institution	Email
Armistead	Paul	US Navy, Office of Naval Research	armistj@onr.navy.mil
Belkin	Shimshon	Hebrew University	shimshon@vms.huji.ac.il
Brenner	Arnold	US-Israel Science & Technology Commission	abrenner@usistf.org
Chaplin	Brian	WaterCAMPWS, UIUC	chaplin@uiuc.edu
Chapman	Michelle	US Bureau of Reclamation	mchapman@do.usbr.gov
Cohen	Yoram	Water Technology Research Center, UCLA	yoram@ucla.edu
Dionysiou	Dionysios	University of Cincinnati	dionysios.d.dionysiou@uc.edu
Dosoretz	Carlos	Technion Israel Institute	carlosd@techunix.technion.ac.il
Elenberg	Irv	American Technion Society	irv@ats.org
Elimelech	Menachem	Yale University	menachem.elimelech@yale.edu
Gentry	James	US Environmental Protection Agency	gentry.james@epa.gov
Georgiadis	John	WaterCAMPWS, UIUC	georgia@uiuc.edu
Hightower	Michael	Sandia National Laboratories	mmhight@sandia.gov
Hinkebein	Thomas	Sandia National Laboratories	tehinke@sandia.gov
Hurd	Jim	NanoScience Exchange	jim@nanoscienceexchange.org
Kilmer	Charles	WateReuse Association	cakilmer@yahoo.com
Landau	Miron	Ben-Gurion University of the Negev	mlandau@bgumail.bgu.ac.il
Lev	Ovadia	Casali Institute, Hebrew University	ovadia.lev@huji.ac.il
Linder	Charles	Ben-Gurion University of the Negev	linderc@bgumail.bgu.ac.il

Last Name	First Name	Institution	Email
Lu	YI	WaterCAMPWS, UIUC	yi-lu@uiuc.edu
Marks	Robert	Ben-Gurion University of the Negev	rsmarks@bgu.ac.il
Mayer	Thomas	Sandia National Laboratories	tmmayer@sandia.gov
Mayes	Ann	Massachusetts Institute of Technology	amayes@mit.edu
Merzbacher	Celia	US Office of Science Policy and Technology	Celia_Merzbacher@ostp.eop.gov
Mintz	Eric	WaterCAMPWS, Clark-Atlanta University	emintz@cau.edu
Nunez	Carlos	US Environmental Protection Agency	nunez.carlos@epa.gov
Oren	Yoram	Ben-Gurion University of the Negev	yoramo@bgu.ac.il
Peterson	Eric	National Science Foundation	epeterso@nsf.gov
Prentice	Geoffrey	National Science Foundation	gprentic@nsf.gov
Roco	Mihael	National Science Foundation	mroco@nsf.gov
Rosenbaum	Bob	Israel National Nanotechnology Initiative	bob.rosenbaum@nanoisrael.org
Royer	Michael	US Environmental Protection Agency	royer.michael@epa.gov
Sagman	Uri	C Sixty, Inc.	usagman@usagman.com
Savage	Nora	US Environmental Protection Agency	savage.nora@epa.gov
Schechter	Israel	Technion Israel Institute	israel@techunix.technion.ac.il
Semiat	Rafi	Grand Water Research Institute, Technion	cesemiat@tx.technion.ac.il
Shang	Jian Ku	WaterCAMPWS, UIUC	jkshang@uiuc.edu
Shannon	Mark	WaterCAMPWS, UIUC	mshannon@uiuc.edu
Shapley	John	WaterCAMPWS, UIUC	shapley@uiuc.edu
Sheintuch	Moshe	Technion Israel Institute	cermsll@tx.technion.ac.il
Strano	Michael	University of Illinois at Urbana-Champaign	strano@uiuc.edu

Last Name	First Name	Institution	Email
Sustich	Rich	WaterCAMPWS, UIUC	sustich@uiuc.edu
Thomas	Treye	US Environmental Protection Agency	thomas.treye@epa.gov
Werth	Charles	WaterCAMPWS, UIUC	werth@uiuc.edu
Wilf	Mark	Hydranautics, Inc.	mwilf@hydranautics.com

Principal Workshop Contacts:

US:
Rich Sustich
WaterCAMPWS - University of Illinois
+1 217-265-0833
sustich@uiuc.edu
http://www.watercampws.uiuc.edu/

Israel:
Bob Rosenbaum
Israel National Nanotechnology Initiative
+972 54-473-8040
bob.rosenbaum@nanoisrael.org
http://www.nanoisrael.org