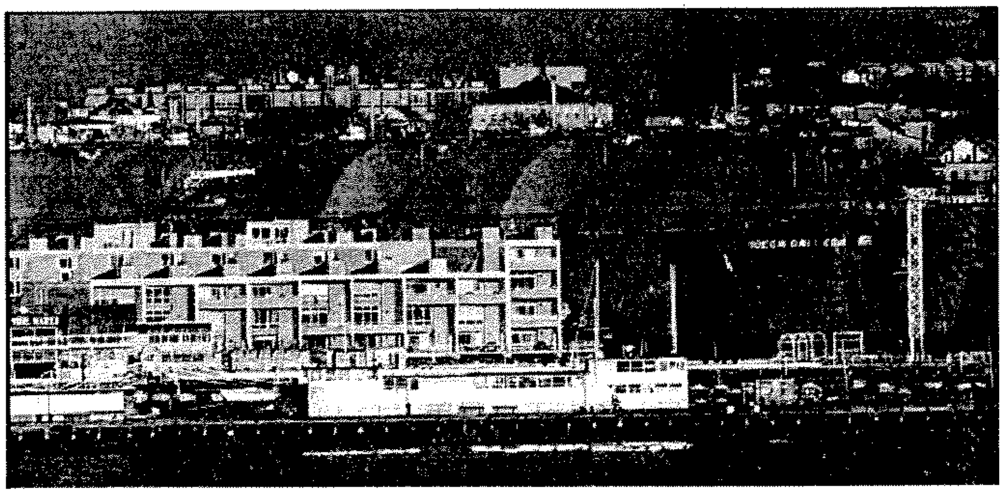
Public Safety and FERC's LNG Spin

What Citizens Aren't Being Told

May 14, 2005



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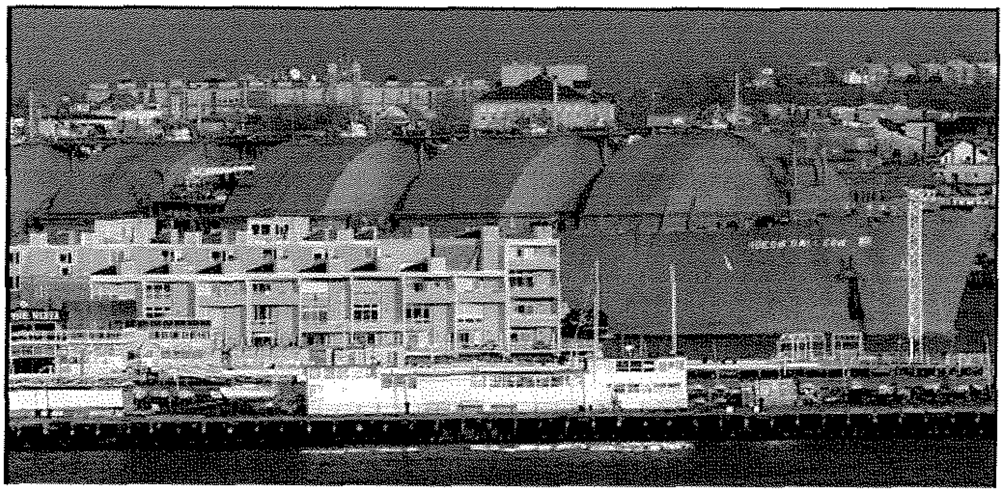

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Public Safety and FERC's LNG Spin

Under an Inter-Agency agreement among the Federal Energy Regulatory Commission (FERC), the U.S. Coast Guard (USCG), and the Office of Pipeline Safety (OPS), the FERC is the lead agency responsible for the environmental, safety, and security review of land-based LNG import terminal applications.[1]

This means that the safety of the populace is dependent on the FERC's proper assessment of the hazards and risks associated with these facilities. Therefore, you might think that the FERC would be a good source of information about the properties of LNG and whether citizens should be concerned when an energy developer targets their community to host an LNG terminal.

Unfortunately, you'd be wrong. The FERC has maintained a consistent, vocal, and naive opinion on the safety of LNG. In spite of numerous scientific studies and real-world disasters, the FERC maintains that LNG terminals belong anywhere project proponents want them.

Over the last two years, and facing a deluge of applications for new and expanded terminals, the FERC has failed to advise any proponent that their proposed location puts too many people at risk. Even though the FERC has already approved more LNG import terminals than are needed to meet demand, the FERC continues to review 16 additional terminal applications and does nothing to discourage the 20 or so more projects that are careening along in the LNG gold rush.[2]

Many fear that the FERC has forgotten its regulatory responsibilities and is hell-bent on allowing, indeed enabling, whatever industry wants. "It's their money. Why not?"

The unique properties of LNG and the scale of the proposed terminals set them apart from many of the facilities FERC regulates. Does FERC appreciate the special consideration that must accompany LNG? An examination of their recent publication, ***A Guide to LNG - What All Citizens Should Know,*** [3] suggests not.

To demonstrate the problem, we present here a comparison of the ***LNG Facts*** found in the FERC guide with the cold reality of LNG, without the pro-industry spin.

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[1] http://www.ferc.gov/industries/gas/indus-act/LNG-Safety-Agreement.pdf
[2] http://www.ferc.gov/industries/gas/gen-info/horizon-lng.pdf
[3] http://www.ferc.gov/for-citizens/my-rights/citizen-guides/citz-guide-lng.pdf

What FERC Says

What is LNG?
Natural gas, primarily methane, is colorless, odorless and non-toxic. LNG is natural gas that has been supercooled to a liquid at -260°F (-162.2°C). Liquefying natural gas reduces its volume by more than 600 times, making it more practical for storage and transportation.

Methane is only flammable at air concentration mixtures of 5%-to-15%. At a higher concentration there is not enough oxygen to sustain a flame, while at a lower concentration the fuel becomes too diluted to ignite.

What The Facts Say

What is LNG?
LNG is a very cold liquid (approximately -260° F), containing mostly methane but typically including other "hot" or "wild" hydrocarbons such as ethane and propane, and other contaminants.

Increases in natural gas prices, and recent technological improvements in the production and shipping of LNG, have made it possible to profitably export otherwise stranded natural gas reserves. In addition, a ruling by the FERC in 2002 called the Hackberry Decision provided investment incentives for land-based LNG import terminals allowing them to be operated with less regulation.[4] As a result, LNG has emerged as an attractive investment opportunity for the energy industry.

LNG is the most energy dense of all the hydrocarbon fuels, yielding 50 million BTUs per metric ton. All other hydrocarbon fuel energy densities fall within the range of 38.1 and 43.3 million BTUs per metric ton.[5]

What FERC Says

Is LNG Explosive?
LNG is not at all explosive or flammable in its liquid state

What The Facts Say

Is LNG explosive?
In the strictest technical sense LNG is not explosive **in its liquid state**. Neither are other flammable liquids such as gasoline, propane, or hydrogen. Unfortunately, because of the extreme cold temperature of LNG, the environment does not want it to remain in a liquid state. Much of the world is roughly 300° F warmer than LNG; therefore the environment around it is continually boiling it. The vaporized LNG must be vented from storage tanks to prevent the buildup of pressure. This boil-off is released, burned, or re-condensed to a liquid and returned to the tank.

Vaporized LNG has a relatively broad flammability range, from 5.3% to 15% concentrations in air. Below these concentrations the mixture is too lean to combust. Above these concentrations the mixture is too rich. By comparison, propane has a narrower range of flammability (2.2% to 9.5%), as does gasoline (1.4% to 7.6%).[6]

Whether or not LNG vapor will explode depends on a variety of factors related to its concentration in air, temperature, pressure, and the amount of "hot contaminants" included in the LNG. Studies performed to date are incomplete in properly characterizing the explosive potential of LNG and its vapors.

4 http://www.poten.com/attachments/LNGopinionJan03.pdf
5 http://www.oilegypt.com/Webpro1/Oil/approxEnergyContent.asp.
6 http://www.eere.energy.gov/afdc/afdc/pdfs/fueltable.pdf

What FERC Says

What happens when LNG is warmed?
As a vapor, natural gas mixed with air is flammable in the air concentrations noted previously. As LNG vapor warms above -160°F (-106.7°C), it becomes lighter than air and will rise and disperse rather than collect near the ground. However, it is not explosive unless flammable concentrations of gas occur in enclosed or otherwise confined spaces.

Spill sizes as well as fire sizes, vapor clouds, and resulting hazard zones are extensively analyzed. The coordinated efforts of FERC, the Coast Guard, U.S. Department of Transportation (DOT), and other state and federal organizations strive to assure the safe transit to and storage at the terminal and are described in great detail in the analysis.

What is the operational safety record of LNG Facilities?
LNG has been delivered across the oceans for more than 45 years without major accidents or safety problems, and no serious accidents involving an LNG terminal facility in the U.S. has happened in over 25 years.

On October 20, 1944, at an LNG storage facility in Cleveland, Ohio, a tank without an impoundment dike failed and spilled LNG into the street and storm sewer system. The resulting explosion and fire killed 128 people.

That tank was built during World War II, when metals were strictly rationed, using a steel alloy that had low nickel content. The low nickel content made the tank brittle when exposed to the extreme cold of LNG.

Modern LNG tanks are constructed with materials proven capable of safely containing LNG at cryogenic (supercold) temperatures. Modern day spill containment/ dike requirements for LNG facilities ensure that in the unlikely event of an LNG spill, none would leave the plant site.

In 1979, at the Cove Point LNG import facility in Lusby, Maryland, an operational accident occurred when a pump seal failed. Gas vapors entered an electrical conduit and settled in a confined space. When a worker switched off a circuit breaker the gas ignited causing a fatality and heavy damage to the building. Lessons learned from this accident resulted in changes to the national fire codes to ensure that a similar situation could not reoccur.

Similarly, a Department of Energy/FERC investigation of an explosion at an LNG liquefaction facility in Skikda, Algeria in 2004, led to design and hazard monitoring requirements at all U.S. import facilities.

What The Facts Say

What happens when LNG is warmed?
When LNG contacts the natural environment it immediately begins to boil and turn into a flammable and potentially explosive vapor. These vapors are usually a combination of methane, ethane and propane in varying proportions, with methane being the predominant component. The vapor mixture is colorless, odorless, and non-toxic. It becomes an asphyxiant when it displaces the amount of oxygen that humans need for breathing. The vapor formed is heavier then air. This heavier than air cloud will spread over the terrain, moving with the wind, until it is warmed to approximately -160° F, at which point it becomes lighter than air and begins to rise.[7]

What is the operational safety record of LNG Facilities?
For a variety of significant reasons, past operating records do not provide an appropriate perspective for the analysis of LNG risks. Overemphasis on past operations to predict future failures is a characteristic of poor risk management techniques, particularly for such complex systems.

The increasing number and complexity of very unique LNG marine receiving energy infrastructures significantly increase the likelihood that a major event will occur.

In the absence of an adequate model for predicting risk and assessing the resulting outcome of an LNG terminal catastrophe, caution must prevail. Siting these unique facilities in remote locations or offshore is the only way to protect the public.

[7] Clarke, R. 2005. LNG Facilities in Urban Areas, p 46. http://www.riag.state.ri.us/

What FERC Says

What is the transportation safety record of LNG ships coming to the US?
During more than 33,000 voyages completed since the inception of LNG maritime transportation in 1959, there have been only eight significant incidents involving LNG ships, none of which resulted in spills from cargo tank ruptures.

Where does LNG come from?
Natural gas is converted to its liquid state (LNG) at export facilities called liquefaction plants. Indonesia, Algeria, Malaysia, Trinidad and Qatar are currently the leading exporters of LNG. Nigeria, Russia, Iran, Australia and other countries also have the potential to export LNG. The LNG is imported by many countries, such as the U.S. and especially Japan, where natural gas needs are far in excess of the local production capacity.

What The Facts Say

What is the transportation safety record of LNG ships coming to the US?
Past voyage statistics clearly ignore the fact that the number of marine voyages will be increasing many orders of magnitude. In addition to the substantial increase in the number of voyages, trips will be longer, more complex, and traverse areas never experienced before. In addition, most of this history occurred pre-9-11 and does not represent the risks that are present on today's oceans.

The number of LNG ships has doubled in the past ten years to approximately 140. To meet the rising demand for LNG worldwide, the LNG ship fleet will have to more than double again within the next several years.[8]

In addition, ships are getting larger and more complex, while their cost per payload capacity has dropped.[8] We can expect to see much larger and more economical LNG ships as competition among Far East ship builders increases. With these newer ships come changes in design such as power trains with their own associated risk not captured in risk analysis based on past historical operation.

Where does LNG come from?
Currently, LNG is produced in Trinidad, Iran, Algeria, Malaysia, Brunei, Libya, Egypt, Bolivia, Indonesia, Venezuela, Oman, Nigeria, Qatar and the United Arab Emirates, which are members of the four-year-old Gas Exporting Countries Forum. Each of these countries are locations where al Qaeda has an already established foothold.[9] Russia has the largest gas reserves in the world and has already begun to position itself as an LNG exporter.

Large liquefaction facilities and export terminals are built to produce LNG and to load it aboard ships. The refrigeration of natural gas is energy intensive, as is its transport and ultimate regasification. From 5 to 20% of the gas is used to power these three steps in the LNG supply chain.

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[8] Trends, Technologies & Investments in the Gas Sector http://www.iea.org/textbase/speech/2004/haug/mh_houston.pdf

[9] Clarke, R. 2005. LNG Facilities in Urban Areas, p 26. http://www.riag.state.ri.us/

What FERC Says

How is LNG shipped?
Specially designed tankers are used to transport LNG to import terminals. The ships can carry LNG over long distances and are constructed of specialized materials and equipped with sophisticated systems designed to store LNG safely at temperatures near -260 °F (-162.2°C).

There are two basic LNG tanker designs, both of which are double-hulled. In membrane tank designs, the cargo containment system consists of a very thin invar or stainless steel double-walled, insulated cargo envelope that is structurally supported by the vessel's hull. The second design, with independent tanks, use externally insulated spherical aluminum tanks or externally insulated prismatic shaped stainless steel tanks that are self supporting within the vessel's hull. LNG tanker ships are required to meet international maritime construction and operating standards as well as rigorous Coast Guard safety and security regulations.

Once on shore, LNG is sometimes transported by truck. LNG tanker trucks typically carry between 10,000 and 12,000 gallons (38-to-45 m3) of LNG; enough to supply the daily needs of approximately 1,000 homes. LNG trucks are used to deliver LNG from import terminals to remote or satellite storage facilities.

Where do ships unload LNG?
LNG tankers dock at specially designed terminals where the LNG is pumped from the ship toinsulated storage tanks at the terminal. LNG is converted back to a gas at the terminal, which is linked to natural gas pipelines that transport the gas to where it is needed.

What The Facts Say

How is LNG shipped?
LNG is shipped in specially designed ships, which contain the –260° F liquid in insulated cargo tanks. The current LNG ships in service carry approximately 30 million gallons of LNG and are approximately 1,000 feet long.

The technology for carrying LNG was developed in Europe, and since 1964, 174 LNG tankers have been built and most remain in service. All are foreign flagged and none have U.S. crew. LNG tanker construction is currently dominated by Korea and Japan.

Some of these vessels employ the characteristic spherical tanks while others, called membrane designs, are more shoebox looking. Tank materials in contact with LNG must be of special alloy to prevent embrittlement and possible cracking due to the extreme cold of the cargo. In many newer, more "economical" designs, thin stainless alloy is backed with plywood and insulated with foam. In many of the ships, this foam is flammable.

Because LNG is less than half as dense as water, the cargo holds of LNG tankers extend well above the hull of the vessel, increasing the vulnerability of their volatile cargo to accident and sabotage risks.

Where do ships unload LNG?
Currently there are no federal regulations defining where unique LNG marine facilities may be sited and the ships unloaded.

Because of the very large size of LNG ships, these vessels must be docked at facilities that can accommodate their large drafts. It is this deep-water requirement that often limits the site selection of LNG marine receiving facilities.

Whether a site selection is in offshore water or in deep water docks in harbors or rivers, the receiving pipelines and connection couplings must be designed to take the very cold liquid and severe temperature cycling as LNG is unloaded as a liquid to the onshore facilities.

In the U.S. there are currently four land-based LNG receiving terminals and one located offshore.

What FERC Says

How is LNG stored?
LNG is stored at more than 100 U.S. facilities, typically either for use during periods of peak natural gas demand ("peakshaving") or as a baseload source of natural gas. Most of the existing facilities in the U.S. were constructed between 1965 and 1975.

LNG is stored at very low (near atmospheric) pressure in double-walled, insulated tanks. The inner tank contains the LNG, while the outer tank contains the insulation and prevents any natural gas vapor from escaping.

All new LNG facilities are required to have a dike or impounding wall capable of containing 110% of the maximum LNG storage capacity. In the unlikely event of a spill, this feature will prevent LNG from flowing off site.

Because LNG is less than half as dense as water, the cargo holds of LNG tankers extend well above the hull of the vessel, increasing the vulnerability of its volatile cargo to accident and sabotage risks.

Storage facilities use advanced monitoring systems to immediately detect any liquid or natural gas leaks or fires at the plant.

Which LNG facilities are authorized by the USCG/MARAD & by FERC?
Under the Natural Gas Act, FERC has primary jurisdiction over the siting and operation of onshore LNG facilities and offshore facilities in state waters, whereas the Coast Guard and Maritime Administration (MARAD) have jurisdiction under the Deep Water Port Act for the siting and operation of offshore LNG facilities in Federal waters.

What The Facts Say

How is LNG stored?
Land-based LNG storage tanks require insulation to prevent the rapid boil-off of the –260° F. liquid. The inner containment is made of materials that can withstand these cold temperatures without becoming brittle. LNG exposure to conventional steels even for very brief periods of time can result in catastrophic metal failure.

Surrounding the insulation is the outer shell, which is made of more conventional materials. Storage tank size varies depending on the throughput of the facility and the delivery schedule. Obviously they must be larger than the 30 million gallons received from the ships, so they are visible for miles.

Which LNG facilities are authorized by the USCG/MARAD & by FERC?
The FERC is responsible for authorizing the siting and construction of onshore LNG facilities under Section 3 of the Natural Gas Act.[10] To date, FERC has never denied an application.

In 1971, the first LNG terminal began operation in Everett, Massachusetts. Then, in the late 70s, three more terminals were approved and built, but they did not remain in operation, and only in the last several years have they resumed operation.

The FERC has recently approved applications for eight new or expanded terminals with a combined vaporization capacity of 11.5 billion cubic feet per day.[11] This is a twelve-fold increase in import capacity compared to the period from 1982 until 2002, when only the Everett Massachusetts terminal was in operation.

The Maritime Administration (MARAD) and the United States Coast Guard (USCG) are jointly responsible for processing offshore LNG terminal applications under the Deepwater Port Act. Due to the safety risks associated with land-based terminals, there has been increased interest in offshore siting. Recently three offshore terminals have been approved in the Gulf of Mexico, and one of these has already been built and begun operation.

[10] 15 U.S.C. § 717 et seq. - http://uscode.house.gov/download/pls/15C15B.txt
[11] http://www.ferc.gov/industries/gas/gen-info/horizon-lng.pdf

What FERC Says

How are terminals designed?
All LNG storage facility designs must comply with stringent regulations as required by the DOT's safety standards in Title 49 Code of Federal Regulations (CFR) Part 193 – Liquefied Natural Gas Facilities: Federal Safety Standards and NFPA (National Fire Protection Association) 59A - Standard for the Production, Storage and Handling of Liquefied Natural Gas.

In accordance with federal safety standards, vapor-gas dispersion distances must be calculated to determine how far downwind a natural gas cloud could travel from an onshore storage facility and still be flammable. As required by these regulations, these exclusion zones must not reach beyond a property line where other development could occur.

Since a fire would burn with intense heat, each onshore LNG container and LNG transfer system must also have thermal exclusion zones established in accordance with Title 49, CFR, Part 193. These exclusion zones must be legally controlled by the LNG facility operator, or a government agency, to ensure adequate separation between members of the public and the heat from a fire.

What The Facts Say

How are terminals designed?
LNG terminals have to be designed only to minimum federal standards (49CFR193)[12] and to minimum National Fire Protection Association (NFPA 59A)[13] standards. In the case of a conflict between even these two minimum requirements, the weaker federal standards supercede the NFPA requirements. Neither standard provides appropriate siting guidance for marine receiving facilities that involve an additional series of risks associated with the presence of LNG ships.

Since LNG facilities are designated as transportation infrastructure, these high-energy-density facilities are exempt from Process Safety Management (PSM) requirements defined under federal law (29CFR1910.119).[14] PSM regulation was promulgated to address the many tragedies that were occurring in refinery and chemical plants in the late 1980s. Ironically, LNG companies appear to be undergoing severe management changes similar to those that were occurring in refinery and chemical plants in the late 1980's.

What FERC Says

Seismic Design Requirements
LNG facilities must meet stringent standards to ensure public safety and plant reliability in the event of an earthquake. Extensive studies of the geological conditions and earthquake history of a proposed LNG site are required to determine appropriate design loads on the critical components of the LNG plant. These critical components must be designed and constructed to maintain LNG containment during and after an earthquake.

What The Facts Say

Seismic Design Requirements
Earthquakes could damage LNG tanks and piping. Therefore, LNG terminal infrastructure should be designed and subject to independent review to ensure that the design is appropriate for the earthquake potential at the site. This should include both the magnitude and the type of earthquakes associated with the proposed location and secondary conditions associated with such events such as soil liquefaction or tsunami.

[12] http://www.access.gpo.gov/nara/cfr/waisidx_04/49cfr193_04.html

[13] http://www.nfpa.org/itemDetail.asp?categoryID=279&itemID=22438&URL=Codes%20and%20Standards/Code%20development%20process/Online%20access&cookie%5Ftest=1

[14] http://www.access.gpo.gov/nara/cfr/waisidx_04/29cfr1910_04.html

What FERC Says

What public safety issues are associated with LNG?

If LNG spills it will vaporize. The resulting natural gas vapors will warm and expand, and become lighter than air. The vapors will disperse with the prevailing wind.

If a source of ignition is present where a vapor cloud exists at a 5%-to-15% concentration in the air, the vapor cloud will ignite and burn along a flame-front, back toward the spill site.

If LNG spills and vaporizes in the presence of an ignition source, a fire likely will result. The fire will burn back toward the spill site

What The Facts Say

What public safety issues are associated with LNG?

No other energy infrastructure brings together the four major risk factors that are associated with LNG marine receiving facilities: 1) high energy density, 2) very large inventories, 3) unusual release dynamics associated with extreme cryogenic temperatures, and 4) very large potential impact zones. Studies that examine LNG releases caused only by spills should be carefully questioned, since it is more likely that a major high rate release will not be simply a spill.

The danger to those caught within the potential impact zones include: asphyxiation due to lack of oxygen, exposure to severe cryogenic temperatures, burn from severe heat/thermal radiation, and damage associated with high pressure blast waves and associated flying debris.

The range of risks that can generate these extensive impact zones can come from operational accidents, intentional acts such as sabotage, or natural events. Though the consequences of an LNG accident have been demonstrated in the LNG disasters that occurred in Cleveland in 1944 and in Algeria in 2004, neither of those events represented the scale of destruction that could occur given the enormous amounts of LNG stored at a typical marine receiving terminal.

Extrapolating from the limited experience we have in the U.S. with LNG would be foolhardy even if the world had not changed on 9-11. LNG terminal siting, planning, and operation must occur with the full realization that such facilities represent an attractive target for terrorist groups. Onshore LNG receiving facilities cannot realistically be protected.

Alternatives to the LNG gold rush

Is this disparity between the facts surrounding LNG and the FERC's blatant spin a purposeful campaign of misinformation or is it due to ignorance? Either way, it is obvious that public safety is not an overriding concern within the commission. Nor does it seem that the commission has any intention of implementing rational siting standards for LNG import terminals.

The FERC ought to be able to recognize and quickly reject applicants for LNG terminals at locations that put citizens at risk. A review of their current docket of filings and pre-filings reveals one simple pattern – provide the paperwork *equals* get your permit. We deserve better from an agency regulating the import and storage of substances as dangerous as LNG. Until the FERC can implement a rational standard for land-based LNG import terminal siting and demonstrate the ability to enforce it, they should cease the processing of any more applications.

In a May 5, 2005 speech on energy policy at the Stanford Washington Research Group, FERC Chairman Pat Wood stated that eight additional LNG terminals are needed to meet the nation's short-term natural gas demand. Of those eight, he envisioned two in Atlantic Canada and two in Mexico.[15] Those Canadian and Mexican import terminals have already been approved. That means six more terminals are needed in the U.S.

As of May 2, the FERC has approved eight new or expanded land-based terminals, and MARAD/USCG has approved two new offshore terminals. That is four more U.S. terminals than Wood says are needed. Clearly a moratorium is called for on any new land-based terminals.

It is also clear that a broadening of the FERC's authority in this area would be a grave mistake. In the absence of suitable federal siting standards, state and local review processes are the only mechanisms in place to protect the public. As unregulated private industrial operations, these terminals come nowhere near the threshold for deserving powers of eminent domain.

The unique hazard posed by LNG terminals means agencies tasked with reviewing construction applications and regulating their operation must see public safety as their prime concern, not the profit-driven incentives of multinational corporations. The LNG gold rush needs to be reined in, as the strategic energy interests of the nation must come first.

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[15] Chairman Wood's speech at the Stanford Washington Research Group 2005 Institutional Policy Conference - http://www.ferc.gov/press-room/speeches.asp

About The Authors

All three of the authors were invited to be panelists to provide a "public" perspective at the February 2, 2005 LNG Community Awareness Workshop put on by the U.S. Department of Transportation in Washington D.C.[16] During the workshop presentations were made by industry and all involved federal agencies. At the end of the day this "public" panel unanimously voiced their concern regarding many of the inaccuracies, misleading statements, pro-industry spin, and lack of clear policy. They were assured that this was the first of a series of such meetings. After the recent release of the FERC's A Guide to LNG - What All Citizens Should Know the authors felt compelled to tell citizens what they really should know.

Cliff Goudey is a research engineer at the Massachusetts Institute of Technology in Cambridge, MA. In addition to coordinating marine outreach at the Sea Grant College Program, he is the Director of the Center for Fisheries Engineering Research. He holds graduate degrees from MIT in Naval Architecture and Marine Engineering and in Mechanical Engineering.

Richard Kuprewicz is President of Accufacts Inc, a company specializing in risk management and forensic analysis of hydrocarbon based energy infrastructure. He serves on various boards and committees concerned with energy regulation. He holds B.S. Degrees in Chemical Engineering and Chemistry, and a Master's Degree in Business Administration.

Carl Weimer is the executive director of the national Pipeline Safety Trust based in Bellingham, Washington. He is a member of the U.S. Department of Transportation's Office of Pipeline Safety's Technical Hazardous Liquid Pipeline Safety Standards Committee. He also is the chairman of the Governor appointed Washington State Citizen Committee on Pipeline Safety.

[16] http://primis.rspa.dot.gov/meetings/Mtg29.mtg

Annexe

Risks of LNG

by Cliff Goudey, MIT, Bailey Island

Much has been said by LNG proponents regarding the exceptional safety of their product. They have explained its exceptional safety based, in part, on its limited flammability ratio (5 to 15 % air mixture) and that is it lighter than air. They have suggested that because of these properties, a leak of LNG would most likely diffuse harmlessly up into the atmosphere. Is there a scientific basis for this claim? Let's look.

Natural gas (mostly methane) is a flammable gas and behaves in ways that are dictated by its chemical composition. Compared to other flammable gases with which we are more familiar, its most unique property is its low boiling point (minus 259 degrees F.).

Flammability Limits

Below is a table of flammability limits of various gases. The values are shown as a percentage volume in air. Below the range indicated the mixture is too lean to ignite. Above that range the mixture is too rich to ignite.

Gas	Flammability Limits
Hydrogen	4.0 - 75.0
Acetone	2.6 - 13
Methane	5.0 - 15.0
Ethane	3.0 - 12.5
Propane	2.1 - 9.5
Butane	1.9 - 8.5
Jet fuel (JP-4)	1.3 - 8.0
Gasoline	1.4 - 7.6

These values can be verified at several web sites including: http://www.jlab.org/, http://www.methanol.org/, and http://www.delphian.com/.

Though the other gases can ignite at lower concentrations, methane has a broader range of flammability than competing fuels such as propane or gasoline. From this standpoint, **it is far more likely to occur at a flammable ratio than propane, gasoline, or jet fuel.**

Density

Proponents of LNG have suggested that a spill of liquid methane would be a harmless event because it is lighter than air and would it would quickly rise into the atmosphere. Let's look at the facts.

The density of a gas depends on its chemical composition and its temperature. If this were not so, hot air balloons would need wheels. Here is a table of densities for common gases.

Gas	Density (kg/cu m)	Specific Gravity
Air	129	1.00
Hydrogen	0.09	0.07
Helium	0.18	0.14
Methane	0.72	0.56
Ethane	1.35	1.05
Propane	2.01	1.56
Butane	2.69	2.09
LPG (average)	2.35	1.82
Acetylene	1.17	0.91

This table makes methane look pretty good - a little more than half as heavy as air. You can also see that methane is eight times heavier than hydrogen and four times heavier than helium. However, these values apply only when the gas is at normal temperatures. At lower temperatures methane gas contracts in volume and becomes more dense. For example:

Temp (Deg. F.)	Density	Specific Gravity
59	0.72	0.56
-260	1.926	1.50

Why does this matter? Because when methane boils off from LNG, the gas is still at roughly the same temperature as the liquid - just like when water boils. **This is why the gas coming off a spill of LNG stays close to the ground or close to the water - it can be 50% heavier than the surrounding air.**

The resulting vapor cloud will travel with the wind until it finds an ignition source. This is especially important during a large release of LNG, as would occur with a catastrophic containment failure.

The cold, growing vapor cloud remains denser that the surrounding air. At its center, the methane concentration is well above the flammability limit so ignition can only occur at its perimeter. Within the inner portion of such a vapor cloud a person would be asphyxiated. If the cloud passes without ignition, then resuscitation might be possible. If the perimeter ignites while someone is in the center, then they would probably die.

Eventually the methane cloud will heat up - absorbing heat from the air as it mixes and picking up heat from the land or water as it is driven along by the wind. The distance such a vapor cloud travels and remains flammable depends on many factors including the size of the spill, the boil off rate, ambient temperature, wind and wind turbulence, topography, and objects in its path.