# Pipeline Failure

A failure of a major pipeline, including crude oil, petroleum, natural gas transmission and natural gas distribution pipelines.

The SNRA Pipeline Failure hazard event is currently part of the SNRA's qualitatively described research base. Substantial work towards the fully quantitative analysis of the Pipeline event within the SNRA framework has been undertaken, and the data sources and interim analysis in progress are provided below for the next analyst or project team to continue this work.

Interim estimates are provided in Table 12 at the end of this summary sheet, for the convenience of the reader or reviewer. These numbers are still under review, and may change substantially when the quantitative analysis of this hazard has been completed.

## Event Background

While many forms of transportation are used to move products such as crude oil, refined petroleum products, and natural gas to marketplaces throughout the U.S., pipelines and pipe networks are major carriers because they are the safest, most efficient, and most economical way to transport all manner of liquid and gaseous commodities throughout the Nation.[44]

Although pipelines have proven to be a safe means of transportation, they are still susceptible to significant and costly failures. These failures may result in system impacts, economic impacts, fatalities and injuries, and can also result in significant environmental impact. When failures occur they result in release of the transported product to the environment, with potential for fire, explosion, and toxic exposure. The nature of the system consequences will vary according the system, the materials involved, and the length of time the system is out of operation. There is a wide variety of causes for the accidents.

Pipelines transport hydrocarbon-based liquids and gases from one site to another, sometimes at great distances as part of a large system. These resources are found in completely different locations than where they are eventually processed or refined into fuels. They are also in very different locations from where they are consumed. While many forms of transport are used to move these products to marketplaces, pipelines remain the safest, most efficient and economical way to move these natural resources.

The U.S. depends on a network of more than 185,000 miles of liquid petroleum pipelines, nearly 320,000 miles of gas transmission pipelines, and more than 2 million miles of gas distribution pipelines to safely and efficiently move energy and raw materials to fuel our Nation's economic engine. This system of pipelines serves as a national network to move the energy resources from production areas or ports of entry throughout North America to consumers, airports, military bases, population centers, and industry every day.[45]

For the purposes of understanding the risk profile of pipelines, it is useful to consider four different types of pipeline:

- Crude oil pipelines

[44] http://www.pipeline101.com/why-do-we-need-pipelines
[45] http://www.eia.gov/forecasts/steo/special/pdf/california.pdf

- Petroleum product pipelines
- Natural gas transmission lines (including natural gas gathering lines and liquid natural gas pipelines)
- Natural gas distribution piping networks

When a *crude oil* pipeline fails, the movement of crude oil into a refinery is disrupted and the refinery may need to scale back production when its feed stocks are reduced (typically one to two weeks). If disruptions to a crude oil pipeline are frequent or prolonged, a refinery could be forced to shut down. Crude oil also produces environmental contamination and clean-up costs. Crude oil pipeline failures may also present significant restart challenges for very heavy crude oil requiring heating to flow; loss of pipeline flow can cause the heavy crude oil to begin to solidify, requiring clearing that could result in an extended loss of service to the refineries they serve, depending on the conditions under which the system managers are operating.[46]

*Refined petroleum products* move in the pipeline consecutively. Each distinct product is referred to as a "batch" and when several products are placed together in the line, they are called a "batch train." As a batch train moves through the pipeline, adjacent products commingle, forming the "interface" zone. The extent of commingling, or the length of the interface, is a function of velocity, density difference between the two products, viscosity, pipe diameter, and distance traveled [47] The long-term failure of a petroleum product pipeline disrupts the supply chain to all of the distribution points downstream, forcing the use of tanker trucks and trains as an inefficient alternative.

Typically when a petroleum pipeline fails there are few fatalities or injuries. Release of other hazardous chemicals may result in fatalities or injuries, but often in small numbers. During 2012 and 2013 (the latest analyzed at a national level) a total of 762 hazardous liquid pipeline incidents occurred. Five of these were classified as serious, resulting in four fatalities and nine injuries. For comparison, there were a total of 1,188 accidents for all pipeline classes in 2012 and 2013, with a total of 22 fatalities and 113 injuries. According to Pipeline Hazardous Materials Substances Administration (PHMSA) data, the hazardous liquid pipeline failures in that two-year period resulted in $412 million in property damage.[48]

Approximately 114,200 barrels were lost due to these incidents, with an estimated current value of over $14 million, based on an average crack spread of $25 per barrel during 2012 to 2013[49] and an average value crude oil price of $100 per barrel.[50] This might be considered a fairly common event, with relatively low consequences, though the costs of environmental remediation have not been captured. This information is provided for the purpose of clarifying the pattern of risks for non-gas pipelines, but was not included in this assessment as a separate break-down of incident types. However, a failure of a major land pipeline transporting refined petroleum products could result in direct economic damages of $100 million or greater.

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[46] http://www.ogj.com/articles/print/volume-96/issue-40/in-this-issue/pipeline/batching-treating-keys-to-moving-refined-products-in-crude-oil-line.html

[47] http://www.ogj.com/articles/print/volume-96/issue-40/in-this-issue/pipeline/batching-treating-keys-to-moving-refined-products-in-crude-oil-line.html

[48] http://www.phmsa.dot.gov/pipeline/library/datastatistics/pipelineincidenttrends

[49] http://marketrealist.com/2013/07/crack-spread-101-part-4-effect-on-refiner-margins/

[50] http://www.eia.gov/forecasts/steo/realprices/

In July 2010 a six-foot break in Enbridge's 6B pipeline occurred, releasing more than 20,000 barrels of heavy tar sands crude into Talmadge Creek, a tributary of the Kalamazoo River in Michigan. The clean-up from this spill has totaled $1.21 billion to date, and is still on-going. It represents the largest inland U.S. oil spill and one of the costliest spills in U.S. history.[51]

The potential for much more problematic petroleum pipeline failures exist on the floor of the Gulf of Mexico, as evidenced by the 2010 Deepwater Horizon spill. These pipelines are not subject to the same maintenance, inspections, and regulations that surface pipelines are, and due to the constant motion of the water, are difficult to precisely locate. The routine observed rate of failure is lower for such pipelines, however, than incidents on land. Maritime oil spills due to pipeline ruptures are discussed more in the Oil Spill section of this assessment.

*Natural gas transmission* pipeline system accidents are also fairly common (229 during the period of 2012-2013), and more likely than petroleum pipelines to result in casualties. However, the casualty numbers typically are still low because these pipelines are not commonly found in heavily populated areas. No fatalities and nine injuries from natural gas transmission pipeline incidents we reported in 2012-2013, and property damages of just over $109 million for all 229 accidents, or an average of close to $476 thousand per incident. While the average transmission accident is more costly, because of its comparative rarity and lower casualty count, transmission pipeline accidents pose lower fatality and injury risk than other pipeline accidents.

When a natural gas transmission pipeline ruptures in an urban area, it can result in a substantial amount of destruction. A good example of this is the explosion of a 30 inch pipeline in downtown San Bruno, CA on September 9, 2010. The loud roar and shaking caused people in the community to initially think it was an earthquake. The USGS registered the explosion and resulting shockwave as a magnitude 1.1 earthquake.[52] Eyewitnesses stated that the initial explosion resulted in a wall of fire more than 1000 feet high. Eight people died in the explosion and 58 people were injured[53]. The explosion also destroyed 35 homes and damaged many more. It took PG&E, the owner of the pipeline, 90 minutes to shut off the natural gas flow through the ruptured pipeline. On April 9, 2015, the California PUC fined PG&E $1.6 billion for the event.[54]

*Natural gas distribution* pipelines are located in heavily populated areas and, thus, are exposed to more frequent accidents from excavators and other sources of outside force. There were a total of 197 incidents on distribution systems in 2012-2013, resulting in about $43.4 million in property damages. This is an average of close to $220.5 thousand per incident, or less than half the average cost for a transmission pipeline failure. However, there were a total of 18 fatalities and 85 injuries in 2012-2013, considerably higher than those for transmission pipeline failures. These occurrences, although carrying a lower average economic cost, are considered higher risk for its higher fatality rate and a higher frequency than the natural gas transmission system failures.

Natural gas distribution systems carry an additional societal burden and potential cascading risk. Loss of supply to residential and commercial customers necessitates, because of safety reasons,

[51] http://www.mlive.com/news/grand-rapids/index.ssf/2014/11/2010_oil_spill_cost_enbridge_1.html
[52] "Magnitude 1.1 – San Francisco Bay Area, California". United States Geological Survey. 09 September 2010.
[53] Melvin, Joshua (October 28, 2010). "Death toll in San Bruno pipeline explosion climbs to eight". San Jose Mercury News.
[54] http://www.mercurynews.com/business/ci_27880159/san-bruno-pg-e-faces-record-penalty-punishment

the relighting of pilot lights, which cannot be initiated until system integrity has been restored. The added time to complete the relight phase can create a major problem. If the reduction in capacity were to occur during the winter, many people in the Midwest and Pacific Northwest (and wherever residential customers rely on natural gas for residential heating) would be without heat. (Residential customers in the New England states typically use fuel oil for heating.) To cope with the situation, many may purchase electric heaters, putting strains on the power distribution system that the system design may be unable to accommodate. This, in turn, could lead to frequent power outages at the distribution level. There is also concern that impatient customers would attempt their own relighting. It is strongly recommended that a qualified service technician light any pilot light that has gone out. If the customer attempts to relight the pilot he is taking the risk of starting a fire or an explosion.[55]

Natural gas pipeline systems are involved not only in the transportation of product but also in its delivery to the end user.

## Assumptions

The SNRA project team used the following assumptions:

- The low, best, and high frequency estimates reflect the low, mean (arithmetic average), and high counts of incidents of major failures of pipelines of all types, as defined and recorded by the PHMSA of the U.S. Department of Transportation (DOT), from 1995 through 2014.
- The best estimates of fatalities, injuries, and direct economic damages reflect the average fatalities, injuries, and direct economic damage per incident of major pipeline failures from the same data set. These were calculated by dividing the 20 year total fatalities, injuries, and direct economic damage by the average annual number of major pipeline failures.
- Low estimates of 0 fatalities and injuries were assumed by the SNRA project team.
- As this PHMSA data set did not report a per-incident breakdown, but only annual totals, high estimates of fatalities and injuries and low and high direct economic damage estimates were not determined by the SNRA.

### *Direct Economic Loss*

Direct economic losses are difficult to assess at the national-level due to the variety of scenarios presented in the PHMSA dataset across the four pipeline-types assessed. The best estimate for direct economic loss based on PHMSA is just under $1,000,000 per incident ($978,639) with the low at $135,735 and high estimate approximately $2.4 million. The Event Background section provides an overview of historical economic impacts in the context of each pipeline: crude oil, petroleum, natural gas transmission, and natural gas distribution.

### *Social*

While social displacement estimates were not reported by this PHMSA data set, an assumption of 0 civilian U.S. residents displaced from their homes for two or more days was made for the

[55] http://staging.usepropane.com/safe-source-of-energy/homeowner-safety-information/#Link 11

low and best estimates by the SNRA project team for the purposes of reporting the SNRA in this document. A high estimate was not made.

By analogy with other technological accidents not releasing highly toxic chemical gases or radioactive substances assessed by subject matter experts for the 2015 SNRA project, a provisional Event Familiarity Factor of 1.0 was assigned to the Pipeline Failure national-level event by the SNRA project team for the purposes of reporting psychological distress estimates for the final SNRA documentation (see Psychological consequences below).

### *Psychological*

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. Observation of gasoline consumers' behavior in cities where pipeline accidents have disrupted fuel supplies suggest that the psychological impact of a pipeline's disruption would be minimal. A major pipeline failure would likely affect those in the transportation sector because it is heavily dependent on pipelines to transport motor fuel.

### *Environmental*

A pipeline accident on land within the scope of the national-level event as defined by the SNRA data set—occurring with a frequency of about one every week in this country—could have minor environmental impact, but would most likely have moderate but localized impacts. Exceptional cases where a very large pipeline ruptures in a sensitive or protected ecosystem could have very high negative environmental consequences, as shown by the 2010 Enbridge crude oil pipeline failure in Michigan. In this incident, a 30-inch diameter pipeline carrying heavy tar sands crude (diluted bitumen or "dilbit") ruptured, pumping an estimated 20,000 barrels of crude oil into the Kalamazoo River near the town of Marshall, Michigan. This event was so severe that cleanup work continued for four years, closing a thirty-five mile section of the river for two years, affected wildlife both in the river and on land.[56] Final cleanup costs to date are in the area of $1.21 billion.

## Potential Mitigating factors

The aging of the Nation's transportation infrastructure is a risk that can be addressed through proactive inspection, maintenance, repair, and replacement of deteriorating assets; however, this requires significant investment from the Federal, state, and local levels, and therefore, such activities will have to be prioritized based on criticality, risk, available funds, and other factors. The recent Federal requirement that state DOTs engage in risk-based asset management[57] to better strategically plan for transportation infrastructure investment and improvement, can make more effective use of existing funding, but expanded funding may also be required for effective mitigation of risk. Additionally, complementary action may be taken for enhanced contingency, response, and emergency preparedness planning. In the event of a transportation system failure, better emergency preparedness and response planning will enable agencies to more immediately respond to and mitigate direct impacts, and better contingency planning (e.g., establishing

[56] http://archive.freep.com/article/20130623/NEWS06/306230059/Kalamazoo-River-oil-spill

[57] Moving Ahead for Progress in the 21st Century Act (MAP-21), U.S. Public Law 112-141 – July 6, 2012

detouring and rerouting plans around higher risk assets) can mitigate indirect costs associated with disruption to the transportation system and supply chain, and associated congestion.

## Additional Relevant Information

On June 26, 1996, a pipeline owned by Colonial Pipeline ruptured near Fork Shoals, South Carolina, releasing over 1 million gallons of diesel fuel into the Reedy River, one of the largest inland oil spills in U.S. history. The resulting spill was devastating to the Reedy, essentially wiping out the entire food chain throughout a 23-mile stretch of the river. Mammals, waterfowl, and shorebirds dependent upon the riverine / riparian food chain were also affected, or at least temporarily extirpated from the Reedy corridor. This disastrous spill was particularly incredible because the reach of the Reedy in southern Greenville and Laurens Counties had previously been among the more healthy reaches of the river.[58]

Another high-end scenario for pipeline failure may be construed to be something comparable to the Deepwater Horizon accident, which resulted in $20 billion paid by BP, and a $4.5+ billion fine. It would take a number of complex interacting failures to have such an incident be considered a pipeline failure. If a deep-water drill head was in safe operating condition, but somehow the ability to shut it off failed, and a downstream physical failure in the pipeline resulted in uncontrolled leakage within the deep-water environs, a comparable physical event could be postulated. However, it is likely that a much more prompt repair to the controls that would allow the wellhead to be shut off would be feasible if it were not also the source of the spewing crude. Thus, an analytic judgment is made that this event is not a suitable analogy.

**Table 10: National All Pipeline Systems Serious Incidents from 1995-2014**

| Year | Number | Fatalities | Injuries | Property Damage (current year dollars) | Gross barrels Spilled |
|---|---|---|---|---|---|
| 1995 | 59 | 21 | 64 | $7,435,010 | 6,564 |
| 1996 | 63 | 53 | 127 | $19,501,368 | 14,315 |
| 1997 | 49 | 10 | 77 | $6,145,793 | 20,000 |
| 1998 | 70 | 21 | 81 | $57,738,002 | 11,117 |
| 1999 | 66 | 22 | 108 | $74,664,129 | 54,456 |
| 2000 | 62 | 38 | 81 | $8,846,912 | 10,981 |
| 2001 | 40 | 7 | 61 | $6,058,891 | 16,114 |
| 2002 | 36 | 12 | 49 | $6,067,785 | 0 |
| 2003 | 61 | 12 | 71 | $12,162,651 | 0 |
| 2004 | 44 | 23 | 56 | $11,250,326 | 860 |
| 2005 | 39 | 16 | 47 | $21,354,868 | 4,048 |

[58] http://www.friendsofthereedyriver.org/the-river/

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|---|---|---|---|---|---|
| 2006 | 32 | 19 | 34 | $8,550,884 | 4,513 |
| 2007 | 43 | 16 | 46 | $20,235,909 | 12,176 |
| 2008 | 37 | 8 | 55 | $52,261,149 | 6,755 |
| 2009 | 46 | 13 | 62 | $20,101,704 | 364 |
| 2010 | 34 | 19 | 104 | $406,772,532 | 3,105 |
| 2011 | 32 | 12 | 51 | $13,421,557 | 0 |
| 2012 | 28 | 10 | 54 | $11,020,309 | 1,500 |
| 2013 | 24 | 9 | 44 | $16,750,062 | 23,702 |
| 2014 | 29 | 19 | 96 | $94,563,684 | 14,270 |
| | | | | | |
| 20 year Totals | 894 | 360 | 1,368 | $874,903,525 | 204,840 |
| 5 Year Average (2010-2014) | 29 | 14 | 70 | $108,505,629 | 8,515 |
| 10 Year Average (2005-2014) | 34 | 14 | 59 | $66,503,266 | 7,043 |
| 20 Year Average (1995-2014) | 45 | 18 | 68 | $43,745,176 | 10,242 |

**Table 11: Pipeline Consequence Statistics**

| Totals | Number | Fatalities | Injuries | Property Damage | Gross Barrels Spilled |
|---|---|---|---|---|---|
| Median | 41.5 | 16.0 | 61.5 | $15,085,810 | 6,660 |
| 5th | 27.8 | 8.0 | 43.5 | $6,067,340 | 0 |
| 95th | 66.2 | 38.8 | 109.0 | $110,174,126 | 25,240 |
| Mean | 44.7 | 18.0 | 68.4 | $43,745,176 | 10,242 |
| Min | 24 | 7 | 34 | $6,058,891 | 0 |
| Max | 70 | 53 | 127 | $406,772,532 | 54,456 |
| Per Incident, Average | | 0.403 | 1.530 | $978,639 | 229 |
| Per Incident, 5th Percentile | | 0.18 | 0.97 | $135,735 | 0 |
| Per Incident, 95th Percentile | | 0.87 | 2.44 | $2,464,746 | 565 |

**Table 12: Summary of Interim Data[59]**

| Category | Fatalities | Metric | Low | Best | High |
|---|---|---|---|---|---|
| Health and Safety | Fatalities | Number of Fatalities | 0[60] | 0.40 | 0.87 |
| | Injuries and Illnesses | Number of Injuries or Illnesses | 0[61] | 1.53 | 2.44 |
| Economic | Direct Economic Loss | U.S. Dollars | $135,735 | $978,639 | 2,464,746 |
| | Indirect Economic Loss | U.S. Dollars | N/A | | |
| Social | Social Displacement | Number of Displaced from Homes for ≥ 2 Days | 0 | 0 | N/A |
| Psychological | Psychological Distress | Qualitative Bins | N/A | | |
| Environmental | Environmental Impact | Qualitative Bins | Low (See Discussion) | | |
| Likelihood | Frequency of Events | Number per Unit of Time | TBD | | |

[59] The quantitative analysis for this hazard event is still in progress. The above estimates from the data that have been collected and analyzed to date are provided for convenience, but they should NOT be considered as final SNRA estimates.
[60] Calculated value is 0.18. Lowest likely assumed to be 0
[61] Calculated value is 1.1. Lowest likely assumed to be 0