Exponent, Inc.
9 Strathmore Road
Natick, MA 01760

telephone 508-652-8500
facsimile 508-652-8599
www.exponent.com

April 8, 2016

Mr. Roy MacDowell
Legacy Farms, LLC
21 Center Street
Weston, MA, 02493

Subject: Legacy Farms Development
Exponent Project No. 1505680.000

Dear Mr. MacDowell:

At your request, Exponent Failure Analysis Associates (Exponent) has reviewed the following materials in regards to this matter:

- Report of Smith & Burgess Project #0639, dated February 9, 2016
- Peer Review Report of Sanborn Head & Associates, Inc., dated March 29, 2016
- Response of Smith & Burgess, dated April 1, 2016

Our scope was to evaluate the assumptions, methodology, and findings of these reports in regards to the potential consequences for releases at the Liquefied Natural Gas (LNG) peakshaver facility operated by NSTAR/Eversource (NSTAR) in Hopkinton, Massachusetts.

When evaluating the risk posed by an LNG facility, numerous accidental release scenarios may be considered, but selection of the scenarios should be consistent with generally-accepted industry practices. The regulatory requirements as set forth by FERC and PHMSA establish those practices in the US for selecting credible worst case design spills. Two credible scenarios that are evaluated for modern LNG facilities are the guillotine rupture of a tank outlet pipe and the guillotine rupture of an LNG transfer pipeline. However, these scenarios usually pose an insignificant risk to society beyond the LNG facility in accordance with the regulations.

The risk of an event is the aggregate of the consequence of that event and the likelihood of the event. The likelihood of an LNG pipe failing is low since it is such a rare event. Typical likelihoods for these two LNG piping failure events are codified in the state-of-the-art safety standard, NFPA 59A (2016 edition) “Standard for the Production, Storage, and Handling of

Liquefied Natural Gas (LNG).” For example, compare the likelihood of the 10-inch pipe rupture scenarios to those of other types of common accidents:

Death in Car Accident – 1 in 10,000 years

Being Struck by Lightning – 1 in 1 million years

10-inch Diameter Pipe Rupture at a Specific Location – 1 in 1 million to 10 million years

The likelihood of a 10-inch diameter pipe rupture is approximately the same as a person’s likelihood of being struck by lightning. In other words, the likelihood of the events that were considered by Smith & Burgess is miniscule, and such catastrophic events have never occurred in the LNG industry since the 1944 Cleveland Accident despite the hundreds of similar peak-shaving facilities in operation in the US.

The February 9, 2016, Smith & Burgess report provided a summary of their model assumptions and methodology, but it did not fully describe their models. Regardless, the report provides sufficient detail on their assumptions and results to render some significant scientific conclusions about the work. Smith & Burgess identified two release scenarios, namely a breach in a tank and a guillotine rupture of the transfer line from the tanks near the road. However, the assumptions, release scenario parameters, and modeling approaches are not consistent with accepted engineering approaches for LNG releases at facilities such as the NSTAR facility in Hopkinton. Specifically, both cases considered by Smith & Burgess would actually result in low pressure liquid spills to the ground, not high velocity jets as they have assumed without any scientific justification. In the case of the tank release, the LNG is at low pressure in the tank, and would not form a high speed jet. In the case of the pipeline rupture, Smith & Burgess overestimated the initial pressure in the pipe by a factor of over 7. Following a guillotine break, the interior of the pipe will quickly depressurize and cause a low pressure spill onto the ground. In both cases Smith & Burgess grossly overestimated the rate of vapor formation and extent associated with the scenarios they considered.

The following sections contain additional comments and observations about the Smith & Burgess analysis, including their incorrect modeling of LNG spills that is inconsistent with how this has been and continues to be carried out in the literature and in industry.

Tank Spill

- The Smith & Burgess tank spill model assumes a high speed jet despite the low pressure in the tank. Their model does not predict any liquid pool formation for this spill. Industry-accepted modeling approaches and the physics of the event result in a spill of almost all the LNG to the ground, in liquid form. The resulting liquid pool will be contained to the area of the tank impoundment and slowly evaporate over a long period of time.

- Smith & Burgess selected an arbitrarily-sized hole in the inner tank. The general industry practice, as codified in NFPA 59A (2001) and 49 CFR 193, is to select the tank hole size as the size of the largest pipe connection to the tank. In this case, that pipe diameter is 10-inches. The resulting hole size is 0.545 square feet in area, which is almost 33 times smaller than the arbitrary hole size that Smith & Burgess selected.
- Smith & Burgess presents a hole formation scenario with no foundation or statement of its likelihood for the deformation and failure of the inner tank due to ice accumulation in the annular space between the outer tank and the inner tank. In practice, this annular space will be filled with insulation material, in this case perlite, and maintained under a nitrogen gas blanket to prevent ambient moisture infiltration.
- Further, NFPA 59A (2001) provides a standard calculation for determining the rate of LNG spill from the tank opening. That rate is 221 kilograms per second, which is 61 times smaller than the spill rate that Smith & Burgess selected.

Pipeline Rupture

- Using 800 psi as the source pressure is incorrect; this pressure only exists downstream of the high pressure pumps feeding the submerged combustion vaporizers. The line pressure at the pipeline where it crosses the road is less than 110 psig, which is the design pressure for the tank discharge pumps. The high pressure 800 psi pipeline is located well within the boundaries of the facility and is not subject to accidental impact by a vehicle on the public roadway.
- For a release at the 10-inch diameter pipeline along the roadway, almost all of the LNG release will be spilled to the ground as a liquid pool. This pool should accumulate within the area surrounding the pipeline and flow into the drainage ditches along the roadway (see images in Figure 1). Evaporation of the LNG will be relatively slow and steady over a prolonged period, certainly much slower than for the artificially high speed jets assumed by Smith & Burgess.
- Further, given the initiating event of a high-energy mechanical impact, such a release is likely to be quickly ignited. No flammable vapor clouds would be created as a result of such a spill. Instead, the consequences will be localized to the immediate area around the ruptured pipeline.

Figure 1. Image of the pipeline road crossing under Wilson St. at the NSTAR facility. Note that any LNG spill from the pipeline will collect in the depression on the right side (west) of the road. Arrows indicate the pipeline impact point identified by Smith & Burgess and the depression.

CFD Model

The LNG liquid dispersion and evaporation is not modelled properly in the Smith & Burgess Star-CCM+ model:

- Due to incorrect modelling assumptions made by Smith & Burgess, the guillotine rupture and tank spill scenarios show that the LNG is dispersed and rapidly evaporates before it reaches the ground, while in reality, close to 100% of the LNG would fall to the ground and evaporate much more slowly.
- In addition, Smith & Burgess impose artificially high velocity to the jets, which propels the vapors much further than would actually happen with correctly modeled low pressure and velocity liquid spills.
- For the guillotine rupture and tank spill scenarios, the evaporation of LNG will be dominated by conduction heat transfer from the ground. This is well recognized in the peer reviewed engineering and scientific literature on LNG. This heat transfer mechanism, however, was not considered at all in the Smith & Burgess model. The LNG evaporation in their model is wrongly governed by convection heat transfer from the surrounding air to the dispersed LNG droplets, causing a gross overestimation of the rate of natural gas vapor formation. A spill of LNG onto the ground also causes the ground to cool rapidly, and as a result, the rate of evaporation also will decrease equally rapidly.
- Contrary to the statements made by Smith & Burgess, porous regions can be modeled using Star-CCM+ and the trees and the forest surrounding the LNG facility will have a significant impact on vapor dispersion, shielding the dense cloud from the wind and causing the vapors to travel downhill following the local topography.

- Smith & Burgess indicate that when it comes to modelling pool evaporation, “the physics are generally not well defined and they depend entirely upon empirical data.” To the contrary, conductive heat transfer from the ground to a LNG pool is very well understood and quantified, and models are readily available. Such models are widely used, constitute standard practice in the industry, and are required to be used by applicable standards.
- According to Smith & Burgess: “As for the source of the heat transfer to vaporize the LNG, this actually predominantly comes from the rapid mixing of the LNG with the air.” This is only a result of Smith & Burgess’s incorrect and non-physical assumption of high-pressure jetting and flashing releases with no rainout. This is not the expected outcome of a guillotine break and rapid depressurization of a pipe (where the flow is limited by the capacity of the pump) or a breach of a low-pressure storage tank.
- According to Smith & Burgess: “the jet is mechanically fragmented due to the very high velocities, and the sudden depressurization from moving from very high pressures to low pressures sends shock waves through the liquid, resulting in rapid vaporization of the liquid and the development of an aerosol spray. This spray in turn has a high surface area contact with the air, and in combination with the large amount of turbulence and mixing that occurs with the air, a large amount of heat transfer occurs, thus leading to the large amount of LNG vaporization seen in the CFD models”. Again, this model result is the consequence of applying incorrect modeling assumptions that artificially enhance the amount of vapor that is formed. This is not the expected outcome of a guillotine break and rapid depressurization of a pipe (where the flow is limited by the capacity of the pump) or a breach of a low-pressure storage tank.
- The FLACS CFD software that is widely used in the industry is fully capable of modeling liquid spills onto the ground and the associated boiling. Likewise, Exponent has routinely modeled LNG liquid spills and their evaporation on the ground, and modeled the dispersion of vapor clouds with both Star-CCM+ and the FLACS software. The VOF method used by Smith & Burgess does not and cannot predict evaporation of the liquid as the LNG boils on the ground. The model as applied by Smith & Burgess is not suited for the type of release they simulated.

Closing

In summary, the modeling reported by Smith & Burgess in their February 9, 2016, report is inaccurate, incorrect, and does not meet the standard expectations for this type of analysis in the LNG industry.

Limitations

At the request of Legacy Farms LLC, Exponent has performed a peer review of the reports generated by Smith & Burgess and Sanborn Head & Associates. Exponent has not visited the HOPCO LNG facility. Exponent has not performed any independent analysis of the risks imposed by the Liquefied Natural Gas (LNG) peakshaver facility operated by NSTAR/Eversource (NSTAR) on the proposed Legacy Farms Development. The scope of services performed to date may not adequately address the needs of other users of this letter report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

The findings presented herein are made to a reasonable degree of engineering certainty. If new data becomes available or there are perceived omissions or misstatements in this report regarding any aspect of those conditions, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them.

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,

H Kytomaa

Harri K. Kytömaa, Ph.D., FASME
Corporate Vice President
Director, Thermal Sciences
and Engineering