

Expanded Uses of Molybdenum in the Energy Industry

By

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October 12, 2007

Introduction

Global demand for molybdenum is driven by diverse applications, not the least of which are in the energy sector. These include steels and alloys used in pipeline systems, in the drilling for oil and gas, and in power plants. Molybdenum is also contained in catalysts used by petroleum refiners.

Beneath the surface of the energy sector, structural changes like the emphasis on environmental preservation, a global decline in the availability of fresh water relative to salt water, and envelope-pushing technology that shows machines operating at better efficiency when they run hotter, seem to have been tailor-made for molybdenum whose unique material properties excel under these conditions.

Pipelines

Global demand has led to soaring energy prices in recent years and there are more than 91,100 miles of pipeline projects planned or under construction this year – a 30.4 percent increase from 2006, according to *Pipeline and Gas Technology* (2007).

The Far East, including eastern Russia, China, India and Indochina, leads in pipeline construction activity, with 22,500 miles planned or under construction, 24.7 percent of the world total.

Russia, for example, is in the midst of building a \$13.7-billion East Siberia-Pacific Ocean (ESPO) pipeline to transport crude oil to markets in China and Japan. China National Petroleum Corp, the parent of PetroChina Co Ltd., will invest up to 8 billion yuan (US\$1.1 billion) to build the China branch of the Siberia-Pacific crude oil pipeline. The 965-kilometer Chinese mainland section of the pipeline will be started this year and finished in 2010. (South China Morning Post).

The United States remains the second-largest builder of pipelines, with more than 16,750 miles of pipeline projects planned or under construction, representing about 18.4 percent of the global total.

Most notable among the U.S. projects is the \$4.4-billion Rocky Express project, a joint venture between Kinder Morgan Energy Partners LP, Sempra Energy, and Conoco Phillips Co., which is expected to run 1,675 miles from Wyoming to Ohio – the country's biggest natural gas project in about 20 years.

Canada's oil sands are also adding to the increase in North American pipeline construction. Enbridge Inc., for example, has begun building a \$500 million line called Southern Access to Illinois and Wisconsin. The project is expected to use 630 miles of 36- and 42-inch pipe. The company is also building Southern Lights, a 675-mile, 20-inch pipeline running from Alberta to Chicago. Enbridge has \$9 billion worth of new pipelines planned, most of which will take Alberta oil sands production to the refineries of the U.S. Midwest and Gulf Coast.

South America is third with about 15,950 miles of pipeline, 17.5 percent of the world total. It is one of the world's fastest-growing regions, with construction this year expected to be more than three times what was built last year. Much of that growth is being driven by the \$25-billion Gran Gasoducto del Sur project, which could see up to 9,000 miles of pipe running from Venezuela to Brazil, Argentina and possibly other South American countries.

European pipeline projects include 13,700 miles of pipe, up 16.7 percent from 2006, and the region continues to lead the world in offshore pipelines, with about 4,400 miles planned or under construction.

Other major projects include:

- Calgary-based TransCanada Pipelines Ltd.'s \$1.7-billion Keystone Oil Pipeline project, which will run 1,845 miles from Hardisty, Alberta, to Patoka, Illinois;
- Brazilian state oil company Petróleo Brasileiro SA's \$6.5-billion, 800-mile project to import and distribute gas;
- The \$5.7 billion, 745-mile Nord Stream gas pipeline, which will connect Vyborg, Russia and Greifswald, Germany;
- State-owned gas utility GAIL (India) Ltd will invest Rs 18,000 crore to lay five new pipelines resulting in an additional 3,300 km of pipe;
- The \$3.5 billion Turkmenistan-Afghanistan-Pakistan-India (TAPI) gas pipeline, that rivals a similar line from Iran;
- The IGI pipeline that Italy, Greece and Turkey hope will be operational by 2012.

The vast majority of pipelines built — about 72 percent of the total — are designed for natural gas. Increasingly, molybdenum is being used in the steels that make these pipelines. The presence of molybdenum significantly reduces weight for overall volume carrying capability. Smaller diameter pipe can be used with lesser wall thickness for the same transmission capability. Alternately, in the same size of pipe, transmission capability (pressure) can be increased. Either way there are significant savings in overall material cost and easing of the transport logistics – a critical consideration given the remote locations of these pipelines.

Over the years, molybdenum levels in the more advanced pipe have crept up from less than 0.1 percent to 0.2-0.3 percent. Depending on the size of pipe, one mile of pipeline at these levels can absorb a ton of molybdenum¹.

(¹For a 30" x 0.625" pipeline at 0.24 percent Mo, the pipeline steel represents a theoretical molybdenum demand of 2,487 pounds Mo per mile (1,554 pounds/km). For a 52" x 1" pipeline, the equivalent is 6,909 pounds per mile (4316 pounds/km) using the X-80 steels called for. This does not include losses in alloying or conversion from concentrates, nor does it include molybdenum in the weld metal, which can be higher on a weight percentage basis than the molybdenum level in the steel. The pipe sections, called "joints", are typically 40 feet long, so the Alaska pipeline, for example, would have over 280,000 welds.)

The newest formulations for oil and gas pipeline steels can double this amount. While the percentage quantity of molybdenum in the steel is small, the reader can see the tremendous leverage on absolute molybdenum demand exerted by the number of miles laid and the new pipeline chemistries.

Capacity for rolling the newer moly-bearing grades is growing, but demand for molybdenum in this application is severely bottlenecked by pipe mill capacity – or lack thereof. The capacity for X-120 pipe (0.4%+ Mo) is very limited as there are only a handful of mills in the world that can produce this relatively high molybdenum grade. Baosteel, the largest Chinese steelmaker came on line this year with X-120 product. Magnitogorsk Iron and Steel Works OJSC (MMK), the largest of the Russian steelmakers, just announced X-120 capacity for late 2009 or early 2010 at their CCM6 basic oxygen furnace, as noted in the announcement, below:

The facilities will be fitted with the state-of-the-art equipment ensuring the processing of any steel grades produced in the BOF Shop including the steel grades used for production of automotive steel sheets, large diameter longitudinal welded pipes of enhanced hydrogen-sulfide resistance and corrosion resistant pipes of X80 and higher strength classes; special steel grades; shipbuilding and high pressure vessels steel grades; steel grades used in automotive industry (ultra low carbon steel, high strength steel, dual phase steel, multi-phase steel and TRIP steel).

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Europipe and three Japanese mills (including Nippon Steel and Sumitomo, for example, which have been extremely aggressive and open in their research and development of X-120 pipe) are the only others.

The capacity constraint is easing, but it remains true that a vast majority of the pipe manufactured today is absent molybdenum. This application remains a huge latent source of demand for the metal given that converting even half of the pipeline miles noted above to a mid-level moly content would add substantially to the world's annual demand for molybdenum.

Oil and Gas Drilling

The current drill rig count is holding about the same as this time last year, this despite a significant pullback in Canadian shallow gas drilling activity. Overall, there is a positive bias to the drill rig count since total feet drilled per rig and the number of holes drilled per rig has been increasing.

Offshore drilling is stronger than last year, operating at over 87 percent of capacity and with an increase in available rigs. (See charts below.)

2007 OIL AND GAS RIG COUNTS				
	Current	Previous	Year Ago	Change
United States	1760	1769	1,776	-1%
Canada	347	359	353	-2%
International	1,009	1,018	954	+6%
World	3,116	3,146	3,083	+1%
US and Canadian statistics are published for the week ending September 28, 2007. International numbers reflect August, 2007. International count excludes Iran and Sudan. Change is calculated from the previous year. Source: Baker Hughes.				

2007 OFFSHORE RIG UTILIZATION REPORT				
	Current	Month Ago	6 Mo Ago	1 Yr Ago
Rigs Working	511	520	500	493
Total Rigs	599	597	587	577
Utilization	85.3%	87.1%	85.2%	85.4%
Competitive rigs. Data for week ending September 28, 2007.				

Increasingly, molybdenum-bearing steels are employed to replace mild carbon steels in drilling under conditions of increased temperature, pressure and/or corrosion.

Just one of many new steel products available is the Timken "Impact8" brand, which was recently certified to exceed the National Association of Corrosion Engineers (NACE) and American Petroleum Institute (API) standards for resistance to sulfide stress corrosion cracking above 95 ksi. This drill pipe assays 0.65-0.75% Mo and serves to replace a popular drill steel, grade 4140, that runs 0.15-0.25 percent Mo. Note the 3-times increase in the use of molybdenum in this application.

Coiled tubing (CT) is becoming one of the fastest growing oilfield technologies. Between 2001 and 2006, CT services expanded 140 percent and these steels show a higher molybdenum level. Most of the world's CT units and strings are made in the United States. In fact, the market is essentially split between two companies, both within 4 miles of Houston.

Coiled tubing is made by seam welding long, flat steel strips which are then coiled on a large reel for field deployment. The CT strings have to be light enough to transport on trailers, yet strong enough to withstand the rigorous exposure: load, operating and

external pressures, and metal fatigue. CT purchases are growing between 10-15 percent per year. In 2006, shipments were as follows:

COILED TUBING SHIPMENTS (2006)	
To:	%
Canada	29
U.S.A.	21
Europe / North Sea	13
Alaska	10
Middle East	9
North Africa	8
Latin America	8
Far East	2

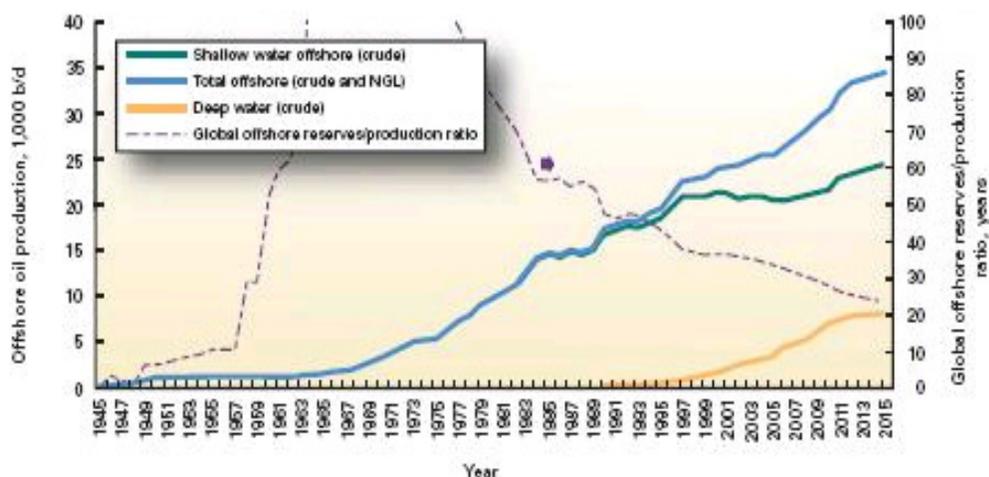
Tenaris recently announced a new depth record using coiled tubing, drilling in the U.S. Rocky Mountain area along with its partner Xtreme Coil Drilling. This product, HS110™, contains 0.25–0.45% Mo. To date, Tenaris has produced 12 strings of the newly developed coiled tubes for Xtreme Coil to use on the project, and it anticipates that demand for 10,000-foot well strings will increase as more experience is gained drilling the deeper wells.

Tenaris holds the record for the world's longest continuously milled coiled tubing work string – 32,800 ft. of 1-3/4" HS90™ used in West Africa. HS90™ uses molybdenum in the 0.10–0.15 percent range: Note how their product development, from HS90 to HS110, entails increasing the molybdenum addition rate by a factor of 2-3 times.

Offshore drilling has always used higher-molybdenum grades than onshore drilling, and this sector is showing no letup. The 2007 Oil & Gas Journal forecast for offshore drilling is shown in the graphic below (blue line), indicating roughly a 30 percent increase in the next 10 years:

Global Offshore Oil Production Outlook

Source: Oil & Gas Journal (2007)



Sandvik, a major supplier of offshore drilling equipment, this year opened a service center and warehouse in Houston, offering master coil stocks of both seamless and laser welded tubing. According to the company, products include stainless steel grades 316L (2-2.5% Mo) and Alloy 825 (2.5-3.5% Mo), "...these stocks cover the most popular grades used in these oil and gas applications. Other grades such as SAF2507 (a super-duplex stainless containing 3-5% Mo), and San28 (3.5% Mo) are also available on short lead times."

Offshore oil and gas drilling and production use much more molybdenum than just what is found in the drill string and well casing. The Sable Offshore Energy Project in Atlantic Canada was a well-documented example of the strong role molybdenum plays:

The most called-upon alloys for Sable were the duplex stainless steels S31803 (2.5% Mo) in the offshore process piping, and S31600 (2-3% Mo) in the cryogenic systems at the Goldboro gas plant.

Separators, although fabricated from carbon steel, are clad with a 3-millimetre-thick layer of N08904 (904L stainless – 4.5% Mo), which makes them resistant to pitting corrosion.

The hydrocyclones, which purify water coming from the separators, are fabricated from S31803 (2.5% Mo). And where there is potential for internal corrosion from carbonic acid in the process fluid, S31803 is used to fabricate the heat exchangers.

The risers (the tubular steel structure that stands on the seabed and upon which platforms sit) are also made of S31803.

In Phase II (2004-2007), the sub-sea pipeline between South Venture and Venture is designed entirely of 8.5-inch S31803 (2.5% Mo) piping instead of the moly-free carbon steel pipelines used in Phase I.

As more oil and gas projects are approved, with concomitant increasing demand for advanced high-strength and corrosion-resistant steels in these applications, there will be a need for still larger quantities of molybdenum additive.

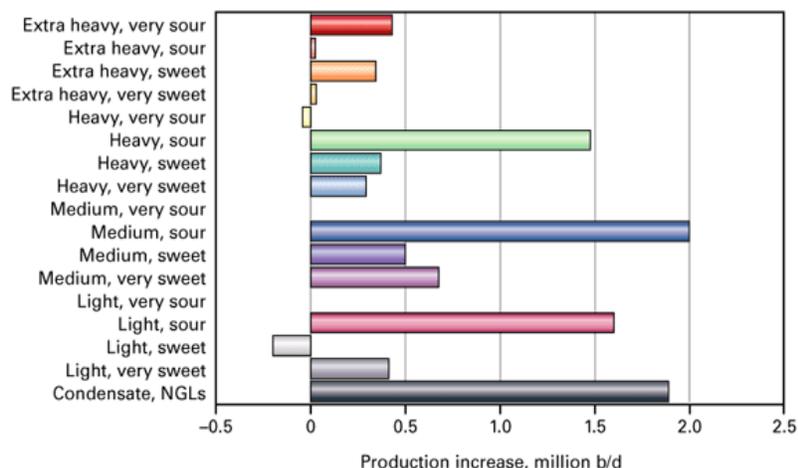
Petroleum Refining

Demand for molybdenum-bearing catalysts in petroleum refining will depend on feedstock qualities and changing product specifications.

From the following chart, it can be seen that supply in the sour (higher sulfur) categories is increasing relative to others. At the same time, product specifications are moving to the lower sulfur limits. So already there is a highly-leveraged call on molybdenum-bearing catalyst that exceeds the typical refining capacity forecasts which typically hover in the 1-2 percent annual range:

Increase in Global Crude Production 2005-2015

Source: Oil & Gas Journal (2007)



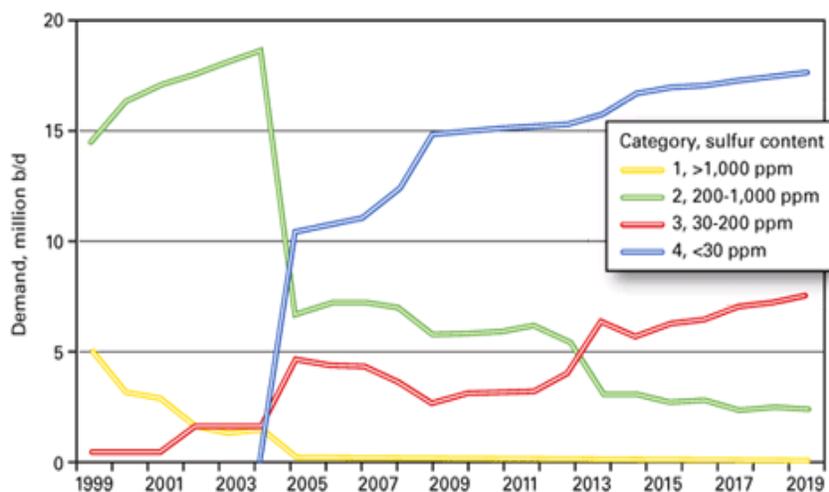
Product specifications are universally changing to lower sulfur:

From the chart below, it can be seen that, with gasoline, there has been a significant shift in production volumes from Category 2 (200-1,000 ppm sulfur) to Category 4 (<30 ppm), largely due to the mandated reduction in gasoline sulfur content in the U.S. in 2005. Another shift in demand by quality is anticipated in 2014-15 when China and a number of African and Asian developing countries are expected to move from Category 2 (200-1,000 ppm) to Category 3 (30-200 ppm).

Demand for low-sulfur gasoline (<30 ppm) is rising quickly, and is forecast to reach 15 million barrels per day (b/d) by the end of the decade. The figure shows that, after representing 100 percent of demand in 2001, gasolines with over 200 ppm sulfur will fall to less than 10 percent of demand by 2020.

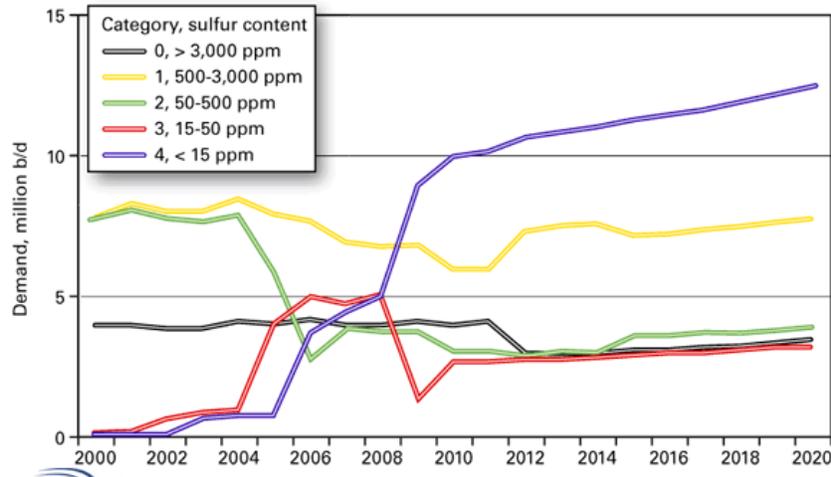
Global Gasoline Demand

Source: Oil & Gas Journal (2007)



For the global diesel market, demand growth will be even stronger than for gasoline. In fact, global diesel demand is forecast to exceed global gasoline demand by 2020, whereas today, gasoline demand exceeds diesel by more than 2 million barrels per day. Like gasoline, diesel is in the midst of a worldwide shift to primarily low-sulfur specifications. (See chart, below.)

Global Diesel Demand
Source: Oil & Gas Journal (2007)



The United States has just changed to 15 ppm ultra low-sulfur diesel (ULSD). With the EU following by the end of the decade, diesel demand in the lowest-sulfur category (<15 ppm) will climb to nearly 12 million b/d by 2020, becoming the largest category.

Demand for the highest-sulfur diesel (> 3,000 ppm) will fall to about 2.5 million b/d.

There is extraordinary new growth occurring in catalyst demand for the production of ultra low sulfur diesel (ULSD). Achieving the reduced sulfur specification of less than 15 ppm more than doubles the use of catalyst at the same refinery.

The production of ultra low-sulfur diesel first treats the distillate stream with a cobalt-molybdenum (CoMo) catalyst to take out the easier sulfur components, then a second catalyst bed of nickel-molybdenum (NiMo) removes the "hard" sulfur components.

About 95 percent of refiners use molybdenum-bearing catalysts for sulfur removal in the ULSD application. Refiners advise that catalyst usage is exceeding the theoretical as operators err on the side of compliance. Catalyst manufacturers are introducing higher grade catalysts to meet the new demand.

ULSD is the single largest environmental mandate since the removal of lead from gasoline 25 years ago, although the complete impact on emissions reduction will not be realized until the highway diesel transportation fleet fully turns over in 25-30 years. It is another entirely new molybdenum demand driver.

Since October 15, 2006, most of the diesel fuel sold in stations in Canada and the United States has been ULSD. The first diesel engines specifically designed for ULSD fuel are in 2007 vehicles. The EPA mandated a June 2007, interim, 500-ppm sulfur cap for off-road diesels, and then a June 2010 deadline for all highway trucks and off-road diesels (except locomotive and marine, and small refiners) to conform to the 15-ppm sulfur limit. Two years later, the lowest sulfur requirement will extend to locomotive and marine diesels, and by June 2014 it will apply to everyone.

The number of diesel-fueled cars and light trucks sold in the United States has grown consistently in the last 10 years and is up 80 percent in the last six.

The European Commission has confirmed a 10 ppm sulfur highway diesel limit starting December 31, 2008, followed by the same limit effective December 31, 2009 for off-road diesel. Inland waterway diesel engines would have to switch to 10 ppm ULSD starting December 31, 2011.

Annual world demand for diesel light vehicles is expected to nearly double over the next decade, increasing to 29 million unit sales, according to J.D. Power and Associates.

Albermarle, a major catalyst producer, says molybdenum use in catalysts is racing ahead at 6-8 percent a year, based in large part upon the new sulfur restrictions in place and still to come for diesel fuels worldwide.

Gas Turbines

Electrical power generation is increasingly developed from gas turbines.

A gas turbine is an internal-combustion engine consisting essentially of an air compressor, combustion chamber, and turbine wheel that is turned by the expanding products of combustion.

There are three kinds of power generating turbine systems: gas turbines, steam turbines, and combined-cycle turbines (CCGT), which employ the first two together. The Integrated gasification combined-cycle (IGCC) gas turbine is a sub-species of the CCGT wherein coal is converted to "syngas" and the syngas is then used as fuel for a gas turbine, whose exhaust provides heat to generate steam to run a steam turbine.

The word "gas" in this instance refers to the gas that is compressed – typically air. A number of fuels are available for a gas turbine, but natural gas is the main one. Simple cycle (gas turbine only), combined cycle (gas turbine with its exhaust producing steam for steam turbine generation), and cogeneration (gas turbine, with its exhaust producing steam for heat) are all generally discussed under the heading "gas turbines".

General Electric's new LMS100 gas turbine, at 46 percent, has the highest efficiency of any simple cycle gas turbine, but when the heat from the simple gas turbine exhaust is used to make steam to run a steam turbine – essentially using the same fuel twice – a combined-cycle gas turbine (CCGT) can demonstrate thermal efficiencies as high as 60 percent.

Forecast International, Inc. predicts significant growth in coming years in the demand for gas turbines in electrical power generation, up 60 percent from 2006 to 2008. This exceptional growth is underpinned by both technical and commercial factors.

Operating efficiencies are increasing. The 46 percent efficiency level noted above for the simple gas turbine is now well above the typical nuclear power plant at 30-33 percent. The combined cycle option at 60 percent is even more promising.

Gas turbines come with a much shorter planning and construction cycle. Increasingly this becomes important as consumers debate the alternatives until it is too late. SaskPower, for example, which had been considering a world-class clean coal project, ran out of time and opted for gas turbines this year in order to meet the province's electricity needs by 2010. The Crown Corporation announced that the planned 300-megawatt (MW) thermal generating station could not be built in time to meet rising electricity demands. Instead of the coal plant, SaskPower will install 400 MW of natural-gas turbines over the next five years.

The Middle East is becoming a high-growth market. Certainly it is one of GE's fastest-growing markets, along with China and India, with revenues derived increasing 15 -20 percent a year, according to the company. GE expects to get about 60 percent of its growth from emerging markets, including the Middle East, China, India and Brazil, in the next decade. Recently, GE announced \$1.8 billion in energy-related orders to the Middle East: The company is providing 20 natural-gas-powered turbines to a 2,500-megawatt power-plant project in Kuwait, and they have sold an additional 12 natural-gas and 5 steam turbines for two projects in Qatar. These contracts come on the heels of another \$2 billion in contracts, announced in December and January, to supply 35 gas turbines to Saudi Arabia.

High growth potential has also been identified for the Central and Eastern European gas turbine markets. Turbine sales will increase over the next few years as a result of the rising demand for electricity and improved electricity pricing, the need to replace obsolete power plant equipment, and the relative improvement in the availability of investment funds as countries in the region have become members of the EU.

Gas turbines are becoming relatively more attractive as delivered coal prices escalate and as natural gas prices drop. Natural gas prices are coming down, and as new LNG projects send meaningful quantities of previously "stranded" gas to the marketplace, the downward pressure should continue, with a corresponding improvement in natural gas-fuelled turbine economics.

The co-generation market for gas turbines will become much stronger in Europe and generally in any country that signed the Kyoto Accord. It is also worthwhile noting that CO₂ emissions are lower with the new combined-cycle turbine projects.

The Integrated Gas Combined Cycle (IGCC) provides an opportunity to "clean" coal. In many countries, like China, the United States, and South Africa, coal is a major energy resource. Of every three power plants currently being built in the world, two are in China, where the major fuel is coal. The IGCC plants convert coal into syngas, a low calorific value gas composed of carbon monoxide and hydrogen; the syngas is then used as fuel for a gas turbine, whose exhaust provides heat to generate steam to run a steam

turbine. Using the same fuel twice, in essence, a combined-cycle power plant can show thermal efficiencies as high as 60 percent.

More than 4 dozen alloys containing molybdenum ranging from 1-25 percent have been identified in gas turbines. Molybdenum-bearing superalloys are used because of their enhanced creep strength¹, fatigue strength, oxidation resistance, and hot corrosion² resistance at elevated temperatures.

(¹Creep is the form of deformation that takes place in metals held for long periods at high temperature. Although most of us know molybdenum in the context of corrosion, its ability to resist creep is without equal in a number of metal products. ²There are more than a dozen different types of corrosion. Hot corrosion is a phenomenon where two or more media present combine synergistically to degrade materials at a rate much faster than any of the individual elements separately. Normal oxidation can be greatly accelerated in the presence of sulfides and/or chlorides because the normally stable oxide film is continually being damaged by lower melting point films allowing reactions to accelerate.)

Related to these phenomena, and based on comments from GE Power Systems, manufacturers have stepped up their orders for the following moly-bearing alloys from the foundries for use in the hot sections of turbines: 718 (3% Mo), 263 (6% Mo), 625 (9% Mo), Hastelloy X (9% Mo), 617 (9% Mo) and Haynes 230 (2% Mo).

Nuclear Power

According to the World Nuclear Association (WNA), the nuclear-power industry's umbrella organization, there are 439 reactors operating globally, generating 371,000 megawatts (MW) of electricity or about 16 percent of total demand. Another 34 are under construction, with 81 planned and 223 proposed – 88 of which are in China.

The WNA estimates nuclear power could double over the next 30 years.

Nuclear power plant construction is well under way in China. Finland's Olkiluoto-3 unit, the first nuclear plant ordered in western Europe since Chernobyl, has been delayed at least two years for a number of reasons, including flawed welds in the reactor's steel liner, unusable water-coolant pipes and suspect concrete in the foundation.

This serves to highlight that we are very much on a learning curve again after many years of nuclear power plant (NPP) construction inactivity.

The United States hasn't broken any new ground yet but even as construction appears slow to start, there is a healthy market for molybdenum bearing steels and alloys in retrofit: power uprates and licence extensions. A 10 percent power uprate on a typical 1,000 MW nuclear unit can supply an additional 50,000 homes. The reactor's useful operating life can in some instances be doubled through a defined set of modifications and indeed these modifications are being fully exhausted (worldwide – not just in the U.S.) prior to any new construction decision.

But molybdenum benefits either way: A variety of molybdenum-bearing alloys are found in the piping and various components like the shells and tubes of steam generators, the turbines, and coolant circuit pipes, for example.

Piping retrofit in power plants (coal or nuclear) can be completed with so-called P91 pipe. This is nominally a 1 percent molybdenum alloy (ASME 0.85-1.05% Mo). Pipes can also be changed to Type 317 stainless (3-4% Mo), 904L (4-5% Mo), or duplex alloys like S32205 (3-3.5% Mo). The original materials, like 304 stainless steel for example, contain no molybdenum.

Condenser tubing is another significant application. The alloys used today run 1-4% Mo. The table below shows the molybdenum composition of superferritic stainless steels used in this condenser tubing.

CONDENSER TUBING ALLOYS	
Name / UNS No.	Mo (%)
E-Brite 26-1 / S44627	0.75-1.50
18-2 / S44400	1.75-2.50
29-4 / S44700	3.50-4.20
29-4-2 / S44800	3.50-4.20
Monit / S44635	3.60-4.20
AL 29-4C / S44735	3.60-4.20
Sea-CURE / S44660	3.00-4.00
Source: Trent Tube	

Work completed at the Browns Ferry nuclear power plant, for example, includes replacement of condenser tubes, core spray piping, turbine cross-over and -under piping, and extraction steam piping. According to the Nuclear Regulatory Commission, any pipe containing fluids over 200°C must now be 316 stainless steel (2-3% Mo).

Another new application for molybdenum in NPPs is in stainless steels resistant to microbiologically induced corrosion (MIC). This is of particular interest to power plant operators where condensers are chlorinated to kill colonies of bacteria in the water. (Chlorine or hypochlorous acid reacts with the metabolic byproduct of certain bacteria to produce hydrochloric acid, which causes pitting of the existing molybdenum-free steels.) Several nuclear power plants built in the United States in the 1970s and '80s are now replacing their water service piping with moly-bearing duplex stainless steel pipe for longer life and corrosion resistance.

The Catawba Nuclear Station in South Carolina, for example, is replacing original carbon steel cooling water piping (mostly API 5L Grade B) with duplex stainless steel S32205 (3-3.5% Mo). This 2.25 gigawatt plant uses fresh-water for cooling, and carbon steel was the material of choice when it was designed in the 1970s. But as it turns out, the water supply has become rich in nutrients, like so many fresh water bodies today, and this has caused MIC.

In general, the choice of alloys for nuclear power remains a work-in-progress.

In September 2007, Thyssen Krupp reported the first commercial application of Alloy 33 (1.6% Mo) as a weld overlay to carbon steel boiler tubes retrofit. This is another new application for molybdenum-bearing material where none existed before.

For reference, the number of components and weights for new nuclear power plants in (the current) Generation III are shown below. It is estimated that one of these plants could use 400,000-500,000 pounds of molybdenum.

GENERATION III+ NUCLEAR REACTOR COMPONENTS		
ELEMENT	NUMBER PER PLANT	MAX WT. PER EACH (tonnes)
REACTOR PRESSURE VESSEL	1	1,200
STEAM GENERATOR	2	730
MOISTURE SEPARATOR REHEATER	4	440
STEAM TURBINE GENERATORS	3	550
LOW PRESSURE TURBINE	3	250
GENERATOR STATOR	1	500
GENERATOR ROTOR	1	250
CONDENSERS	3	660
PUMPS	138	n/s
VALVES +3 INCH	3-6,000	n/s
VALVES 2.5 INCH / UNDER	6-12,000	n/s
CONTROL ROD DRIVES	200	n/s
PIPING > 2.5 INCHES	260,000 ft.	n/s
PIPING < 2.5 INCHES	430,000 ft.	n/s
NOTES: 1. Not all types of reactors use all these components. 2. Each Gen III unit will use either 2 steam generators or 2-4 moisture separator reheaters 3. Each steam turbine generator would have up to 3 condensers 4. Quantities are listed as maximum per plant 5. These designs in general are considered: General Electric (GE): Economic Simplified Boiling Water Reactor (ESBWR); Toshiba-Version, GE-Design: Advanced Boiling Water Reactor (ABWR); and Westinghouse: Advanced Pressurized Water Reactor (AP1000). The Framatome ANP (Areva). European Pressurized Water Reactor (EPR) design, occurred too late to be included. 6. n/s = not specified		

Another development that involves molybdenum in the nuclear fuel cycle is Brazil's research into the use of uranium-molybdenum fuel alloys.

In-vessel retention (IVR) of core melt that may fall to the lower head of a reactor vessel is a severe accident management strategy adopted by some operating nuclear power plants and is also proposed for several of the advanced light water designs. Molten core

materials that burn through to the ground below would cause a catastrophic steam explosion when contacting ground water. A U.S.-Korean International Nuclear Energy Research Initiative project is exploring design enhancements that could increase the margin for IVR for advanced reactors power levels up to 1,500 MW. One such design includes an oxide-coated Inconel 718 plate (3% Mo) with thickness sufficient to support and contain the mass of core materials that may relocate during a severe accident.

A relatively new development is the use of nuclear power for desalination – itself a significant end-use application for molybdenum. The concept is becoming popular in the Middle East and North Africa.

During a visit to Libya by French President Nicolas Sarkozy in late July, the leaders signed a memorandum of understanding that would allow French nuclear-giant Areva to build a nuclear power plant there. Egypt has said it will pursue a similar scheme, as have Saudi Arabia and the other Gulf Cooperation Council countries -- Bahrain, Qatar, Oman, Kuwait and the United Arab Emirates.

Japan and Kazakhstan already have working nuclear-powered desalination plants.

The Middle East, like much of the rest of the world, is increasingly in need of fresh water. About 60 percent of the roughly 7,500 traditionally powered desalination plants can be found in the Middle East. In fact, Saudi Arabia holds about a quarter of the world's desalination capacity, according to the International Desalination Association.

Removing enough salt from seawater to make it usable for irrigation and drinking takes a tremendous amount of energy – between 2.8 and 9.8 megawatts of energy to produce 100,000 cubic meters of drinkable water per day, depending on source salinity and the method used, according to the Argonne National Laboratory.

Using nuclear power for desalination has some very powerful backers. Not only do Japan's Mitsubishi Heavy Industries and Areva hope to build in North Africa and the Middle East, but the International Atomic Energy Agency has thrown its weight behind the idea as well with its Nuclear Desalination Project.

The use of nuclear power in desalination changes the conventional wisdom that ties nuclear power to the electricity grid and thereby enhances its growth potential.

A gas-cooled reactor known as the pebble bed moderated reactor (PBMR) is being developed in South Africa. Instead of fuel rods, the PBMR uses coated graphite pebbles filled with uranium fuel. The decay heat is transferred to helium, an inert gas, which eventually moves to a gas turbine to produce electricity. In fact, this reactor will take advantage of turbines in a closed-cycle gas turbine configuration which will give it a thermal efficiency of just about double that of a conventional light water reactor. These turbines are also rich in molybdenum-bearing alloys. (See Gas Turbines, above.)

The generation of reactors that will see development after what we are building today – the so-called Generation IV – will produce more heat and less radioactive waste with different cooling mechanisms than light water reactors, and will be able to produce hydrogen as a replacement for fossil fuels.

An international effort has been under way since 2000 to examine various technologies, using a gas such as carbon dioxide, water, liquid metal or even molten salt for cooling. As a class, these are also known as the Very-High Temperature Reactors (VHTR) and include exotic names like Supercritical Water-Cooled Reactor (SCWR), Sodium Cooled Fast Reactor (SFR), Lead-cooled Fast Reactor (LFR), Molten Salt reactor, and Gas-Cooled Fast Reactor (GFR).

These new designs typically run with average coolant temperatures well above our existing reactors (a typical LWR around 320 °C as compared to gas reactors up to 700-950 °C) and with more corrosive liquids. As such, they will require more robust piping. In these more extreme operating environments and given the requirement for interconnection with hydrogen-producing capacity, this 4th generation of reactors seems likely to provide a great new opportunity for molybdenum-bearing alloys and steels.

Although nuclear power production has a future again, the United States hasn't solved the long-term disposal problem for spent fuel rods. The permanent repository at Nevada's Yucca Mountain is not scheduled to open until 2017 (already 19 years late).

The 11,000 containers at the proposed storage facility could require as much as 33 million pounds of molybdenum, according to reports. The inner container would be made of 316L stainless steel (2.2%Mo) and Alloy 22 (13.5%Mo) has been nominated for the outer container.

The nation's 103 operating nuclear power plants are storing spent fuel onsite using casks made of both 304 stainless steel (no moly) and 316 stainless steel (2-3% Mo).
