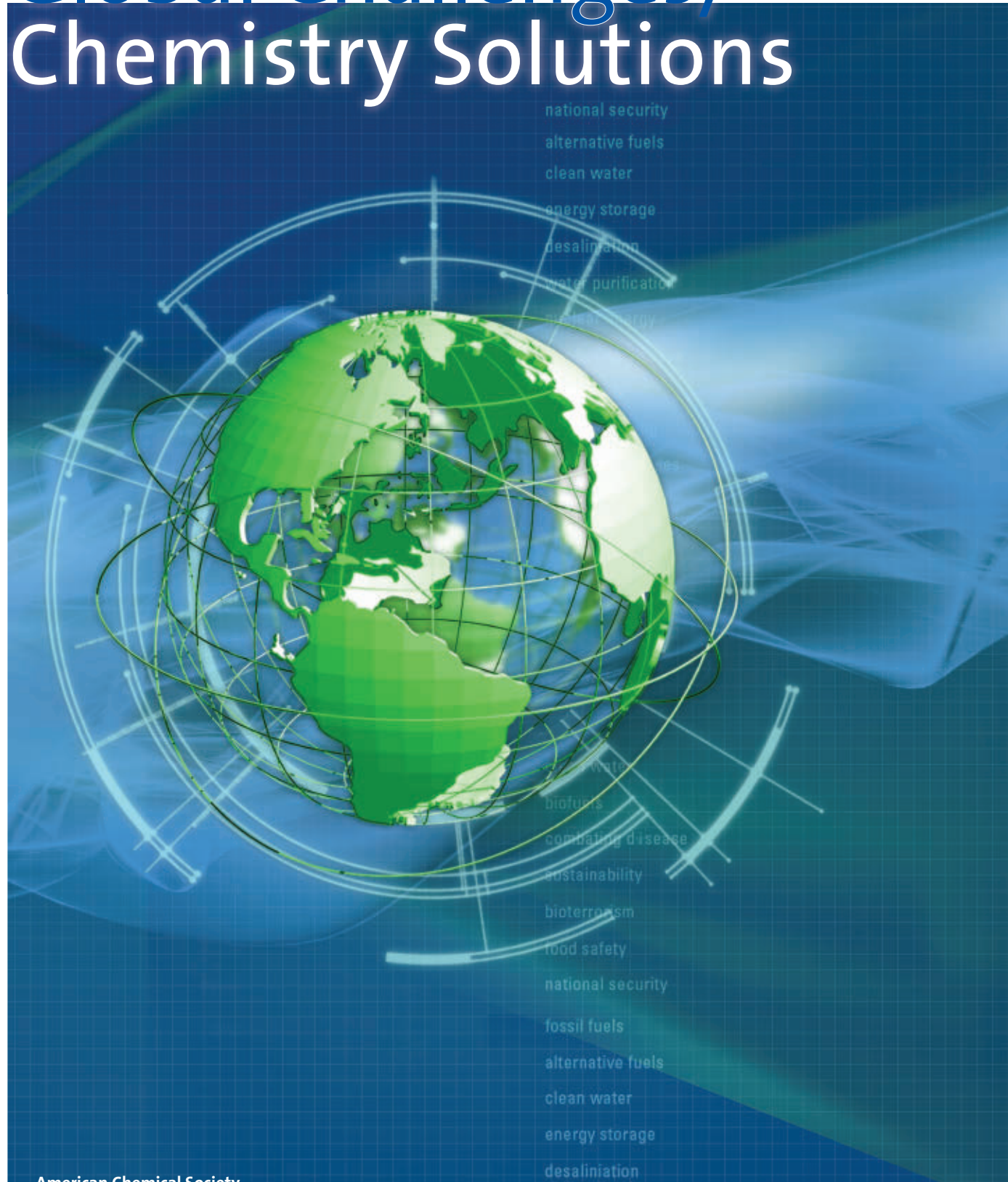




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# Global Challenges/ Chemistry Solutions



national security

alternative fuels

clean water

energy storage

desalination

water purification

nuclear energy

water

biofuels

combating disease

sustainability

bioterrorism

food safety

national security

fossil fuels

alternative fuels

clean water

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water purification

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American Chemical Society



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## 10 Water Desalination: Freshwater from the Sea

“Water, water, everywhere, nor any drop to drink.” So lamented Samuel Taylor Coleridge’s ancient mariner 210 years ago about the saltwater that surrounded his ship. Now scientific advances in water desalination promise to dramatically increase our ability to economically transform seawater into freshwater. If successful, the world’s oceans could become a drought-proof source of water for agriculture, industry, and 1.2 billion people locked in the embrace of a global water shortage.

## 16 Confronting Climate Change: Part 1. Stopgap Measures to Reduce Greenhouse Gas Emissions

Wagon trains of pioneers heading West to settle the American frontier encountered oceans of grass swaying in the wind in the prairies. This grass grew 7–10 feet high — almost to the second-story windows on a modern house. Much of that green ocean consisted of switchgrass. Today switchgrass looks greener than ever to new generations of pioneers. These chemists, chemical engineers, and other scientists are searching for solutions to the challenges of global warming.

## 22 Confronting Climate Change: Part 2. The Quest for Permanent Solutions

As the quest for permanent solutions to global warming gains urgency, scientists are working to harness the chemical magic that plants use to produce hydrogen from sunlight and water. Hydrogen fuel produced in artificial photosynthesis units could replace some of the fossil fuels that now account for almost 70 percent of the carbon dioxide released in the United States every year. Scientists imagine cars with an artificial photosynthesis unit that converts water to non-polluting hydrogen fuel.

## 30 Our Sustainable Future

People are consumers. We consume energy, food, and thousands of other essentials. Faced with concerns about petroleum supplies and environmental pollution, we must begin to consume in a new and more sustainable way. Simply put, sustainability means meeting the needs of people today without compromising the ability of future generations to meet their own needs. Scientists are responding to that challenge with innovations in “green chemistry” and a range of exciting new processes and technologies.

## 36 Promoting Personal Safety & National Security

September 11, 2001, put a new topic on the radar screen for many people in the United States and other countries. That tragic day, and the anthrax attacks that followed, made us more aware of threats to personal safety and national security. Chemists and other scientists are responding to a host of threats that range from terrorist attacks to germs that collect on kitchen countertops. The response promises to improve our everyday health, safety, and peace of mind as individuals and as a nation.



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### 42 Combating Disease

Despite all the revolutionary medical advances in the 20th century, great challenges lie ahead in our fight against disease. Heart disease. Cancer. Alzheimer's disease and other chronic diseases of aging. Infection with the AIDS virus. Antibiotic-resistant microbes. And those are just a few of the challenges. Fortunately, chemists and other scientists are determined to launch new revolutions in medicine — revolutions that enable us to prevent disease more effectively, diagnose earlier, and cure more often.

### 48 New Fuels: Part 1. Biofuels

Concerns about high gasoline prices and global warming are fostering a world-wide scientific quest for new fuels. They are seeking alternatives to conventional petroleum, natural gas, and coal. At the head of the line are biofuels, fuels that can be produced in a sustainable fashion from plants. Future fuels include not-new sources of ethanol produced from biomass that do not require strain the food supply. And watch for esoteric new fuels like “green gasoline” and “designer” hydrocarbons.

### 54 New Fuels: Part 2. Fuels from Ice, Water, and Sunshine

Ice that burns? Yes, indeed. Gas hydrates are icy cages filled with methane, the main ingredient in natural gas. They are among a suite of new energy sources that may power society in the years ahead. Scientists are developing these new energy sources to supplement the coal and conventional natural gas now used to produce electricity for heating, cooling, and lighting. They hold special promise as sustainable energy sources that help combat global warming.

### 60 Providing Safe Foods

Every Thanksgiving, family and friends gather to celebrate round dinner tables heaped high with roasted turkey and other traditional dishes. There's praise for the food, of course, and thanks for the year's blessings. For good health. For the love and support of family and friends. Maybe we should add a word at Thanksgiving for the scientific advances that are helping to keep our food supply safe from a host of threats that can really spoil a meal.

### 66 Providing Nutritious Foods

Blueberries, raspberries, and grapes bursting with flavor. A luscious, silky morsel of chocolate melting into a mouthful's rush of pure pleasure. Fresh, ripe tomatoes. Years ago, people ate for that gratification. Food also provided the calories for people to work, and drove away hunger pangs. Today, people in industrialized countries are selecting food not just for taste and sustenance, but also for its potential effects in promoting good health.

### 72 Promoting Public Health

Life expectancy in the 20th Century rose by about 30 years. Advances in protecting the public health were responsible for about 25 of those precious years. Vaccination programs. Improved sanitation to better control infectious diseases. The development of antibiotics. Better prenatal care. And much more. Scientists are making strides toward sustaining that progress by fostering continued improvements in the health of the population as a whole.



# Introduction

**Combating disease . . . providing clean water and safe food . . . developing new sources of energy . . . confronting climate change.** *Hello, from Washington, DC, this is “Global Challenges,” a special podcast from the American Chemical Society — whose 160,000 members make up the world’s largest scientific society. Today’s headlines are a drumbeat of dilemmas that affect the everyday lives of people everywhere. “Global Challenges” takes you behind those headlines for eye-opening glimpses of how chemistry is responding to those challenges — improving and sometimes saving people’s lives. You’ll hear the stories and meet the scientists whose discoveries are helping to make life longer, healthier, and happier for millions of people. Today’s global challenge in this ongoing saga of chemistry for life is. . . .*

Since June 2008, thousands of people have both read and heard those words as the American Chemical Society (ACS) moved forward with Global Challenges/Chemistry Solutions. These words introduced each of the 12 episodes in this major project, launched to help ACS meet a fundamental goal of enlisting the world’s scientific professionals to address, through chemistry, the challenges facing our world.

As the introduction promises, Global Challenges focuses on daunting problems, selected by a diverse group. The topics range from global climate change and the crisis in supplying clean water to the quest for new fuels and innovative ways of safeguarding personal safety and national security. In developing each topic, we called on thought leaders — those individuals recognized among their peers for innovative ideas and insights. They included editors of scientific journals and *Chemical & Engineering News*, ACS Technical Division members, and high-level U. S. Government officials. We drew heavily from scientific advances reported during 2008 in the scientific literature, including the 33,000 reports published in ACS’s 34 peer-reviewed journals.

We took a fresh approach in presenting the challenges and solutions, one responsive to the growing public preference for accessing news and information in a wide assortment of formats. ACS chose the podcast format for Global Challenges. Podcasting is a way of accessing audio and video content on portable digital devices like the iPod. If you subscribe to a podcast on iTunes or another website, new episodes automatically download into your digital device every time you connect it to the computer. People listen to podcasts with earphones while jogging, commuting, or working. We’ve all seen these people!

In order to make Global Challenges as accessible as possible, ACS also built web sites for each of the episodes. Visit our website at [www.acs.org/globalchallenges](http://www.acs.org/globalchallenges) and you can listen to the audio on your computer, read a script on the monitor, or print out the text. We also populated the web site with compelling images, resources and sources for teachers and students, and other content.

Now we take great pleasure in welcoming you to Global Challenges — the book, which makes our story of science tackling daunting challenges even more accessible. These pages reproduce the Global Challenges scripts just as they were voiced in the podcasts. Just like radio or TV scripts, they were written to please the ear rather than the eye. The italicized blocks of text represent audio clips of scientists interviewed for the podcasts. They are speaking in informal style, with all the natural pauses and faux pas of everyday conversation.

We wish it were possible to include the wonderful sound effects woven into the fabric of the podcasts. These sounds — of storm-tossed oceans, pioneers’ wagon trains heading West, historical and literary figures, animals, and much more — enhance the narrator’s voice and the scientists’ audio to create a memorable listening experience. We hope this book will encourage readers to give Global Challenges a listen, on [www.acs.org/globalchallenges](http://www.acs.org/globalchallenges), iTunes, or your favorite podcasting site.

Madeleine Jacobs  
Executive Director & CEO



# The Crisis in Clean Water: Water Purification

**C**ombating disease . . . providing clean water and safe food . . . developing new sources of energy . . . confronting climate change. Hello, from Washington, DC, this is Global Challenges, a special podcast from the American Chemical Society — whose 160,000 members make up the world's largest scientific society. Today's headlines are a drumbeat of dilemmas that affect the everyday lives of people everywhere. Global Challenges takes you behind those headlines for eye-opening glimpses of how chemistry is responding to those challenges — improving and sometimes saving people's lives. You'll hear the stories and meet the scientists whose discoveries are helping to make life longer, healthier, and happier for millions of people. Today's global challenge in this ongoing saga of chemistry for life: providing a thirsty world with clean drinking water.

From San Diego to Santiago to Seville to Sydney, billions of people are facing shortages of clean water. At least 80 countries already have water shortages that threaten health and economic activity. More than 1 billion people have no access to clean drinking water.

And things are getting worse. World population is growing. Farms, factories, and cities are using more water. Demand for water is doubling every 21 years — and faster in some areas.

Global climate change adds an unsettling element of uncertainty to what many experts term a global water crisis. What effect will global warming have on water supplies to homes, factories, and farms — especially during parched summer months when demand peaks?

## A Naturally Scarce Resource

Look down at Earth from space and you see a sparkling blue-and-white jewel. Most of what you see is water. Earth is the “water planet.” How can a planet with 71 percent of its surface covered by water face a water shortage?

In reality, we face a natural shortage of water that people can use. About 97 percent of Earth's water is saltwater in the oceans and brackish water on land. Polar ice caps and glaciers hold another 2 percent in their frozen embrace. Barely 1 percent of the world's total supply of water is in lakes, rivers, and groundwater sources. This is freshwater that people can use.

## The Liquid Fantastic

This natural shortage involves a substance that — second only to air — is the most essential material for life. As Dr. Julie Beth Zimmerman put it, shortages of clean water are at the basis of other global problems.

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## Did You Know?

- ◆ *Water covers 71% of Earth's surface.*
- ◆ *Barely 1% is freshwater that people can use.*
- ◆ *It takes 39,000 gallons of water to make one car.*
- ◆ *A 5-minute shower uses 50–100 quarts of water.*
- ◆ *Water is the only substance that exists naturally as a solid, liquid, and gas.*
- ◆ *The United Nations declared 2005–2015 “Water for Life,” the International Decade for Action on water-related issues.*



## HIGHLIGHTS

- ◆ **The “Professor of Plumbing” says water may stagnate and go bad in home pipes.**
- ◆ **Water contaminated with disease-causing bacteria claims a terrible toll from diarrheal diseases.**
- ◆ **About 1.5 million children die annually in the developing world due to contaminated water.**
- ◆ **The “Miracle Packet,” a mini-water filtration plant the size of a tea bag, purifies water inexpensively.**
- ◆ **Cell phones take on new role in telemedicine, helping to diagnose water-borne disease.**

## Meet the Scientists



Julie Beth Zimmerman, Ph.D.



Jerald L. Schnoor, Ph.D.



Greg Allgood, Ph.D.

*The water crisis seems to be at the crux of so many other things like population increase, climate changes scenarios, land use changes.*

*“The water crisis seems to be at the crux of so many other things like population increase, climate changes scenarios, land use changes. All of it really goes back to water quality — water quantity and availability. We wanted to bring that to the forefront for the ES&T community.”*

A chemical engineer at Yale University, Zimmerman was a guest editor of a special edition of *Environmental Science & Technology*, one of ACS’s 34 peer-reviewed scientific journals. Dr. Jerald L. Schnoor, *ES&T*’s editor-in-chief, who is with the University of Iowa, explains that the issue, entitled “The World’s Water,” focused on global water problems. Here is Dr. Schnoor:

*“It is a global focus, everything from how we look into the future and how various countries are going to obtain safe drinking water to details on the technology side. How do we prevent build-up of lead? How do we prevent deterioration of home water supply systems in the connection from the city supply to the home? And even within the home. I am very pleased with the articles. The authors really are among the leaders in this field in the nation and even the world.”*

Water is the liquid fantastic, a scientific marvel with secret properties that still puzzle and perplex chemists. It is the only substance, for instance, that at room temperature can exist in all three states of matter. Water can be a solid, a liquid, and a gas.

Few people realize it, but almost everything we eat, wear, or rely upon in everyday life requires water. It takes 150 gallons of H<sub>2</sub>O to make one loaf of bread. Growing the cotton in a pair of jeans takes 1,800 gallons. Cars don’t roll off the assembly line. They float off, on an invisible river of water. Producing a passenger car slurps up 39,000 gallons of water.

Unfortunately, most freshwater available to meet humanity’s needs cannot be used straight from lakes, rivers, or wells. Water naturally contains suspended and dissolved impurities. Natural sources of water often bear disease-causing bacteria, viruses, and parasites. This water must be purified.

### In Sickness and in Health

In 1999, the U.S. Centers for Disease Control and Prevention — the CDC — tallied up the 20th century’s 10 greatest public health achievements. Control of infectious diseases — especially cholera and typhoid — by providing clean water was No. 4 on that list. Public water purification and supply systems in the United States and other developed countries provide clean drinking water.

Those systems do not exist in parts of many developing countries. The lack of clean water claims a terrible toll. Water-related diseases are among the leading causes of illness and death among the poor in developing countries.

Consider just one plague — diarrhea and other gastrointestinal illness. The World Health Organization estimates that 1.5 million children under age 5 die each year from such diseases. That’s almost 4,000 deaths each day. Millions of others fall ill each year from these diseases. And almost all of this toll could be prevented.

### The Miracle Packet

April 2008 brought a dramatic example of how advances in research and development are having clear applications in addressing this global challenge — and in improving the quality of



human life. The place: A rural health clinic near Ibadan, Nigeria, a country in which 66 million people lack safe drinking water. The occasion: a celebration of the production of the one-billionth quart of clean drinking water with a purification technology developed by chemists at Procter & Gamble and the CDC.

The technology consists of small, easy-to-use packets that people in rural areas can add to a container of dirty water. These so-called PUR water purification packets work like a mini-water treatment plant. PUR packets contain powdered water clarification and disinfectant chemicals similar to those used in municipal water purification plants.

One ingredient: calcium hypochlorite, which kills parasites, bacteria, and viruses. Another: ferric sulfate, which removes dirt and other impurities. PUR packets kill microbes that cause cholera, typhoid, and dysentery. They remove potentially toxic metals like lead, arsenic, and mercury. PUR packets also remove pesticides like DDT and other undesirable materials. It takes less than 30 minutes to purify 10 quarts of water. The packets are provided in the developing world for only pennies.

At the clinic, John Pepper, P&G's former Chief Executive Officer, President, and Chairman, donated the PUR packet that provided the one-billionth liter of safe drinking water. Local and national government officials and others gathered at the clinic to observe the milestone. Among them was Dr. Greg Allgood, director of Children's Safe Drinking Water Program at P&G, which supplies the packets. Here is Dr. Allgood:

*"We're thrilled about reaching 1 billion liters of safe drinking water provided so far by PUR purified water. It's a little packet of powder, and it transforms dirty, contaminated water into clear, safe drinking water. You add it to 2½ gallons, stir for 5 minutes, and the water visibly and physically transforms in front of your eyes to clear water. Pour it into a cloth, wait 20 minutes, and then it's safe to drink."*

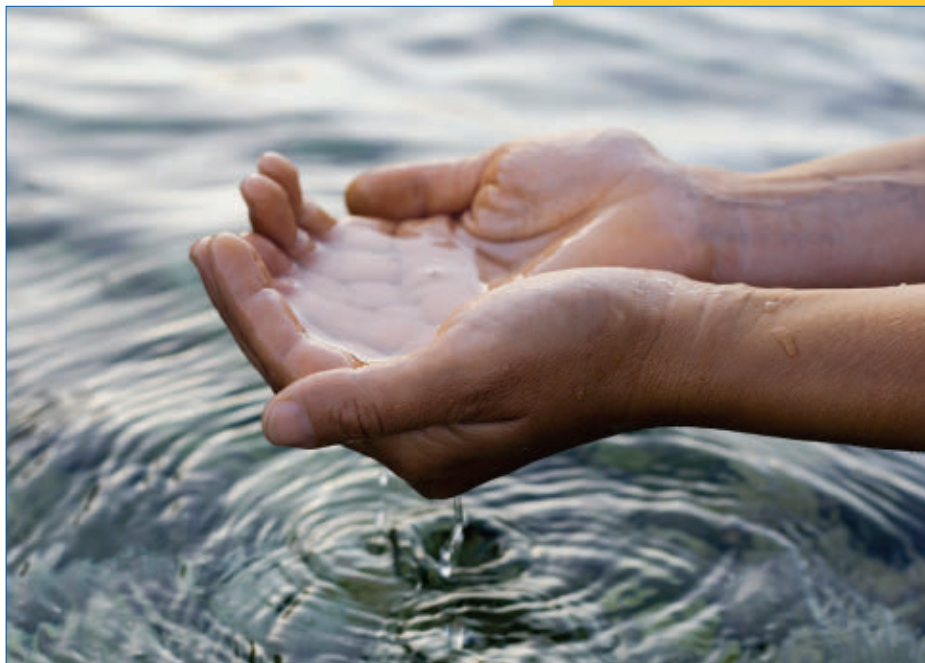
How effective is this chemical magic? Dr. Allgood's report at one ACS national meeting described the clinical trials. One involved 25,000 people in four countries — Guatemala, Pakistan, Kenya, and Liberia. PUR packets reduced the incidence of diarrhea by an average of 50 percent. One of the trials in a refugee camp found a 90 percent reduction in diarrhea.

### Tales of Telemedicine

Many of the countries without access to clean water are impoverished lands, with per capita incomes of barely \$1 per day. More than 1 billion people — one-sixth of humanity — struggle under these conditions of extreme poverty. They lack more than clean water. There is no basic equipment to test water for purity. And there are shortages of medical personnel and laboratories to test water for purity and diagnose water-borne diseases and select the proper treatment.

A team of scientists led by Dr. George M. Whitesides described a solution to those challenges in May 2008. They published the results of a study in *Analytical Chemistry*, another ACS journal. Their solution combines chemistry and . . . you guessed it. Cell phones. Almost 3 billion people — about half the world's population — now own cell phones.

After launching a communications revolution, cell phones are talking up a potentially life-saving new role in telemedicine. That's the use of telecommunications technology to provide



## Meet the Scientists



George M. Whitesides, Ph.D.



Marc Edwards, Ph.D.

*Unless you're immune-compromised, most people are just as well off drinking tap water as bottled water.*

medical diagnosis and patient care when the physician and patient are hundreds or thousands of miles apart.

### Simple, Inexpensive System

Dr. Whitesides and his colleagues at Harvard University and the University of Sao Paulo in Brazil developed and tested a simple, inexpensive telemedicine system. It is ideal for developing countries or remote areas lacking advanced medical equipment.

The system combines a cell phone camera with easy-to-use, paper-based diagnostic tests that undergo color changes when exposed to certain disease markers. The paper strips analyze urine, saliva, or other samples from patients and show the results with a color change. The cell phone camera records the results as a digital picture and transmits the image for reading by off-site medical personnel. Here is Dr. Whitesides:

*“Water is probably the key element in public health. There are many approaches to measuring clean water. Contaminants in water range from microorganisms to arsenic. You often must have an analysis carried out locally. If one can't afford to have the information collected by an expert and that means hours of travel just to get one point of information, our idea is to use a very simple and inexpensive analytical system. People can collect the information locally and then the device records and reports the information as a colorimetric or color change. That information can be transmitted by a cell phone to a central facility staffed by an expert who would not have to travel. The facility could receive information from a number of agents who were out collecting information in a different way.”*

### Global Challenges at Home

Can people in the United States and other developed countries trust their drinking water? With almost universal municipal water purification, developed countries do not face ongoing problems with water-borne diseases. Epidemics of typhoid and cholera transmitted by contaminated water — a major cause of illness and death early in the 20th century — are not even a memory.

However, other concerns do exist about the quality and safety of our tap water. Consumers in some areas complain about unpleasant taste and odor in drinking water. In other areas, water supplies have levels of lead and other substances.

Scientists are concerned about an emerging group of water pollutants that challenge traditional water treatment plants. Among them are the so-called PPCPs — pharmaceuticals and personal care products. These contaminants include ingredients in prescription and nonprescription medicines, cosmetics, and other products.

### Professor of Plumbing

So how safe is our tap water? For answers, Global Challenges turns to Dr. Marc Edwards, who *Time* magazine dubbed “The Plumbing Professor” and featured in 2004 as one of the nation's leading scientific innovators.

One focus of this Virginia Tech professor's research is lead leaching into drinking water as a result of water purification plants switching to chloramine disinfectant. Edwards reported on the topic in that special issue of *Environmental Science & Technology*. Dr. Edwards' overall assessment of drinking water quality in the United States is reassuring.

*“The biggest issue is really lead in water. Unless you're immune-compromised, most people are just as well off drinking tap water as bottled water, but the big exception is young children who are very susceptible to lead's effects. There are some situations, rare*



*as though they may be, where tap water from the homes has extraordinarily high lead levels that are very unsafe for children. So we have to do a better job of finding those problems and making sure people take the simple steps necessary to avoid that exposure through use of Brita filters or flushing or other approaches or even bottled water. But in general, the state of tap water in the United States is very good.”*

With traditional health threats like bacterial contamination largely under control, scientists are tackling new challenges, such as corrosion caused by new disinfectant and others that many people do not even suspect exist. Some even result from well-intentioned efforts to conserve this precious resource. Here again is Dr. Edwards:

*“As you know, water conservation is moving to the forefront as we try to become more sustainable, and that means lower-water-use shower heads, using rainwater or reclaimed water to flush toilets, and other issues. One of the things we are discovering is that because we are not drawing as much freshwater into the home, the quality of water is sometimes adversely impacted, meaning a few years ago you would flush the toilet and you would draw large amounts of freshwater into your house. But nowadays, we are using less of that water for flushing of toilets,*

*showers, and those types of activities. The potable water just sits in the line for much, much longer periods of time. So just like milk can go bad if it stays around too long, so too can potable water go bad, and we are discovering this is a downside of water conservation, and that we’ve got to come up with ways to maintain this higher water for a longer period of time in our house as it sits. So there’s always new challenges, and that can involve changing the water treatment so that the water stays fresher longer, to oversimplify the problem. Or changing the type of plumbing materials involved so that they might have a lesser impact, or can preserve the purity of water for a longer period of time.”*

## Conclusion

We face enormous challenges in meeting global needs for clean water. Some of the roadblocks are not strictly scientific. They result from extreme poverty and national priorities that limit use of existing water purification technology. However, as these glimpses of chemistry’s responses show, progress is being made. Here is Dr. Whitesides:

*“Drinking water is really a tough problem because it involves a commodity, which people use a lot of and they want at very low cost. So I have to be candid and say that parts of this problem strike me as extremely difficult. It is a problem of getting pure water — a problem that would benefit enormously from smart chemists thinking in creative ways. We just desperately need as many new ideas as possible about how to purify water.”*

Smart chemists. Innovative thinking. That’s the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we’ll examine what could be a magic bullet for water shortages — efforts to put water on a salt-free diet and produce freshwater from the limitless resource of H<sub>2</sub>O in the oceans.



# Water Desalination: Freshwater from the Sea

*Day after day, day after day,  
We stuck, nor breath nor motion;  
As idle as a painted ship  
Upon a painted ocean.*

*Water, water, everywhere,  
And all the boards did shrink;  
Water, water, everywhere,  
Nor any drop to drink.*

Samuel Taylor Coleridge penned *The Rime of the Ancient Mariner* 210 years ago. At one point, parched by thirst, the mariner muses on a dilemma that ranks among today's great scientific challenges. Water is everywhere, covering more than 70 percent of Earth's surface. And yet at least 1.2 billion people face shortages of water to drink. Water to irrigate farm fields and orchards. H<sub>2</sub>O for the mills and factories that produce food, medicine, computers, cars, clothing, and thousands of other products.

Our great dilemma — and science's challenge — involves that “nor any drop to drink.” About 97 percent of Earth's water is saltwater in the oceans and brackish water on land. People cannot drink saline water, nor can it quench the thirst of agriculture or industry. However, a technology called desalination — literally de-salting — promises to further tap this enormous resource as a source of freshwater.

In June, the Global Innovation Imperatives project convened experts on water in New Delhi, India. Dr. Mark Shannon, of the University of Illinois at Urbana-Champaign, was among speakers in this collaboration between the ACS Committee on Corporation Associ-

## DID YOU KNOW?

- ◇ Ocean water contains about 35,000 parts per million of salt. Freshwater contains less than 1,000 parts per million.
- ◇ The first scientific paper on desalting was published by Arab chemists in the eighth century.
- ◇ Desalination/distillation is one of mankind's earliest forms of water treatment. In ancient times, many civilizations used this process on their ships to convert seawater into drinking water.
- ◇ Today, desalination plants are used to convert seawater to drinking water on ships and in many arid regions of the world, and to treat water in other areas that is fouled by natural and unnatural contaminants.
- ◇ The largest inland desalination plant in the world, the El Paso-Fort Bliss desalination plant, has a design capacity of approximately 27.5 MGD (30,800 acre-feet).
- ◇ The average cost to produce 1 acre-foot of desalinated water from seawater ranges from approximately \$800 to about \$1,400.
- ◇ The size of each reverse osmosis membrane pore used in the desalination process is about 1/100,000th the size of one human hair.

## HIGHLIGHTS

- ◆ About 1.2 billion people face drinking water shortages.
- ◆ Desalination — desalting the world's oceans — could provide a bounty of fresh, clean water.
- ◆ More than 13,000 water desalination plants worldwide produce 12 billion gallons of freshwater daily.
- ◆ Cost and other challenges limit production.
- ◆ Technological advances could streamline processes.
- ◆ Nanotechnology — technology built from atoms and single molecules where dimensions are measured in nanometers, or billionths of a meter — shows promise in providing new membranes or “filters” to remove salt from water.
- ◆ Carbon nanotubes may become one new membrane material. These hollow tubes of pure carbon have an inner channel or pore 100,000 times smaller than a human hair. Water can pass through, but not salt.
- ◆ Nanocomposite membranes, polymers containing nanoparticles, may reduce the frustrating problem of membrane fouling or clogging.

## Meet the Scientists



James D. Birkett, Ph.D.



Ben Corry, Ph.D.



Menachem Elimelech, Ph.D.

ates and the Society of Chemical Industry. It's a collaboration that seeks science-based solutions for global health, environmental, and societal problems.

*"So the world's clean water supply is in crisis now — and it's only getting worse.... If one could desalinate that water affordably, effectively, and in an environmentally sound way, then much of the world's problems with water disappear."*

### A Dash of Salt

So what *is* salt, or saline, water? That's water with high amounts, or concentrations, of dissolved salts. One is sodium chloride — common table salt. Saline water also has salts made from calcium, magnesium, and other chemical elements. Seawater is unfit for human consumption because it contains too much salt. About 3.5 percent of its weight is salt. Drinking water normally quenches your thirst. But drinking saltwater will make you thirstier. The salt draws water out of cells in your body by a process called osmosis. We will hear more about osmosis a little later. That water winds up in your urine. Drink enough saltwater, and you're dead from dehydration.

Water desalination expert Dr. James D. Birkett told Global Challenges that desalting is a very ancient technology:

*"Desalination probably was recognized prior to Aristotle, but that's the first reliable, recorded piece of history. Aristotle, probably among others, noted that if you took saltwater and evaporated it, that the vapors thereof were pure, and when condensed, they would produce pure water."*

Two ancient desalination methods — distillation and what might be described as “filtering” — remain our mainstays today. More than 13,000 water desalination plants now operate worldwide. They produce at least 12 billion gallons of freshwater each day.

About 80 percent of that water comes from distillation. In modern distillation, we no longer hang sponges over pots of boiling seawater, catch the steam, and wring freshwater out of the sponges. We use high-tech processes, like the multi-stage flash distillation at the Jebel Ali Desalination Plant. Located in the United Arab Emirates, Jebel Ali is the world's largest desalination facility. In flash distillation, seawater heats in chambers where it evaporates or flashes into steam at about 160° Fahrenheit, rather than 212° F. The remaining water flows to the next stage where it flashes again, and to the next stage and the next. That approach saves energy. The freshwater condensate from each stage goes into storage tanks.

### Water's Salt-Free Diet

And methods for filtering salts out of saline water have come a long way from the ineffective wool and cloth filters used in ancient times. Most modern desalination plants in this genre use high-tech membranes in a process called reverse osmosis. Chemists and chemical engineers who developed reverse osmosis borrowed the idea from Mother Nature.

Osmosis is a natural process. The body uses it to keep cells in liquid chemical balance. In osmosis, water molecules flow from less concentrated salty solutions to areas that are more concentrated. Osmosis would dehydrate anyone drinking seawater, with water flowing out of cells and into the urine.

In reverse osmosis, water molecules move out of a more highly concentrated salt solution — that's seawater — so they can be collected as freshwater. This process filters water at the molecular level, by forcing it through high-tech membranes. The largest water desalination plant in North America uses reverse osmosis. That's the Tampa Bay Seawater Desalination Plant in Florida. That facility can desalt up to 25 million gallons of water per day, providing drinking water for 2.4 million residents of the Tampa Bay area.

### Salty Problems

Both modern methods — flash distillation and reverse osmosis — have serious drawbacks that limit the use of desalination. Here is Dr. Julie Beth Zimmerman of Yale University. Zimmerman was a guest editor of a special June edition of *Environmental Science & Technology*

devoted to global water problems. It is one of ACS's 36 peer-reviewed scientific journals.

*"The big challenges with it are the energy demands, which obviously have their own environmental impacts in terms of using fossil fuel-based energy and CO<sub>2</sub> emissions. The other big challenge has to do with the concentrated saltwater brine that you get as a result of desalination. On top of that — because so much energy is required — there is the economic cost. Unfortunately, the people who need the water the most live in poor, developing countries where this technology is not feasible for those reasons."*

First, the dollars and cents that Zimmerman mentioned. Desalination is the most expensive kind of water supply. It takes a lot of energy to heat water for distillation. In the United Arab Emirates, it costs more to produce a gallon of freshwater than a gallon of crude oil. The pumps at reverse osmosis plants slurp up electricity to push seawater through those filters. At Tampa Bay, for instance, it takes a pressure of 1,000 pounds per square inch to push saltwater through reverse osmosis filters. Your car tires have about 30 pounds of pressure.

As a result, it may cost \$1 to produce 1,000 gallons of freshwater with desalination. Drinking water produced from lakes and rivers sells for less than 30 cents per 1,000 gallons. Water for irrigation costs less than 5 cents per 1,000 gallons.

The environmental concerns about desalination stem from the leftovers of distillation and reverse osmosis. Both produce large volumes of brine — concentrated saltwater that can endanger fish and other marine life. Disposing of brine is a big problem, especially for inland desalination facilities. They currently have no cost-effective, environmentally sustainable way to get rid of brine.

### A Matter of Membranes

Some of the solutions are a matter of membranes — of making it easier for water molecules to pass through reverse osmosis membranes. Getting water to pass at lower pressures means less energy and lower costs. Those costs can be lowered further through renewable sources of energy for electricity, such as wind turbines that partially power the Perth, Australia, desalination plant.

Dow Water Solutions produces the membranes that are currently in use at Perth, Tampa Bay, and many other large desalination facilities. These thin-film polyamide FILMTEC™ Reverse Osmosis membranes represent a major improvement over the cellulose acetate membranes used in the 1950s and 1960s. Polyamide membranes are more permeable. They need about 50 percent less pressure and use up to 40 percent less energy. More advances are occurring in the next-generation membranes, including larger-diameter membrane modules to drive down the cost of producing potable water from seawater. David Klanecky, global director of research and development for Dow Water Solutions, told Global Challenges that while these technological leaps are important, they're just one element to making desalination a viable solution:

*"Dow believes that the world's water problems can be solved through technology, sound management and pricing policies, cooperation of the public and private sectors, and education. The company's commitment to deploy science and technology to provide pure water for both industrial applications and human consumption, globally, is part of its 2015 Sustainability Goals."*



## Meet the Scientists



Benny D. Freeman, Ph.D.



David Klanecky



Wolfram Kloppmann, Ph.D.

While most agree that desalination is only one solution for helping to bring fresh, potable water to those who need it, innovation continues. We need membranes that are more permeable and let water pass with even lower pressures and reduced energy consumption. We need membranes that are stronger and more durable, less prone to getting clogged with minerals and requiring less frequent replacement.

### Big Challenges/Small Solutions

Some desalination researchers are responding to those challenges in a small way with huge implications for providing a drought-proof source of water. That response involves nanotechnology — technology built from atoms and single molecules where dimensions are measured in nanometers, or billionths of a meter. One nanometer is about 50,000 times smaller than the width of a human hair.

The next-generation reverse osmosis membranes may be nanocomposite membranes. These polymers contain small particles that produce major improvements in the polymers' ability to transport and separate saltwater. Nanocomposites may be the key to solving another problem with existing membranes. That is the tendency to foul, or clog up, with salts so that more pressure is needed to force seawater through the membrane. Here is Dr. Benny D. Freeman, of the University of Texas at Austin, who reported on nanocomposites this year in ACS's peer-reviewed journal *Macromolecules*:

*"Fouling is recognized to be one of the most ubiquitous and highest-priority problems facing membranes in virtually any water purification application that is currently practiced or envisioned. Membrane fouling is the process by which small particulates and other components in water that is being treated deposit on the surface of membranes. They act to impede the flow of water through the membranes. As a result, the amount of membranes that are needed to process a given amount of water is increased. One of the examples of fouling is the flux, or amount of water coming through a unit surface area per unit time of a membrane such as an ultra filtration membrane, which can decrease more than a thousand fold as a membrane becomes fouled with particulate matter (or proteins or emulsified oil droplets, depending on the application)."*

### Water "Wires"

Researchers are discovering that another product of nanoscience — carbon nanotubes — shows great promise as a new filter membrane. These hollow tubes of pure carbon have an inner channel or pore 100,000 times smaller than a human hair. Water can pass through, but not salt. And water molecules move with amazing speed through these tubes, which have been called "water wires." In a study in ACS's *Journal of Physical Chemistry B*, Dr. Ben Corry and colleagues at the University of Western Australia reported on the potential of these "water wires" in nanotube membranes that require less pressure and energy.

*"Indeed, a membrane made from nanotubes could be expected to obtain 95 percent desalination with a flow rate over 1,500 times that of existing membranes. Lower pressures could be used in carbon nanotube membranes, provided they overcome the osmotic pressure difference between seawater and freshwater."*

Scientists are taking one step forward toward that challenge with a new desalination process called . . . well . . . forward osmosis. Forward osmosis saves energy and money because it does not need the high pressures for reverse osmosis. Rather than pushing water through membranes with pumps, forward osmosis draws it through with the chemical energy of osmotic pressure.

*"It's all about chemistry — in forward osmosis desalination, the main principle is the use of ammonia and CO<sub>2</sub> that dissolves in water. They form ammonium salts, ionic species, which create such huge osmotic pressure that it can drive the water through the membrane."*



*We need to innovate. We need to change the paradigm. We can't just keep on doing what we're doing.*

That was Dr. Menachem Elimelech, who leads a Yale University team working on a forward osmosis pilot plant that has reported at ACS national meetings. Imagine a membrane with seawater on one side and a highly concentrated solution of dissolved ammonia and carbon dioxide gases on the other. The ammonia and CO<sub>2</sub> create osmotic pressure that draws the water on the other side through the membrane. Freshwater can then be recovered from the draw solution by heating it to about 136 °F so that ammonia and carbon dioxide bubble out. They are captured and recycled to the next batch.

### Greener Desalination

In addition to offering potential savings on energy, forward osmosis produces less brine than existing desalination processes. Desalination brine is about 1.5 times as salty as seawater, and has raised environmental concerns. The challenge to chemists and other scientists: Forward osmosis requires membranes that are very thin, very porous, and resistant to highly alkaline water.

Scientists are pursuing many other solutions to the energy and environmental drawbacks of desalination. Solar energy, for instance, could substitute for fossil fuel. And the environmental impact of returning brine to the ocean can be reduced by planning and smart desalination plant placement. One approach: Locating desalination plants near wastewater treatment or electric power plants so that brine can be diluted in the outfall streams from those plants before entering the ocean.

### Meeting the Demand

These solutions will be more crucial in the future as water shortages intensify demand for desalinated water. Dr. Wolfram Kloppmann, of French Geological Survey BRGM, described future demand for desalination in a paper in June in *Environmental Science & Technology* on fingerprinting of desalination-derived freshwater in the environment.

*“Over the next decade, we will probably double desalination capacity worldwide, with the most steep increase in the Mediterranean area and in the Middle East with a growth rate of more than 100 percent in the Mediterranean countries.”*

The challenge of meeting that demand is fostering new ways of thinking and encouraging new approaches. Dr. Mark Shannon and his colleagues have presented some of those at ACS national meetings, and Shannon emphasized it in an address at the U.S. Department of State in June and to Global Challenges:

*“We need to innovate. We need to change the paradigm. We can't just keep on doing what we're doing. I even invoked Einstein, ‘Doing the same thing again and again and expecting a different outcome is the definition of insanity.’ We do the same thing over and over again to try and solve the world's problems — and it's not getting better. Let's think of something else.”*

### Conclusion

Yes, let's think of something else. Let's think of these and other 2008 research advances in chemistry paying off in the years ahead. Paying off in ways that foster a 21st-century rewrite of Samuel Taylor Coleridge's script. Water, water, everywhere ... and every drop to drink. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we'll examine solutions to global warming. Today's podcast was written and edited by Michael Woods.



Mark Shannon, Ph.D.



Julie Beth Zimmerman, Ph.D.



# Confronting Climate Change: Part 1

## Stopgap Measures to Reduce Greenhouse Gas Emissions

In the late 1700s and 1800s, wagon trains of pioneers headed West to settle the American frontier. They encountered oceans of grass swaying in the wind in the prairies. Erase any mental image of Kentucky bluegrass growing a few inches high in a carefully manicured suburban lawn.

The pioneers found grass that grew 7–10 feet high — almost to the second-story windows on a modern house. This grass was so tall and thick that cattle got lost in its midst, as if in an impenetrable forest. Men had to stand on the back of a horse to find the lost steers. The monster grasses were part of a vast ecosystem that covered millions of acres of the United States up to the eastern approach to the Rocky Mountains.

Much of that green ocean consisted of switchgrass. Today switchgrass is looking greener than ever to new generations of pioneers. Those pioneers are chemists, chemical engineers, and other scientists who are searching for solutions to the challenges of global warming.

*“There is very little doubt among the great majority of scientists that observed climate trends are due to human activities. These anthropogenic threats are serious, and action is urgently needed to mitigate the risks of climate change. The vast weight of scientific evidence indicates that warming trends over the next 50 years will have profound effects, not only on climate but on food supply, on our current ecosystem, and on world socio-political structures. Without rapid action to reduce the impact of excessive greenhouse gas emissions, humanity needs to fear that the effects of climate change may become irreversible.”*

The U.S. Congress got that stark assessment of global warming’s potential impact in June 2008. The speaker: Dr. Bruce E. Bursten, president of ACS and dean of the College of Arts and Sciences at the University of Tennessee, Knoxville. ACS, like other scientific groups, has warned of “potentially disastrous” consequences from climate change — including floods, heat waves, and droughts. So, how did we get into such a predicament? Bluntly put, we did it ourselves. Most research concludes that global warming probably is anthropogenic — caused by humans, not Mother Nature.

Over the past 150 years or so, the world has become more industrialized, mobile, and heavily populated. Fossil fuels have fed that growth. And burning these fuels — especially coal, oil, and natural gas — fosters the process behind global warming, which is known as the “greenhouse effect.” Intensive agriculture to sustain population growth is another major contributor to the greenhouse effect.

### Did You Know?

- ◆ *Warming trends in the next 50 years may have profound effects.*
- ◆ *Burning oil, coal, and natural gas promotes global warming.*
- ◆ *Solutions include alternative fuels and greener industrial processes.*
- ◆ *Using a mixture of coal and biofuels can help reduce carbon dioxide emissions.*
- ◆ *Eating chicken, fish, or vegetables instead of red meat just once a week could help fight climate change.*

### HIGHLIGHTS

- ◆ The challenges of reducing greenhouse gas emissions are “the biggest ever to confront mankind”.
- ◆ Developing artificial photosynthesis technology could enable cars to run on water and sunlight.
- ◆ New ways of burning coal cleanly would enable the U.S. to tap its vast domestic reserves of this fuel.
- ◆ Scientists are developing innovative technologies for capturing carbon dioxide from smokestacks before it gets into the atmosphere.
- ◆ Consumers can reduce their carbon footprint by making simple lifestyle changes.

## Greenhouse Earth

The greenhouse effect results from a build-up of gases — such as carbon dioxide and methane — in Earth's atmosphere. CO<sub>2</sub> comes from burning. Burning coal in electric power generating plants. Burning gasoline in car engines. Burning trees in rainforests to clear land for farming, and from other sources.

Much of the methane, which is 21 times more potent as a greenhouse gas than carbon dioxide, comes from raising cattle, and growing rice in flooded fields. Cattle release methane from their bodies, and in their manure. Swamps also generate methane in a natural process. Those gases accumulate in Earth's atmosphere and act much like the panes of glass in a greenhouse.

Sunlight passes right through and heats things up. But heat gets trapped and cannot escape back into space. Scientists are seeking solutions, ways to stop and even reverse the rapidly rising levels of carbon dioxide.

Atmospheric levels of carbon dioxide reached nearly 385 parts per million in 2007, up from 280 in 1850 and an increase of 2.6 parts per million from 2006. And we need new ways of raising cattle and growing rice — staple food for one-third of the world's population — that minimize releases of methane. You will hear about some of those longer-term solutions in Part 2 of this podcast. Scientists also are working on stopgap measures that can be put into effect in the short term.

*“What's important to remember about climate change, in solving it, is that we're not going to get there tomorrow. We're starting basically at business as usual. For all the talk, you know, we haven't changed anything in the last 20 years.”*

That's Dr. Frank S. Zeman of Columbia University, an expert who reported on responses to global warming in March in *Environmental Science & Technology*, one of ACS's 34 peer-reviewed scientific journals. Some of those solutions include more energy-efficient buildings, greener industrial processes, alternative energy sources, improved fuel-efficient vehicles, and urban planning that encourages mass transit.

## Capturing Carbon Dioxide

One of the most promising ways of reducing releases of carbon dioxide is to capture and sequester, or store, the gas — lock the gas away so it can't get out again. Proposals for CO<sub>2</sub> sequestration include collecting the gas and pumping it down into spent oil or natural gas wells, storing it in the deep ocean as an icy material, and reacting CO<sub>2</sub> with metal oxides to produce stable carbonates. Power plant smoke stacks in the United States alone release almost 2.5 trillion tons of CO<sub>2</sub> annually. Researchers are looking at several new technologies to capture and eliminate some of that enormous volume of gas in an economical fashion. Dr. Dianne Wiley, a chemical engineer with Australia's University of New South Wales and the Australian Cooperative Center for Greenhouse Gas Technologies, is one of those researchers.

*“I guess the thing to understand with all of these technologies is that those costs are quite high, particularly if you compare to the European Union estimate for carbon trading, we should be looking around about the \$30 per ton to enable this to be an implementable technology.”*



*What you eat can  
have a very big impact on  
climate change.*

Some current CO<sub>2</sub> capture technologies typically cost about \$50 to \$60 per ton. In a report published in June 2008 in the ACS journal *Industrial and Engineering Chemistry Research*, Wiley examined some adsorption technologies and explained what's needed to bring costs down to about \$30 per ton.

*"According to our calculations, we would need the scientists who are developing the adsorbents to probably at least double the capacity at which carbon dioxide can be adsorbed and almost triple the selectivity. This would reduce the weight and costs of the adsorbents needed significantly. For example, if you want to capture 3 million tons of CO<sub>2</sub> from a typical power plant, if you're using current commercial products you'd need something around about 500 tons of adsorbent and that would cost approximately \$6 million. By developing better adsorbents, we'd hope that we'd be able to halve the costs. So the capture costs would go down from about \$60 a ton to about \$30 a ton."*

#### A Fondness for Fossil Fuels

Despite worldwide concern about CO<sub>2</sub> emissions, and research on alternative fuels, the U.S. Department of Energy says dependence on oil, coal, and other fossil fuels may actually increase between now and the 2020s. In an address at ACS's 2008 national meeting in New Orleans, Dr. Raymond Lee Orbach, the energy department's undersecretary for science, said that it will be difficult to move away from those fuels.

Orbach described the energy quandary in the 21st century as one of the biggest challenges humanity has ever faced. Two of the most important questions, according to Orbach, are: How will we supply all the needed new energy? And how can we do it without adding greenhouse gases to the atmosphere?

Meeting that challenge, Orbach said, will demand "transformational breakthroughs in basic science." He meant once-in-a-lifetime revolutionary discoveries, rather than the one-small-step advances that happen all the time in science.

#### "Bridge" Fuels and "Stranded" Gas

So, what's to be done in the meantime while scientists are tackling that challenge? One stop-gap measure to reduce CO<sub>2</sub> emissions involves the use of so-called "bridge fuels." Here is Dr. Zeman:

*"A bridge fuel is, as the name implies, something to get us from here to there; here being our current system, which is gasoline derived from oil or diesel derived from oil, to there, which would be something I guess you could call the hydrogen economy, something akin to the hydrogen economy ... you know, where we have a fuel that we can use that does not affect the climate. So, a carbon-neutral fuel or fuel that doesn't have carbon."*

Global Challenges asked Dr. Zeman about an idea for using so-called "stranded" natural gas. Natural gas of this kind may be located in fields so far away from markets that building pipelines would be uneconomical. The gas is marooned, left high and dry and unusable.

*"We were proposing to use stranded gas as the main feedstock. Now, we know natural gas is a sort of climate-friendly fuel compared to coal in the sense that for the energy released per unit, carbon dioxide is twice that of coal. So, if you want to look at it that way, it's twice as good for the climate as coal is. But not all of it can make it to market because some of it is just left somewhere where there's no pipeline and there's no infra-*

#### Meet the Scientists



Raymond Lee Orbach, Ph.D.



Christopher L. Weber, Ph.D.

## Meet the Scientists



Dianne Wiley, Ph.D.



Frank S. Zeman, Eng. Sc.D.

*structure or it's too expensive to build the infrastructure to get this fuel to market. So what we thought was rather than bring the fuel to market, why don't we bring the market to the fuel? And in some ways, instead of a pipeline network like the trans-Canadian or the Alberta ... the Alaskan pipeline, you have this modular or movable plant that can go up to the fuel, make liquid carbon ... like make liquid fuels, which then you can transport back away from it. The process is based on combining this stranded gas with carbon dioxide. So, there you can see how it's a bridge fuel because we're taking a waste product and turning it back into a fuel."*

### Saudi Arabia of Coal

With crude oil prices at record levels, coal is getting more and more attention as a more economical alternative with abundant domestic supplies. The United States is the Saudi Arabia of coal. U.S. coal reserves total almost 270 billion tons — 27 percent of the world total. Saudi Arabia has about 20 percent of the world's oil reserves.

Coal-fired electric power plants long have produced almost 50 percent of the electricity consumed in the United States. Coal, however, is the single largest source of carbon dioxide released into the atmosphere.

### Switching to Switchgrass

Is there any way to increase use of coal, while minimizing releases of that greenhouse gas? The answer takes us back to those pioneers and seas of switchgrass that launched this episode of Global Challenges. Energy and Environmental Economics, Inc.'s Dr. William Morrow believes there's a way to reduce CO<sub>2</sub> emissions while still using coal to fire our power plants. In April 2008, Morrow reported in the ACS journal *Environmental Science & Technology* that mixing switchgrass with coal can help reduce carbon dioxide emissions.

*"Let's say that you're putting a ton of switchgrass into an existing coal-fired power plant, you will displace roughly a half a ton of coal when you do so. And a ton of coal will produce a certain amount of CO<sub>2</sub>, depending on the carbon content of the coal. So, displacing a half a ton of that coal will displace half of the CO<sub>2</sub> that would have been emitted from that ton of coal."*

Morrow tackled the research to check on the impact — the CO<sub>2</sub> reduction — of using switchgrass in the generation of electricity rather than in producing ethanol for cars. He found that roughly 2–3 times the amount of CO<sub>2</sub> could be displaced if switchgrass is used to displace coal, rather than using it for ethanol production.

*"Our estimate is roughly between 200 to 350, 325 million English short tons per year ... that's about ... 10 to 16 percent of the CO<sub>2</sub> that is emitted in the electricity sector within the United States.*

*If all of the switchgrass that is forecasted to be capable of being grown were to go into the electricity sector, this quantity of switchgrass has the capability, depending on what future technologies are going to be, of producing maybe about 26 to 40 billion gallons of ethanol per year, whereas we're currently consuming 140, 150 billion gallons of gasoline per year. So, it depends on the values that the United States as a public wants to go for in the future. Do we want to have alternative transportation fuels or do we want to mitigate CO<sub>2</sub>? You mitigate more CO<sub>2</sub> by using this switchgrass in the electricity sector than you would if you used it in the transportation sector."*

Switchgrass is just one of the many so-called biofuels — corn and other organic matter that comes from renewable plants, trees, crops, and waste materials. Future episodes of Global Challenges will focus on biofuels, and differing views on their potential.

For the average person though, controlling climate change by using switchgrass or capturing and storing carbon dioxide are things that only scientists and engineers really understand and can accomplish. Some people might very well ask, so what can I do about climate change?

As it turns out, more than you might think. You've probably heard most of these suggestions for reducing your personal carbon dioxide footprint:

- carpool, take public transportation, or maybe even walk or ride a bicycle;
- turn off the lights and TV when you leave a room;
- turn down the heat and raise the a/c setting on your thermostat;
- recycle; and
- replace old appliances with ones that are more energy-efficient.

### Science to Chew On

The latest research is giving consumers some surprising new information on how to minimize their own role in global warming. Here is Christopher Weber, of Carnegie Mellon University in Pittsburgh, who reported in a May 2008 paper in *Environmental Science & Technology*.

*“What you eat can have a very big impact on climate change, mostly because agriculture is a very greenhouse-gas-intensive production process, as well as all the processing that goes into making food, all the transportation that goes into delivering the food, all of that uses a lot of energy. You combine all that stuff together, and agriculture actually accounts for a fairly significant chunk of global greenhouse gas emissions, something on the order of 25 to 30 percent, depending on how you measure it.”*

Weber reported that substituting chicken, fish, or vegetables for red meat just once a week could help fight climate change. Red meat is much more greenhouse-gas-intensive than chicken, fish, or vegetables.

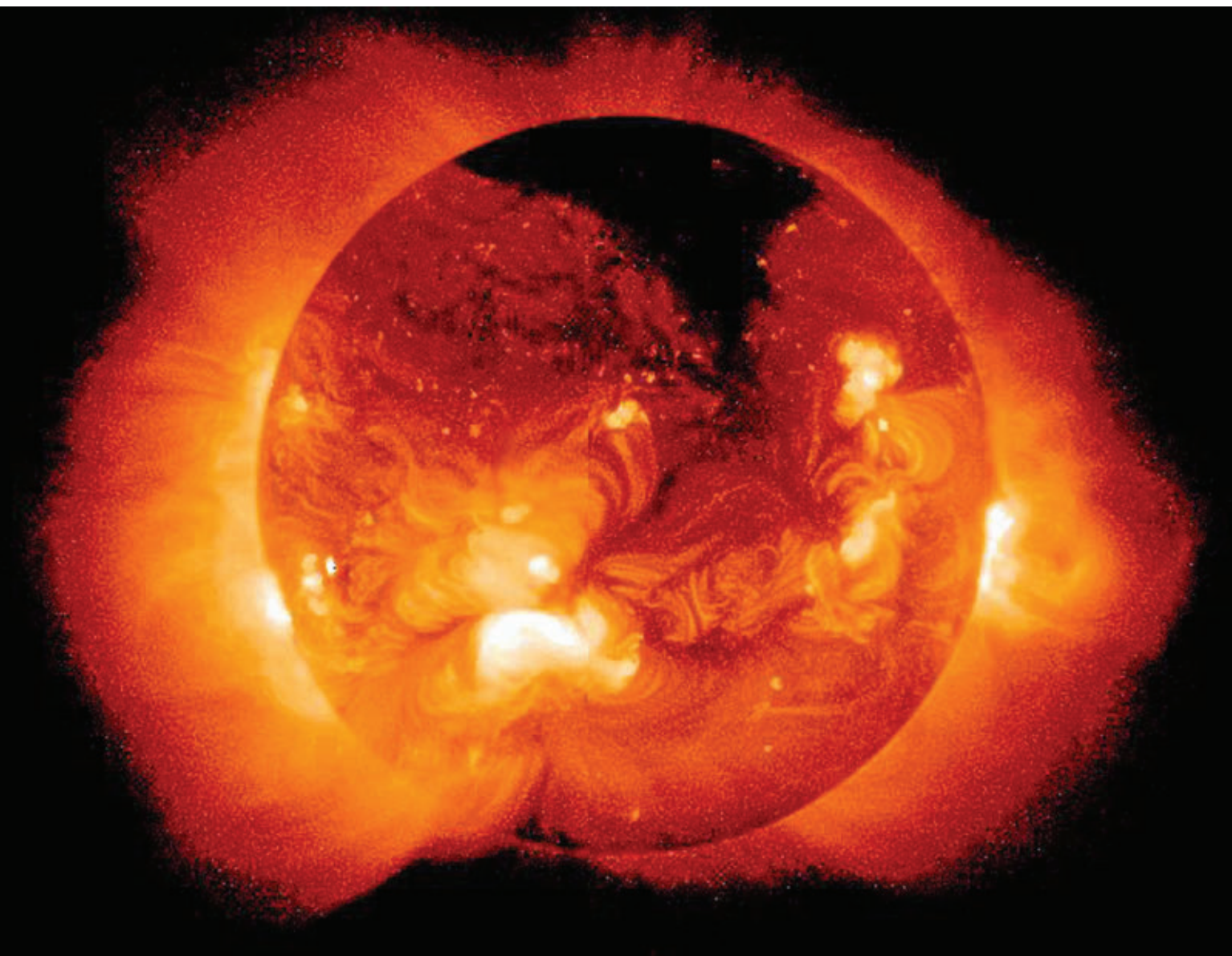
*“Red meat, and specifically beef cattle, is about 150 percent more greenhouse-gas-intensive than chicken or fish is. And there's a series of reasons for this, the first of which being that beef cattle are not nearly as efficient as chickens at converting grain calories into animal calories. It takes about eight calories to make a calorie of beef, whereas it only takes two to make a calorie of chicken. The second factor is that beef cattle belong to a class of animals called ruminants that can have multiple stomachs, of course, and they release methane from their natural digestion of food, and methane is a very potent greenhouse gas. The third is that they produce a lot of manure, and the way that manure is typically managed on large-scale farms ends up releasing even more methane and nitrous oxide, which are very potent greenhouse gases.”*

Weber says some dairy products also are climate change culprits. Cheese production, for instance, means more greenhouse gases than chicken.

### Conclusion

Meeting the challenge of global warming requires the one-small-step insights, like Dr. Weber's research on food that consumers themselves can use right now. It takes the stopgap measures like using switchgrass and stranded natural gas. Ultimately, however, it will take the revolutionary changes like those that DOE's Dr. Orbach suggested. Please join us here at ACS for that next chapter in this ongoing saga of chemistry for life. We'll take a futuristic look at definitive solutions to this great scientific challenge of the 21st century. Today's podcast was written by Marvin Coyner and Michael Woods. Our editor is Michael Woods. I'm Adam Dylewski in Washington.







# Confronting Climate Change: Part 2

## The Quest for Permanent Solutions

The sounds of New Orleans. And the sounds of a scientific conference. Both sounds mingled in April, when thousands of scientists from around the world gathered in the Crescent City for one of the year's biggest scientific conferences. The 235th ACS National Meeting and Exposition began with an eye-opener of a talk by Dr. Raymond Lee Orbach. An undersecretary of the U.S. Department of Energy (DOE), Dr. Orbach directs the agency's Office of Science. It was an eye-opener for anyone who expects quick, simple, permanent scientific solutions to global climate change.

Our first climate change podcast described stopgap solutions. Chemists and other scientists, for instance, are developing ways to capture carbon dioxide before it pours from the smokestacks of coal-fired electric power plants. They are working on ways to lock away, or sequester, that CO<sub>2</sub> — underground or deep below the ocean surface.

Dr. Orbach caught the thrust of this second climate change podcast. We will talk about advances toward permanent solutions to global warming. In environmental science, like medicine, prevention always is better than treatment.

The best solutions to global warming involve not releasing those greenhouse gases in the first place. That means finding new sources of energy, and finding cleaner ways of using coal, oil, and other existing energy sources. It also means development of new energy sources that do not release carbon dioxide.

### Humanity's Biggest Challenge

Dr. Orbach described such 21st-century challenges as “monumental.” He ranked them among the biggest challenges in human history. Dr. Orbach predicted that routine workaday scientific discoveries would not be enough. The one-small-step advances traditionally at the core of the scientific process certainly will continue to be important. However, Dr. Orbach talked about the need for revolutionary discoveries — he calls them “transformational discoveries” — in which scientists respond to global warming with totally new technology.

What did this scientist, who oversees a fiscal 2008 DOE research budget of \$4 billion, have in mind?

*“What if we could do what the plant does without the plant? What if we could take sunlight, CO<sub>2</sub>, nutrients, and go directly to fuel? Now that would truly be transformational because we have not been successful in the past at such an approach.”*

### Did You Know?

- ◆ **Ancient Greeks and Romans incorporated passive solar design into their architecture. They constructed buildings that faced south to help heat and light them.**
- ◆ **A French mathematician designed and built the world's first solar-powered motor in the mid-19th century.**
- ◆ **In 1880, the first commercial electric lighting powered by water turbine debuted in Grand Rapids, Mich.**
- ◆ **Hydroelectricity accounts for 20 percent of the world's electricity.**
- ◆ **The first wind farm in the United States was established in New Hampshire in 1980.**
- ◆ **Producing 20 percent of the nation's electricity from wind power would reduce carbon dioxide emissions by about 800 million tons.**

### HIGHLIGHTS

- ◆ **Today's energy and environmental challenges are among the biggest ever to confront mankind.**
- ◆ **Scientists must make “transformational discoveries” in order to combat climate change.**
- ◆ **Solutions include alternative fuels and greener industrial processes.**
- ◆ **Chemists and other scientists are making key advances in meeting those challenges.**
- ◆ **Developing artificial photosynthesis could mean revolutionary changes in our lives.**
- ◆ **Greater use of solar energy could have a major impact in reducing carbon dioxide emissions.**
- ◆ **New energy sources will need ingenious new ways of storing wind and solar energy for use on calm days and at night.**

## Meet the Scientists



Robert Disselkamp, Ph.D.



Harry B. Gray, Ph.D.



Julian D. Marshall, Ph.D.

Dr. Orbach was talking about artificial photosynthesis. That means harnessing the process plants have used for almost 3 billion years. It is pure simplicity. Water plus sunlight equals energy. Plants use sunlight to break apart chemical bonds between hydrogen and oxygen atoms in water —  $H_2O$ . Plants use the hydrogen for generating energy. We could use it as a fuel.

*“Hydrogen would be a superb fuel, either through fuel cells that would power our automobiles electrically, or as a fuel itself for combustion in a power plant or other devices. We’re going to have cars around for a long time. It’ll be a while before people will give up their special relationship to the automobile — as they now know it. Is there any way to deal with all the cars on the road today? And that’s what I’m talking about: Ways of taking nature and producing combustion fuels that automobiles can use.”*

*Hydrogen would be a superb fuel, either through fuel cells that would power our automobiles electrically, or as a fuel itself for combustion ...*

### Looking Back to Part One

Hmmm. Hummm. So let’s see. In the first part of this podcast, we learned how global climate change — global warming — happens. The culprit? The greenhouse effect, which involves a build-up of gases — such as carbon dioxide and methane — in Earth’s atmosphere.  $CO_2$  comes from burning. Burning coal in electric power generating plants. The tailpipes of motor vehicles. Burning rainforests to make way for farms and pastures for cattle, and from other sources.

Much of the methane comes from raising cattle, growing rice in flooded fields, and the decay of plant matter in swamps. Cattle, for instance, release methane in their intestinal gas, and in their manure. Those gases accumulate in Earth’s atmosphere. Atmospheric levels of carbon dioxide, for instance, have risen from 280 parts per million in 1850 to nearly 385 parts per million in 2007.

Those gases act much like the panes of glass in a greenhouse. Sunlight passes right through and heats things up. Then the heat gets trapped and cannot escape back into space. And Earth warms up.

### Magic on the Roof

The artificial photosynthesis that Dr. Orbach mentioned could mean revolutionary changes for consumers. Just imagine it. Imagine filling up the car of the future with water rather than pricey gasoline. Cars could have a photosynthesis unit on the roof that uses the plant’s magic to free hydrogen from its embrace with oxygen in water. Voilà. There you go. Hydrogen to power the car — producing only water vapor as it burns, rather than  $CO_2$  and a bevy of air pollutants.

Developing artificial photosynthesis could mean another tremendous benefit for the United States — energy security. Here is Dr. Orbach:

*“It would free us of 30 percent of our transportation fuels. And we are projecting up to 70 percent of our transportation fuels having to come from foreign oil. So it makes a huge difference.”*

In June, scientists in Switzerland and China announced one advance toward artificial photosynthesis. Dr. Michaël Grätzel and colleagues reported achieving a record light-conversion efficiency of 8.2 percent with a solvent-free version of the dye-sensitized solar cells. Dr. Grätzel, of the Swiss Federal Institute of Technology in Lausanne, invented dye-sensitized



solar cells in the 1990s, and has reported on them in ACS journals and at ACS national meetings.

Dye-sensitized cells are already being produced commercially, and the technology can create energy from a broad spectrum of light, both indoors and outdoors. Because they are relatively inexpensive and easy to produce, the cells are widely expected to become competitive in price with fossil fuels in the long term.

Compared to standard solar cells, the new cells work more like plants in the way they convert sunlight to energy. If they use a dye that is structurally similar to chlorophyll, they become green in color. They also are easier and less expensive to produce. Dye-sensitized cells also have a longer working life than amorphous silicon-based solar cells, which have a 6 percent light conversion efficiency.

The revolutionary discoveries — the “eureka!” moments — that Dr. Orbach mentioned earlier sometimes do happen suddenly, almost overnight. More often, however, the revolutions rise out of one-small-step advances, scientific discoveries that quietly build one atop the other until we reach a tipping point.

Chemists, chemical engineers, and other scientists made many other advances toward harnessing artificial photosynthesis in 2008. ACS’s 34 peer-reviewed scientific journals were among the showcases.

### Clean Energy Solutions

Artificial photosynthesis is based on solar energy, and solar is among the energy technologies that experts view as likely permanent solutions to global climate change. The others already are in use and making contributions to reducing carbon dioxide emissions today. Clean hydroelectric power, for instance, now supplies an estimated 20 percent of the world’s electricity. Another 16 percent comes from nuclear power. What lies ahead for nuclear power, which is available right now and releases no carbon dioxide? Dr. Jerald L. Schnoor, editor of ACS’s *Environmental Science & Technology*, and a professor at the University of Iowa, has these thoughts:

*“Nuclear may become a bigger part. My students don’t like it when I say it, but I don’t think we can rule out nuclear of the energy mix in the future for the simple reason that we have to come to terms with how to dispose of the waste anyway. We have nuclear*

## Meet the Scientists



Raymond Lee Orbach, Ph.D.

*wastes already sitting above ground at commercial sites, and we have nuclear defense waste as well. We have to come to grips with how to dispose of that and that means that the next generation of nuclear plants could be far, far safer. I would prefer not to do that. I would prefer to do it with energy efficiency and wind and solar, but I don't think we can rule it out of the mix because it has such a small carbon footprint, emitting almost no carbon dioxide."*

Wind power is just beginning to blow its way onto the list of major power sources, supplying about 0.3 percent of the nation's electricity. Globally, it has amazing potential to reduce use of fossil fuels. One 2006 study, for instance, concluded that wind turbines could supply 34 percent of the world's electricity by 2050. If implemented on a large scale, wind power would prevent 113 billion tons of global warming gases from entering the atmosphere by 2050, the study found. Here is Dr. Schnoor:

*"Wind is economically competitive right now. And it's growing at more than 30 percent per year. Sort of like the growth of cell phones in the 1990s. So wind is on its way with a little government help. There is a government subsidy of about a little more than a cent per kilowatt hour helping wind along. But it's competitive certainly with new coal right now, and we're building an awfully lot of wind turbines."*

### The Solar Challenge

Another permanent solution to global warming lies in wide use of solar energy in photovoltaic cells — solar cells — and other technology. Dr. Harry B. Gray, of the Caltech Center for Sustainable Energy Research, makes it clear that solar energy has vast potential. He also spoke at that ACS 235th National Meeting in New Orleans.

*"There's enough energy reaching the Earth's surface from the sun every hour or so, maybe it's a couple of hours, but a reasonable number of hours, say in a day, to power the planet for an entire year."*

With the sun such a vast potential resource, why does solar energy provide less than 0.1 percent of the country's electricity? The problem is solar energy's high cost compared to other sources of energy. Here is Harry Gray:

*"Right now, it's about four to five times as expensive per kilowatt hour for solar electric. I priced it. Right now, it's about 25 cents a kilowatt hour versus about five, or six, seven cents, something like that for conventional sources."*

*I think if we get it down to 10 cents a kilowatt hour, there'll be a large-scale buy-in, and there are great advantages of course to using solar electric. Once you make the initial investment, you can run lots of things then at lower cost than you are just ... paying the power station for electric every day. Once you make the initial investment, your ... monthly costs are much less. So, I think at 10 cents per kilowatt hour, people will buy in. I think that will happen over the next five years."*

Dr. Schnoor points out that while solar now lags, government policy — for instance, subsidies for early adopters of solar — can have a major impact while scientists continue the search for more efficient photovoltaic devices.

*"But subsidies are in place in California, Japan, Europe, for solar roofs. For example, why should we have shingles on the roofs of our houses? Why shouldn't we capture that sun's energy and turn it into electricity or even turn it into hydrogen to run the appliances in our homes. We'll soon have a million homes doing it in California, with subsidies."*

Dr. Gray says that scientists face two major challenges in bringing down the costs of solar energy:



Jerald L. Schnoor, Ph.D.



*“We have to get cheaper solar cells made out of Earth-abundant materials that can be scaled up. That’s the first thing that we have to do. The second thing, which is very important, is that we have to make fuel. Instead of electricity, we need to make fuel, hydrogen fuel, by splitting water so that at night we can run fuel cells and get electricity when the sun isn’t shining.”*

### The Energy Storage Challenge

That potential show-stopper is the challenge of developing technology to store energy produced with alternative sources. To store solar energy for use during the night or on cloud-filled days. To store wind power for times when winds are calm. Dr. Robert Disselkamp, of United Research Service’s Washington Division, is among the chemists addressing that challenge.

*“It’s a two-pronged approach. Certainly one of the areas that needs to be pursued is alternative energies and certainly another area that is just as important would be storage of that energy. And then certainly the use of that energy at some later time via some large-scale energy storage, or on smaller scales as well, would be another area to pursue work in, and it’s also well underway by various groups.”*

Traditional fossil fuels are always available. Simply burn as needed. With wind and solar however, there’s a need for technology to store the energy and for release when needed. The energy source may be unavailable at times of greatest consumer demand. Disselkamp describes it as an “out-of-phase issue.”

*“Sometimes the use of our energy is out of phase with the production of energy, say by solar means or other renewable energy source production mechanisms. If it’s directly put into the electrical grid throughout the United States and within countries with well-established electrical grids within the countries, then certainly the idea would be to hopefully have sequestration of energy on a large scale to meet that out-of-phase issue that can arise.”*

*We have to get cheaper solar cells made out of Earth-abundant materials that can be scaled up.*

In an article in June 2008 in the ACS journal *Energy & Fuels*, Disselkamp reported on one approach to the challenge, a new energy storage concept — a fuel cell based on hydrogen peroxide that could be used to power cars.

*“One can think of it as an aqueous solution of hydrogen peroxide. And then there would be an anode and cathode exposed to that solution. At the cathode you generate hydrogen, and at the anode you generate oxygen. Then at those respective electrodes you could take those different gases, send them into a polymer electrolyte membrane fuel cell, and generate electricity out of the system.”*

### Climate-Friendly Cities

We could make a huge dent in CO<sub>2</sub> emissions by focusing just on the generation of electric power and transportation. In the United States, generating electric power with coal and other fossil fuels accounts for about 40 percent of CO<sub>2</sub> emissions. Powering cars and trucks with gasoline and diesel accounts for another 29 percent. Those are the No. 1 and No. 2 sources — almost 70 percent — of the total CO<sub>2</sub> from human activity.

However, experts agree that other changes may help. We may need new agricultural technologies, for instance, that reduce methane emissions from cattle farming and rice growing. “Green chemistry” may provide new processes that reduce greenhouse gases from industrial processes. And entire communities and their infrastructures may have to become more energy-efficient.

*“One of the solutions for addressing climate change is urban form — that is, the way a city is laid out. And commonly, people mean addressing and reducing urban sprawl. So, we know from significant evidence that as cities sprawl, people who live in more distant communities need to travel farther each day to get to where they’re going.”*

That’s Dr. Julian D. Marshall of the University of Minnesota. In a May 2008 article in *Environmental Science & Technology*, he described how controlling urban sprawl and urban form plays an important role in addressing climate change.

Dr. Marshall says cities that are sprawled out tend to be less energy-efficient than those with a more compact design. In part, that’s because people in cities with better urban form don’t have to travel as far to get to where they’re going. And there’s more mass transit available. Combined, that equals fewer transportation emissions. So how does controlling urban sprawl compare to other energy-saving approaches?

*“When we look at other approaches that are commonly discussed in the media and that people talk about quite a bit — such as improving vehicle efficiency or trying to lower carbon fuels — when I evaluated sprawl reduction, the magnitude of impact that I see is comparable to the other more commonly discussed technological solutions. So that suggests to me that if we want to we can include sprawl reduction as one of several solutions toward addressing climate change.”*

Dr. Marshall noted that 2008 has special relevance for scientists studying urban sprawl’s potential for mitigating climate change:

*“This is a very important year in the study of cities because this is the year that our globe*

*switches from having a majority of the population live in rural areas, which is how it's been for a very long time, and then this year it's expected to switch, so we'll have a 50–50 rural–urban population. And then looking forward into the future, it's projected that urban population will roughly double while rural populations will level off or decline.”*

The human migration from rural to urban populations is an ongoing global phenomenon. The urban sprawl of large cities has given way to megacities, those with more than 10 million population. In 1995, there were 14 megacities. By 2015, there will be 21.

### Conclusion

Amid all the concern and controversy over global warming and its consequences on everyday life, there are few certainties. Most scientists agree on one: In confronting this challenge, society must explore multiple solutions.

What if the quest for artificial photosynthesis or low-priced solar cells fails? Then we must have back-ups such as clean coal technology, safer nuclear, more wind and geothermal power, and climate-friendly cities.

Most scientists also agree on another certainty: We must move ahead now on the quest for solutions. Today's reductions in CO<sub>2</sub> emissions may have little effect on global warming until our children's children are experiencing life in a greenhouse world.

DOE's chief scientist Ray Orbach put it well:

*“If we don't address the issues of what causes climate change now, we're going to leave our children and grandchildren with a problem that will only get worse.”*

Please join us here at ACS for another chapter in this ongoing saga of chemistry for life. Our next special Global Challenges podcast focuses on efforts to achieve sustainability — the challenges of developing technology for agriculture, industrial production, transportation, and other essentials that can continue for the long haul, without damaging the world that will be home to future generations. Today's podcast was written by Marvin Coyner and Michael Woods. I'm Adam Dylewski at ACS in Washington.







# Our Sustainable Future

W

e humans are consumers. We consume food. We consume gasoline and electricity. We consume paper and plastics, cotton and polyester. And above all, we consume chemicals, millions and millions of tons of chemicals that go into manufacturing every product we buy and sell.

The great majority of these chemicals come from materials that we extract from the Earth, things such as oil, coal, natural gas, and a wide variety of minerals. While we once thought, perhaps naively, that the supplies of these materials were limitless, we now know this to be untrue. Just look at the price of a gallon of gasoline today, a consequence of a shortage of oil at a time when the world's growing population is demanding more of it.

And we also know that extracting those materials from the Earth and turning them into the cornucopia of products that make modern society possible are not without other costs — deforestation, polluted waterways, open-pit mines, Superfund sites, and global climate change, to name a few. Clearly, we humans cannot keep using resources in such an unrestrained way.

*“The world is becoming aware of this at every level. Companies are becoming aware of it, governments are becoming aware of it, and the scientific community is beginning to view it as a mission. View it — what do I mean by it: to try to continue to make many of those things and provide many of those services in a way that doesn't trash the planet, in a way that keeps the planet going for future generations.”*

## Meeting Needs Today and Tomorrow

That was Ivan Amato, managing editor of *Chemical & Engineering News*, ACS's weekly news magazine, which in August 2008 published a special issue devoted to sustainability. What do we mean by sustainability? To put it simply, sustainability means meeting the needs of the present without compromising the ability of future generations to meet their own needs.

The issue of sustainability is not a new one. In 1798, The Reverend Thomas Robert Malthus, an English economist, published a small treatise titled *An Essay on the Principle of Population*. In this book, Malthus predicted that human population growth would outpace our ability to produce food and other resources. Since then, many scientists, including Nobel laureate Dr. Paul Ehrlich, have warned about resource shortages. In 1987, the United Nations' report “Our Common Future” drew worldwide attention to the notion of sustainable development.

## DiD YOU KNOW?

- ◇ *The United States has 5 percent of the world's population and uses 23 percent of the world's energy.*
- ◇ *Only 10 percent of the electricity in an incandescent light bulb becomes light. The other 90 percent is wasted as heat.*
- ◇ *A compact fluorescent light bulb uses 75 percent less energy than an incandescent bulb — and it can last up to four years.*
- ◇ *An energy-smart clothes washer can save more water in one year than one person drinks in an entire lifetime.*
- ◇ *80 percent of Earth's original forest cover is gone.*

## HIGHLIGHTS

- ◆ **Sustainability is environmentally benign.**
- ◆ **The principles of sustainability should be an integral part of all future manufacturing processes.**
- ◆ **Green chemistry techniques — designing things so they are sustainable — leads to technology that is environmentally and economically viable.**
- ◆ **This year, green chemistry techniques will eliminate the need for 193 million pounds of hazardous chemicals and solvents and save 21 billion gallons of water.**
- ◆ **As they strive to become sustainable, more and more chemical and pharmaceutical companies are embracing green chemistry.**

## Meet the Scientists



Ivan Amato



Paul T. Anastas, Ph.D.



Rajender S. Varma, Ph.D.

*Green chemistry comes at the challenges of sustainability with the recognition that everything we see, touch, and feel is a chemical. . .*

Soon after, in 1991, Dr. Paul T. Anastas coined a new term, “green chemistry,” and established the Green Chemistry program at the U.S. Environmental Protection Agency — the EPA. Anastas later headed the ACS’s Green Chemistry Institute before moving to Yale University.

*“Green chemistry comes at the challenges of sustainability with the recognition that everything we see, touch, and feel is a chemical, and as we look at the products and the processes that are the basis of our society and our economy, if we care about sustainability, environmental protection, that ranges from energy to the materials that we use, green chemistry shows us how to design things fundamentally so that they’re sustainable and environmentally benign.”*

### A Win–Win Situation

Together with colleague Dr. John Warner, who now heads the Warner Babcock Institute for Green Chemistry, Dr. Anastas has led the charge to radically alter the way we make and use chemicals. At first, the two scientists met significant resistance to the idea that the principles of sustainability must be an integral part of all good manufacturing processes. But as Dr. Anastas explains, making things in a sustainable manner is not all about conserving resources and protecting the environment.

*“The wonderful thing about green chemistry, and people think I’m joking when they ask me how did I come up with this term green chemistry, but I tell them that green is the color of the environment, but it also happens to be in the U.S. the color of our money, so what we’re talking about is being able to meet our environmental and economic goals simultaneously. It’s no longer simply a trade-off between one or the other. It’s aligning environment and economics hand in hand and synergistically.”*

Many great examples of how green chemistry can be a win–win proposition for our environment and our pocketbooks can be found among the winners of the coveted Presidential Green Chemistry Challenge Awards, an annual program administered by the EPA. Since the program’s inception in 1995, it has recognized 67 groundbreaking developments that together have reduced chemical use by some 1.1 billion pounds over the past 13 years. That’s 1.1 billion pounds of chemicals that manufacturers didn’t have to purchase. And since manufacturers didn’t have to pay for those chemicals, ultimately, neither did consumers. The EPA estimates that in this year alone, these technologies will eliminate the need for 193 million pounds of hazardous chemicals and solvents and save 21 billion gallons of water. Green is indeed the color of money.

### The Three “Rs” in Sustainability

Most of us are familiar with the universal recycling symbol, three arrows chasing each other around the sides of a triangle. The arrows stand for the three Rs of sustainability — reduce, reuse, and recycle. Green chemistry contributes to each of these three Rs.

One chemist whose work typifies a green chemistry approach is Joseph DeSimone of the University of North Carolina and North Carolina State University. Dr. DeSimone is a past winner of the Presidential Green Chemistry Challenge Award. He is also this year’s recipient of the prestigious Lemelson–MIT Award, considered by many to be the Nobel Prize for inventors. Since the early days of his career, Dr. DeSimone has focused his research on developing new ways of making polymers that follow the principles of green chemistry.



*“The way you do research today, that’s got to be an integral part of how you do anything. There’s still some stalwarts out there that aren’t integrating green approaches into what they do, and that’s a mistake, but anything we do going forward we think about that.”*

Many of Dr. DeSimone’s big successes, including one published in the May 2008 issue of *Macromolecules*, one of ACS’s 34 peer-reviewed journals, involve replacing caustic and hazardous solvents used to manufacture polymers with benign carbon dioxide. Yes, the same carbon dioxide that’s involved in global climate change can play an important role in protecting the atmosphere from the release of potentially harmful gases. Here’s how.

### Being Supercritical

Until recently, polymers such as Teflon and Gore-Tex, which contain many atoms of the element fluorine, are made using surfactants known as C8 fluorochemicals, which have been identified as persistent organic pollutants, and so manufacturers of these so-called fluoropolymers have been searching for more benign methods of manufacture. That’s where carbon dioxide comes in.

Normally, CO<sub>2</sub> is a gas, but when subjected to a high enough pressure, known as the critical pressure, CO<sub>2</sub> behaves more like a liquid. In fact, as Dr. DeSimone discovered, supercritical CO<sub>2</sub> is an excellent solvent for a wide variety of chemical reactions, including those used to make fluoropolymers. The DuPont company has now invested hundreds of millions of dollars to convert its fluoropolymer manufacturing processes to use supercritical carbon dioxide.

But that’s just the beginning of the benefits of switching to CO<sub>2</sub> as a solvent. The old way of making these polymers also involved several energy-intensive steps that were needed to obtain pure polymer from the chemical reaction mixture. With the new process, the carbon dioxide simply evaporates when the chemical reaction is complete, leaving behind a bone dry powder that requires no further cleanup. The result — the new process generates about 1,000 times less waste than the old process.

## Meet the Scientists



Joseph DeSimone, Ph.D.



James E. Hutchison, Ph.D.

## Turning to the Kitchen for Help

The ubiquitous microwave oven. A huge time-saver for the cook in a hurry. And now, an environmental benefactor? That's what Rajender S. Varma is working to accomplish in his research as a chemist at the EPA. In the May 2008 issue of the ACS journal *Accounts of Chemical Research*, Dr. Varma reviewed his and other researchers' work that uses modified microwave ovens to carry out the wide variety of chemical reactions needed to make pharmaceuticals and other fine chemicals without the use of toxic solvents.

*"We started doing this chemistry using kitchen microwaves for doing reactions in the solid state, meaning no solvent use at all. You just mix two things together, sometimes using clay, silica, or alumina as a support or even as a catalyst, to do the things. Actually, I started this chemistry with a high school student who wanted to do some chemistry with me, and I wondered how I can give some high school student who was not exposed to chemical techniques something valuable to do.... And that was the humble beginning, which grew into a big, big area afterward, and we were so busy ourselves and folks around the globe doing all kinds of experiments. Initially, there was no controlled microwave devices available for chemical reactions, and people were using kitchen microwaves."*

Microwave ovens designed for home use proved to be too powerful for chemists, but now there are commercial chemical microwave reactors that researchers can use to carry out chemical reactions in a finely tuned manner. As a result, microwave-assisted chemistry has become an important tool in the green chemistry workshop. Using microwaves to power chemical reactions enables chemists to eliminate solvents completely in some instances. In other cases, water or the environmentally friendly solvent known as polyethylene glycol can replace a variety of organic solvents.

The ability to fine-tune chemical reactions has also improved the efficiency of these reactions, meaning that they use fewer raw materials to create more useful chemicals with less waste. Microwaves can also slash the amount of energy used to make drugs and other useful chemicals.

But ask Dr. Varma if he's pleased that microwave-assisted chemistry is being widely adopted by the green chemistry community, and the answer is not what you might expect.

*"The 'green' word should go away, that everything we do should pertain to green. Everybody should think about the implications of using a reagent or a chemical or a catalyst or a solvent that is not going to be that harmful once you're done with the materials. Once you have that thinking process embedded in the psyche of the practicing chemist, we won't have to use the word green anymore."*

## From Ultra Big to Ultra Small

Each year, chemical companies manufacture thousands and thousands of tons of polymers and other bulk chemicals that are essential for everyday life. Pharmaceutical companies make hundreds of tons of the biologically active ingredients that make up the drugs we take for a wide range of ailments. When chemicals are produced on such an enormous scale, the potential is huge for saving some green by going green. Not surprisingly, then, chemical and pharmaceutical companies are remaking themselves into more sustainable, resource-conserving operations. No longer is the attitude one of make it, sell it, and worry about cleaning up any mess later. Instead, green chemistry is now, by and large, an ethos that is spreading rapidly throughout these two industries.

Today, though, there is an opportunity to get things right from the get-go in what many experts are hailing as an industry that will become an integral part of nearly every aspect of modern life. Here is Dr. James E. Hutchison of the University of Oregon, who in March 2008 discussed nanotechnology and sustainability in ACS's peer-reviewed journal *ACS Nano*:

*"I expect nanomaterials or nano-enabled materials will touch every single sector of our society, of our economy and our society, so the distribution of this technology is likely to be broader than any single thing we've seen before.... Nano is also viewed as the*

*technology that's going to bail us out of the huge environmental problems that we face in terms of climate change, energy generally, clean water, and on and on, so really significant problems and nanotechnology is being looked at, as this is going to solve the big problems for us. It's particularly important in those cases, where again the technology is going to be widely distributed, that we don't screw things up while trying to fix these big problems — replacing one problem with another is not going to be a good move.”*

Fortunately, long-time advocates of sustainability, such as Dr. Hutchison and Dr. DeSimone, are applying their green chemistry skills to the development of new nanomaterials. Both Dr. DeSimone and Dr. Hutchison have developed methods for crafting precisely defined nanoparticles of a wide variety of sizes and shapes. These libraries of nanoparticles can then be studied in a systematic manner for toxicity. Dr. Hutchison's goal is to develop a set of rules that relate any given nanoparticle's size and other physical properties to their behavior in the environment or in the human body.

*“The approach we've been taking is to look and figure out early on what's harmful and what's not harmful, but the most important thing is let's start developing the alternatives now, let's start developing the design rules now so that instead of this being viewed as, Oh my God, I have to put my technology up to this scrutiny, you should be able to say, there are alternatives that are being developed, and should something bad happen, I have options.”*

Nanotechnology and green chemistry. One new field, the other nearly two decades old. Just where nanotechnology will take us in terms of sustainability has yet to play out. But as Dr. Anastas reflects on the field he helped start, it's clear that the impact of green chemistry is already being felt.

*“The biggest example today of green chemistry that I think is most striking is not an individual product or a process or an individual company. The example is more a reflection of the breadth of the applicability of green chemistry. When I take a look, for instance, at the Presidential Green Chemistry Challenge Awards, and I look at the winning technologies having spanned everything from aerospace to cosmetics to pharmaceuticals to agriculture to energy to automotive to electronics, I recognize that in the same way that we've always known that chemistry touches every part of our daily lives, green chemistry has the potential to impact all parts of our daily lives and our society.”*

But Dr. Anastas also adds:

*“I have to say that all of the joy that I get from seeing what the green chemistry community has accomplished so far, I just have to recognize that it pales by comparison to the power and the potential of what it can do in the future, and what it needs to do in the future if we're going to be a truly sustainable civilization.”*

## Conclusion

Smart chemists. Innovative thinking. That's the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we'll examine how chemists are addressing the twin problems of how to ensure our personal safety and our national security in the 21st century.





# Promoting Personal Safety & National Security

September 11, 2001. The day the world as we knew it changed. An undertone of fear swept America in the wake of the attacks on the World Trade Center and the Pentagon and the downing of United Airlines Flight 93 in a Pennsylvania field. The nation went on high alert. U.S. Air Force jets patrolled the skies over our nation's cities. Shopping malls were deserted. Parents kept their children out of school. Everyone, it seemed, was waiting for the next attack.

Then, a week later, the proverbial other shoe dropped. Anthrax attack! Network news offices and newspapers in New York and Florida started receiving letters packed with a coarse brown granular material resembling dry dog food. Then, three weeks later, letters filled with a fine white powder arrived at the offices of U.S. Senators Tom Daschle of South Dakota and Patrick Leahy of Vermont. Both sets of envelopes contained spores of the bacterium *Bacillus anthracis* — the cause of anthrax disease — and the letters that implied they were a followup to the September 11 attacks. Twenty-two people became ill. Five of them died of anthrax.

Today, law enforcement officials say that the Amerithrax incident, as the FBI named it, was actually perpetrated by a misguided government research scientist. He may have been trying to call attention to our vulnerability to such attacks. Whether that was really his intention will never be known. The suspect committed suicide on the eve of his arrest.

But in the aftermath of 9/11 and the anthrax attacks, the federal government has poured millions of dollars into research with one purpose in mind: developing technologies that can detect potential threats from both biological and chemical weapons before they endanger the public's health or the safety of our first responders. They are the soldiers, firefighters, police officers, and health-care workers who put their lives on the line to protect the public.

## A Host of Threats

Inhalation anthrax starts off with symptoms resembling a bad cold or the flu, and then rapidly progresses to severe and often fatal respiratory collapse. Not a pleasant way to die. But anthrax is one of the least dangerous of the biological threats that the National Institutes of Health (NIH) calls Category A agents.

These are the real nasties, the bacteria, bacterial toxins, and viruses that are not only incredibly potent, but also have the potential to be spread among large numbers of people in a bioterrorism attack. Joining anthrax on the Category A list are smallpox; botulism toxin; plague; viral hemorrhagic fevers such as Ebola and Marburg; and tularemia, or rabbit fever.

Analytical chemist Dr. Troy A. Alexander, of the U.S. Army Research Laboratory, is one of the many scientists who are developing a rapid, high-tech approach to detecting the first signs of a Category A bioterrorism attack.

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## DiD YOU KNOW?

- ◆ *Anthrax infection can occur in three forms: Cutaneous (skin), inhalation, and gastrointestinal. About 95 percent of infections involve the skin and are rarely fatal.*
- ◆ *The last naturally occurring case of smallpox in the world was in Somalia in 1977. The last case in the United States was in 1949.*
- ◆ *A 2002 study found that the average office desk harbors more bacteria than a toilet seat. Toilet seats had 49 germs per square inch, but desktops had 21,000 and phones 25,000.*



## HIGHLIGHTS

- ◆ Researchers are developing a “chemical radar” that could provide early warning of nerve gas attacks, just as regular radar detects incoming aircraft.
- ◆ One new technology promises to provide “optical fingerprints” that alert officials to the presence of smallpox and other bioterrorism agents.
- ◆ USDA researchers have found a way to detect ricin, a potential bioterrorism agent that may be concealed in processed foods.
- ◆ Nanotubes that are 1/50,000th the diameter of a human hair coated with a natural microbe-fighting enzyme could help prevent the spread of germs on kitchen countertops, door-knobs, and other surfaces.

## Meet the Scientists



Troy A. Alexander, Ph.D.



John Mark Carter, Ph.D.

*... this is where we really ought to apply most of our effort to address this problem of being able to detect biological threat agents ...*

*“When I started this work, I first looked at the listing of Category A pathogens that’s published by the NIH, and if you look at the category A pathogens, about 75 percent of them are viral in nature. So my thought was that this is where we really ought to apply most of our effort to address this problem of being able to detect biological threat agents — bacteria, viruses, and toxins — that have been put in a weaponized form.”*

### Optical Fingerprints

The product of Dr. Alexander’s research is a device that generates what is essentially an optical fingerprint. Within minutes, it can identify specific bioterrorism threats. In a paper that he published in ACS’s *Analytical Chemistry*, Dr. Alexander describes experiments in which he used viruses from the smallpox family as a proof of concept for this device.

*“When you start to look at work that’s been done with pox viruses, you quickly realize that they are unique in the sense that they are invariant irrespective of what the animal host is or even what part of the world they come from. In that respect, they are a good model system to start with, and more closely to our application, smallpox is still a really big threat that can be used in a military application or a bioterrorism threat.”*

The device that Dr. Alexander created is based on a technology known as SERS, short for surface enhanced Raman spectroscopy. SERS works like this: When infrared light shines onto a precisely machined gold surface, known as a SERS substrate, it excites the electrons in the metal atoms and causes them to ripple in unison across the gold surface, much like waves on pond.

When a virus particle or bacterium lands on the SERS substrate, it gets energized by those ripples and gives off light at multiple wavelengths. That pattern of light, or spectral signature, depends on the exact type of virus or bacterium stuck to the SERS substrate. For example, smallpox virus produces one spectral signature, while the closely related cowpox virus produces a different signature.

Even better, using software that can run on a personal computer, Dr. Alexander found that his device can analyze the light emitted from the SERS substrate and identify specific pox viruses within a matter of minutes even when there are multiple types of viruses present on the substrate. That’s an important finding because in the real world, the air is full of harmless viruses and bacteria that might interfere with the detection of bioterrorism agents.

And in fact, Dr. Alexander has already shown that this device can detect and identify members of the *Bacillus* family of bacteria that includes anthrax, and could find use with other threat agents, too.

*“Yes, this could be extended to include not only the pox viruses but also *Bacillus* spores and also it’s very easily applicable to chemical threat agents such as mustard gas and VX, and one of the big challenges, of big military interest right now, is detection of explosive materials. It could really be used to develop a broadly applicable sensor platform that could be used to sense all of those different categories of agents of interest.... For more civilian applications, this could be used in football stadiums, airports, shopping malls, areas where you have high volume, high numbers of people, and it could be really easily automated.”*

### “Chemical Radar”

In 1935, Sir Robert Watson-Watt, a British physicist, developed the first practical radar system. By 1939, at the outbreak of World War II, the United Kingdom had installed a string



of radar stations along its south and east coasts to provide advanced warning of potential attacks from both sea and land. For the first time in history, a nation could use machine-enabled remote sensing to prepare its defenses in advance of an imminent attack. Undoubtedly, the invention of radar saved countless lives, both soldier and civilian.

Today, researchers such as Dr. Claire Hartmann-Thompson, of the Michigan Molecular Institute, are developing what might be called chemical radar. Instead of using radio waves to see distant bombers and battleships, these new technologies use laser beams to detect atmospheric chemical weapons.

*"It's nice to detect something dangerous at a distance, and obviously it's safer for humans.... The main challenge is getting high-quality information from a distance, and you find there's a trade-off between the number of things you can detect and the sensitivity. So you normally find a sensing technique that can easily detect one thing down to very, very low levels, and an example of that would be land mines. Some techniques can detect parts per trillion of a nitroaromatic vapor above ground, above a buried land mine or buried ordinance, and then at the other end of the spectrum one has a system where you don't know what to expect — you could expect any one of a number of different chemical warfare agents and you may want to be able to distinguish those, but you normally find that the more things you can distinguish, the higher the levels have to be before you can detect them, so you're always working with that trade-off and trying to strike a balance for the application you're working on."*

Dr. Hartmann-Thompson's research involves that trade-off between versatility and sensitivity. In the ACS journal *Chemistry of Materials*, she and her colleagues provided details on a system that uses a collection of laser-sensitive nanoparticles to detect at a distance chemical warfare agents such as the nerve gas VX.

The nanoparticles in the collection carry different fluorescent dyes, each of which emits light of a unique color when struck by a laser beam. But more importantly, those colors change when the nanoparticles come in contact with various chemicals, in this case nerve agents. The exact manner in which the array of particles change colors depends on which chemicals are interacting with the nanoparticles. The set of colors associated with a particular chemical is like a fingerprint for that chemical.

In its current form, this technology would be useful for detecting nerve agents drifting into an area in a suspicious-looking cloud and distinguishing them from chemically similar but less harmful pesticides that might have been sprayed on a farm field.

*"In a real-world setting I can imagine some kind of military or homeland security application where you could launch a mixture of these particles into a cloud and then monitor what comes back from the cloud. All these techniques exist — the military is good at launching projectiles to defined locations. A lot of technologies are good at detecting various wavelengths of radiation coming back from the remote location, from the IR to the visible to the UV. So it's a matter of putting together existing technologies to apply this in the real world. "*

But Dr. Hartmann-Thompson is already thinking beyond this current system to one that could be set up to create a permanent monitor for airborne chemical weapons.

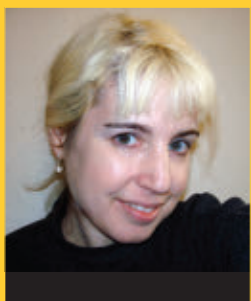
*"We're working on that right now. We've managed to create analogous sensors in the*



## Meet the Scientists



Virginia A. Davis, Ph.D.



Claire Hartmann-Thompson,  
Ph.D.

*form of a coating, and once you can coat something you can deploy it.”*

### Keeping Food Safe

Most of us are confident in the safety of our food supply here. Yes, there was the recent outbreak of Salmonella that sickened a few hundred people who had eaten contaminated jalapeño peppers, but by and large, we don't spend much time worrying about terrorists poisoning our hamburgers.

Fortunately, there are experts who do worry about that possibility. One such expert is Dr. John Mark Carter, a supervisory research chemist at the U.S. Department of Agriculture's Agricultural Research Service. Dr. Carter leads a team of researchers who have developed a method for rapidly detecting ricin, a plant toxin found in castor beans. Ricin is on the NIH's list of Category B agents, which includes potential bioterrorism threats that aren't quite as dangerous as the Category A agents. Nonetheless, the amount of ricin obtained from eight beans is enough to kill the average person, and terrorism experts have stated that al Qaeda has experimented with ricin. There is also no known antidote for ricin poisoning.

Enter Dr. Carter and his team at the USDA, who reported on their work in the ACS's *Journal of Agricultural and Food Chemistry*.

*“Ricin is considered a biosecurity threat agent, and a more efficient detection was required.... Immunochemical assays are available, but they're unsuited for use with complex foods such as hot dogs or powdered eggs. Animal tests are simple but expensive, and enzymatic tests are subject to interference by food.”*

The unusual thing about ricin as a potential bioterrorism threat is that it's very simple to isolate in a slightly impure, but still potent form, from beans that almost anyone can grow. Another potential source of ricin is the more than 100 million pounds of waste generated during the production of castor oil, which is used as a laxative and for other purposes. But that simplicity also created an opportunity for Dr. Carter and his colleagues.

*“The RT-PCR test that we developed doesn't actually detect the ricin toxin itself. Instead, it detects castor bean DNA, which is present in partially purified preparations of ricin.”*

RT-PCR is short for real-time polymerase chain reaction, a technology used widely in research, medical, and crime laboratories to identify DNA. RT-PCR has gained such wide use because of its exquisite sensitivity and accuracy — it can accurately detect even the slightest amount of castor bean DNA. In fact, Dr. Carter's team showed that their test can detect ricin contamination in ground beef at levels nearly 1,000 times lower than the lethal oral dose for the typical adult. Dr. Carter says that when coupled with new technologies such as microfluidics that can automate RT-PCR assays:

*“They have the potential to provide a faster and more definitive result coupled with reduced expense, which is critical for routine food safety analysis.”*

### Touchy, Touchy. . .

Of course, terrorists aren't the only threat to our health and well-being. Mother Nature, with our ready cooperation, occasionally does a pretty good job of making us sick. Think door-knobs. Think escalator handrails. Think grocery carts. The places that dozens or even thousands of people touch every day. Numerous scientific studies have shown that viruses and bacteria can survive on such surfaces, just waiting to be picked up when that surface comes in contact with the human body.

*“There's certainly been growing concern and certainly growing media coverage about the transmission of germs through surfaces. Every flu season and whenever there's another disease outbreak, we hear the stories where they swab people's grocery carts or desks or computer laptops or trays on airplanes and find germs there, so having surfaces that are not good for the germs to grow on will help cut down on some of this contamination.”*

That was Dr. Virginia A. Davis, a chemical engineer at Auburn University, who teamed with colleague Dr. Aleksandr Simonian to create a rugged antibacterial coating made of carbon nanotubes coated with a natural microbe-fighting substance known as lysozyme. Lysozyme is an enzyme found in egg whites, as well as in human saliva and tears, and it kills bacteria by chewing up their cell walls. But by itself, lysozyme doesn't stick well to surfaces. Carbon nanotubes, which are about 1/50th the width of a human hair, form the strongest materials known, and they adhere strongly to surfaces. However, they also form big clumps, rather than a uniform coating, when applied to most surfaces.

*"It's easy to make a coating of large clumps of nanotubes, but then you're not getting the benefit of the nanotubes."*

But a strange thing happened when Drs. Davis and Simonian tried to combine the two substances — they found that they could firmly attach lysozyme to the surface of carbon nanotubes and when they did, the nanotubes stopped clumping. Voila! Two problems solved. As described in the ACS journal *Nano Letters*, the new coating is easy to apply to a wide variety of surfaces. Once dried, it is tough as nails. In fact, initial tests on the new coating show that it remains untouched by common household cleaners and repeated contact, though further tests are needed outside of the laboratory to determine how useful the coating will ultimately be in public settings.

### Conclusion

Smart chemists. Innovative thinking. That's the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we'll examine how chemists are developing new ways of combating disease that may reshape the practice of medicine in the 21st century.





# Combating Disease



A

Almost 100 years ago, in 1909, the great German biochemist and Nobel Laureate Paul Ehrlich conducted a series of experiments that ushered in the era of modern medicine. In his laboratory at the Royal Institute of Experimental Therapy in Frankfurt, Ehrlich and his colleagues tested more than 900 different chemicals. They were searching for what Ehrlich called a “magic bullet,” a medicine that would kill the microbe that caused sleeping sickness but not the patient suffering from the disease.

These experiments failed to produce a treatment for sleeping sickness. However, chemical number 606 in their search proved to have a remarkable effect on the then-newly discovered microbe that caused syphilis. After testing this drug — in rabbits, mice, and then humans — compound 606, which Dr. Ehrlich named Salvarsan, became the first chemotherapy agent in medicine’s arsenal.

Chemotherapy today means anticancer medicine. Originally, it meant any chemical treatment. Salvarsan was the first chemical compound designed specifically to treat a human disease. And Ehrlich became the founder of modern chemotherapy.

Ehrlich’s task wasn’t finished, however. Salvarsan produced a number of toxic side effects. Undaunted, Dr. Ehrlich and a team of chemists determined the correct structure of Salvarsan and then modified the chemical structure to make Salvarsan more harmful to the syphilis microbe and less harmful to patients.

## Living 30 Years Longer

Today, pharmaceuticals are the keystone of modern medicine. Their development, along with other improvements in public health, have helped expand human life expectancy by almost 30 years since the turn of the 20th century.

Think of where we would be without penicillin and cephalosporin, Lipitor and lisinopril, doxorubicin and Dilantin. A half century ago, cancer was a death sentence. Today, there are over 10 million cancer survivors. Twenty years ago, AIDS was invariably fatal. Today, people infected with HIV take a single pill containing three drugs and are more likely to die of old age than of AIDS.

## Great Advances/Great Challenges

But as great as the advances in medicine have been over the past century, enormous challenges remain if we are to make further substantial progress in the fight against disease and its toll on society.



## DID YOU KNOW?

- ◆ *Antibiotics, vaccines, and other advances against infectious diseases helped boost U.S. life expectancy by 29 years during the 20th century.*
- ◆ *Scientists have linked infection with bacteria and viruses to an increased risk of heart disease, obesity, and other diseases.*
- ◆ *Chronic inflammation, most familiar in arthritis, may also play a role in some forms of cancer and heart disease.*
- ◆ *21st-century medicine faces enormous challenges from bacteria that have grown resistant to many antibiotics.*

## HIGHLIGHTS

- ◆ **A new “laboratory on a chip” the size of a sugar cube may detect disease-causing bacteria by analyzing urine and saliva flowing through “pipes” the diameter of a human hair.**
- ◆ **One new technology is laying the foundation for diagnosing cancer in minutes from blood samples or biopsies.**
- ◆ **A new generation of medications may treat Alzheimer’s disease and other afflictions facing Baby Boomers by correcting disorders in mitochondria – the cell’s energy factories.**
- ◆ **Researchers are dealing with the challenge of cancer cells that become resistant to chemotherapy with a potent one-two technology that makes cancer cells self-destruct.**

## Meet the Scientists



Mansoor Amiji, Ph.D.



Neil Reginald Beer, Ph.D.



Niren Murthy, Ph.D.

*The best way to get a jump on a disease is by preventing it in the first place — eating a healthy diet, exercising regularly, staying up to date on vaccinations. . .*

Take cancer, for example. Cancer is largely a disease of aging, and the population of the U.S., Canada, Europe, Japan, and other developed nations is aging. Indeed, unless researchers develop radically different kinds of anticancer therapy, cancer will soon surpass heart disease as the leading cause of death in the industrialized world.

Fortunately, as in Ehrlich's day, chemists are poised to bring about a second revolution in medicine. This 21st-century revolution promises an age of more effective therapies with fewer side effects, and perhaps most importantly, one that won't bankrupt the national treasury.

### Lab on a Chip

*"The best way to get a jump on disease is by preventing it in the first place — eating a healthy diet, exercising regularly, staying up to date on vaccinations, and so on. But not all diseases are preventable — yet — so the next best option is to detect disease as early as possible."*

That was Dr. Neil Reginald Beer of the Lawrence Livermore National Laboratory. This chemist is developing a disposable device about the size of a packet of sugar that would detect specific DNA and RNA molecules associated with specific diseases or infections. In a paper that was published in the ACS journal *Analytical Chemistry*, Dr. Beer and his colleagues describe their use of microfluidics to detect the genetic material — the RNA — of single virus particles.

What is microfluidics? Think laboratory on a chip, where liquid samples of blood or saliva flow through microscopic pipes about the thickness of coarse hair. Think mixing chambers smaller than a comma. And it's all built with essentially the same technology used to create computer chips.

Imagine your doctor taking a tiny fraction of a drop of blood or saliva, injecting it into a microfluidic pipe, or channel, and within minutes taking an optical measure that provides critical diagnostic information. That's the promise of microfluidic devices such as the ones that Dr. Beer is building. And then imagine doing that on hundreds or even thousands of samples, one right after the other.

### The Golden Touch

Microfluidic devices represent one powerful new technology that is about to change the way doctors diagnose disease. Dr. Weihong Tan, of the University of Florida, is taking another approach, one that relies on some clever chemistry combined with gold nanoparticles, to find the molecules, known as biomarkers, that distinguish diseased cells from healthy ones.

Dr. Tan's research relies on molecules known as aptamers. Aptamers are small pieces of synthetic RNA that recognize and bind to very specific molecular markers, acting very much like artificial antibodies.

Earlier in 2008, Dr. Tan and his colleagues described their work with aptamers as diagnostic agents in the ACS journal *Analytical Chemistry*. In this report, the researchers showed that they could create aptamers that would stick to distinct types of cancer cells. One aptamer, for example, recognized lung cancer cells, while another would bind only to liver cancer cells, and a third stuck to a specific type of leukemia cell.

Dr. Tan then showed that he could spot those aptamers — and the cancer cells they were sticking to — by linking them to gold nanoparticles, which emit powerful optical signals. If the results of these experiments are confirmed in larger studies, physicians could diagnose cancer within minutes of taking a blood sample or biopsy.



But beyond its importance for disease detection, Dr. Tan's work also promises to help researchers better understand the molecular basis of a wide variety of diseases, including cancer.

### Quicker... Faster...

If the first step in building the foundations for 21st-century medicine is to develop quicker, more accurate, and less expensive ways to diagnose illness, then the second step is to discover medicines that more effectively target the molecular basis of disease while leaving healthy cells alone. And while Paul Ehrlich managed to accomplish this task largely by trial and error, today's researchers are taking advantage of the accelerating expansion of biochemical knowledge that has occurred over the past several decades.

Dr. Peter Wipf of the University of Pittsburgh is one such chemist. His focus is on targeting mitochondria, the cell's energy factories, to prevent degenerative diseases such as Alzheimer's disease and Parkinson's disease and the damage that results from stroke and heart attack.

### The Cell's Power Plants

Mitochondria are like small cells within a cell. Like the larger cell that houses them, mitochondria are surrounded by a two-sided membrane designed to keep what's inside of the membrane separate from what's outside of it. However, both the cell and the mitochondria would die if those membranes were impenetrable. Nature's solution is a set of molecular passwords that can gain passage through those membranes. Some of those passwords work for with cell membrane, others with the mitochondria.

In ACS's *Accounts of Chemical Research*, Dr. Wipf describes some of the work that he and his collaborators have done to create a series of small molecules that mimic those entry signals. The goal of this work has been to develop a way of targeting only those mitochondria that are functioning poorly as a result of some degenerative disease process.

So far, Dr. Wipf and his colleagues have shown that their molecular passwords do indeed target mitochondria. They have also demonstrated that these targeting agents can transport an attached drug molecule into mitochondria, and most importantly, that the drug molecule can exert the desired protective effect within the mitochondria. Based on these initial results, Dr. Wipf is now developing mitochondrial drugs for specific diseases, particularly those that plague us as we age.



### Shutting Off Inflammation

In general, degenerative diseases work slowly, destroying the human body molecule by molecule, cell by cell. At the other end of the disease spectrum are so-called acute diseases that do their damage more quickly — shock and awe versus slow and stealthy. Acute lung injury and acute liver failure are two such diseases, and both are caused, at least in large part, when immune system cells called macrophages release a group of chemical signals that trigger inflammation.

Macrophages are the body's scavengers. They patrol the body, engulfing invading microbes and the debris released by dying cells. They also release chemicals called cytokines that act as an alarm call, triggering a mass migration of other immune system cells to the site of an infection or injury.

Normally, this is a welcome response, but in some instances, the immune system reacts far too aggressively to a macrophage's call to arms. When that happens, the immune system can actually damage, rather than protect, the body. And that is exactly what happens in acute inflammatory diseases such as acute lung injury and acute liver damage.



*One of the most severe limitations of modern drug therapy is that some very good drugs lose their effectiveness over time.*

Dr. Niren Murthy, of the Georgia Institute of Technology, may have a solution to the problem of reining in an over-responsive immune response by specifically targeting macrophages. His approach involves creating microparticles made of polymers called polyketals.

Polyketals are unusual in that they are very stable when they are in the neutral environment of the blood stream, but they fall apart rapidly when exposed to a low-pH, or acidic, environment. Why might that be important for targeting macrophages? Because while the blood stream's pH is typically 7.4, the inside of a macrophage is pH 4.5.

In one set of experiments, which Dr. Murthy describes in the ACS journal *Bioconjugate Chemistry*, he and his collaborators created polyketal microparticles containing a powerful anti-inflammatory drug that at its normal dose would be too toxic to use with patients suffering from acute liver failure, for example. However, when Dr. Murthy and his collaborators loaded this drug into their polyketal microparticles and injected this formulation into mice suffering from liver failure, the results were dramatic — measures of liver disease dropped precipitously with a mere one-tenth of the dose of drug normally needed to produce this effect.

### Delivering a One-Two Punch

One of the most severe limitations of modern drug therapy is that some very good drugs lose their effectiveness over time. Many microbes, for example, have evolved the ability to detoxify even the most powerful antibiotics. Some pump antibiotics out of the cell. And cancer cells are notorious for their ability to evolve into resistant forms that shake off the effects of anti-cancer drugs and radiation. This ability to develop drug resistance is one reason why anticancer drugs lose their effectiveness and patients relapse.

Almost all anticancer drugs work by triggering a process that causes cells to commit suicide when they suffer some kind of severe damage. This process, known as apoptosis, occurs naturally as cells age or if they develop some defect that prevents them from functioning normally.

*"Apoptosis is one way in which the body renews itself. But one of the hallmarks of a cancer cell is its ability to avoid apoptosis, and researchers have discovered that cancer cells can do this because they can destroy the cell's major suicide signal, molecules known as ceramides."*

That was Dr. Mansoor Amiji of Northeastern University, who has developed a new type of nanoparticle capable of releasing an anticancer drug and ceramide at separate times inside a cancer cell. In the ACS journal *Molecular Pharmaceutics*, Dr. Amiji described the new particle.

In fact, that's exactly what Dr. Amiji and his colleagues developed — one nanoparticle that can be taken up by a cancer cell and provide a quick blast of an anticancer drug, followed hours later by a second blast of ceramide. So far, tests results with this nanoparticle are encouraging, and the impact on cancer therapy could be huge.

### Conclusion

Smart chemists. Innovative thinking. That's the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we'll examine how chemists are developing the new fuels that will power society in the 21st century.

Today's podcast was written by Joe Alper. Our editor is Michael Woods. I'm Adam Dylewski at ACS in Washington.

### Meet the Scientists



Weihong Tan, Ph.D.



Peter Wipf, Ph.D.



# New Fuels: Part 1

## Biofuels

Get set for a trip back to the future — Global Challenges’ recreation of a September day in 1925 when American automobile pioneer Henry Ford made a prophetic comment to *The New York Times*. Ford, we know, invented the mass production automobile assembly line. Off those lines rolled the first widely available car, Ford’s Model T. Ford had fuel on his mind in that interview with *The Times* more than 70 years ago.

*“The fuel of the future is going to come from fruit like that sumac out by the road, or from apples, weeds, sawdust — almost anything. There is fuel in every bit of vegetable matter that can be fermented. There’s enough alcohol in one year’s yield of an acre of potatoes to drive the machinery necessary to cultivate the fields for a hundred years.”*

Strange as it may seem, Henry Ford did not design the Model-T to run on gasoline. Ford built the “Tin Lizzie” to putt along on today’s most popular biofuel — ethanol. Although Ford lobbied for ethanol as the standard motor vehicle fuel, gasoline won out. In 1898, Rudolph Diesel, the inventor of the diesel engine, demonstrated that his new engine ran just fine on peanut oil. Now, it really is back to the future, as society rediscovers the virtues of biofuels like ethanol from corn and diesel fuel made from plant oils.

### A Perfect Storm

A “perfect storm” of factors is forcing society to seek alternatives to gasoline and other fossil fuels. It includes sticker shock prices for gasoline and home heating oil. Concerns about global climate change due to carbon dioxide release in smokestacks and tailpipes. Potential shortages of petroleum. And national security concerns about dependence on foreign sources of oil.

In a two-part podcast, Global Challenges explores scientific advances toward providing us with new fuels. First, we will look at biofuels, the most familiar kind of alternative fuel. Biofuels already are a reality and in wide use. Most of us fill it up with gasoline that contains a biofuel — Henry Ford’s biofuel, ethanol made from corn. In Part 2, we will look into the future, when scientific advances may allow us to fill it up with water, sunlight, and other new fuels that may seem straight out of science fiction

### Brewing Up Fuels

So exactly what are biofuels? Biofuels are combustible substances made from plants.

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### Did You Know?

- ◆ *Biofuels are not new. Henry Ford designed the “Tin Lizzie” to run on alcohol, while Rudolph Diesel’s engine could run on peanut oil.*
- ◆ *New fuels must be liquid fuels to power the 230 million motor vehicles on today’s roads.*
- ◆ *There are many different types of biofuels, including ethanol, biodiesel, green gasoline, and designer hydrocarbons.*
- ◆ *In 2007, the United States consumed 6.5 billion gallons of ethanol, which were mixed into the domestic supply of 142 billion gallons of gasoline.*



## HIGHLIGHTS

- ◆ **Almost half of all gasoline sold in the United States contains a first-generation biofuel — ethanol made from corn.**
- ◆ **Scientists are developing second-generation biofuels made from non-food plant materials such as switchgrass and other biomass.**
- ◆ **Sugars from biomass can be converted into gasoline additives that have 40 percent more energy per gallon than ethanol.**
- ◆ **Biofuels are just one part of a comprehensive solution to our energy problems that includes conservation and greater energy efficiency.**

## Meet the Scientists



Bruce E. Dale, Ph.D.



Jerald L. Schnoor, Ph.D.



Cathleen Hapeman, Ph.D.

There are two main types of biofuels. There's ethanol, which is the same type of alcohol found in wine, beer, and hard liquor. Ethanol is a renewable fuel that can be made by fermenting corn and other plant material. We call that material "biomass." And biofuel producers use it in a process similar to the one brewers use to make beer. As Henry Ford said, the process is fermentation. To make ethanol, we mash up corn, add yeast, and let those microorganisms churn out alcohol.

Nearly half of all gasoline sold in the United States contains ethanol. In 2007, 6.5 billion gallons of ethanol were mixed into the domestic supply of 142 billion gallons of gasoline. Almost all of that ethanol was made from corn. Other countries produce ethanol from different plants. Brazil, for example, makes ethanol from its most abundant crop, sugarcane.

The other main type of biofuel is oily stuff. Biodiesel, for instance, can be made from soybean oil, palm oil, peanut oil, and other vegetable oils; animal fat; and even cooking oil recycled from restaurant French fry makers. Biodiesel can be added to regular diesel fuel. It also can be a stand-alone fuel, used by itself as an alternative fuel for diesel engines. The most common biodiesel blend used in the United States, called B20, contains 20 percent biodiesel and 80 percent regular diesel. Europe's biofuels come from multiple sources, including canola oil and palm oil.

### Biofuel Benefits

Both ethanol and biodiesel can help to reduce greenhouse gas emissions and air pollution in comparison to conventional gasoline. Moreover, both are renewable and can be produced domestically, dramatically reducing our dependence on foreign oil and ultimately lowering fuel prices for consumers. With skyrocketing oil and gas prices, biofuels will power civilization into the future.

For now, ethanol remains the most successful biofuel. The U.S. Department of Energy — the DOE — estimates that gasoline prices would be between 20 cents and 35 cents per gallon higher without ethanol as a fuel additive. For the U.S. overall, that means that use of ethanol saves an estimated \$28 billion to \$49 billion per year based on annual gasoline consumption of roughly 140 billion gallons. Corn-based ethanol also reduces America's dependence on oil. DOE estimates that biofuels will reduce gasoline consumption by 7.2 billion gallons in 2008.

### On a Liquid Diet

The Energy Independence and Security Act of 2007 requires American fuel producers to use at least 36 billion gallons of biofuel in 2022. This is almost five times more than current levels. Crude oil is the source of our mainstay liquid fuels — gasoline and diesel. The liquid nature of these fuels is critical because the 230 million cars and trucks in the United States run on liquid fuels.

*"We need biofuels primarily because they're drop-in replacements for the petroleum fuels upon which we're nearly completely dependent. Our society is really committed to liquid fuels, and biofuels are the only renewable option that I know of to provide these fuels. We're going to be committed to liquid fuels for a long time, and biofuels are the only way I know to get there."*

That was Dr. Bruce E. Dale, of Michigan State University. Dr. Dale, a pioneer in the development of so-called "cellulosic ethanol," described the promise and challenges of biofuels in the *Journal of Agricultural and Food Chemistry*, one of ACS's 34 peer-reviewed journals.

Cellulosic ethanol is one of the most exciting biofuels on the horizon today. It is ethanol made from cellulose. That cellulose could come from the inedible parts of plants, such as stems and leaves, that are not used as food or animal feed. Cellulosic ethanol also could be made from trees and grass like switchgrass grown for fuel rather than food. Chemistry is playing a key role in efforts to trap cellulose as a fuel source. Intensive research is underway on enzymes to break cellulose down into sugars, for instance, and other enzymes to increase the efficiency with which those sugars ferment into alcohol.

Cellulosic ethanol is a centerpiece of the federal government's Biomass Program, which

aims to discover less-expensive ways of producing cellulosic ethanol. The program's goal: Make cellulosic ethanol cost-competitive with corn-based ethanol by the year 2012. Here again is Dr. Dale:

*"Cellulosic ethanol looks attractive, or any cellulosic biofuel, because the volume of cellulosic material is so large that we can make these materials really cheaply and also because they don't interfere with the food chain at all. I think we'll see tens of billions of gallons of cellulosic biofuels being produced within about the next 20 years. They'll be much cheaper than current petroleum-derived fuels."*

#### Four "Fs" of Farming

Cellulosic ethanol and new ways of making biodiesel also could ease concerns about the potential consequences — unwanted, indeed — of switching from fossil fuels to biofuels.

One concern is biofuels' impact on food prices and the global food supply. As more of each year's corn crop goes to biorefineries to produce fuel, less is available to feed chickens and cows and produce corn oil and other food products. Prices rise and consumers feel the pinch. Here again is Bruce Dale:

*"Regarding the food vs. fuel controversy: The cellulosic materials, which I call "grassoline," basically gasoline replacements and woody materials, doesn't really exist for cellulosic materials. However, obviously corn and grain oilseeds in particular also have alternative uses as foodstuffs. Really, they're animal feeds. But they do contribute to some degree to the rise in food prices, so that has made them much more controversial."*

Dr. Jerald Schnoor, editor of *Environmental Science & Technology* and a scientist at the University of Iowa, points out that biofuels put a fourth "F" in farming:

*"Farmers grow the three Fs — food, feed, and fiber — for the entire world. Now, for the first time, they are being called upon to produce a fourth F: fuel. But the burgeoning growth of corn and soybeans for biofuels could gravely impact the environment, increasing our soil and nutrient runoff from the land, adversely affecting water quality, and causing conservation reserve lands to be brought back into production."*

There's a widespread assumption that biofuels will reduce carbon dioxide emissions. CO<sub>2</sub>, of course, is the main greenhouse gas. Those gases contribute to global warming. However, some researchers are concerned that biofuels may not be as beneficial as expected. Look at biofuels' "life-cycle" impact — from production through processing and transportation to



## Meet the Scientists



George W. Huber



Wei Huang

burning in a car engine — and biofuels actually could contribute more CO<sub>2</sub> than they save.

In August, a panel of experts convened on Capitol Hill to discuss the impact of biofuels on greenhouse gas emissions. Dr. Cathleen Hapeman, a research chemist with the U.S. Department of Agriculture's Agricultural Research Service, moderated the panel discussion on this topic.

*"Biofuels production is actually quite complex. We have to consider the amount of energy and environmental issues associated with production. We have to look at the processing and conversion part, and we have to look at the market aspect of this. And part of the piece that's not been studied very much is the environmental issues. That is, what are the issues in terms of soil erosion, greenhouse gas emissions, are there water quality or air quality issues. And sometimes we can actually use biofuels production to be a positive aspect but it may also have negative aspects. And we have to make sure we're not contributing to environmental degradation."*

Another involves environmental effects of biofuel, especially of Europe's recent attempts to use palm oil as a biofuel. Much of that oil comes from plantations in areas like Borneo and Sumatra. Those plantations are carved out of rainforest that provides habitat for threatened or endangered species like the orangutan.

### The Allure of Algae

So scientists are now eagerly looking at a second generation of biofuels that are made from other sources, such as algae. Yes, we're talking about those weeds of the water world, most familiar as the green coating known as "pond scum" and the seaweeds that decay and stink on some beaches.

Scientists have figured out how to produce both ethanol and biodiesel from algae. Unlike food-based biomass that takes up hundreds of acres of farmland, algae needs comparatively little space and grows quickly. Although algae-based fuel produces more energy than cellulosic ethanol, it also costs more to produce.

But researchers are hoping to lower its cost. Last year, the U.S. Department of Energy's National Renewable Energy Laboratory and Chevron forged a collaboration to develop advanced technologies for making fuel from algae. A few other companies, such as Green-Fuel and Solix, plan to produce algae-based biofuel.

### Green Gasoline

Gasoline doesn't grow on trees — not today's gasoline, anyway. But tomorrow, we may be filling up with gas that does, with green gasoline. Green gasoline is a liquid identical to traditional gasoline in energy content, but made from sawdust, switchgrass, or other biomass.

In April 2008, the National Science Foundation, DOE, and ACS released a report on the latest efforts to produce not just green gasoline, but green diesel and green jet fuel. One contributor to the report was Dr. George W. Huber, a chemical engineer at the University of Massachusetts in Amherst. Huber and colleagues also reported their own major advance toward producing green gasoline. It was the first direct conversion of plant cellulose into gasoline components. Here is Dr. Huber:

*"We've developed a new process to make green gasoline called catalytic fast pyrolysis. In this process, we take this biomass and thermally heat it, it decomposes and enters into the catalyst's pores and out of it comes gasoline, CO, CO<sub>2</sub>, and water. We're focusing on everything that's found in gasoline today and trying to make that from biomass."*

Dr. Huber points out that green gasoline has other advantages, in addition to being produced from renewable resources in a sustainable fashion.

*"The big advantage of this process is there are no net CO<sub>2</sub> emissions. So the advantage of this process is its greenhouse gas neutral. So environmentally, it will be a lot better than gasoline."*

*Are biofuels a panacea for our energy problems?  
I don't think so...  
we cannot grow our way out of this problem.*

In Latin America and the Caribbean, another non-food plant is getting attention as a potentially rich source of biodiesel. It is the jatropha, which grows well in this area, and especially Haiti, which experiences chronic shortages of diesel fuel and electricity.

### Designer Hydrocarbons

Other research advances promise to improve the qualities of conventional gasoline. Dr. James Dumesic, a chemical engineer at the University of Wisconsin–Madison, developed a two-stage process for turning biomass-derived sugars into dimethylfuran. That potential gasoline additive has 40 percent more energy per gallon than ethanol. Other scientists are trying to use genetic engineering technology to get microbes like *E. coli* and yeast to convert sugars to gasoline and diesel rather than ethanol. At least two companies, LS9 and Amyris, are leading the way in producing these so-called designer hydrocarbons.

At LS9, a biotechnology company based in California, researchers are developing a petroleum product from sugars using genetically engineered bacteria. The company expects the biofuel to serve as a drop-in replacement for conventional gasoline. Wei Huang, the company's Vice President of Process Development and Engineering, characterizes the company's biofuel as a revolutionary product that could be on the market in three years:

*"We are very excited and proud of our technology. We believe that LS9's Renewable Petroleum Technology will profoundly change the future of the transportation fuel industry. We will have a second-generation biofuel that is non-fossil based, non-food based, sustainable, cost competitive, and can be readily fit into the existing infrastructure. We have a pilot plant in operation right now. We make gallons of products, mainly for research purposes right now. We expect to make millions of gallons per year in the future."*

These biofuels certainly will make a huge contribution to our energy needs in the 21st century. However, let's keep biofuels in perspective, the kind of perspective that Jerry Schnoor talks about:

*"Are biofuels a panacea for our energy problems? I don't think so. Unfortunately, our gluttony for liquid fossil fuels is so large, so gargantuan that we cannot grow our way out of this problem. The U.S. consumes 21 million barrels of petroleum each day. That's about three gallons for every man, woman, and child in the country. Even if we utilized all 72 million acres of corn planted in the nation for ethanol and biodiesel, it would satisfy only 10 percent of our current petroleum consumption. And it would leave us with little room for the other three Fs: food, feed, and fiber. Clearly, conservation and energy-efficiency are still our greatest energy resources if we choose to get serious about them. Wind and solar can help, too. Biofuels are one element of a rational and strategic response to the problem, but they are not a panacea."*

### Conclusion

As Dr. Schnoor suggested, it will take smart chemists working on biofuels and a range of other options as we seek to power our economy. It also will take innovative thinking. Those are the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing chapter of chemistry for life. In our next special Global Challenges podcast, we will examine other alternative energy sources, including solar energy and hydrogen.

Today's podcast was written by Mark Sampson. Our editor is Michael Woods. I'm Adam Dylewski at ACS in Washington.





# New Fuels: Part 2

## Fuels from Ice, Water, and Sunshine

**C**ombating disease ... providing clean water and safe food ... developing new sources of energy ... confronting climate change. Hello from Washington, D.C. This is Global Challenges — a special podcast from ACS, whose 160,000 members make up the world's largest scientific society. Today's headlines are a drumbeat of dilemmas that affect the everyday lives of people everywhere. Global Challenges takes you behind those headlines for eye-opening glimpses of how chemistry is responding to those challenges — improving and sometimes saving people's lives. You'll hear the stories and meet the scientists whose discoveries are helping to make life longer, healthier, and happier for millions of people. Today's global challenge in this ongoing saga of chemistry for life: Providing cleaner, cheaper, and sustainable sources of fuel to meet our growing energy needs — gas hydrates, solar energy, hydrogen, nuclear power, and the continuing quest for conventional oil resources.

### The Ice that Burns

Step onto the deck of a scientific research vessel in the Atlantic Ocean off the East Coast of the United States. Special gear hauls up chunks of ice the size of softballs from beneath the ocean floor. Lying on the ship's deck in the open air, those chunks of ice come alive. The chunks sizzle and pop like bacon in a hot frying pan. Left alone, they just sputter away, disappearing into little puddles of water. But put a lighted match next to a chunk of ice. And it catches fire. This is no ordinary ice. This is “the ice that burns.” These are gas hydrates, one of the most exotic of a suite of new fuels that may help meet the world's energy needs in the 21st century.

In the first episode of this two-part podcast on new fuels, we focused on biofuels. These renewable fuels are made from plants. They include the familiar ethanol that is produced from corn in the United States and added to gasoline. Biofuels are liquid fuels that supplement gasoline and diesel to power cars and trucks. But transportation accounts for only one-third of the energy consumed in the United States every year.

The rest goes to other purposes. Producing electricity, for example, to light, heat, and cool homes, stores, and other buildings. Coal and natural gas now supply most of that energy. We need new fuels to join them. New fuels suitable for a world concerned about sustainability, global warming, and minimizing releases of carbon dioxide.

### Icy Energy Bonanza

That's why gas hydrates are generating a buzz. Gas hydrates form when methane gas from decomposition of organic material comes into contact with water at low temperatures and

### Did You Know?

- ◇ *Natural gas is odorless but suppliers add a chemical compound called mercaptan to give it an odor so that people can detect leaks.*
- ◇ *The sun is a gigantic nuclear fusion reactor that by some estimates produces enough energy in barely a minute to supply the world for one year.*
- ◇ *We measure energy with British thermal units (BTUs). One BTU is about equal to the energy released as a wooden match burns.*
- ◇ *Energy conservation by turning a room thermostat down just 1 degree Fahrenheit this winter will save about 3 percent of the energy needed to heat the room.*

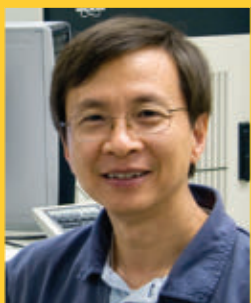
### HIGHLIGHTS

- ◆ **Discovering an economical way to “mine” gas hydrates would yield a bonanza of new natural gas — at least 100 times more than exists in all known resources of conventional natural gas.**
- ◆ **Scientists are making key advances in producing less-expensive and more-efficient solar cells that produce electricity from the sun.**
- ◆ **Motorists someday may “fill ‘er up” with water, fueling cars and trucks from self-contained solar energy systems that use sunlight to break water into hydrogen and oxygen.**
- ◆ **Nuclear fuel already provides 20 percent of electricity in the United States and advances in technology may boost its importance.**
- ◆ **Many other new sources of energy are on the horizon, including expanded use of thermoelectric technology devices that directly convert electricity into thermal energy for cooling or heating.**

## Meet the Scientists



Chris Hollinsed, Ph.D.



Yong Ba, Ph.D.



Harry B. Gray, Ph.D.

high pressures. Methane is the main ingredient in natural gas, which burns cleanly, with a smaller carbon dioxide footprint than any other fossil fuel.

Those cold, high-pressure conditions exist on land and sea in certain parts of the world. Beneath the seafloor in deep waters, for instance, and in permafrost areas of the Arctic. In those conditions, molecules of methane get trapped inside the crystalline cages that exist inside water ice. It's the methane that makes the ice that burns.

Estimates suggest that tremendous amounts of gas hydrates exist, including rich deposits in the United States. Areas about the size of Rhode Island off the coast of North Carolina and South Carolina, for instance, may contain enough methane to supply energy for the United States for 50 years. Alaska has vast hydrate deposits. So does the Gulf of Mexico. Globally, there may be 100 times more methane in gas hydrates than in all known deposits of conventional natural gas.

*“Tapping just two or three percent of that resource could produce an energy bonanza. The United States, Japan, India, and other countries are funding research programs to do exactly that. However, the challenges are every bit as great as the opportunities. We need economical ways of producing methane from these deposits, so that methane hydrates become competitive with conventional natural gas. That means scientific breakthroughs in chemistry, engineering, and other fields to make commercial production possible. I am optimistic that we will meet those challenges”*

That was Dr. Chris Hollinsed, director of the ACS Office of Research Grants, whose Petroleum Research Fund has been among the pioneers in supporting gas hydrate studies. Success in producing gas hydrates from the ocean floor will depend in part on research now underway in laboratories around the world.

Dr. Yong Ba, at California State University in Los Angeles, for instance, reported one such advance in ACS's scientific journal *Energy & Fuels*. It was a rapid method for making artificial methane hydrates in the laboratory, to help scientists study the structure of gas hydrates:

*“Our lab has discovered a way to grow artificial gas hydrates in a sealed glass tube. By growing hydrates in the laboratory, we can get a better understanding of the chemistry involved in the formation of natural gas hydrates. We also do NMR — nuclear magnetic resonance — to study the molecular dynamics of water and methane to understand the stability of gas hydrates. We hope that this study will lead to a better understanding of how to extract methane from these hydrates and to eventually use methane as fuel”*

### Fuel from the Sun

Now let's move from the cold ocean floor into the warm sunlight and another new source of fuel: solar energy. People are already using solar energy on a small scale. Solar water heating systems, for instance, substitute for natural gas in thousands of homes, mainly in Sunbelt areas. Photovoltaic cells, rather than coal, are producing electricity from sunlight.

Although some solar cells feed into the electrical grid, most photovoltaic energy powers on a small scale, in applications such as lighting street signs and phone booths. Solar currently provides barely 0.1 percent of the electricity used in the United States. That's a drop in what could be an enormous bucketful of new fuel.

*“There's enough energy reaching the Earth's surface from the sun every hour or so, maybe it's a couple of hours, but a reasonable number of hours, say in a day, to power the planet for an entire year.”*

That was Dr. Harry B. Gray, of the Caltech Center for Sustainable Energy Research, who spoke at ACS's spring 2008 national meeting in New Orleans. High cost, of course, is perhaps the major barrier to expanded use of solar energy. Here is Dr. Gray:

*“Right now, it's about four to five times as expensive per kilowatt hour for solar electric.*

*I priced it. Right now, it's about 25 cents a kilowatt hour versus about five, or six, seven cents, something like that for conventional sources."*

*"I think if we get it down to ten cents a kilowatt hour, there'll be a large-scale buy-in and there are great advantages of course to using solar electric. Once you make the initial investment, you can run lots of things then at lower cost than you are just paying . . . paying the power station for electric everyday. Once you make the initial investment, your . . . monthly costs are much less. So, I think at 10 cents per kilowatt hour, people will buy in. I think that will happen over the next five years."*

Dr. Gray says that scientists face two major challenges in bringing down the costs of solar energy:

*"We have to get cheaper solar cells made out of Earth-abundant materials that can be scaled up. That's the first thing that we have to do. The second thing, which is very important, is that we have to make fuel. Instead of electricity, we need to make fuel, hydrogen fuel, by splitting water so that at night we can run fuel cells and get electricity when the sun isn't shining."*

### Dr. Grätzel's Cells

In October, scientists in China and Switzerland reported a major advance toward meeting those challenges. Dr. Peng Wang and a group of colleagues that included Dr. Michaël Grätzel achieved record light-conversion efficiencies as high as 10 percent with a new type of so-called "dye-sensitized" solar cell. They made it with a ruthenium-based dye that helps boost the cells' light-harvesting ability. The new cells also show better stability at higher temperatures than previous versions, whose performance tends to drop after relatively short exposures to sunlight. Dr. Grätzel, of the Swiss Federal Institute of Technology in Lausanne, invented the first dye-sensitized solar cells in the 1990s and has reported on them in ACS journals and at ACS national meetings.

Compared to standard solar cells, the new cells work more like plants in converting sunlight to energy. Dye-sensitized cells also have a longer working life than amorphous silicon-based solar cells, which have a light-conversion efficiency of about 6 percent. Many scientists think that these dye-sensitized solar cells offer the best hope for making the sun a mainstay source of energy in the future.

Dye-sensitized cells are already being produced commercially, and the technology can create energy from a broad spectrum of light, both indoors and outdoors. Because they are relatively inexpensive and easy to produce, dye-sensitized cells have a good chance to become competitive with fossil fuels in the long term.

### Fill 'er Up! — With Water

Dr. Gray also mentioned the need for using solar energy to produce hydrogen fuel by splitting water molecules. In July of 2008, scientists described a key advance in that direction in *Science*, the journal of the American Association for the Advancement of Science. It is a new process that may allow ordinary water to be used as fuel in cars equipped with hydrogen fuel cells. Dr. Daniel Nocera, of the Massachusetts Institute of Technology, described development of a catalyst that can cheaply and efficiently split water into hydrogen and oxygen:



## Meet the Scientists



Daniel Nocera, Ph.D.



James B. Roberto, Ph.D.

*So water can be fuel.  
Water is fuel if you combine it  
with one other thing  
— light.*

*“We’ve discovered a catalyst that splits water into oxygen. The protons that are left behind we send over to another electrode and that’s a standard platinum electrode to make the hydrogen. And why is that important? It’s because if you can feed current from a photo-voltaic or use the sun directly on a material that has this catalyst on it you can then store the energy in the rearranged bonds of water to make hydrogen and oxygen. Now a lot of people might be thinking: “Now wait a minute. I remember seeing this experiment in high school. There was a teacher maybe that took two electrodes and put them in water and you saw hydrogen and oxygen bubbling off of them.” And we did the same thing. And what’s the big deal? The interesting piece of science is that we can do it out of just a glass of water. That’s it. With some Earth-abundant metals in it ... cobalt and phosphate. You can almost set this up at home and you could do it. You certainly could do it in a high school lab now. So it’s that simple. We have this very simple material that just deposits from solution onto an electrode and then it can split water into hydrogen and oxygen.”*

So there you have it: That familiar process called electrolysis, made faster and more efficient thanks to the power of chemistry. It has major implications for efforts to use the sun in producing liquid fuels for transportation. Here again is Dr. Nocera:

*“So water can be fuel. Water is fuel if you combine it with the one other thing — light. In itself water isn’t a good fuel. We all know that. But if I can take the water and water has an h-hydrogen, and o-oxygen bond. And I can take two water molecules and rearrange the bonds to make hydrogen and oxygen then that is then a fuel because you can take hydrogen and oxygen at some later time, put them over a fuel cell, and then get water back and electricity. And so that’s one way you can use water as fuel. That’s an indirect way as a fuel cell.”*

But Dr. Nocera isn’t just talking about fueling cars in the future. He envisions using these catalysts to solve our other electricity needs as well. And he’s optimistic that, given enough commitment and resources, a self-contained, solar energy system can be developed within just 10 years:

*“I’m also talking about even more than about transportation fuel because I’m also talking about getting off the grid at a power station. Two-thirds of your energy use is electricity. One-third is transportation. And so if you solve the transportation problem, you still haven’t solved the energy problem. And so the way I’m describing this I’m doing the whole thing: electricity generation and transportation.”*

Other new sources of energy that reduce greenhouse gas emissions and cut dependence on fossil fuels also are on the horizon. Consider just one technology — for making better thermoelectric devices. These semiconductor systems can directly convert electricity into thermal energy for cooling or heating, replacing conventional climate-control systems. Thermoelectric devices also can recover waste heat and convert it into electricity.

This technology already is being used on a small scale in portable beverage and picnic coolers, for instance, and to heat and cool seats in some cars. Advances in developing more economical and efficient thermoelectric devices could expand that application, according to a review of the technology in the September 2008 issue of *Science*.



### Nuclear Power

Experts believe that new technology will make nuclear fuel an increasingly important source of energy in the years ahead. More than 100 nuclear power plants in the United States already provide about 20 percent of our electricity. Globally, that figure stands at 16 percent. Unlike coal and oil, nuclear power does not release carbon dioxide that contributes to global warming. One form of nuclear energy, still a dream, offers the prospect of turning the world's oceans into a new source of fuel. That, of course, is nuclear fusion. Abundant supplies of its fuel — deuterium — exist in the world's oceans. Nuclear power also promises many countries increased energy security, with reduced dependence on imported oil.

*“The global utilization of nuclear energy has come a long way from its humble beginnings. But the effective utilization of nuclear power will require continued improvement in nuclear technology, particularly with regard to safety and efficiency. The projected growth in nuclear power has focused increased attention on the development of advanced materials, fuels, waste forms, and separations technologies. In all of these areas, the performance of materials and chemical processes under extreme conditions is a limiting factor.”*

That was Dr. James B. Roberto, deputy director for science and technology at Oak Ridge National Laboratory in Tennessee. Dr. Roberto reported on nuclear energy at the ACS spring 2008 national meeting in New Orleans. Scientists and engineers are responding to the challenges that have limited use of nuclear energy in the United States. For instance, a new generation of so-called “inherently safe” nuclear reactors are moving from design to reality. And the United States is moving ahead in addressing thorny problems such as how to deal with spent nuclear fuel and nuclear waste. Here is Dr. Roberto:

*“Chemists are heavily involved in addressing this challenge and in the future of nuclear energy through research on advanced fuels and waste forms. This is a scientific challenge of enormous proportions with broad implications for materials science and chemistry. Addressing this challenge provides an opportunity to revolutionize the science and technology of advanced nuclear energy systems for a brighter, more sustainable future.”*

### Conclusion

Revolutionizing science and technology. Addressing great challenges. Fostering a brighter and more sustainable future. Dr. Roberto's words go to the very heart of this series of podcasts. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life, when we focus on food. Today's podcast was written by Mark Sampson. Our editor is Michael Woods. I'm Adam Dylewski at ACS in Washington.



# Providing Safe Foods

It's that time of year again — Thanksgiving and the official start of the 2008 holiday season. Every Thanksgiving, family and friends gather to celebrate round dinner tables heaped high with those classic dishes. Roasted turkey, cornbread stuffing, cranberry sauce, mashed potatoes, yams, green beans, salad, pumpkin pie, pecan pie. The works!

There's praise and thanks for the food, of course. But we're also thankful for all the year's blessings. For grandma and grandpa. The love and support of family and friends. And, of course, thankful for all the scientific advances that make our meals safe during the holiday season and throughout the year.

Hold on there, now! What was that last "thankful"? Perhaps scientists do deserve a word of thanks for their often-invisible role in protecting our food supply. It takes just one encounter with food poisoning from *E. coli*, Salmonella, or other microbes to make a person oh-so-very-thankful. We are thankful to avoid a second dreaded bout of nausea, vomiting, cramps, and diarrhea.

## A Host of Food Safety Threats

Data from the U.S. Centers for Disease Control and Prevention — the CDC — suggests that 76 million cases of food poisoning occur in the United States every year. High-profile outbreaks linked to spinach, peanut butter, frozen pot pies, tomatoes, jalapeño peppers, and other foods have heightened public concerns.

In 2008, CDC reported significant declines in foodborne illnesses between the mid-1990s and early 2000s. However, there has been no significant improvement since 2004. New threats also are arising. Think the variant form of mad cow disease that can infect humans and cause an incurable brain disease.

Think the *E. coli* variant known as O157:H7. Think melamine contamination in certain imported foods. Scientists are responding to these and other challenges, from Thanksgivings past and present, with discoveries that promise to keep our food supply as safe as possible.

## Putting Poultry on a Germ-Free Diet

For example, Dr. Dan Donoghue, of the University of Arkansas, is attempting to reduce one of the major causes of food poisoning that arises from eating contaminated poultry.

*"Our ultimate goal is to reduce foodborne pathogens, which in our case is poultry, in the poultry gut. Foodborne pathogens are very prevalent in a lot of our domestic animals, and especially in poultry. We're trying to use a number of different techniques to reduce the incidence of foodborne pathogens in poultry."*

## DID YOU KNOW?

- ◆ About 76 million cases of food poisoning occur in the United States every year.
- ◆ Simply keeping cold foods cold and hot foods hot before serving can prevent many cases of food poisoning.
- ◆ Salmonella is better known, but another bacterium called *Campylobacter* (found on foods like raw chicken) is the No. 1 cause of food poisoning in the United States and the world.
- ◆ There are two main kinds of food poisoning. One results from toxins or poisons produced by microbes in food before consumption. The other results from microbes in food that infect the body and grow after consumption.
- ◆ Most cases of "24-hour flu," with its vomiting and diarrhea, actually are food poisoning.

## HIGHLIGHTS

- ◆ Researchers have discovered that simple changes in diet to include "natural feed ingredients" can reduce levels of the disease-causing bacteria in poultry that cause food poisoning in people.
- ◆ Sanitizing fruits, vegetables, and other foods eaten raw with irradiation kills dangerous microbes without making the food radioactive or less nutritious.
- ◆ A new antibacterial coating may lead to food wraps and other packaging materials with built-in disinfectants incorporated directly into their chemical structure.
- ◆ Miniature sensor devices based on cantilevers — that resemble a diving board — are being developed to quickly detect a wide variety of food poisoning bacteria before food reaches consumers.
- ◆ Chemists are developing a method that will allow meat packers to scan entire animal carcasses at once for the presence of spinal and brain tissue, which can harbor the infectious proteins that cause mad cow disease.

## Meet the Scientists



Dan Donoghue, Ph.D.



Brendan A. Niemira, Ph.D.



S. D. Worley, Ph.D.

*We've actually used natural feed ingredients, changing the birds' diet [to reduce food poisoning bacteria in poultry]. . .*

The two biggest bacterial threats associated with poultry are Salmonella and Campylobacter. Cooking chicken and turkey properly kills both microorganisms, and since eating undercooked poultry is not common in the U.S., few people become ill from eating roasted turkey at Thanksgiving. What does happen, though, is that cooks sometimes get sloppy in handling the raw birds, with the result that they may transfer Salmonella or Campylobacter to a utensil or other food that doesn't then get cooked. And though Salmonella is the hardier of the two organisms, Campylobacter contamination is actually the more difficult problem to solve.

*"One issue with Campylobacter versus Salmonella, and these are the two major pathogens in poultry, is that Salmonella is treated as an outside invader by the bird, and you can actually develop an immune response, and you can treat birds for Salmonella. It can be difficult and it can be expensive, but you can give them antibiotics and actually eliminate Salmonella from the birds. With poultry, until recently, we haven't had any treatments at all for Campylobacter because it's a normal microflora, so when you use an antibiotic it may reduce the concentration, but not eliminate it."*

Since antibiotics don't have the desired effect on Campylobacter living in the poultry gut, Dr. Donoghue decided to see if altering the birds' diet would have any effect. And based on the results of experiments that he and his colleagues published earlier this year, it appears that they may have hit upon a simple and inexpensive solution.

*"We've actually used natural feed ingredients, changing the birds' diet. These natural feed ingredients are already approved for use in poultry diets by the FDA, and one of those is caprylic acid that we've been working with. It's a medium-chain fatty acid, it's found in cow's milk, and in coconut milk, and it has antibacterial activity. We found that when you add it to the diet of poultry, it seems to consistently inhibit or reduce Campylobacter colonization of poultry."*

Though large-scale tests are still ongoing, Dr. Donoghue is optimistic that supplementing chicken and turkey feed with caprylic acid will soon lead to a safer Thanksgiving for all.

### For Uncooked Foods

Reducing the number of foodborne pathogens living on the farm is one obvious approach to keeping our food supply among the safest in the world. Another important tack is to sanitize food — particularly foods we usually eat raw — after it leaves the field using high-energy gamma rays or an electron beam, a technique known as food irradiation.

*"Some foods, such as meat, poultry, and seafood, are typically cooked before consumption, and this final heat treatment serves as an antimicrobial process, a kill step for these foods. However, for foods that are consumed either raw or only minimally processed, such as fresh and fresh-cut fruits and vegetables, the options are more limited. Aside from cooking, which is a thermal process, and irradiation, which is a non-thermal process, fresh produce doesn't have any other effective kill steps."*

That was Brendan A. Niemira of the U.S. Department of Agriculture's Agricultural Research Service. At the 235th ACS National Meeting, held this past April in New Orleans, Dr. Niemira reported on the studies that he and colleagues have undertaken to determine if food irradiation can kill *E. coli*, Salmonella, and other foodborne pathogens that can con-



taminate leafy green vegetables such as spinach and lettuce.

Exposing food such as lettuce or meat to gamma rays or high-energy electrons creates what are known as free radicals, highly reactive molecules that kill microorganisms by damaging their genetic material. Hydrogen peroxide works exactly the same way to sterilize a fresh wound. Within minutes of their formation, free radicals vanish, leaving behind nothing but dead bacteria.

Irradiation does not make foods radioactive, just as an airport luggage scanner does not make suitcases radioactive. Nor does it cause harmful chemical changes in food. The process may cause a small loss of nutrients, but no more so than with other processing methods such as cooking, canning, or heat pasteurization.

*“Research into the safety of irradiated foods began with the first applications of the technology back in the 1950s. Throughout the 1950s, ’60s, ’70s, and ’80s, these investigations used the best tools available, including chemical analysis and animal feeding studies that lasted for several generations, and the conclusions drawn by U.S. and international scientific bodies was that there was no evidence of any adverse effects of a diet that included irradiated food. In the 1990s, and even continuing today, the much more modern tools of cellular and molecular biology and advanced analytical chemistry have examined irradiated foods and have come to the same determination.”*

In fact, food irradiation has been used safely and effectively for decades to kill insects and bacteria on imported spices, and it’s also approved by the U.S. Food and Drug Administration and regulatory agencies in other countries to treat meat and poultry. But there’s been some question as to whether it will work with fresh produce. That’s where Dr. Niemira’s work comes in to play.

*“Currently, I’m researching how effective irradiation is at killing human pathogens that are hiding in sheltered spaces between the cells inside the lettuce leaf as well as pathogens that are protected within complex microbial communities called biofilms that are on the surface of the leaf. Ultimately, I’d like to know what effect these microscale life habitats are going to have on our real-world ability to use irradiation to make food safer. I’m also working on irradiation treatment of tomatoes and peppers to kill Salmonella, as these are products for which not much data exists.”*

In his research, Dr. Niemira has studied the effects of washing with plain water or a dilute bleach solution and irradiation on *E. coli* living deep within the cells of romaine lettuce and baby spinach. Data from these studies showed that washing, even with bleach, removed or killed less than 90 percent of the bacteria. Irradiation, however, killed at least 99.9 percent of the pathogens.

### A Food Wrap with a Zap

Of course, food can leave a processing plant free of any pathogens, but still end up contaminated as it winds its way through the food supply chain. But S. D. Worley, a chemist at Auburn University, may have a solution: a food wrap that incorporates its own disinfectant within its chemical structure. Dr. Worley described this coating in a recent report in the ACS journal *Biomacromolecules*. Here’s how this new polymer film works.



## Meet the Scientists



Arun Bhunia, Ph.D.



Raj Mutharasan, Ph.D.



Jacob Petrich, Ph.D.

*“We take a group called an N-halamine, which is a cyclic compound, and we modify a polymer so as to bond these structures onto the polymer. And then in all cases, once the polymer is coated onto a surface one can just expose that surface to a dilute solution of household bleach. That, of course, is aqueous chlorine. The chlorine binds to a nitrogen on the group that’s been put on the polymer. So what you then have is a source of anti-microbial chlorine. As we all know, chlorine is used to disinfect most of the water supply in America. This is the same idea except that the chlorine is bound to the surface until it’s needed. When a microbe lands on the surface, it extracts the oxidative chlorine from this polymer and it’s killed by an oxidation process.”*

Dr. Worley says that this N-halamine-containing polymer can be easily coated onto the surface of the same plastic food wrap that grocers and consumers now use. He adds that this same polymer could be used to coat nearly any surface that you’d want to keep free of bacteria, including paint that might be used in food processing plants or hospitals, and a variety of fabrics.

### Advance Warning Systems

No matter how successful chemists and other scientists are at developing methods for keeping our food free of pathogens, one fact remains. Bacteria are nearly impossible to eliminate completely from certain foods. Some, including ground beef and turkey, pose special problems.

Even small numbers of bacteria can quickly multiply to dangerous levels on the large surface area in ground meat. Chemists are responding to that challenge with new ways for rapidly and accurately detecting contaminated food before it reaches our dinner plates.

*“In light of all the recent outbreaks we’ve had with different food products, primarily meat and ground beef, and fruits and vegetables, one of the ways we could have impact in terms of controlling these pathogens is to develop some rapid method of testing. Some of the traditional methods take a long time to get positive or negative results. Sometimes it can take a week or 10 days. By this time products will have been sold or will have been consumed, so that’s not going to provide us with a strategy to reduce food-borne outbreaks. So for that reason, we need rapid methods that can give us results in a day or in some cases a few hours.”*

That was chemist Arun Bhunia of Purdue University, who is developing technology for detecting food pathogens. One of these systems uses living cells as biosensors.

*“And in that sensor we are actually allowing a million cells to be embedded in a three-dimensional configuration in the shape of a well, and when you have any pathogens or toxins, they cause damage to those cells, and you can detect the pathological action on those cells.”*

### Diving Board Detectors

Taking a different approach, Drexel University chemical engineer Raj Mutharasan is using tiny cantilevers — miniature devices about the thickness of a dime that resemble a diving board — to detect a wide variety of foodborne pathogens in as little as 10 minutes.

Over the past year, Dr. Mutharasan and his colleagues have published several papers, including two in the ACS’s *Analytical Chemistry*, demonstrating that their new sensor can detect trace amounts of *E. coli* contamination on spinach, spring lettuce mix, ground beef, apple juice, milk, and drinking water.

The key to this device is a property called the piezoelectric effect. Piezoelectricity refers to the ability of some materials to generate an electrical signal as they bend. Dr. Mutharasan’s team creates their cantilevers by first depositing a thin layer of a lead-based ceramic material onto a flexible slab of glass wired to circuitry that can measure the electrical signal from the cantilevers. They then coat these cantilevers with antibodies that recognize specific bacteria or bacterial toxins — the chemicals that pathogens release that actually make us sick.

### Good Vibes for Bad Bugs

When the device is turned on, the cantilevers begin vibrating rapidly, generating a baseline electrical signal. But when an *E. coli* cell, for example, binds to one of the antibodies, the frequency at which the cantilever vibrates changes, producing a change in the electrical signal.

And how will this device be used? Dr. Mutharasan explains that the first uses would be in a food processing facility, but that he can imagine that one form of the technology might even make it into our homes some day.

*“I envision two or three versions of the applications of this method. One that is currently being developed in which you have a little test tube that contains your sample and you insert the sensor, somewhat like a thermometer, and you have a little electronic device that interfaces, perhaps something like a smart phone, and in a matter of a short time period, maybe 15 minutes, you’ll get information that is adequate enough for you to take corrective action. That’s one version of this application, and we’ve done enough tests to be confident that format will work.”*

### Food Hot Spots

Even the best sensing technology has a major limitation: the quality of the samples used in the analysis. Workers usually obtain those samples by taking random swabs of food during processing. The approach may miss “hot spots,” isolated areas of contamination that later may spread throughout the batch. Food scientists address this problem by taking a large number of swabs that will hopefully pick up any contamination that’s present on a particular food.

Dr. Jacob Petrich, a chemist at Iowa State University, is taking a different approach. As described in the ACS’s *Journal of Agriculture and Food Chemistry*, this method enables meat packers to scan an entire animal carcass at once for the presence of spinal and brain tissue, which can harbor infectious proteins known as prions. Those agents cause bovine spongiform encephalopathy — mad cow disease — and its human counterpart, the incurable brain condition called Creutzfeldt–Jakob disease. Here is Dr. Petrich:

*“This all stems from research we began in 1997 to see if there was *E. coli* contamination on these products. Instead of deciding to look for single *E. coli* 0157 bugs on a carcass, we decided to look for the agent that puts it there in the first place, which is feces. And we discovered that feces fluoresces intensely when irradiated and that’s enabled us to develop devices that are actually in packing plants now. In the course of testing that device, we were in the course of irradiating a carcass with light and we realized that spinal cord fluoresced.”*

It fluoresced with a soft glow that could help safeguard meat from the agent responsible for a fatal brain disease. That’s really shining a light on our subject of providing safe food. Thousands of other scientists are doing the same, with discoveries that respond to challenges old and new of taking worry off the menu — on special occasions like Thanksgiving and every day of the year.

### Conclusion

Smart chemists. Innovative thinking. That’s the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we’ll examine how chemists are helping to make our food more nutritious.





# Providing Nutritious Foods

**B**ite into that chocolate. Make it a butter crisp. A maple walnut cluster. An orange cream. Or maybe chocolate toffee. Then savor the decadence as that luscious silky morsel melts into a mouthful's rush of pure pleasure. Years ago, that gratification was why people ate. Food also provided the calories for people to work, and filled the belly to drive away hunger pangs.

And that was pretty much the extent of it. A full stomach still remains a dream for billions of people today, especially in developing countries. The World Health Organization has estimated that one-third of the world is starving and one third underfed. For the other third — the well-fed and the overfed — food has taken on a new cache. Increasingly, people in industrialized countries are selecting food not just for taste and sustenance, but also for its potential effects in promoting good health.

*"I think people are beginning to focus more on food as a source of optimizing health and preventing disease rather than just providing the basic nutrients to just survive. I think as we go forward there's going to be a greater focus on the notion of functionality of food, and optimizing not just its nutritional capability but its ability to protect us against some of the debilitating diseases that are a real focus of Western medicine at the moment."*

## Foods with Function

That was Martina Newell-McGloughlin, director of the University of California's Biotechnology Research and Education Program. She was talking about a renewed emphasis among chemists, nutritional scientists, and plant biotechnologists to better understand how the foods we eat can protect us against some of our most serious health problems. Cancer. Heart disease. Alzheimer's disease, diabetes.

Be sure to remember one sound bite from her comments. The "functionality" of food. "Functional foods" are foods that may provide medical or health benefits beyond basic nutri-

## DID YOU KNOW?

- ◇ *Diet is derived from the Greek word **diata**, which means "way of life".*
- ◇ *Worldwide agriculture production boomed in the 20th century after development of the Haber–Bosch process for producing large amounts of inexpensive nitrogen fertilizer.*
- ◇ *Proteins, not sugars, are the world's sweetest substances. One protein, **thaumatin**, isolated from the African Serendipity Berry, may be the world's sweetest substance. Ounce for ounce, this protein is almost 3,000 times sweeter than table sugar.*
- ◇ *Herbalists have used rosemary for centuries for stomach upsets and other ailments. Modern food scientists are repurposing that aromatic evergreen with rosemary extracts in "active" packaging material that preserves food. The darker the color of a fruit or vegetable, the more nutrients it usually contains.*
- ◇ *A diet loaded with white bread, chips, sugars, and other rapidly absorbed carbohydrates is linked to age-related macular degeneration, a leading cause of blindness in older Americans.*
- ◇ *A diet low in animal fat and high in fiber, fruits, vegetables, and grain products can reduce the risk of many forms of cancers, according to the National Cancer Institute.*

## HIGHLIGHTS

- ◆ Scientists are developing "functional foods" that provide medical or health benefits beyond basic nutrition.
- ◆ Certain fruits and vegetables contain large amounts of "phytochemicals" — plant chemicals — that seem responsible for the healthful effects.
- ◆ One potent phytochemical is sulfurophane, found in broccoli, Brussels sprouts, cauliflower, and cabbage. It seems to have special effects in reducing risks of certain kinds of cancer.
- ◆ The color of health? Scientific discoveries indicate that it is bright, with brightly colored foods like blueberries, deep green vegetables, tomatoes, and purple grapes containing the most healthy substances.
- ◆ A material made from oat and barley hulls shows promise as a fat substitute that may reduce the calorie content of many processed foods.



## Meet the Scientists



Barbara Shukitt-Hale, Ph.D.



Richard Weindruch, Ph.D.



Navindra Seeram, Ph.D.

*Phytochemicals may protect the body against certain diseases and promote good health.*

tion due to the presence of certain chemical compounds. You've heard the terms: Antioxidants. Phytochemicals. And you know how scientific research has uncovered functionality — beneficial health effects — in some unlikely foods that once were considered bad for you.

We mean chocolate, especially dark chocolate. And red wine. And coffee. Some people even term these foods “nutraceuticals” because their effects do seem to mimic those of actual pharmaceuticals, or medicines. Developing these new foods will have major benefits, as Dr. Newell-McGloughlin notes:

*“The focus on modification of foods to improve the nutritional and functionality characteristics I think will help to alleviate the large medical costs that occur in the U.S.”*

### Casimir Funk Coins a Word

We have long known that food contains certain chemicals that we must eat in order stay healthy. In 1911, Polish-born chemist Casimir Funk, working in a lab in the United States, coined the familiar word used to describe these important components of food. Funk called them “vitamins.” Funk combined the word “amine” — that’s an organic compound derived from ammonia — with “vita,” the Latin word for “life.”

And over the next few decades, 10 scientists won Nobel Prizes in recognition of their pioneering work discovering and studying vitamins. Diseases such as beriberi, pellagra, scurvy, and rickets are rare or unknown in most developed countries thanks to the discovery of vitamins. So, too, are the nutritional deficiencies that used to be the major causes of blindness and anemia. Indeed, the U.S. Centers for Disease Control and Prevention considers conquering these ailments by improving the nutritional quality of food as one of the 10 great public health achievements of the 20th century.

### From Vitamins to Bioactives

Food scientists and others are now focusing on a relatively new cornucopia of chemicals produced by plants and often called phytochemicals. Phytochemicals may help protect the body against certain diseases and promote good health. These chemicals go by names such as lutein and lycopene, resveratrol and sulforaphane, polyphenols and triterpenoids, A-3-omegas and  $\beta$ -glucans.

Elizabeth Jeffery, a nutritional scientist at the University of Illinois in Urbana–Champaign, favors the term “bioactives” for these exciting chemicals:

*“The reason that I call them bioactives is that we have an idea about nutrients. Nutrients are compounds in our diet that we specifically need to help build the normal components of our bodies and to give us energy. The compounds that I study are bioactive, that is to say, our body will survive without them, but they’re like gentle probes causing our physiology to work better.”*

Among the particular bioactives that Dr. Jeffery studies is a particularly potent chemical called sulforaphane. Scientists’ research suggests that this compound has almost magical effects in reducing the risk of certain types of cancer, including prostate cancer and colon cancer. Dr. Jeffery’s work has shown that among other effects, sulforaphane boosts the body’s ability to detoxify and excrete a wide range of substances that can cause cancer. And recent data reported in the ACS’s *Journal of Agricultural and Food Chemistry* by Dr. Dipak Das, of the University of Connecticut School of Medicine, suggests that sulforaphanes foster changes in the body that could protect us from cardiovascular disease.

## Bravos for Broccoli

So what foods are good sources of sulfoxaphane and related compounds? Cruciferous vegetables such as broccoli, cauliflower, Brussels sprouts, and cabbage can be prodigious producers of sulfoxaphane. The same for radishes and wasabi, the green paste served with sushi. But the operative words here are “can be.” Dr. Jeffery’s research on sulfoxaphane in broccoli has shown that the amount of this bioactive varies greatly depending on the particular variety of broccoli and how it’s grown.

*“What I’m interested in is helping the growers know how to chose a broccoli that will grow with high levels of sulfoxaphanes so that it will protect you against cancer when you eat it.”*

Dr. Jeffery says that eating three servings a week of broccoli or any other cruciferous vegetable should provide enough sulfoxaphane to significantly reduce the chances of developing cancer. Even better, add some cooked tomatoes to the same meal. Tomatoes are a rich source of the healthful phytochemical, lycopene. Dr. Jeffery and University of Illinois colleague John Erdman, Jr., have found that tomatoes and broccoli appear to boost each other’s anticancer effects.

## Color Them Bright!

Broccoli and the other crucifers are certainly in the running for the title “Most Nutritious Veggies” thanks to the large number of bioactives they produce. On the fruit side of the plate, says Navindra Seeram of the University of Rhode Island, berries sit at the head of the class nutritionally.

*“Berries are very beautifully colored for a specific reason, and that reason is that they have antioxidants called anthocyanins, and these anthocyanins are really pigments, for example, blueberries are blue because of anthocyanins, which give you this color, whereas strawberries are red because of anthocyanins again, related compounds that give them their color.”*



Dr. Seeram is one of growing group of chemists and nutritional scientists who are striving to identify the bioactives in berries that benefit human health. In an issue of the *Journal of Agricultural and Food Chemistry* published earlier this year, he and other scientists working in the berry patch published a series of papers with the latest findings on how berries may protect against cancer, heart disease, and perhaps even Alzheimer’s and other degenerative conditions that affect the aging brain.

A good portion of what makes berries so good for us lies with the large number of antioxidants they contain, including the anthocyanins. Scientists think that antioxidants help the body protect itself from reactive chemicals known as free radicals. Natural cellular processes generate most of the free radicals in our bodies, a consequence of the fact that our cells use oxygen to produce energy. Smoking, infection, and stress can increase the body’s production of free radicals.

Dr. Seeram says that berry bioactives also boost a cell’s ability to repair DNA damage. That activity may help explain why diets rich in berries protect against many types of cancer.

## Meet the Scientists



Elizabeth Jeffery, Ph.D.



Dipak Das, Ph.D.



George Inglett, Ph.D.

*Eating a mix of berries on a regular basis may boost our health in many different ways.*

But all berries are not equal. Indeed, each berry has its own particular mix of bioactives. As a result, each type of berry is likely to have a unique set of beneficial effects on our health. Take cranberries, for example. Cranberries, alone among the berries Americans favor, produce a particular chemical that interferes with the ability of bacteria to stick to human tissues. Hence, the recommendation that we drink cranberry juice when we have a urinary tract infection.

### Berry, Berry Healthful

Blueberries and strawberries, our two most favorite berries, contain bioactives that may protect the brain against the effects of aging. Work by Dr. James Joseph and Dr. Barbara Shukitt-Hale at the U.S. Department of Agriculture's Human Nutrition Research Center on Aging has shown that strawberries appear to protect one particular region of the brain. Known as the hippocampus, it is involved in short-term memory and in our ability to remember spatial information, including directions on how to get to work or school in the morning. At the same time, a diet containing blueberries seems to protect the striatum. That area of the brain involved in planning our movements as well as in higher-order decision-making.

The bottom line from Seeram: Eating a mix of berries on a regular basis may boost our health in many different ways. The other lesson to learn from recent research, he says, is that eating berries themselves provides a greater health benefit than taking the various extracts and berry-based supplements available at the grocery store.

### Grrrr. .Great — Grapes

From a nutritional standpoint, grapes are one of the most widely studied fruits. And for good reason. Grape skins contain plentiful amounts of a chemical called resveratrol, which happens to be one of the most potent anticancer compounds known. Resveratrol also appears to fight heart disease, Alzheimer's disease, and perhaps even the most common form of diabetes and brain damage associated with strokes.

More intriguing still are the results from research published earlier this year by a large team of scientists led by Tomas Prolla and Richard Weindruch of the University of Wisconsin in Madison. Dr. Newell-McGloughlin didn't participate in this study. However, she has followed this research, and explains:

*"The actual effect has been found to simulate research that was done many, many years ago where scientists severely calorie-restricted rats. They give these rats perfectly nutritionally balanced foods, but at way below the calorie level you would need for a high level of activity on a day-to-day basis, and they found they could extend the life of these rats by up to 20%.*

*Resveratrol replicates some of these activities and if we can find a way of delivering this at sufficient levels we can effectively increase lifespan, but we can increase lifespan without noticeably impacting quality of life, because those rats may be living longer, but they were seriously mean because they did not have a good quality of life because they were starving.*

*Perhaps most importantly, this research showed that resveratrol is active at doses that would be easy to get from eating a handful of grapes a day."*

### Oh, Those Oats

Based on the accumulating evidence, nutritional scientists agree that everyone should eat a wide variety of colorful foods, such as grapes, broccoli, and blueberries. But one of the most



potent disease fighters comes not from a succulent fruit or brightly colored vegetable, but from the rather plain-looking oat.

Oats, like all other grains, contain a large amount of fiber, which is nothing more than indigestible material in food. The main molecular component of oat fiber — a particular type of sugar polymer known as a  $\beta$ -glucan — seems to be unique among fibers in its remarkable effect in lowering levels of LDL in the blood. LDL is the so-called “bad” cholesterol, which helps to deposit cholesterol inside blood vessels. Oat bran’s effect on LDL cholesterol is significant enough that the U.S. Food and Drug Administration allows foods made of oats to make the claim that they are heart healthy. Barley also contains significant amounts of  $\beta$ -glucan-based fiber.

As if that wasn’t enough, it turns out that  $\beta$ -glucans from oats or barley can be turned into a zero-calorie fat and carbohydrate substitute. And having an all-natural fat replacement could go a long way toward improving human health, says George Inglett of the USDA’s Agricultural Research Service laboratory in Peoria, Ill.

*“The facts of the matter are that you can most rapidly eat a more healthy diet if you cut out calories. Either these calories are from fat or carbohydrates, but getting foods in the diet that are not so rich in calories is the easiest way to reduce the caloric load in the diet and for health purposes it is by reducing the amount of fat.”*



Dr. Inglett, a food chemist, invented the process of turning oat and barley hulls into fat substitutes, a transformation that almost seems like something an alchemist would do, akin to turning lead into gold. But according to Dr. Inglett, there was nothing magical involved in this process.

*“Oh, it was a big challenge, but this is where the science comes in. This is why science and chemistry are extremely important in relating to food and health and the world in general.”*

Used primarily by the food industry, this oat-based fat replacement not only reduces the calorie content of many processed foods, but also stands to help eliminate the use of trans-fats in baked goods. And given that trans fats are the latest dietary villain in the ever-evolving story of nutritional science, that’s good news indeed.

### Conclusion

Smart chemists. Innovative thinking. That’s the key to solving global challenges of the 21st century. Please join us at ACS for the next chapter in this ongoing saga of chemistry for life. In our next special Global Challenges podcast, we’ll examine how chemists are addressing the challenge of protecting the public health.

## Meet the Scientists



James Joseph, Ph.D.



Martina Newell-McEloughin



Tomas Prolla, Ph.D.



# Promoting Public Health

**T**hat first precious cry of an infant. It will happen about 4 million times in the New Year. Parents in the United States will hear those precious sounds about once every eight seconds throughout 2009. A newborn next year can look forward to living an average of 78 years. That's nearly 30 years longer than children born a century ago. The U.S. Centers for Disease Control and Prevention — the CDC — estimates that about 25 years of that gain resulted from advances in public health.

Public health is the health of the population as a whole, rather than health considerations focusing on individual people. What were those life-extending public health advances? The CDC cited vaccination programs, better control of infectious diseases through improved sanitation and the development of antibiotics, better prenatal care, and safer workplaces, cars, and foods.

Whether the next 100 years will bring an equally dramatic increase in human lifespan is anyone's guess. But chemistry is playing a major — although often invisible — role in fostering continued improvements in public health in the 21st century.

These activities in protecting the health of the whole community of people range far afield. And they involve multiple areas of science. New methods for preventing, diagnosing, and treating infectious diseases that could trigger epidemics. Improved ways of safeguarding the supply of blood used for transfusion. "Green chemistry" that minimizes use and release of potentially toxic substances in industry. Confronting the challenge of antibiotic-resistant bacteria. And developing new vaccines.

## The Value of Vaccines

Take vaccines, for example. The CDC cited vaccination as one of the 10 great public health achievements of the 20th century. Today, vaccines are available to prevent almost 30 different infectious diseases in children and adults. Yet scientists are still struggling to develop vaccines against some of the most devastating human ailments.

We need a safer and more effective vaccine for tuberculosis, for instance, which causes almost 1.6 million deaths, mainly in developing countries. There is no vaccine to prevent

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## Did You Know?

- ◆ *Public health deals with the health of whole populations, rather than the health of individual people.*
- ◆ *Advances in public health are mainly responsible for the increased life expectancy at birth, which averages 75 years for men and 81 for women.*
- ◆ *The U.S. Public Health Service, the main health agency of the federal government, dates to a 1798 law establishing hospitals for seamen in the merchant marine.*
- ◆ *Experts regard vaccines as the most cost-effective way of preventing infectious diseases.*
- ◆ *A vaccine for HIV, the virus responsible for AIDS, could have major impact on public health, especially in sub-Saharan Africa, where more than 2 million new HIV infections occur annually.*
- ◆ *More than 60,000 people in the United States die annually from bacterial infections that are resistant to antibiotics.*



## HIGHLIGHTS

- ◆ **The science of objects 1/50,000th the diameter of a human hair — nanotechnology — promises to produce a new generation of life-saving vaccines.**
- ◆ **Chemists are meeting the challenge of antibiotic resistance by producing "two-for-one" antibiotics and other disease-fighters that attack bacteria in new ways.**
- ◆ **A chemist is helping to lead efforts to make affordable medications for HIV and malaria available in sub-Saharan Africa, where those diseases are on a rampage.**
- ◆ **Researchers are developing new ways to detect counterfeit drugs, the source of increasingly serious problems in some parts of the world.**
- ◆ **By merging chemistry and detective work, scientists are using "environmental forensics" to identify and track down the origin of environmental pollutants.**

## Meet the Scientists



Darrell Irvine, Ph.D.



Lester Mitscher, Ph.D.



Rolande R. Hodel, Ph.D.

*Developing vaccines that are stable at room temperature — unlike today's vaccines that must be refrigerated — is critical.*

scourges like malaria — 2.7 million deaths annually — or AIDS — almost 2 million deaths each year.

Why? Because training the immune system to recognize most microbes and launch effective attacks on them is amazingly complicated. That's how vaccines work, and making a new vaccine requires almost as much art as science.

### Taking the Ouch Out of Vaccination

Darrell Irvine, of the Massachusetts Institute of Technology, is among the scientists responding to that challenge. It's the challenge of developing the next generation of life-saving vaccines. Dr. Irvine and his collaborators are using nanotechnology to make vaccine cargo containers. These packets are about 50,000 times smaller than the width of a human hair. However, they can deliver walloping doses of the chemicals that signal the body to launch a protective immune response to infection. Here is Dr. Irvine:

*“Nanomaterials, and in particular nanoparticles, are quite interesting because they offer the ability to deliver high concentrations of vaccine antigens to various tissue sites, and particularly to the lymphoid organs where immune responses get started. They can enable the co-delivery of other signals that the immune system needs to receive, because when you have an infection the immune system responds very effectively because of factors that are called danger signals that are present in pathogens. The immune system then recognizes there's an antigen present and it needs to respond with a protective response. So nanomaterials give you the possibility to try to mimic the delivery of those signals.”*

### Invasion! Invasion!

Dr. Irvine reported on this work at the 236th ACS National Meeting in Philadelphia this past August. He points to one in developing effective vaccines: getting blood cells known as dendritic cells to take up and process antigens.

Antigens are the molecules that warn the body, “Invasion! Invasion!” They are on disease-causing viruses, bacteria, and even the pollen and mold spores that plague allergy sufferers. Dr. Irvine's nanoparticles do just that. They process antigens. Better yet, these nanoparticles have the potential to take the sting out of being vaccinated.

*“You can use nanoparticles to carry antigens through oral delivery, something you take as a pill to give you a vaccine, or you can use particles to carry antigens safely through the skin so that, for example, you could have immunization through a patch instead of with a needle, which could give you some advantages to how you store vaccines in addition to how you deliver them.”*

Developing vaccines that are stable at room temperature — unlike today's vaccines that must be refrigerated — is critical. Refrigeration is unavailable in many parts of the developing world, especially rural areas that lack electricity. That makes vaccinations difficult.

### Drugs vs. Bugs

Mention miracle drugs and people think, “penicillin.” Sir Alexander Fleming discovered penicillin in 1928. In the 1940s, Howard Florey, Norman Heatley, and Andrew Moyer turned Fleming's scientific curiosity into a medical mainstay by developing technology for mass production of the drug.

Penicillin signaled a dramatic victory in the age-old war between humans and microbes. But that victory was fleeting. By 1947, doctors began seeing the first signs of penicillin resistance in some bacteria. A new war had begun — drugs versus bugs.

*“It’s a growing problem. It has been with us since the beginning of antibiotics, but it’s gained steam over time as we use more and more antibiotics and as bacteria become more and more adaptable to their presence.... So it’s a conundrum — we can’t live without antibiotics these days, nor do we want to, but on the other hand, the more we use them, the more we tend toward resistance towards them.”*

That was Lester Mitscher, a medicinal chemist at the University of Kansas. His paper in the ACS’s *Journal of Natural Products* reviewed the multiple ways that chemists are meeting the challenge of antibiotic resistance. Mitscher points out that antibiotic resistance is a natural outcome of the same processes that drive evolution. Humans and microbes, after all, have lived together in a state of equilibrium for millions of years. In fact, we’ve made peace with many microorganisms that live in and on our bodies. Some actually are important for good health. But the discovery of antibiotics upset that equilibrium. Here is Dr. Mitscher:

*“This was actually a disaster for the bacteria. They die in enormous numbers, but we didn’t eradicate them — we didn’t expect to. But what we did is reset the equilibrium more in our favor. Well, they reproduce at a very rapid rate, and they’re genetically very versatile. And so what you have is co-evolution in action here. The bacteria have learned how to survive the effects of antibiotics, and they are now resetting the equilibrium point more in their favor. It hasn’t risen very high yet, but it’s risen more than we’re comfortable with, so we’ve become quite conscious of these problems lately.”*

### **Bacteria Shrugging Off Antibiotics**

Today, a spectrum of infections have become difficult to treat with antibiotics. They include tuberculosis, pneumonia, and certain staph infections. Fortunately, scientists have a wealth of tools available that are allowing them to better understand how resistance arises.

John Blanchard and colleagues at the Albert Einstein College of Medicine are one example. Reporting in the ACS journal *Biochemistry*, they described the molecular shape of a key enzyme that destroys several important antibiotics. Earlier this year, Xuan-Xian Peng and colleagues at Sun Yat-Sen University in the People’s Republic of China identified an entire network of proteins involved in bacterial resistance to the antibiotic streptomycin. Dr. Peng detailed this work in the ACS’s *Journal of Proteome Research*.

### **Two-for-One Antibiotics**

Medicinal chemists can use those insights to identify new ways of attacking microbes where they are still vulnerable. For instance, Paul Charifson and colleagues at Vertex Pharmaceuticals, writing in the ACS’s *Journal of Medicinal Chemistry*, describe a new antibiotic that can strike not one, but two bacterial targets simultaneously. The targets are two distinct enzymes that bacteria need to make copies of their DNA before splitting into two identical cells.





Just this summer, researchers at Forest Laboratories announced that a new cephalosporin antibiotic, named Ceftaroline, successfully treated serious skin infections caused by staph bacteria resistant to all other antibiotics. A week later, biochemist Shahriar Mobashery, of the University of Notre Dame, reported another advance in the *Journal of the American Chemical Society*. He described exactly how this new antibiotic works. It attacks the protein that makes these bacteria resistant to other antibiotics. The antibiotic actually prevents bacteria from making their outer cell wall, causing them to die.

### Supplying Life-Saving Drugs to Sub-Saharan Africa

The challenges of infectious diseases are especially great in sub-Saharan Africa, which faces epidemics of AIDS, tuberculosis (TB), malaria, and other diseases. While drugs are available in affluent Western countries to fight these deadly diseases, they are prohibitively expensive for many poor areas of the world. Here is Dr. Rolande R. Hodel of AIDSfreeAFRICA, a non-profit organization that hopes to increase access to life-saving drugs in sub-Saharan Africa:

*“Malaria, AIDS, and TB are still the big killers, and let me tell you a couple of things that are not widely known. For example, people don’t know that every day 8,500 people die in sub-Saharan Africa due to lack of access to drugs. And what we also found out is that we have proof that these diseases are worse together than they are individually. So the death rate increases greatly for someone with malaria who then contracts HIV-AIDS and vice-versa. Furthermore, if we want to get serious about making an impact on these diseases, we have to increase the aid to Africa from the current 0.17 percent of the gross domestic product to 0.7 percent that the United Nations calculated is needed. We’re basically treating Africa like we’re buying a car tire and thinking we have the whole car. And then we have the tire and wonder that it’s not working. If there’s not enough money to do the job, then we shouldn’t be surprised it’s not working.”*

*Yes, scoundrels do make a living — a very good one by all accounts — by manufacturing and selling fake antibiotics and other medications.*

Dr. Hodel's mission is also to empower Africans to become self-sufficient in producing these life-saving drugs. Her organization is currently supporting the development of Diamond Pharmaceuticals in Cameroon, a company that aims to reduce the cost of drugs in that country by packaging bulk generic drugs rather than importing the finished product.

This do-it-yourself drug packaging facility hopes to reduce the cost of needed drugs by as much as 25 percent. The company eventually plans to move into drug manufacturing, where it could reduce the cost by as much as 40 percent. Cheaper drugs could greatly boost needed supplies, ultimately saving lives among populations who need the drug the most.

In addition to its efforts in Cameroon, AIDSfreeAFRICA is hoping to expand its lifesaving-mission to other African countries, including Ghana and Rwanda. Here again is Dr. Hodel:

*“On top of my wish list is that we really need to add access to essential drugs as a basic human right to the other human rights we have. I want to share that my life has been enriched and changed in ways that I could have never predicted. I really want to encourage anyone and invite people to consider visiting or volunteering in Africa.”*

### Fighting Fake Drugs

Multiple-drug resistance is one consequence of the widespread use of antibiotics. Another is the result of greed and deceit — the rise of drug counterfeiters. Yes, scoundrels do make a living — a very good one by all accounts — by manufacturing and selling fake antibiotics and other medications.

Fake drugs are a chronic problem in many developing countries in South America, Africa, and Asia. Americans are by no means immune, with counterfeit drugs being offered for sale on the Internet. So how big a problem is drug counterfeiting?

*“The real answer is we honestly don't know, because the first thing you need to do to know if this is a growing problem is to have more measurements.... So you need to do surveys to tell what percentage of the drugs collected are fake. So I think that at the national level in the U.S., no it's not growing, but that doesn't include what you're purchasing online. If you're purchasing online, then all bets are off because you really don't know who you're buying from.”*

That was Facundo Fernandez of the Georgia Institute of Technology. This analytical chemist is developing new ways for detecting counterfeit drugs. Dr. Fernandez highlighted the problems of drug counterfeiting in the ACS journal *Industrial Engineering and Chemistry Research*. In a talk at the ACS national meeting in New Orleans this past April, he reported on a new test that he and his colleagues developed. It can quickly detect fake Tamiflu, the mainstay medication for preventing and treating both bird flu and common influenza.

*“Most people would agree that the conditions that a drug has to meet to be a good target for counterfeiters is that (a) it has to be in fairly high demand and (b) it has to be fairly expensive so the counterfeiting business can make a profit. Tamiflu is such a case; with the fears of pandemic influenza, there was a lot of scare and even many states were stockpiling Tamiflu.”*

### Testing with a Cell Phone

The new test relies on a method known as DESI-MS. It can analyze samples of Tamiflu in less than a minute with very little sample preparation. The standard method of analysis can

### Meet the Scientists



Facundo Fernandez, Ph.D.



Paul Philp, Ph.D.



William T. Cooper, Ph.D.

*We all live in the environment, and some of the most daunting public health challenges of the 21st century involve environmental pollution.*

take up to an hour. DESI-MS may be useful for large-scale monitoring of drug quality. However, it is not yet ready for consumer use. So Dr. Fernandez is collaborating with Michael Green of the CDC to develop a technology that would require a boxed testing kit and a cell phone. So what about Dr. Green's work?

*"He came up with a method where you will use your cell phone to check on the quality of your medicine. It's based on simple chemistry. You do a colorimetric reaction, your drug with a given reagent will develop a certain color, and then you take a picture with your cell phone and then you process that picture through software that will measure the absorbance, and you can relate that to a calibration curve and you can know that your drug is not only genuine, but that it has the right amount of the active ingredients."*

We all live in the environment, and some of the most daunting public health challenges of the 21st century involve environmental pollution. Confronting those challenges is a little-known group of researchers who combine science and detective work in a discipline known as environmental forensics.

*"Environmental forensics is related to the identification of contaminants in groundwater and in the environment in general and basically we're looking for these compounds because it's necessary to find out what the contamination is in the first place and then to figure out where it came from, who was responsible for it, how long it's been there, whether or not it is degrading. In a lot of cases, the aim of all these investigations is to find out who's responsible and who's going to pay for the cleanup."*

That was Paul Philp of the University of Oklahoma, who in August reported on his group's work in identifying common groundwater contaminants at the ACS national meeting in Philadelphia.

*"In groundwater the types of chemicals that we're looking at range from compounds such as MTBE — methyl tertiary butyl ether — which was used until recently as an oxygenate in gasoline; chlorinated solvents such as TCE, which are used at dry cleaning facilities and at military bases for cleaning engine parts and machinery; the BTEX compounds — benzene, toluene, ethylbenzene and xylene — which are the common contaminants that arise from gasoline. There are some pesticides that we look at that are in groundwater. There's a wide range of compounds, basically."*

### **Awash in Trash**

While Dr. Philp is concerned about the fate of industrial chemicals, William T. Cooper at Florida State University is helping solve a potential health-related pollution problem that every one of us contributes to — municipal landfills. People in the United States produce more than 250 million tons of solid waste each year. Most of that winds up in landfills. Dr. Cooper explains:

*"Surprisingly enough, when our household wastes are put into a landfill they degrade, and they exude a lot of very complicated chemicals that filter down through the waste and reach the bottom of the landfill.... And indeed, it's so concentrated in these materials that we can't normally send it to a waste-water treatment plant."*



Using their skills as analytical chemists, Dr. Cooper and his colleagues analyze this dark, smelly, contaminated liquid — known as landfill leachate. This stuff leaches, or seeps, through piles of solid waste. As reported at the August ACS national meeting, his group uses the resulting information to invent a simple, low-cost process to break down the most worrisome substances in this potentially toxic liquid. This process uses ozone and ultraviolet radiation. And as Dr. Cooper explains:

*“The results have been very promising. What we’ve seen is that the combination of ozone and UV irradiation tends to remove a lot of the aromatic compounds in this mixture, and it’s the aromatic compounds that give this leachate its dark color. And an additional byproduct has been that these aromatic compounds are losing their color, but we’ve also been adding oxygen atoms to these molecules, and once you add oxygen to these molecules, it’s much easier for the microorganisms to degrade the compounds.”*

In fact, this treatment works so well that the resulting liquid can then be sent safely to a standard waste-water treatment plant. Problem solved.

### Conclusion

“Smart chemists. Innovative thinking. That’s the key to solving global challenges of the 21st century. Today’s podcast was written by Joe Alper. Our editor is Michael Woods. I’m Adam Dylewski at ACS in Washington.





# Acknowledgments

## **Global Challenges/Chemistry Solutions (GC/CS)**

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**Scriptwriters:** Joe Alper, Marvin Coyner, Mark Sampson, Michael Woods

**Design:** Julie Farrar with assistance from Rhonda Saunders and Michelle Powell

**Copyeditor:** Kelley Carpenter

**Podcast voice:** Adam Dylewski

**Audio production:** Adam Dylewski and Janali Thompson

**Creative Commons-licensed sound effects:** freesound.org

**Music:** ccmixer.org and Kevin Macleod

**Web content:** Doug Dollemore and Kirsten Dorans

**Spanish language podcast:** Bradley Miller, Francesco Gomez, Lourdes Echegoyen

**Advisory committee:** Jane Shure, chair. Pamela Ayre, Rudy Baum, Nancy Blount, Brian Crawford, James Corning, Stacey Emans, Analisa Fulwood, Chris Hollinsed, Flint Lewis, Kevin McCue, Janice Mears, Beth Merricks, Jonathan Morgan, Meka Parker, Robert Rich, Gabriel Rojas, Maureen Rouhi, Glenn Ruskin, Cheryl Shanks, Kathleen Thompson, Raman Venkatesh

**Global Challenges/Chemistry Solutions web site ([www.acs.org/globalchallenges](http://www.acs.org/globalchallenges)):** Asa Baylus, Tamara Combs, Dave Pelovitz, Rebecca Presgraves, Trevor Rees, Elizabeth Rupert, Annie Sinakou, Laurie Trayers, Louise Vorees

**Cover credit:** Illustration by Julie Farrar with images courtesy of Dosch Design

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ACS' Chemical Abstracts Service (CAS) Division provided SciFinder® research support for GC/CS.

The ACS Publications Division provided financial support for production of GC/CS

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