LONG-TERM ASSESSMENT OF NATURAL GAS INFRASTRUCTURE TO SERVE ELECTRIC GENERATION NEEDS WITHIN ERCOT: APPENDIX A

Prepared for

The Electric Reliability Council of Texas

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APPENDIX A

Black & Veatch, at the request of ERCOT, has summarized in this Appendix, the factors that cause gas supply disruptions due to freezing weather.

In 2012, Black & Veatch identified and reviewed 216 historical curtailment incidents from the various data sources. A key finding from review of those incidents is that the majority of historical curtailments to electric generators within ERCOT's service region during freezing weather appear to have been contractually permitted and triggered by a temperature threshold. A small number of cold-weather-related incidents were attributed to physical disruption of upstream supply or infrastructure. Figure 1 shows a fishbone diagram[1] outlining possible causes and effects leading to gas system failure related to freezing weather.

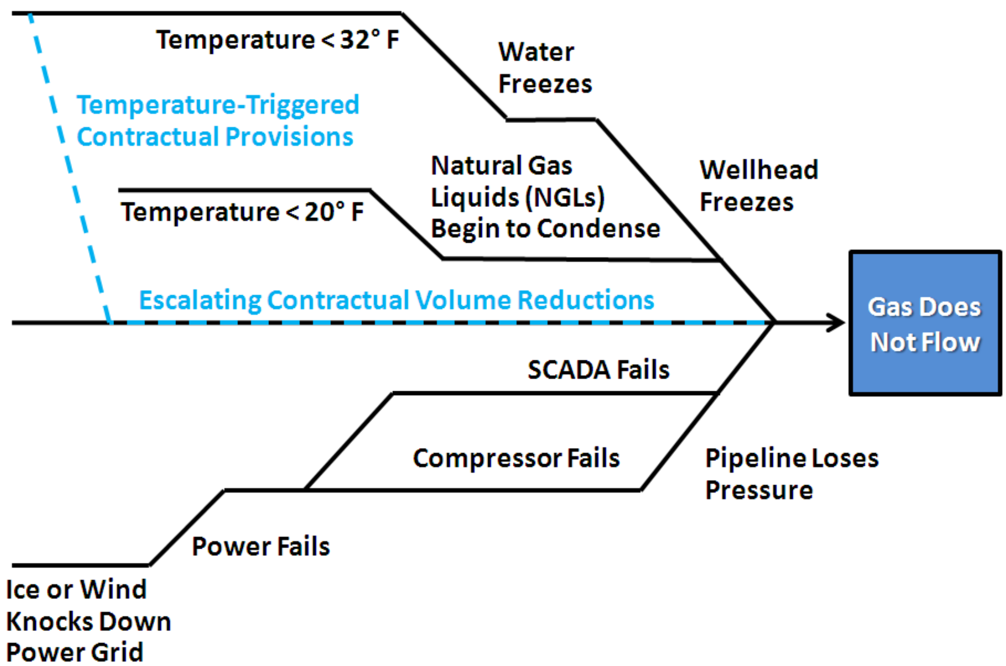


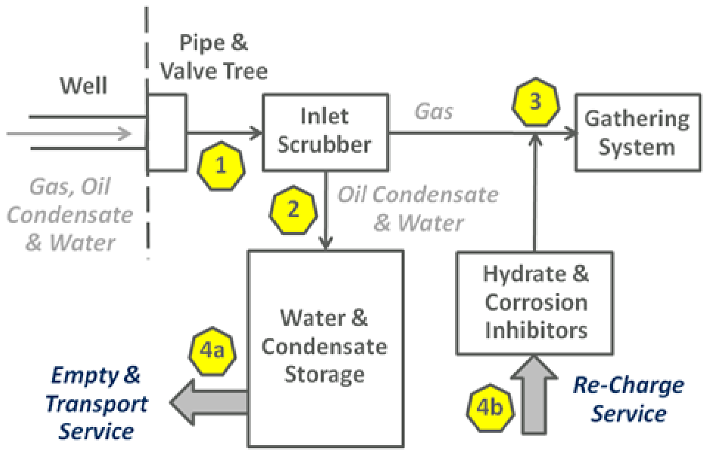
Figure 1 Fishbone diagram for possible freezing-weather causes of gas curtailments.

In a failure modes and effects analysis (FMEA), these are possible cause-and-effect strings that can affect gas-system performance, based on general historical experience. The precise cause-and-effect string is not always expressly published for every curtailment event. The potential factors leading to gas supply disruptions due to freezing weather are 1) freezing of onshore gas wellheads, 2) onshore power grids trip and pipelines lose pressure as gas compressors and/or Supervisory Control and Data Acquisition (SCADA) systems lose power

[1] A fishbone diagram (also known as an Ishikawa diagram) is a tool used to identify failure pathways in a failure mode and effects (FMEA) analysis. In the current study, fishbone diagrams are used to summarize how causative agents might lead to gas curtailments but without identifying likelihood of the alternative pathways.

and 3) contractual provisions with gas suppliers/transporters that allow curtailment of gas supply to power generators based on temperature thresholds.

Freezing weather can reduce gas flow at the wellhead through abnormal accumulations of liquids or ice which become problematic only at cold temperatures (Figure 2). The product stream from the well generally contains raw gas mixed with various amounts of water and oil condensates which must be promptly separated before the gas can be placed in a gathering-system pipeline and sent to a processing plant.



Temperature	Significance
60° F	Standard temperature for gas metering & transmission
40-20° F	C_{4+} NGL gases condense to liquids or hydrates (if not de-hydrated)
32° F	Water freezes

Figure 2. Freeze-off risks at an onshore natural gas wellhead.

Direct freeze-off effects include blockage of gas flow through (1) water frozen in the pipe-and-valve tree ("Christmas Tree") atop the wellhead; (2) water frozen in the scrubber/separator which splits the product streams; (3) natural gas liquids (NGLs) or hydrates condensed before the gas can exit to the gathering system. Indirect freeze-off effects most commonly are breakdowns in the field services needed to keep the wellhead processes operational, including (4a) removal of separated water and oil condensate from limited onsite storage; (4b) replenishment of consumable chemicals (hydrate and corrosion inhibitors) which comprise the first line of gas treatment to prevent condensation in gathering pipelines. Modern wellhead systems include automated SCADA systems which normally are programmed to recognize empty/full tank conditions and shut-off product stream flow at the tree to prevent larger problems of spillage or line clogging. Interruptions to field services commonly are related to access problems created by inclement weather conditions.

Based on principles of thermodynamics, wind chill[2] increases the rate at which an object loses heat to the environment (Figure 3). Under influence of a strong wind, thermal conductive cooling is dominant whereas under calm conditions cooling is slower when more limited by thermal radiation. Nonetheless, the physical low temperature – not wind chill -- ultimately determines whether freezing occurs.

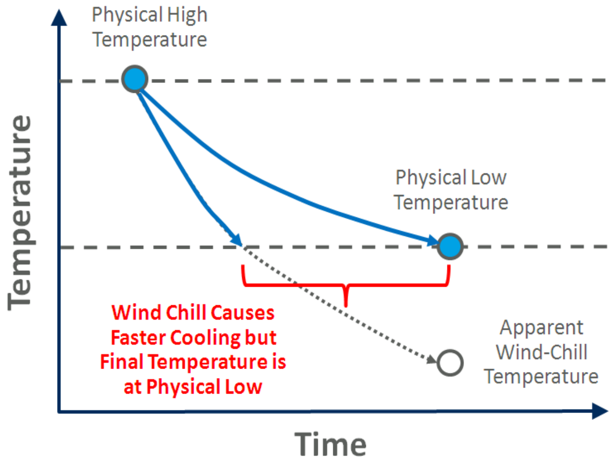


Figure 3. Significance of physical temperature relative to wind chill.

Freezing of water and condensation of NGLs are different problems which vary according to the composition of the product stream from each well. Associated gas which is produced from oil wells generally will flow greater proportions of water as the well ages. Therefore, older "conventional" gas wells tend to be at greater risk of water-related freeze-offs. "Unconventional" gas, such as from shales or other tight formations, will be at relatively greater risk of water-related freeze-offs if the wells are relatively young (i.e., completed within the last few months) because the flow-back of hydraulic-fracturing water probably still is in progress. NGL contents will be at risk for condensate formation both in conventional and unconventional wells and the risks will increase as the NGL contents increase. Therefore, risks of wellhead freeze-offs are expected to exist for all types of gas fields although specific risks for any specific field will depend on the types and ages of the wells in the field.

Black & Veatch utilized Barnett Shale data to develop the models for production loss because it was the largest gas resource with the longest baseline of production data in the 2011-2012 timeframe. Accordingly, empirical models for production losses during freezing-weather events were focused on the Barnett Shale data with the premise that the Barnett loss functions can be used as proxies for other gas fields which supply ERCOT. Our analysis also examined the production loss in the Haynesville, and Eagle Ford as a

[2] Wind chill is an apparent temperature calculated from wind speed and real physical temperature. It is a theoretical index designed to guide decisions about human exposure to cold environments. Wind chill is only defined for temperatures at or below 50º F and wind speeds above 3 mph. Bright sunshine may increase the wind chill temperature (i.e., make it less severe) by 10-18º F. http://www.nws.noaa.gov/om/windchill/

comparison to Barnett Shale during the February 2011 freezing weather event. While there was some variation in production loss due to gas liquid content, the range in production loss during the event between the various plays was not significant.

Empirical production-loss curves were developed both for physical temperature and for wind chill using historical production and weather data (Figure 4). Both linear and non-linear regressions were calculated based on analysis of historical production losses versus historical weather for the six major freezing-weather events captured in the ERCOT Operator Logs (2002-2011; solid dots in Figure 4). Loss functions for wind chill are statistically stronger (higher R^2 values) but loss functions for physical temperature predict the highest production losses. Both for temperature- and wind chill-based functions, the non-linear models appear to be statically more robust (higher R^2 values). Therefore, to estimate "worst case" freeze-off losses, the model chosen was the non-linear Production Loss vs. Physical Low T(F) from the left-hand chart in Figure 4.

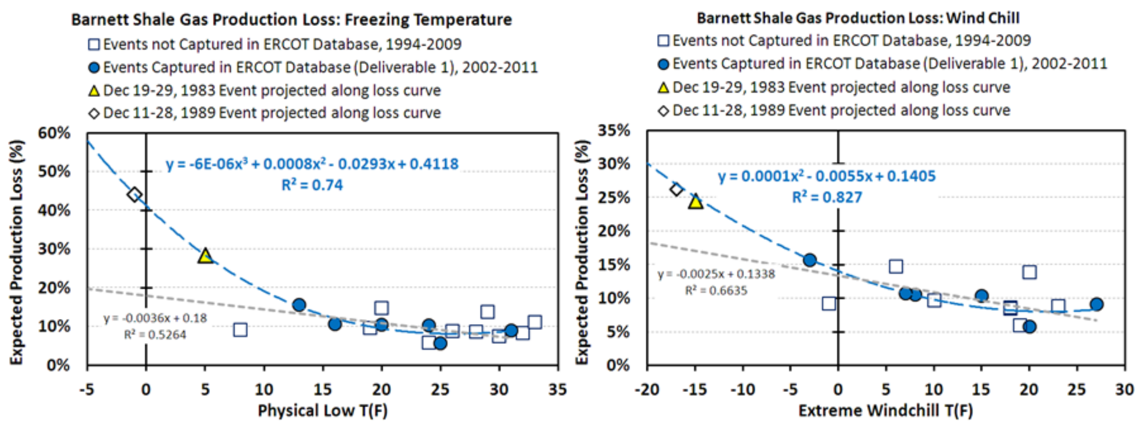


Figure 4. Empirical production-loss models based on production-weather data regressions.

In Figure 4, the fitted production-loss indicates a 10% production loss at temperatures between 20^0-35^0. Assuming low temperatures on the flat part of the curve and this 10% production loss, Texas production in 2015 would be about 17 Bcf/day and total Texas demand would be about 13 Bcf/day. The associated production loss would serve to reduce exports out of state, particularly with the supplies currently coming from the Marcellus and other plays out of state that reduce the dependence of other states on Texas pipeline exports.

In general, Gulf Coast fields (including Texas) do not routinely have freeze protection. With gas prices being low – and storage being full – the risk of 2-3 days of possible freeze-off every several years is a risk that Gulf Coast producers have been willing to take. It is a tradeoff between lost revenue from lost production vs. lost revenue from higher annual operating costs needed to freeze-protect individual wells.