warm to the bottom. Sea-level rise is not going to stop, even if we turn the carbon dioxide tap off tomorrow.

Another impact is more heat waves. A heat wave in Europe in 2003 killed over 20 000 people. It was completely unprecedented, way outside the bounds of normal natural variability. Scientists who have studied it concluded that most of the risk of that event arose from the increase in greenhouse gases. As the Earth warms further, such a summer is likely to be normal by the middle of the century and [be considered] a cool summer by 2100. That's something to make one sit up and think.

The third impact is on the hydrological, or water, cycle. With more water vapor in the atmosphere because of more evaporation from the warmer oceans, there will be more average rainfall. That is already occurring in some parts of the world. But that extra water vapor provides more energy for the hydrological cycle through the release of latent heat as water vapor condenses to form clouds. The result is that rainfall will tend to come down in more intense storms—hence more floods. It also means there will tend to be more frequent and intense droughts.

Climate models, which include all the physical processes and all the dynamics and so on, don't tell you exactly where all this is going to occur, because we are not clever enough yet. But the tendency to more frequent and intense floods and droughts is a robust result. Recent scientific papers estimating the likely increase in such events suggest possible increases of factors of 5 and even 10 by later this century. An increase by a factor of 5 in the number of floods in many parts of the world would be very devastating. And droughts lasting years rather than months—an expectation from the models—is a very frightening prospect, particularly in parts of the world which are prone to drought and where they don't have the ability to cope with it.

So there are going to be lots of environmental refugees. We are talking perhaps hundreds of millions of environmental refugees in the world by 2050.

That's the story I tell. I don't hype it up. I believe in giving the most conservative picture I can while being faithful to the evidence. It has been generated through much lively discussion and debate within the IPCC by hundreds, even thousands, of the world's best climate scientists.

PT: Before the G8 meeting in Germany last June, you told me about a statement that the presidents of the science academies of the G8+5 nations—the G8 plus observer countries Brazil, China, India, Mexico, and South Africa—had signed, appealing to the G8 to take action on climate change.

JH: Yes, those academies don't get together over many issues. They don't write statements of this kind very often. There could not be a stronger statement from the world's top scientific community.

PT: In the end, though, the G8 nations did not make climate change a major topic at their recent summit.

JH: Their actions did not meet the gravity of the problem. Some progress was made, in that the nations are still engaged. But the lack of urgency was very disappointing, especially on the part of the US. President Bush said there could be no definite agreements or targets until 2009, when he will have left office. That was a great shame because we really need to get on with it. Certainly [German chancellor Angela] Merkel was very much behind our statement. She is a scientist by background, she understands climate-change science, and she is very keen to see the G8 really move on the subject. She even spoke about limiting the temperature increase to 2 °C above preindustrial temperatures. That's the sort of target we should be discussing. It will be a tough target to reach, but then we have a tough problem.

The task nations are faced with is, How do you treat all the nations of the world—or at least the nations who are significant emitters—fairly? How can they agree to targets for their emissions to be reduced when the disparity between per capita emissions is so enormous? The United States, Canada, and Australia emit about six tonnes of carbon per capita per year. It's about two and a half tonnes for the European states, about one tonne for China, and about a quarter of a tonne for India.

PT: Some people would say that having ruined or used up resources on Earth, we should set our sights on colonizing Mars or other planets. What's your view?

JH: Well, it could be interesting to go to Mars and see what's there. But the practicalities of moving even small numbers of people to other planets, the energy and resources required to get them there, are just enormous. So it's really not a sensible idea. The Earth will not become wholly uninhabitable, although because of lack of water, droughts and floods, and sea-level rise, substantial areas will become less habitable. But you cannot put hundreds of millions of people on Mars or the Moon or anywhere else in space. You'd be lucky if you put two or three there. The scale of the operation is completely out of kilter with what is required to do something about global warming. We'd be much better off in putting efforts in doing something here.

PT: Is there any area that the US is doing well in regarding combating climate change?

JH: The US is pushing the technology quite hard, and that is good. But we don't only need technology. Governments need to set a framework in which the technology can thrive and can really get into the marketplace. The opportunities for industry to help reduce carbon dioxide emissions are large. We have, for instance, to sequester the carbon dioxide emitted by big fossil-fuel-powered stations. We need very large growth in renewable energy sources—solar, biomass, use of waste of all kinds, et cetera. We have to get on with these things, fast. The challenges to the world are very strong. What will the cost of action be? Actually not that much—less than the loss of one year's economic growth over 50 years is often quoted—and certainly very much less than the cost to the world of doing nothing.

Toni Feder

Multiple problems push LHC start to next spring

CERN engineers are relieved to have more time to finish constructing the LHC.

In June CERN director general Robert Aymar announced that the $7 billion Large Hadron Collider would start up in May 2008, eight months later than planned. The delay was no surprise to accelerator and particle physicists, and it was generally blamed on a highly publicized failure related to magnets made at the US's Fermilab. Actually, the magnets only added to other complications at the LHC.

"We've had to adjust the schedule to take into account the problems we've had," says LHC project leader Lyn Evans. The current plan is to begin engineering trials at 900 GeV next May and then ramp up to 14 TeV by mid-July. Even with the delays, Aymar says that for physics experiments, "the startup date remains exactly the same—July 2008."

The LHC was first proposed in 1984,

PAUL GUINNESSY

Some 85 meters underground at the Large Hadron Collider, Peter Limon stands next to some of the Fermilab magnets that need fixing.

and installation began in 2000 after an earlier accelerator, the Large Electron–Positron (LEP) Collider, was shut down. To save costs the LHC uses the same tunnel 85 meters below the surface and some of the same equipment as the dismantled LEP.

The LHC will be able to study the inner structure of matter on the smallest scale yet, says CERN theoretical physicist John Ellis, and should help answer questions such as why quarks, leptons, gauge bosons, and neutrinos have mass, and also explain the asymmetry between matter and antimatter.

Industrial contracts for the LHC were first awarded in 1994. "Thirteen years is not long for a project of this magnitude," says Evans, "but it is a long time for industry, and we've had to face issues such as companies going bankrupt and litigation, issues that have given us problems in four or five instances. I'm very happy now to have all of the hardware at CERN, and it's now in our hands."

Magnet malaise

In the LHC, protons will be accelerated in two counterrotating beams. At four points along the ring, the protons collide; one of four detectors—ATLAS, the Compact Muon Solenoid (CMS), LHC*b*, or ALICE (see page 90 of this issue)—sits at each collision point. The LHC uses an unprecedented 6000-plus superconducting magnets to position and focus the beams. "We did a lot of prototyping work to validate our design principles before building the machine," says Evans.

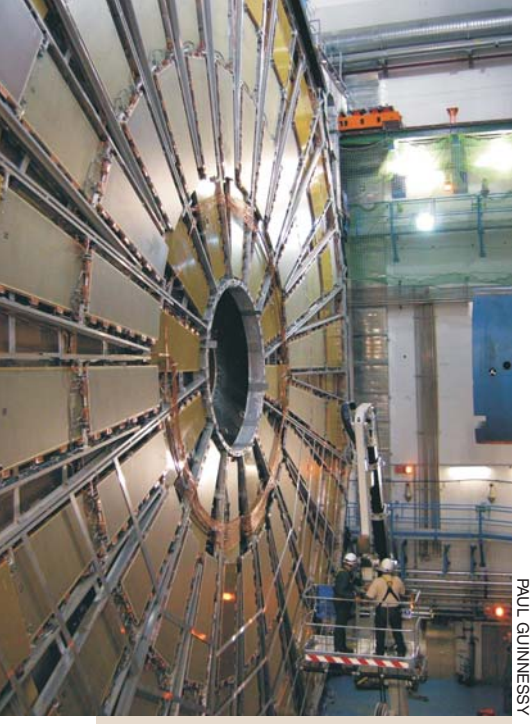
The LHC delays were initially blamed on the 24 focusing magnets provided by Fermilab that were designed to squeeze the proton beams together to create collisions. In March, during a pressure test while cooling a magnet in vacuum to 1.9 K with liquid helium, "there was an unbalanced longitudinal force that was not taken account of in the design that was the equivalent of about 15 tons at the peak of the pressure test. The structure supporting the magnet in the cryostat broke and the magnet lurched forward," says Fermilab's Peter Limon, who helped commission the magnets. The pressure test, he adds, "is at a higher pressure than we would see operationally."

Engineers at first thought the magnets had to be removed from the LHC tunnel and brought to the surface for repairs, which would have meant significant delays to the project. Instead, says Limon, the support beams are being fixed in place. Four metal cartridges are being fitted to each of the affected magnets. The extra bracing transmits the force to the floor and should stabilize the magnets when the LHC is operational, he explains. (See PHYSICS TODAY's website for a video demonstration.) The cost of the repairs and what Fermilab and CERN will each pay are still being negotiated.

While fixing the Fermilab magnet supports, workers discovered that some of the beam supports around the ring-shaped tunnel were not up to safety specifications. Extra braces are being installed. "The only remaining safety hazards in the tunnel are the bicycles," says Limon. "They are too quiet and can sneak up on you."

A leaky schedule

Among the other things CERN has had to fix was a leak in a vacuum pipe. As part of the final preparations for startup, sections of the vacuum pipe are being baked to remove foreign materials. Cooling a section of pipe to near absolute zero in vacuum and then



PAUL GUINNESSY

Two workers check the wiring on part of the 7000-ton ATLAS detector.

bringing it back to room temperature can take more than six weeks. In a recent section test, a leak required time-consuming repairs. CERN has also experienced problems with regulating the compressors that cool the machine to 1.9 K. Says Evans, "Some sections have now been cold for three or four months and are working perfectly, except for a few of these teething problems."

In addition, researchers working on the CMS experiment discovered a noise problem in the photomultipliers when they observed cosmic rays as part of a test. "Fortunately, [the noise problem] disappears when we reach our operating standards, although we have no idea what is causing it," says Pawel de Barbaro of the University of Rochester. The delayed schedule is proving advantageous to the experiment teams, especially ATLAS and the CMS, says Evans.

But perhaps the LHC's weakest link will prove to be the initial injector, which fires particles into the ring and is a relic of LEP and earlier machines. The injector is old, says Evans. "It's very flaky and needs a major investment and refurbishment or it needs to be replaced." Aymar agrees and says that his concern is the lack of spare parts for the machine. Construction of a new $150 million injector will start in 2012 when CERN finishes paying off the loans it took out to build the LHC (see PHYSICS TODAY, December 2001, page 21). Says Aymar, "Once the LHC is up and running, building a replacement injector will be a high priority."

Paul Guinnessy

Big boost in science funding authorized by Congress

Congress authorized billions of dollars more for science than the president requested. But authorizing is not the same as appropriating, and skeptics are saying "show me the money."

Just 22 months after Norman Augustine sat before a congressional committee to urge support for the recommendations in the landmark report *Rising Above the Gathering Storm,* the retired CEO of Lockheed Martin Corp was working the phones from his car as he zipped from meeting to meeting in Washington, DC. Congress was about to vote on the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act, which would authorize funding for science programs in almost every federal agency at levels higher than even advocates for science had thought possible.

Augustine, who was chair of the National Academy of Sciences committee that issued the *Gathering Storm* report (see PHYSICS TODAY, December 2005, page 25), was talking mostly to reluctant Republicans who were worried about voting for legislation that allocated $21 billion more in domestic spending than President Bush had requested. Although almost everyone on the Hill was willing to support science funding increases called for in the administration's American Competitiveness Initiative, fiscal conservatives in Congress were reluctant to authorize a research budget that over the next seven years could be more than $30 billion above the spending envisioned by the administration.

Representative Ralph Hall (R-TX), the ranking member of the House Committee on Science and Technology, was concerned about $300 million authorized to establish the Advanced Research Projects Agency–Energy, an office in the Department of Energy (DOE) that would focus on high-risk energy-research projects. Other legislators were concerned about expanded science education programs and some 20 other science initiatives the administration had complained about in a letter to Senate majority leader Harry Reid (D-NV).

On 2 August, after the intense last-minute lobbying by Augustine and a host of other science advocates, the House passed the COMPETES Act 367 to 57, a veto-proof majority. The Senate also approved the legislation overwhelmingly, and it was sent to President Bush. On 9 August, despite earlier threats to veto the legislation, Bush signed it into law.

Although the legislation gives substantial amounts of money to almost every field of science, rejoicing in the science community should be tempered, Augustine said. "I sent out a note this morning [the day the House passed the act] congratulating all of the people who worked on it. The first line of the note said, 'Congratulations.' The second line of the note said, 'Now, about the FY 09 budget, let's get to work.'

"This is just one step in a many-year undertaking," he said. "We've got to maintain this year after year after year. As a mathematician would say, it's necessary but not sufficient." Augustine's fear, shared by many in the science community, is that next year Congress will move on to other priorities and science funding will slip. "It's hard to sustain things," Augustine said.

Augustine's other fear is that although the COMPETES Act authorizes billions of dollars for science, it doesn't actually appropriate. That process, done by House and Senate appropriations committees, will come in September when Congress returns from its summer recess.

That is also the fear of Stanley Williams, director of quantum science research at Hewlett-Packard. Williams has been outspoken for several years about what he sees as the decline in American science, both in education and federal research funding. "People like me have been trying to point out that there really is a problem," he said. "At the Washington, DC, level, what often happens is [politicians] nod their heads sagely, and then a piece of legislation is passed, and the funding doesn't come through, and the problem isn't solved. You go back, and they say they've already dealt with that problem."

Williams points to legislation, passed by Congress and signed by Bush in 2002, that authorized a doubling of the NSF budget over five years. The money was never appropriated by Congress, and Bush's later budget proposals fell far short of meeting the doubling goal.

The COMPETES Act puts NSF on the path for doubling its budget in seven years. But Williams is skeptical. "We attempted that doubling five years