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Oil & Gas Production and Processes Fundamentals

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OIL & GAS PRODUCTION AND PROCESSES
FUNDAMENTALS

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I. INTRODUCTION:

Petroleum is an oily, flammable liquid that occurs naturally in deposits, usually beneath the surface of the earth, also called crude oil. Petroleum is a naturally occurring liquid found in rock formations consisted of a complex mixture of hydrocarbons of various molecular weights, with traces of various nitrogenous and sulfurous compounds.

It is generally accepted that petroleum is formed by decayed plant and animal remains, buried under thick layers of rock, over the past 600 million years, together with small microscopic plankton organisms, largely responsible for the high organic carbon content of the fossil oil buried underneath sedimentary rock subjected to intense heat and pressure, distributed in some places of the earth and under the sea, gradually transformed into oil reservoirs.

The word petroleum may come from the Greek: “petra” for rocks and “elaion” for oil or from the Medieval Latin, “petra” (or petrous) for rock and “oleum” for oil. The term was found (in the spelling "petrosoleum") in 10th century Old English sources and used in the treatise De Natura Fossilium, published in 1546 by the German mineralogist Georg Bauer, also known as Georgius Agricola.

In ancient times in Asia, Europe, and other places of the Earth, it was scooped from streams or holes in the ground, originally used as mortar, for coating walls and boat hulls, and as a fire weapon in defensive warfare. Oil has also been used for lighting purposes for many years. Historically, we know of tales of eternal fires where oil and gas seeps would ignite and burn. One example is the famous oracle of Delphi always burning, in 1000 B.C., and in 500 B.C., the Chinese were using natural gas to boil water.

II. HISTORY:

According to the historians Herodotus and Diodorus Siculus, more than 4000 years ago, asphalt was used in the construction of the walls and towers of Babylon. Great quantities of crude oil were found on the banks of the river Issus, one of the tributaries of the Euphrates. Ancient Persian tablets indicate the medicinal and lighting uses of petroleum in the upper levels of their society. By 350B.C, oil was produced from bamboo-drilled wells in China. Early British explorers to Myanmar documented a flourishing oil extraction industry based in Yenangyaung that, and in 1795, had hundreds of hand-dug wells under production.

Early industrial societies used whale oil widely in oil lamps and to make soap and margarine. The demand for petroleum as a fuel for lighting in Europe and other countries quickly grew, to provide a cheaper alternative to scarce whale oil. Then, there was a considerable petroleum activity in various parts of the world in the mid-19th century. A group directed by Major Alexeyev of the Bakinskii Corps of Mining Engineers hand-drilled a well in the Baku region in 1848. An early commercial well was hand dug in Poland in 1853, and another in nearby Romania in 1857, searching alternative fuels, till reaching the kerosene.

The process of distilling crude oil/petroleum into kerosene, as well as other hydrocarbon compounds, was first written about in the 9th century by the Persian Rhazes. Kerosene is a combustible hydrocarbon liquid and the name is derived from the Greek “keros” meaning wax. In his Book
of Secrets, he described two methods for the production of kerosene, termed "white naphtha", using an apparatus called an alembic.

In 19th century, kerosene was produced from coal oil (or shale oil) and bitumen by heating rock to extract the oil, which was then distilled. Since, the cost of extracting kerosene from coal was too high, in 1846 a Canadian geologist Abraham Gesner gave a public demonstration of a new kerosene process extraction he had discovered, in Charlottetown, Prince Edward Island, using a mineral asphalt, very similar to coal rock, designated as albertite.

Albertite is a type of coal named after the Albert County in New Brunswick, Canada, from whence it was first found. It is a type of solid hydrocarbon shiny black bitumen, and resembles coal, less soluble in turpentine than the usual type of mineral asphalt. Abraham Gesner heated the albertite in a retort and distilled a clear, thin fluid which he made an excellent lamp fuel. Despite the clear priority of his discovery, Gesner did not obtain his first kerosene patent. He was blocked from using albertite by the New Brunswick coal conglomerate because they had coal extraction rights, and lost a court case when their experts claimed that albertite was a form of coal.

In 1847, the Scottish chemist James Young noticed a natural petroleum seepage in the Riddings coal mine at Alfreton, Derbyshire from which he distilled a light thin oil suitable for use as lamp oil, at the same time obtaining thicker oil suitable for lubricating machinery, which he named "paraffine oil" because at low temperatures resembled paraffin wax. In 1848, Young set up a small business refining the crude oil and became the first to patent the process of distilling the cannel coal into coal oil. In 1852 Young left Manchester to live in Scotland and that same year took out a US patent for the production of paraffin oil by distillation of coal. Both the US and UK patents were subsequently upheld in both countries in a series of lawsuits, however other producers were obliged to pay him royalties.

In 1851, Samuel Martin Kier began selling kerosene to local miners, under the name "Carbon Oil". He distilled this by a process of his own invention from crude oil. He also invented a new lamp to burn his product. The first commercial oil well in Canada became operational in 1858 at Oil Springs, Ontario (then Canada West). The businessman James Miller Williams dug several wells between 1855 and 1858 before discovering a rich reserve of oil four meters below ground. Williams extracted 1.5 million liters of crude oil by 1860, refining much of it into kerosene lamp oil.
By 1859 James Miller Williams owned 800 acres of land in Oil Springs, Canada and reincorporated in 1860, the Canadian Oil Company. His company produced oil, refined it, and marketed refined products. That mix of operations qualified the Canadian Oil as the world's first integrated Oil Company. Because of Canada's unique geography, geology, resources and patterns of settlement, the discovery of petroleum applications touched off an oil boom, which brought hundreds of speculators and workers to this area.

Exploration in the Lambton County, in Southwestern Ontario, Canada, quickened the first flowing well in 1860, relied on hand pumps. The first gusher erupted on January 16, 1862, when struck oil at 158 feet (48 m). For a week the oil gushed unchecked at levels reported as high as 3,000 barrels per day, eventually coating the distant waters of Lake St. Clair with a black oil film. There is historical controversy concerning whether it was John Shaw or another oil driller, named Hugh Nixon Shaw who drilled this oil gusher; the local newspaper identified John Shaw.

The history of the petroleum industry in the United States goes back also to the early 19th century, when petroleum was discovered in Pennsylvania in 1859. The oil rush began in Titusville, Pennsylvania, when "Colonel" Edwin Drake, for the sole purpose of finding oil, drilled the first successful oil well in the Oil Creek Valley. The wells were shallow, less than 50 meters, but could give quite large production for that time. The picture below shows the Oil Creek Valley where the oil was flowing initially at 4000 barrels per day, in October 1861.

However, unfortunately for Drake, his success would not last. He had not purchased much land in the region and therefore the oil industry exploded around him outside of his control. His first well yielded only modest returns and he was fired by the Seneca Oil Company. He never patented the drilling method he pioneered, and lost his modest earnings from the oil business speculated on Wall Street. He would eventually die as a poor pensioner in 1880.
In Europe, Ignacy Lukasiewicz, a Polish pharmacist residing in Lwów, was experimenting different kerosene distillation techniques trying to improve the Gesner's process, using local seep oils. On the night of 31 July 1853, doctors at the local hospital needed to perform an emergency operation, impossible using candlelights. They sent a messenger for Lukasiewicz to try his new lamps. The lamps burned so brightly and cleanly that the hospital officials ordered several lamps plus a large supply of fuel. Lukasiewicz quit the pharmacy and travelled to Vienna to register his technique with the government. Then, moved to the Gorlice region of Poland in 1854, and sank several wells across southern Poland over the following decade, setting up a refinery near Jaslo in 1859.

By the end of the 19th century, the Russian Empire, particularly the Branobel Company in Azerbaijan had taken the lead in production. Access to oil was, and still is, a major factor in several military conflicts of the twentieth century, including the World War II, during which oil facilities were strategic assets and extensively bombed. The goal of German invasion in the Soviet Union included the capture of the Baku oilfields, to provide the necessary oil-supplies for the German military, suffering from Europe blockades.

A large portion of the world's total oil exists as unconventional sources, such as bitumen in Canada and extra heavy oil in Venezuela. While significant volumes of oil are extracted from oil sands, particularly in Canada, logistical and technical hurdles remain, as oil extraction requires large amounts of heat and water, making its net energy content quite low relative to conventional crude oil. Thus, Canada's oil sands are not expected to provide more than a few million barrels per day in the foreseeable future.

In 1901, the U.S.'s first deep oil well out poured in Spindletop, near Beaumont, Texas. Captain Anthony F. Lucas's combined use of fishtail bits, water-based drilling mud, and steam-driven rotary drill rig resulted in such success that after, triggers the Texas oil boom. By the end of the 19th century, oil exploration in North America, led the US to become the leading producer. However, after 1960 the United States was surpassed by Saudi Arabia and the Soviet Union. Today, the top three oil producing countries are Russia, Saudi Arabia and the United States. About 80 percent of the world's readily accessible reserves are located in the Middle East, with 62.5 percent coming from the Saudi Arabia, UAE, Iraq, Qatar and Kuwait.

**Discovery of Natural Gas:** In 1859 an oil explorer, H.C. Tweedle, found a natural gas seep near Moncton, New Brunswick, Canada, what became the Dover field, but water seepage prevented production of these wells. In 1889, Eugene Coste, a young geologist who became the father of Canada's natural gas industry, brought in the first producing gas well in Essex County, Ontario. In 1891, Canada started to export natural gas from the Bertie-Humberstone field in Welland County to Buffalo, New York. Later, gas was exported to Detroit from the Essex field using 8 inches pipeline under the Detroit River.

In 1897, the pipeline stretched the Essex gas supply to its limit with the extension of exports to Toledo, Ohio, but the Ontario government revoked the license for the pipeline, and in 1907 the province passed a law prohibiting the export of natural gas and electricity. In 1909, New Brunswick's first successful gas well came in to supply customers at Stoney Creek near Moncton, although, nowadays, the city has a propane air plant to augment the limited natural gas supply.
In 1911 a milestone for the natural gas industry was founded, when three companies using Ontario's Tilbury gas field joined to form Union Gas Company of Canada. In 1924, the Union Gas was the first company to use the new Seabord or Koppers process to remove poisonous hydrogen sulfide from Tilbury gas. Union became one of the largest corporations in Canada before its acquisition by Duke Energy, a US firm.

Natural flows of oil and gas led to the successful early exploration in Alberta's foothills. Those discoveries were not unique, however. Early settlers frequently found oil and gas seeps in Western Canada, generally near rivers, streams and creeks. In 1922, at Rolla, British Columbia, for example, the company Imperial Oil financed exploration to investigate. A well was drilled and oil and gas found. By 1940, the New Brunswick Gas and Oilfields (NBGO) and its predecessors had drilled 126 wells. There were 27 exploratory and 99 production wells, and from those, 73 were producers in the Stoney Creek Field.

The first large scale liquefaction of natural gas in the U.S. was in 1918 when the government liquefied natural gas to extract helium, which is a small component of some natural gas. Then, helium was intended for use in British dirigibles for World War I. The key patents having to do with natural gas liquefaction came in 1915 and the mid-1930s. In 1915 Godfrey Cabot patented a method for storing liquid gases at very low temperatures. It consisted of a Thermos bottle type design which included a cold inner tank within an outer tank; the tanks being separated by insulation.

In 1937, Lee Twomey received patents for a process for large scale liquefaction of natural gas. The intention was to store natural gas as a liquid so it could be used for shaving peak energy loads during cold snaps. Because of large volumes it was not practical to store natural gas, near atmospheric pressure. However, when the natural gas was converted to a liquid form, cooled to -162°C (-260°F) to shrink the volume 600 times, it could be stored in a volume 600 times smaller. Thus, this became a practical way to store the natural gas, stored at -260°F.

In 1938, however, with the growing importance of natural gas, concern over the monopolistic tendencies of interstate pipelines to charge higher than competitive prices due to their market power, the U.S. government began regulating the interstate natural gas industry with passage of the Natural Gas Act. The Act was intended to protect consumers from possible abuses such as unreasonably high prices. In 1989, Congress completed the process of deregulating the price of natural gas at the wellhead, which was begun in 1978 with the passage of the Natural Gas Policy Act, by passing the Natural Gas Wellhead Decontrol Act (NGWDA).

Today, natural gas is a vital component of the world's supply of energy and currently supplies more than one-half of the energy consumed by residential and commercial customers, and about 41 percent of the energy used by U.S. industry. It is one of the cleanest, safest, and most useful of all energy sources. Natural gas is the cleanest burning fossil fuel, playing an increasing role in helping to attain goals of a cleaner environment, energy security and a more competitive economy.

The two million-mile underground natural gas delivery system has an outstanding safety record. In this 2004 American Public Gas Association (APGA) consolidates that the liquefied natural gas (LNG) is beginning to play a more prominent role in the overall gas supply picture. Although about
one percent of the natural gas consumed in this country is currently imported as LNG, it is estimated that USA imports of LNG will grow to approximately 7 or 8% by the end of this decade. This will require more than the four LNG facilities that currently exist in USA.

III. CRUDE OIL:

Crude Oil is a complex mixture consisting of up to 200 or more different organic compounds, mostly hydrocarbons. The API (American Petroleum Institute) measures the specific gravity of crude oil and compounds. The higher the API number expressed as degrees API, less dense (lighter, thinner) is the crude oil. Crude from different fields and from different formations within a field can be similar in composition or be significantly different, characterized for other non-wanted elements like sulfur which is regulated by environment rules and needs to be removed.

Crude oil varies greatly in appearance depending on its composition. It is usually black or dark brown (although it may be yellowish, reddish, or even greenish). In the reservoir it is usually found in association with natural gas, which being lighter forms a gas cap over the petroleum, and saline water which, being heavier than most forms of crude oil, generally sinks beneath it. Crude oil may also be found in semi-solid form mixed with sand and water, as in the Athabasca oil sands in Canada, where it is usually referred to as crude bitumen.

In Canada, bitumen is considered a sticky, black, tar-like form of crude oil which is so thick and heavy that it must be heated or diluted to easily flow. Venezuela also has large amounts of oil in the Orinoco oil sands, although the hydrocarbons trapped in them are more fluid than in Canada and are usually called extra heavy oil. These oil sands resources are called unconventional oil to distinguish them from oil which can be extracted using traditional oil well methods. An oil well produces predominantly crude oil, with some natural gas dissolved in it. In its strictest sense, petroleum includes only crude oil, but in common usage it includes all liquid, gaseous, and solid hydrocarbons.

Under surface pressure and temperature conditions, lighter hydrocarbons, methane, ethane, propane and butane occur as gases, while pentane and heavier are in the form of liquids or solids. The hydrocarbons in crude oils are mostly alkanes, cycloalkanes and various aromatic hydrocarbons while the other organic compounds contain nitrogen, oxygen and sulfur, and trace amounts of metals such as iron, nickel, copper and vanadium. However, in an underground oil reservoir the proportions of gas, liquid, and solid depend on subsurface conditions and on the phase diagram of the petroleum mixture.

Petroleum is recovered mostly through oil drilling, after tiresome studies of structural geology (at the reservoir scale), sedimentary basin analysis, reservoir characterization (mainly in terms of the porosity and permeability of geologic reservoir structures). Then, it is refined and separated, most easily by distillation, into a large number of consumer products, from gasoline (petrol), kerosene to asphalt and chemical reagents used to make plastics and pharmaceuticals. The proportion of light hydrocarbons in the petroleum mixture varies greatly among different oil fields, ranging from 97 percent by weight in the lighter oils to as little as 50 percent in the heavier oils and bitumens.
API Gravity: The American Petroleum Institute (API) gravity is a measure of how heavy or light a petroleum liquid is compared to water; if its API gravity is greater than 30, it is lighter and floats on water; if less than 10, it is heavier and sinks. Thus, API is used to compare the relative densities of petroleum liquids. Crude oil API gravities typically range from 7 to 52 corresponding from about 750 kg/m³ (46.8 lb/ft³) to 970 kg/m³ (60.5 lb/ft³), but most fall in the 20 to 45 API gravity range. Although the light crude (i.e., 40-45 degree API) is good and lighter crude (i.e., 46 degree API and above) is not necessarily better for a typical refinery.

Crude lighter than 40-45 degrees API contains shorter molecules, or less of the desired compounds, useful as high octane gasoline and diesel fuel that maximize the production of most refineries. On the other side, heavy crude oil less than 25 degrees API contains longer and bigger molecules that are not useful as high octane gasoline and diesel fuel, more difficult for further processing. Heavy crude can be processed in a refinery by cracking that reduces the carbon number to increase the high value fuel yield.

API Classification: Generally speaking, oil with API gravity between 40 and 45 commands the highest prices. Above 45 degrees the molecular chains become shorter and less valuable to refineries. Crude oil is classified as light, medium or heavy, according to its measured API gravity, as shown below:

- **Light crude oil**: API gravity higher than 31.1° API (less than 870 kg/m³);
- **Medium crude oil**: API gravity between 22.3°API and 31.1°API (870 to 920 kg/m³);
- **Heavy crude oil**: API gravity below 22.3° API (920 to 1000 kg/m³);
- **Extra heavy oil**: API gravity below 10.0° API (greater than 1000 kg/m³).

Crude oil with API gravity less than 10° API is referred to as extra heavy oil or bitumen. Bitumen derived from the oil sands deposits in Alberta, Canada, has an API gravity of around 8° API. It can be diluted with lighter hydrocarbons to produce diluted bitumen, with an API gravity of lower than 22.3° API, or further "upgraded" to an API gravity of 31° API to 33°API as synthetic crude.

For example, consider 1 barrel of tar dissolved in 3 barrels of naphtha (lighter fluid) to produce 4 barrels of a 40° API mixture. When this 4 barrel mixture is fed to a distillation column of a refinery, 1 barrel of tar, and 3 barrels of lighter fluid is all that will come out from the still. On the other hand, when 4 barrels of a naturally occurring 40° API South Louisiana sweet crude is fed to the distillation column at a refinery, could come out as 1.4 barrels of gasoline and naphtha, 0.6 barrels of kerosene (jet fuel), 0.7 barrels of diesel fuel, 0.5 barrels of heavy distillate, 0.3 barrels of lubricating stock, and 0.5 barrels of residuum (tar).

This example above illustrates weight percent distributions of three different hypothetical petroleum stocks that could be fed to a refinery with catalytic cracking capacity. The chemical composition is generalized by the carbon number which is the number of carbon atoms in each molecule. The medium blend is desired because it has the composition that will yield the highest output of high octane gasoline and diesel fuel in the cracking refinery. Though the heavy stock and the light stock could be mixed to produce a blend with the same API gravity as the medium stock, the composition of the blend would be far different from the medium stock.
Extra heavy crude are hydrocarbons with an API grade of about 15º or below. The most extreme heavy crude currently extracted is in eastern Venezuela (Orinoco basin), 8º API. In other areas, such as Canada, the reservoir temperature is lower, and steam injection must be used to stimulate flow from the formation. When reaching the surface, the crude must be mixed with a diluent (often LPGs) to allow it to flow in pipelines. Syncrude Canada is one of the world's largest producers of synthetic crude oil from oil sands and the largest single source producer. It is located just in the Athabasca Oil Sands, and has a capacity of 350,000 barrels per day (56,000 m³/d) of oil, equivalent to about 13% of Canada's consumption.

**Tar Sands:** Also referred to as oil sands are a combination of clay, sand, water, and bitumen (heavy black viscous oil). Tar sands can be mined and processed to extract the oil-rich bitumen, which is then refined into oil. Basically two tons of tar sands may produce approximately one barrel of oil. Typical tar sands contain sand grains with a water envelope, covered by a bitumen film that may contain 70% oil. Various fine particles can be suspended in the water and bitumen and can be processed through water extraction. Hot water is added to the sand, and the resulting slurry is piped to the extraction plant where it is agitated and the oil is skimmed from the top.

The bitumen froth floats to the top of separation vessels, further treated to remove residual water and fine solids, transported and processed the same way as for extra-heavy crude. It is estimated that around 80% of tar sands are too far below the surface, for the current open-pit mining technique. Techniques are being developed to extract the oil below the surface, using a massive injection of steam into a deposit to liberate the bitumen underground, and channeling it to extraction points where it would be liquefied before reaching the surface. Tar sands of Alberta, Canada and Venezuela are estimated at 250 billion barrels, equivalent to the total reserves of Saudi Arabia.

In northern Alberta, mostly foreign-owned oil companies are aggressively extracting bitumen from tar sands, which they turn into one of the dirtiest and most destructive forms of energy on the planet. In the process, they are creating serious social, economic and environmental problems in North America and all over the world. Tar sands development infringes on the constitutional rights of aboriginal peoples that have lived in the Northern Alberta, destroying wildlife habitat, polluting air.
and water with toxins and carcinogens, and rendering traditional food sources, such as caribou and fish, extinct or inedible. It also obliterates forests, rivers and wetlands from an area the size of Florida, destroying an internationally recognized ecosystem and reducing the amount of habitat available for a number of sensitive and endangered wildlife species.

**Oil Shales:** Is an organic-rich fine-grained sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons, called shale oil, contain amounts of oil and combustible gas that can be extracted by destructive distillation. One of the largest known locations is the oil shale locked in the Green River Formation, Colorado, Utah, and Wyoming. Oil shale differs from coal where the organic matters in shales have higher atomic Hydrogen to Carbon ratio. Coal has an organic to inorganic matter ratio of more than 4.75 to 5.0 while oil shales have a higher content of sedimentary rock. Sources estimate the world reserves of Oil Shales as more than 2.5 trillion barrels.

Shale oil is a substitute for conventional crude oil; however, extracting is more costly than the production of conventional crude oil, both financially and in terms of its environmental impact. Oil shales were formed when algae and sediment deposit in lakes, lagoons and swamps where ananaerobic (oxygen free) environment, thus allowing to be accumulated in thick layers, with overlying rocks baked under high temperature and pressure. The shale can be strip mined and processed with distillation. Extraction with fracturing and heating is still relatively unproven. Companies are experimenting direct electrical heating and scarcely using steam injection. Extraction cost is currently around 25-30 USD per barrel.

**Oil Barrels:** An oil barrel (abbreviated as bbl) is a unit of volume whose definition has not been universally standardized. In the United States and Canada, an oil barrel is defined as 42 US gallons, which is about 159 liters or 35 imperial gallons. Oil companies typically report their production in terms of volume and use the units of bbl, Mbbl (one thousand barrels), or MMbbl (one million barrels). Since medieval times, the term barrel has various meanings throughout Europe, ranging from about 100 liters to 1000 liters, or more in special cases.

A barrel is one of several units of volume applied in various contexts; there are dry barrels, fluid barrels (such as the UK beer barrel and US beer barrel), oil barrels and so on. Outside the United States and Canada, volumes of oil are usually reported in cubic meters (m³) instead of oil barrels. For example, one ton of heavy distillates might occupy a volume of 256 US gallons (6.1 bbl). In
contrast, one ton of crude oil might occupy 272 gallons (6.5 bbl) and one ton of gasoline will require 333 gallons (7.9 bbl).

Other terms are used when discussing only oil. One common term is *barrels per day* (BPD, BOPD, bpd, bd, or b/d), where 1 BPD is equivalent to 0.0292 gallons per minute or 49.8 tons per year. At an oil refinery, production is sometimes reported as *barrels per calendar day* (bc/d or bcd), which is total production in a year divided by the days in that year. Likewise, *barrels per stream day* (BSD or BPSD) are the quantity of oil product produced by a single refining unit during continuous operation for 24 hours. Lastly, the terms “mbd and mmbd” are sometimes used to denote one thousand or *one million barrels per day*, respectively.

**IV. NATURAL GAS:**

Liquefied Natural Gas (LNG) is a clear natural gas colorless, non-toxic and non-corrosive liquid (predominantly methane, CH4) that has to be converted to liquid form, cooled to -162ºC (-260ºF) to shrink the volume of the gas 600 times, making it easier for storage and transport when pressure is set at around 25 kPa (4 psi). The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream. The gas may contain heavier hydrocarbons such as pentane, hexane, and heptane in the gaseous state.

A gas well produces predominantly natural gas. At ambient conditions the gas condensates to form natural gas, often shortened-term to *condensate*. This *condensate* resembles petrol in appearance and is similar in composition to some volatile light crude oils and because of the underground temperature pressure is higher than at the surface. The exact molecular composition varies widely and the proportions of chemical elements also vary over fairly narrow limits. One of the risks of LNG is a rapid phase transition explosion (RPT), which occurs when cold LNG comes into contact with water.

![Schematic geology of natural gas resource](image-url)