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PIPELINES: Past, Present, and Future.

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ABSTRACT

This paper gives an overview of the history of oil and gas pipelines, and their status today. It concludes with a glimpse at future pipelines, and issues we will be facing as we continue to burn fossil fuels and look for alternatives.

Pipelines have been used for thousands of years, but modern day pipelines have their origins in Pennsylvania, USA in the mid-1800s. As technology improved, larger and longer pipelines were built, and the demand for energy during World War II increased both the need and extent of pipelines in the USA, then around the world.

Most countries now have large oil and gas pipelines systems: Russia has huge pipeline networks, and if you laid the Canadian pipeline system, end to end, it would extend 17 times around the world! Worldwide, there are about 3,500,000km of transmission pipelines transporting oil and gas.

The big issue facing this vast pipeline system today is age; for example, over 50% of the 1,000,000 km USA oil and gas pipeline system is over 40 years old. The continuing demand for oil and gas will mean these ageing systems will need to function safely and efficiently for many more years.

Therefore, the future for our current pipelines will see an emphasis on inspection and maintenance. But what about new pipelines? Certainly, we will be building many new oil and gas pipelines, some in hostile environments, such as deep water. We will also be building pipelines to carry differing products, such as carbon dioxide and hydrogen, as the drive for cleaner and alternative fuels continues.

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1. INTRODUCTION

Most people associate ‘pipes’ with the hot and cold water they see in their houses. Also, most of us will have seen the plastic pipes laid under our streets and roads to locally distribute natural gas. But what many people do not know is that there are hundreds of thousands of kilometres of very large ‘pipelines’ crossing our nations and oceans delivering (‘transmitting’) huge quantities of crude oil, oil products, and gas, Figure 1. Most are underground or undersea: out of sight, out of mind!

Crude oil is often transported between continents in large tankers, but oil and natural gas is transported (‘transmitted’) across continents by pipelines. These pipelines are very large diameter (the Russian system has diameters up to 1422mm), and can be over 1000km in length.

Figure 1. Most of today’s oil and gas pipelines are welded together and buried underground

‘Transmission’ pipelines are the main ‘arteries’ of the oil and gas business; working 24 hours per day, seven days a week, continuously supplying our energy needs. They are critically important to most countries' economies. They have a long history: pipelines have been used to transport liquids and gases for thousand of years: the Chinese used bamboo pipe to transmit natural gas to light their capital, Peking, as early as 400 BC.

The oil and gas are transported in these large transmission pipelines to refineries, power stations, etc., and converted into energy forms such as gasoline for our automobiles, and electricity for our homes. Oil and gas provides most of the world with its energy. The fuels providing the world with its primary energy needs are:

- Oil = 34%
- Coal = 24%
- Gas = 21%
- Nuclear = 7%
- Hydro = 2%
- ‘Other’ = 12%

Without pipelines we would not be able to satisfy the huge oil and gas needs of our planet. These pipelines are also very safe forms of transporting energy:

- Pipelines are 40 times safer than rail tanks, and 100 times safer than road tanks;

- Oil pipeline spills amount to about 1 gallon per million barrel-miles, according to the USA Association of Oil Pipelines. One barrel, transported one mile, equals one barrel-mile, and there are 42 gallons in a barrel. In household terms, this is less than one teaspoon of oil spilled per thousand barrel-miles.

These high pressure, large capacity pipelines carry hazardous products, and consequently, they are designed, constructed and operated using recognised standards that all have a focus on safety. Additionally, these pipelines have to satisfy safety regulations in most countries. These high standards and regulations ensure safe and secure pipelines.

This paper gives a history of pipelines, and reviews the pipelines in use today. It ends by considering how these pipelines will change in the future. The paper makes extensive use of the references listed in the Bibliography at the end of the paper, and acknowledges the web resources that provide much information and illustrations[2]. This Bibliography includes both historical references, and the most modern pipeline reference books.

[2] www.oilhistory.com and www.petroleumhistory.com are particularly acknowledged.

2. THE HISTORY OF PIPELINES

Early history

Ancient water pipes

For thousands of years, pipelines have been constructed in various parts of the world to convey water for drinking, and irrigation for agriculture. These pipes include baked clay and hollow bamboo: the ancient Chinese used bamboo pipes to transport water. Indeed, wood (hollowed-out logs) was used as recently as about 100 years ago, to transport brine water in the developed world, Figure 2.

Figure 2. Hollowed-out logs used to transport brine circa 1880

There are references to the Egyptians using copper pipe to transport water in 3000BC, the Cretians used earthenware pipe for water in 2000BC to 1500BC, and the Greeks used earthenware, lead, bronze and stone pipes from 1600BC to 300BC. In that era, 'blacksmiths' connected the metal pipes together by simply hammering the red hot ends together.

Ancient civilisations such as the Persians and Romans all used pipes of some type; for example, metal pipe was used as far back as 500 BC when the Romans used lead pipes to distribute water in highly developed towns.

Ancient hydrocarbon pipelines

The first recorded use of a pipe to transport a hydrocarbon was in China: about 2,500 years ago, the Chinese used bamboo pipe to transmit natural gas from shallow wells: they could burn it under pans to boil seawater to separate the salt, and make the water drinkable. Later records indicate that the Chinese used bamboo pipe, wrapped in wax, to light their capital, Peking, as early as 400 BC.

Pipelines in the 18th century and into the 19th century

These early pipeline pioneers were restricted by materials, joining technologies, and the ability to 'pump' (raise the pressure) of the fluids; but this did not prevent pipeline systems being developed: in England in the mid-18th century the London Bridge Waterworks Company had over 54,000 yards (49km) of wooden pipe and 1,800 yards (1.6km) of cast iron.

The use of wood, iron, lead, and tin pipes were common into the 1800s to transport water, and in 1821 wood pipe transported natural gas in New York State, USA. In 1843 iron pipe was used, and this reduced the obvious hazards of transporting a flammable, explosive gas in a flammable material.

In 1820, cast iron[3] musket barrels left over from the Napoleonic wars were used in the UK to transport manufactured gas.

The 19th century was a time of scientific and technological advances in many industries; for example: lap-jointed wrought iron pipe, riveted or flanged together, became available; the Bessemer steel making process produced higher quality steel from 1850; and seamless pipe was introduced towards the end of this century. These advances paved the way for the pipeline industry.

USA, 1859… barges and railways … and pipelines

Today's pipeline industry has its origins in the oil business; therefore we need to briefly review how the oil business developed.

The oil business

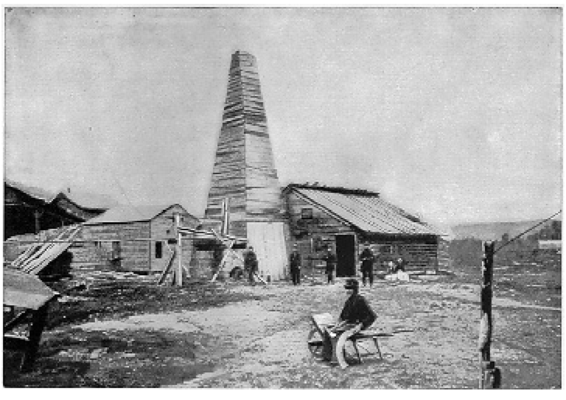
Oil naturally seeps to the Earth's surface along fault lines and cracks in rocks, and ancient communities made use of this material. We can consider the oil business beginning over five thousand years ago; for example, the Bible refers to pitch (thick bitumen) being used for building purposes (cementing walls) in Babylon, and it is known that communities in the Middle East used it to waterproof boats and baskets, in paints, lighting and even for medication. There are records of oil being dug on the Greek island of Zante in 400BC and used to light lamps, and the Egyptians used pitch to coat their mummies and seal their pyramids.

Oil and gas has been extracted and sold for thousands of years, all over the world, but coal was our primary energy source in the 1800s and early 1900s. The oil business was insignificant until the 19th century.

In the 19th century and before, the 'oil' in demand was whale oil. This oil was used as a source of light; however, the high demand for whale oil decimated whale populations and as their numbers dropped the prices rose and rose. The demand for 'oil' was then far higher than the supply.

Many companies and individuals were looking for an alternative and longer lasting source of oil. There was a brief period of coal oil, but then a long term solution arrived with the development of drilling for crude oil.

Up to the 19th century, oil was only obtained from natural seepages to the earth's surface, although there are records of a hand-dug (to 35 metres) oil well in Azerbaijan in 1594. In the 19th century, oil was discovered underground by persons drilling for water, but it was considered a nuisance! However, entrepreneurs soon realised that this 'land oil' could be used as a lubricant and luminant. Oil had been drilled in Baku, Azerbaijan in 1848, and Poland in 1854, but the first major exploitation and commercialisation started 150 years ago in the USA, by a certain 'Colonel' Drake.

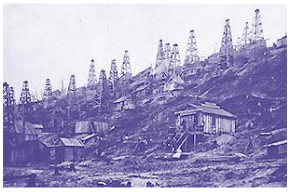


[3] Cast iron is brittle (i.e. it cracks easily), but has good corrosion resistance.

Figure 3. 1859: Titusville, USA

In 1859, Edwin Drake drilled two oil wells, near a surface oil seepage, in Titusville, Pennsylvania, USA, Figure 3. The wells had a combined value of $US40,000. They produced 2,000 barrels (bbl) of ‘crude’ oil, but this smelly, muddy crude was not popular until 1860, when simple ‘refineries’ were in operation to process the oil. These refineries boiled the crude: naptha, then kerosene boiled off, leaving heavy oil and tar. The kerosene alone was a perfect replacement for the whale oil used for lighting, and allowed the oil to be sold for $20/barrel. In these early days, gasoline and other products made during refining were simply thrown away because people had no use for them, but in 1892, the "horseless carriage" solved this problem, since it required gasoline.

By 1900, oil fields had been discovered in many states in the USA, and oil fields were also found in Europe and East Asia. In 1900, crude oil production worldwide was over 100 million barrels: about half of this total was produced in Russia (the Russian oil ‘boom’ had started in the 1860s in Baku), and most of the rest was produced in the USA. As the world entered the 20th century, refined oil was used primarily for lighting, but this use was soon exceeded by the needs of automobile and aircraft, making oil a more significant fuel than even coal by 1920.



The early oil rush

Transport by water

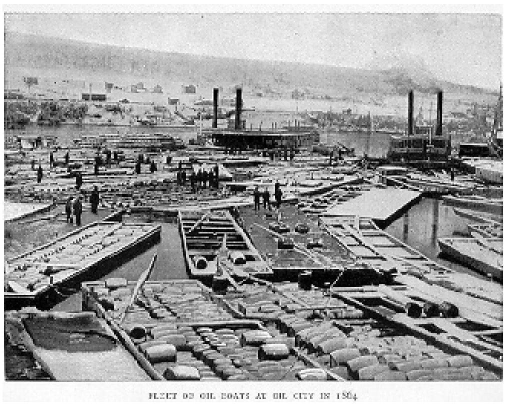
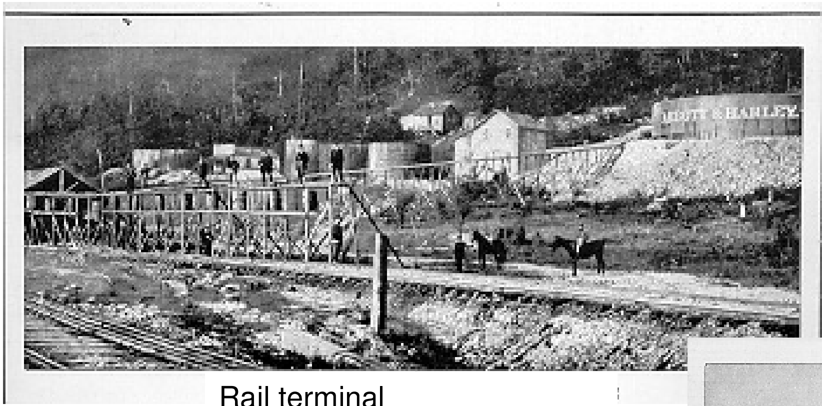


Figure 4. Oil was originally transported by barge, in wooden barrels

The first 'pipelines'

In the early 1860s, the oil was transported in wooden barrels on rivers by horse-drawn barges, Figure 4. This was dangerous: weather, and labour disputes, often disrupted flow. The railway relieved this (Figure 5), but the oil was now controlled by the rail bosses and their workers… the 'teamsters'. Pipelines were an obvious solution to this transport problem, and the early oil workers were familiar with pipes: cast iron and wrought iron[4] pipes of various diameters were in use around the producing wells from the start of the industry. The pipes were used as drive pipe, conductor, casing, tubing, and for conveyance of oil in and around the lease.



Rail terminal

Wooden storage tanks

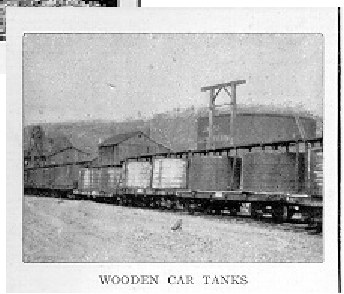


Figure 5. Oil was later transported on wooden tanks on rail trucks

Iron pipe had been in use since 1843, and short pipelines were in use in the USA to transport manufactured gas (gas obtained from coal). These pipelines often used cast iron pipe with bell-and-spigot joints sealed with rope or jute packing and molten lead. In 1861 to 1863 short cast iron oil lines were laid with associated pumps in the USA; for example, a short (1,000 feet) 2 inch diameter cast iron oil line successfully carried oil from a producing well to a field refinery in Pennsylvania. Unfortunately, the joints were soldered using lead, which caused many to leak, but threaded joints, screwed together using tongs, were later to solve this problem. The pipelines were successful: a 2½ mile long (4km), 2 inch diameter pipeline was laid in 1863, and it moved 800 barrels (33,600 gallons) of oil per day. The threaded pieces of pipe were joined end-to-end by screwed collars.

This success and progress with pipelines was not well-received: most of the oil workers still relied on river and rail transportation using wooden barrels. Consequently, pipelines were both an obvious solution to the transportation problems, and a threat to employment.

Indeed, the teamsters were reported to have sabotaged or dug up and destroyed some of the early pipelines, and in 1863 there was a 'war' between pipelines and these teamsters.

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4 Wrought iron is almost pure iron (it contains <0.5% carbon) and very malleable, whereas cast iron has relatively high carbon content (2 to 4%), but both these materials are either too low strength or too brittle to function well as structural materials.

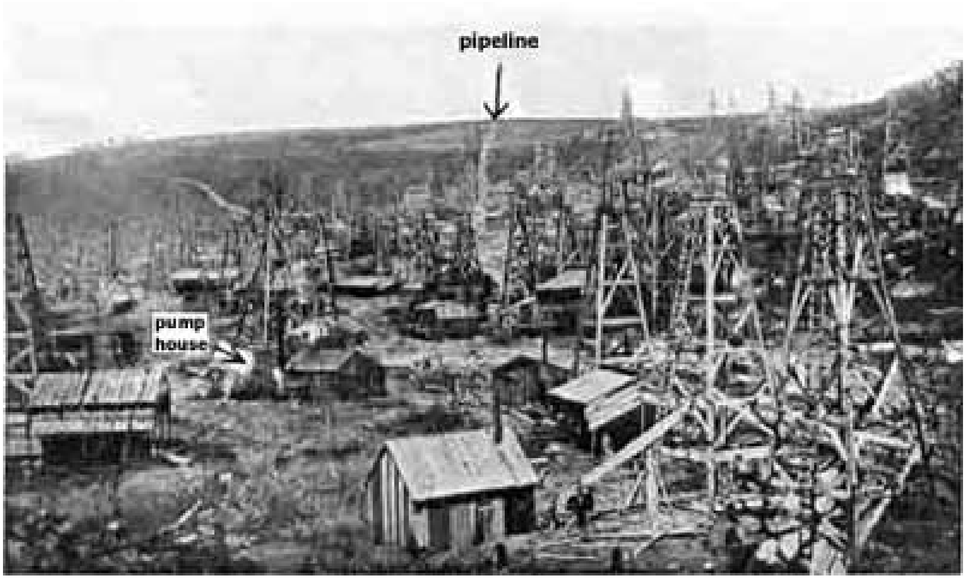

Figure 6. Benninghoff Run (farm) oilfield

In 1864 a proposed oil line in Pennsylvania was opposed because it would 'affect local prosperity' (probably teamsters' opposition). However, in 1865 a 6" gravity (no pumps) oil line was built in Pennsylvania, transporting 7000 barrels/day. It was completed by the Pennsylvania Tubing and Transportation Company along Pithole Creek from the Pithole oilfield to the mouth of the creek where it flows into the Allegheny River.

The first pipeline with a pump is thought to have been in 1865 at the Benninghoff Run (farm) oilfield, built by Henry Harley of Shaffer on Oil Creek. The fields consisted of 87 wells, most with derricks. The right-of-way of Harley's 1865-66 Benninghoff Run-Shaffer Farm oil pipeline is seen as a straight white streak on the hill (see arrow) in Figure 6. A pump-station for the line is also indicated.

The pipeline had one pump at Benninghoff Run which eventually allowed it to deliver 800 to 1000 barrels (some sources say 2000 barrels) of crude daily to Shaffer. Actually two lines were put into use, doubling the delivery. It was not completed until 1866 due to harassment[5] and destructive attacks by the large number of teamsters in the region where the line was being laid. The teamsters viewed the pipelines as an infringement on their rights as 'common carriers'.

The growth of pipelines in the late 1800s

Many pipelines were laid in the latter half of the 1860's, displacing some 6000 teamsters who had relied on the wooden barrel. The situation was simple: the pipeliners charged less than the teamsters: a 5 mile (8km) pipeline pumping 1000 barrel of oil per day could replace 300 teamsters working a 10 hour day! 3000 teamsters were eventually to leave Pennsylvania to become employed hauling pipe sections for new pipelines.

The railroad companies continued to attempt to monopolise oil transportation and dictate prices to producers. Oil producers responded by constructing lines directly from the producing fields to the refineries. By 1874 a 4" line had been laid from the producing fields to Pittsburgh. The railroad companies reacted: they formed associations with pipeline

[5] The teamsters threatened Harley's life, threatened his staff and, at night, burned down his large wooden tanks which were filled with oil. During one 'battle' a teamster was killed.

transportation companies. Standard Oil Company, then the nation's largest refiner, reacted to these associations by building its own pipelines and storage facilities. Standard Oil's chief competition was the Tidewater Pipe Line Company, formed by a group of producers. In 1879, they built a line between the producing centre of Coryville and the railroad loading facilities at Williamsport, Pennsylvania. The 6" diameter, 115 mile (184km) Tidewater pipeline represented a major technological advance in pipeline engineering; it was the longest pipeline, and at the highest altitudes.

Initially, all wrought iron pipes had to be threaded together with workers using large tongs. This was difficult to do for large pipes, and they often leaked under high pressure, and this limited the pressures that the pipelines could operate at, but pipelines rapidly expanded: in 1886 an 87 mile (139km), 8 inch (203mm) diameter natural gas pipeline was laid from Kane, Pennsylvania to New York. The pipeline expansion was helped by technology:

- the 1870s saw 'Bessemer' steel replacing wrought iron (which had replaced cast iron);
- in 1885, the Mannesmann brothers in Germany devised a machine that could make pipe with no seam, hence eliminating the problematic (weak) welded seam of existing pipes.

The 1880s also saw pipelines being buried rather than laid on the ground: this was due to pipeline operators in Pennsylvania observing their heavy, screwed together, cast iron pipes expand in the hot weather and bend and buckle, and in cold weather they contracted, pulling the threads apart and causing large leaks. Burial a few feet underground eliminated these problems.

Other areas in the world were developing pipeline systems and realising huge transportation savings: in 1878, in Baku, the Nobel brothers built a 3" diameter, 6.25 mile (10km) oil pipeline that reduced transportation costs by 95%, and paid for itself in a year! The pipe was imported from the USA because of its low cost and high quality, but it is interesting to note that pipelines in Baku around this time was also opposed by companies and workers with interests in cooperages, etc..

One of the first long pipelines was built in 1891. It was 120 miles (192km) long, and it carried gas from fields in central Indiana to Chicago. It used no artificial compression, mainly because the gas was naturally pressurised underground, at approximately 525 psi. This allowed transportation through the pipeline without the need for compressor stations.

The growth of pipelines: into the 1900s

Most of these early pipelines were five or six inches in diameter (although pipe of 30" diameter was made in 1897), and laid 'by hand' (Figure 7). Eight inches became the standard pipe size and remained so until the early 1930s, as it was the largest diameter that could function at the normal operating pressures of the times. By the end of the 1920s major refineries were capable of processing 80,000 to 125,000 barrels of oil a day, to feed huge increases in demand (for example, from 1910 to 1920 the number of cars and trucks on American roads grew from fewer than 500,000 to more than 9 million). Unfortunately an eight-inch pipeline could only deliver 20,000 barrels per day. To increase capacity, an additional line, was usually looped, or was laid alongside of, the existing line. Ten-inch and 12-inch pipelines required lower operating pressures, and this was needed due to their tendency to split at the seams.

 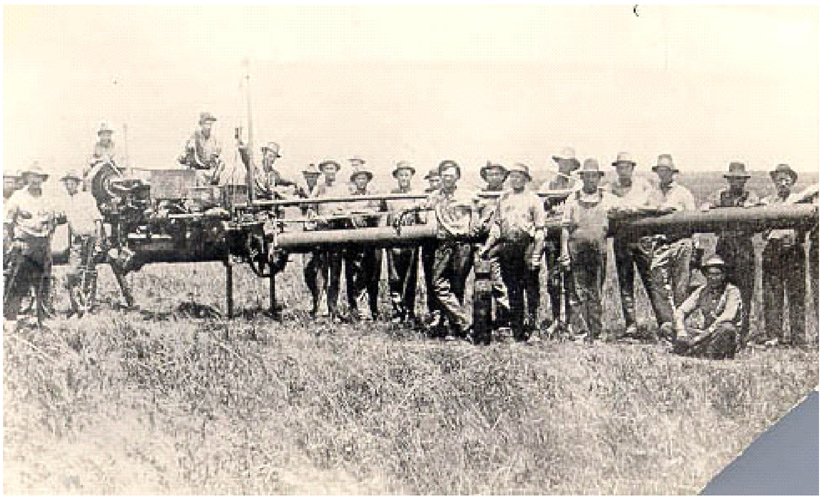

Figure 7. Early pipelines were joined and laid 'by hand'

The operating pressures were still low compared to today's pressures:

Year	Pressure (bar)	Largest Diameter (mm)
1910	2	400
1930	20	500
1965	66	900
1980	80	1420
2000	120	1620

and this was partly due to poor pipe materials, although most new pipelines by 1900 were made using steel pipe, and poor pipe joining technologies. This started to change in 1911, when oxyacetylene welding of pipe was started, by the Philadelphia and Suburban Gas Company, and by the 1920s the use of steel pipe and electric arc welding became popular in the USA. The first all-welded pipeline over 200 miles in length was built--from Louisiana to Texas. Welding made it possible to construct leakproof, high-pressure, large-diameter pipelines. Diameter is important for transportation efficiency: a 36in diameter pipeline can carry 17 times more oil and gas than a 12in pipeline. The larger the diameter the more economical the pipeline.

During the 1920s, driven by the growth of the automobile industry, the total USA pipeline length grew to over 115,000 miles (184,000km). The 1930s and 1940s saw technological improvements; for example, coatings (coal tar) started to be applied to the pipelines during installation, and girth welds were inspected using radiography from 1948.

The early pipelines were all onshore, as there was an abundance of onshore reserves, and technologies to explore, drill, and extract oil from offshore locations were not developed. There was some oil extraction from underwater at the end of the 19th century, but this was using short piers built from land; however, in the middle of the 20th century, offshore pipelines started to be built to extract the huge offshore oil and gas reserves in locations such as the Gulf of Mexico.

Similarly, the early years of the oil and gas business were dominated by oil, with little use for natural gas: the first natural gas was produced as a by-product of crude oil and was considered a waste product! Also, oil, a liquid, was easy to store and transport, but in the early years there was no method to economically store natural gas during the early years of oil production, and transportation of the gas was hazardous. So, early oil drillers considered natural gas a nuisance and vented or burned it off at the well site.

Manufactured gas was in extensive use around the world from the 19th century, and this 'coal' gas was transported in low pressure pipes. There were major natural gas pipelines built at the turn of the 20th century, but there were very few natural gas pipelines built until after World War II in the 1940s.

Going long distance… and innovation

The next big change in pipeline engineering was the building of long distance, large diameter pipelines: these were pioneered in the USA in the 1940s due to the energy demands of the Second World War.

'Long' pipelines had been built at the turn of the century; for example:

- in 1906 a 472mile (755km), 8in diameter pipeline was built from Oklahoma to Texas;
- similar length, small diameter (8 in to 12 in) lines were built in Baku at the same time;
- in 1912, a 170 mile (272km), 16" diameter manufactured gas pipeline was built in 86 days, in Bow Island, Canada to make it one of the longest pipelines in North America.

These were short pipelines compared to those built in the 1940s. The best examples of these early long distance pipelines were the 'Big Inch' and 'Little Big Inch' pipelines laid during World War II from East Texas to the northeast states.

In 1941 oil industry executives began to plan the building of two pipelines: twenty-four inches in diameter, called the 'Big Inch', to transport crude oil; and another, twenty inches in diameter, called the 'Little Big Inch', to transport refined products. Big Inch was to travel 1400 miles (2240km): the longest pipeline ever built up to that date.

The Second World War also forced innovation in pipeline technology: in 1944, 'Pluto', the 'Pipeline Under The Ocean' was commenced. This project was to construct undersea oil pipelines under the English Channel between England and France, to provide vital fuel from Britain to Allied forces in France. These small diameter (~75mm), cable pipelines eventually totalled 500 miles (800km), and delivered 1,000,000 gallons of fuel per day across the channel: an amazing feat.

As the world emerged from the Second World War it was able to build high pressure, long distance, oil and gas pipelines. Indeed, during the 1950s and 1960s, thousands of miles of natural gas pipeline were constructed throughout the United States as the demand for this energy form increased.

The changes….

The 20th century saw many improvements in pipeline engineering, too many to describe in this paper, but here are some key changes:

- from wrought iron to steel pipe;
- from brittle, low toughness iron to ductile, high toughness steel;
- from lap welds to submerged arc welds or seamless pipe;
- from low strength materials to high strength materials;
- from small diameter pipe to large diameter pipe;
- from low pressure operation to high pressure operation;
- from threaded joints to welded joints;

- from horses and mules to tractors and trucks;
- from picks and shovels to ditching machines;
- from bare pipe to coated, cathodically-protected, pipe;
- from horse patrols to aerial surveillance;
- from simple above ground inspections, to sophisticated internal inspections using smart ‘pigs’;
- from oil pipelines, to oil, gas and product pipelines;
- from solely onshore construction to offshore and deepwater construction;
- from no standards and regulation, to benchmark standards and safety regulations;
- etc..

These advances, and long history, allow us to build and operate huge, effective, and safe pipeline systems today.

3. PIPELINES TODAY

The oil and gas business is big, and it is going to become bigger. Consider these facts:

- the US Energy Information Administration's World Energy Outlook has predicted fossil fuels will remain the primary sources of energy, meeting more than 90% of the increase in future energy demand;
- global oil demand will rise by about 1.6% per year, from 75 millions of barrels of oil per day (mb/d) in 2000 to 120 mb/d in 2030;
- demand for natural gas will rise more strongly than for any other fossil fuel: primary gas consumption will double between now and 2030.

This expanding, secure industry is also highly profitable: Exxon Mobil, the world's largest oil company, announced (January, 2006) profits of $US36 billion, the largest ever by a listed company. In February 2006, Shell announced a record profit for a British company: $US23 billion. These profits are expected to continue in the foreseeable future, as the price of a barrel of oil continues on record highs of over $US60/barrel.

Pipelines in the oil and gas business

To support this growth in energy demand, pipeline infrastructure has grown by a factor of 100 in approximately 50 years. It has been estimated that world pipeline expansion could be up to 7% per year over the next 15 years. This means over 8000km/annum of pipeline being built in the USA alone, at a cost of $US8 billion/annum.

Figure 8. New, large diameter pipelines are expanding

Internationally, 32,000km of new pipelines are constructed each year: this is a $US28billion business, and 50% of these new builds are expected in North and South America. Additionally, 8,000km of offshore pipelines are being built per year: this is a $5billion business with 60% in NW Europe, Asia Pacific, and the Gulf of Mexico.

The total length of high pressure transmission pipelines around the world has been estimated at 3,500,000km. The 'split' is:

- ~64% carry natural gas;
- ~19% carry petroleum products;
- ~17% carry crude oil.

These systems can be huge; for example, if you laid the Canadian pipeline system, end to end, it would extend 17 times around the world! In the USA, the vast pipeline oil and gas pipeline system consist of:

- Onshore Gas Transmission 295,000 miles (472,000km);
- Offshore Gas Transmission 6,000 miles (10,000km);
- Onshore Gas Gathering 21,000 miles (34,000km);
- Offshore Gas Gathering 6,000 miles (10,000km);
- Liquid Transmission Lines 157,000 miles (251,000km).

This lists ignores the 1,000,000 miles of low pressure gas distribution pipelines in the USA, and pipelines carrying water, sewerage, slurries, etc..

We now have many types of pipelines in the world. The types of oil and gas pipelines can be summarised as:

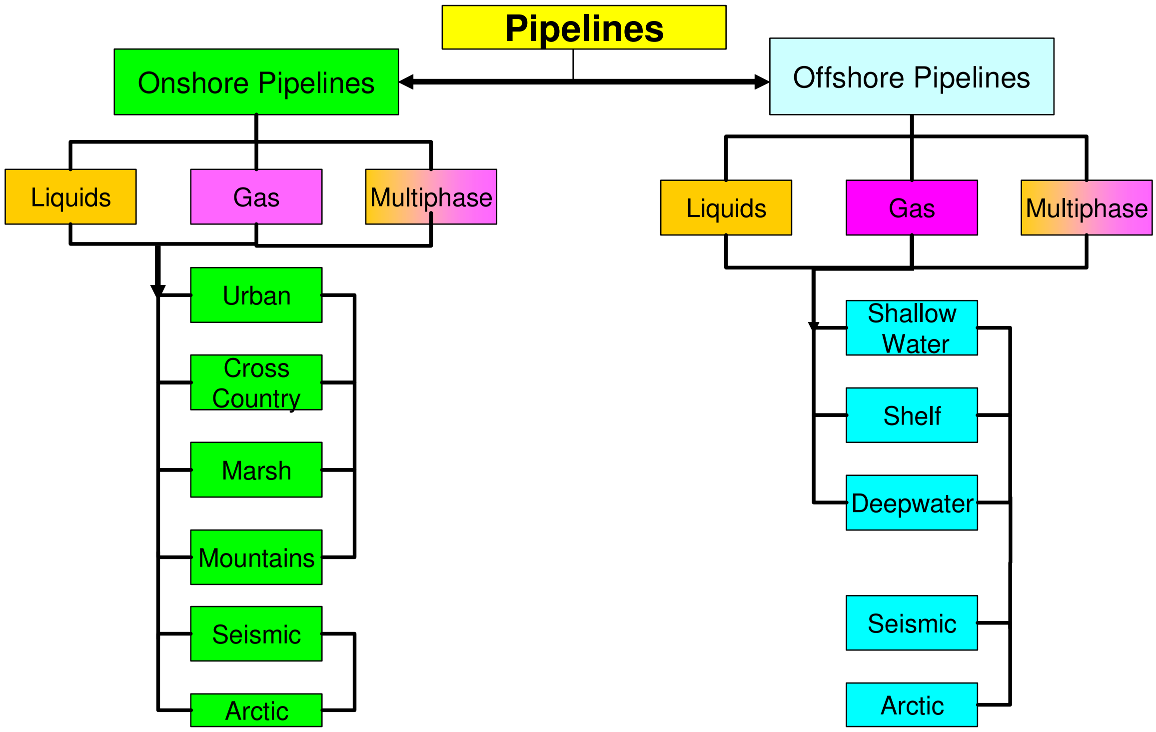

Figure 9. Types of hydrocarbon pipelines

Why we all should be interested in pipelines

We rely on pipelines to deliver our energy needs, but everyone is a stakeholder in oil and gas transportation:

- pipeline operators (transporters) want a safe, reliable supply, and a reasonable profit;
- the general public (consumers) want cheap gasoline, natural gas, etc., delivered reliably and safely, with minimal environmental damage;
- shippers (producers) want cheap, reliable supplies and transportation, and a reasonable profit;

- regulators want a fair and competitive market;
- government groups want safe, environmentally-friendly, delivery;
- advocacy groups (focussing on environmental, cultural, etc., aspects);
- etc..

These stakeholders have differing and often competing demands between themselves (e.g. pipeline companies want high transportation charges, whereas shippers want low transportation charges), and within themselves (the customer wants a cheap product, but delivered safely and reliably). These stakeholders are complemented by the media, who will look to report on any profitable industry, and will always be interested in a sensational story.

Figure 10. Pipelines are critical transportation infrastructures

Pipeline systems are now critical transportation infrastructures in most nations (in the USA gas pipelines are designated 'critical infrastructure' by the Department of Homeland Security, as they deliver about two thirds of America's energy needs), and essential to both standards of living, and economies.

4. PIPELINES TOMORROW

Energy changes

Pipelines are energy transporters, and hence their growth in tomorrow's world will follow future energy demands. There are three 'drivers' for energy demand/price:

- The Gross Domestic Product (GDP) Driver: this describes the demographic, institutional, and technology feedbacks on GDP growth;
- The Energy Demand Driver: this covers the nature and evolution of energy consumption in stationary, mobility, and electricity services, and how they impact the environment; and,
- The Energy Supply Driver: this deals with the availability and cost of energy and their feedbacks on prices or the prospects for economic growth and energy demand.

The Middle East (primarily Saudi Arabia, Iran and Iraq), and Russia posses the largest proven oil and gas reserves, and it is these regions that will provide most of tomorrow's oil and gas.

Energy demand is predicted to increase rapidly over the coming years: world energy consumption is projected to increase by 71 percent from 2003 to 2030, with fossil fuels continuing to supply much of the energy used worldwide, and oil remaining the dominant energy source. This means continuing use of our existing, ageing, pipeline systems, and a great need for new systems.

Alternative energy forms will be needed, but oil and gas, with their proven reserves of 50 years, will continue to dominate the market, and will see large increases in demand as the developing world continues to modernise. These large increases are projected by the Energy Information Administration (EIA): in 2006 EIA predicted the most rapid growth in energy demand from 2003 to 2030 will be in nations outside the Organisation for Economic Cooperation and Development (non-OECD nations). Energy demand growth averages are:

- 3.7 percent per year for non-OECD Asia (which includes China and India);
- 2.8 percent per year for Central and South America;
- 2.6 percent per year for Africa;
- 2.4 percent per year for the Middle East; and
- 1.8 percent per year for non-OECD Europe and Eurasia.

The increases result from projections of strong regional economic growth. For all the non-OECD regions combined, economic activity (as measured by GDP, in purchasing power parity terms) is predicted to expand by 5.0 percent per year on average, as compared with an average of 2.6 percent per year for the OECD economies.

The location of most of our oil and gas, and the economic growth and emphasis on non-OECD nations will see many new pipelines being built within, out of, and into, these nations.

This does not mean that pipeline technologies will see the most changes: traditionally, most change and investment in the oil and gas business is focussed on the 'upstream' market (exploration and production), where most money is spent and where the highest risk is experienced. In the upstream section, the research and changes we expect are:

- Reservoir management (discrimination of oil, gas and water, with reservoir performance measured in real time);

- Fewer wells/reservoirs (deepwater will mean fewer wells, producing at higher rates using infrequent and low costs interventions);
- Smaller fields (there are more smaller fields to develop than large ones. We need extended tie-backs, minimal facilities, and remote operation);
- Composite materials (for use on production platforms and vessels);
- Well bore information (system control telemetry, real time communications);
- Flow assurance (technologies are needed for predicting wax and hydrate formation, with chemical and mechanical technologies developed to alleviate flow assurance problems);
- 'Semis' versus 'Spars' (as we go deeper and deeper, the spar platform is being preferred to the semi-submersible because they facilitate the use of surface trees and have a good design history. However, the semi-submersibles do not incur the technical issues of going deeper and deeper (they are insensitive to depth), and they could overtake spars as the preferred technology);
- Reduced cycling time (we need to reduce deep-water project time with, for example, parallel drilling and production).

But we can now look at pipelines, and consider what challenges and changes we can expect.

Figure 11. What future challenges do pipelines face?

Some (big) future issues for pipelines

Pipelines will change in the future; for example:

- numerous long distance onshore pipeline systems are either being built or planned in the North American Arctic, Central Asia, and Russia, and these will require novel materials and designs.
- research into high strength steel, and low weight composites, will certainly mature and be part of tomorrow's pipeline industry;
- trans-ocean pipelines to release all the 'stranded' gas will be pursued;
- long distance liquefied natural gas pipelines will be built;

The future will test our designers, plus others in the oil business:

- the need to build bigger, better pipelines, quicker and cheaper, will test investors, designers, constructors and regulators;

- the markets will be tested by balancing increasing demand with decreasing supplies, or highly contested supplies.

The future will not be focussed on new pipelines in new locations: we must acknowledge that many of the existing pipeline networks in Russia, USA and Europe are reaching the end of their cost-effective lives, and they will require substantial investment, including re-builds, to maintain supplies.

Also, we must realise that the pipeline industry is 'risk averse': it will not take high risks for low rewards, as the cost of mistakes, such as failures, can have huge safety, environmental, and fiscal consequences. This means that most of our future pipelines will be the same as today's pipelines, so the future, in terms of basic engineering, is predictable and conservative.

But there are some very big issues that the pipeline industry must deal with, and we can now consider some of the big generic issues, and the big challenge. This section gives some of the author's views on these topics.

People

There is a major need to improve the intellectual capital in the pipeline industry, as there is a major, world-wide shortage of pipeline engineers. Additionally, many engineers have either left the pipeline industry, or have retired, with limited replacements. This means that the oil and gas industry workforce is 'old': a 'young' worker is about 43 and an 'old' worker is 55. With early retirement still popular, the industry could lose half of its experienced workforce by the end of this decade.

Figure 12. Where will our future staff come from, and how will we ensure they are skilled?

The oil and gas business and pipeline industry need to urgently attract new staff to replace an ageing workforce. Unfortunately, the industry and engineering does not have an attractive image, yet it offers decades of employment, in companies that record the highest profits in the world.

An additional problem for the future is that many of our new pipelines will be built in regions that have socio-economic, political, or security problems. This will mean that staffing many of our new projects will be difficult, and carrying them out will not be easy.

Recruitment is not the only problem: we need to recruit staff with either the required skills, or we need to train inexperienced staff. Traditionally, pipeline staff have been recruited, trained, and developed in large private or state-owned oil and gas companies. Many of the state-owned companies have disappeared, and many of the technician and graduate training programs have also disappeared; hence, there is a shortage of training programs, and companies willing to invest in this training.

Consequently:

- there is an urgent need for universities to offer pipeline engineering courses at undergraduate, graduate, and professional development levels, to help provide the new blood;
- many of tomorrow's pipelines will be built in 'difficult' (environmental, political, socio-economic, and security) regions, and this will require indigenous staffing, who will require intensive training;
- research is needed into learning methods and tools (distance learning, modular, continuing professional development, etc.) for today's and tomorrow's pipeline engineers.

Change in emphasis to existing infrastructures

Poor quality materials and a lack of understanding of major risk meant that 30 years ago, and before, we needed standards that ensured we had good quality pipe, decent pipeline routeing, etc.. But now we have good materials, good knowledge of design, etc..

A big issue for today's pipeline operator is not thinking about new materials, or new joining methods, but how he/she can maintain pipeline safety and security of supply as their assets age, and they are required to transport more and more product. This ageing presents corrosion problems (Figure 13), impact damage, fatigue cracking, etc., that threaten the safety of pipelines.

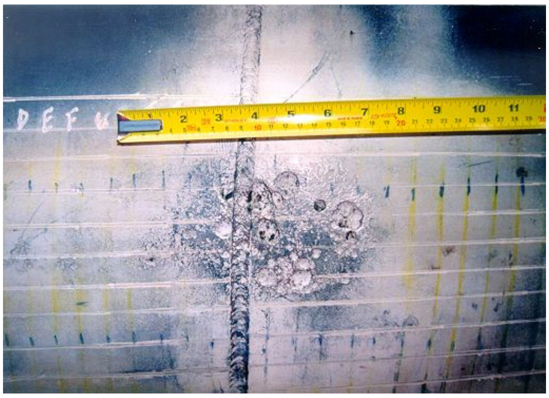

Figure 13. Corrosion crossing a pipeline girth weld.

We can understand this change in emphasis by drawing an 'S-curve': these types of curves can be used to define and describe the progress of technologies. Figure 14 gives an S-curve for research, which will have three parts:

- Bottom: fundamental research, learning;
- Middle: proof of concept, type testing, development;
- Top: maturity, diminishing return.

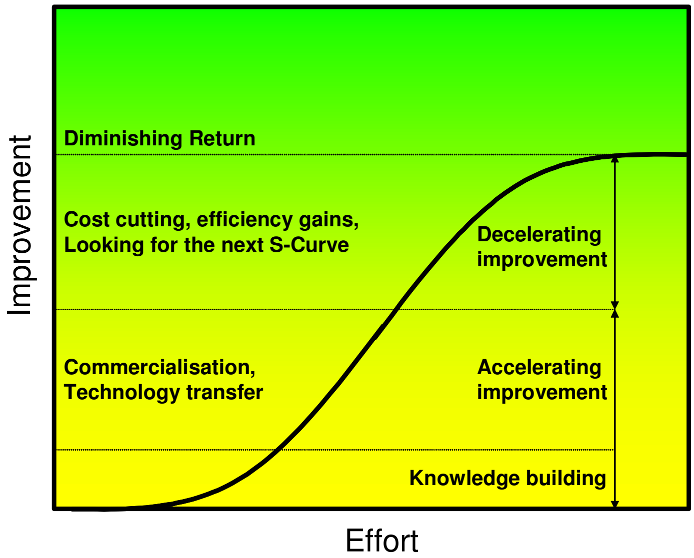

Figure 14. The research 'S-Curve'

The S-curve can be used to illustrate how technologies mature, and how technologies change, as previous ones mature. Consider the method of joining pipes, Figure 15. Here we see how one technology (e.g. threading) was both useful and effective, but oxyacetylene welding replaced it. But quickly, electric arc welding replaced oxyacetylene.

This S-curve concept can also be used to show why we need to focus on the safety of existing pipelines. We know that we have 3,500,000km of existing high pressure pipelines, and we are only expanding this system by a few percent per annum The effect is that we are, and will continue to, operate 'old' pipelines: most of the USA oil and gas system is over 40 years old.

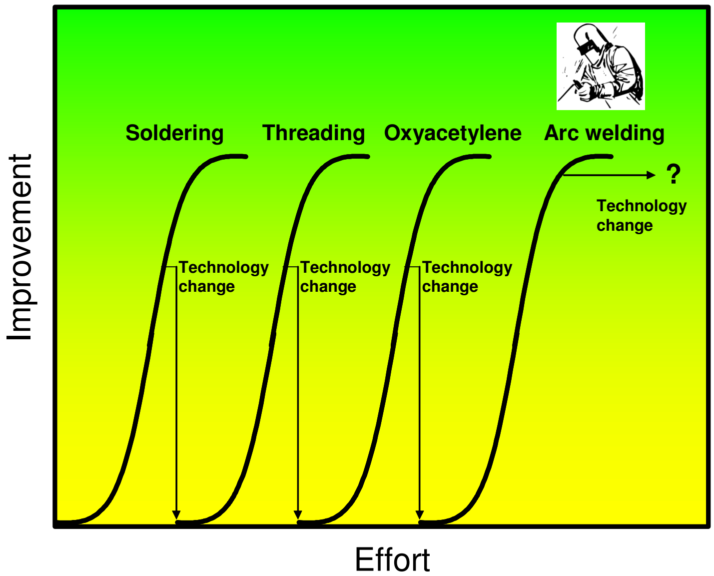

Figure 15. Evolution of pipeline joining technologies

This means we have to look at the needs of an ageing pipeline system. Let us use this S-curve to understand these needs, Figure 16:

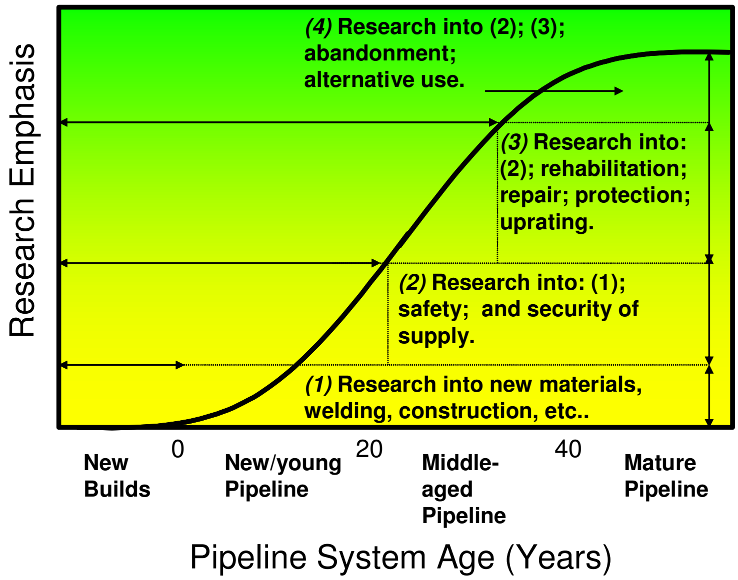

Figure 16. The changing needs of a pipeline system

The conflict for operators is that there is an expectation that their pipelines will be required to not only continue safely and economically into the future, but also be able to carry greater loads (there are general moves in many countries to raise allowable operating pressures), or differing fluids (e.g. from natural gas to liquefied natural gas). This leads to the following future issues, needs and improvements:

- corrosion, corrosion monitoring, and corrosion failure models;
- investigations into 'time dependent' deterioration mechanisms in transmission systems;
- damage detection, behaviour, mitigation and prevention;
- pipeline control (SCADA);
- leak detection (improve current methods, introduce new methods), mitigation, and control;
- pipeline awareness programmes (e.g. improved 'one call' systems);
- pipeline surveillance (ground, air, space);
- pipeline inspection (external, internal);
- emergency planning and procedures;
- risk assessment and management;
- data management;
- rehabilitation and repair;
- abandonment;
- security of pipelines against terrorism (structural, communications, cyberspace);
- alternative/future uses of transmission system (hydrogen, carbon dioxide, etc.);
- impact of liquefied natural gas imports on gas transmission system;
- impact of increased demand on transmission systems;
- impact of differing imported oils and gases on the transmission systems, and its effect on storage needs;

- etc..

Sabotage, theft, and terrorism

One of the big changes in pipelines in recent years has been the rapid increase in acts of terrorism, sabotage and theft.

The world's oil and gas pipelines pass within and across regions that are poor, politically unstable, inhospitable, corrupt, or prone to terrorist attacks. Consequently, pipelines and facilities such as pumping stations are vulnerable to attack, sabotage and theft. The world's pipeline system is growing; for example, Saudi Arabia has 20,000km of pipelines and this length may grow to 96,700km in the future. This may be a big, easy target for terrorist attack: the Cano Limon pipeline in Colombia was attacked 170 times in 2001 by a terrorist group, despite the heavy and constant presence of armed guards. Theft of products from pipelines and vandalism are also problems: the Niger-Delta region of Nigeria recorded the deaths of about 5000 people from oil pipeline 'vandalisation and explosions' in 2000. Technology can help; for example, satellite surveillance is a practical solution today, as is the use of more sophisticated leak detection systems and remote sensing devices to detect tamperings on the pipeline.

The pipeline industry will need to change its operations to allow some protection against sabotage, theft and terrorism.

Environment

Pipeline design, construction and operation take care not to damage the environment, but oil and gas are not environmentally-friendly fuels. They damage the environment, but the companies marketing the fuels are not taxed or penalised for causing this damage. The New Economic Foundation in the UK says *"… The way we view economic success in the UK has become a fossil-fuelled fantasy. No accounting system with a hint of common sense would view profiting for a never-to-be-repeated natural asset as a good thing – even less so when it leads to climate change chaos".*

The biggest challenge facing the pipeline operator may be keeping their ageing pipelines operating safely, but the biggest challenge facing the oil and gas business is its effect on the environment. Pipelines can help: they can be used to capture the harmful emissions from power stations and factories burning fossil fuels (see below).

Both the oil and gas business and pipeline industry will be affected by increasing environmental and climate change scrutiny, and heavy control and taxation can be expected.

The start of an exciting era in pipeline engineering

The above issues for the pipeline industry are contrasted by a general view that the industry is probably entering its most exciting era. Here are some of the challenges that will both excite and stretch tomorrow's pipeline engineers:

- CARBON CAPTURE: Electricity generation using fossil fuels generates carbon dioxide (CO_2). The use of cleaner fuels (e.g. using clean coal technology) and the capture of the emissions provide the most significant means of reducing the emissions. The CO_2 would be sequestrated from carbon-burning industrial plants, and stored in geological structures such as saline aquifers or old oil and gas fields. The CO_2 will need to be transported in large quantities, in pipelines. CO_2 is a difficult fluid to transport (e.g. it needs to be transported at very high pressures), and there is an urgent need to design and develop CO_2 pipelines if carbon capture is to become a reality, and help prevent climate change. Governments are already committing to reduce CO_2 emissions: the UK is committed to reduce its CO_2 emissions by 60% by 2050.

- HYDROGEN ECONOMY: Developed nations rely heavily on oil, gas and coal, but hydrogen is the most abundant element in the universe and can be used for a fuel. Countries are looking at long distance hydrogen pipelines as an alternative fuel supply to natural gas, etc.. Hydrogen can be transported as a liquid (e.g. by trucks and tankers) or as a gas (by pipeline). Pipelines offer the most economical transport mode, but hydrogen is a problem fluid to transport; for example, it embrittles many steels. Much work is needed on hydrogen pipelines before the new 'hydrogen economy' arrives, but BP is now planning a $US1 billion plant in California to obtain hydrogen from petroleum coke.
- BIOFUELS[6]: Biofuels (for example, bioethanol obtained from sugar cane) are alternatives to fossil fuels, without the damaging levels of CO_2 emissions. These fuels will be ethanol, methanol, etc., and new pipelines will be needed to transport both the raw products and the new fuels to/from their refineries. The biofuel industry is already with us: Brazil intends to power 80% of its transport fleet with ethanol derived mainly from sugar cane within five years.
- WATER: This paper is primarily aimed at hydrocarbon pipelines, but water pipelines need a mention. One third of the world's population does not have a safe water supply: this leads to 25,000 people dying per day because of poor water quality. Here are some more shocking facts: in the next 24 hours, 4,000 children will die from diarrhoea caused by unclean water and poor sanitation; at any time, half the population of the developing world are suffering from water-related diseases; one billion people have no source of drinking water. New pipelines can help solve the water problem. This will require huge investments, huge infrastructures, and international co-operation. The politics will not be easy: in 1995 the World Bank viewed 'water' and its effects on world peace, and it stated that in the past wars had been fought over oil, but the future wars could be over water.
- DEEPWATER AND DISTANT ENVIRONMENTS: The next decade will see a huge increase in exploitation of reservoirs in deepwater, in the Gulf of Mexico, and off the coasts of Brazil and West Africa. Our technologies work well in 1000m, even 2000m water depths. But some of our deepwater exploration will take us beyond 3000m and onto 4000m, and these fields can be hundreds of kilometres away from land, and subjected to extremes of weather, etc. These depths and locations require new technologies and new skills, particularly pipeline technologies.
- HOSTILE/DIFFICULT ENVIRONMENTS: Most of the world's total recoverable (by conventional means) oil has already been discovered; what remains is mostly located in smaller fields or in more difficult environments (e.g. under ice, or in permafrost).
- OIL SANDS/ULTRA-HEAVY OIL, AND OIL SHALE: 'Oil sands' are unconsolidated sands held together by pore-filling bitumen. In its natural state this bitumen is very thick with a viscosity which prevents it flowing to a wellbore. Oil shale is a fine-grained mudstone, which tends to have a plate-like structure. The shale is a source rock for hydrocarbons, and oil can be extracted from it, but this oil has a low energy value. New technologies will be needed to extract the oil from the oil sands and shale, but the prize is huge; for example, Canada and Venezuela have recoverable resources estimated at >180 billion barrels (bbl) and >272 billion bbl respectively. Many countries have large shale resources (there are over 1,500 billion bbl in the USA alone). New pipelines will be needed to carry these new resources in new locations.

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[6] A 'biofuel' is a liquid or gaseous fuel produced from 'biomass'. Biomass is a product of agriculture, forestry or related industries, as well as the biodegradable fraction of industrial and municipal waste.

5. CLOSING COMMENTS

The oil and gas pipeline industry is mature (nearly 150 years old), but it faces many new challenges. The major challenge the pipeline operator faces is maintaining a safe and secure supply, as his/her system ages. These systems are now entering ‘old age’ (over forty years old), and like all old systems they will need extra attention and spending.

The major challenge facing the oil and gas business is its effect on the environment. For over 150 years the business has not been directly taxed for its damaging effect on the environment, and it has not been controlled or regulated to minimise this damage. This will change, and this will bring major changes and challenges to both the oil and gas companies, and its pipeline operators.

The good news is that all these issues, challenges, etc., present real engineering problems and hence exciting opportunities for pipeline engineers. This means that anybody entering the business today will be both challenged and rewarded.

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32. http://www.culturalresourcegroup.com/
33. www.naturalgas.org/
34. http://www.transneft.ru

[7] Web sites and contents change, and these resources may not now be available.

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