U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

Urgent Recommendations

Summary of Board Actions:

On June 9, 2009, four workers were killed and 67 others were injured in a natural gas explosion at the ConAgra Foods Slim Jim™ meat processing facility in Garner, North Carolina. Less than eight months later, on February 7, 2010, six workers were killed and at least 50 others were injured in a natural gas explosion at the Kleen Energy power plant under construction in Middletown, Connecticut. Both incidents had the potential to cause even more severe damage and loss of life. The U.S. Chemical Safety Board investigated both incidents and reviewed the facts surrounding other serious fuel gas incidents in the United States in recent years.

Both the explosions at ConAgra Foods and Kleen Energy resulted from planned work activities that led to large releases of flammable natural gas in the presence of workers and ignition sources. The CSB determined that no specific federal workplace safety standards prohibit such intentional releases of natural gas into workplaces. The CSB also determined that feasible alternatives exist to the unsafe practices that led to the explosions at Kleen Energy and ConAgra Foods, and that many companies (though not all) use safer methods for handling or venting natural gas. The Board issues the following urgent safety recommendations to the U.S. Occupational Safety and Health Administration, the National Fire Protection Association, and other parties and votes to conclude its investigations of the ConAgra Foods and Kleen Energy incidents.

Whereas:

Background and Findings

1. On Sunday, February 7, 2010, Kleen Energy, a combined-cycle[1] natural gas-fueled power plant under construction in Middletown, Connecticut, experienced a catastrophic natural gas explosion that killed six and injured at least 50.[2]

2. The incident occurred during the planned cleaning of fuel gas piping, part of the commissioning and startup phase of the Kleen Energy project. At the time of the incident, workers were conducting a "gas blow," whereby natural gas is forced through the piping at a high pressure and volume to remove debris. The natural

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[1] In a combined-cycle plant, power is generated by two different processes: in the first, a gas turbine (similar to a jet engine) drives an electric generator to produce electricity; the second uses the turbine exhaust heat to generate steam. The steam powers a turbine to drive a second electric generator.

[2] The general contractor provided an evidentiary record indicating that 50 individuals were injured. Due to conflicting company reports, a more accurate number cannot be determined.

gas and debris are subsequently released directly to the atmosphere. At the Kleen Energy construction site, workers used natural gas at a pressure of approximately 650 pounds per square inch gauge (psig).

3. A total of 15 natural gas blows were completed intermittently over approximately 4 hours through a number of open-ended pipes located less than 20 feet off the ground. These vents were adjacent to the south wall of the main power generation building at the site.

4. On the day of the incident, the pipe cleaning crew did not have a safety meeting that specifically discussed the hazards of natural gas blows, nor did they receive and review the natural gas blow procedure.

5. At the time of the explosion, natural gas was being blown from an open-ended pipe between two large structures, known as heat recovery steam generators (HRSGs), in an area immediately south of the power generation building. This location, while outdoors, was congested by the surrounding power generation equipment (Figure 1). The vent pipe itself was installed in a relatively horizontal orientation. Both the congested area and the orientation of the vent pipe likely adversely affected the dispersion of the natural gas.

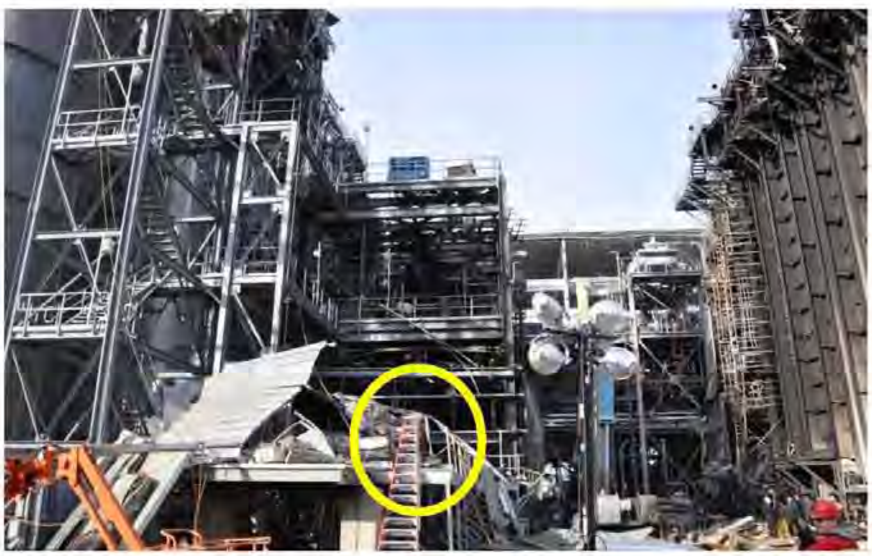

Figure 1. The general location of open-ended pipe where natural gas was vented to the outdoors at time of incident (yellow oval). The actual vent piping is obscured by the structure and scaffolding.

6. Efforts were made to eliminate or control potential ignition sources outside of the power generation building. However, ignition sources remained outside and inside. The gas blows themselves could have been self-igniting due to expelled debris creating a spark or through static accumulation from the flow of the gas. Many ignition sources also existed inside the building: electrical power to the building was on, welders were actively working, and diesel-fueled heaters were running.

7. Initial calculations by the CSB investigators revealed that approximately 480,000 standard cubic feet of natural gas were released outdoors near the building in the final 10 minutes before the blast. Just over 2 million standard cubic feet of natural gas were released in total over the course of the morning.[3]

8. At approximately 11:15 a.m., the released natural gas found an ignition source and exploded.

9. Approximately 150 workers were at the construction site on Sunday, February 7, the day of the explosion. Non-essential personnel were restricted from the area immediately south of the main power generation building during the gas blows. However, more than 50 people were working inside the power generation building at the time of the explosion; only about 15 of the 50 were actually involved in the natural gas blow activities.

10. While some workers were informed that natural gas blows would be occurring on February 7, others did not learn about the planned natural gas blows until they reported to work that morning. Some contractors were instructed to continue working inside the power generation building during the natural gas blow activities, while other groups were directed to leave while the work was being completed. A few individuals made the personal decision to vacate the building because they were alarmed by the smell of the natural gas odorant.

11. The six individuals fatally injured were all within the power generation building at the time of the explosion; five were involved with the natural gas blow activities and one was not.

Similar Natural Gas Blow Incidents

12. A similar natural gas blow incident occurred on January 26, 2003, at Calpine's Wolfskill Energy Center natural gas power plant in Fairfield, California, during its pre-commissioning phase of construction (Figure 2). High-pressure natural gas at approximately 630 psig was vented through four-inch diameter piping directly to atmosphere to flush out debris.

[3] Two million standard cubic feet of natural gas is more than two billion BTUs worth of gas – enough to fuel a typical American home every day for more than 25 years, assuming typical consumption of 77,900 standard cubic feet per year for a household. (Analogy provided by http://www.aga.org/Kc/aboutnaturalgas/additional/HowtoMeasureNaturalGas.htm, accessed June 23, 2010.)

Figure 2. The Calpine Wolfskill Energy Center gas blow incident

13. The natural gas blow was performed in a congested area; the open-ended pipe was located 10.5 feet off of the ground and situated approximately 10 feet from the gas turbine building. The pipe outlet was located near an overhang of the building that provided between 2,000 and 9,000 cubic feet of confined area in which the dispersed gas could accumulate to an explosive level. While the close proximity of these structures presented potential ignition sources, as their metal surfaces could have caused sparking from expelled debris,[4] Calpine determined that the explosion was most likely ignited by static electricity generated from the natural gas flowing at a high velocity through ungrounded piping.

14. Seven people were present, directing or observing the gas blows on January 26, 2003, including a representative from both the turbine manufacturer and the local fire department. They were standing in different locations, from 80 to 140 feet from the venting location, when the explosion occurred. The explosion was powerful enough to shatter windows a quarter of a mile away and was heard up to 10 miles from the site. When the explosion occurred, the debris was projected over the heads of those workers in the vicinity. No injuries were reported.

15. Calpine's investigation report of the Wolfskill incident identified several factors determined to be causal to the explosion, including that safer alternative means of cleaning the fuel gas piping were not used. The report states: "Use of natural gas is convenient, but certainly is not the only method for cleaning the pipes. Other Calpine facilities do not allow the use of natural gas for such purposes and instead use compressed air."

[4] Lees, F.P. *Loss Prevention in the Process Industries – Hazard Identification, Assessment and Control;* Oxford, UK: Butterworth Heinemann, 1996; Vols. 1, 2, 3.

16. Another natural gas blow incident occurred in October of 2001, during the commissioning of fuel gas piping at a FirstEnergy power generation station in Lorain, Ohio. The fuel gas piping leading to the turbine was cleaned through the use of an air blow, pigging, and finally a high pressure natural gas blow. The incident report indicates that a relatively short, three-foot stack was installed to serve as the fuel gas outlet during the blow. Shortly after commencing the gas blow, the gas unexpectedly ignited, causing a flame to shoot approximately 30 to 40 feet into the air from the stack outlet. Personnel immediately shut off the gas flow to extinguish the fire. No injuries resulted, but the fire caused damage to nearby electrical cables. Investigators concluded that the gas was most likely ignited by a metal particle exiting the piping during the blow which impacted a nearby metal surface, causing a spark. Gas outlet stacks for subsequent blows were increased to 16 feet in height in order to rise above nearby metal structures.

Industry Practices and Safer Alternative Methodologies

17. Natural gas power plants generate electricity with combustion turbines that use natural gas as fuel. Piping from a natural gas supply line to the turbine must be installed as part of the construction process. When new piping is installed, debris such as rust, welding slag, or other foreign material that may have been introduced into the piping during construction can remain. Common practice is to clean the piping after it is installed to ensure that no significant debris remains that, upon startup, could damage the gas turbine (Figure 3).

Figure 3. The cleaning of fuel gas piping at the Kleen Energy site on January 30, 2010, one week prior to the incident; a "gas blow" method was used to remove debris from the piping. The brown cloud seen here is indicative of debris being blown from the line.

18. Turbine manufacturers typically require power plants to meet fuel piping cleanliness standards as part of the turbine warranty requirements. Cleanliness criteria are usually met by demonstrating that the number of impact marks made on a target placed in the flow of the natural gas blow by debris exiting the piping falls below pre-determined limits and sizes. The targets can be made of a variety of materials, including plywood or metal strips. Approximately half of power plants coming online between 2010 and 2015 have already reported the turbine manufacturers they intend to use.[5] Six turbine manufacturers – General Electric (GE), Siemens, Solar, Mitsubishi Power Systems, Pratt & Whitney, and Rolls-Royce – are currently expected to supply 100 percent of the reported gas turbines.[6]

19. In a recent industry survey conducted with the cooperation of the Combined Cycle Users' Group (CCUG) in April 2010, the CSB learned that half of the respondents substitute the use of gas blows with a variety of other techniques to clean newly installed fuel gas piping, including pigging[7] with air or nitrogen, air blows, nitrogen blows, steam blows, water, and chemical cleaning. Although these alternative methodologies are inherently safer from a fire or explosion hazard perspective, use of a natural gas blow is reported by respondents as the primary method to clean newly installed fuel gas piping. At the Kleen Energy site, Siemens, the turbine manufacturer, recommended both natural gas and air blows as acceptable methods for the cleaning of fuel gas piping.

20. About half of survey respondents have no technical basis for determining the natural gas flow needed to adequately clean the piping during a natural gas blow. The lack of a technical evaluation can result in substantially greater quantities of released natural gas than major turbine manufacturers recommend to clean the piping.

21. Companies that do a technical evaluation prior to cleaning newly installed fuel gas piping commonly refer to a technical criterion called the Cleaning Force Ratio (CFR). The CFR is a ratio that expresses the momentum of the gas used to clean the piping with respect to the normal natural gas flow design conditions. The technical concept assumes that if the momentum of the cleaning gas used in a gas blow is greater than the momentum of the natural gas during normal operation, no debris should remain in the piping that could be picked up by the natural gas flow when the turbine is operating. Turbine manufacturers vary the recommended target for the CFR, but the CSB observed a range from 1.0 to 2.0.

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[5] *Platts World Electric Power Plants Database,* 2010. http://www.platts.com/Products.aspx?xmlFile=worldelectricpowerplantsdatabase.xml&commodityName=&category=PriceAssessmentIndices&productname=World%20Electric%20Power%20Plants%20Database.

[6] *Ibid*

[7] Pigging is a process where a device is propelled though a pipeline. The propelled device is commonly referred to as a "pig," and the propellant is typically a gas or liquid. When the pig is used to mechanically scrape and clean the inside of the pipe, it is sometimes called a "cleaning pig."

22. Siemens provided a recommended CFR target of 2.0 in its requirement for the fuel gas system, but no clear upper limit was specified. The natural gas flow data for the day of the incident indicate that the CFR target for the fuel gas piping at the Kleen Energy site was greatly exceeded and, as a result, significantly more natural gas was released than was actually needed to remove debris from the piping.[8]

23. Air blows and nitrogen blows perform the same cleaning function as natural gas blows. According to several major turbine manufacturers, the recommended CFR can easily be obtained using either air or nitrogen. However, the CSB notes that nitrogen can present an asphyxiation hazard.[9] Both air and nitrogen blows have an inherent safety advantage in that no flammable gas cloud would be developed.

24. Another cleaning method is pigging. While fuel gas can be used as the motive fluid to force the pig through the piping, air or nitrogen is commonly used. This technique – when conducted with air or nitrogen – is inherently safer than fuel gas blows to prevent fires and explosions.

25. Liquid cleaning with water or chemicals is also sometimes used to remove rust or other debris from piping. These techniques do not necessarily remove the larger debris, and a fairly common practice is to follow a chemical or water cleaning with a natural gas, air, or nitrogen blow to satisfy the turbine manufacturer cleanliness particle impact testing.

26. For the power plants being built between now and 2015 that have reported the turbines they intend to use, GE will supply 63 percent of the gas turbines.[10] GE has been an industry leader in moving to recommend air blows as a safer alternative method and states that natural gas blows are not the preferred method to clean fuel gas piping. Following the Kleen Energy tragedy, GE's policy is to prohibit its employees from being onsite while a customer conducts a natural gas blow. The policy also states that GE itself will not conduct a natural gas blow unless no other satisfactory method is available. Exceptions to either aspect of this policy can be made only with approval of high-level GE management.

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[8] Determining the CFR of a piping system is complex. The calculated CFR for a given system will vary for a variety of reasons: the gas travels between different sized piping, the design flow rate changes, pressure drops, or the gas temperature changes. For the system at Kleen Energy just downstream of the isolation block valve where the gas was introduced, the CSB estimates a CFR of approximately 10. As the gas travels through the system towards the vent pipe, the CFR is expected to increase to values greater than 50. To calculate the CFR used at Kleen on February 7, the CSB estimated an inlet pressure just downstream of the isolation valve of 300 psig; the design flow rate changed from about 200,000 lbs/hr at the isolation block valve to approximately 72,000 lbs/hr just prior to the vent; the actual flow rate was approximately 470,000 lbs/hr; and the inlet gas temperature downstream of the isolation block valve was 18° F.

[9] The CSB produced a Safety Bulletin and video on the hazards of nitrogen: http://www.csb.gov/investigations/detail.aspx?SID=77&Type=2&pg=1&F_InvestigationId=77.

[10] *Platts World Electric Power Plants Database,* 2010. http://www.platts.com/Products.aspx?xmlFile=worldelectricpowerplantsdatabase.xml&commodityName=&category=PriceAssessmentIndices&productname=World%20Electric%20Power%20Plants%20Database

27. The CSB has not identified a scenario where natural gas blows are necessary to clean fuel gas piping.

28. The independent, nonprofit Electric Power Research Institute, Inc. (EPRI) conducts research and development relating to the generation, delivery, and use of electricity for public benefit.[11] A review of publicly available technical documents from EPRI indicates that the organization does not provide guidance on safe methods to clean fuel gas piping.

Hazards of Releasing Natural Gas Near Work Areas

29. Natural gas blows release large quantities of flammable gas near work areas, which can pose significant safety risks to workers.

30. Methane, the primary component of natural gas, is extremely flammable with a National Fire Protection Association (NFPA) flammability rating of "4," the designation indicating the highest degree of hazard. It has a lower explosive limit (LEL) of 4.4 volume percent and an upper explosive limit of 16.5 volume percent in air. Methane can readily form explosive mixtures that are easily ignited when mixed with air. Methane is also an asphyxiant and may displace oxygen.[12]

31. In any natural gas blow, flammable mixtures will unavoidably occur downstream of the vent outlet. To minimize the extent of the flammable atmosphere, a complex technical evaluation of various factors is necessary, including height, location and orientation of the vent pipe, velocity and density of the natural gas being discharged, potential sources of ignition, personnel location, wind speed, and a dispersion analysis to verify that the natural gas will rapidly dissipate. The complex requirements for discharge design support the use of safer methods to clean fuel gas piping.

32. The CSB has examined a number of natural gas blow procedures. Several serious deficiencies were noted that could result in unsafe work practices, including
    - A lack of a technical evaluation of the vent piping to ensure adequate air mixing and that the release is directed to a safe location,
    - Ill-defined instructions to control or eliminate potential ignition sources, and
    - Failure to recognize that the natural gas blow itself may provide a source of ignition from a potential static charge accumulation in the vent pipe or from

[11] EPRI brings together its scientists and engineers, as well as experts from academia and industry, to help address challenges in electricity, including reliability, efficiency, health, safety, and the environment. EPRI's members represent more than 90 percent of the electricity generated and delivered in the U.S. (www.epri.com)

[12] Canadian Centre for Occupational Health and Safety. http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/methane/working_met.html, (accessed June 3, 2010).

discharged debris sparking upon impact with objects downstream of the ejected natural gas.[13]

33. Well-recognized industry consensus safety guidelines emphasize the importance of eliminating hazards when feasible. *The American National Standard for Occupational Health and Safety Management Systems,* ANSI/AIHA Z10-2005, defines minimum requirements for safety management systems to reduce injuries and fatalities. The standard states "[w]hen controlling a hazard[,] the organization should first consider methods to eliminate the hazard or substitute a less hazardous method or process." This basic process safety system concept is also well-established by the Center for Chemical Process Safety (CCPS) publications on inherent safety.[14] The CCPS documents that Inherent Safety is an approach focused on eliminating or reducing the hazards associated with a set of conditions. A process is inherently safer if it reduces or eliminates hazards and if this reduction or elimination is permanent and inseparable. An inherently safer process should not be viewed as "absolutely safe," as all processes have some element of risk. One important element of inherent safety is substitution, where a less hazardous material is substituted for a more hazardous material. In the case of natural gas blows, cleaning fuel gas piping can be made inherently safer by substituting the more hazardous natural gas with a less hazardous material, such as air, to eliminate the potential for fire and explosion.

34. The possibility of catastrophic consequences, a complex technical evaluation, the extreme difficulty in eliminating and controlling all ignition sources, and the common use of safer methods are compelling reasons to implement safer alternatives to flammable gas releases.

Codes and Standards

35. The National Fire Protection Association (NFPA) and the American Gas Association (AGA) have adopted fire safety consensus code requirements for installing fuel gas piping systems and natural gas usage equipment in *National Fuel Gas Code* (NFPA 54/ANSI Z223.1). The International Code Council (ICC) has adopted the same requirements in the *International Fuel Gas Code.* These requirements are commonly adopted as regulations by various state and local governmental entities throughout the U.S. More than 35 states have adopted NFPA 54, and Connecticut has adopted the 1996 version of NFPA 54.

36. NFPA 54 and the International Fuel Gas Code broadly address fuel gas piping system safety including requirements for design, installation, operations, and maintenance. The codes do not address safe practices for cleaning fuel gas piping.

[13] Lees, F.P. *Loss Prevention in the Process Industries – Hazard Identification, Assessment and Control*; Oxford, UK: Butterworth Heinemann, Oxford, 1996; Vols. 1, 2, 3.

[14] Center for Chemical Process Safety (CCPS). *Inherently Safer Chemical Processes – A Life Cycle Approach*; American Institute of Chemical Engineers (AIChE), 2009.

Moreover, the codes explicitly exempt from coverage fuel gas piping in power plants and piping operated at a pressure of more than 125 psig.

37. NFPA 37, *Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines,* establishes criteria for minimizing the hazards of fire while installing and operating stationary combustion engines and gas turbines. However, NFPA 37 provides no guidance about how to effectively clean new gas piping to gas turbines without creating a fire and explosion hazard and endangering workers. The NFPA's internal interpretation of this standard is that it is not applicable to the type of piping that was being cleaned in the Kleen Energy incident.[15]

38. American Society of Mechanical Engineers (ASME) Code B31.1-2007, *Power Piping*, provides guidance for constructing the temporary piping used to clean or flush foreign material from piping systems. The standard references cleaning out piping by using air or steam but does not explicitly prohibit using natural gas. The standard offers no guidance about the technical or safety aspects for conducting natural gas blows.

39. FM Global Property Loss Prevention Data Sheets for Power Generation include document 7-54, "Natural Gas and Gas Piping." This document calls for the use of air or inert gas to clean or test piping, but allows for the use of fuel gas when the pressure is 0.5 psig or less.

40. NFPA 850, *Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations,* provides fire hazard control recommendations for the safety of construction and operating personnel, the physical integrity of plant components, and the continuity of plant operations. Under NFPA 850, natural gas piping should comply with NFPA 54, *National Fuel Gas Code;* NFPA 55, *Compressed and Cryogenic Gases;* and ASME B31.1, *Power Piping*. NFPA 850 references NFPA 54 even though power plants have been exempted from that standard. NFPA 850 does not address safe practices for cleaning power plant fuel gas piping. As a recommended practice, the provisions of NFPA 850 are not safety requirements and are voluntary in all jurisdictions.

Other Natural Gas Release Incidents

41. There is an underlying common theme among the tragic incidents at Kleen Energy, the ConAgra Foods Slim Jim™ plant explosion in North Carolina, and many other flammable gas-releasing incidents: companies should use safer methods and not release flammable gases in close proximity to ignition sources and workers.

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[15] The NFPA's position is that NFPA 37 applies only to gas piping downstream of the final block valve before the gas turbine. At the time of the Kleen incident, the piping being cleaning and vented was upstream of the block valve. However, this distinction is not explicit in the standard.

42. On June 9, 2009, the ConAgra Foods production facility in Garner, North Carolina, experienced a catastrophic natural gas explosion that caused four deaths, three critical life-threatening burn injuries, an amputation, and other injuries that sent 67 people to the hospital. The explosion caused serious structural damage to the approximately 87,000 square foot south packaging and warehouse area of the Garner plant. The walls and roof collapsed and piping from the plant's large ammonia-based refrigeration system was damaged, causing toxic anhydrous ammonia gas to be released to the atmosphere.

43. At the time of the explosion, natural gas was being purged from a line connected to a newly installed water heater within a central location of the ConAgra Foods facility. This was not a pipe cleaning activity, but parallels the Kleen Energy incident in that fuel gas piping was installed to supply new combustion equipment at both locations. Additionally, flammable natural gas was intentionally released to the atmosphere in the presence of ignition sources and workers.

44. A number of other similar natural gas purging incidents have occurred: the Dearborn, Michigan, Ford Rouge power plant explosion in 1999 (six fatalities); the San Diego, California, Hilton Hotel explosion in 2008 (14 injuries); and the Cheyenne, Wyoming, hotel construction explosion in 2007 (two severely burned).

45. The CSB determined that the version of NFPA 54 that existed at the time of the ConAgra explosion did not require fuel gas piping to be vented safely outdoors. As a result, the CSB made an Urgent Recommendation to NFPA and AGA to enact temporary and permanent changes to NFPA 54 to require that purged fuel gases be vented to a safe location outdoors away from personnel and ignition sources.

46. In response to the CSB Urgent Recommendation addressing the history of serious natural gas purging incidents, the full NFPA 54 committee voted unanimously in February 2010 to adopt stricter standards in the form of a Tentative Interim Amendment (TIA) requiring that larger fuel gas piping systems be purged directly to a safe location outdoors away from workers and sources of ignition. However, in April 2010, the full NFPA 54 committee failed to pass the TIA during a required second ballot. Recently in June 2010, a revised TIA passed. Further action by NFPA is expected in August 2010.

Regulatory Coverage

47. The Occupational Safety and Health Administration (OSHA) has issued general industry and construction regulations[16] that address flammable gas safety, including standards on *Hydrogen* [1910.103]; *Acetylene* [1910.102]; and the

[16] While the Kleen Energy incident occurred during construction activities, cleaning of power plant fuel gas piping can occur under circumstances that are regulated by either OSHA general industry or construction standards.

Storage and Handling of Liquefied Petroleum Gases [1910.110 and 1926.153]. However, OSHA has not issued a standard that addresses the safe handling of natural gas or the hazards of methane – the primary component of natural gas.

48. The consumption of natural gas as a fuel in the U.S. far exceeds that of liquefied petroleum gases (LPG) and ethane (Figure 4).[17,18] Natural gas usage exceeds that of propane, the second most used fuel gas, fifteen times over; however, natural gas is one of only two fuel gases not regulated by OSHA (Figure 4).

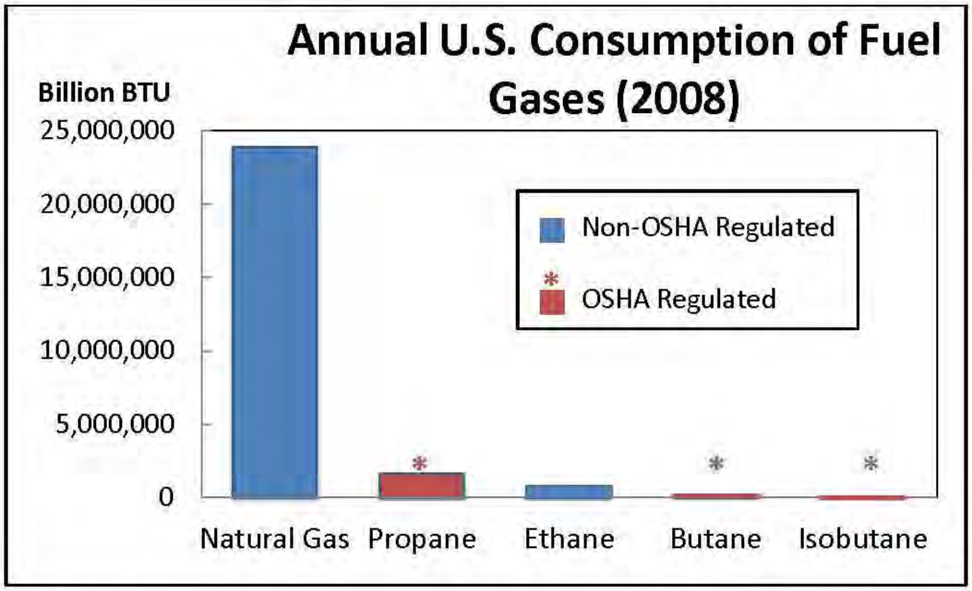

Figure 4. Natural gas is used far more, then the regulated fuel gases shown here.

49. The use of natural gas also far exceeds the use and/or production of other flammable gases in the U.S., including hydrogen and acetylene. However, unlike hydrogen and acetylene, it remains unregulated by OSHA (Figure 5).[19,20,21] Eighty percent of natural gas is used in sectors covered by OSHA; 49 percent is used in

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[17] Energy Information Administration (EIA). Office of Coal, Nuclear, Electric and Alternate Fuels. Natural Gas Consumption by End Use. May 2010. http://www.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm (accessed June 7, 2010).

[18] EIA. Product Supplied. June 2009. http://www.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm (accessed June 7, 2010).

[19] Ibid. footnotes 12 and 13.

[20] EIA. The Impact of Increased Use of Hydrogen on Petroleum Consumption and Carbon Dioxide Emissions, SR/OIAF-CNEAF/2008-04, Aug. 2008. www.eia.doe.gov/oiaf/servicerpt/hydro/pdf/oiafcneaf(08)04.pdf, (accessed June 7, 2010).

[21] Davis, S; Schlag, S.; Funada, C. *Chemical Economics Handbook*: SRI Consulting, 2008. http://www.sriconsulting.com.

industrial and commercial applications and 31 percent is used in power plants. The remaining 20 percent is residential.[22]

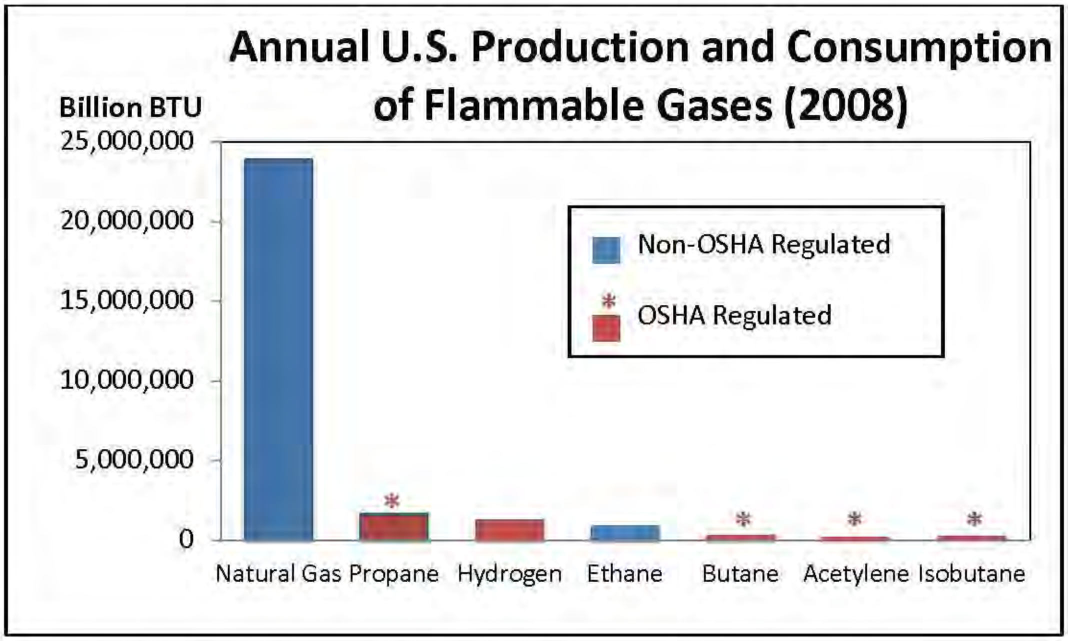

Figure 5. Fuel gas consumption and hydrogen and acetylene production

50. The OSHA standard for LPG was based on the 1969 edition of NFPA 58. The most recent (2008) edition of NFPA 58 contains safe venting provisions that are more protective than OSHA's LPG Standard. These include additional provisions for safe purging of LPG vapor, requiring that vented product be conveyed outdoors "under conditions that result in rapid dispersion" or else combusted.

51. OSHA has issued the *Electric Power Generation, Transmission and Distribution* standard [1910.269(a)(1)(ii)(A)] that covers the operation and maintenance of electric power generation; however, the standard does not apply to the construction work being performed at Kleen Energy on the day of the incident.

52. OSHA's regulatory scheme provides requirements for controlling ignition sources in hazardous locations that may have flammable atmospheres [e.g., 1910.307 *Hazardous* (classified) *locations* and 1910.252 *Welding, Cutting and Brazing*]. However, OSHA's regulations that are otherwise applicable to this incident do not expressly prohibit the planned release of flammable gas in the vicinity of workers. OSHA's Process Safety Management (PSM) Standard [1910.119 and 1926.64] addresses requirements for preventing the consequences of the catastrophic release of highly hazardous chemicals, including flammables. The PSM Standard, however, exempts flammable liquids or gases that are used solely for workplace

[22] McDowell, B. "Natural Gas 101 & Current Industry Issues," American Gas Association, http://www.aga.org/NR/rdonlyres/A66D328D-0D50-4770-BDFC-84D342207381/0/0605NG101.pdf, retrieved June 23, 2010.

fuel consumption, which was the case at Kleen Energy, where the design intent was to use natural gas as a fuel.[23]

53. The Connecticut Governor's Commission investigating the Kleen Energy explosion also found that, although the construction project was heavily regulated by a variety of agencies, no agency regulated the process used – or any process that might be used such as gas purging – to clean the natural gas pipeline that was the source of the explosion.

54. Other U.S. and international workplace safety regulations not only require that ignition sources in hazardous areas be eliminated, but also prohibit workers from being exposed to a work environment with a potential flammable atmosphere. California construction safety regulations[24] require that "flammable vapors shall be controlled so as to avoid hazard to workers." The California construction regulations define adequate ventilation for flammable gases as that which is sufficient to keep the concentration of flammable gas below 20 percent of the LEL.[25] The majority of Canadian provinces prohibit work activity in an area if more than 20 percent of the LEL of a flammable is present in the atmosphere. OSHA has no similar general workplace requirements protecting workers from exposure to flammable atmospheres.

55. At the Kleen Energy site, no safety meeting was conducted, nor was the gas blow procedure reviewed, with the pipe cleaning crew before work began on February 7. Safety meetings and procedural reviews provide personnel opportunities to discuss potential safety risks involved in planned work and suggest safer alternatives. Presently, there are no OSHA regulatory requirements for workers to participate in developing procedures or training related to fuel gas safety.

56. The Environmental Protection Agency (EPA) has reporting regulations for hazardous substances that pose a potential threat to public health, welfare, and the environment, as listed in 40 CFR 302.4. The reportable quantities are based on several intrinsic characteristics, including ignitability; however, methane, which is highly flammable, does not appear in 40 CFR 302.4.

57. Individual states can implement their own environmental reporting requirements and at least two, Louisiana and Michigan, have specific rules concerning releases of natural gas. In Louisiana, releases greater than 1.0 but less than 2.5 million

[23] The PSM standard requires that operating procedures such as those for start-up and temporary operations "provide clear instructions for safely conducting activities," including hazards of the chemicals used in the process and "precautions necessary to prevent exposure." Preliminary CSB analysis indicates that despite the occurrence of a catastrophic incident from the release of a highly hazardous chemical (flammable gas), the amount of flammable gas onsite in the piping would not have met the threshold quantity of 10,000 pounds that would trigger PSM coverage. However, a much larger quantity of flammable gas than 10,000 pounds was released to the atmosphere the morning of the incident.

[24] California Code of Regulations, Title 8, Section 1534, Construction Safety Orders, Flammable Vapors.

[25] The Lower Explosive Limit, LEL, is the concentration of a combustible material in air capable of propagating a flame in the presence of an ignition source (California Code of Regulations, Title 8, Section 1504, Construction Safety Orders, Application).

cubic feet in volume require a permit, but no controls. Releases greater than 2.5 million cubic feet require "flaring"[26] the natural gas. In Michigan, when the release of natural gas exceeds 1.0 million cubic feet, "[t]he venting includes, at a minimum, measures to assure safety of employees and the public [and to] minimize impacts to the environment…." The 23 other states the CSB contacted indicated that they have no specific regulations concerning natural gas releases.

Standard and Basis for Urgent Recommendations

58. Under 42 U.S.C. §7412(r)(6)(C)(ii), the U.S. Chemical Safety and Hazard Investigation Board is charged with "recommending measures to reduce the likelihood or the consequences of incidental releases and proposing corrective steps to make chemical production, processing, handling and storage as safe and free from risk of injury as is possible …."

59. Board procedures authorize the development of an urgent safety recommendation "if an issue is identified during the course of an investigation that is considered to be an imminent hazard and has the potential to cause serious harm unless it is rectified in a short timeframe, or a hazard is identified that is likely to exist in a large segment of industry such that the probability of an incident is significant."

60. General contracting companies and commissioning agents surveyed by the CSB acknowledge that the most common practice to clean fuel gas piping is with natural gas. From a fire and explosion perspective, releasing large volumes of natural gas in the vicinity of workers or ignition sources is inherently unsafe.

61. Approximately 125 power plants will commission new natural gas-fired combustion turbines between 2010 and 2015.[27] Figure 6 depicts the location density of these various plants across the U.S.

[26] Flaring is a process by which combustible gas is directed to disposal equipment so that it may be destroyed by burning rather than being released to the atmosphere.
[27] *Platts World Electric Power Plants Database,* 2010. http://www.platts.com/Products.aspx?xmlFile=worldelectricpowerplantsdatabase.xml&commodityName=&category=PriceAssessmentIndices&productname=World%20Electric%20Power%20Plants%20Database.

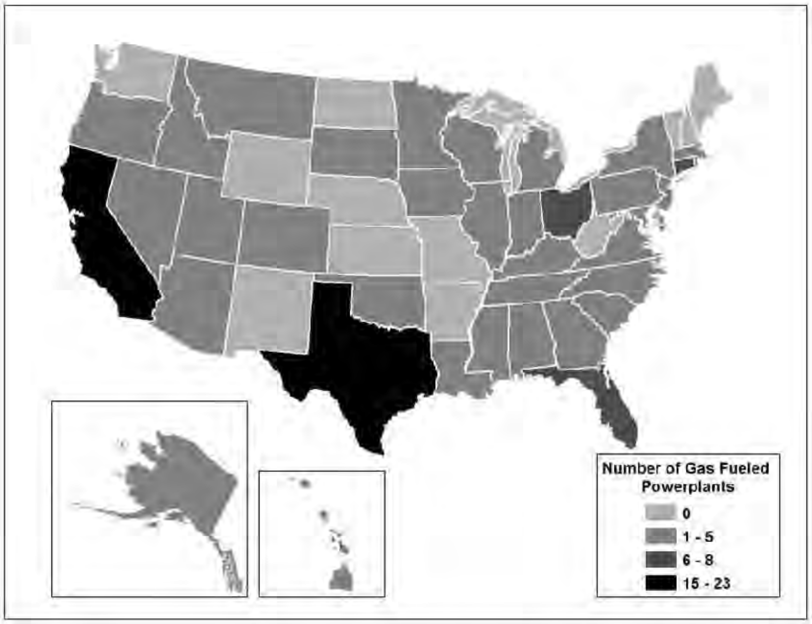

Figure 6. Location density of power plants with new natural gas-fueled combustion turbines (2010-2015)

62. The CSB has documented previous incidents where flammable gas was released in the vicinity of workers and ignition sources that led to serious fires and explosions.[28]

63. Companies continue to conduct natural gas blows after the Kleen Energy explosion. The CSB contacted 33 natural gas power generation plants currently under construction or planned to be constructed in the near future, and learned of two plants that have conducted a natural gas blow since the Kleen Energy incident and several others that are actively planning natural gas blows. Other plants the CSB contacted indicated that, because of the incident, they will not conduct a natural gas blow or will look into safer alternatives.

64. Well-recognized safety guidance requires that safety hazards be eliminated where feasible. Safer alternatives to natural gas blows, such as using air, nitrogen or pigging with air, are commonly practiced. GE and Siemens, two major turbine manufacturers, acknowledge that safer alternatives, such as using air, are just as effective as natural gas for cleaning fuel gas piping.

65. The electric power generation sector and related industry associations do not currently operate a safety standards development program or publish industry-recognized safety standards. No recognized good practice safety standards or technical guidelines address the conduct of cleaning power plant fuel gas piping.

[28] Paragraphs 12, 16, 41, and 44 of this Urgent Recommendation document these releases.

66. Although the use of natural gas far exceeds that of other regulated flammable gases, OSHA has not issued a standard that addresses the safe handling of natural gas or that prohibits the release of fuel gas in the vicinity of workers and/or ignition sources.

Accordingly:

Pursuant to its authority under 42 U.S.C. § 7412(r)(6)(C)(i) and (ii), and in the interest of preventing the serious harm that could result if the hazards underlying the explosions at Kleen Energy, ConAgra and other related incidents are not promptly rectified, the Board makes the following urgent safety recommendations:

Occupational Safety and Health Administration (OSHA)

2010-01-I-CT-UR1 Promulgate regulations that address fuel gas safety for both construction and general industry. At a minimum:

a. Prohibit the release of flammable gas to the atmosphere for the purpose of cleaning fuel gas piping.

b. Prohibit flammable gas venting or purging indoors. Prohibit venting or purging outdoors where fuel gas may form a flammable atmosphere in the vicinity of workers and/or ignition sources.

c. Prohibit any work activity in areas where the concentration of flammable gas exceeds a fixed low percentage of the lower explosive limit (LEL) determined by appropriate combustible gas monitoring.

d. Require that companies develop flammable gas safety procedures and training that involves contractors, workers, and their representatives in decision-making.

National Fire Protection Association (NFPA)

2010-01-I-CT-UR2 Enact a Tentative Interim Amendment and permanent changes to the National Fuel Gas Code (NFPA 54/ANSI Z223.1) that address the safe conduct of fuel gas piping cleaning operations. At a minimum:

a. Remove the existing NFPA 54 fuel gas piping exemptions for power plants and systems with an operating pressure of 125 pounds per square inch gauge (psig) or more.

b. For cleaning methodology, require the use of inherently safer alternatives such as air blows or pigging with air in lieu of flammable gas.

American Society of Mechanical Engineers (ASME)

2010-01-I-CT-UR3 Make appropriate changes to the 2012 version of *Power Piping*, ASME B31.1, to require the use of inherently safer fuel gas piping cleaning methodologies rather than natural gas blows. At a minimum, for the cleaning or flushing methods discussed in B31.1 paragraph 122.10, require the use of inherently safer alternatives such as air blows and pigging with air as the motive force in lieu of flammable gas.

Major Gas Turbine Manufactures

General Electric	**2010-01-I-CT-UR4**
Siemens	**2010-01-I-CT-UR5**
Solar	**2010-01-I-CT-UR6**
Mitsubishi Power Systems	**2010-01-I-CT-UR7**
Pratt & Whitney	**2010-01-I-CT-UR8**
Rolls-Royce	**2010-01-I-CT-UR9**

Provide to your customers:

a. Comprehensive technical guidance on inherently safer methods for cleaning fuel gas piping, such as the use of air or pigging with air.

b. Comprehensive Cleaning Force Ratio (CFR) guidelines, specifying both the upper and lower limits required to obtain satisfactory cleaning for the fuel gas piping for purposes of the warranties of the turbines.

c. Warnings against the use of fuel gas to clean pipes.

General Electric	**2010-01-I-CT-UR10**
Solar	**2010-01-I-CT-UR11**
Siemens	**2010-01-I-CT-UR12**
Mitsubishi Power Systems	**2010-01-I-CT-UR13**
Pratt & Whitney	**2010-01-I-CT-UR14**
Rolls-Royce	**2010-01-I-CT-UR15**

Work with the Electric Power Research Institute to publish technical guidance addressing the safe cleaning of fuel gas piping supplying gas turbines. At minimum:

a. For cleaning methodology, require the use of inherently safer alternatives such as air blows and pigging with air in lieu of flammable gas.

b. Provide technical guidance for the safe and effective use of alternative methods for cleaning such as air and pigging with air.

The Governor and Legislature of the State of Connecticut

2010-01-I-CT-UR16 Enact legislation applicable to power plants in the state that prohibits the use of flammable gas that is released to the atmosphere to clean fuel gas piping.

2010-01-I-CT-UR17 Adopt the current version of NFPA 54 as amended pursuant to 2010-01-I-CT-R2.

The Board further authorizes and directs the chairperson to send correspondence to the governors of the other 49 states urging them to review the Board's findings concerning the explosion at Kleen Energy, the Board's recommendations to Connecticut, existing state regulations concerning natural gas safety, and to enact any necessary changes to state regulations and codes to prohibit the release of natural gas to the atmosphere during pipe cleaning operations at power plants and other similar facilities.

Electric Power Research Institute (EPRI)

2010-01-I-CT-UR18 Work with the six turbine manufacturers identified in this document – General Electric, Siemens, Solar, Mitsubishi Power Systems, Pratt & Whitney, and Rolls-Royce – to publish technical guidance addressing the safe cleaning of fuel gas piping supplying gas turbines. At minimum:

a. For cleaning methodology, require the use of inherently safer alternatives such as air blows and pigging with air in lieu of flammable gas.

b. Provide comprehensive technical guidance on inherently safer methods for cleaning fuel gas piping, such as the use of air or pigging with air.