the seasonal variation and geographical distribution of substances that influence air quality and climate."

As MOZAIC enters a new phase as part of IAGOS, better, lighter-weight instruments are key, says Volz-Thomas. The aim is to reduce the total instrument weight to 100 kg while also expanding the measurement capabilities. "We have to keep transport costs at a limit acceptable to airlines—so far they have carried our instruments for free, and we hope they continue." The first IAGOS instruments are slated to fly next year. The aim is to raise enough funding to fly instruments on 20 planes within 10 years.

For its part, CONTRAIL combines air sampling and continuous measurement. Air samples are collected on twice-monthly flights between Tokyo and Australia and other equipment monitors CO_2 continuously. The project uses five planes.

The three projects have different scientific emphases and "also have quite different flight routes," says MOZAIC coordinator Jean-Pierre Cammas of the CNRS Laboratoire d'Aérologie in Toulouse, France, which along with Jülich and France's national weather service is one of the project's main science partners. "The projects are complementary."

Blue skies research

Examples of CARIBIC research include using mercury measurements in three-dimensional global atmospheric transport models, characterizing aerosols in the upper troposphere and lower stratosphere, and deducing vertical profiles of gases from scattered light. "We have three tiny telescopes built into the pylon. We let in light, not air," says Ulrich Platt of the University of Heidelberg. "The advantage of spectroscopy is that you can see the unknown. We are looking in the near-UV at 300–400 nm." One highlight, he adds, "was finding precursors to OH [hydroxyl] radicals, which provide self-cleaning of the atmosphere. We have found that thunderstorms might contribute a lot to self-cleaning of the atmosphere."

In the aerosol intake, air is slowed from about 250 m/s to a few m/s so the particles don't smash into the walls of the collection tube. Nuclear physicist Bengt Martinsson of the University of Lund, Sweden, and colleagues analyze samples using transmission electron microscopy, particle-induced x-ray emission, and other methods to identify and quantify aerosols. "The picture emerges of little transport of particulate matter from low altitudes by deep convective systems," says Martinsson. Instead, he adds, aerosols in the upper troposphere are produced from gaseous precursors that have been transported up from lower altitudes.

Among MOZAIC's most important findings so far, says Cammas, is the presence of ice supersaturation. "The upper atmosphere is much wetter than we thought. It's quite important for the formation of cirrus clouds and the formation of contrails by aircraft. Contrails can generate other cirrus clouds, which could impact climate." MOZAIC also discovered high summertime levels of nitric oxide over the eastern coast of the US, says Volz-Thomas, and ozone levels depend on NO. "There is NO from automobile exhaust, brought up by convection. A lot comes from lightning, too, and there is NO from aircraft." Because of the incomplete vertical transport description in models, he adds, "the impact of aircraft on ozone is at least disputable."

Indeed, says Volz-Thomas, a big debate at the moment is whether it's true that "because of their additional effect on ozone, methane, and cloudiness, aircraft emissions influence climate three times more than the same amount of CO_2 emitted from a ground-based power plant." In a new emissions trading scheme, the European Commission (EC) plans to apply charges based on that assumption. "Airlines want to know if the factor of three is correct. Our data will help answer this."

Seeking sustainability

"We are trying to get IAGOS to be a global, sustainable infrastructure with long-term funding," says Volz-Thomas. "If you want to look at trends, you need 30 years or so of continuous record keeping. But funding agencies usually want to see something sexy, something new." IAGOS leaders put the cost of modifying aircraft, building new instruments, and running the project at about $10 million a year.

Making a united case for funding is one reason CARIBIC has teamed up with MOZAIC. Says Volz-Thomas, "We hope IAGOS will be an important part of the in situ infrastructure for the atmospheric part of GMES"—Global Monitoring for Environment and Security, a new European service expected to go online around 2012—"and GMES could help fund IAGOS." Gathering data with commercial airliners "is turning into a combination of research and monitoring climate," adds Cammas.

Starting in September, IAGOS has EC funding for four years to get countries to sign on to the project. "The main objectives are to prepare the legal and organizational framework for IAGOS and to raise funds for operating it over a long time," Volz-Thomas says. Potential sources of money are participating institutions, national funds, and, via GMES, the EC, he adds. "Will they consider this project important enough?"

Toni Feder

DOE urged to proceed more deliberately with global plan to expand nuclear power

Critics of the Global Nuclear Energy Partnership say the Department of Energy is rushing to commercialize unproven technologies.

In March the UK became the 21st country to sign a nonbinding "statement of principles" that attempts to address the conflicting Global Nuclear Energy Partnership goals of spreading nuclear energy generation throughout the world while preventing the spread of technologies needed to manufacture and recycle nuclear fuel to nations that don't already possess them. Signatories to the GNEP include the nuclear haves Russia, China, Japan, and France, have-nots like Senegal, Jordan, and Ghana, and nations that have relied on other countries for their nuclear fuel, including the former Soviet satellites Hungary, Bulgaria, and Lithuania.

Many experts believe that a vast expansion of nuclear power is the only plausible option for meeting the anticipated explosion in electricity demand from the developing world while mitigating global warming. According to one widely accepted computer model, the Mini Climate Change Assessment Model, stabilization of atmospheric carbon dioxide concentrations at 550 ppm—a level that many climate scientists fear is still too high—will require as many as 4000 new nuclear reactors, said Victor Reis, a senior adviser at DOE. "This is an area where the US can provide some serious leadership," Reis recently

told an audience at the American Association for the Advancement of Science.

But the GNEP's opponents argue that the program's adoption will increase the risk of proliferation of fissile materials that could be fashioned into a nuclear explosive. They charge that the program can't be justified on economics and say it will add to the environmental problems resulting from the use of nuclear energy by creating new waste streams.

Reactors and nuclear fuel

Unveiled in 2006 by President Bush, the GNEP envisions the US and other nuclear powers supplying aspiring nuclear nations with both advanced reactors and the nuclear fuel for them. For their part, recipient nations would agree to return their spent fuel to its nation of origin and pledge not to develop uranium-enrichment or spent-fuel reprocessing capabilities of their own. The US and other fuel-supplying nations would reprocess the spent fuel and recycle its plutonium into fresh fuel.

The GNEP blueprint includes R&D and construction of a reprocessing and fuel-fabrication facility and a fast neutron "burner" reactor that would transmute the long-lived actinides from spent fuel as it generates electricity. Together, the two technologies could so reduce the amount of waste needing storage that the Yucca Mountain dump in Nevada will suffice for the rest of the century. But achieving that goal would require deploying 40 to 75 advanced fast reactors.

DOE's implementation strategy for the GNEP calls for the formation of a government–industry partnership by the end of this year to proceed with detailed design and planning to build the two technologies at a commercial scale. According to the plan, construction would proceed as soon as final designs can be validated. But it is unlikely that the agency's schedule will be met; last year Congress slashed DOE's $405 million GNEP request to $179 million and expressly prohibited construction, technology demonstration, or commercialization activities, saying the technologies were not ready for deployment. The agency has requested $301.5 million for the Advanced Fuel Cycle Initiative, the GNEP's technology component, for fiscal year 2009, but lawmakers are widely expected to put off action on appropriations bills until after the November elections.

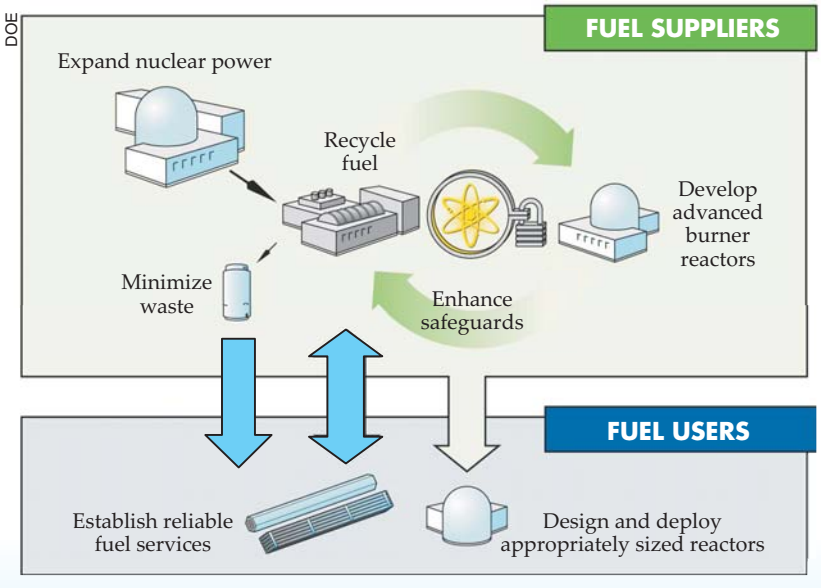
Immature technologies

Two groups of outside reviewers also have urged DOE to apply the brakes to the GNEP. The Government Accountability Office warned in a May report that moving to construction too rapidly will "likely require using unproven evolutions of existing technologies" and ultimately limit their usefulness for nuclear waste reduction and proliferation prevention. A National Research Council review completed late in 2007 reached the similar conclusion that the GNEP technologies are immature. The NRC committee recommended that DOE continue with R&D, but said the agency could do more to revitalize nuclear power in the near term by focusing on assisting domestic utilities with the licensing and construction of advanced light-water reactors. Thomas Cochran, senior scientist with the Natural Resources Defense Council and a GNEP opponent, advised the nuclear industry to place highest priority on enacting a cap on US carbon emissions. A charge of $40–$60 per metric ton of carbon dioxide emissions likely will be needed for nuclear energy to compete with fossil-fuel generation, he told the House Committee on Science and Technology in April. Cochran said the GNEP "would be a disaster for international security and a multinational economic boondoggle of staggering proportions."

Robert Fri, chair of the NRC review panel, told a House hearing in April that the GNEP's accelerated deployment strategy "will create significant technical and financial risks by prematurely narrowing technical options." Although DOE argues that building the facilities sooner rather than later will save time and money, "just the opposite is likely to be true," Fri warned.

Defending the GNEP, Idaho National Laboratory director John Grossenbacher told the same hearing that "waiting until someone determines the economics are right to begin investing in alternate and advanced technologies tends to produce the kind of crises the world faces today, with oil prices well over $100 a barrel."

Officials at DOE are continuing to assess the feasibility and projected costs of building the GNEP facilities. In March four industry consortia received follow-on awards from the department totaling $18.3 million to study the fuel-recycling and fabrication plant and the burner reactor. Preliminary designs and cost and schedule estimates that those consortia prepared under earlier contracts were released this spring. By one estimate, the cost of the fuel-recycling and fabrication facility alone would be $16.6 billion, and it could be operating as early as 2023. An initial burner reactor could be built by 2025, although one study suggests it's likely to be



The Global Nuclear Energy Partnership plan by the Bush administration would promote more widespread use of nuclear power abroad by having the world's major nuclear powers supply reactors and fuel to developing nations. Those nations would return their spent fuel to the country of origin for recycling into new fuel.

mid-century before commercial versions are in operation.

Reprocessing revival?

No feature of the GNEP is more controversial than reprocessing, a technology that the US forswore for civilian use in the late 1970s out of concern that reprocessed plutonium could be stolen or diverted for weapons purposes. Princeton University professor Frank von Hippel, a longtime opponent of a closed nuclear fuel cycle, told a May roundtable discussion at the Carnegie Endowment for International Peace that nearly all nations that have acquired reprocessing capabilities—Pakistan, Brazil, and India among them—started nuclear weapons programs. South Korea, a GNEP member, recently declared its intention to develop a reprocessing capability. The GNEP does not require its members to renounce reprocessing, acknowledged Carter Savage, DOE associate deputy assistant secretary for nuclear energy. On the other hand, he added, GNEP members have no obligation to provide their reprocessing technology or know-how to the South Koreans.

Environmental and antinuclear activists are skeptical of public pledges by DOE to not deploy a reprocessing technology that yields weapons-usable plutonium, as does the plutonium–uranium extraction process that is used by France and the UK. But it isn't clear what chemical separation process will be used, and the experts don't agree on the extent to which various alternatives will serve as a barrier to proliferation.

Critics of the GNEP also argue that reprocessing can't be justified economically. A dozen European nations have stopped buying reprocessing services from France, the UK, and Russia, von Hippel said, because they found that storing their spent fuel after a single pass through the reactors is less costly. But Alan Hanson, executive vice president of Areva, the French nuclear conglomerate that operates La Hague reprocessing complex, countered that the economics will vary with the price of uranium, which has fluctuated between $31 and $138 per pound in recent years. Reprocessing adds about 6% to electricity rates in France, which has the lowest rates in Europe, he said. "We know exactly what it costs to reprocess, but nobody has even the slightest idea what it will cost to store spent fuel," Hanson told the May roundtable.

Indeed, storage costs can't be estimated as long as the already decades-long delay with building the Yucca Mountain site drags on. But even if the repository is completed—not before 2020, according to DOE—it will have only enough room for spent fuel that is generated through the year 2010 (see PHYSICS TODAY, June 2008, page 28). Without reprocessing, DOE warns, a second repository will need to be built to accommodate the growing quantities of spent fuel that will result from a revitalized US nuclear industry, let alone material that will be shipped back to the US under the GNEP. **David Kramer**

Social networks link interdisciplinary scientists

Analysis of social networks has become a many-body problem, attracting physicists and uniting once-divergent disciplines.

Ten years ago newly hired mathematical physicist Jennifer Chayes told her boss, Microsoft Corp founder Bill Gates, about new methods, derived from the phase-transition theory of spin glasses, to solve constraint-satisfaction problems in social and other networks. She warned him, however, that they "would take 100 years to pay off."

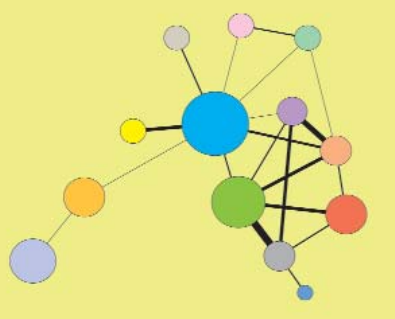
Chayes, who cofounded Microsoft's theory group with her husband and fellow physicist, Christian Borgs, recently contacted Gates to say, "I can't believe it, Bill. It has only taken 10 years to pay off."

Now, as director of Microsoft's new research laboratory in Cambridge, Massachusetts, Chayes will assemble and lead groups of social, computer, and physical scientists to model and design online social networks. Microsoft Research New England is the company's sixth research lab and the first with the mission of bringing together social and computer scientists to work on algorithms for social computing applications. More than just message boards, online social network applications such as Facebook, MySpace, and LinkedIn have become popular venues for advertising and search companies; industry analysts speculate that the new Microsoft lab and the company's bid for internet rival Yahoo Inc point to the urgency that the software giant is placing on competing online. Microsoft Research New England is expected to open this summer, just less than a year after it was first proposed, says mathematician Henry Cohn, a founding member of the new lab. "One of the advantages of industry is that when there is a compelling case for something, it can get done quickly."

Use of the Web has surged with the popularity of so-called Web 2.0 applications, which allow users to generate content and form communities. Several physicists, including Chayes, saw opportunities in the late 1990s to apply statistical mechanics principles to analyze complex networks like the Web. Peter Norvig, director of research at Google Inc, says the online search and advertising company employs "well over 100 people with one or more degrees in physics" to work on mathematical problems. "The reason I think that physicists do so well [in network theory] is that we are used to dealing with very large systems with lots of similar and interacting entities," says Chayes. "In the case of the World Wide Web, for example, there are on the order of 100 billion static webpages and even more dynamically generated webpages."

Highly connected hubs

Researchers studying self-organizing social networks look at how links are formed between individuals, whether some individuals or nodes are better connected than others, and the collective action or behavior of the entire network. In the past social scientists relied on surveys and questionnaires, but on the Web "social behavior is self-documenting—it leaves traces behind," says Microsoft research sociologist Marc Smith, who studies and designs improvements for



MARK NEWMAN

A network of coauthors among physicists who had published papers on networks as of 2003 shows the formation of discrete communities, denoted by colored nodes; the size of nodes corresponds to the size of the community. The thickness of the links connecting the nodes is proportional to the number of pairs of collaborators between communities.