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November 1, 2016

Via Federal Express/Electronic Mail

Todd Anthony Bianco, EFSB Coordinator
RI Energy Facilities Siting Board
89 Jefferson Blvd.
Warwick, RI 02888

Re: Invenergy Docket No. SB-2015-06

Dear Mr. Bianco:

On behalf of Invenergy Thermal Development LLC ("Invenergy"), enclosed please find an original and ten (10) copies of Invenergy's Response to the Town of Burrillville's 17th Set of Data Requests.

Please let me know if you have any questions.

Very truly yours,

ALAN M. SHOER
ashoer@apslaw.com

Enclosures

cc: Service List

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: INVENERGY THERMAL DEVELOPMENT LLC's APPLICATION TO CONSTRUCTION THE CLEAR RIVER ENERGY CENTER IN BURRILLVILLE, RHODE ISLAND

DOCKET No. SB-2015-06

INVENERGY THERMAL DEVELOPMENT LLC'S RESPONSES TO THE TOWN OF BURRILLVILLE'S 17th SET OF DATA REQUESTS

17-1 Is there any possibility, no matter how small, that there could be an explosion at the Spectra/Algonquin compressor station which could cause an explosion at the Invenergy plant? If it is your opinion that this is impossible, please explain. If it is your opinion that it is in any way possible, please explain the conditions under which this could occur, the likelihood of this occurring and your reasoning. Also, if this is possible, no matter how unlikely, please calculate the size of the blast area that would be affected by such an explosion.

RESPONSE 17-1 Invenergy Thermal Development LLC ("Invenergy") does not believe there is a possibility that an explosion at Spectra's Burrillville Compressor Station ("BCS") could cause an explosion at Clear River Energy Center ("CREC"). As discussed in our response to questions 17-2, 3 and 17-4 Invenergy engaged Exponent as an expert consultant who has ample experience in evaluating the types of events that are being postulated in the question. Exponent estimated the area that could be impacted by an event at either location is really a function of the size of the enclosed area (e.g. building) where gas could accumulate and given that the powerhouse building at CREC is larger and has more volume than the building at Spectra's site, an event at CREC would be governing. Please refer to the response to question 17-2 for the results of this event.

As it relates to the potential of an explosion at the Spectra/Algonquin compressor station which could cause damage at CREC, Invenergy contacted Spectra with regard to this question, and Spectra provided the attached letter that highlights the diligence associated with safe operation and maintenance of natural gas compressor facilities and outlines the federal standards they use for the design and maintenance of their facilities. In the attached response Spectra indicates that their Integrity Management Program has determined the Potential Impact Radius ("PIR") of a possible event, and the PIR is limited to their site and more specifically the fenced area of their site (as it relates to an event at the BCS itself).

The physical separation of the Algonquin compressor station and the CREC minimizes the possibility of direct impacts to the CREC in the remotely possible event of a fire or explosion.

RESPONDENT: John Niland, Invenergy Thermal Development LLC

DATE: November 1, 2016

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: INVENERGY THERMAL DEVELOPMENT LLC's APPLICATION TO CONSTRUCTION THE CLEAR RIVER ENERGY CENTER IN BURRILLVILLE, RHODE ISLAND

DOCKET No. SB-2015-06

INVENERGY THERMAL DEVELOPMENT LLC'S RESPONSES TO THE TOWN OF BURRILLVILLE'S 17th SET OF DATA REQUESTS

17-2 Is it at all possible that a problem at the Invenergy plant could cause an explosion at the Spectra/Algonquin compressor station? If it is your opinion that this is impossible, please explain. If it is your opinion that it is in any way possible, please explain the conditions under which this could occur, the likelihood of this occurring and your reasoning. Also, if this is possible, no matter how unlikely, please calculate the size of the blast area that would be affected by such an explosion.

RESPONSE 17-2: We do not believe it is possible that a problem at the Clear River Energy Center (CREC) could cause an explosion at the Spectra/Algonquin compressor station. The codes and standards incorporated into the design and construction of the CREC and the physical separation of the Algonquin compressor station and the CREC minimizes the possibility of direct impacts to the Spectra/Algonquin compressor station in the remotely possible event of a fire or explosion at CREC.

The design of the CREC incorporates the requirements of dozens of industry standards including but not limited to American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, National Fire Protection Association (NFPA), National Electric Code (NEC), American Petroleum Institute (API). Adherence to these standards minimize the likelihood that there would ever be a fire or explosion at the CREC.

In order to determine potential scenarios that should be examined, Invenergy examined the systems and associated design features at CREC. These systems and features are typical to gas fired power plants, and as such, the Project design will also include design features to mitigate consequential damage to other portions of the CREC facility and keep any impact area within the confines of the CREC property. The key systems that could have a potential to cause a fire or explosion are listed below and their associated specific design features include:

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: INVENERGY THERMAL DEVELOPMENT LLC's APPLICATION TO CONSTRUCTION THE CLEAR RIVER ENERGY CENTER IN BURRILLVILLE, RHODE ISLAND

DOCKET No. SB-2015-06

INVENERGY THERMAL DEVELOPMENT LLC'S RESPONSES TO THE TOWN OF BURRILLVILLE'S 17th SET OF DATA REQUESTS

1. Natural gas: The natural gas piping systems and components are separated from the other sections of the Project (to the extent possible) and all areas where natural gas systems and components are located are designated with an area classification that requires special design features that include explosion proof electrical components, gas detectors that are linked to automatic isolation systems and fire detection and suppression systems. Should a leak occur, the gas detection sensors are set to detect the gas before a concentration level is reached that would be capable of creating an explosion that could impact a larger area of the plant. For these reasons, the amount of any gas that could leak is limited such that it would not spread to an ignition source.

The CREC fuel gas system will be equipped with automatic detection and emergency shutdown systems, including the following:

- The natural gas will be odorized for detection.
- A network of low concentration natural gas detectors will be installed to monitor for fuel gas leaks in the gas yard and within all areas where fuel gas equipment is located, both indoors and outdoors. The detectors will be set to alarm in the facility main control system ("DCS"). The custom-designed fire alarm and detection system will be in accordance with NFPA 72.
- In accordance with NFPA 850 the plant will include emergency shutdown systems to isolate the gas piping, stop equipment and safely vent station gas. The natural gas supply pipeline will include an emergency shutoff valve (ESV) at the outlet of the metering yard and the ESV will automatically close in the event that a fire is detected.
- Individual unit shutdown systems in case of mechanical or electrical failure of a compressor unit system or component.
- Main line isolation valves will be fire safe, as defined by API 607.

- Nitrogen hose connections and vent lines will be provided between all isolatable sections of the fuel gas piping to allow nitrogen purges and inerting for maintenance activities.
- The fuel gas piping will be cleaned and purged in accordance with NFPA 56.
- Pressure control devices to maintain the operating pressure at or below the maximum allowable operating pressure. In addition, overpressure protection devices with sufficient capacity and sensitivity will be installed to ensure that the maximum allowable operating pressure of the station piping and equipment will not be exceeded by more than 10 percent (10%) in the case of a malfunction of the pressure control equipment.
- All electrical equipment will be explosion proof.
- System design to accommodate changes in gas quality, periodic maintenance (e.g., filter change-out), redundancy, separation of ignition sources (e.g., National Electric Code compliance), combustion controls and hardened to resist impacts.
- Prevent damage to pipe by as-built mapping, below-grade flagging (above grade) and clear labeling of gas-bearing components.
- Flame detection that uses ultraviolet sensors.

Safe operating practices will include the following at a minimum:

- Periodic walk-through surveys of pipeline systems with hand-held gas detectors at all flanges, valves and other fittings; this is particularly important in the Gas Yard at filter, dewpoint heater equipment, pressure control valves and metering runs where many fittings and gas state changes occur that may contribute to leakage events.

- Strong operating and maintenance procedures, including use of inert gas purging, maintenance of coating and cathodic protection systems, dewpoint heating, filtration and verification of valve and instrument functionality.

The gas system design features include, controls utilizing gas detection, fire detection and suppression and when combined with regular inspections and proper maintenance of gas system equipment, limits this type of event to be confined within a smaller area thereby virtually eliminating the potential for undetected gas leaks that could lead to a fire or explosion.

2. Hydrogen: Modern utility generators larger than about 300 MW are hydrogen or hydrogen and water cooled. Hydrogen has safely been used as the coolant medium in utility generators for over 70 years. General Electric ("GE") estimates that there are more than 2,400 hydrogen cooled GE designed generators in service today. The generator and associated hydrogen cooling system include a number of features to ensure the safe operation of the equipment:

The generator applied to CREC is hydrogen cooled, and as with the potential for a natural gas leak, there will be hydrogen leak detection sensors located on the generator which stringently monitor for potential leaks. These detectors will be set to monitor, alarm and take protective actions when hydrogen is detected at a level that is below the lower explosive limit.

The generator is equipped with end shields on each end, designed to support the rotor/bearings, to prevent gas from escaping, and to be able to withstand a hydrogen explosion in the unlikely event of such a mishap. In order to provide the required strength and stiffness, the end shields are constructed from steel plate and are reinforced. Horizontally split inner and outer oil deflectors are bolted into the end shield and provide sealing of the oil along the shaft.

Furthermore, the hydrogen systems and components will be located in areas that are designated with an area classification that requires special design features including explosion-proof electrical components, gas detectors that are linked to automatic isolation of systems and integrated with the fire detection and suppression systems.

The generator will have an internal volume of hydrogen that will be maintained in a sealed condition using multiple redundant seals. The seals will include mechanical seals and a seal oil system that uses pressurized oil barrier between the mechanical seals and the rotating shaft. The seal oil maintains an air-side seal and a hydrogen-side seal by forcing oil in both directions. The oil is monitored to detect any hydrogen that may get entrained into the oil and provide a means to scrub the hydrogen from the oil.

Hydrogen, like all flammable gases, is only reactive when it is present in concentration levels between the lower explosion limit and the upper explosive limit. That is, when there is sufficient oxygen present to sustain combustion. The generator will be equipped with a purity monitoring system that measures the quality of hydrogen in the generator. If the purity level begins to decrease toward the upper explosive limit, this system adds hydrogen to maintain purity.

The generator will also be equipped with an inert gas (one that does not react with hydrogen) purge system to purge the generator of hydrogen should generator maintenance be necessary. This system will also be used to purge and dilute the hydrogen to below the lower explosive limit if there is a leak. These systems are used throughout the power industry and have successfully controlled and prevented hydrogen explosions. Daily inspections and proper maintenance of equipment help to reduce this hazard.

3. Main Transformer: The potential for an explosion is remote, its causes include lightning strike or transformer fault. The design features fire detection and suppression systems, location within a three sided concrete wall structure to protect immediately adjacent equipment systems and buildings and such that the open side has adequate space separation for protection for adjacent transformers and other equipment. Given the small impact area and the three sided walled enclosure, this scenario was ruled out as having any potential to impact Spectra's Burrillville station.

While we believe that the impact of any conceivable event at CREC will not migrate to the Algonquin compressor station, in order to address the question on the likelihood of an explosion occurring, we contacted Exponent, Inc., who is an industry recognized expert in conducting the type of analysis that was requested and asked that they conduct an evaluation of the probability of either a natural gas explosion or a hydrogen explosion event and to determine the maximum impact radius of the worst case scenario, no matter how unlikely. Exponent performed the evaluation which is included as an attachment.

As can be seen in the attached study provided by Exponent, the likelihood of either the Algonquin Station or the CREC facility suffering a gas explosion event as described in the question is anticipated to be on the order of 10^{-5} to 10^{-6}/yr, or once every 100,000 to 1 million years.

We also requested Exponent to describe what conditions, along with any assumptions and associated reasoning, would be necessary, no matter how unlikely, in order for such an event to occur and to determine the size of the impact radius that could result from such an event. Their inputs, assumptions and analysis are included in the attached report which concludes that even with postulating physically impossible scenarios like having the maximum possible volume of gas be released instantaneously and fill the largest contained area (the power block building) with a "stoichiometric natural gas/air mixture in order to maximize the confined volume of fuel involved in the explosion," the resulting impact area does not impact the Spectra compressor station.

Also, as addressed in the response to question 17-4, Exponent determined the distance away from the source of a worst case hypothetical explosion, where the blast wave pressure threshold of 1 pound per square inch gauge could reach. This threshold is the lowest pressure criterion for damaging explosion effects described in the ALOHA technical documentation and the EPA Risk Management Program Offsite Consequence Analysis. At 1 psig of pressure, a blast wave could shatter glass windows, however much higher pressures are necessary to damage the buildings or equipment at the compressor station. The calculated distance to the 1 psig pressure threshold for the maximum postulated scenario (no matter how improbable) was found to be no more than 884 feet from the source on the CREC site which does not create any damage to equipment at the Spectra/Algonquin compressor station, please refer to the attached Exponent letter response for the details of this analysis.

RESPONDENT: John Niland, Invenergy Thermal Development LLC

DATE: November 1, 2016

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: INVENERGY THERMAL DEVELOPMENT LLC's APPLICATION TO CONSTRUCTION THE CLEAR RIVER ENERGY CENTER IN BURRILLVILLE, RHODE ISLAND

DOCKET No. SB-2015-06

INVENERGY THERMAL DEVELOPMENT LLC'S RESPONSES TO THE TOWN OF BURRILLVILLE'S 17th SET OF DATA REQUESTS

17-3 Please explain/calculate the probability of a certain blast events [sic] occurring, including the Algonquin Station exploding, the hydrogen storage tubes or generator igniting, and/or the proposed CREC facility itself exploding.

RESPONSE 17-3: Please refer to the response to question 17-2 and the attached Exponent Report that calculated the probability of a certain blast events occurring.

RESPONDENT: John Niland, Invenergy Thermal Development LLC

DATE: November 1, 2016

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: INVENERGY THERMAL DEVELOPMENT LLC's APPLICATION TO CONSTRUCTION THE CLEAR RIVER ENERGY CENTER IN BURRILLVILLE, RHODE ISLAND

DOCKET No. SB-2015-06

INVENERGY THERMAL DEVELOPMENT LLC'S RESPONSES TO THE TOWN OF BURRILLVILLE'S 17th SET OF DATA REQUESTS

17-4 Please conduct an ALOHA (Area Locations of Hazardous Atmospheres ("ALOHA") Model developed by the EPA and the National Oceanic and Atmospheric Administration) analysis to determine the extent of the impact area of any possible explosion at the Invenergy facility and/or the Spectra/Algonquin facility, no matter how remote the possibility.

RESPONSE 17-4: Please refer to the response to question 17-2 and the attached Exponent report for the response to this question.

RESPONDENT: John Niland, Invenergy Thermal Development LLC

DATE: November 1, 2016

INVENERGY THERMAL DEVELOPMENT LLC
By its Attorneys,

/s/ Alan M. Shoer
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Dated: November 1, 2016

CERTIFICATE OF SERVICE

I hereby certify that on November 1, 2016, I delivered a true copy of the foregoing responses to the Town of Burrillville's 17th Set of Data Requests via electronic mail to the parties on the attached service list.

/s/ Alan M. Shoer

SB-2015-06 Invenergy CREC Service List as of 10/04/2016

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Spectra Energy Partners

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October 4, 2016

John Niland
Invenergy
One South Wacker Drive
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Chicago, Ill. 60606

Dear John:

Natural gas transmission pipeline facilities are regulated by the Pipeline and Hazardous Materials Safety Administration (PHMSA) which is a United States Department of Transportation agency created in 2004, responsible for developing and enforcing regulations for the safe, reliable, and environmentally sound operation of the United States pipeline transportation system. Algonquin Gas Transmission Company ("AGT") is committed to building and operating one of the safest natural gas pipeline facilities ever built in the U.S. AGT has implemented rigorous standards and practices to design, construct, inspect, test, operate and maintain the pipeline with a goal of zero incidents for the life of the pipeline. The federal regulations that govern the design and operation of interstate facilities are specifically designed to ensure the safety of the public in the vicinity of these pipeline facilities.

Potential Impact Radius (PIR)

- Federal law and pipeline safety regulations require natural gas transmission pipeline operators to implement Integrity Management Programs for pipelines to identify and prevent potential impacts around areas with greater populations, ecological sensitivities or dense infrastructure and buildings. These areas are referenced to as "High Consequence Areas" or "HCAs" in the federal regulations.
- The Potential Impact Radius (PIR) is a key measurement element of an Integrity Management Program. The PIR model is based on a federally mandated calculation utilizing the diameter of the pipeline and the pressure of the gas moving through the pipeline. The PIR is incorporated into the federal regulations primarily to define where hypothetical consequences would be most significant in order to define HCAs for interstate gas transmission pipelines.
- The PIR for the BCS Pipeline is solely a formulaic element used to identify HCAs.

- With the identification of HCAs, additional maintenance and monitoring criteria are utilized by pipeline operators with the purpose of ensuring public safety in these specific areas.

PIR Mischaracterization

- The term "blast zone" has been used recently by people opposing projects to promote fear of energy transportation facilities. The idea of a "blast zone" is a mischaracterization of the U.S. DOT's regulations for identifying HCAs.
- PIR was not designed as a model for so called "safe distances" and does not prescribe setbacks from a pipeline.

Safety Standards for Compressor Stations

- The Code of Federal Regulations CFR 49 Part 192.163 requires the location of each main compressor building of a compressor station be on property under the control of the operator. The station must also be far enough away from adjacent property, not under control of the operator, to minimize the possibility of fire spreading to the compressor building from structures on adjacent properties. The Burrillville Compressor Station (" BCS"), is sited on an open 105 acre parcel within which the station occupies approximately 20 acre is fenced.

- CFR 49 Part 192.163 also requires each building on a compressor station site be made of specific building materials and must have at least two separate and unobstructed exits to provide an unobstructed passage to a place of safety. The station must be in an enclosed fenced area and must have at least two gates to provide a safe exit during an emergency. BCS was designed, constructed, operated, and maintained to meet or exceed Part 192 applicable specifications, as described below.

    - **<u>Codes, Standards, Specifications and Procedures</u>.** BCS incorporates engineering consensus standards as published by associations that are recognized world-wide such as the American Society of Mechanical Engineers, the American Petroleum Institute, and the American Society of Testing Materials. BCS uses its own technical specifications and operating procedures which reflect many years of expertise and experience and improvements in designing, constructing, and operating safe and reliable compressor stations.

    - **<u>Design</u>.** BCS was designed to meet and in many cases exceed the code requirements for station facilities. The Compressor Station safety systems are highly engineered with automated control systems to ensure the station and pipeline pressures are maintained within safe limits, and will have several additional over-pressure protection systems that provide an additional layer of safety to back-up the primary controls. System alarms are designed to notify the Gas Control center should any abnormal conditions occur, allowing them to take appropriate measures using remote control systems if the station operations personnel are unable to respond to a particular situation. The station has two different communication systems so that station monitoring and controls would still be operational if the primary communications method were to become disabled. In the event the systems in the station were to become inoperative, remote control valves will also be at the existing nearby pipeline facilities that could be closed.

- **Compressor Stations and Emergency Shutdowns.** Compressor stations are highly regulated facilities that must meet rigorous siting, safety and environmental standards established respectively by the FERC, the USDOT and the U.S. Environmental Protection Agency. Part 192.163 requires that each compressor station have an emergency shutdown system (except for unattended field compressor stations of 1,000 horsepower or less) that must meet several specifications. The BCS is equipped with automatic detection and emergency shutdown systems. These systems will include:
  - Flame detection that uses ultraviolet sensors;
  - Gas detection for detecting low concentrations of natural gas;
  - Emergency shutdowns to isolate the gas piping, stop equipment, and safely vent station gas;
  - Individual unit shutdown systems in case of mechanical or electrical failure of a compressor unit system or component;
  - Emergency shutdowns will be operable from at least two locations; and
  - Pressure control devices to maintain the operating pressure at or below the maximum allowable operating pressure. In addition, overpressure protection devices with sufficient capacity and sensitivity are installed to ensure that the maximum allowable operating pressure of the station piping and equipment will not be exceeded by more than 10 percent in the case of a malfunction of the pressure control equipment.

- **Compressor Stations Safety Systems and Equipment.** A gas control center is maintained in Houston, Texas. The gas control center monitors system pressures, flows, and customer deliveries. Further, the gas control center is staffed 24 hours a day, 365 days a year. Data acquisition systems are present at all metering stations along the system. If system pressures fall outside a predetermined range, an alarm is activated and notice is transmitted to the Houston gas control center. The alarm provides notice that pressures at the station are not within an acceptable range. To ensure safe operations, well trained gas controllers work around the clock in a high-tech control center to monitor and control the gas as it travels through all sections of the pipeline network. Compressor stations are maintained by highly skilled and experienced pipeline personnel along Algonquin's pipeline systems. Spectra Energy's employees operate over 100 compressor station sites around the clock – with nearly two million horsepower in the United States, 19,100 miles of interstate transmission pipeline, and over 65 years of success.

Sincerely,

Michael J. Dirrane
Director, Marketing

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October 27, 2016

Mr. John Niland
Director, Business Development
Invenergy
One South Wacker Drive
Suite 1800
Chicago, Illinois 60606

Subject: Invenergy Clear River Energy Center
Exponent Project No. 1608155.000

Dear Mr. Niland:

This letter report summarizes Exponent analysis performed to assist Invenergy in response to the Town of Burrillville (RI) data requests regarding potential impact areas associated with "blast events" at the Invenergy Clear River Energy Center facility (hereafter indicated as CREC). A summary of Exponent's qualifications is attached, and more information is available at *www.exponent.com*.

Exponent's analysis relied upon information regarding the proposed facility supplied by Invenergy. Exponent performed overpressure calculations using the PHAST, consequence analysis tool developed for the evaluation of hazardous consequences (including vapor dispersion, thermal radiation, and explosion overpressure). PHAST is widely used in industry, has been validated and approved as a tool of choice by numerous US regulatory agencies including the US DOT. Based on the material inventory present at the Invenergy Clear River Energy Center facility supplied to Exponent and the questions posed by the town, combustion of two potential flammable gases was analyzed for hypothetical release scenarios. These involve the release and ignition of (1) the hydrogen gas that is used to cool the turbine-generators, and (2) natural gas feeding the gas turbine generators.

The following sections of this letter report contain (1) the Town of Burrillville (RI) data request questions and (2) the corresponding responses drafted by Exponent. Relevant standards and model input conditions are also described in the responses.

> **<u>Question 17-3:</u>** *Please explain/calculate the probability of a certain blast events [sic] occurring, including the Algonquin Station exploding, the hydrogen storage tubes or generator igniting, and/or the proposed CREC facility itself exploding.*

<u>Response to 17-3:</u> We interpret the term "blast" to refer to a damaging vapor cloud explosion involving either released hydrogen or natural gas. For a vapor cloud explosion to occur, the released hydrogen or natural gas must be of sufficient volume, it needs to be ignited, and in the case of natural gas, the gas must be confined in an enclosed volume or in a highly congested area. In many circumstances, even if the gas is ignited, no damaging overpressures will occur. For example, early ignition (i.e. shortly after the release) will result in a small flash fire followed by a jet fire if gas is still being released from the equipment or piping. In order to produce a damaging explosion, it is necessary, but not necessarily sufficient for the gas release to occur for a long period of time without being ignited.

The probability of this type of event occurring can be estimated as the product of the probabilities of the gas release occurring (i.e., annual probability of component failure), having sufficient time for gas to accumulate without being ignited (i.e., probability of accumulating a large volume of gas), having that gas be ignited (i.e., probability of ignition), and having the necessary level of confinement or congestion to lead to damaging overpressure.

Accidental releases of gas from piping and process equipment that could lead to a catastrophic explosion have a low annual probability of occurrence, on the order of 10^{-4}/yr, or once every 10,000 years. A summary table of the probabilities for such releases taken from NFPA 59A[1] is provided below for reference. Additionally, a catastrophic explosion will require that a significant amount of fuel be released (i.e. a significant portion of the hydrogen inventory or high pressure natural gas for several minutes) within a volume having a sufficient level of confinement or equipment congestion. To calculate the probability of a damaging explosion, the probability of the gas release is multiplied by the probability of the necessary steps from a probabilistic event tree analysis. Thus, the probability of an explosion is most often found to be 1-2 orders of magnitude lower than the probability of the initial release occurring.[2] Thus, the likelihood of either the Algonquin Station or the CREC facility suffering a gas explosion event as described in the question is anticipated to be on the order of 10^{-5} to 10^{-6}/yr, or once every 100,000 to 1 million years.

1 NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), 2016 edition, National Fire Protection Association. Chapter 15 provides guidance on risk assessment for natural gas facilities.

2 See for example, "Publication Series on Dangerous Substances (PGS 3), Guidelines for quantitative risk assessment" (The Purple Book), or MPACT Theory (December 2010) for DNV's PHAST Risk software.

Table 15.6.1 Example Component Failure Database

Component	Annual Probability of Failure
Atmospheric cryogenic tanks	
(1) Instantaneous failure of primary container and outer shell, release of entire contents (single containment tank)	5E-07
(2) Instantaneous failure of primary container and outer shell, release of entire contents (double containment tank)	1.25E-08
(3) Instantaneous failure of primary and secondary container, release of entire contents (full and membrane containment tanks)	1E-08
Pressurized storage (Containers) — instantaneous release of entire contents	5E-07
Pressure relief valves — outflow at the maximum rate	2E-05
Process equipment	
(1) Pumps — catastrophic failure	1E-04
(2) Compressors with gasket — catastrophic failure	1E-04
(3) Heat exchanger — instantaneous release of entire contents from plate heat exchanger	5E-05
Transfer equipment — rupture of loading/unloading arm	3E-08
Piping — aboveground	**Annual probability of failure per meter**
(1) Rupture for nominal diameter <3 in. (75 mm)	1E-06
(2) Rupture for nominal diameter from 3 in. (75 mm) up to and including 6 in. (150 mm)	3E-07
(3) Rupture for nominal diameter >6 in. (150) mm	1E-07

> **Question 17-4**: *Please conduct an ALOHA (Area Locations of Hazardous Atmospheres ("ALOHA") Model developed by the EPA and the National Oceanic and Atmospheric Administration) analysis to determine the extent of the impact area of any possible explosion at the Invenergy facility and/or the Spectra/Algonquin facility, no matter how remote the possibility.*

Response to 17-4: Based on the ALOHA software tool being identified in the question, this question is requesting a vapor cloud explosion analysis for the Invenergy facility and/or the Spectra/Algonquin facility. A vapor cloud explosion results from ignition of a flammable vapor, gas, or mist, in which the flame speeds accelerate to sufficiently high velocities to produce significant overpressure. A vapor cloud explosion will cause a transient change in the gas density, pressure, and velocity of the air surrounding the explosion point. The initial change in the pressure can be either discontinuous or gradual. A discontinuous change is referred to as a shock wave, and a gradual change is known as a pressure wave.[3] The effects of the explosion are related to the volume of the flammable gas, the reactivity of the gas, and the degree of confinement and/or congestion of the flammable gas during the combustion event. Vapor cloud explosions that form a shock wave (i.e., a blast wave) tend to be more damaging. Low reactivity gases such as methane do not tend to form such shock waves. The magnitude or strength of a blast wave drops as it moves away from the explosion source. The dynamics of a vapor cloud explosion can be quite complex depending upon the specific details of the scenario, but simplified methods have been developed and implemented in industry for decades to calculate the effects of a vapor cloud explosion. The Baker-Strehlow-Tang (BST) vapor cloud explosion model is one of these methods.

The ALOHA software uses the BST vapor cloud explosion model for calculating the effects of the ignition of flammable vapor clouds. The BST model is employed in many software packages including PHAST v6.7 supplied by DNV. PHAST is an industry-accepted software package used for calculation of the hazardous outcomes due to accidental release of toxic and flammable materials. PHAST calculates material release dynamics, vapor dispersion, liquid pool fires, pressurized jet fires, and vapor cloud explosion effects. PHAST has been validated by industry and is a tool of choice for the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) for use in natural gas hazard analyses, and as such, is an appropriate substitute for ALOHA to respond to this query.

The physical layout of the area where a flammable vapor cloud is combusted will have a direct effect on the outcome of a vapor cloud explosion. The layout is described by two parameters: congestion and confinement. Confinement refers to physical obstructions, such as walls, that limit the movement of the flame front and unburnt gases in one or more dimensions. Congestion refers to obstacles in the path of the flame front that generate turbulence and increase the flame velocity as the combustion front moves around them. Confinement and congestion increase the

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3 Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards, 2nd edition, Center for Chemical Process Safety, American Institute of Chemical Engineers (2010).

pressure of the blast wave over the unconfined and uncongested cases. The calculation of vapor cloud explosion effects using the BST method requires several input parameters from the user, such as: material type, flammable mass, material reactivity, obstacle density, flame expansion factor, and ground reflection factor. The obstacle density, flame expansion factor, and ground reflection factor are used in the model to approximate the effects of confinement and congestion on the vapor cloud explosion. The BST model calculates the blast wave pressure versus distance for a vapor cloud explosion given these parameters.

The U.S. EPA's General Guidance on Risk Management Programs for Chemical Accident Prevention (40 CFR Part 68)[4] provides guidance on selecting worst-case release scenarios such as that requested in the Town's question:

> A vapor cloud explosion is specified as the worst-case scenario for flammable substances. For the worst-case analysis for flammable substances, you need to estimate the distance to an overpressure endpoint of 1 pound per square inch (psi) resulting from a vapor cloud explosion of a cloud containing the largest quantity of the regulated flammable substance from a vessel or process pipe line failure.

Exponent has not conducted a regulatory review of the requirements for the facility, but two flammable gases are suggested by the Town's questions about the CREC facility: hydrogen and natural gas. For each substance, a maximum estimate of fuel gas volume was assumed to be released instantaneously and to be present in a highly congested volume. This conservative assumption is intended to provide an upper bound to the effects of potential accidental releases at the facility as requested in the Town's questions. This assumption neglects the mitigating effects of equipment and procedural safeguards and other factors that would likely lead to a smaller volume of gas release in an incident. Other scenarios such as a smaller volume of gas, a smaller congested volume, or an outdoor release, will have less significant over-pressures than the conservative assumptions employed in the analysis and in many instances no blast wave at all. The two vapor cloud explosion cases are described as follows:

1. **Hydrogen Gas Explosion**
   Hydrogen gas is a high reactivity fuel. It is used to cool the turbine-generators at the facility. One generator contains approximately 20,300 standard cubic feet (scf) of hydrogen gas and is connected to a storage system with a capacity of approximately 1,600 scf of hydrogen gas. For the explosion calculation, it was conservatively assumed that all of the hydrogen for one unit (approximately 22,000 scf) contributed to the explosion. Conservative BST model parameters were also applied in the calculation: high obstacle density (which provides the highest flame speeds) and a ground reflection factor of 2 (which results in the highest calculated blast wave pressure).

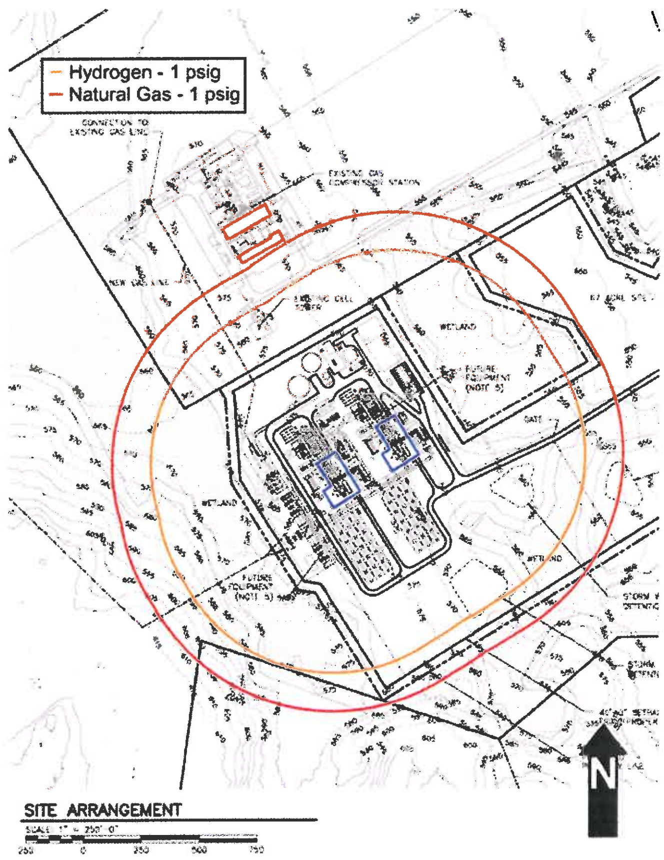
[4] General Guidance on Risk Management Programs for Chemical Accident Prevention (40 CFR Part 68), EPA 555-B-04-001, United States Environmental Protection Agency, p. 4-4, March 2009.

2. **Natural Gas Explosion**
   Natural gas is a low reactivity fuel, which requires either a high degree of congestion or confinement in order to cause damaging overpressure if it is ignited. In reality, the configuration of the power plant building is unlikely to have high obstacle density, but it will provide some confinement of the gas. Buildings of this type with insulated metal panels are known to fail at a pressure less than 1 psig; therefore, the confinement is not anticipated to contribute significantly to the overpressure. Thus, a BST model employing high congestion assumptions will conservatively bound the upper blast wave pressure. It was conservatively assumed that the volume of one entire unit's building (approximately 1,250,000 ft^3) was filled with a stoichiometric natural gas/air mixture in order to maximize the confined volume of fuel involved in the explosion. Conservative BST model parameters were also applied in the calculation: high obstacle density (which provides the highest flame speeds) and a ground reflection factor of 2 (which results in the highest calculated blast wave pressure).

The blast wave pressure will drop as the wave moves away from the source of the explosion with the highest pressure being generated near the source. The blast wave pressure threshold of 1 pound per square inch gauge (psig, i.e., pressure rise above atmospheric pressure) is the lowest pressure criterion for damaging explosion effects described in the ALOHA technical documentation and the EPA Risk Management Program Offsite Consequence Analysis. At 1 psig of pressure, the blast wave is expected to shatter glass windows, as described in the ALOHA documentation. Much higher pressures are necessary to damage the equipment at the compressor station. The calculated distance to the 1 psig pressure threshold for the two scenarios, using the BST method, was found to be:

1. **Hydrogen Gas Explosion** = 718 feet to 1 psig
2. **Natural Gas Explosion** = 884 feet to 1 psig

It should be noted that conservative assumptions were made in developing these calculations. For instance, it is unlikely that the entire hydrogen inventory from one unit will contribute to a vapor cloud explosion for multiple reasons. For example, the gas has a low ignition energy thus is likely to be ignited early in a release. Likewise, it is not likely that a stoichiometric mixture of natural gas and air will fill one entire building without being ignited. Despite these conservative assumptions, the resulting calculations indicate that pressures of 1 psig or greater are not expected to be observed at the Algonquin facility. The minimum distance from one of the CREC units to the nearest building at the Algonquin facility is approximately 900 feet, which is farther than the either of the distances calculated for hydrogen and natural gas explosions. The figure below shows a plot plan of the CREC and Spectra/Algonquin facilities including (1) CREC turbine buildings (see blue outlined area), (2) Algonquin compressor station (see green outlined area). The calculated 1 psig overpressure distances for hydrogen gas explosion (yellow curve) and natural gas explosion (red curve) are also shown.


Hydrogen - 1 psig
Natural Gas - 1 psig
SITE ARRANGEMENT
N

Limitations

The study presented in this letter report is intended for use by Invenergy in relation to the Town of Burrillville (RI) data requests regarding potential impact areas associated with overpressure events at the Invenergy Clear River Energy Center facility. Proper application of this report requires recognition and understanding of the limitations of both the scope and methodology of the study.

The scope of the study was to answer specific questions in the Town data request, more specifically to estimate overpressure distances resulting from the ignition of hydrogen and natural gas vapor clouds. Model calculations were performed consistent with guidance in 40 CFR 68 and the ALOHA technical manual and engineering and process specifications provided by Invenergy. The scope of this analysis was strictly limited to analyzing the hypothetical hydrogen and natural gas overpressure scenarios as requested by Invenergy in relation to the Town data request responses. Exponent did not participate in any hazard or risk analyses, design reviews, or onsite inspections related to the proposed or existing facilities.

The methodology forming the basis of the results presented in this report is based on mathematical and statistical modeling of physical systems and processes as well as data from third parties. Given the nature of these evaluations, significant uncertainties are associated with the various hazard and loss computations, some of which are accounted for in the methodology, while other uncertainties such as for example, as-built construction details, modifications, current conditions, material characteristics, among others cannot be readily incorporated into the analyses. These uncertainties are inherent in the methodology and subsequently in the generated hazard and loss results. These results are not facts or predictions of the loss that may occur as a result of future events or any specific event; as such, the actual losses at a given risk factor relevant to this study may be materially different from those presented in this study. Furthermore, the assumptions adopted in determining these loss estimates do not constitute the exclusive set of reasonable assumptions, and use of a different set of assumptions or methodology could produce materially different results. The scope of this report is narrowly defined, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user.

If you have any questions or require additional information, please do not hesitate to contact me at (508) 652-8519 or hkytomaa@exponent.com.

Sincerely,

Harri Kytomaa, Ph.D.
Principal Engineer & Group Vice President

Ryan Hart, Ph.D.
Senior Engineer

Delmar "Trey" Morrison, Ph.D.
Principal Engineer

Francesco Colella, Ph.D.
Senior Associate

Overview of Exponent's Services for Facility Siting & Risk Analysis

Date: 10/27/2016

Exponent®
Engineering & Scientific Consulting

Company Profile

The Exponent name is recognized for its integrity, objectivity, independence, and professionalism.

Our corporate core values drive a commitment to client service that enables us to provide consistently high quality work to clients worldwide. For nearly 50 years we have provided engineering, scientific, environmental and health consulting services to corporations, insurance carriers, government agencies, law firms, and individuals. The firm has been best known for analyzing accidents and failures to determine their causes, but in recent years it has become more active in assisting clients with human health, environmental, engineering and regulatory issues associated with new products or processes to help prevent problems in the future.

Our multidisciplinary organization of scientists, physicians, engineers, and regulatory consultants brings together more than 90 technical disciplines to address complicated issues facing industry and government today. We employ the best and the brightest from the major academic institutions around the world as well as technical specialists from a variety of industries. Over 50% of our staff hold a Ph.D. or M.D. in their chosen field of study.

With its roots in Silicon Valley, Exponent has offices located in the United States, Europe and China.

Practice Area and Industries

Exponent's integrated practices offer a multifaceted perspective that leads to innovative solutions that produce bottom line results. Through our network of U.S. and international office locations, we offer more than 90 different disciplines, including capabilities in:

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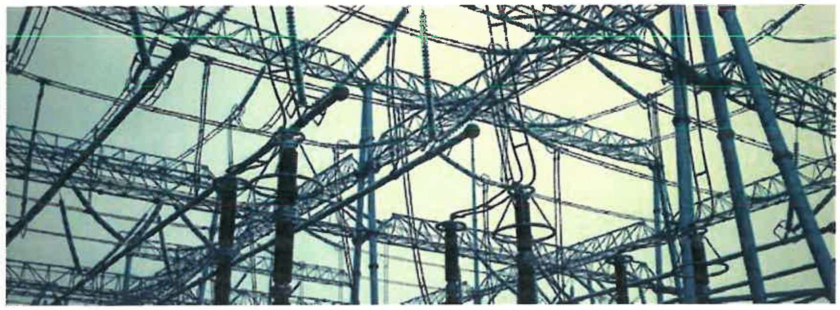
- Defense
- Electronics, Security & Information Technology
- Food & Beverage
- Life Sciences & Healthcare
- Manufacturing Technology & Industrial Equipment
- Oil & Gas
- Transportation
- Utilities

Industries



Utilities

Whether for utilities, independent power producers (IPPs), regulatory bodies, emerging industry players or new/existing technology developers, Exponent is the "go to" solution provider for utility industry participants struggling with complex technical and commercial issues including those involved in:

- Electric generation facilities (fossil, nuclear, wind, solar and other renewable sources)
- Electric transmission & distribution
- Distributed energy and storage
- Gas production & storage
- Gas transmission & distribution
- Water & wastewater
- Local and interexchange telecommunications

Our multi-disciplinary expertise, detailed engineering and commercial insights enable us to provide unique and advanced services to this dynamic industry segment. From risk and reliability assessment and mitigation to forensic analysis to proactive support in launching and integrating new technologies, Exponent can provide a wide range of support. Some examples of our utility project engagements include:

- Failure analysis and root cause investigation
- Aging infrastructure assessment and risk management
- Asset management
- Reliability improvement, resilience optimization and system hardening
- Risk assessment and mitigation
- Technology strategy and deployment
- Business process re-engineering and technology assimilation
- Environmental and health issues
- Regulatory and litigation support

We have comprehensive expertise in the planning, construction, operation, and maintenance of traditional utility systems and their components and newly emergent technologies reshaping the industry. Our consultants have worked with the major industry participants throughout North America and globally, giving us a deep understanding of typical and best industry practices, and the implications of emerging technologies. We apply this knowledge to solve complex technical and business problems, reduce risk, and improve business performance.

Oil & Gas

For more than 40 years, we have provided consulting services to most of the major international oil and gas companies, in all aspects of their operations. With our experience analyzing complex projects and evaluating thousands of failures, Exponent is a leader in loss investigation and failure analysis in the petroleum industry, with investigations ranging from high-loss disasters to small incidents for major national and international exploration and production companies. Because of this knowledge, we are able to assist pro-actively with design assessments; health studies; environmental evaluation and regulatory compliance.

Exponent combines unparalleled technical expertise with the ability to respond rapidly and to focus this knowledge in extremely short time frames. The value that Exponent brings to its oil and gas clients includes:

- Proven experience on high-profile projects — often in a dispute resolution setting
- Deep, functional knowledge of engineering fundamentals: mechanical, structural, metallurgical, materials, chemical, electrical, and others
- Scientific depth in environmental and health perspectives
- Convergence of our skills in risk, reliability, and vulnerability analyses
- Operational knowledge of the oil and gas industry.

Exponent engineers and scientists have unique insights in various risk and reliability, environmental impact, and health assessments, to help clients improve the safety practices and procedures for their personnel, processes, and facilities, and minimize operational disruptions and property loss. Additionally, our expertise in risk assessment, release characterization, dispersion modeling, vapor-cloud explosion analysis, industrial hygiene, toxicology, and epidemiology allows us to comprehensively examine the consequences of both hypothetical and actual releases of toxic and flammable substances. Our expertise in site investigation, environmental fate and transport, modeling, and remediation allows us to provide groundwater and soil remediation support, as needed.

Sectors

- Exploration and Production
- Hydraulic Fracturing Operations
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- Pipelines
- Refining and Petrochemicals

Liquefied Natural Gas (LNG)

Exponent has broad experience with the LNG industry and assists with engineering design reviews, third-party technology evaluation, research and development, and process hazards assessments associated with LNG facilities. Our capabilities include conducting inspections and safety audits, environmental impact studies, and consequence modeling, which involves computer modeling of fire radiation and vapor dispersion hazard zones. This work has included numerous site-specific LNG vapor dispersion analyses using computational fluid dynamics (CFD) modeling. Exponent engineers have project experience with material selection and material performance issues (metals and concrete) that are unique to LNG and cryogenic applications. We also provide services in process safety management, construction management, and wetland restoration planning. Using this experience, we routinely assist our clients in solving performance-based design challenges and in providing technical support for regulatory applications.

Natural gas is converted to its liquid state (LNG) at export facilities called liquefaction plants. LNG is natural gas that has been cooled to the liquid state at -260 °F and atmospheric pressure. Liquefying natural gas reduces its volume by more than 600 times, making it more practical to store and transport. The LNG imported to the United States comes via ocean tanker, primarily from Asia, Africa, and the Caribbean. The ships can carry LNG over long distances; they are constructed of specialized materials and equipped with sophisticated systems designed to store LNG safely. The LNG industry continues to maintain one of the safest records in all maritime transportation industry.

After a period of approximately 30 years during which only five LNG receiving terminals were operating in the United States and Puerto Rico, there are now over 60 LNG receiving terminals that have either already been approved, have entered the permitting process, or are being proposed throughout North America; a sixth LNG receiving terminal has begun operations in the Gulf of Mexico. Both onshore and offshore terminals are being pursued, and the strong demand for gas has led to numerous technological developments in all segments of this industry (liquefaction, marine transportation, and regasification). An example of this is the use of large arrays of ambient air vaporizers to regasify LNG without burning fuel or pumping large quantities of sea water.

If LNG is spilled, it vaporizes. The natural gas vapors are initially heavier than air and they form a cloud close to the ground, which is pushed downwind and eventually dissipates. If a viable ignition source is present where a vapor cloud exists at a 5%-15% concentration in air, the vapor cloud can ignite and burn. Therefore, the permitting of LNG terminals requires thermal radiation and vapor dispersion hazard distances to be quantified and demonstrated to pose no threat to people or property outside the plant.

The possibility of large releases from LNG tankers has raised the need to analyze larger spills than have been investigated previously. Models have been developed to address these scenarios; however, these models are based on the extrapolation of small-scale experimental data and/or the adaptation of light hydrocarbon spill models. The lack of experience with large LNG spills continues to challenge the engineering community to develop better fire and atmospheric dispersion models.

Practices

Exponent®

Thermal Sciences

Exponent's Thermal Science practice provides a wide array of services, ranging from addressing engineering and regulatory challenges for industry, to investigating fires and explosions. Our staff have a combined experience of thousands of projects investigating failures involving petrochemical, chemical, and oil and gas installations, fire protection systems, and consumer products as well as the origin and cause of structural, wildland, vehicle, and industrial fires and explosions, including dust explosions. Such investigations are a core competency of the practice and often involve testing and sophisticated computer analyses using Computational Fluid Dynamics (CFD) or process simulation tools.

As a result of this considerable experience, our personnel are often called upon to provide services for the purposes of ensuring that facilities, buildings, processes, and equipment are compliant with chemical, fire, and explosion safety requirements and accepted codes, standards, practices, and guidelines. Our proactive work includes fire protection engineering for new buildings and structures, asset integrity management in the oil and gas industry, chemical process safety and risk analysis consulting, and regulatory and engineering consulting for the LNG Industry. Our team also consults on combustion systems such as boilers, heaters, furnaces, and turbomachinery (gas turbines, compressors, expanders), as well as HVAC equipment. We provide dust explosion safety consulting for manufacturing facilities that handle powders and bulk solids. Our consultants also address thermal management issues related to batteries and energy storage technology.

Our team comprises a diverse group of professionals with backgrounds in mechanical engineering, chemical engineering, and fire protection engineering. Most of our consultants are registered professional engineers and accredited fire investigators who are nationally and internationally recognized leaders in the development and implementation of innovative approaches in safety and regulatory compliance and major accident investigation and prevention. Many serve on code-making standards committees for national and international organizations, including the NFPA, ASTM, UL and ASME. Our staff often works closely with other Exponent practices to find objective and often multidisciplinary solutions to complex problems.

Capabilities

- Aviation & Aerospace Services
- Batteries & Energy Storage Technology
- Chemical & Biochemical Engineering
- Combustible-Dust Testing Laboratory
- Commercial & Industrial Heating and Drying
- Computational Fluid Dynamics & Fire Dynamics Modeling
- Dust Explosions
- Explosions, Deflagrations & Detonations
- Fire & Flammability Testing
- Fire Origin / Cause Investigations
- Fire Protection Engineering
- Heating, Ventilation, Air Conditioning & Refrigeration (HVAC&R)
- Heavy Equipment Fires
- Liquefied Natural Gas (LNG)
- Liquefied Petroleum Gas (LPG)
- Process Safety Engineering
- Reactive Chemicals
- Scalds & Burn Injuries
- Turbines, Power Plants & Rotating Machinery
- Unmanned Aerial Systems (UAS)
- Vehicle Fires
- Wildland Fires
- Wind Power

Exponent

Engineering Management Consulting

The Engineering Management Consulting practice (EMC) helps clients address business-driven issues that are technical in nature, and where it is critical to have a deep understanding of business issues, technical issues, and how they relate to each other. As such, all EMC consultants have both engineering and business expertise. EMC consultants routinely address issues such as risk management, asset management, reliability planning, technology planning, business planning, business operations, capital budgeting, and economic analysis.

Utility Services - EMC has extensive experience in both electric and gas utility issues. Our services include major event investigations, rate case support, regulatory compliance, system reliability, infrastructure hardening, aging infrastructure management, infrastructure integrity management, system planning, capital spending justification, smart grid, renewable energy, OT/IT convergence, litigation support, and many more.

Process Industry Services - EMC also has extensive experience in process industry reliability and risk management, with a focus on the investigation and prevention of accidents. This includes analyses of the existing state using techniques such as Failure Mode and Effects Analysis (FMEA), Preliminary Hazards Analysis (PHA), Hazard and Operability Analysis (HAZOP), Mean Time Between Failure (MTBF), reliability, root cause, fault tree, event tree, and Bayesian uncertainty. It also includes mitigation analyses including process risk mitigation, new technology adoption, and human factors.

Capabilities

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- Fossil Plant Services
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Professionals

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Professional Profile

Within Exponent's Thermal Sciences group, Dr. Morrison's practice areas encompass product safety, product liability, and process safety through hazard and risk analysis, failure analysis, and post-incident investigation. He specializes in evaluations of origin, cause, and engineering issues related to catastrophic incidents involving fires, explosions, and chemical process technology. His expertise includes chemical engineering, fire dynamics, process safety management, and the system safety of products and industrial equipment. Dr. Morrison's practical research encompasses self-heating materials and reactive chemical hazards and evaluating scenarios such as spontaneous ignition of vegetable oil-contaminated fabrics and self-heating of reactive chemicals.

Dr. Morrison provides consulting services for a variety of industries. Beyond the wide range of consumer and industrial systems that he evaluates, he has focused on heating systems including residential and commercial clothes dryers and industrial process dryers, ovens, and furnaces. He has also focused on oil-flooded screw air compressors and other major industrial equipment failures. As a chemical engineer, his projects include analyzing the effects of chemical process design, plant operator actions, control system response, and process unit response during upset situations and operations that may lead to a hazardous loss of containment.

As part of Dr. Morrison's proactive safety consulting services, he leads hazard and risk assessments using industry-accepted process hazard analysis (PHA) methods such as HAZOP studies, What-If studies, and LOPA studies, combined with analytical techniques such as Fault Tree Analysis, Event Tree Analysis, Root Cause Analysis, Consequence Analysis, and Quantitative Risk Assessment. He routinely applies this expertise to risk analysis for natural gas, LNG, propane, and other gas processing facilities.

Dr. Morrison is an active professional in the product safety and chemical process safety communities. In addition to his technical committee memberships, international presentations, and publications, he serves in leadership roles in the field of chemical process safety through process safety conferences sponsored by the American Institute of Chemical Engineers in North America and in Latin America. Dr. Morrison has chaired many industry conferences including the 45th AIChE Loss Prevention Symposium in 2011, the 8th Global Congress on Process Safety in 2012, the 5th Process Safety Management Mentoring Forum in 2016, and the 7th Latin American Conference on Process Safety in 2016. The objectives of these activities are to aid in the prevention of major loss incidents that involve fires, explosions, runaway reactions, and hazardous material releases in the chemical, petrochemical, and related industries.

Academic Credentials & Professional Honors

Ph.D., Chemical Engineering, Illinois Institute of Technology (IIT), 2008

M.S., Chemical Engineering, Oklahoma State University, 1998

B.A., Chemistry, Knox College, 1996

Licenses and Certifications

Licensed Professional Engineer, Illinois, #062-059506

Licensed Professional Engineer, North Carolina, #037722

Licensed Professional Engineer, South Carolina, #28918

Licensed Professional Engineer, Iowa, #22945

Licensed Professional Engineer, Michigan, #6201062901

Certified Fire and Explosion Investigator, Reg. No. 12900-6508

40-Hour OSHA Certification, Hazardous Waste Operations and Emergency Response

40-Hour Training, Process Hazard Analysis (PHA) for Team Leaders

Member of Underwriters Laboratories Standards Technical Panel (STP) for UL 2157, Standard for Electric Clothes Washing Machines and Extractors

Member of Underwriters Laboratories Standards Technical Panel (STP) for UL 2158, Standard for Electric Clothes Dryers

Member of Underwriters Laboratories Task Group for Clothes Dryer Exhaust Duct Power Ventilators

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Professional Profile

Dr. Kytömaa specializes in mechanical engineering and the analysis of thermal and flow processes. He applies his expertise to the investigation and prevention of failures in mechanical systems. He also investigates fires and explosions and their origin and cause. He consults in the utilities, oil and gas, and chemical industries. Dr. Kytömaa's project experience includes consumer products, intellectual property matters, automobiles, aircraft, turbines, compressors, boilers, steam generators, pneumatic and hydraulic systems, instrumentation, nuclear waste management, heat transfer systems, fuel distribution, delivery and storage systems, including LNG facilities.

Dr. Kytömaa has decades of experience in the area of dynamics and thermal hydraulics of piping systems, valves and pipelines. He has developed flow modeling tools for such systems and their components and has applied these to drilling and downhole applications. He pioneered the modeling of the acoustics of drilling fluid piping systems for acoustic telemetry and Measurement-While-Drilling (MWD), which was one of the enabling technologies for directional drilling. Dr. Kytömaa has also developed ultrasonic techniques for both medical and engineering applications, including instrumentation for flow measurement and the characterization of dense suspensions.

Dr. Kytömaa was Assistant Professor and Associate Professor of Mechanical Engineering at the Massachusetts Institute of Technology, where he was head of the Fluid Mechanics Laboratory. He has also held positions as Visiting Professor at the Helsinki University of Technology and at the DOE Pacific Northwest Laboratory in Washington, and served as Lecturer at the Worcester Polytechnic Institute. Dr. Kytömaa consulted for Teleco Oil Field Services, Inc., developing MWD technology and other downhole applications.

Academic Credentials & Professional Honors

Ph.D., Mechanical Engineering, California Institute of Technology (Caltech), 1986

M.S., Mechanical Engineering, California Institute of Technology (Caltech), 1981

B.Sc., Engineering Science, Durham University, England, *First Class with Honors*, 1979

Session Chairman, LNG Plant Safety and Protection: 2014, 2013, 2012 and 2011 AIChE Spring Meetings & 10th, 9th, 8th and 7th Global Congress on Process Safety

Keynote Speaker: AIChE 2014 Spring National Meeting, 14th Topical Conference on Gas Utilization, New Orleans, LA, March 30-April 3, 2014

Liquefied Natural Gas (LNG) installations and equipment, ISO /TC 67/ WG10: Committee Member, 2008-2014

Outstanding Presentation Award, AIChE Spring Meeting, 2013

Excellence Award at the SAE 2006 World Congress & Exhibition

Lewis F. Moody Award for best paper on a subject useful in engineering practice presented to American Society of Mechanical Engineers (ASME), 1993

Henry L. Doherty Professor in Ocean Utilization, 1991-1993

Chairman, Organizing Committee, Engineering Foundation Workshop, Davos, Switzerland, 1993

National Science Foundation Review Panelist, Washington, DC, 1990

National Science Foundation Group Leader, Acoustic Methods Workshop on Visualization of Particulate Two-Phase Flows, Washington, DC, 1990

Diver in the Finnish Navy, rank Able Seaman, Distinguished Service, 1980

Institute of Mechanical Engineers Prize for Outstanding Project Work (United Kingdom), 1979

Licenses and Certifications

Registered Professional Mechanical Engineer, California, #34290

Registered Professional Mechanical Engineer, Massachusetts, #48202

Registered Professional Mechanical Engineer, Louisiana, #PE.0035054

Registered Professional Mechanical Engineer, Maine, #12370

Registered Professional Mechanical Engineer, Michigan, #6201057546

Registered Professional Mechanical Engineer, Washington, #47486

Registered Professional Mechanical Engineer, New York, #089361 (2011-2013)

Registered Professional Mechanical Engineer, Arkansas, #16481

Registered Professional Mechanical Engineer, Alabama, #35697-E

Registered Professional Mechanical Engineer, Oklahoma, #28024

Certified Fire and Explosion Investigator (CFEI, Registration No. 13524-6843) in accordance with the National Association of Fire Investigators (NAFI) National Certification Board per NFPA 921 Section 11.6.4

Certified Fire Investigator (CFI certificate No. 20-005) in accordance with the International Association of Arson Investigators (2009-2014)

Fire Investigation 1A Certification accredited by the California State Fire Marshal

Short Course on Aircraft Fire protection/Mishap Investigation, AFP Associates, November 9, 2001

National Waste Operations and Emergency Response Training, 29 CFR 1910.120 (1994-2000)

Asbestos Worker, Certificate No. 97-164-112-102, pursuant to Title II of the Toxic Substance Control Act, 15 USC 2646, 1997

Short Course: Research state-of-the-art in two-phase flows and thermal hydraulics. Faculty: Professors R.T. Lahey Jr, D.A. Drew, O.C. Jones, M.Z. Podowski, A.E. Bergles, Rennselaer Polytechnic Institute, 1988.

Nordic Sportsdiver's Certificate, CMAS International Diving Certificate "2 stars," No 1076Open Water Certified Scuba Diver, NAUI Certification #: kyto062958harsd

Enriched Air Diver, Nitrox, Max 40% O2 concentration, PADI Diver No. 0604055220

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