28th March 2011

Opportunities in the Natural Gas, LNG and GTL markets for ANSYS software

Sanitised version

Rob Woolhouse, ANSYS UK Ltd (Sheffield, UK)
robert.woolhouse@ansys.com

This document is aimed at ANSYS/Channel staff who are involved with customer facing activities in the Natural Gas (NG), Liquefied Natural Gas (LNG) and Gas to Liquids (GTL) industries. Each section contains information on part of the supply chain, and comprises technical and market information to aid in the sales/support of the software. Further documents are planned to cover aspects of the oil industry; upstream (drilling, platforms etc) and process equipment are common to both fields so will not be fully covered here; however where significant variations between oil and gas exist these will be included.

It is intended to update the document as information/technology/market trends evolves, and the date (page header) will reflect the last revision. Where possible ANSYS staff with expertise in a specific area have been identified and their contact details listed.

Contents:

Introduction

Oil, natural gas and coal are all hydrocarbon fuels formed from the compression and heating of organic materials over millions of years. Coal is formed from "dry" materials (i.e. onshore), oil from "wet" materials (i.e. offshore) and gas in both scenarios (although predominately found in oil bearing formations). Typically oil and gas are considered to be part of the same industry, and both are obtained (for the most part) by drilling. Figure 1 shows the formation depths and associations of oil and gas formations.

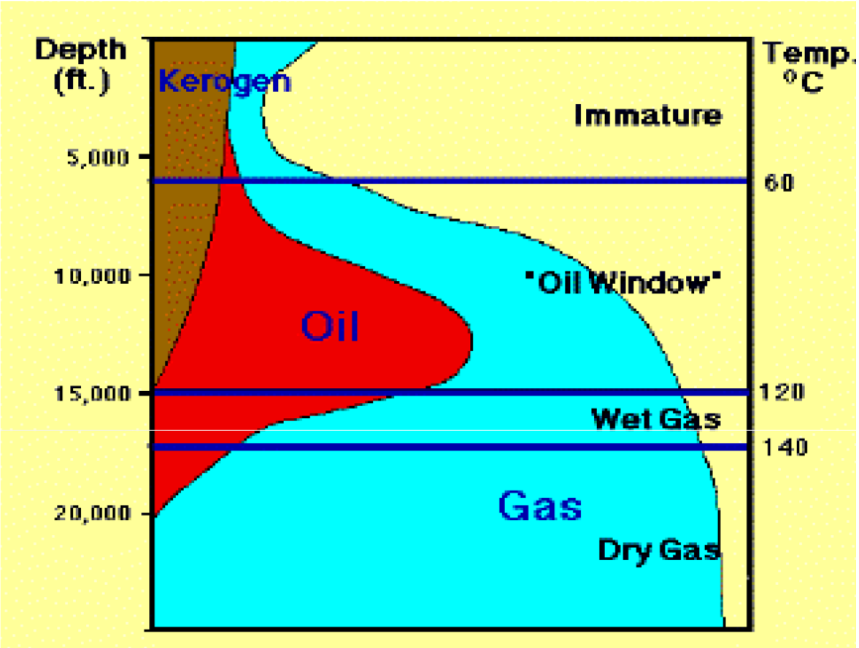


Figure 1: Hydrocarbon formation conditions [19]

Historically oil has been the desired product, often with natural gas being re-injected to maintain reservoir pressure or flared. Hence drilling and separation equipment is common to both materials – i.e. removing oil from gas is a similar process to removing gas from oil. Hence upstream operations (drilling etc) are almost identical for both fuel types.

Net exporters of natural gas include Russia, Australia, Nigeria, Egypt and Australia. However a significant proportion of Russia's gas is exported via pipeline rather than use liquefaction technologies. Figure 2 shows the main regions where gas/LNG is produced and consumed, Figure 3 the production figures and Figure 4 the consumption (thought to be correct at 2006).

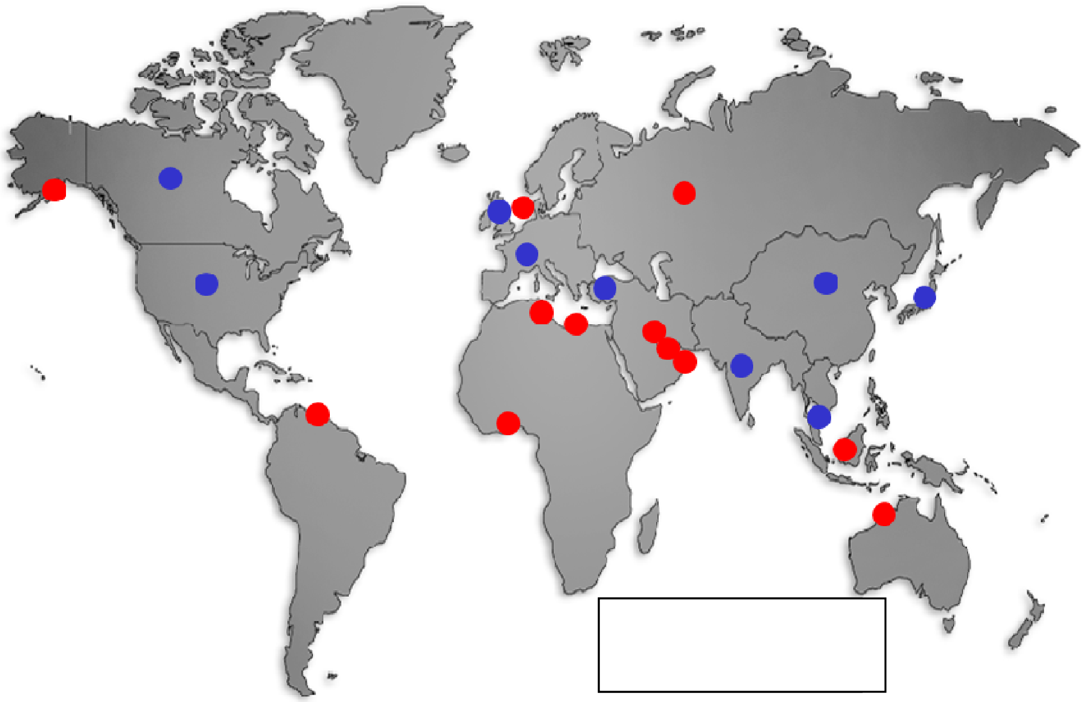


Figure 2: Global supply and consumption of LNG

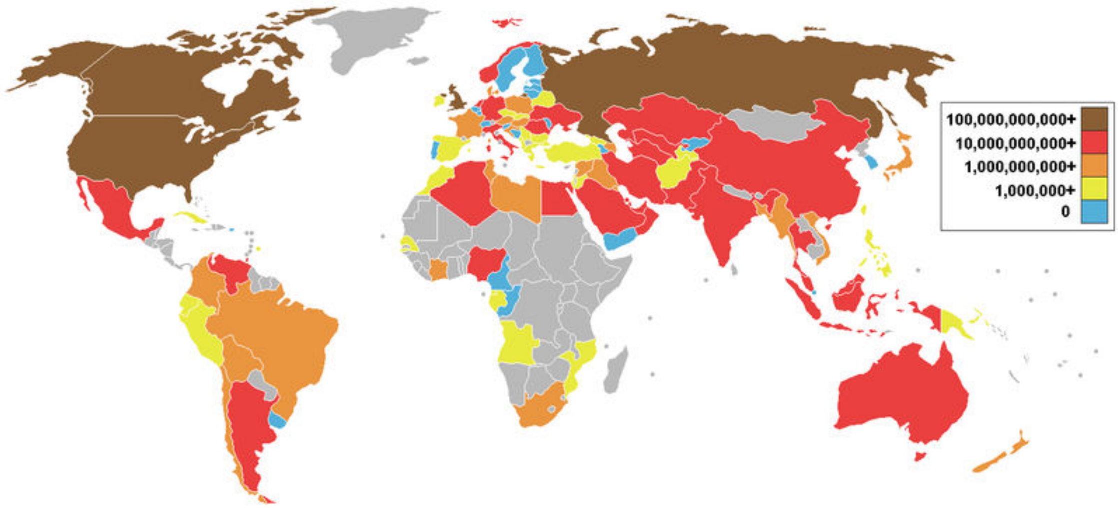


Figure 3: Natural gas production by countries in cubic meters per year (2006 data) [8]

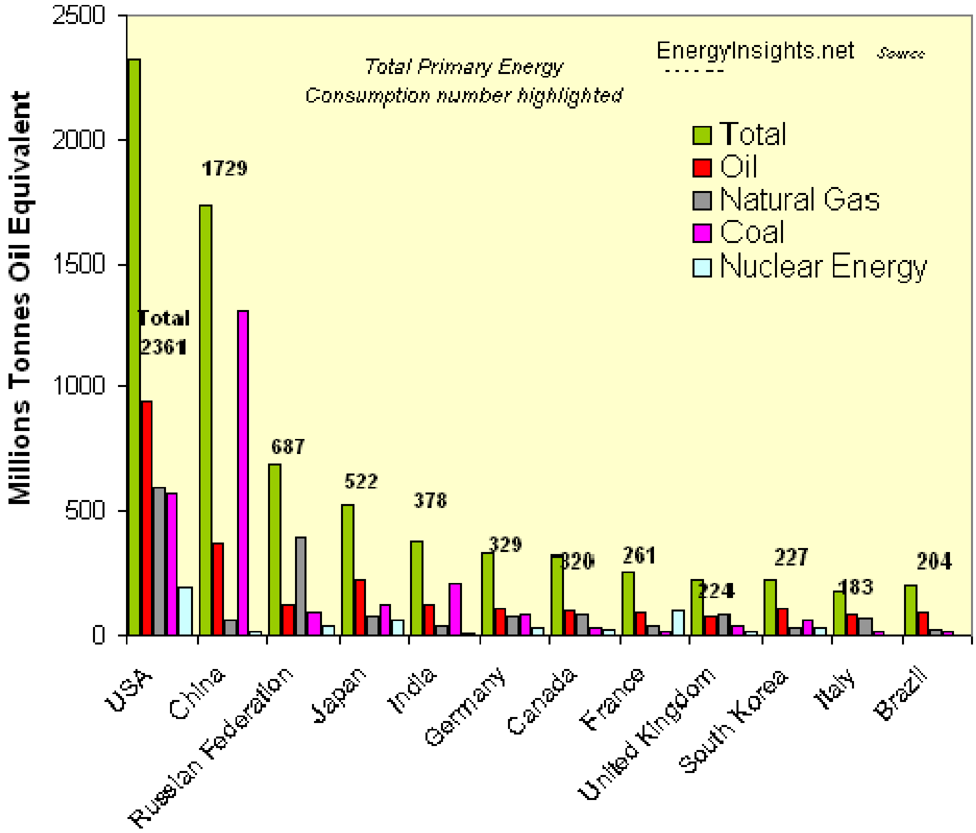
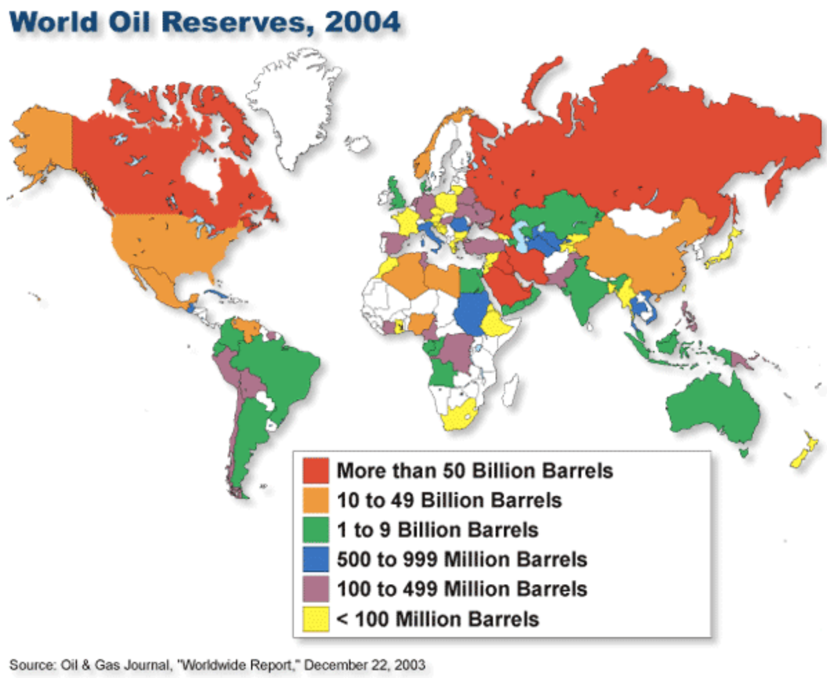


Figure 4: Energy used by fuel type, accounting for 69% of global consumption (2006 data) [20]

Total gas (and oil) reserves are shown in Figure 5. These values are the subject of much political wrangling, corporate accounting and must therefore be viewed with some scepticism. Additionally, recent (significant) finds off Australia's North West shelf and other unexplored regions is expected to have skewed the data.



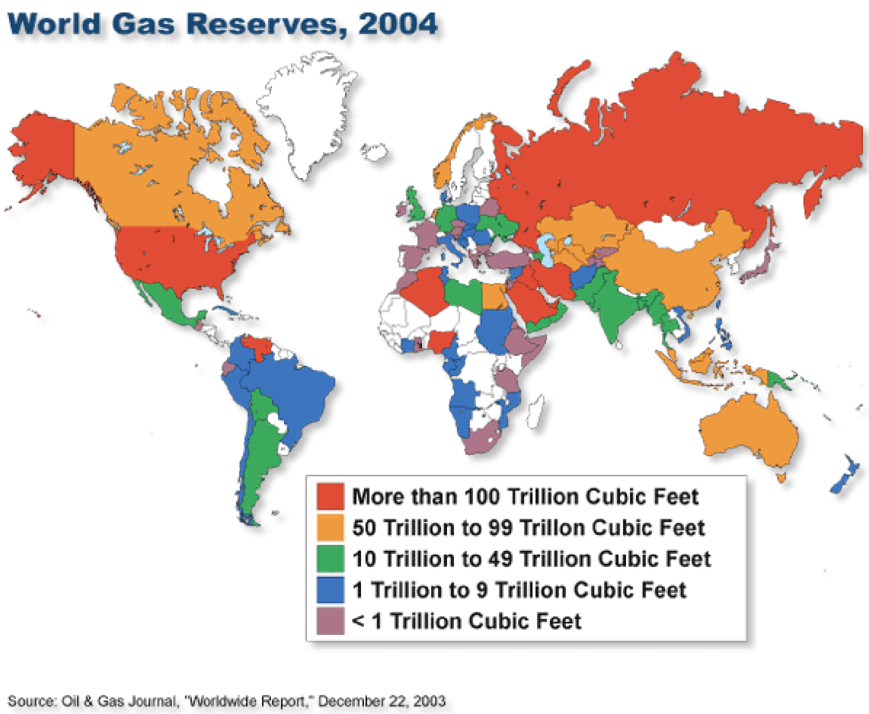


Figure 5: Global Oil and Gas reserves (as of 2004) [21 top and 22 bottom]

The use of natural gas as a fuel or chemicals feedstock is widespread and the market is growing, particularly for electric generation and domestic heating. Unfortunately, the main suppliers of gas are separated from the main consumers by large bodies of water, huge distances and politically unstable territories making pipelines impractical. The main exceptions to this are Alaska supplying the US) and Russia (supplying Western Europe). The alternative is to liquefy the gas and then transport it. Two liquefaction technologies currently exist; LNG (Liquefied Natural Gas) where the gas is cooled to cryogenic temperatures of around -160°C at a maximum of 25kPa gauge and GTL (Gas to Liquids) where the gas is chemically reacted to create longer chain hydrocarbon molecules which exist in liquid form at "normal" temperatures. LNG must then be transported in specially designed vessels, and maintained at -160°C; GTL products can be transported in standard oil tankers, either as a single product or blended with the equivalent crude fraction.
Liquids technology also makes the exploitation of stranded gas more economic as transport requirements are reduced, and is also an environmentally acceptable alternative to flaring.

The global market in LNG has been steadily growing since about 1960 with a rapid increase in demand in the last 10-15 years. The increase in demand has led to an increase in the cost per unit of gas. This has now resulted in an increased capital expenditure for liquefaction, transport, storage and re-gasification processes as new exploration has yielded new gas fields and plant is built to meet the demand. The Energy Information Administration of the US Department of Energy estimates global consumption of natural gas to rise at an annual rate of 2.4% per annum and account for 26% of global energy use by 2030 [23]; much of this rise being attributable to power generation. Current LNG liquefaction capacity is roughly 188 million tons per annum (2006), an increase of 46% since 2002. Additional plants are also in the planning stage as part of the projected increase in gas usage will be met by LNG imports. Additionally the GTL process has begun to be exploited commercially.
Coupled to the increasing capacity in liquefaction, the need for transport, storage and receiver terminals has increased. Here the problems are related to safety issues, cooling load to maintain the low temperatures and the equipment to re-gasify the LNG for supply to the grid.

Douglas-Westwood Ltd [24] predicts that global capital expenditure over the period 2007 to 2011 to exceed $110 billion, almost three times the amount spent in the previous 5 years. Of this, $42 billion is expected to be spent on new liquefaction (and associated) facilities and another $42 billion on roughly 200 new LNG carriers. It is assumed that the remaining $26 billion may be spent on import terminals and re-gasification plants: these were not specifically mentioned, but there are several sites worldwide in the planning stages.

The main purpose of this document is to outline:

1) LNG supply chain (Survey to Regasification facility)
2) Technology and business drivers of the market
3) Successes using ANSYS CAE tools
4) Software requirements to increase revenue from this sector

Rather than break each of the four points out as a section, each will be discussed as part of a section of the supply chain.

Upstream

In this document the upstream section of the gas supply chain includes exploration (find the fields), drilling (and associated platforms/equipment) and any transport/processing required the LNG/GTL sites or the injection into national gas grids.

Keywords

Drilling, methane, frac, fracture, perforation

The survey and drilling phases for gas fields are virtually identical to those for an equivalent oil field, and will be fully covered in a separate document. A brief overview is included here covering where differences are noted.

"Conventional" gas supplies (with oil)

The only difference is that in gas fields no pumps/gas lift equipment is required as the pressure gradient is sufficient to guarantee flow. Where enhanced recovery is required injection of water/CO_2 can be deployed. Although using CO_2 could present problems should the two gases mix.

"Unconventional" gas (tight shale and coal bed methane)

Significant trade press being given to the collection of gas from tight shale and coal seams. Currently two regions are publically producing unconventional gas in commercial quantities, and it is likely that other regions can also benefit from the technology.

In Australia coal bed methane is being used to supply the proposed LNG plant in Gladstone [13] and the work has been positively received.

A tight shale band exists in the US, stretching from (roughly) Michigan to Texas [16]. This zone is thought to contain between 13.5 and 16.2×10^{12} cubic metres; roughly 25 years supply at 2008 rates [26]. In the US (Pennsylvania) the gas is trapped in tight shale formations, and requires a combination of horizontal wells and hydraulic fracture to recover in economic quantities. Given the size of the US, local production of LNG may be appropriate in places rather than a direct hook-up into the gas grid.

Additional sources have been identified under Morecambe Bay (UK), the Paris Basin (France) and parts of Poland. To date little, if any, drilling has been carried out in the UK and Poland. France is marginally further forwards, but have banned further exploration pending the results of a study into the effects of hydro-frac pending the results of a study (expected June 2011) [14].

The hydraulic fracture (hydro frac) process uses high pressure water (plus a small fraction of chemicals) at high pressure to break up sections of the formation. The increased permeability then increases the gas flow rate, potentially returning a well to commercial viability. There are a number of potential environmental problems associated with hydro-frac; these being the causation of earthquakes as the bedrock is fractured, leaching of the hydro-frac chemicals into the aquifer (or leaching of water trapped within the shale into the aquifer) and spills of the hydro-frac fluid from storage lagoons. However, conclusive evidence is not available as yet [3].The forcing of steam through bedrock to generate power may be linked to earthquakes in Switzerland [29].

In the US case, the resource aligns with one of the main North-South gas pipelines on the national grid, as shown in Figure **6**6. To fully exploit this reserve small scale LNG plant may be required to supply the mid-west and other isolated regions. More importantly if fully exploited the tight shale gas could displace LNG imports further altering the global market [47].

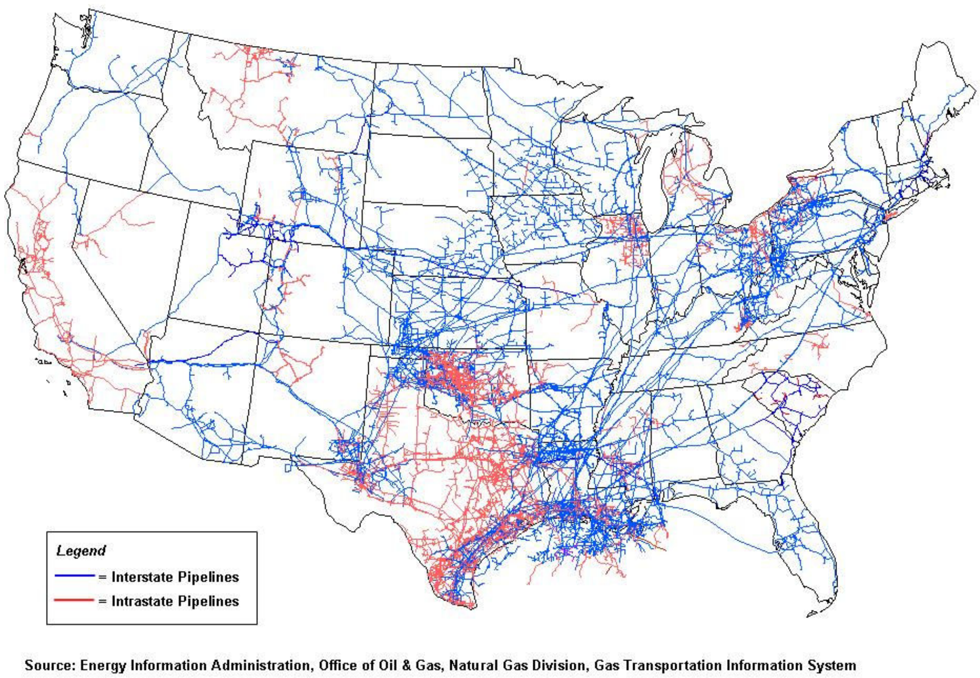


Figure 6**: Map showing the US National gas pipeline [28]**

Technical needs and opportunities

ANSYS CFD software has been used to show the flow within the reservoir, and subsequently into the well under various conditions. Using multiphase modelling the likelihood of slug formation can be predicted (but transition not modelled as yet) and the areas in which liquids can pool. Drilling operations either employ staff to do this, or regional specialists:

- senergy Ltd (UK, but also operations worldwide. ANSYS users). Paper written showing use of ANSYS FLUENT for reservoir modelling; [30]
- Halliburton have a reservoir modelling tool, [31]

Technical needs for gas recovery modelling

- Porous media model
- Method to account for turbulent boundary condition on reservoir interior surface with the well rather than outer pressure boundary
- High aspect ratio meshing and geometry (tolerance issues)
- Ability to read porous coefficients from geological packages (e.g. Gohfer) and/or Excel
- Richards equation for single phase flow (single scalar rather than full CFD; ability to link back to full CFD in the near well position)

Drilling

Similarly several companies have used CFD on drill bits to look at fluid caused erosion. Structural can be used to measure stresses/fatigue on teeth and the cutting edges. Using Workbench the fluid induced stresses can also be transferred.

Drilling equipment

- stl import into DM
- Ability to mesh complex geometry
- mrf models for drill
- Non-Newtonian fluid flow
- 1-way FSI
- Moving mesh to allow erosion of metal due to particulate and hole friction (might need full FSI?)
- Shear stress/distortion calculations to ensure tools fit for purpose
- Friction wear and vibration data to ensure teeth remain attached (newer tools tend to have diamond teeth, the loss of one of these into the well can be catastrophic)

Fracture

- Full FSI into porous material where fluid pressure and rock matrix can be included

Perforation

- Explicit modelling of the shaped charge detonation and impact on formation
- Most likely of use to charge designers to reduce testing on different rock types

Marketing materials

Webinar presented on Flow assurance (24/9/09) and Drilling and Reservoir Flow (17/11/09) Both added to EKM and session recording on web.

Senergy paper [30]. Posters also available on EKM, see permissions attached to this file.

28th March 2011

Liquefaction process (LNG production)

Keywords:
Liquefaction, air cooler, train, heat exchanger, FLNG, LNG

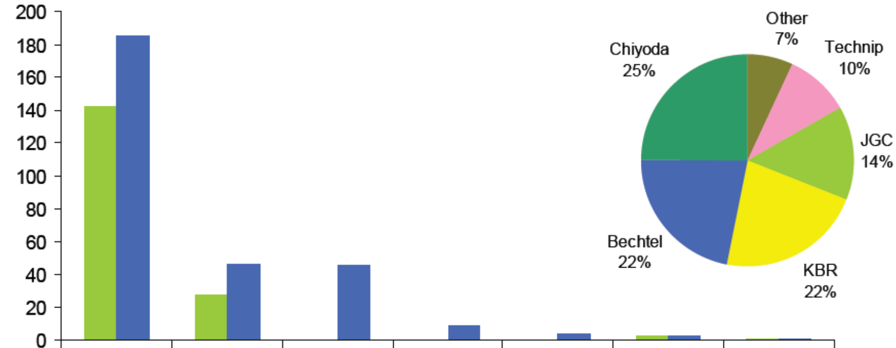
Background

In economic terms the liquefaction process accounts for between 30% and 40% of the total costs, from well to gas user. Roughly 8-9% of all gas leaving the well is used (or lost) prior to the tanker leaving the pier of the LNG liquefaction plant.

The LNG plants currently being planned and built tend to be air cooled as opposed to older plant which tended to use water. Ambient temperature air/water is used to supply the cooling to the liquefaction process and associated equipment. Historically water was the preferred cooling media as the heat transfer is better, and hence heat exchanger costs are lower. However pre/post treatment is an issue with water, and reliability can suffer where bio films and corrosion occur. Additionally many LNG sites are in regions where fresh water is scarce. Air coolers require larger heat exchangers due to lower heat transfer coefficients (so are marginally less efficient), but do not require any pre/post treatment of the air. As a result of the cooling load on air cooled LNG plant, warm air is exhausted from both chimneys and process units at a rate of the order of 5,000 MW for a 15mtpa site operating in a warm environment (includes waste heat from process equipment, air coolers and turbines), i.e. the equivalent of a large UK power station.

Plant efficiency has been progressed to the point where it demands a tight tolerance on supply air temperature. Exceeding this tolerance is detrimental for efficient plant operation. Currently the preliminary heat exchanger sizing and plant layout uses a combination of experience and rule of thumb to determine the allowance (how much hot air can be tolerated, typically 2°C). Insufficient allowance would mean that the plant could not operate at full capacity resulting in a lower than planned production of LNG and, in extreme situations, interrupted production. Increasing the intake temperature allowance means that the reduced performance is negated, but this adds considerably to the initial capital cost. The layout may also be influenced more by the desire to minimise cryogenic pipelines than to reduce warm air re-entrainment into the cooler intakes.

Figure 77 shows the global break-down of the branded technology used to liquefy the gas, with the mixed refrigerant process accounting for over 80% of the world capacity [25].



	Air Products	Cascade	Undecided	SDMR	Linde	PRICO	Tealarc
2005	142.5	27.7	0	0	0	2	0.9
2010	185.5	46.2	45.5	8.6	4.1	2	0.9

Figure 7: Gas Liquefaction Technology, in mtpa [25]

A new development in the area is the use of Floating Liquefaction plants, FLNG. These are proposed for use in the stranded fields of the Australian NW Shelf, more specifically for the Greater Sunrise and Prelude fields (subject to East Timor government approval). A number of hulls have been ordered; Shell having ordered from Samsung Heavy Industries (South Korea), with design topsides by Total. An artist's impression of the FLNG vessel and a carrier can be seen in Figure 8.

Figure 8: Artist impression of the Shell FLNG [18]

Areas where modelling can be employed

Air cooler and gas turbine intake temperatures are known to be affected by the wind speed and direction which in turn influence the motion of warm air exhaust plumes across the plant. During layout design little information on the flow field local to the intakes is available. This can be supplied by using either CFD or wind tunnel testing. CFD is superior to wind tunnel testing because the buoyancy effects of the warm air plumes are included, and the models required for experimental testing are large and expensive. Another experimental technology, the salt bath, is typically unsuitable for large models. Data gathering is also far easier in CFD, with data available at every grid point rather than from preset sensors.

As well as plume re-entrainment studies, most sites require pier loading facilities to the tankers; additionally FLNG requires mooring, offloading and general stability calculations for deep water locations. These should benefit from the ASAS/AQWA suite of tools.

On-site storage tanks are covered later in the document as these are similar to those used at the receiver regasification sites facilities.
Similarly process equipment is used through the supply chain, and therefore is discussed elsewhere.

Commercial

To date plume motion on six separate sites on three continents has been modelled using the existing capabilities within GAMBIT, TGrid and FLUENT. Roughly 3-4 serial plus 20-40 parallel seats are required for each project. Mesh sizes range from 3M up to 25M cells. Given the drive to larger sites and decreased gas quality, which will require further pre-processing and therefore additional process units leading higher capex and operating costs, these sites are likely to become larger and require greater mesh counts.

Market analysis has shown that the LNG plants themselves are owned/operated by local companies, often with a major oil company acting as technical advisor and holding a share of the operation. Several of the projects have also been passed between contractor (design and build) companies, either at a local or international level. It is therefore vital that worldwide pricing and technical approach is co-ordinated within ANSYS.

Given the nature and size of these sites, companies normally considered as competitors are often found in close collaboration within Joint Venture shell companies. As a result extreme care must be taken when discussing projects and no data can be re-shown without explicit permission; this includes within the company that commissioned the work!

In extreme conditions it is possible that two teams within one company could be working on different (competing) bids for the same work. Staff nationality is also an issue on some projects.

The main players then sub-contract work to specialist suppliers for site components, these are known to include:

- GEA-BTT (fans & motors). ANSYS CFX users, article published, [48]

Additional equipment is sourced from local manufacturers, or shipped in as pre-installed modules from elsewhere.

Business drivers

Ultimately the driver for the site operators is to minimise the energy usage on site, as this leads to greater amounts of LNG product for less gas burnt. As a result reducing warm air re-entrainment by small amounts can lead to a massive cost saving over a year.

Typically a modern land based LNG train has a capacity of 4-5 million tons per annum (mpta) throughput.
Capital expenditure (capex) for an LNG plant were in the range $400 (2004 price) to $1000 (2008 price) [4] no primary source available)but newer data suggests a cost ranging from $1,300 to £1,500 [34] per ton of production depending on location and the fluctuating price of steel. It is unknown whether these costs include pipeline infrastructure, but it is likely to include the jetty/breakwater structures.
Various long term deals have been struck over the last few years, with LNG price per ton varying from $460 to $1,000 (internet, unknown initial source).
Anecdotal evidence suggests that reducing the height of the trains by approximately 1m can save in excess of $1M in construction and materials costs. However, reducing the height too far can lead to excessive warm air recirculation and fan pressure load – both of which lead to increased operating cost.
Using these figures the output from a typical train 5mtpa is valued at between $2,300m and $5000m per annum, so an efficiency saving of just 0.1% adds $5M to the profit, easily justifying a CAE study, especially where most sites plan on 1-3 trains at the early design stage and can subsequently expand to 5-6 trains.

Comparatively speaking the FLNG capex is relatively cheap at £450 to $1,000 per ton [34] - source suggests cost is per mtpa, which is highly unlikely), but with an unknown operating cost. The saving is likely due to removing the need for pipeline and fixed facilities, but the capacity is likely to be limited to 1-2mtpa. An additional advantage of FLNG is that the hull can be redeployed to a new gas field once the original find has been depleted.

28th March 2011

Technical needs

A robust and well defined approach has been developed using the GAMBIT/tfilter/TGrid combination for geometry build and meshing. CAD is available for these sites, but tends to be PDMS based and is excessively complex. No additional features are needed, but additions to these tools are likely to further improve this methodology (e.g. size functions in TGrid 5.x).

For the CFD section of the work the following are required:

- Turbulence models (RNG k-ε with buoyancy terms currently used)
- Porous media (porosity and object size required. Further work may be needed to validate porosity values)
- Thermal models (warm buoyant plumes, no heat transfer equipment included)
- User profiles on velocity inlets (UDF currently used for wind profile)
- Custom post-processing (report intake temperatures above ambient value)

Again a methodology, including code for journaling the model set-up has been developed for ANSYS FLUENT.

The ANSYS FLUENT methodology is available on the ANSYS Sales Portal and EKM. This document is being updated as new technology and techniques are developed.

Authors note, the use of DM/AMP has been explored on a simple LNG train and may be suitable. As of Q3 2010, work is ongoing to validate and streamline the approach.

Marketing material available

A demonstration model has been created in ANSYS FLUENT. An article and PowerPoint have been written using this example for external submission (Rob Woolhouse, ANSYS UK Ltd). These can be found on the ANSYS Sales Portal and EKM server.

Technical expertise

Rob Woolhouse and Jasper Kidger, ANSYS UK Ltd (Sheffield, UK)

Gas to Liquids (GTL) process

Process involves catalytic reaction of methane to form long chain hydrocarbons and hydrogen. Liquid has similar properties to diesel, but significantly lower sulphur content. The process can be scaled to suit the gas source, and may be a prime technology to reduce the global flaring of waste gas as the resultant liquid can be blended with the liquid products.

Two main processes are used in the GTL route [5]. These are the Fischer-Tropsch process and the Mobil process, developed in the early 1970s. In both techniques the methane is partially reacted with oxygen to form a syngas, along with CO_2 and water. The syngas is then reacted over a catalyst to form longer chain hydrocarbons. The Mobil process claims over 80% of C_5 or greater products.

Improvements to theses two main processes via new catalysts are likely, with many smaller companies/research groups involved in addition to the larger oil majors. Research in this area will also benefit from investment in syngas production from underground coal combustion (UCC) and waste pyrolysis.

GTL Transport

As the GTL product has a range of properties, and is essentially a liquid hydrocarbon it is transported in the same way as the equivalent crude products – i.e. in tankers.

Market information

Commercial site in Qatar [35], known as the Pearl GTL Plant (140,000 barrels per day output). The plant is based on the technology used at Bintulu GTL plant (Malaysia, 14,700 barrels per day output).

Gas2 (http://www.gas-2.com), based in Aberdeen (UK) are currently developing a reactor/catalyst combination to improve efficiency of the syngas production.

Technical needs

Process level

- Multispecies chemical reactions on:
  - Volume
  - Surface
  - Porous media
- Phase change during reaction:
  - Gas to liquid

At the site scale a similar approach can be used to that for LNG.

LNG transport

Background

LNG is transported in bulk from the liquefaction plant to the receiver terminal on specially designed ships. Transportation of LNG requires slightly pressurised containers with cooling systems to maintain the gas in a liquid state at -160°C. Load capacities are currently of the order 200,000 m^3 and this is likely rise.

Not only must the gas be maintained in the liquid state but the containers must be protected from both accidental (collisions) and malicious (e.g. terror attacks) damage. As a result of this requirement (and like for most oil tankers following the Exxon Valdez spill) most LNG tankers are double hulled.

Specialised vessels are used, with two main designs currently dominating the market. These are the spherical Moss Tanks and the prismatic membrane system.

Moss Type LNG carrier [36]

Prismatic LNG carrier "British Trader" [38]

Figure 9: LNG carrier types

The two types both have advantages, the Moss design being more stable in rough conditions, whereas the Prismatic design better utilises the space within the hull. Because of the relatively low density of LNG and its containment system LNG carriers tend to "ride high" when compared to vessels of an equivalent size [39]. It is estimated that between 0.1% and 0.25% of the cargo boils off each day during transit [6]; in early vessels this boil off was used to fuel the engines, but newer designs incorporate a small liquefaction plant and use high efficiency diesel engines for propulsion.

The filling process includes 4 main stages [37]:

- Chilling the cargo fill lines (key side)
- Pumping nitrogen into the system to inert the system
- Chilling the vessel loading arms (done from key side when loading, and ship side when unloading)
- Filling of the cargo tanks. The filling rate is governed by international rules, specifically the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (1/7/1986) and the International Convention on the Safety of Life at Sea (1983 and replaced/amended the 1974 SOLAS Convention).

The areas which are likely to benefit from the use of ANSYS software include:

- Vessel filling (discussed in more depth under storage). CFD and Mechanical
- Cooling load under transport conditions. CFD and possibly Mechanical for thermal stresses
- Effect (and forces on equipment) of sloshing under bad weather. CFD and Mechanical. This is an area where we can expect additional work as vessels partially offload at offshore terminals [40]
- Effect of containment breach, and resultant fire. CFD and possibly explicit dynamics (ANSYS AUTODYN or LS-Dyna)

Both the containment system and hulls are proven technology. Therefore the application of software to the actual design stage may be limited.
However the piers and loading systems may need to be improved for newer receiver systems.

Technical needs

Coupling between CFD and explicit dynamics would likely be required for any explosion and fire analysis.

The existing coupling between CFX or FLUENT and ANSYS Mechanical could be used for vessel filling or sloshing analysis. Full 2-way FSI is unlikely to be required for this application.

ASAS/AQWA for stability and hull design. May be become more important as FLNG becomes more common and cargo transfer occurs without the benefit of large breakwaters.

Marketing material available

FLUENT case move of LNG leak from a tanker, and vapour cloud fire – AN 339 (HAL), also found in [45] and [46]

Technical expertise

Good knowledge of the CFD code, including multiphase for tank sloshing. Large transient data sets will be required.

Expertise required with Mechanical and coupling technology in addition to CFD if combined study to be carried out. It may be possible to simply report forces resulting from the CFD and use these in standard design rules rather than use a fully coupled computational solution.

28th March 2011

LNG Import terminals and storage

Stephen McCormick, ANSYS UK Ltd (Sheffield, UK)

Keywords:
Stratification, rollover, top-fill, bottom-fill, cryogenic, stress, seismic, cylindrical, cooldown, boil-off, density

Background

Multiple terminal/ receiver sites are either in planning or design stages. Many are planned for offshore locations in the US on environmental, safety or NIMBY grounds.

LNG is typically stored in cylindrical tanks designed to contain large volumes (of the order 100,000m^3) at low temperature (around -160°C) at little more than atmospheric pressure. They use a two-skin design with insulation between the skins to minimise the heat leak. The skin in contact with the liquid is made from cryogenic (9% Nickel) steel – an increasingly expensive commodity due to global prices of Nickel and steel. The base makes use of a structural insulation (e.g. aerated concrete). The ceiling may be rigid or floating with a pressurised inert (Nitrogen) gas-space filling a domed roof. Natural gas is allowed to boil off at some design criteria and will be re-liquefied or flared to atmosphere.

There has been recent interest in alternative designs to the conventional tank. One study looked at a more radical rectangular section tank which allows a rapid installation and commissioning time thanks to prefabricated modular sections. Another design is looking at using cryogenic concrete to reduce the amount of cryogenic steel required for a cylindrical tank. CFD has been used to investigate the thermal cooldown characteristics of a tank during commissioning; the tank is cooled down by spraying LNG into the warm, empty tank to bring down the temperature at a controlled rate, while avoiding high thermal stress. The thermal characteristics of a filled tank must also be considered with a view to understanding the temperature variation which may give rise to thermal stresses. Clearly this is a good application for partnering CFD and structural analysis approaches. As well as investigating stress characteristics due to thermal effects, seismic events must also be considered during cooldown and operational periods.

A critical problem for all LNG storage tanks is the formation of stratified layers in their contents, typically as a result of different grades (and therefore densities) of LNG being added to a tank and not mixing homogeneously. In a stratified tank, liquid circulates in two or more *cells* of different density, with very little interfacial mixing between the cells. There is a danger a dense stratified cell may heat up quicker than a lighter cell above it, until it becomes lighter than the upper contents. This will force it to rise up quickly causing a massive boil-off of superheated LNG (an event known as *rollover*), potentially causing structural damage. The safety aspects of this are covered later in this document. Typically light LNG is added to the bottom and heavy LNG to the top during filling, and in-tank recirculation (draw-off from bottom, returned to top) during storage. However, the design of this is based on experience more-so than detailed understanding of the process and/ or physics. Further information can be found in [9]

Technical needs

Thermal studies require the common capabilities of a rounded CFD software: transient solution, conjugate heat transfer, temperature dependent properties, radiation (surface to surface, possibly participating media), lagrangian particle tracking (with evaporation), multiple species (for gas purge), turbulence models.

Stratification studies require multiple species, heat transfer, turbulence models. Filling studies potentially involve a characterisation of the top-fill process, requiring a VOF or Eulerian multiphase model.

Modelling rollover has not been conducted internally. As well as the requirements of stratification studies, this will require some definition of the phase change mechanism.

Stress analysis will require specialist knowledge of modelling seismic events with superposition of thermal effects. Data exchange between a CFD and structural tool is required, though only on an intermittent (as opposed to live, coupled) basis.

Floating receiver systems may benefit from ASAS/AQWA depending on capability.

Marketing material available

No material presently available.

Technical expertise

Stephen McCormick, ANYS UK Ltd (Sheffield, UK)

Regasification

Background

Once the LNG has arrived at its destination it must be re-gasified before use. Simply, heat is added to the LNG and the pressure decreased to convert the liquid back into a gas. The gas then passes into a short term storage system before being used or piped into the local distribution network. At this stage nitrogen or re-gasified LPG may be added to the natural gas to meet the local calorific requirements.

The heat can be supplied in one of two ways. The preferred approach is to use low temperature water from a process cycle which would usually be wasted (one area of concern is for fish protection on water intake structures). As little temperature (but potentially large amounts of energy) is required this can further increase a cycle efficiency. Alternatively a small amount of LNG can be burnt to then supply the heat; this reduces profits by wasting the valuable cargo.

Commercial

One project carried out in the UK. These looked at the icing of the heat exchanger under low flow conditions and the flow maldistribution in the event of pumping failure.

Given the bulk of the heat transfer equipment can be designed from standard rules the use of CFD may be limited in this area.
Mechanical could be used to calculate the stresses found on these systems, specifically at start-up where cold shock is a potential problem.

A commercial project was done under a subcontract to Cook Legacy Coating Company in the U.S. to calculate the Region of Influence (ROI) in order to determine the region from which fish larvae would be entrained in the intake structure. In this system "warm" seawater is used to evaporate the LNG, and is returned slightly chilled.

Technical needs

Two approaches may be needed for CFD models:

- Flow of heating material (water or combustion products)
    - Turbulence models
    - Heat transfer
    - Reactions/combustion
    - Porous media (heat exchanger bundle and seawater intake cover)

- Evaporation of LNG
  - Heat transfer
  - Multiphase with phase change (boiling/vaporisation)
  - Turbulence

As little work has been forthcoming in this application area little time has been spent devising a strategy.

Marketing material available

http://www.fluent.com/solutions/examples/x256.htm

Technical expertise

Standard CFD expertise in process equipment, multiphase and combustion may be required.

Karl Kuehlert for intake structures, ANSYS Inc (New Hampshire, US)

Process Equipment

Written 26/8/2010

Process equipment used on LNG and NG sites is well known to the industry. However some simulation work may be needed where temperatures (e.g. cryogenic systems) or sizes (e.g. high duty) exceed the range of the normal design rules.

Slug catchers

Large vessel or pipe network designed to protect downstream equipment from fast moving “lump” (slugs) of liquids emerging from oil or gas pipelines. The three main designs are large spherical vessel, single pipe ('parking loops') and multi-pipe (or finger-type) (e.g. the 'Hannibal' slug catcher [42] shown in Figure 1012).

Figure 10:Multi-pipe slugcatcher at the BG Hannibal Terminal showing the inlet pipe and header, and the short separation fingers above the much longer liquid fingers.

Flares

These are commonly added to LNG sites to handle excess gas under extreme operating conditions (e.g. surge). Typically two main types of flare are used, ground flares and towers. The former are designed to cope with an entire trains worth of natural gas, whereas the later are for more "reasonable" operating excursions.
Two scales of CFD model have been used for this application.
Smaller models looking at combustion processes for a tower flare or single section of ground flare. These assess the effectiveness of the burner design, and highlight local problems associated with the combustion process

Larger scale models have been used to assess the position of the ground flare thermal plume over the main LNG site. Energy output of a ground flare is significantly greater than for a LNG train under normal operating conditions, and plant efficiency is not a concern. However, the scale of the plume is of concern for airport flight paths, and a project of this type has been supported at M.W. Kellogg Ltd (UK) concerning Barrow Island (Gorgon) LNG project.

Technical need

Slug catchers

- Multiphase
- FSI
- Turbulence

Flares

- Combustion models
- Radiation
- Turbulence
- One way FSI (thermal load on structures)
- Acoustics (legislative limits set)

Marketing Material

Webinar presented on Flow assurance (24/9/09) added to EKM and session recording on web.
Hannibal slug catcher, see Sales Portal for information.

28th March 2011

Fire and safety

Gilles Eggenspieler, ANSYS Inc (Berkeley, US)
Yehuda Sinai, formerly ANSYS UK Ltd (Milton Park, UK). New contact: Mark Owens
Dave Schowalter, formerly ANSYS Inc (New Hampshire, US)

Background

Safety covers many topics, with fire and explosion being just two out of those many which are specifically relevant to LNG safety. It is usually necessary for companies planning to build receiving terminals to prove environmental safety, both for shipping channels to the terminal and for the terminal regions themselves. Examples include sloshing in the LNG tanks (roll over and rapid evolution of gas from the liquid state), gas/liquid leakage and mooring dynamics (the latter is related to the AQWA activities in ANSYS).

The risks associated with natural gas (in the gaseous state) are well known and understood. The flammable limits are between roughly 5 and 15% by volume in mixture with air. They can involve Vapour Cloud Explosions (VCE, although this is generally the case only for enclosed or semi-enclosed spaces, addressed by AutoReaGas), fires, and general escalation. The physics of releases of LNG, a cryogenic substance, is more complex, and involves heat transfer and phase change even if no fire exists. The LNG industry has to address cases of LNG releases on land and on water. Such releases lead to evaporation of dispersion of the hydrocarbons, possible ignition, and possible VCE and fire. Rapid Phase Transition (RPT) is a non-combusting phenomenon created by the rapid evaporation of the LNG and which can produce shock waves and accelerated mixing of the liquid and the atmosphere. It may be necessary to show how a release (and subsequent fire) would impact local property and populations under various wind conditions.

Commercial

A few examples are given below, from the many projects done in the safety sphere.

- Pool fires
- Gas/plume motion and dispersion
- Dispersion and explosive cloud size (before detection) within confined spaces, e.g. turbine enclosures

It should be noted that the ANSYS fire activities, both in terms of sales and consultancy, have been affected by the free CFD package from NIST known as FDS.

Technical needs

For fire simulations, user functions are required for mass transfer from the liquid to gas phases and for LNG spread over water. The current fire and radiation models contained within CFX and FLUENT are suitable for modelling the actual combustion process. The marketing example (FLUENT – breach of tanker hull) used a scaled geometry to control the time step that was required. Some R&D should be anticipated in any proposal made in this area.

Cold natural gas (NG) cloud dispersion has been studied extensively and specific codes and numerical models have been developed to predict NG dispersion (anisotropic turbulent dispersion, additional terms in the k-ε turbulence model). One of these models was implemented in FLUENT via a UDF (DOE-NETL project). Examples of NG cloud dispersion are available. However, they cannot be used as marketing material without DOE approval. Additionally, a water evaporation/condensation model was incorporated in the above-mentioned UDF. This accurate water evaporation and condensation model is critical to accurately predict NG cloud dispersion in a high humidity environment (for example, NG dispersion around a LNG tanker). Including phase change modelling (from LNG liquid pouring out of the tank to heavy NG gas), anisotropic NG dispersion and water (air humidity) phase change can be challenging and was not tested.

Marketing material available

A marketing example was generated showing the liquid being expelled from a hole in a ship hull, phase change, and ensuing combustion. A movie and explanatory powerpoint slides can be found on the sales portal, [43 and 44]

Other more general material available on Sales Portal and HAL.

Technical expertise

Amarvir Chilka, ANSYS Inc (New Hampshire, US)
Mehrad Shanam, Kartik Mahalatkar and Gilles Eggenspieler, ANSYS Inc (West Virginia, US). NG cloud dispersion
Greg Fairlie, Century Dynamics Ltd (Horsham, UK). VCE, AutoReGas, AUTODYN.

References/Further reading

1. http://en.wikipedia.org/wiki/Oil_drilling
2. http://en.wikipedia.org/wiki/File:Natural_gas_production_world.PNG
3. http://en.wikipedia.org/wiki/Hydraulic_fracturing
4. http://en.wikipedia.org/wiki/Liquefied_natural_gas#Cost_of_LNG_plants
5. http://en.wikipedia.org/wiki/Gas_to_liquids 26/8/2010)
6. http://en.wikipedia.org/wiki/LNG_carrier
7. http://wapedia.mobi/en/Liquefied_natural_gas?t=8
8. http://www.iomosaic.com/iomosaic/products/whitepapers/whitepapers.html
9. http://www.iomosaic.com/iomosaic/products/whitepapers/whitepapers.html
10. http://www.chemsystems.com/about/cs/news/items/PERP%200708S10_Floating%20LNG.cfm
11. SPE 122361; Understanding the Near-wellbore Phenomena for Hydraulically Fractured wells: A Comprehensive Inflow Performance Numerical Model; Maria-Alejandra Jimenez, SPE and Juan Carlos Chavez, SPE, Senergy (GB) Ltd; Copyright 2009, Society of Petroleum Engineers; This paper was prepared for presentation at the 2009 SPE European Formation Damage Conference held in Scheveningen, The Netherlands, 27–29 May 2009.
12. http://www.glng.com.au/
13. http://www.glng.com.au/
14. http://www.ogj.com/index/article-display/4753617168/articles/oil-gas-journal/drilling-production-2/20100/march-2011/french-pm_extends.html
15. http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf
16. http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf
17. http://www.upstreamonline.com/live/article211948.ece 9/8/2010
18. http://www.upstreamonline.com/live/article211948.ece 9/8/2010
19. NOF Workshop, An Introduction to the Oil & Gas Industry, 1/9/10, uploaded to EKM
20. http://www.energyinsights.net/cgi-script/csArticles/uploads/134/Primary%20Energy%20Consumption%20-%20per%20country%20in%202007%20-%20nuclear,%20coal,%20natural%20gas,%20oil%20and%20total.gif
21. http://www.rrc.state.tx.us/commissioners/williams/energy/images/2919953WORLDOILRESERVES.gif
22. http://www.rrc.state.tx.us/commissioners/williams/energy/images/2919957WORLDGASRESERVES.gif
23. http://www.offshore-mag.com/index/article-tools-template/_printArticle/articles/offshore/volume-67/issue-12/transportation-amp-logistics/lng-capacity-to-grow-through-2011.html
24. http://www.dw-1.com/files/files/Robertson%20LNG.pdf 7/9/10 (filed 8/12/06)
25. http://www.dw-1.com/files/files/Robertson%20LNG.pdf 7/9/10 (filed 8/12/06)
26. http://www.eia.gov/dnav/ng/hist/n9140us2a.htm
27. http://www.eia.gov/dnav/ng/hist/n9140us2a.htm
28. http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/ngpipelines_map.html 20/8/2010

29. http://www.swisster.ch/news/science-tech/boss-trial-causing-earthquakes-basel.html
30. http://www.onepetro.org/mslib/app/Preview.do?paperNumber=SPE-122361-MS&societyCode=SPE
31. http://www.halliburton.com/ps/default.aspx?pageid=848&navid=934&prodid=PRN::IQTT7GB9O_SRC=FD_Nexus
32. Tania Simonetti, Dominique Gadelle, Rajeev Nanda "USING CFD AND DYNAMIC SIMULATION TOOLS FOR THE DESIGN AND OPTIMIZATION OF LNG PLANTS", World Gas Conference, 2009? – links disabled
33. http://www.ogj.com/index/article-display/9890159905/articles/oil-gas-journal/transportation-2/lng/2010/09/doe-approves_lng_export.html
34. http://www.energy-profile.com/files/LNG.pdf
35. http://www.chemicals-technology.com/projects/pearl-gtl/
36. http://liquefiedgascarrier.com/LNG-carrier.jpg
37. http://liquefiedgascarrier.com/loading-LNG.html
38. http://www.offshore-technology.com/projects/harding/images/3-lng-carrier.jpg
39. http://www.globalsecurity.org/military/systems/ship/tanker-lng.htm
40. http://www.ingenia.org.uk/ingenia/articles.aspx?Index=619
41. http://www.hamworthy-combustion.com/resources/res.aspx/Product/pdfFilename/20/AMOxsafe%20Datasheet.pdf
42. http://www.ansys.com/assets/testimonials/hannibal-slug-catcher.pdf
43. http://www1.ansys.com/teamansys/fileHitting.asp?id=10075
44. http://www1.ansys.com/teamansys/fileHitting.asp?id=10322
45. http://www1.ansys.com/teamansys/fileHitting.asp?id=10075
46. http://www1.ansys.com/teamansys/fileHitting.asp?id=10322
47. http://www.downstreamtoday.com/news/article.aspx?a_id=24805 29/3/2011
48. Provost J. of GEA-BTT, 2008; There is modelling in the air; Hydrocarbon Engineering; Vol. 13, No. 8 August 2008, pp 121- 127.