Understanding Carbon Capture and Geologic Sequestration (CCS):

Why CCS is a key strategy in the portfolio to reduce greenhouse gas emissions

This section seeks to familiarize the reader to carbon capture and geologic sequestration/storage (CCS) through the following:

- Identifying the entities and reports* recommending CCS as an important strategy in the reducing of greenhouse gas (GHG) emissions;
- Highlighting the basis for the recommendation;
- Addressing the cost of not reducing CO_2 emissions;
- Describing how CCS works;
- Responding to some common concerns regarding CCS;
- Showing that some CCS technology and practices are already commercially proven;
- Listing entities engaged in further research and development of CCS for large-scale projects necessary for the reduction of GHG emissions; and
- Other useful resources.

Entities/Reports recommending carbon capture and storage (sequestration) as an important strategy in the reducing of greenhouse gas emissions:

- The Intergovernmental Panel on Climate Change (IPCC Special Report on Carbon dioxide Capture and Storage)
- Stern Review: the Economics of Climate Change
- Massachusetts Institute of Technology (The Future of Coal)
- US Climate Action Partnership (A Call for Action)
- Coal Gasification Working Group (federal policy recommendations on carbon capture and sequestration)
- European Technology Platform for Zero Emission Fossil Fuel Power Plant (Strategic Overview)

Basis of recommendation

- "The risks of global warming are real and . . . the United States and other governments should and will take action to restrict the emission of CO_2 and other green house gasses."
- "Coal will continue to play a large and indispensable role in a greenhouse gas constrained world."
- "The use of coal will increase under any foreseeable scenario because it is cheap and abundant."
- "Although carbon-free technologies, chiefly nuclear and renewable energy for electricity, will continue to play an important role in a carbon-constrained world, absent of technological breakthrough that is not foreseen, coal, in significant quantities, will remain indispensable."

- "Carbon dioxide capture and sequestration (CCS) is the critical enabling technology that would reduce CO_2 emission significantly while also allowing coal to meet the world's pressing energy needs."

(From MIT Study *The Future of Coal*, p. ix.)

- "If we do not succeed in keeping the average global temperature increase below 2 degrees Celsius (relative to pre-industrial level), the consequences - even as early as 2050 - could be grave. Every region in the world will be affected . . . . "
- "The solution is, of course, unanimous: reduce greenhouse gas (GHG) emissions - especially CO_2 - and by 50% -80% by 2050, according to the IPCC. This is confirmed by the European Union Green Paper on energy."
- "Yet with the world energy demand predicted to increase by 60% between 2002 and 2030, and renewable energies to make up only a third of the energy mix by 2050, the immensity of the challenge becomes clear. Clearly, fossil fuels - coal, oil, gas - must remain the primary energy resource for a long time to come."
- "A portfolio of solutions is therefore essential, including renewable energies, improved energy efficiency, and nuclear power. But that still leaves an enormous gap between global energy demand and their potential to reduce CO2 emissions on the massive scale required. To these, we must therefore add CO_2 capture and storage (CCS) technology."

(From European Technology Platform for Zero Emission Fossil Fuel Power Plants, *Strategic Overview*, pp.10 -11)

"Illustrating the Challenge of Scale for Carbon Capture"

- "Today fossil sources account for 80% of energy demand: Coal (25%), natural gas (21%), petroleum (34%), nuclear (6.5%), hydro (2.2%) and biomass and waste (11%). Only 0.4% of global demand is met by geothermal, solar and wind."
- "50% of the electricity generated in the U.S. is from coal."
- "There are the equivalent of more than five hundred, 500 megawatt, coal-fired power plants in the U.S. with an average age of 35 years."
- "China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity comparable to the entire UK power grid each year."
- "One 500 megawatt coal-fired power plant produces approximately 3 million tons/year of carbon dioxide."
- "The United States produces about 1.5 billions tons per year CO_2 from coal-burning power plants."
- "At present the largest sequestration project is injecting one million tons/year of carbon dioxide (CO_2) from the Sleipner gas field into a saline aquifer under the North Sea."

(Excerpts from MIT Study, *The Future of Coal*, p. ix)

A Christian Science Monitor analysis shows the potential for an extra 1.2 billions tons of carbon released into the atmosphere per year. To follow is a summary of the analysis.

China

- "China accounted for two-thirds of the more than 560 coal-fired power units built in 26 nations between 2002 and 2006.
- The Chinese plants boosted annual world CO_2 emissions by 740 million tons.
- In the next five years, China is slated to slow its buildup by half, according to industry estimates, adding 333 million tons of new CO_2 emissions every year.
- That's still the largest increase of any nation. But other nations appear intent on catching up."

"Nations that have pledged to reduce global warming under the Kyoto treat are slated to accelerate their buildup of coal-fired plants.

- Eight EU nations - Germany, Italy, Poland, Spain, Bulgaria, Hungary, Slovakia, and the Czech Republic - plan to add nearly 13 gigawatts of new coal-fired capacity by 2012.
- That's up from about 2.5 gigawatts over the past five years."

The United States

- "The US is planning to build more than 150 coal-fired power plants that don't sequester their emissions, according to the US Department of Energy.
- Platts short list of those most likely to be built in five years lists 64 power plants - which would still vault the US into a virtual tie with India at 38,000 megawatts of new output.
- If that happens, the US alone would add 250 million tons a year of CO2 emissions to the atmosphere - on top of the billions its power plants already emit."

"At least 37 nations plan to add coal-fired capacity in the next five years – up from the 26 nations that added capacity during the past five years.

- With Sri Lanka, Laos, and even oil-producing nations like Iran getting set to join the coal-power pack, the world faces the prospect five years from now of having 7,474 coal-fired power plants in 79 countries pumping out 9 billion tons of CO_2 emissions annually - out of 31 billion tons from all sources in 2012."

(CSM, *Global boom in coal power - and emissions*, March 22, 2007)

"CCS can remove 85-90% of the carbon emissions associated with conventional fossil-fuel power generation, such as coal- or gas-fired."

(Form Carbon Capture & Storage Association, March 21, 2007, Press Release)

The cost of not reducing CO_2 emissions

"While we can broadly estimate the investment required to implement CCS, this is expected to fall as we gain experience and advance technological development. Any estimation of costs, however, must also include that of not implementing it, i.e. dealing with the tangible effects of climate change from unchecked CO_2 emissions.

According to the latest report published by the Intergovernmental Panel of Climate Change (IPCC) - "Climate Change 2007" - GHG emissions have already made the world 0.76 degrees C warmer and, if no action is taken, there is likely to be an increase of between 2.4 degrees and 6.4 degrees by 2100. Climate change models established by the IPCC indicate that if we fail to keep below 2 degrees, dramatic climate effects will occur, including:

- Increased flood, landslide, avalanche, mudslide damages.
- Increased risks of infectious diseases epidemics.
- Increased property and infrastructure losses.
- Increased damage to coastal ecosystems.
- Decreased water resources, both quantity and quality.
- Increased risk of forest fire.

The IPCC has confirmed that CCS is one of the key technologies required to reduce CO_2 emissions."

(From European Technology Platform for Zero Emission Fossil Fuel Power Plants, *Strategic Overview* p. 13)

How does carbon capture and geologic storage (sequestration) (CCS) work?

Download *Storing CO_2 Underground* to understand how CCS works.

The following most frequently asked questions about Carbon Dioxide Capture and geological Storage (CCS) are also answered in *Storing CO_2 Underground*:

- Can CO_2 be stored deep underground?
- What difference could CCS make to global warming?
- How can CO_2 be captured from industry?
- Where can CO_2 be geologically stored?
- Why does CO_2 stay underground?
- Where are the good geological storage sites?
- Where is CO_2 geological storage happening today?
- What is the future of CO_2 geological storage?

Responding to Some Common Concerns Regarding CCS

Does storage of carbon dioxide underground bring with it a risk of contaminating drinking water supplies?
"Research is focused on understanding and addressing the risks. It is important to understand that there are no natural connections between drinking water aquifers and potential carbon dioxide storage formations, because if there were, the brine or hydrocarbons in those formations would have already contaminated the drinking water over millions of years. There is a possibility that carbon dioxide, because of its buoyancy and low viscosity, could escape where other fluids did not. These possibilities are well understood by geologists and the sites considered for carbon dioxide storage are those where there is virtually no chance of such a thing happening. Furthermore, the Carbon Sequestration Program is making a strong investment in technologies that can monitor carbon dioxide once it is injected underground and detect any movement." **(Source: National Energy Technology Laboratory)**

What about seismic activity caused by geologic sequestration of CO_2?
"Initial concerns about induced seismicity and associated leakage are likely to be misplaced. An experiment at Rangely field, CO, attempted to induce earthquakes in 1969-1970. It did so, but only after enormous volumes injected over long times on a weak fault. There were no large earthquakes. The seal worked, even after 35 years of water and CO_2 injection. Most injection sites are less severe than this one. This phenomenon can only be studied at scale." **(Source: S. Julio Friedmann, Carbon Management Program APL/Energy and Environment Directorate, LLNL)**

If the CO_2 is used for enhanced oil recovery, wouldn't this lead to more greenhouse-gas emissions from the use of the additional oil recovered as a result?
Enhanced oil recovery (EOR) does not mean increasing the demand for oil. EOR offsets oil production that would happen elsewhere. EOR using CO_2 has been happening in the US since 1970, and it will continue to happen in the future. With CCS for EOR, you would be using CO_2 that would otherwise be released into the atmosphere rather than naturally occurring CO_2 from a well. **(Sources: NRDC, Fall 2005 One Earth/Wired Magazine, November 2004)**

Is geologic storage of carbon dioxide safe?
"Many of the reservoirs that are being considered have already stored gases and liquids for thousands of years. Oil and gas fields are known to be effective stores for hydrocarbons and natural gas. Similarly, methane has been trapped in coal seams since the coal was formed and deep saline reservoirs in sedimentary basins have held water for many thousands of years. There are also many cases throughout the world where naturally occurring CO_2 from volcanic activity has been stored in sedimentary rocks for millions of years. These examples give confidence that CO_2 can be stored safely for thousand of years.

Once it is stored, slow releases of CO_2 from geological reservoirs, especially those under the ocean, are unlikely to give rise to safety concerns, unless the CO_2 is inadvertently trapped. The risk of a large-scale sudden release of CO_2 can be avoided by careful selection of the storage reservoirs. For example, storage in regions that are liable to tectonic or seismic activity should be avoided. Any selection procedure needs to consider:

- The integrity of the overlying cap rock.
- Regional geology and possible faulting.
- Groundwater flow."

(Source: *Geologic Storage of CO_2,* The International Energy Agency Greenhouse Gas R&D Programme (IEA GHG))

Will any mechanisms be in place to ensure that the CO_2 stays underground?
Monitoring, mitigation, and verification (MM&V) are aimed at providing an accurate accounting of stored CO_2 and a high level of confidence that the CO_2 will remain sequestered permanently. This would be an integral component of large-scale CCS projects. (For more information on MM&V)

Isn't CCS as problematic as dealing with nuclear waste as we are looking at keeping CO_2 underground for thousands of years?
No, CCS is not as problematic as nuclear waste because with the passage of time, the storage security of injected CO_2 increases. With CSS there are 4 trapping mechanisms: structural, residual, solubility, and mineral. When first injected, CO_2 is in a supercritical state and acts like liquid, and structural storage takes immediate effect. Depending on the physical and chemical characteristics of the rocks and fluids, all or some of remaining trappings mechanism will occur. Although the remaining mechanism take time, as they occur they provide increased storage security. Consequently, the longer the CO_2 remains underground, the more securely it is stored because as it is dissolved and mineralized, CO_2 is permanently fixed. (**Sources: S. Julio Friedmann, Carbon Management Program APL/Energy and Environment Directorate, LLNL, and *Storing CO_2 Underground*, The International Energy Agency Greenhouse Gas R&D Programme (IEA GHG))**

Showing that some CCS technology and practices are already commercially proven

"CO_2-enhanced oil recovery (EOR) is commercially proven. It is used extensively in the USA, where 74 projects are now operating, injecting some 33 million tonnes of CO_2 annually. Although most of this CO_2 comes from natural sources, about 3 million tonnes per year is from natural gas processing plant, from ammonia production and other man-made sources. . . . A limited amount of CO_2 is used for EOR projects in other countries." **(Source: *Depleted Oil & Gas Fields for CO_2 Storage*, The International Energy Agency Greenhouse Gas R&D Programme (IEA GHG))**

What is already known and being done commercially would need to be scaled up.

For a list of "Carbon Dioxide Capture and Geologic Storage (CCS) International Activities and Projects," go to Link.

Examples of entities engaged in further research and development (R & D) of CCS for large-scale projects.

In order to identify environmentally sound and optimal sites for CO_2 sequestration, R & D includes:

- "Developing criteria for subsurface geologic formations that could be used for CO_2 sequestration."
- "Developing a general modeling capability for analyzing CO_2 sequestration in geologic formations."
- "Identifying the geochemical, hydrologic, and structural constraints on successful geologic CO_2 sequestration."

(From *A Solution for Carbon Dioxide Overload* go to)

The CO_2 Capture Project

An international effort that addresses "the issue of reducing emissions in a manner that will contribute to an environmentally acceptable and competitively priced continuous energy supply for the world."

A 26-minute film of the CO_2 Capture Project is available at the website. (go to)

Carbon Sequestration Leadership Forum (go to)

"An international climate change initiative focusing on development of improved cost effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage.

CSLF's purpose is to make these technologies broadly available internationally, and to identify and address wider issues relating to carbon capture and storage. This could include promoting the appropriate technical, political, and regulatory environments for the development of such technology."

For more information on CSLF projects (go to)

The International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) (go to)

"An international collaborative research program. IEA GHG focuses its efforts on studying technologies to reduce greenhouse gas emissions. IEA GHG was established in 1991 and aims to provide its members with informed information on the role that technology can play in reducing greenhouse gas emissions. The Programme's three main activities are:

- Evaluation of technologies aimed at reducing greenhouse gas emissions;
- Promotion and dissemination of results and data from its evaluation studies; and
- Facilitating practical research, development and demonstration activities."

Lawrence Livermore National Laboratory, University of California

"Lawrence Livermore research on geologic sequestration combines fieldwork, laboratory experiments, and modeling and includes scientists and engineers from the Laboratory's Energy and Environment (E&E), Engineering, Chemistry and Materials Science, and Computation directorates. For example, one project is developing methods to capture CO_2 at smokestacks. Another project is helping monitor CO_2 movement after the gas has been injected underground. Laboratory scientists are also studying the safety of carbon sequestration and how CO_2 injection affects a formation's geophysical and geochemical properties. Computer simulations of sequestration techniques will also help decision makers evaluate potential storage sites across the nation."
For more information go to

National Energy Technology Laboratory (NETL)

"NETL manages a portfolio of laboratory and field R & D focused on technologies with great potential for reducing greenhouse gas emissions and controlling global climate change. Most efforts focus on capturing carbon dioxide from large stationary sources such as power plants, and sequestering it using geologic, terrestrial ecosystem, or oceanic approaches. . . . In its core R&D efforts, NETL focuses on developing new sequestration technologies and approaches to the point of pre-commercial deployment. Primary objectives are (1) lowering the cost and energy penalty associated with CO_2 capture from large point sources, and (2) improving understanding of factors affecting CO_2 storage permanence, capacity, and safety in geologic formations and terrestrial ecosystems."
For more information go to

Other Useful Resources

National Perspectives: **Carbon Sequestration Atlas of the United Sates and Canada**. On North American CO2 sources and determining carbon sequestration capacity estimates for various geologic formations.

Researchers examine carbon capture and storage to combat global warming Stanford News Service.