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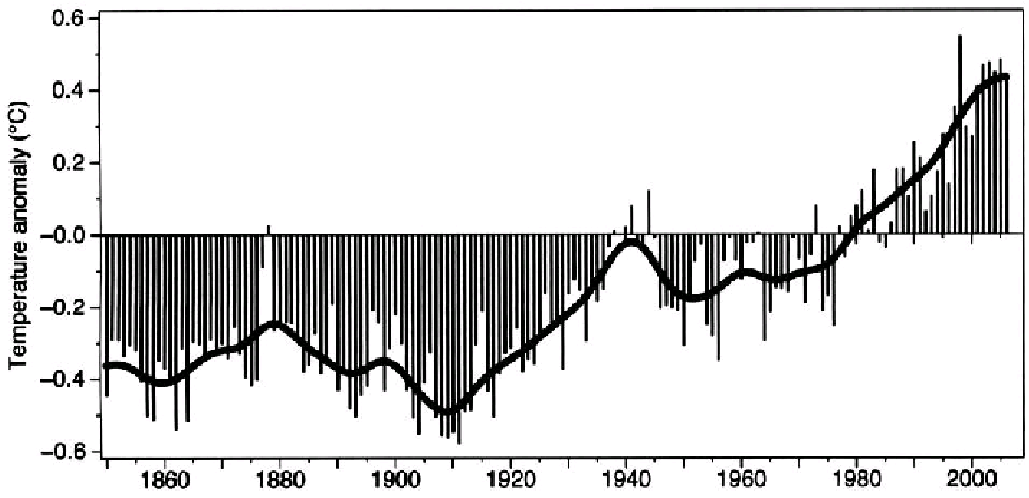
When Moly meets Carbon

Carbon dioxide emissions from the use of fossil fuels like coal, natural gas and oil are the largest man-made contributor to greenhouse cases, which are believed to contribute to climate change. Researchers are looking at a number of methods to stabilize CO2 concentrations in the atmosphere, in an effort to slow climate change. Molybdenum plays a role.



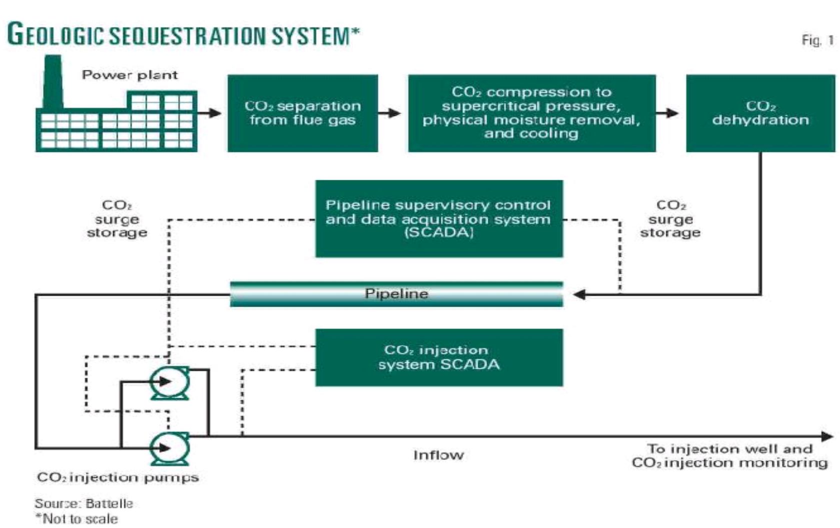
Global Average Surface Temperatures
(Source: University of East Anglia, Norwich)

Carbon sequestration, also called carbon capture and storage (CCS) – permanently storing CO2 in the earth – is one carbon management technology. There are two broad subtypes of carbon sequestration: terrestrial and geologic.

In terrestrial sequestration, CO2 from the air is absorbed in biological materials such as crops, grasses and trees. Ultimately, the carbon is transferred to the soil.

With geologic sequestration, CO2 is captured, compressed, transported, and injected into reservoirs such as saline formations, oil and gas reservoirs, or coal seams. This geologic sequestration is more amenable to reducing CO2 emissions from point sources such as a refinery or power plant. About half of all CO2 emissions are attributed to these point sources.

Let's look at the geologic sequestration first. A carbon sequestration system with CO2 from a power plant "source" is shown in the diagram below. The "sink" is the injection well at the bottom right.



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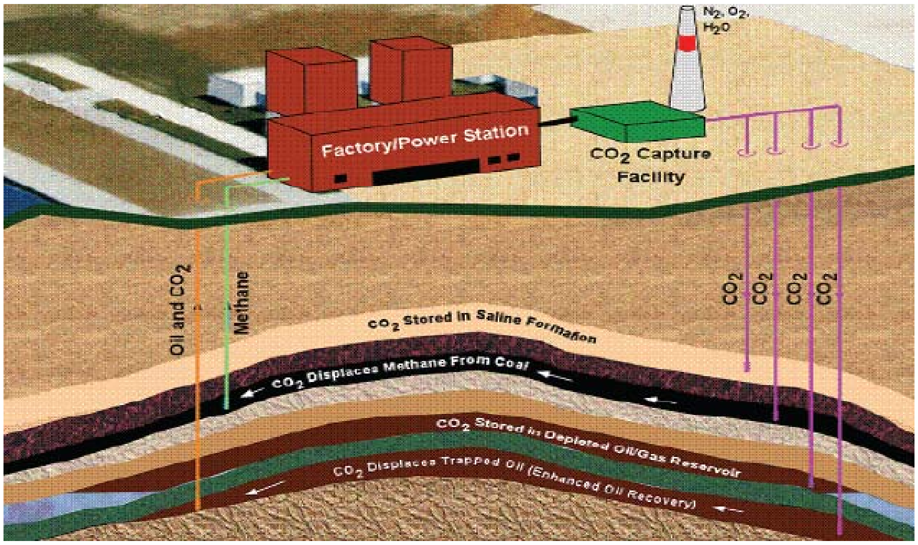
Readers will immediately note the potential for molybdenum in pipeline steels, valve alloys, pumps and compressor stations.

Below is a carbon sequestration system located at the point source. Even without a pipeline, we consider molybdenum in steels for drilling and casing these injection wells and again in valves and compressors.



Carbon sequestration at a point source

Most CO2 sinks will not be adjacent to the source, however, and transportation will be a big part of the molybdenum connection. CO2 pipelines already exist in Wyoming, North Dakota, Colorado, New Mexico, Texas, Mississippi, Michigan, and some northeastern states – 3,500 miles of CO2 mainline pipe at present in the United States.

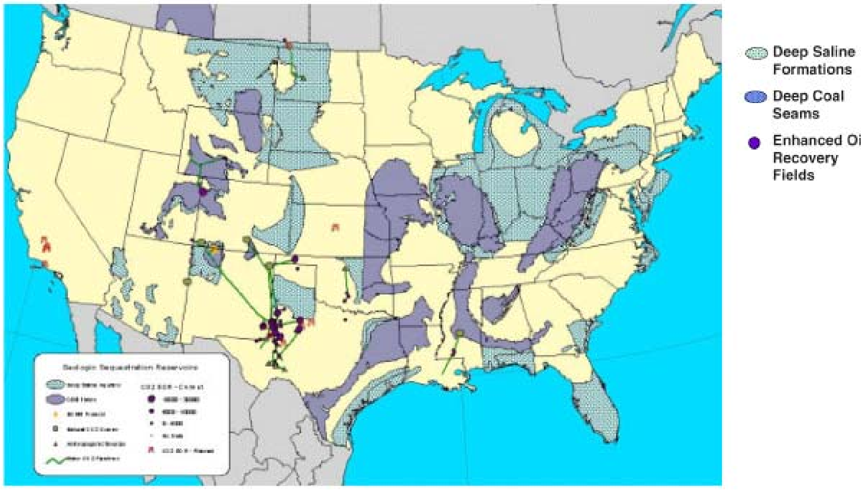
A study by the Carnegie Mellon Electricity Industry Center published in October 2007 said that the U.S. CO2 pipeline system would have to increase by 10- to 40 times to enable us to make significant progress on controlling emissions.

Indeed, since CO2 runs at much higher pressure than natural gas, 2,000-3,000 psig versus 600-1,200 psig, existing pipelines are not suitable, and new lines will have to be built.

This high pressure requirement becomes a perfect fit for the new pipeline steels X-100 and X-120, which we've seen can contain 0.4-0.5 percent molybdenum. CO2 is sent dry, and with little or no H2S (<20 ppm) so mild steel pipe works. If there is a chance of a little moisture getting in, the solution to the problem tends to involve slightly more molybdenum (say 1-2%), like a 13Cr-1Mo or 13Cr-2Mo steel, for example.

In the interim, while we wait for pipelines, tanker trucks are used, and research reported here earlier indicates lean duplex stainless steels containing molybdenum are becoming more popular due to weight versus strength considerations.

Opportunities for sequestration exist in deep saline formations, coal seams and enhanced oil recovery (EOR) fields. Areas which have been identified as suitable in the U.S. are shown in the chart on the next page. We'll define EOR in a minute.



U.S. areas identified as suitable for carbon sequestration

In Canada, Alberta's Energy and Utilities Board has outlined nearly 1,000 oil and gas fields large enough, they say, to store decades' – if not a century's – worth of CO2 from coal fired plants and the tar sands. These are the largest of some 45,000 oil and gas reservoirs in Alberta, Northeast BC, and Saskatchewan – those that would justify the cost of infrastructure, and with a total capacity of about eight billion tonnes of storage. To put that in context, Alberta produces about 230 million tonnes of CO2 a year.

Canadians are well versed in carbon sequestration and EnCana Corp. is running one of the world's larger CO2 projects in southern Saskatchewan, taking CO2 from Colorado. Other major world projects include the Sleipner project with CO2 going to an offshore saline formation in Norway, and the Salah project, in a gas field in Algeria.

The most exciting opportunity however is not just to store the CO2 but to do something with it along the way. This is where enhanced oil recovery (EOR) comes in.

First, a little on oil reserves and recovery factors:

REGIONAL DISTRIBUTION OF GLOBAL OIL RESERVES
(billion barrels)

	Remaining Reserves (2006)			
	Conventional		Unconventional	
	B bbl	%	B bbl	%
Middle East	734	64		
FSU	78	7		
South America	62	5	128[1]	44
North Africa	60	5		
West Africa	46	4		
North America	41	4	165[2]	66
North Sea	14	1		
Others	112	10		
World remaining reserves	**1,147**	**100**	**293**	**100**
Cumulative production	**1,011**		**7**	
World ultimately recoverable reserves	**2,158**		**300**	
Estimated original oil In place (EOIP)[3]	**9,800**		**3,000**	

[1]Orinoco Oil Belt. [2]Canadian Oil Sands. [3]EOIP = ultimately recoverable reserves at a given recovery factor considered 22% for conventional- and 10% for unconventional oil.
Source: OPEC, Oil & Gas Journal, ENI

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Oil recovery factor is the percentage of the in-place discovered oil that is technically recoverable.

The primary phase of oil production from a reservoir depends on its existing natural energy source, and can be one of many, as shown below:

TYPICAL OIL RECOVERY EFFICIENCIES

	Original oil In place (%)
Primary methods	
Liquid and rock expansion	Up to 5
Solution gas drive (most common)	20
Gas cap expansion	30
Gravity drainage	40
Water influx	60
Secondary methods	[1]Up to 70
Gas reinjection	
Water flooding	
Tertiary methods (= EOR)	Up to 80
Thermal (steam, combustion, hot water)	
Miscible (CO_2, hydro-C, N_2, flue gas)	
Chemical (polymners, surfactants)	

[1] While 70% is theoretically possible, 60% is considered good, and 45-50% more typical. (Source: Oil and Gas Journal)

Solution gas drive is the most widespread natural drive mechanism in the majority of the world's reservoirs and can provide recovery of up to 20 percent of the original oil in place. Roughly one-third of the world's reserves have natural water drives.

This primary process is normally supplemented early in the reservoir's life, by secondary processes consisting of stranded gas reinjection and waterflooding.

Enhanced oil recovery (EOR) methods are applied at the end of the secondary phase. They can be thermal, chemical or miscible processes. The most common of these techniques is CO2 flooding.

The 30-year history of this technique in the United States suggests that it is possible to recover an additional 7-15 percent after waterflooding (Lake et al.).

Not all secondary and tertiary techniques are applicable to all reservoirs and oil types. Many of the small fields that account for half the world's oil production have been left without the application of supplemental pressure maintenance. There are more than 40,000 oil fields, each with multiple reservoirs.

The USGS indicates an overall recovery factor of about 39 percent in the United States. Saudi Arabia's is 23 percent. The North Sea province, the highest in the world, is 46 percent. Prudhoe Bay is expected to reach 47 percent due to early gas and water injection, followed later by miscible hydrocarbon flooding. Experience has shown that delayed pressure maintenance programs result in recoveries up to 10 percentage points less that projects that start from day one. In the case of Saudi's giant Ghawar field, for example, gas and water injection didn't begin until 10 years after production start-up.

A schematic diagram showing CO2 flooding is shown below.

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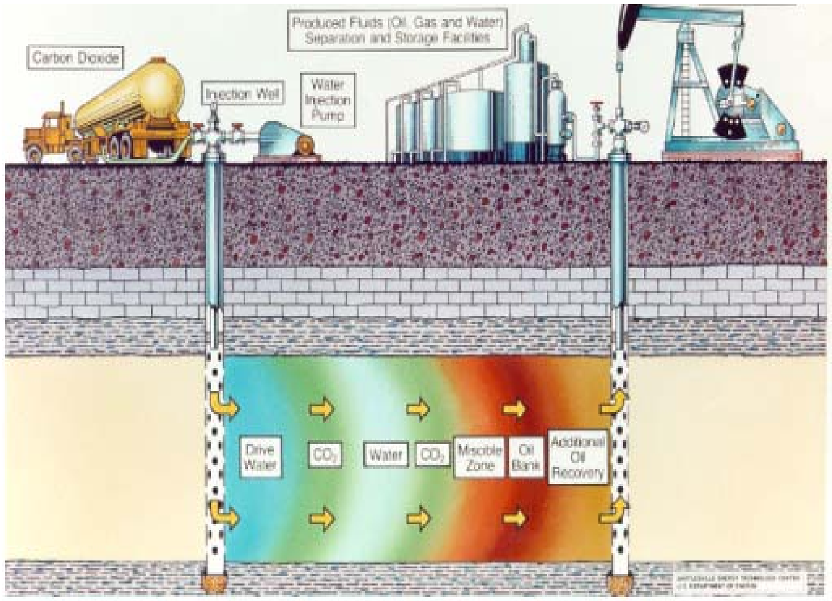

Enhanced oil recovery (EOR) using CO2

Examples of some current carbon sequestration and EOR projects follow:

The Apple Tree gas plant in the Rock Mountain foothills near La Vata, Colorado is recovering about 400 kilotonnes annual CO2 emissions for piping and injection into an aging Permian Basin oilfield in West Texas.

The Basin Electric Power Cooperative in North Dakota is planning to capture CO2 from its Antelope Valley coal power plant, and sell it for EOR in the Williston Basin oilfield. Only 4 million of the nearly 13 billion barrels of oil here would be recoverable without CO2 injection.

CO2 from a new coal-to-liquids plant in Natchez, Mississippi will be used in Gulf Coast oil fields.

Denbury Co. will buy CO2 from a gas plant to be built in Donaldsville, Louisiana, and pipe it to fields south of Houston.

The world's largest CO2 capture EOR project is planned off Dubai. Dubai Petroleum is the company that took over operations on April 2nd this year for a concession area off Dubai that had been operated by a ConocoPhillips consortium since 1961 – the Fateh Field discovery in 1966.

Secondary recovery started with seawater in 1974. Currently there are 240 active wells and 120 active injection wells.

DP says that experimental testing in 1999 using a water-alternating CO2 gas (WAG) scheme showed good results but failed because of a shortage of CO2. The current plan would capture about 13,000 tonnes CO2 a day from onshore power plants and then compress and pipe the gas for injection offshore. The first phase will be complete by 2013.

Europe is siting a network of 12 demonstration coal-fired stations by 2015 – typically 200-400 MW each – with a view to cutting coal plant CO2 emissions 20-30 percent by 2020. The EC sees coal as playing a key role in its security of energy supply strategy and all coal generating plants built after 2020 will require carbon capture and storage (CCS).

Brussels is in talks with South Africa, China and India for storage

For transport of European CO2, shipping seems likely to play a greater role than pipelines. An artists conception of a compressed CO2 carrier is shown below. These are similar to compressed LNG carriers, and designers are looking at the possibility of mixed cargoes. The same considerations apply for the use of 316 stainless and duplex stainless steels in maritime environs.

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Conceptual view of compressed CO2 carrier, courtesy Statoil

Nippon Steel, for one, has turned to X-120 to build tanks for compressed natural gas, and these would work for CO2 as well.

Eight coal power CCS projects are scheduled for startup between 2008 and 2016 in the U.K., Germany, Italy and the U.S., backed by BP, Enel, FutureGen, RWE, and Vattenfall.

Now a brief look at terrestrial carbon sequestration:

In terrestrial sequestration, CO2 from the air is absorbed in biological materials such as crops, grasses and trees. Ultimately, the carbon is transferred to the soil.

Numerous studies have reported a surge in plant growth after a rise in atmospheric CO2. In other words, rising levels of CO2 are thought to increase C sinks in terrestrial ecosystems. So if increased carbon (C) assimilation by plants is translated into increased soil organic carbon content, terrestrial ecosystems might help to mitigate rising CO2 emissions from human activity – the earth healing itself to some degree, it seems.

But is it an infinite sequestration capacity or are there limits?

Results of an international study published in 2006 by the University of California at Davis showed that nitrogen (N) must be added to really make this work. The carbon sequestration mechanism is constrained by the amount of atmospheric nitrogen. Soil C sequestration under elevated atmospheric CO2 is constrained both directly by N availability and indirectly by nutrients needed to support N2 fixation, the standard process by which nitrogen is converted to the usable form.

The other nutrients are, specifically, phosphorus (P), potassium (K) and molybdenum (Mo).

Nothing happens without molybdenum.

Local molybdenum depletion in some soils has been recognized for years and molybdenum is added through fertilization to certain specialty crops where low soil molybdenum levels have been found to limit plant growth. Examples shown below include clover, beets and peas. Some common molybdenum fertilizers are shown in the chart following the plant pictures.

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Note yellowing and stunted growth in the molybdenum-deficient clover on the right.

Stunted growth is evident in the molybdenum-deficient beets on the left.

Molybdenum-deficient peas on the left exhibit stunted growth and severe yellowing compared to a healthy plant (right).

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COMMON MOLYBDENUM FERTILIZERS (Western U.S. application rates)					
	Mo rate (lbs./acre)				
Fertilizer material	**% Mo**	**1/8**	**1/4**	**1/2**	**1**
		amount to apply (lbs./acre)			
Ammonium molybdate	54	0.23	0.45	0.93	0.85
Molybdenum sulfide	60	0.21	0.42	0.83	1.67
Molybdenum trioxide	66	0.19	0.38	0.76	1.52
Sodium molybdate	39	0.32	0.64	1.28	2.56

But moly's role as part of a terrestrial carbon sequestration solution hasn't been widely discussed.

The new perspective raises some interesting questions for the molybdenum resource sector:

Would governments or organizations like the UN at some point consider a subsidy on molybdenum added to fertilizers in order to raise the terrestrial sequestration capacity of soils?

Will investors begin to look more closely at molybdenum equities given this metal's unique position in the greenhouse gas equation?

Would investment banks or (emission reduction certificate - CER) traders take a look at the molybdenum resource sector specifically for financing and development of carbon offsetting projects? Barclays says that carbon trading will become the world's largest commodities market.

Would a fertilizer marketer consider financing a molybdenum resource company in order to assure molybdenum supply in the face of what is becoming withering demand from the steel industry?

Although it is not going to have the product jumping off the shelves tomorrow like purchase orders from the steel mills or the aerospace alloy foundries or catalyst manufacturers, for example, it does have important implications for molybdenum demand longer-term.

Overall, in the carbon sequestration affair, it's looking like a meaningful relationship when Moly meets Carbon.