

THE NETL CARBON SEQUESTRATION NEWSLETTER: ANNUAL INDEX

AUGUST 2002 – AUGUST 2003

This is an indexed compilation of the past year's monthly National Energy Technology Laboratory Carbon Sequestration Newsletter. The newsletter is produced by the NETL to provide information on activities and publications related to carbon sequestration. It covers domestic, international, public sector, and private sector news. This compilation covers newsletters issued between September 2002 and August 2003. It highlights the primary news and events that have taken place in the carbon sequestration arena over the past year. Information that has become outdated (e.g. conference dates, paper submittals, etc.) was removed.

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Sequestration in the News

September 2002

Utilities Challenged to Meet President's Goal. An analysis conducted by six utilities finds that half of the fossil-fired generation fleet would have to cap their CO₂ emissions at roughly 2000 levels by 2012 to meet the President's carbon intensity goal. Although the analysis is not publicly available, an article in the *White House Weekly* summarizes results. The study finds the President's goal is more rigorous than previously thought. An 18 percent reduction from the power sector would require all fossil-fired generators to cut greenhouse gas (GHG) intensity from the current 1.94 pounds of CO₂ per kilowatt-hour to 1.59 lbs. per kWh. The analysis recommends U.S. companies be allowed to use credits for projects that reduce, avoid, or sequester GHG emissions. "Coal Utilities Find Cold Comfort in Bush Climate Goals," *White House Weekly*, August 20, 2002, <http://www.kingpublishing.com/publications/whw>.

October 2002

Colin Powell Touts U.S. Climate Change Program. In a speech at the World Summit on Sustainable Development, U.S. Secretary of State Colin Powell said the U.S. is taking action to address environmental challenges such as climate change. He used the nation's commitment to a "multi-billion dollar program to develop and deploy advanced technologies to mitigate GHG emissions" as an example of U.S. dedication to the environment. "Powell Touts Billion Dollar Program on Climate Change: *Africa News Service*," CO2E.com, September 4, 2002, <http://www.co2e.com/News/story.asp?StoryID=768>.

December 2002

The Millennium Project. An international think tank is exploring the idea of wireless energy transmission and carbon sequestration as options to meet growing energy demands safely and efficiently. The article mentions several sequestration strategies, including creative high-risk approaches, and more traditional approaches such as injecting CO₂ into the earth or ocean, and planting trees. The Millennium Project has been named one of the best foresight organizations by DOE. "Millennium Project Explores Potential for Wireless Energy; Analyzes Approaches to Carbon Sequestration," American Council for the United Nations University Millennium Project, November 18, 2002, <http://www.acunu.org/millennium/press.html#energy>.

Stanford becomes scientific hub of climate research. \$225 million in private sector donations helped Stanford University launch the Global Climate and Energy research Project (G-CEP). CO₂ separation, capture, and storage methods are listed as one of a broad range of low GHG emission energy technologies to be developed. ExxonMobil plans to invest up to \$100 million over the next 10 years, and General Electric \$50 million. "Stanford University to Lead Search for Solutions to Global Climate and Energy Needs," November 20, 2002, <http://gcep.stanford.edu>.

Stanford Partners with Industry to Form Global Climate & Energy Project. Stanford University's \$225-million, ten-year sponsorship deal with ExxonMobil, General Electric, Schlumberger, and E.ON form the Global Climate & Energy Project (G-CEP). Carbon sequestration technologies are a focus of G-CEP. All patents resulting from Stanford's research will ultimately be vested in Stanford, but the sponsors will be granted first-usage rights for five years, free of royalties. "Fuel for thought," *Nature*, February 6, 2003. The G-CEP, <http://gcep.stanford.edu>.

Integrating international global environmental research programs. The International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme (IHDP), and World Climate Research Programme (WCRP) have established a "Global Carbon Project" (GCP) to integrate carbon research for the various programs. The GCP will contribute research to the IPCC assessment process and to the coupled human-carbon-climate system. November 2002, <http://www.globalcarbonproject.org/>.

January 2003

Cleveland Plain Dealer highlights sequestration. An article highlights NETL program goals and activities. "Looking to stash greenhouse gases," *The Plain Dealer*, December 26, 2002, <http://www.cleveland.com/plaindealer/>.

Shell's alternative scenarios. Royal Dutch/Shell Group uses a series of scenarios to anticipate and deliver energy-environment solutions. One scenario considers a continuation of the evolutionary progression from coal to gas, to renewables, or possibly to nuclear by 2050. A second scenario shows a progression to a hydrogen economy through advanced hydrocarbon technologies and CO₂ sequestration. "Shell sees fossil fuels central to global energy supply through 2050," *Octane Week*, November 25, 2002.

March 2003

U.S. carbon sequestration leadership forum. President Bush and Secretary Abraham announced the creation of an international Carbon Sequestration Leadership Forum to advance carbon capture and storage technologies. The Forum, organized by DOE and the U.S. State Department, will be joined by representatives from invited countries. "U.S. Department of Energy and U.S. Department of State to Announce Carbon Capture and Storage Initiatives," U.S. Department of State, February 26, 2003, <http://www.state.gov/r/pa/prs/ps/2003/18007.htm>.

FutureGen first zero-emissions coal plant. The U.S. government will sponsor the world's first coal-based, zero-emissions electricity and hydrogen production plant with a \$1 billion, 10-year public-private partnership. CO₂ emissions from the 275 MW gasification plant will be captured and stored. The DOE is seeking assistance from more than 20 countries, including the EU, Australia, India, Japan, South Africa, and China. Site selection will take place in the first phase of the initiative. "U.S. Seeking Cleaner Model of Coal Plant," *The New York Times*, February 28, 2003, <http://www.nytimes.com/2003/02/28/science/28COAL.html?ex=1047438171&ei=1&en=20a234a2e9129e05>.

AAAS webpage. Curt White, leader of the NETL Carbon Sequestration Science Focus Area, is featured in an audio news clip from the NETL-sponsored American Association for the Advancement of Science (AAAS) carbon sequestration symposia, which took place in Denver. The clip can be accessed on the AAAS website at <http://www.scienceupdate.com/feb03.html#030217>. Click on February 17th: Carbon Cloisters to listen.

Economist article combines hydrogen and sequestration processes. The opportunity for hydrogen production from fossil fuels combined with CO₂ capture and storage is highlighted in this article. "These fuelish things," *The Economist*, February 15, 2003.

April 2003

FutureGen press. The U.S.' \$1 billion, ten-year clean coal-fired power plant project will produce electricity and hydrogen, and sequester CO₂ emissions underground. Financed with Federal, private and international funds, it will serve as a working prototype for clean-coal technologies. "Coal-fired power plant to bury issue of emissions," *Nature*, March 6, 2003, <http://www.nature.com/>.

May 2003

NETL in the news. National Energy Technology Laboratory Director, Rita Bajura and Scott Klara, product manager for Carbon Sequestration, were quoted in an article on GHG emissions and what to do about them. "Reducing greenhouse gases," *Pittsburgh Tribune Review*, May 1, 2003, http://www.pittsburghlive.com/x/tribune-review/business/s_132081.html.

Nine electric utilities and Wyoming coal companies join FutureGen initiative. Peabody Energy, Kennecott Energy (through its parent company Rio Tinto Group), RAG American Coal Holding Inc., PacifiCorp, American Electric Power, CONSOL Energy Inc., the North American Coal Corporation, Southern Co., and TXU are part of a technical group that will discuss the design of a near zero-emission power plant and hydrogen production facility. After the design project is agreed upon, a location and a construction plan will be decided. "Coal firms join 'zero-emissions' effort," *Casper Star Tribune*, April 29, 2003, <http://www.casperstartribune.net/articles/2003/04/29/news/wyoming/6dda4492fccb74ef6e3900ad34cc06b8.txt>.

Climate Change Central newsletter features GHG technologies. A discussion of clean coal and combined heat and power includes technology overviews. "Sparking a Less Carbon-Intensive Future - Greenhouse Gas Technologies," *C3 Views*, April 2003, http://www.climatechangecentral.com/info_centre/C3Views/default.asp.

June 2003

FutureGen Alliance forming. Four of the nation's largest coal-burning utilities and five of its biggest coal producers announced the formation of an alliance that may finance up to 20 percent of the Bush administration's \$1 billion FutureGen project. "Industry Answers Bush's Call On 'FutureGen' Power Plant," *New Technology Week*, April 28; "Firms join 'zero-emissions' effort," *Casper Star Tribune*, May 1, 2003, <http://www.casperstartribune.net/articles/2003/05/01/news/wyoming/6dda4492fccb74ef6e3900ad34cc06b8.txt>. Also, Eastern Montana has the natural and human resources needed to attract "FutureGen" initiative, this article says: "Energy Project promoted," *Montana Forum*, May 1, 2003, <http://www.montanaforum.com/rednews/2003/04/30/build/energy/gasify-plant.php?nnn=2>.

National Research Council: hydrogen and sequestration. Dr. Lynn Orr of Stanford University's Global Climate and Energy Project, and Gardiner Hill of BP and the CO₂ Capture Project (CCP), told a National Research Council committee that if hydrogen is produced in substantial quantities from fossil fuels, CO₂ sequestration will be required to reduce carbon emissions into the atmosphere. "CO₂ sequestration seen as key to hydrogen energy future," *Inside Energy /with Federal Lands*, April 28, 2003, <http://www.platts.com/>.

July 2003

Carbon Sequestration Leadership Forum. Along with the U.S., delegations from thirteen countries and the European Union attended the June 23-25, 2003 inaugural meeting of the Carbon Sequestration Leadership Forum (CSLF). Participants included: Australia, Brazil, Canada, China, Colombia, India, Italy, Japan, Mexico, Norway, Russian Federation, South Africa, the United Kingdom, and the European Commission. A charter document was signed by countries wishing to be participatory members of the CSLF. "International carbon sequestration pact signed," *ENS*, June 25, 2003, <http://www.ens-news.com>; see also DOE, http://www.energy.gov/engine/content.do?PUBLIC_ID=13600&BT_CODE=PR_PRESSRELEASES&TT_CODE=PRESS_RELEASE.

U.S. CO₂ strategy focuses on coal-fired plants. A press briefing held by Mike Smith, Assistant Secretary for Fossil Energy, and Scott Klara, NETL Carbon Sequestration Project Manager, generated several articles covering: NETL Carbon Sequestration program efforts, the International Leadership Forum, CCP, Weyburn,

and FutureGen. "Power plants pose challenge for CO₂," *Inside Energy Extra*, June 16, 2003; also "Permanence Issues loom over CO₂ storage," *AIR Daily*, June 17, 2003; "Bush's Climate Policy Touts Oil Recovery Technology," *Oil Daily*, June 16, 2003; and "Too much CO₂? Just pump it underground," *Christian Science Monitor*, June 24, 2003, <http://www.csmonitor.com>.

Montana expresses interest as FutureGen site. In a document submitted to the DOE, Montana has offered both its university system and geological resources for FutureGen. Dave Gibson of the Governor's Office of Economic Opportunity was named project coordinator for Montana's involvement in FutureGen. "Montana makes pitch for hosting big federal project," *The Associated Press State & Local Wire*, June 21, 2003.

August 2003

The Carbon Sequestration Leadership Forum news. The Carbon Sequestration Leadership Forum (CSLF) met for the first time at the end of June. Several more stories have been reported in addition to what was covered last month. These are: "World Coal Forms CO₂ Sequestration Group," *The Electricity Daily*, July 2, 2003; "U.S.: Carbon sequestration 'critical' to continued fossil energy reliance," *Inside Energy /with Federal Lands*, June 30, 2003; and "Abraham Pushes Carbon Sequestration Technologies," *New Technology Week*, June 30, 2003, <http://www.fe.doe.gov/programs/sequestration/cslf/>.

Plan to capture and store CO₂ under South Wales seabed. Greenhouse gases captured from the Valleys Energy Ltd. clean coal Integrated Gas Combined Cycle power station may be buried off the South Wales coast. The potential for CO₂ storage depends on the legal resolution of London and Oskar Convention issues. Project planners look to Sleipner for precedence. "Plan to bury tons of CO₂ off coast," *Western Mail*, June 27, 2003, <http://icwales.icnetwork.co.uk/0100news/0200wales/page.cfm?objectid=13115106&method=full&siteid=50082>.

CO₂ sequestration in Waste News. An article covers the Air & Waste Management Association's 96th annual conference on CO₂ sequestration technology. NETL's Carbon Sequestration Science Focus Area Leader, Curt White, and Antonia Herzog of the Natural Resources Defense Council give their views on the role of carbon sequestration technology in the electric-generating industry. "Injecting two points of view: Experts debate carbon sequestration," *Waste News*, July 7, 2003, [http://www.netl.doe.gov/coalpower/sequestration/pubs/articles/Waste News Carbon Sequestration Story.pdf](http://www.netl.doe.gov/coalpower/sequestration/pubs/articles/Waste%20News%20Carbon%20Sequestration%20Story.pdf).

Events & Announcements

GHGT-6 in Kyoto. 500 participants from 36 countries attended The Sixth International Conference on Greenhouse Gas Control Technologies in Kyoto, Japan, the first week of October. The 334 presentations included 90 posters, with the U.S., Canada, and Japan representing the greatest participation. 100 more papers were presented than at GHGT-5 (Australia, 2000) with geologic storage emerging as a favored topic. In the twelve years since the conference started, research and development has shown significant progress. Acid gas injection projects in Canada, progress reports and updates from the Sleipner Field, planned field tests of geologic storage in Japan, and a BP project re-injecting captured CO₂ into natural gas reservoirs in Algeria set a precedent for continuing field research. Topics also included novel capture methods such as molten carbonate reactions, "anti-sublimation," pre-combustion capture for Fischer-Tropsch fuel processing, modeling of leakage rates, reservoir characteristics, and economics. Terrestrial and ocean sequestration, public outreach, and the role of industry were also discussed. The conference was organized by the Research Institute of Innovative Technology for the Earth (RITE), the IEA Greenhouse Gas R&D Programme, and the Japan Society of Energy and Resources (JSER). Papers will be published by Elsevier *Science* in March of 2003. GHGT-7 will be held in Vancouver, Canada, in September of 2004. Papers for GHGT-6 are now available, <http://www.ieagreen.org.uk/ghgt6info.htm>.

Technology

Clean Coal Editorial. An article in *Mechanical Engineering* surveys the state of clean coal technology in the U.S. The article discusses gasification and fluidized bed technologies, costs of repowering systems, and commercial utilization of available technology. "Old King Coal," *Mechanical Engineering*, August 2002, <http://www.memagazine.org/>.

Zero emissions coal. Scientists at Los Alamos National Laboratory say they have reconfigured well-known chemical reactions and energy technologies in a way that could soon produce the world's first coal-fueled energy plant that would be completely free of emissions. The proposed system is centered on a hydrogasification process that would combine coal with hydrogen to form a synthetic gas that would then pass through a bed of hot lime (CaO) with steam, producing more hydrogen and a pure stream of CO₂. "Researchers begin developing emission-free coal plant," *Civil Engineering*, July 2002.

Hybrid CO₂ natural gas separation technologies. Removal of CO₂ can be accomplished via absorption using amines or hot potassium carbonate, or by adsorption using membranes. Classic separation technologies, such as distillation, extraction, catalytic reaction, and membrane filtration can often be combined in a single unit operation to create a hybrid separation system. An article in *Chemical Engineering* concludes that hybrid separation schemes consisting of membranes and downstream solvent processes provide higher selectivity and flexibility. Much of the research and development of hybrid separation schemes involves membranes. "Hybrid Separation Schemes for CO₂ Removal: Conditioning Natural Gas," *Chemical Engineering*, August 2002, <http://www.che.com>.

High-Temperature Membrane. Los Alamos National Laboratory has developed a new high-temperature polymer membrane for separating and capturing CO₂. The new membrane is operationally stable at temperatures up to 370°C, which is 220°C higher than current commercially available polymer membranes. The high-temperature operating membrane could greatly reduce energy consumption associated with CO₂ capture in certain applications. "High-Temperature Polymer Helps Clear the Air," *JOM, Journal of the Minerals, Metals, & Materials Society*, September 2002, vol. 54, issue 9, p.7.

Integrated Capture and Fertilizer. Researchers from NREL and ORNL are working with Eprida Scientific Carbon to improve an integrated bioenergy and sequestration system, whereby 20 percent of CO₂ emissions can be sequestered; NO_x and SO_x are captured as well. The process creates hydrogen and a slow release nitrogen fertilizer. "Is Profitable Sequestration of Power Plant Emissions Right Around the Corner?" *Internet Wire*, October 24, 2002, <http://www1.internetwire.com/iwire/iwprf?id=47945>.

Climate Technology Awards. The winner of the 2002 CTI Climate Technology Leadership Award (individuals) was René Núñez-Suárez, for developing a low temperature combustion process for fossil and non-fossil fuels (which results in a slower rate of material combustion, and therefore less GHGs). The winner of the 2002 CTI World Climate Technology Award (organizations) was The Centre for Power Efficiency and Environment Protection (CenPEEP), for supporting the adoption of more-efficient coal power plants in India, <http://www.climatetech.net/>.

Enhanced frozen methane recovery. Researchers at Pacific Northwest National Laboratory, University of Alaska at Fairbanks, and BP Exploration Alaska Inc. will examine a new concept designed to simplify and maximize methane production from frozen gas hydrates by injecting and sequestering CO₂. The project is a first collaboration between PNNL and the Arctic Energy Technology Laboratory. "DOE-industry partnership targets carbon 'swap' technology," *Inside Energy /with Federal Lands*, December 2, 2002, <http://www.uaf.edu/aetdl/witmer.pdf>.

Canadian coal plant retrofit with CO₂ capture and sequestration. The Canadian Clean Power Coalition (CCPC), a group of coal producers and coal-dependent power producers, announced a plan to retrofit an existing 300-MW coal-fired plant with new capture technology by 2007 and build a new zero emissions 300-megawatt

plant by 2010. Syngas is targeted as the most promising technology for use in a new zero emissions greenfield plant. "Detested by environmentalists, coal may be fuel of the future: New technology may enable burning without any emissions," *Edmonton Journal*, November 28, 2002, <http://www.canada.com/edmonton/>.

Exergetic and environmental life cycle assessments were performed for three CO₂ low-emission power cycles: a semi-closed gas turbine combined cycle, an IGCC, and an O₂/CO₂ innovative cycle – which burns methane in oxygen. The gas turbine combined cycle and IGCC both utilized amine absorption methods for CO₂ capture while the excess CO₂ from the innovative cycle was removed in liquid phase. "Life cycle assessment comparison of technical solutions for CO₂ emissions reduction in power generation," *Energy Conversion & Management Journal*, Volume 44 (1), January 2003.

Three methods to capture CO₂ from natural gas-fired combined gas/steam turbine power plants are evaluated and compared: (1) CO₂ separation by amine absorption, (2) Gas turbine combined cycle (CC) using a semi-closed gas turbine with near stoichiometric combustion using oxygen, and (3) Decarbonization via an autothermal reforming reactor with catalytic partial oxidation of natural gas. Total fuel-to-electricity conversion efficiencies, including CO₂ compression, were reported at: (1) 49.6%; (2) 47.2%; and (3) 45.3%, as compared to 58% efficiency with no CO₂ capture. "A novel methodology for comparing CO₂ capture options for natural gas-fired combined cycle plants," *Advances in Environmental Research*.

Use of CO₂ to maintain pressure in natural gas wells. Natural gas storage – the process of keeping natural gas underground and under pressure to provide a smooth supply – requires the use of a "cushion gas" to provide pressure support. It is common for leftover methane to be used, but preliminary simulations show 30 percent more methane can be stored when using CO₂. Research at Lawrence Berkeley National Laboratory well investigate whether carbon sequestration tax credits could make the use of CO₂ as a cushion gas economically feasible. Critical issues include limiting CO₂/natural gas mixing and gas prices. "Carbon dioxide as cushion gas for natural gas storage," *Energy Fuels*, 17 (1), January 15, 2003, <http://pubs.acs.org/journals/enfuem/>.

Flue Gas CO₂ capture by gas-phase ammonia carbonation. CO₂ capture by ammonia carbonation - typically performed by bubbling flue gas through an aqueous ammonia solution - is prohibitively expensive for the power industry, so researchers at Oak Ridge National Laboratory are investigating a gas-phase reaction that captures up to 50 percent of the CO₂. The reaction produces a solid common fertilizer, ammonium bicarbonate (NH₄HCO₃). Higher removal efficiencies are expected with optimization of reactor geometry and operating conditions. "Removal of carbon dioxide from flue gas by ammonia carbonation in the gas phase," *Energy Fuels*, 17 (1), January 15, 2003, <http://pubs.acs.org/journals/enfuem/>.

Solid adsorbent technology development. A technology combining lithium silicate (Li₄SiO₄) absorbent with a rotary heat exchanger absorbs CO₂ in the temperature range 450-700°C and releases it above 700°C. Li₄SiO₄ is able to capture and release roughly 500 times its own volume of CO₂, and the use of a rotary heat exchanger enables continuous operation. The cost of capturing one ton of CO₂ is estimated to be roughly \$20. Alstom KK in Japan and Toshiba Corporate R&D Center (developer of the CO₂ absorbing material) presented a paper at the 21st annual meeting of the Japanese Society of Energy and Resources, June 2002. "Coal-fired plant technology; the CO₂ wheel: A revolutionary approach to carbon dioxide capture," *Modern Power System*, January 31, 2003.

Synthetic trees for CO₂ capture. An artificial tree designed by Klaus Lackner captures CO₂ from the air at a capture rate of 90,000 tons of CO₂ per year. However, the specific absorbent has yet to be chosen and engineering issues, such as absorbent regeneration, have yet to be worked out. "Synthetic trees could purify air," *BBC World News*, February 21, 2003, <http://news.bbc.co.uk/2/hi/science/nature/2784227.stm>.

Flare gas recovery system. Emissions of CO₂ and hydrogen sulphide from Statoil's refinery near Bergen, Norway will be reduced by a new flare gas recovery plant. The plant can recover about five tons of gas per hour, sufficient to cut flaring by 50 percent, reducing annual CO₂ and hydrogen sulphide emissions by 42,000 tons and 50 tons respectively. The company expects to recover its \$5.08 million investment in the recovery plant within three years. The system was developed by ABB Gas Technology in co-operation with Statoil.

“Statoil cuts emissions with new flare gas recovery plant,” *Chemical News & Intelligence*, January 27, 2003, <http://www.cnionline.com/>.

Power plant CO₂ emissions used to produce methanol or gasoline. Reco-Maxam Solar Energy, LLC announced it will build a prototype power plant that will include a facility to capture CO₂ and use it to produce either hydrogen or simple liquid fuels. CO₂ is reduced to carbon monoxide and oxygen using a proprietary direct solar dissociation process, followed by a watergas shift reaction to produce hydrogen from the water. Additionally, the carbon monoxide and hydrogen can be synthesized into liquid fuels. “Maxam Gold Corporation Enters Solar Energy Industry in Quest for Clean Environment,” *E-Wire*, February 5, 2003, <http://www.ewire-news.com>.

SOFC with CO₂ capture. A methane and oxygen powered solid oxide fuel cell achieves a thermal efficiency of 63.6% with carbon capture, according to this paper. “Performance of High Performance SOFC Combined Power Generation System with Carbon Dioxide Recovery,” *Energy Conversion & Management*, Mar 2003, Vol. 44 (4), <http://www.sciencedirect.com/science/journal/01968904>.

East to West Texas: Connecting CO₂ supply and demand. Falcon Environmental Services has been working closely with Ontario Power Generation, Oxy Permian, a Texas oil producer and buyer of CO₂ for 13,000 producing wells, and others to work on aggregating CO₂ from multiple producers, then storing it and redistributing it to end users. “Connecting the CO₂ dots,” *Houston Business Journal*, March 21, 2003, <http://houston.bizjournals.com/houston/stories/2003/03/24/story1.html>.

CO₂ captured from new ethanol facility. Utica Energy, LLC, Wisconsin, is the 73rd ethanol plant to begin operating in the U.S. The plant will turn eight million bushels of corn into 20 million gallons of ethanol and 175,000 tons of distillers wet grains annually. It will also capture 175 tons of CO₂ per day for commercial use. “Wisconsin Ethanol Plant Begins production,” *AgWeb*, May 22, 2003, http://www.agweb.com/news_show_news_article.asp?file=AgNewsArticle_20035221534_2812&articleID=98055&newscat=GN.

MCCF to start testing capture technologies. The National Energy Technology Laboratory’s Pittsburgh site is preparing to fire up the Modular CO₂ Capture Facility (MCCF), which tests carbon-capture technologies. NETL designed and constructed MCCF to operate in two ways: (1) In flue gas form, where it will mimic coal-fired combustion processes that generate electricity using coal, natural gas, or a combination of the two. Burning 40 pounds of coal per hour results in a flue gas flow of 110 scfm. (2) In fuel gas mode, where the facility will simulate the gas composition found in advanced conversion systems, such as coal gasification. NETL reached a tentative agreement with Toshiba to test the company’s carbon sorbent. “NETL sets up facility to gauge how carbon capture technologies stack up,” *Inside Energy /with Federal Lands*, June 9, 2003.

Sequestration outlined as a necessary solution. Capture and geologic sequestration of power plant emissions is a reasonable way to curtail world CO₂ output, according to Dr. Lackner of Columbia University. The best long-term option, he claims, is to chemically neutralize the CO₂ to form insoluble carbonates. “A Guide to CO₂ Sequestration,” *Science*, June 13 2003: 1677-1678. Also, “Is Sequestration the Only Way to Deal with Carbon?” *The Electricity Daily*, June 13, 2003.

Equipment for lowering carbon intensity. Equipment manufacturers in the US, which account for about half the global market for electricity generation systems, are responding to demands for new equipment and upgraded technology to meet carbon emissions standards. They are also exploring renewable energy sources such as solar, wind, and fuel cells. “Finding new niches in a saturated market: The US,” *Financial Times* (London), April 30, 2003.

Analysis predicts large carbon reductions necessary by 2050. Researchers from LLNL, University of Illinois at Urbana-Champaign, and NYU model a variety of stabilization pathways to show that massive reductions in carbon emissions will be required by 2050, even in the case of low climate sensitivity. “Climate Sensitivity

Uncertainty and the Need for Energy Without CO₂ Emission," *Science*, March 28, 2003, <http://www.sciencedaily.com/releases/2003/03/030328073115.htm>.

Geology

Measuring CO₂ dispersion after injection. Researchers at the British Geologic Survey used a time-lapse seismic technique to look at how CO₂ disperses when injected one kilometer under the seabed. The technology was tested at the Sleipner injection site in the North Sea and showed that CO₂ was contained by an impermeable cap of shale and clay. "Scientists Find Eco-friendly Use for Old Oil Fields" and "Waste Gas Buried in North Sea Reservoirs," *The Financial Times*, September 11, 2002; and "Carbon Burial Experiment Works," *BBC News*, September 10, 2002, http://news.bbc.co.uk/2/hi/in_depth/sci_tech/2002/leicester_2002/2248707.stm.

A Wall Street Journal feature article. In early January, an article with the sub-heading "Potential solution to global warming lies two miles deep, both underground and in the ocean" covered: the Weyburn-Dakota EOR project, AEP's early exploration beneath the Ohio River Valley, the challenges and potential of ocean storage, and the current costs of capture technology. "In the Pipeline: A Pollution Solution: Bury It," *The Wall Street Journal*, January 8, 2003, <http://online.wsj.com/public/us> (Subscription required).

Mechanical Engineering. Mineral carbonation and other carbon sequestration options are presented in an article featuring Bob Kane of DOE. "Carbon underground," *Mechanical Engineering*, February 2003, <http://www.memagazine.org/contents/current/features/carbonug/carbonug.html>.

Coal industry issues carbon emissions management report. Energy Secretary Spencer Abraham addressed the National Coal Council at a meeting where the Council approved a draft report on managing the coal industry's GHG emissions. The report calls on the DOE to conduct large-scale, long-term field tests of CO₂ sequestration options. According to the report, carbon capture and storage could ultimately account for more than 40% of global CO₂ emission reductions. The report is available at: <http://www.nationalcoalcouncil.org/Documents/fpb.pdf>, *Inside Energy*, May 2003.

Second Phase of Sleipner CO₂ Storage Project. Building on the success of a Statoil-led project in the Sleipner field in the North Sea, the second phase of the European Union project will study and simulate onshore CO₂ geologic storage possibilities in Denmark, Germany, South Wales in the UK, and an area on the mid-Norwegian coast. Partners are: Statoil, BP, ExxonMobil, Norsk Hydro, TotalFinaElf and Sweden's Vattenfall, as well as scientific bodies in Denmark, France, the Netherlands, Norway and the UK. "Studying Carbon Storage on Land," Statoil, August 16, 2002,

<http://www.statoil.com/press/2002/081602/0208160201.htm>

Statoil Receives Technology Prize. The World Petroleum Congress awarded an annual technology prize to Statoil for its CO₂ gas re-injection and monitoring program in the Sleipner West field 3,300 feet below the seabed. Roughly one million metric tons of CO₂ emissions per year have been avoided since the project began in 1996. "Statoil Wins WPC 2002 Technology Prize," *Oil and Gas International*, August 8, 2002, <http://www.oilandgasinternational.com>.

CO₂ Sequestration Seen as a Powerful Tool. "CO₂ sequestration is one of the most powerful tools we have of reducing CO₂ emissions to the atmosphere," said Andy Chadwick, principal geologist at the British Geological Survey. Chadwick noted the relatively high cost of sequestration, but said that research is being conducted to find ways to reduce the cost and suggested that depleted oil and gas fields could prove to be useful storage areas. He also stated that sequestration is an intermediate measure over the next 50-60 years to help realize the major emissions reductions that are needed. "Inject CO₂ Emissions Into Earth's Crust," *Reuters*, September 10, 2002.

Progress on EOR project using anthropogenic CO₂. Anadarko Petroleum Corp. agreed to buy Howell Corp., which has Salt Creek field, one of the largest remaining EOR opportunities in the Lower 48 states. Anadarko will also purchase exclusive rights to market and transport CO₂ captured from the LaBarge oilfield into Wyoming's Powder River Basin. Anadarko also announced plans to build a \$27 million, 125-mile CO₂ pipeline, with nominal capacity of about 250 million cubic feet per day in 2003. "Anadarko's Purchase of Howell is Part of a larger Domestic EOR Initiative," *Petroleum Finance Week*, October 7, 2002, http://www.corporate-ir.net/ireye/ir_site.zhtml?ticker=apc&script=411&layout=0&item_id=338587.

NRDC Protests Natural CO₂ Drilling. The Natural Resources Defense Council requested that the Bureau of Land Management review one of its field office's decisions to allow a Texas company to drill CO₂ wells (for use in EOR in Texas) in the Canyons of the Ancients Monument in Colorado on grounds that the field office should consider the UNFCCC as well as U.S. law. "Crazy About Carbon," *Wall Street Journal*, October 17 2002, <http://online.wsj.com/public/us> (subscription required).

Weyburn. An article describes the Weyburn field enhanced oil recovery operation, with an emphasis on carbon sequestered. "Injection may be 'wey' to go," *The Calgary Sun*, November 13, 2002.

"Sparkling a Less Carbon-Intensive Future – Greenhouse Gas Technologies." An EOR technology overview and a case study of the Weyburn operation, *C3 Views*, November 2002, http://www.climatechangecentral.com/info_centre/C3Views/C3Views200210_issue4.pdf.

Chicago Tribune stopgap solution to global warming: sequestration. The Illinois Basin's deep saline aquifers, depleted oil wells, and coal seams were mentioned for long-term storage of several billion tons of CO₂. "Earth a solution to air pollution? Scientists seriously consider injecting gases in ground," *Chicago Tribune*, Julie Deardorff, January 27, 2003, <http://www.chicagotribune.com/news/chi-0301270196jan27,1.515748.story>.

U.S. News & World Report. This article discusses the Sleipner, Weyburn, and Ohio valley projects, as well as deep sea sequestration, ocean fertilizations, capture cost, trading carbon, and the Chicago Climate Exchange. "A Deep-Six Fix," *U.S. News & World Report*, February 10, 2003, http://www.usnews.com/usnews/issue/archive/030210/20030210039090_brief.php.

Geologic sequestration project in West Virginia. American Electric Power's Mountaineer Plant in West Virginia will be the site for a \$4.2 million, 18 month geologic carbon sequestration research project funded by DOE and a consortium of public and private sector participants. Scott Klara, program manager for carbon sequestration at NETL, is quoted in the *Charleston Daily Mail*, saying the project will specifically answer the questions of whether and how much compressed CO₂ the Mount Simon sandstone formation can hold. Scientists from Battelle will lead the project. The Mount Simon formation ranges from 3,000 to 12,000 feet deep beneath the Ohio River Valley and extends as far west as Illinois and Wisconsin. "AEP'S Mountaineer Plant to be Site for Research Project on Climate Change Technology," *PR Newswire*, November 21, 2002, <http://www.aep.com/newsroom/newsreleases/default.asp?dbcommand=DisplayRelease&ID=971&Section=Environmental&colorControl=on>; and "Project will determine if gas can go underground Government footing the bill for most of the work," *Charleston Daily Mail*, December 2, 2002. Also, "Energy Technology: AEP, Battelle To Study Storing CO₂ Underground," *New Technology Week*, December 2, 2002.

Plans for capturing CO₂ as a commodity and resource. Houston-based Falcon Environmental Services plans to operate a commercially viable process to capture, gather, aggregate, store, and distribute CO₂ for enhanced oil recovery, coal bed methane projects, and sequestration in the Dallas/ Ft. Worth region. FES's facility currently has natural gas capacity of 10-12 bcf, upgradeable to 24bcf, and planned daily throughput of up to 350mm bcf; carbon storage will be double the natural gas storage capacity. Contact: Mike Moore (713) 623-5942. "Falcon Environmental Services a CO₂ Aggregation Facility," *The Risk Desk weekly*, volume 3 (1), http://www.scudderpublishing.com/the_risk_desk/index.php.

Focus on ECBM. The fifth issue of *C3 Views* focuses on Enhanced Coalbed Methane and Biopower. *C3 Views*,” Climate Change Central, Spring 2003, http://www.climatechangecentral.com/info_centre/C3Views/C3Views200301_issue5.pdf.

First U.S. geologic sequestration field test underway in depleted oil well. In early 2003 researchers injected 2,100 tons of CO₂ into Strata’s West Pearl Queen reservoir, New Mexico – about 40 tons per day. The plume migration will be tracked by 3-D seismic survey equipment for 3 years. NETL, SNL, LANL, and Strata Production Co. are partnering in the reservoir injection and monitoring project. Kinder Morgan CO₂ Company, LP supplied the CO₂. Department of Energy Office of Fossil Energy, <http://www.fossil.energy.gov>; and “DOE Tests Oil Fields To Store CO₂ Emissions,” *AIR Daily*, March 21, 2003.

Mining the possibilities for carbon storage. Carbon can be stored in saline aquifers, depleted oil and gas fields, unmineable coal seams, oil shales and mafic (e.g., olivine and serpentine) rocks, plants, soils, ocean water, or converted to solid chemicals. Key questions, according to this article, surround reservoir heterogeneity - the distribution of porosity, permeability, and large-scale connectivity associated with facies changes, diagenesis, stratigraphy, and fracture characteristics. Sealing, interactions among brine, rock and gas, geomicrobiological interactions, analogs, monitoring, and verification are also important aspects of CO₂ storage efforts. “Storing Carbon in Earth,” *Geotimes*, March 21, 2003, http://www.geotimes.org/mar03/feature_storing.html.

Carbon storage field experiments. A *Geotimes* article covers the various activities in the carbon sequestration program of the U.S. Department of Energy’s National Energy Technology Laboratory, as well as other projects in the world. According to the article, Statoil’s Sleipner natural gas field in the North Sea saves about \$110,000 per day in Norwegian CO₂-taxes. Also mentioned in the article are EnCana’s Weyburn oil field in Saskatchewan, Canada; the Texas Bureau of Economic Geology plan to inject 3,000 tons of CO₂ below an abandoned oil field; the SACS partnership; CONSOL Energy’s seven-year \$9-million sequestration project to inject CO₂ into coal seams in West Virginia; Burlington’s San Juan Basin New Mexico ECBM project, BP’s injection of more than 300,000 tons CO₂ in San Juan wells; the European Union’s RECOPOL: ‘Reduction of CO₂emissions by means of CO₂ storage in coal seams in the Silesian Coal Basin of Poland’; and the Canadian Alberta Resources Council’s coal seam experiments. “Demonstrating Carbon Sequestration” *Geotimes*, March 21 2003, http://www.geotimes.org/mar03/feature_demonstrating.html.

Commercial CO₂ sequestration in EOR and ECBM operations. Enhanced oil production (EOR) and enhanced coalbed methane production (ECBM) in wells or depleted gas reservoirs improve fuel recovery and sequester carbon, increasing production by roughly 7-15% of the original oil in place over the 10-30 year life span of the project. Current costs for capturing and processing CO₂ from anthropogenic sources is \$1-3/Mcf. Projects using anthropogenic CO₂ in the U.S. and Canada are: Encana, of the Weyburn project; Pan West Petroleum Ltd.’s Joffre Viking CO₂ flood in Alberta; Petro Source Carbon Co. of Midland, Texas supplied by gas plants; ChevronTexaco Inc.’s Ranglely CO₂ flood in Colorado; and Merit Energy Co.’s CO₂ floods near Bairoil, Wyoming. Also, Anadarko Petroleum Corp. is constructing a pipeline from ExxonMobil Corp’s LaBarge gas processing plant in Wyoming, to the Salt Creek CO₂ flood. Natural gas processing plants and a fertilizer plant in Enid, Oklahoma are CO₂ sources. “Special Report: CO₂ sequestration adds new dimension to oil, gas production” *Oil & Gas Journal*, March 3, 2003.

Australian zero CO₂ emissions from power and sequestration. The Australian Federal government and Australian Coal Association set up “Coal 21” to research and develop capture technology and underground storage of CO₂ emissions from energy generation. “Coal sector seeks carbon cuts,” AAP, Geoscience Australia and the University of NSW, March 2003. Also, the Australian Co-operative Research Center (CRC) is planning a demonstration of the large-scale disposal of CO₂ in a saline reservoir deep underground. “Storing carbon dioxide underground,” *Yorke Peninsula Country Times*, March 11, 2003, http://www.abc.net.au/science/news/scitech/SciTechRepublish_803348.htm.

Geosequestration in Australia. An Australian geological survey conducted by the Australian Petroleum Co-operative Research Centre and Geoscience Australia identified 65 sites where large quantities of CO₂ could be

injected deep underground. The sites studied could safely store half the annual CO₂ emissions from stationary sources of GHGs, and ultimately could store 1,600 years of Australia's total emissions. The Petroleum Co-operative was recently renewed for seven years with a \$22 million government grant to become the Co-operative Research Centre for GHG Technologies, or CO₂CRC. "Underground sites may store GHG emissions," *Sydney Morning Herald*, April 22, 2003, <http://www.smh.com.au/articles/2003/04/21/1050777215083.html>.

Opposing view: Australian geosequestration infeasible. A report on Australia's GHG polluters has dismissed the option of underground storage of CO₂ emissions as not feasible on the basis of economics. "Report rejects CO₂ storage option," *Australian Broadcasting Company*, April 7, 2003, <http://www.abc.net.au/news>.

Prep infrastructure development for EOR. Houston-based Anadarko Petroleum Corp. is replacing pipes and retooling wells at the Salt Creek oilfield 40 miles north of Casper to prepare for the first phase of its \$200 million CO₂ enhanced oil recovery project. 30 million tons of CO₂ have been sequestered in the Anadarko project, according to the article. "Anadarko begins salt creek project," *Casper Star Tribune*, April 10, 2003, <http://www.casperstartribune.net/articles/2003/04/10/news/wyoming/8e4bb1469a59e690b9a1115fc55892ae.txt>.

Knowledge sharing on EOR and hydrogen. INCO2 presented experiences from the U.S. that indicate CO₂ EOR could prolong production from Norway's oil fields in the North Sea. The CENS project (CO₂ for Enhanced oil recovery in the North Sea), owned by ELSAM, Denmark's largest producer of electrical power, and Kinder Morgan, a US energy company with experience in CO₂ transport, aims to prepare a CO₂ transport and injection infrastructure in the North Sea. The value of avoiding CO₂ emissions needs to be \$20-25/ton, before CO₂ for EOR is financially sound, according to CENS. "More oil, less CO₂," *Bellona*, April 1, 2003, <http://www.bellona.no/en/energy/hydrogen/29199.html>.

Seismic tests open Mountaineer sequestration study. As part of a \$4.2 million carbon sequestration research project at AEP's Mountaineer Plant in the Ohio River Valley area, Appalachian Geophysical Services will seismically survey a 5-10 mile radius of the plant and Batelle will drill a 10,000-foot borehole. The 18-month study is funded primarily by DOE and led by Battelle. "Seismic Survey To Take Place Near Mountaineer Plant; Drilling at Plant Will Begin Soon," AEP, May 22, <http://www.aep.com/newsroom/newsreleases/default.asp?dbcommand=DisplayRelease&ID=1031&Section=Environmental&colorControl=on>.

ECBM domestic capacity assessment. Scott Reeves of Advanced Resources International provides detailed reservoir studies of two enhanced coalbed methane recovery (ECBM) field projects in the San Juan basin of New Mexico in this article. Potential by basin totals about 90 Gt for CO₂ sequestration and 152 tcf for ECBM recovery. The study found that between 25 and 30 Gt of CO₂ can be sequestered at a profit and between 80 and 85 Gt can be sequestered at costs less than \$5/ton. "Enhanced CBM recovery, coalbed CO₂ sequestration assessed," *Oil & Gas Journal*, July 14, 2003.

Incentives for Alberta CO₂ EOR. Alberta Energy's new royalty program offers a maximum of \$15 million worth of royalty credits over five years to offset 30 percent of costs for CO₂ EOR projects. The oilpatch industry has recently come under criticism for using waterfloods over CO₂ due to cost concerns. "CO₂ future in oilpatch; government encouraging industry to move from water to carbon dioxide injections," *The Daily Herald-Tribune* (Grande Prairie, Alberta), June 30, 2003.

Terrestrial

Uncertainty in Sinks and Modeling Projections. An article by Sarmiento and Gruber in *Physics Today* provides a summary of the carbon cycle, carbon sequestration, and climate modeling projections. Assumptions regarding the response of natural sinks (e.g. oceans and forests) to increasing atmospheric CO₂ concentration

affects modeling results markedly. "Sinks for Anthropogenic Carbon," *Physics Today*, August 2002, <http://www.aip.org/pt/vol-55/iss-8/p30.html>.

Bioenergy Technology and Carbon Storage. The hydrogen research team from Clark Atlanta University, Georgia Institute of Technology, DOE National Renewable Energy Laboratory, Scientific Carbons, Inc. and Envirotech, Inc., produced hydrogen from biomass while sequestering 25 percent of the material by weight. The resulting carbon is highly adsorbent and can be combined with co-products of the process to form a slow-release nitrogen fertilizer. "High Volume Carbon Sequestration and a Nitrogen Fertilizer Offer a Sustainable Future," *PR Newswire*, August 27, 2002, <http://www.prnewswire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/08-27-2002/0001790040&EDATE=>.

No-till soil solution. The total carbon content of the country's soil has been reduced by about 50 percent since the advent of plowing. According to CASMGS (Consortium for Agricultural Soils Mitigation of Greenhouse Gases), practices by U.S. farmers could restore the original level of carbon within 40 years, potentially reducing the expected increase in CO₂ emissions by 20 percent per year. "On Farms, a No-Till Tactic on Global Warming," *The Washington Post*, August 26, 2002, <http://www.washingtonpost.com>.

Carbon sequestration through riparian restoration. The Deschutes Resources Conservancy (DRC) and The Climate Trust have signed an innovative Carbon Dioxide Offset Purchase Agreement, under which the Climate Trust will provide the DRC with \$780,000 in CO₂ offset funds to help landowners in the Deschutes Basin restore riparian areas. "The Climate Trust Awards Contract to the Deschutes Resources Conservancy," *Climate Trust*, August 15, 2002, <http://www.climatetrust.org/>.

Compilation of global terrestrial sequestration projects. WRI has compiled a list of forest and land-use change carbon sequestration projects. There are 21 projects in 14 countries, representing over 130 million tons of carbon. Total cost is roughly \$40 million. WRI, August 22, 2002, <http://www.wri.org/climate/sequester.html>.

Entergy donates land to U.S. government. Entergy Corp. is donating 600 acres of land along Louisiana's Red River to the U.S. Department of the Interior as a voluntary GHG emissions offset. The new federal wildlife refuge will store an estimated 275,000 tons of CO₂ over 70 years. The public-private partnership was facilitated by The Conservation Fund, which arranged the \$500,000 land purchase from farmers. "U.S. Utility Donates Land for Refuge – Entergy Corp. Will Receive Credit if Government Later Regulates CO₂ Emissions," *The Wall Street Journal Europe*, August 27, 2002, <http://www.conservationfund.org/?article=2597&back=true>.

The State of Food and Agriculture 2002. Released by The United Nations Food and Agriculture Organization (FAO), this report has a special chapter entitled "Harvesting Carbon Sequestration Through Land-use Change: A Way Out of Rural Poverty?" According to the report, paying farmers to change to carbon-sequestering land-use methods can play a significant role in promoting sustainable development in poor areas, assuming effective design of incentives and compensation programs. "UN FAO's Food and Agriculture 2002 Examines the Potential Impact of Carbon Sequestration on Hunger and Poverty," *AScribe Newswire*, September 16, 2002. The report is available on the FAO web site at: <http://www.fao.org/english/newsroom/news/2002/9040-en.html>.

Protein in Soil Helps Sequester Carbon. Scientists at USDA's Agricultural Research Service (ARS) discovered the protein glomalin helps stabilize soil and keeps carbon from escaping to the atmosphere. The protein is shed from fungi living on plant roots and has a 'sticky' consistency. Tests on U.S. soils showed the protein stores close to one third of soil carbon, an amount much greater than humic acid, which was thought to store the majority of organic carbon. Scientists say that, depending on conditions, glomalin stays in the soil between 7 and 42 years. USDA is also studying glomalin levels to measure the amount of carbon stored in tropical soils. "Rich Soil Good for Trapping Carbon Dioxide - Study," *Reuters*, September 9, 2002, <http://www.planetark.org/dailynewsstory.cfm?newsid=17668&newsdate=09-Sep-2002>.

Soil Carbon Sequestration in Sub-Saharan Africa. In an article in *Climatic Change*, author Lasse Ringius looks at soil carbon sequestration in sub-Saharan Africa as a way to mitigate greenhouse gases and increase

agricultural productivity. Ringius documents improvements in agricultural practices and land-use management that could result from increased carbon sequestration initiatives. "Soil Carbon Sequestration and the CDM: Opportunities and Challenges for Africa," *Climatic Change*, September 1, 2002, vol.54, issue 4.

Land Use and Climate: a Close Link. A NASA study suggests that impacts to climate from changing land use are at least as important as the effects of GHGs, when one considers that farm irrigation, urban development, and clearing forests redistribute heat within the atmosphere by adding moisture to the ecological system. "Land-use changes may rival greenhouse gases as cause of climate change," NASA, October 1, 2002, <http://www.gsfc.nasa.gov/topstory/20020926landcover.html>. For the original paper, which was published in *Philosophical Transactions of the Royal Society of London* see, <http://blue.atmos.colostate.edu/publications/pdf/R-258.pdf>.

Quantifying Terrestrial Storage. Preliminary research conducted by CarboEurope found that clearing soil for tree plantations releases as much carbon to the atmosphere as would be absorbed in the first ten years of growth. "Environment - State of Research on Carbon Sinks," *Europe Energy*, October 29 2002.

Forest Offset Project. Kansai Electric Power Co. of Japan will support a tree plantation in Australia estimated to absorb 860,000 tons of CO₂ over the 20 year term of the project. Japan does not yet have a GHG trading market, but is increasingly active in international trading of CO₂. "Kepeco to Plant Trees in Australia," October 18, 2002, <http://www.co2e.com/News/story.asp?StoryID=845>.

Fires and the carbon cycle. After analyzing the 1997 Indonesian fire, researchers from the UK and Germany found that widespread fires burned much of the forested peatlands, releasing an estimated 0.81 to 2.57 gigatonnes of carbon, or 13-40 percent of the mean annual global carbon emissions from fossil fuels. Lowland tropical peatlands support a peat swamp forest overlying peat deposits up to 70 feet thick. Persistent environmental change such as drainage and forest clearing makes them susceptible to fire. "The amount of carbon released from peat and forest fires in Indonesia during 1997," *Nature*, November 7, 2002.

Terrestrial impact. A recent report from the Royal Society of Britain indicates that carbon sequestration from changes in agriculture and forestry practices can potentially achieve 25 percent of the necessary CO₂ reductions globally in the next half-century to avoid large increases in temperature. "Carbon copy: profitable ways to reduce emissions," *Energy User News*, November 2002, http://www.energyusernews.com/CDA/ArticleInformation/features/BNP_Features_Item/0,2584,86369,00.html.

Algae adding complexity. Researchers found that floating ocean algae cause the ocean surface to darken and absorb more energy from the sun. According to the article, this counteracts climate benefits from absorbed atmospheric CO₂. The research was reported in the November *Journal of Geophysical Research*, and NASA, DOE, and the California Space Institute supported the research. "Microscopic algae may heat up oceans," *San Francisco Chronicle*, November 12, 2002, <http://www.sfgate.com/cgi-bin/article.cgi?f=/news/archive/2002/11/12/state1957EST0141.DTL>.

Grasslands sequester large amounts of carbon. Reports from the 11-state Agricultural Research Service CO₂ monitoring network in the central and western U.S. show that the 126 million acres of grassland in the Great Plains could be storing 9 million tons of carbon annually, and U.S. rangeland soils have the potential to store a total of 30 to 110 million tons of carbon a year, 5 percent of the annual U.S. carbon emissions. Rangeland, about half the Earth's land surface, has an advantage over forests for carbon storage because most of the carbon is stored underground, protected from fire. "Is the mystery carbon hidden under grass?" *M2 Presswire*, October 30, 2002, <http://www.ars.usda.gov/is/AR/archive/oct02/carbon1002.htm>.

Soil carbon in the market. A piece on Voice of America summarized issues of soil carbon sequestration. A variety of tillage practices, winter cover crops, and other practices can create a gradual carbon sink in the soil. The U.S. Department of Agriculture estimates an additional \$300 million per year could go to American farmers. Research on measurement and verification technologies will allow accurate documentation of

agricultural carbon sequestration. "Carbon Sequestration in Farming Could Offset Carbon Dioxide Emissions," *VOA*, November 13, 2002, <http://www.voanews.com/article.cfm?objectID=133D895B-F050-4544-B0E4A2BADFB34B6C>.

Land-use Change Flux Update. DOE's Carbon Dioxide Information Analysis Center (CDIAC) has updated "Carbon Flux to the Atmosphere from Land-Use Changes" with estimates from 1850 through 2000 for nine regions of the world. "CDIAC Updates Carbon Flux Estimates from Land Use Changes," CDIAC, November 2002, <http://globalchange.gov/#carbon-flux>.

Sudan soil carbon potential. Researchers find that increasing fallow periods in Sudan results in increased soil carbon content, and converting marginal agricultural areas to rangeland will restore the carbon levels to 80% of the natural savannah carbon levels in 100 years. Potentially important synergies between the Convention on Climate Change, the UN Convention to Combat Desertification and the UN Convention on Biodiversity are explored. "Soil carbon sequestration on degraded semiarid agro-ecosystems; perils and potentials," *Ambio*, November, 2002, <http://ambio.allenpress.com/ambionline/?request=get-abstract&issn=0044-7447&volume=031&issue=06&page=0471>.

Meta-analyses of the biotic effects of global warming. Two articles in the journal *Nature* investigate the effect of climate change on natural ecosystems. In an analysis of more than 1,700 species, researchers show that recent biological trends match climate change predictions in a robust correlation. Significant range shifts average 6.1 kilometers per decade towards the poles. Spring events, such as egg laying and tree leaf-out, were shown to occur a mean of 2.3 days per decade earlier in the year. These analyses generate 'very high confidence' that climate change is already affecting living systems according to several definitions of a 'systematic trend' from the Intergovernmental Panel on Climate Change. "A globally coherent fingerprint of climate change impacts across natural systems," and "Fingerprints of global warming on wild animals and plants," *Nature*, January 2, 2003.

Climate change depresses plant growth. An experiment conducted at 128 grassland plots in California found that a combination of increased atmospheric CO₂ (to 700 ppm), increased temperature (one degree F on average), increased nitrogen deposition, and increased rainfall stunted plant growth. The research was presented in the December 6, 2002 issue of the *Journal Science*. "Warming may stunt plants, study finds," *MSNBC*, December 6, 2002, <http://www.msnbc.com/news>.

Rainfall variability reduces productivity but increases the diversity of grasslands, according to the results of a four-year field study conducted at NSF's Konza Prairie Long Term Ecological Research (LTER). The biologists, from Kansas State University, NSF, and UC Santa Barbara found that more extreme swings in rainfall patterns – without changing total amount of rainfall received in a growing season – elicited responses similar to those that would occur under drought conditions. NSF, USDA, and DOE funded the study. Results were published in the December 13, 2002 issue of the journal *Science*. "Increase in rainfall variability related to global climate change; Impacts on ecosystems are greater than previously anticipated," National Science Foundation via *Science Daily*, December 13, 2002, <http://www.sciencedaily.com/releases/2002/12/021213062719.htm>.

High levels of CO₂ reduce forest isoprene emissions. University of Colorado at Boulder researchers found that two pollutants – CO₂ and hydrocarbons emitted from agricultural forest trees – offset each other somewhat in mitigating air quality problems. Growth of a poplar plantation under increased CO₂ (800 ppmv and 1,200 ppmv) reduced ecosystem isoprene (a GHG) production by 21 percent and 41 percent, while above-ground biomass accumulation was enhanced by 60% and 82%, respectively. Results showed that negative air-quality effects of proliferating agriforests may be offset by increases in CO₂. "Increased CO₂ uncouples growth from isoprene emission in an agriforest ecosystem," *Nature* 421, January 5, 2003, <http://www.earthinstitute.columbia.edu/news/2003/story01-16-03.html>.

Japan's forests to contribute to GHG reductions. Japan plans to plant trees and implement other forest development steps in 17.5 million hectares of forests, about 70 percent of Japan's overall woodlands, according to this article. The government increased its afforestation expenditures by one percent in the fiscal 2003 budget. "Japan to develop forests to achieve Kyoto Protocol target," *Jiji Press*, December 26, 2002, <http://www.co2e.com/News/story.asp?StoryID=952>.

Wheat, CO₂ and SO₂. Wheat grown with 600 ppm CO₂ and 0.06 ppm SO₂, singly and in combination, showed that individual SO₂ treatment reduced protein and starch contents and increased respiration rate, total soluble sugars, and total phenolics. Combination treatments increased concentrations of total soluble sugars, starch, and total phenolics. Individual CO₂ treatment stimulated photosynthesis and reduced stomatal conductance and transpiration rate. "Physiological and biochemical responses of two cultivars of wheat to elevated levels of CO₂ and SO₂, singly and in combination," *Environmental Pollution*, February 2003.

Bio-indications of fossil carbon sequestration in plants. By measuring the ratio of carbon-13 and carbon-12 contained in plants scientists are able to determine how much of the CO₂ absorbed by the plant came from the natural carbon cycle and how much came from CO₂ emissions. Plants growing in fossil-fuel- CO₂-contaminated areas, such as major cities, assimilate a mixture of global atmospheric CO₂ and of fossil fuel CO₂ with different ratios of ¹³C. Calculations based on contaminated and non-contaminated grass show urban grasses assimilate up to 29.1 percent of fossil-fuel- CO₂-derived carbon in their tissues. "¹³C Values of Grasses as a Novel Indicator of Pollution by Fossil-Fuel-Derived Greenhouse Gas CO₂ in Urban Areas," *Environmental Science and Technology*, 37 (1), January 2003.

Forest management with a carbon sequestration goal. This paper reveals the difficulty of obtaining good harvest schedules compatible with high levels of carbon captured, from an economic and forestry viewpoint. Theoretical aspects are applied to a Spanish forest. "Forest management optimisation models when carbon captured is considered: a goal programming approach," *Forest Ecology and Management*, Vol 174 (1-3), February 17, 2003.

Saskatchewan's forest carbon. The first forest carbon sequestration project formally approved under the Canadian Greenhouse Gas Emission Trading (GERT) Pilot is a 50-year (2000-2050) project in which Saskatchewan Environment sells an expected net 1.6 Mt carbon sequestered in white spruce plantations and forest protection to the electrical utility Saskatchewan Power Corporation. "Saskatchewan forest carbon sequestration project," *Forestry chronicle* 78 (6), December 2002.

Canadian environmental projects. Fifty-three environmental projects in communities across Canada will be funded through Environment Canada's EcoAction Community Funding Program. Among the projects are climate mitigation projects, such as an urban forest preservation project in Montreal. "Environment Minister David Anderson announces \$1.9 million for community environmental projects," *Environment Canada*, January 7, 2003, http://www.ec.gc.ca/Press/2003/030107_n_e.htm.

Rainforest tree grows faster in high CO₂ environment. A botanist in Brazil has discovered that at 720 ppm CO₂ – the predicted CO₂ level for 2075 and double today's concentrations of 360 ppm – photosynthesis doubles for the Jojoba tree, or *hymenaea*. The genetic mechanism which causes increased CO₂ absorption could be isolated. "Rainforest tree eats up pollution," *BBC Science*, February 24, 2003, <http://news.bbc.co.uk/2/hi/science/nature/2785403.stm>.

Swedish policy strategies to reduce CO₂ emissions. Given adequate incentive, the forest industry could contribute significant renewable energy to the energy system. "Strategic choices: Swedish climate intervention policies and the forest industry's role in reducing CO₂ emissions," *Energy Policy*, Volume 31 (10) 2003.

Forest response to increased CO₂ lessens over time. Results from North Carolina loblolly pines show that for the first four years tree growth increased by up to 25 percent when ambient levels of CO₂ were increased 50

percent, but then trees settle back to growing 6 percent faster than controls. "A fading green hope for climate," *US News & World Report*, February 10, 2003, <http://www.co2e.com/News/story.asp?StoryID=1001>.

Soil carbon sequestration in Saskatchewan. Two Saskatchewan farm lobby groups, the Saskatchewan Soil Conservation Association (SSCA) and the Agricultural Producers Association of Saskatchewan (APAS) advocate "the potential for farmers to gain monetary value for farmland conservation practices that reduce GHGs. "Group wants farmers paid for carbon sinks," *The Star Phoenix* (Saskatoon), February 20, 2003, <http://www.canada.com/saskatoon/starphoenix/index.html>.

2002 Farm Bill to pay farmers who use carbon-friendly methods. The 2002 Farm Bill has provisions to pay farmers to use these carbon-friendly farming techniques, either as a flat fee per acre or according to the amount of carbon captured. "Get Paid for Storing Carbon," *Soybean Digest*, February, 2003, <http://www.cornandsoybeandigest.com>.

Soil carbon flux in response to warming. In a decade-long soil warming experiment in a mid-latitude hardwood forest, a group of researchers from Massachusetts documented changes in soil carbon and nitrogen cycling in order to investigate the consequences of these changes for the climate system. Soil warming accelerates soil organic matter decay and CO₂ fluxes to the atmosphere, but this response is small and short-lived for a mid-latitude forest, because of the limited size of the labile soil carbon pool. Warming is also shown to increase the availability of mineral nitrogen to plants. "Soil Warming and Carbon-Cycle Feedbacks to the Climate System," *Science*, December 13, 2002, <http://www.sciencemag.org/content/vol298/issue5601/index.shtml>.

Diffuse light increases carbon sequestration. Researchers at ORNL, UCB, Harvard, and SUNY Albany correlated a sharp decrease in atmospheric CO₂ levels with the 1991 Philippines' Mt. Pinatubo eruption. They suggest that plants' photosynthesis rates increased up to 23% in the two years of increased diffuse radiation, where light bounced back and forth on volcanic aerosols. The article, published in *Science*, is entitled "Response of a Deciduous Forest to the Mount Pinatubo Eruption: Enhanced Photosynthesis." "In Aftermath of Volcanic Eruption, Photosynthesis Waxes, Carbon Dioxide Wanes," *Scientific American*, March 28, 2003, <http://www.sciam.com/article.cfm?chanID=sa003&articleID=000BA112-8AB6-1E83-85F7809EC588EEDF>.

Net carbon storage in Boreal forest trees dependent on age. Scientists from UC Irvine and Harvard used solar-powered anemometers and infrared gas analyzers to monitor carbon emissions of five black spruce stands in Manitoba, Canada. They found that most of the net carbon absorption takes place 20-50 years after a fire. The study appeared in the *Journal of Geophysical Research – Atmospheres*. NASA data from the Boreal Ecosystem-Atmosphere Study (BOREAS) was also used. "Fire frequency determines forest carbon storage," NASA/Goddard Space Flight Center, March 21, 2003, <http://www.gsfc.nasa.gov/topstory/2003/0311firecarbon.html>.

Sequestration project in Bolivia receives award. Harvard presented an award to the Noel Kempff Mercado Climate Action Project for sequestering carbon and protecting 4 million acres of tropical forest. The project partners are AEP, BP, PacifiCorp, the Nature Conservancy, Friends of Nature Foundation, and the Government of Bolivia. "Kennedy School Bestows Inaugural Roy Family Award to Bolivia-U.S. Public-Private Partnership," JFK School of Government, March 24, 2003, <http://www.ksg.harvard.edu/press/>, <http://www.noelkempff.com/>.

Continuous global measurements of Earth's carbon metabolism: net primary production. Scientists are combining space-based measurements of plant properties collected by the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) with data surface-based measurements, updating maps every 8 days. The new maps show that the highest mid-summer productivity rates are found at temperate latitudes, not at tropical latitudes. However tropical forests are more productive over a full year because of a longer growing season. Launched in December 1999 and May 2002, the Terra and Aqua satellites are the flagships of the Earth Observing System series of satellites. "NASA satellite measures Earth's carbon metabolism," *Space Flight Now*, April 28, 2003, <http://www.spaceflightnow.com/news/n0304/28carbon/>.

International science of forests and carbon sequestration. A project at Biosphere Two joined a global network of testing sites measuring how much carbon forests can sequester. Some test sites show promising results: forests grown on arid land in Israel take up around 1.8 tons per hectare, close to the world average of 2.3 tons per hectare. CO₂ appears to help plants make more efficient use of their limited water supplies, and the average rate of plant fixing of carbon is going up by 0.5% a year, according to this article. “Carbon in the balance: fitting forests into climate change agreements,” *Edie weekly summaries*, April 4, 2003, <http://www.edie.net/news/Archive/6845.cfm>.

Partnership to restore forest. Texas Parks and Wildlife Department (TPWD), Reliant Energy, The Conservation Fund and Environmental Synergy Inc. (ESI), unveiled a carbon sequestration project in which planted trees on 580 acres in east Texas will capture an estimated 215,000 tons of CO₂ from the atmosphere over the next 70 years. Carbon credits “will be retained by Reliant as part of the U.S. Department of Energy’s Climate Challenge Program. “Public-Private partners join forces in carbon sequestration project,” *E-Wire* April 4, 2003, <http://www.ewire-news.com>; and “162,000 trees to help remove carbon dioxide,” *Houston Chronicle* April 7, 2003, <http://www.chron.com/cs/CDA/ssistory.mpl/metropolitan/1856705>.

Arid lands and CO₂ fertilization. An experimental planting conducted by scientists at the edge of an Israeli desert 35 years ago is expanding at an unexpected rate. The findings, published in *Global Change Biology*, suggest that forests in other parts of the globe could also be expanding into arid lands. The Negev Desert research station is the most arid site in a worldwide network (FluxNet) established to investigate terrestrial CO₂ absorption. “Greenhouse gas might green up the desert; Weizmann Institute study suggests that rising carbon dioxide levels might cause forests to spread into dry environments,” *Science Daily*, May 8, <http://www.sciencedaily.com/releases/2003/05/030509084556.htm>.

USDA to reduce and sequester 12 million tons by 2012. The U.S. Department of Agriculture will consider GHG management practices when evaluating applications for conservation grants and subsidies. The department will offer financial incentives, technical assistance, demonstrations, pilot programs, education and capacity building. USDA also announced it will target 500,000 acres in the CRP toward hardwood tree planting beginning this summer. “Farmers who cut down gas to be rewarded,” *Associated Press*, June 7, 2003. “Veneman announces new incentives for GHG reduction and carbon storage,” USDA, June 6, 2003, <http://www.usda.gov/news/releases/2003/06/0194.htm>.

Turfgrass captures CO₂, stores it in soil. Soil scientists from the Agricultural Research Service and Colorado State University found that turfgrass in the Denver area stores CO₂ in the soil at a rate of roughly one ton carbon per acre per year. 16 soil records from golf courses, some of which go back 45 years, show that carbon is sequestered for up to 31 years in fairways and 45 years in greens. “Golf greens hide benefit, CSU researchers find,” June 8, 2003, <http://www.greeleytrib.com/apps/pbcs.dll/article?AID=/20030608/BUSINESS/306070023>. Details can be found in the June issue of *Agricultural Research* magazine, <http://www.ars.usda.gov/is/AR/archive/jun03/golf0603.htm>.

Review of the gaps in understanding ecosystem response to high CO₂. Two articles in *Environment International* address the need for research to understand terrestrial response to elevated CO₂ concentration and the possibility that escalating levels of CO₂ may serve as a selection pressure altering the genetic diversity of plant populations. “Impacts of elevated atmospheric CO₂ on forest trees and forest ecosystems: knowledge gaps,” and “The long-term effects of CO₂ on natural systems: issues and research needs,” *Environment International*; Volume 29, Issues 2-3, June 2003, <http://www.sciencedirect.com/science/journal/01604120>.

Europe’s large carbon sink. A team of scientists studying carbon storage in European biosystems report that ecosystem carbon stock transfers not detected by atmospheric models account for the gap between the small carbon-stock changes and the larger CO₂ uptake estimated by atmospheric models. They estimate a net carbon sink between 135 and 205 teragrams per year in Europe’s terrestrial biosphere, the equivalent of 7 to 12% of the 1995 anthropogenic carbon emissions. “Europe’s Terrestrial Biosphere Absorbs 7 to 12% of European Anthropogenic CO₂ Emissions,” *Science*, Vol. 300, Issue 5625, 1538-1542, June 6, 2003.

Climate warming raises net primary productivity. Using nearly two decades worth of data on climate and vegetation (1982 to 1999), a team of scientists found that globally, shifts in rainfall patterns, cloud cover, and warming temperatures allowed a six percent increase in the amount of carbon stored in trees, grass, shrubs, and flowers. Amazon rain forests accounted for nearly half the increase seen globally over the 18-year period, owing mainly to decreased cloud cover. “Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999,” *Science*, Volume 300, Number 5625, Issue of 6 Jun 2003, pp. 1560-1563. Also, “World's vegetation is cleaning more carbon from skies,” *The Christian Science Monitor*, June 6, 2003, <http://search.csmonitor.com/2003/0606/p02s02-usgn.html?related>.

Soil erosion reduces soil organic carbon. According to soil scientist R. Lal of Ohio State University, soil erosion has impacted the global carbon cycle through a combination of mineralization and carbon export of the soil organic carbon (SOC) pool. The amount of total carbon displaced by erosion on the earth may be 4.0–6.0 Pg/year. With 20 percent emission due to the mineralization of the displaced carbon, erosion-induced emission may be 0.8–1.2 Pg C/year on the earth. “Soil erosion and the global carbon budget,” *Environment International*, Volume 29, Issue 4, July 2003, pages 437-450, <http://www.sciencedirect.com/science/journal/01604120>.

Free Air Carbon Dioxide Enrichment (FACE). FACE technology modifies vegetation microclimates to simulate climate change conditions. CO₂-enriched air is released from a circle of vertical pipes into plots up to 30m in diameter, as tall as 20 m. Hundreds of investigators use FACE facilities at about eight sites worldwide. Four stories in the news have referred to FACE; they are summarized below. Brookhaven National Laboratory, <http://www.face.bnl.gov/>.

Mojave desert ecology CO₂ study. Some, but not all of the four desert shrub species exposed to an atmospheric CO₂ concentration of 550 ppm for three years were found to have reduced green leaf nitrogen content with respect to carbon. “Effects of elevated carbon dioxide on green leaf tissue and leaf litter quality in an intact Mojave Desert ecosystem,” *Global Change Biology*, 9: 729-735, 2003.

Australian ozFACE. The ozFACE facility was established in North Queensland to examine potential impacts of climate change on tropical grassland systems, more than a quarter of Australian land. “Researchers now watching grass grow,” *Northern Miner* (Australia), July 4, 2003.

Illinois soyFACE. University of Illinois soyFACE researchers found that higher concentrations of CO₂ raised soybean yields 17 percent, while ozone lowered crop yield as much as 20 percent. Plants under increased CO₂ were found to return less water to the atmosphere. “Researchers test climate change’s impact on crops,” *Associated Press*, July 15, 2003, http://www.enn.com/news/2003-07-15/s_6552.asp. University of Illinois at Urbana-Champaign researchers collaborating with Soy-FACE found that photosynthesis of maize increased 10 percent on average under projected 2050 CO₂ conditions. The jump in photosynthesis likely resulted from the plant maintaining higher water content in the leaves during the dry period. Also, at the end of a dry spell, carbon fixation increased as much as 41 percent. July 25, 2003, http://www.eurekalert.org/pub_releases/2003-07/uoi-icd072503.php.

Open field crop fertilization with CO₂. AG Gas uses CO₂ emissions for open-field crop yield enhancement, using microtubes to distribute gas to the crops. AG Gas claims tomato production has increased up to 120%. “CO₂ Emissions: Turning a liability into an asset,” *PR Newswire*, July 8, 2003, <http://www.aggas.com/>.

Deciduous trees store sufficient carbon for future growth. Researchers at the University of Basel Switzerland found that trees in a 100-year-old forest use an average of 33-45% of their carbon stores during the year. The team looked at leaves, branches, and trunks in ten species, including deciduous oak, beech, and maple plus evergreens spruce, fir, and pine, and found that deciduous species store sufficient carbon to replace all of their leaves at least four times over. Evergreens stockpile enough for half a new set of needles. “Non-structural carbon compounds in temperate forest trees,” *Plant, Cell and Environment*, 26, 1067-1081, (2003); “Old trees poor carbon sponge? Carbon stockpiles question idea that forests will counteract global warming,” July 23,

2003, <http://www.nature.com/nsu/030721/030721-6.html>; and “New research suggests trees are bad carbon sinks,” *Edie weekly summaries*, July 25, 2003, http://www.edie.net/gf.cfm?L=left_frame.html&R=http://www.edie.net/news/Archive/7310.cfm.

ORNL Poplar research. Scientists at Oak Ridge National Laboratory are studying genes and hormones in the poplar tree that could be modified to improve carbon transport to roots. The research is part of DOE’s Genomes to Life program. The poplar tree grows up to 4 meters annually and matures in about six years. “Poplar Trees: Getting to the Roots of Carbon Storage,” *Genome News Network*, July 25, 2003, http://www.genomenewsnetwork.org/articles/07_03/poplar.shtml.

Urban trees not stunted by ozone pollution. Researchers from Cornell University grew the same cottonwood clone in urban and rural sites and found that urban plant biomass was double that of rural sites. Apparently, higher rural ozone (O₃) exposures reduced growth at rural sites. “Urbanization effects on tree growth in the vicinity of New York City,” *Nature*, 424, July 10, 2003.

Rivers transport CO₂ to the ocean for storage. A study demonstrates a decade-long increase in the export of carbonate-dissolved alkalinity from soils to the Mississippi River. The research also suggests that agricultural lands may sequester more atmospheric CO₂ in rivers through soil weathering than forests. “Increase in the Export of Alkalinity from North America’s Largest River,” *Science*, July 4, 2003. Also, “Yale University Study - Agricultural lands may store more CO₂ in rivers than forests,” *M2 Presswire*, July 8, 2003; and “New research on the accumulation and storage of carbon,” National Public Radio, All Things Considered, July 4, 2003.

Farmers sequestering carbon. An article reviews last month’s news about the USDA working to pay for land-use carbon sequestration, and gives an update on Entergy Corps’ contract with nearly 80 farmers representing 6,470 production acres in northern Idaho, eastern Oregon and Washington State through the Pacific Northwest Direct Seed Association. The energy company paid \$75,000 to claim 30,000 tons over 10 years of estimated carbon reduction, about \$2.50 per ton. The estimated rate of storage is 0.55 tons of CO₂ per acre per year, which will be monitored and verified as direct seeded by local NRCS Conservation Districts. “Bush plan looks to natural ways to reduce gaseous emissions,” *Gannett News Service*, June 27, 2003.

Coastal ocean may not be a carbon sink. Recent evidence shows the continental shelf of the Gulf of Papua is a source of CO₂ to the atmosphere, which is contrary to most current climate change models depicting the coastal ocean as an important site of removal of CO₂ from the atmosphere. The Australian Institute of Marine Science (AIMS) called TROPICS – Tropical River-Ocean Processes in Coastal Settings –found that the decomposition rate of organic matter is equal to or greater than the measured supply rate of organic matter from rivers and plant growth. The research has evolved into a new research program called Margins. “Wet tropics carbon sink? Are the wet tropics really a sink for carbon?” AIMS, June 16, 2003, <http://www.aims.gov.au/pages/about/communications/backgrounders/20030616-wet-tropics-carbon-sink.html>.

Non-CO₂ GHGs

Methane and rice cultivation. A NASA-funded study observed a decline in the net methane emissions over the last 20 years. Changes to rice farming practices in China may have contributed to the decrease. “Shifts in Rice Farming Practices in China Reduce Greenhouse gas Methane,” NASA/Goddard Space Flight Center, December 20, 2002, <http://www.sciencedaily.com/releases/2002/12/021220074643.htm>.

Climate Change Feedback Loops Involving Sequestered GHGs

Half of U.S. climate warming results from land use changes. Evidence found by meteorologists Dr. Eugenia Kalnay and Dr. Ming Cai suggests that land use changes have a larger role in the general increase of minimum

temperature and the slight decrease of maximum temperature than previously expected. These conclusions were reached by comparing urban and rural weather station data and are expected to correspond to the effects of urbanization and the "urban heat island" effect as well as increased agricultural development and irrigation. The study is published in *Nature*. "Half U.S. Climate Warming Due to Land Use Changes," *Environmental News Service*, May 28, 2003, <http://ens-news.com/>.

NASA finds soot has impact on global climate. A team of researchers, led by NASA and Columbia University scientists, found that airborne, microscopic, black-carbon (soot) particles are even more plentiful and absorb two-to-four times more sunlight than previously assumed by the Intergovernmental Panel of Climate Change (IPCC). "NASA finds soot has impact on global climate," NASA, May 14, <http://www.spaceflightnow.com/news/n0305/14soot/>.

Global warming news. Articles in *CNN*, *The New York Times* and others have appeared in the past month focusing on evidence suggesting a possible global warming trend. A panel of scientists at a meeting of the American Geophysical Union discussed reducing sea ice across the Arctic Ocean, melting the ice sheet in Greenland, and spreading shrubs into the Alaskan tundra. "Compelling evidence of global warming," *CNN*, December 7, 2002, <http://www.cnn.com>; "Temperatures Are Likely to Go From Warm to Warmer," *New York Times*, December 31, 2002, <http://www.nytimes.com/2002/12/31/science/earth/31WARM.html>. Also, a study of snowfall on Canada's highest peak, Mount Logan, that provides longer-term evidence that atmospheric temperatures are on the rise, *ENN*, December 12, 2002, http://www.enn.com/news/enn-stories/2002/12/12122002/s_49117.asp.

UC Irvine research. Using a \$1.5 million particle accelerator to compare the amount of carbon-14 actually in the atmosphere to a projected amount if fossil combustion were not taking place, scientists have confirmed that the rise in GHG is due to fossil fuel combustion. "Scientists track building-block carbon to show global warming," October 26, 2002, *Orange County Register*, <http://www.ocregister.com/>.

Tropical rainforests release more CO₂ during warm years. In findings published in the *Proceedings of the National Academy of Sciences*, scientists matched tree growth with local temperature readings and found growth was often stunted during the hottest years. During warm years, atmospheric gas samples revealed tropical regions as a whole also released more CO₂ than they absorbed. "Rainforests might speed up global warming," *UPI*, April 24, 2003, <http://www.upi.com/>.

Methane hydrates released at end of Ice Age. Scientists at the Woods Hole Oceanographic Institution (WHOI) published a study in the April 4, 2003 issue of *Science* suggesting warmer waters trigger the release of deep-sea methane. California fossils from methane-consuming bacteria found in sediments deposited 70,000 to 12,000 years ago suggest that large amounts of methane were repeatedly released from the seafloor during warmer weather. An estimated 2 trillion to 8 trillion tons of methane are thought to be in under-sea clathrates. "Global warming could trigger more global warming – Via the sea," *Edie weekly summaries*, April 4, 2003, <http://www.edie.net/news/Archive/6846.cfm>. At a joint meeting of the American Geological Union, the European Geological Society and the European Union of Geosciences, scientists explained an increase in methane release at the end of the last ice age to be a combination of ocean methane hydrate release, due to ocean warming, and release from tropical wetlands and forests, formed as glaciers retreated. "Methane and climate change," *The Economist*, April 17, 2003, <http://www.economist.com/>.

Ocean

Ocean robots in the Indian Ocean. Cycling between the surface and a depth of two kilometers every 10 days, an array of ocean robots help scientists understand Australia's and the world's changing climate. Nearly 600 of the ocean profilers have been deployed globally with 3,000 profilers due in place by 2006, ultimately forming part of a larger monitoring program. "Ocean robots watching our climate," CSIRO,

http://www.globaltechnoscan.com/28thNov-3rdDec02/ocean_robots.htm;
<http://www.marine.csiro.au/LeafletsFolder/49float/49float.html>; <http://www-argo.ucsd.edu/>.

Ocean sequestration concerns and questions. An interview with Patricio Bernal, Executive Secretary of UNESCO's International Oceanographic Commission covers the current state of ocean sequestration, as well as concerns, including pH change, deepwater injection, and iron fertilization. The Intergovernmental Oceanographic Commission of UNESCO (IOC) with the Scientific Committee on Oceanic Research (SCOR) have set up an Advisory Panel on ocean CO₂. A symposium: "The Ocean in a High CO₂ World" is scheduled for March 2004. UNESCO, March 12, 2003, www.unesco.org/science.

Norway rejects ocean direct-injection research. The Norwegian government denied permission for an international research experiment to inject 5.4 tons of liquid CO₂ into the deep ocean. "Norway Scraps Experiment to Dump CO₂ at Sea," *Reuters*, August 23, 2002, <http://www.reuters.com>.

Depth of direct ocean sequestration critical. Results from a modeling simulation study at Lawrence Livermore National Laboratory suggest that the depth of the CO₂ injection into the ocean, rather than radiocarbon dating, is a good predictor of how effective that location is at long-term carbon sequestration. "Ocean Depths Critical to Sequestering CO₂," *Space Daily*, August 25, 2002, <http://www.spacedaily.com/news/greenhouse-02h.html>.

Private Interest in Indirect Ocean Sequestration. Three areas in the world's oceans – the North Pacific off the coast of Canada, the equatorial Pacific around the Galapagos Islands, and the area around Antarctica - contain relatively little phytoplankton, possibly due to low iron content. A recent international study 1,000 km northwest of Victoria spread small amounts of iron over an eight-km-square area of open ocean, observed the bloom of phytoplankton, and measured the concentration of gases. Private companies are now starting to think of ways to make money off such blooms. For example, the California-based Planktos Foundation is selling "green tags" for \$4 each that are supposed to represent the removal of one metric ton of CO₂ from the atmosphere. "Entrepreneurs see profit in pollution-fighting plankton plan to seed oceans with blooms of CO₂-absorbing phytoplankton," *The Ottawa Citizen*, August 5, 2002, <http://www.canada.com/ottawa/ottawacitizen/>.

Dust Causes Ocean Blooms. In the spring of 2001, two Carbon Explorer floats recorded the rapid growth of phytoplankton in the upper layers of the North Pacific Ocean after a passing storm deposited iron-rich dust from the Gobi Desert. This observation supports one of the key assumptions of the iron hypothesis: wind-blown dust stimulates plankton growth in otherwise unproductive waters. The U.S. Department of Energy's Office of Science, Ocean Carbon Sequestration Program supported this research. "Robotic observations of carbon biomass enhancement after the April 2001 Asian dust event in the subarctic North Pacific," October 25, 2002, *Science*, <http://www.lbl.gov/Science-Articles/Archive/ESD-Gobi-plankton-Bishop.html>.

Fertilizing Phytoplankton. An article in *Scientific American* on ocean carbon sequestration highlights the science of iron fertilization. "The Little Plankton That Could...Maybe," *Scientific American*, October 7, 2002, <http://www.sciam.com/article.cfm?chanID=sa004&articleID=000A5750-8AC2-1D9C-815A809EC5880000>.

Modeling climate feedbacks and ocean sequestration. Researchers at the University of Illinois at Urbana-Champaign developed an atmosphere-ocean, climate-carbon cycle model to study the impact of climate change on the oceans' ability to store injected CO₂ at different locations and depths. With feedback mechanisms, retention time in the Atlantic Ocean is superior to the Pacific Ocean. The findings, funded by DOE were presented at the American Geophysical Union meeting. "Climate change will affect carbon sequestration in oceans, scientists say," *Science Daily*, December 4, 2002, <http://www.sciencedaily.com/releases/2002/12/021204080934.htm>. Also see, "A short-term sink for atmospheric CO₂ in subtropical mode water of the North Atlantic Ocean," *Nature*, December 2002, http://www.nature.com/nlink/v420/n6915/abs/nature01253_fs.html.

Ocean algal blooms less efficient than lab studies and emit non- CO₂ GHGs. Iron fertilization involves adding iron sulphate to the ocean surface to encourage the growth of phytoplankton. The Southern Ocean Iron Fertilization Experiment (SOFeX) showed that although the bulk of the carbon absorbed by the phytoplankton stayed near the surface, one metric ton of iron spread at the ocean surface could force 1,000 metric tons of carbon below 100 meters, 100 times less than indicated in previous laboratory experiments. In addition, the blooms produced other GHGs, such as methyl bromide and isoprene. Preliminary findings were revealed at a meeting of the American Geophysical Union. "Ocean tests raise doubts over use of algae as carbon sink," *Nature*, December 26, 2002.

Technology solidifies CO₂ in seawater. Kaken Co., an R&D firm, uses electrolytic reactions to create insoluble calcium carbonate (CaCO₃) from seawater. The CaCO₃ particles precipitate to the seabed, and seawater then absorbs atmospheric CO₂. At a cost of \$2-3 billion to build an electrolytic cell equipped with power facilities and installed in the sea, the electrolytic reaction also recovers hydrogen gas in the process. "Method developed to solidify carbon dioxide for seabed burial," *The Nikkei Weekly*, January 6, 2003, <http://www.nni.nikkei.co.jp/FR/TNW/>.

Australian and U.S. researchers monitored ocean tracers, in this case chlorofluorocarbons (CFCs), to find that less anthropogenic CO₂ is absorbed by the world's oceans than previously estimated by models. Their findings were published in the January 10, 2003, issue of *Science*. "Oceans' uptake of carbon dioxide is increasing, but slower than forecast," *NewsRx.com*, January 30, 2003, <http://www.co2e.com/News/story.asp?StoryID=990>.

Ocean productivity. An ocean fertilization section in the January 9th journal *Nature* explored work in understanding the correlation between ocean productivity (thus a carbon sink) and iron-containing dust from the continents. "New era of ocean stewardship unveiled by Planktos Foundation," Planktos, January 12, 2003, <http://www.planktos.com/pressroom.htm#nature>.

Trading

Public-private partnerships in voluntary carbon trading. An article on the Chicago Climate Exchange describes goals of the companies and entities involved in the project, scheduled to open trading in 2003. "A New Approach to Global Warming," *The Economist*, October 17 2002, http://www.ieta.org/Library_Links/IETAEnvNews/Oct18_Chicago.htm.

PG&E Joins California Climate Action Registry. PG&E Corporation has become a Charter Member of the California Climate Action Registry, a private, nonprofit voluntary registry for GHG emissions. The Registry's other 23 Charter Members include Natural Resources Defense Council and the State of California Environmental Protection Agency. "PG&E Corporation Joins California Climate Action Registry," *PR Newswire*, October 24, 2002, <http://www.prnewswire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/10-24-2002/0001827370&EDATE>.

Tools for estimating GHG emissions from paper production. The International Council of Forest and Paper Associations developed methodology for estimating GHG emissions from paper operations. "International calculation tools issued to assess greenhouse gas emissions from pulp and paper mills," ICFPA, November 28, 2002, <http://www.paperloop.com/>.

Carbon Ring Consortium. Rothschild Australia and Australia-based environmental group E3 International have launched a fund which will allow highly polluting companies to offset their emissions by buying carbon credits from cleaner firms. With individual investments of no less than \$100,000, the Consortium hopes to raise \$2 million. It is expected that by June 2003 the carbon credits purchased will be ready for distribution among investors. "Rothschild, E3 Launch Carbon Credit Investment Fund," *Reuters*, September 3, 2002, <http://www.planetark.org/dailynewsstory.cfm/newsid/17562/story.htm>.

Public Carbon Trading Website. 500 PPM has developed a website that allows the general public to offset CO₂ emissions they create through personal air travel. Website users can calculate their emissions and then offset them by purchasing verified emission offsets that come from emission reduction projects in South Africa, Brazil, India, and Jamaica. The money collected goes back to the local community or business that sold the offsets and can be used for additional emission reduction projects. The new website address is:
<http://travel.500ppm.com>.

New Jersey trading plan scrapped. New Jersey plans to scrap an air-pollution-control program entitled The Open Market Emissions Trading Program, which allows companies to buy credits from other companies that have successfully reduced their emissions if they pollute above permitted levels; some 39 companies have made use of it to meet emissions standards. State Department of Environmental Protection Commissioner Bradley Campbell is pulling the plug, saying the program has hurt state efforts to reduce air pollution. "Jersey Spiking Whitman Plan," *New Jersey Star-Ledger*, September 17, 2002.

Carbon trades more than triple in 2002. Worldwide trading of credits in CO₂ emissions linked to global warming is poised to more than triple this year to an estimated 67 million tons as companies prepare for the Kyoto Protocol. "Global Carbon Credit Market Seen Tripling This Year," October 21, 2002, *Reuters*,
<http://www.planetark.org/dailynewsstory.cfm/newsid/18244/story.htm>;
http://www.natsource.com/uploads/features/State_and_Trends_of_the_Carbon_Market_Presentation_FINAL.ppt#1.

Database of Country and Regional Trading Strategies. A new report from Point Carbon focuses on the increasing number of regional, national, and international systems for trading of greenhouse gas emission allowances and emission reduction credits. The analysis builds on a database developed by Point Carbon for the International Emissions Trading Association (IETA), that covers all known trading schemes and programs, which is also available for viewing. "Emerging Systems for Carbon Trading," Point Carbon, October 30 2002,
<http://www.pointcarbon.com/>.

The Biocarbon Fund. A public/private partnership launched by the World Bank will provide funds for offset projects that reduce GHGs, promote biodiversity, and encourage sustainable development, including projects not covered in the Kyoto Protocol such as conserving or restoring existing forest. Fourteen businesses, from power utilities to insurance companies, indicate interest in participating. "Launch of US\$100 Million Biocarbon Fund," The World Bank, November 5, 2002,
<http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:20073597~menuPK:34463~pagePK:34370~piPK:34424~theSitePK:4607,00.html>.

German trading simulation. Twelve companies from Baden-Württemberg in Germany participated in an emissions trading simulation. A summary of the project with conclusions is available. "Simulating emissions trading," Fraunhofer Institute, <http://www.isi.fhg.de/u/e-projekte/e-bawueplan.htm>.

Experimental Trading regime in Japan. The Japanese Environment Ministry will test-run a regional GHG market starting January 2003, involving roughly 30 firms. A full-fledged national market will be established in 2005 or later. The firms will set their own maximum emission levels for a year. "Japan to test-run greenhouse-gas emission market in January," *Kyodo News*, November 17, 2002.

Rainforest emissions offset project. Conservation International and an Ecuadorian conservation organization will reforest 680 acres of degraded pastureland in northwest Ecuador. The Oregon Climate Trust provided \$186,000 for the project. "Oregon Power Companies Offset Carbon Through Investment in Ecuador's Rainforest," CSRwire, November 20, 2002, <http://www.socialfunds.com/news/release.cgi?sfArticleId=1410>.

Australian and U.S. GHG trades. BP and Australian waste-to-energy operator Global Renewables traded 1.05 million tons of GHG abatement over a three to five-year period with an option for a further 50,000 tons. "BP buys Eastern Creek credits," *Sydney Morning Herald*, November 6 2002,
<http://www.smh.com.au/articles/2002/11/05/1036308313404.html>. In the U.S., chemical company DuPont made a

demonstration trade to utility Entergy Corp. "Greenhouse trade needs US mandate to grow - Entergy," *Reuters*, November 4, 2002, <http://www.planetark.org/dailynewsstory.cfm/newsid/18428/story.htm>.

Slovakia and Japan trade carbon in first emissions trading deal under the Kyoto Protocol. The government of Slovakia sold \$1-million worth, of GHG emission credits, or 200,000 AAUs, to a Japanese trading house by way of the international emissions trading mechanism outlined by Kyoto. Evolution Markets acted as broker. "First Kyoto Greenhouse Deal Snapped Up by Slovakia," *Reuters*, December 6, 2002, <http://www.reuters.com>.

European Union environment ministers to create international GHG emissions trading system. Subject to final approval by the European parliament, the scheme will cap the amount of CO₂ that industries can emit from 2005, while allowing them to trade emissions rights with other firms in the 15-bloc nation. The UK and Denmark already have voluntary emissions trading schemes, and Norwegians tax offshore production CO₂ emissions at \$32/ton. "EU agrees pollution market: On the EU emissions trading decision," *BBC*, December 9, 2002, <http://news.bbc.co.uk/2/hi/business/2560175.stm>. The European Commission has retained CDC IXIS, with the help of PricewaterhouseCoopers and the law firm Baker & McKenzie, to advise on the drafting of the technical, legal, and IT aspects of the future GHG registry systems of the Member States. CDC IXIS, December 16, 2002, <http://www.cdcixis.com>.

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October 2002

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November 2002

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December 2002

New South Wales energy providers face mandatory GHG limits. Australia's New South Wales Government tightened legislation, requiring energy providers to reduce GHG emissions or invest in offset projects within New South Wales only. The legislation comes into force on January 1, 2003 and calls for power companies to reduce emissions 5 percent below 1990 levels by 2007, and maintain those levels for a further five years. "No Green Credit Across The Border," *Sydney Morning Herald*, November 21, 2002, <http://www.smh.com.au/>.

Kyoto ratification. New Zealand recently passed a Climate Change Response Bill, and intends to follow through with Kyoto Protocol ratification. South Korea has already handed in the Kyoto Protocol instrument of ratification to the UNFCCC (South Korea is not among the 38 developed countries that agreed to limit their GHG emissions, but will likely be obligated to make reductions between 2013 and 2017). Both Canada and Russia are still uncertain, though Chretien announced at August's Earth Summit in Johannesburg that his government will ratify Kyoto before the end of the year, and Russia has announced it will take another year to consider ratification. "New Zealand to ratify Kyoto Protocol in weeks," *New Zealand Herald*, November 14, 2002. "Korea Sends ratification of the Kyoto pact to UN," *JoongAng Ilbo*, November 12, 2002. "Chretien vows to stop talking and ratify Kyoto," *Inter Press Service*, November 28, 2002, <http://www.co2e.com/News/story.asp?StoryID=921>.

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reforestation; forest preservation; and any other appropriate method of capture, long-term separation, isolation, or removal of GHGs from the atmosphere, as determined by the Administrator. It does not include any conversion of, or negative impact on, a native ecosystem; any introduction of non-native species or genetically modified organisms; or forest monocultures. The draft of McCain and Lieberman's Climate Stewardship Act of 2003, http://www.ieta.org/Library_Links/IETAEnvNews/McCainLiebermanBill.pdf. See also "New players on global warming," *New York Times*, January 15, 2003, <http://www.nytimes.com/2003/01/15/opinion/15WED1.html?ex=1043298000&en=989b7d5eff3e4269&ei=5062&partner=GOOGLE>.

The Global Climate Security Act of 2003. Daschle introduced S.17 on January 7th, which establishes a National Greenhouse Gas Emissions Information System and requires a National Assessment of Climate Change Impacts; establishes a 1990 GHG emissions level goal by 2013 for Federal government; requires a report on the most cost-effective policy options to reduce net Federal Government GHG emissions to zero by 2025; establishes grants to states or local governments for operating GHG data collection, inventory, or trading systems; implementing GHG emission reduction or sequestration projects; and conducting research intended to reduce net GHG emissions in the U.S. through sustainable economic development, <http://thomas.loc.gov>.

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