DOE Hydrogen and Fuel Cells Program Record	
Record #: 16011	**Date:** May 16, 2016
Title: Hydrogen Delivery Cost Projections – 2015	
Originator: Neha Rustagi, Amgad Elgowainy, Erika Gupta	
Peer Reviewers: Representatives from Argonne National Laboratory, Lawrence Livermore National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, California Fuel Cell Partnership, U.S. Department of Transportation, Praxair, and other industry stakeholders	
Approved by: Rick Farmer, Sunita Satyapal	**Date:** May 24, 2016

Item

The modeled cost of delivering hydrogen from a centralized production facility and dispensing to fuel cell electric vehicles (FCEVs) ranges from \$3.00/gge–\$5.00/gge for 700-bar dispensing, and \$2.70/gge–\$3.70/gge for 350-bar dispensing. These modeled costs cover a range of gaseous and liquid hydrogen delivery options using current (2015) technologies projected at economies of scale.

Overview of Results

Figure 1 shows the range of the hydrogen delivery cost projections in dollars per gallon of gasoline equivalent (\$/gge)[a] at 350 bar in 2005, and at 350 bar and 700 bar in 2011, 2013, and 2015. The large circles denote the 2015 and 2020 targets and the smaller circles denote the targets for 2005, 2011, and 2013, which were extrapolated from the 2015 and 2020 targets. In 2015, the 700 bar cost target of \$3.00/gge was met by the tube trailer pathway, largely due to the cost advantages of high-pressure tube trailers and implementation of the tube trailer consolidation strategy at the refueling station. [1] The range of cost estimates for 700 bar dispensing increased in 2015 (compared to prior years) primarily due to increases in the estimates of liquefaction cost.

The 2011 and 2013 cost estimates were calculated using the H2A Hydrogen Delivery Scenario Analysis Model (HDSAM) V2.3 along with assumptions of the commercial readiness of delivery/dispensing technologies in the respective years. In 2015, HDSAM was updated to Version 3.0 to reflect the then-current status of delivery technologies. Before its release, the model was vetted through comparisons of its projections with the real-world cost estimates provided by station developers in funding applications to the California Energy Commission. The 2015 cost estimates and 2020 projections in this record were made using HDSAM 3.0 along with assumptions about the readiness levels of each technology in the delivery pathway for commercialization. The technological assumptions used to derive these cost estimates and projections are defined in Table 1 (p. 8).

---

[a] gge is approximately equivalent to kg of hydrogen on energy basis and can be used interchangeably.

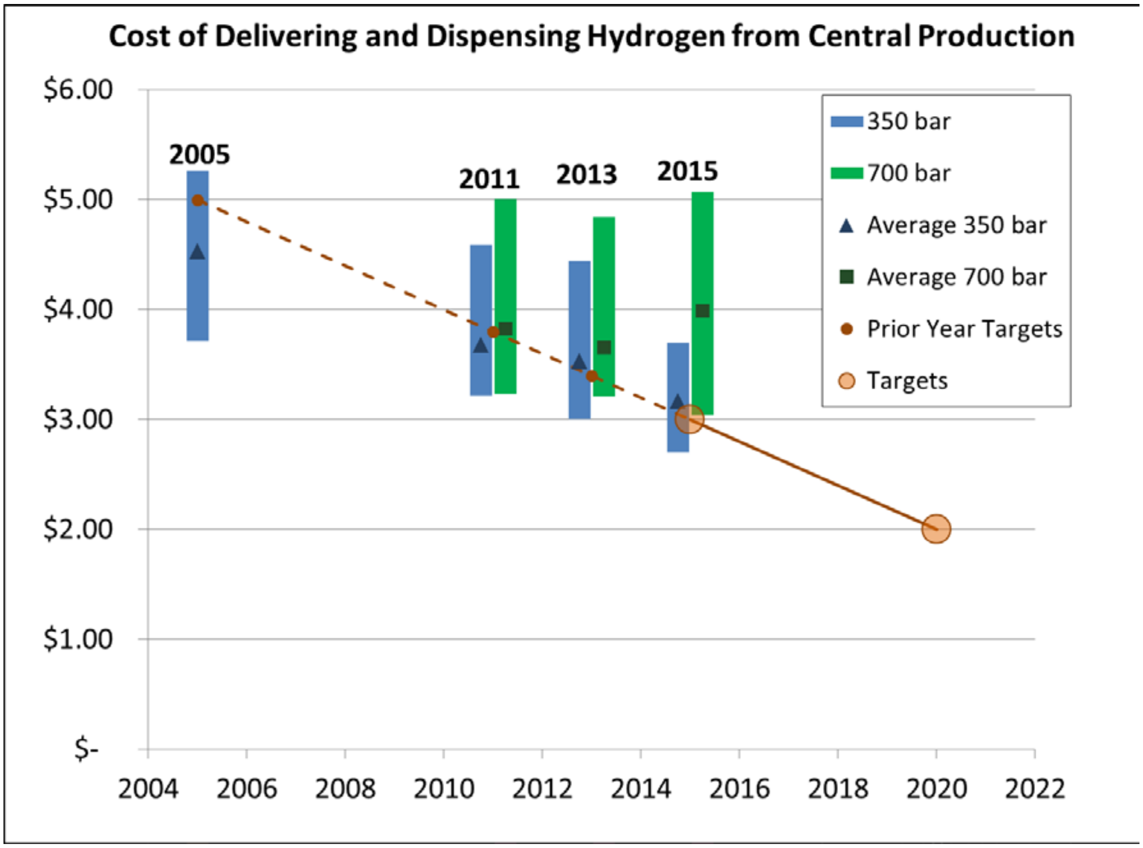

Figure 1: Range of HDSAM projected costs of hydrogen delivery and dispensing from central production facilities in 2005, 2011, 2013, and 2015 along with the relevant targets[b]. Range of costs in any given year is due to variety of delivery pathways considered.

The cost estimates and targets assume that all equipment for hydrogen delivery and dispensing is manufactured at large commercial scales (i.e. "high volume").

Data and Assumptions

A. Technological Assumptions

In fiscal year 2015, the Program's delivery analysis technical experts[c] updated HDSAM, to its current public version, 3.0, to capture the current state of the hydrogen industry. HDSAM projects the cost of hydrogen delivery and dispensing in a user-defined scenario. Key inputs that define the scenario include the capacity of the fueling station, the mode of hydrogen delivery to the fueling station (e.g. gaseous tube trailer, pipeline, or liquid tanker), as well as the method of dispensing (e.g. cascade storage of gaseous hydrogen or cryopumps). Updates that were made in HDSAM 3.0 include:

---

[b] Prior year targets have been extrapolated from the 2015 and 2020 targets.

[c] Delivery analysis technical experts are: Amgad Elgowainy (Lead) – Argonne National Laboratory (ANL), Krishna Reddi – ANL, and Daryl Brown – Pacific Northwest National Laboratory (PNNL).

1. Compression at tube trailer terminals and refueling stations is simulated with diaphragm compression rather than reciprocating compression due to the higher reliability of diaphragm compressors.
2. The estimate of the quantity of buffer storage at tube trailer terminals was increased.
3. Cost estimates of centrifugal compression in pipelines were improved with industry input.
4. Cost estimates of cryopumps at liquid terminals and refueling stations were improved with industry input.
5. Estimates of liquefaction capital cost were improved with industry input.
6. Additional refueling station configurations and operational strategies were incorporated to reflect current practices. For example, HDSAM 3.0 allows users to model dispensing at liquid stations via compressors that capture hydrogen boil-off within the station's bulk liquid storage, rather than via cryopumps that pump liquid hydrogen.

HDSAM 3.0 was used in conjunction with a series of additional assumptions regarding technology readiness in 2015 and 2020 to estimate the costs of hydrogen delivery in these years. Table 1 provides the key technologies that were assumed in the cost projections for 2005, 2011, 2013, 2015, and 2020. [1] The following three 2015 assumptions (also listed in Table 1) required HDSAM to be run in a customized manner, overriding its defaults:

1. Transmission and distribution pipelines were assumed to operate at 100 bar rather than 70 bar and 40 bar, respectively, and distribution pipelines were assumed to be made of fiber reinforced polymer (FRP) rather than steel. Transmission pipelines are defined as those that carry hydrogen from a production source to the city gate, and distribution pipelines are those that carry hydrogen from the city gate to the refueling station. Transmission pipelines are generally much larger than distribution pipelines.

   Recent analysis from Sandia National Laboratories and the National Institute of Standards and Technology has shown that steel pipelines are capable of operation at 100 bar with conventional grades of steel (X52 and X70). [3,4] Additionally, in recent years, research at Savannah River National Laboratory has demonstrated that FRP is capable of hydrogen service at 100 bar with a life of 50 years at the duty cycles expected for distribution pipelines. [5] FRP is significantly lower in cost than steel because it is elivered in 0.5-mile long spools rather than segments about 80 feet long. [6].

   It is important to note that, in the delivery pathways involving pipeline supply to liquefiers, the operating pressure was still assumed to be 40 bar (rather than 100 bar). In these pathways, a higher operating pressure appears to be a disadvantage because it increases the cost of the pipeline compressor without sufficiently lowering the cost of liquefaction or compression at the forecourt.

2. Tube trailer consolidation was assumed to be implemented at fueling stations supplied by tube trailers. Tube trailer consolidation is a strategy that researchers at ANL developed (U.S. Patent Application No. 14/039, 120) to operate stations in a way that reduces the capital cost of forecourt compression by up to 60%.

Under conventional station operation (Figure 2), compressors are used intermittently throughout the day to transfer and pressurize hydrogen from the vessels in a tube trailer to a series of high-pressure storage vessels at the station (i.e., “cascade storage”). When vehicles come to the station to refuel, high-pressure hydrogen flows out of the cascade storage to the dispenser. The compressor replenishes the cascade storage with hydrogen from the tube trailer. The motor power that the compressor requires increases as the tube trailer vessels empty; the motor power required is a strong function of the compressor’s suction pressure. Accordingly, the compressor is sized such that it can meet a station’s daily demand profile even as the pressure in the tube trailer vessels falls. The compressor is therefore over-sized for many hours of the day.

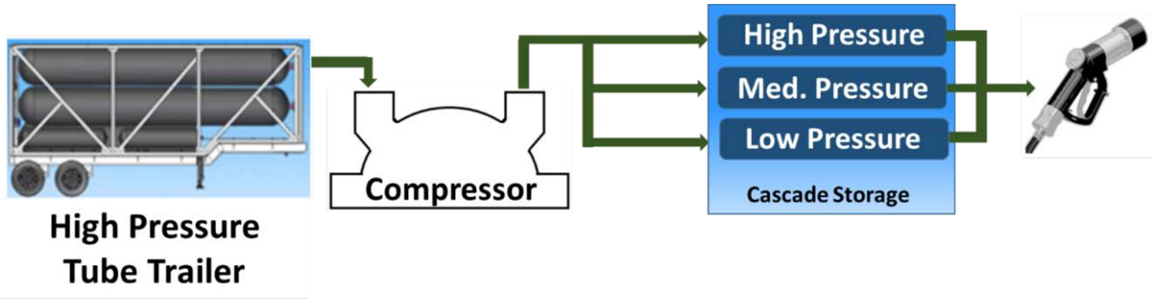

Figure 2: Typical gaseous hydrogen fueling station configuration

Under tube trailer consolidation (Figure 3), the compressor is run throughout the day to maintain high pressures of hydrogen in both the cascade of storage vessels and the vessels within the tube trailer itself. During hours of low demand, the compressor transfers (i.e., “consolidates”) hydrogen from vessels in the tube trailer that are emptying to those that are more full, increasing pressure within the latter vessels. During hours of peak demand, the compressor therefore has a high-pressure source of suction (the consolidated vessels in the tube trailer), and is able to meet the demand with less motor power than would otherwise be necessary; as described in the preceding paragraph, the motor power necessary increases as suction decreases. If a high-pressure source of hydrogen is maintained at the station in this way, a smaller compressor can meet the station’s daily demand. [1]

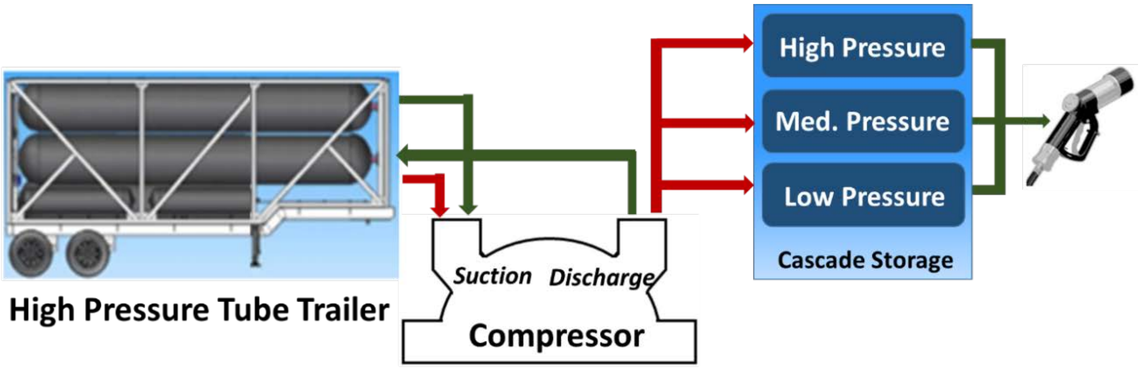

Figure 3: Gaseous hydrogen fueling station configuration under tube trailer consolidation

3. Storage at tube trailer terminals was assumed to utilize the steel concrete composite vessel (SCCV) technology recently developed by Oak Ridge National Laboratory (U.S. Patent Application No. 13/940, 567). The SCCV lowers the cost of hydrogen storage by minimizing use of stainless steel. An inner stainless steel vessel is layered with carbon steels and wrapped with pre-stressed concrete. The carbon steel layers incorporate diffusion holes that allow hydrogen molecules that may have escaped the inner vessel to diffuse out, such that they do not remain in contact with the carbon steel long enough for embrittlement to occur. By minimizing the risk of hydrogen embrittlement, these diffusion holes allow low-cost carbon steels to be used in the vessel rather than stainless steel. A 90-kg prototype of this vessel has been built and is currently under fatigue testing. The 430-bar vessel is projected to cost about $270,000 ($2007) if it is manufactured at high volumes and in capacities of 564 kg each; it was assumed that the impact of high-volume manufacturing would lower the cost of this vessel from its current projection [8] by 25%.

The assumptions of technologies that were appropriate and ready for use in each of the hydrogen delivery pathways in any given year (Table 1) were determined through significant collaboration with industry experts (quotations, cost analyses, and information on design and operating conditions from original equipment manufacturers, suppliers, researchers, station developers and consultants, and publicly available reports), along with the accomplishments of DOE-funded research. For example, the 2005 tube trailer scenarios assume 180 bar steel tubes for transport and distribution (as Type 4 tanks were not available at that time). The 2015 tube trailer scenarios instead assume 540 bar vessels, as they are now commercially available, along with the implementation of tube trailer consolidation at the forecourt. For the cases denoted as "2020 projection" in Table 2, assumptions were made regarding the lowest cost possible through research advancements, for each technology in the pathway. Assumptions of research advancements were typically based on Multi-Year Research, Development, and Demonstration (MYRD&D) Plan targets for the respective technologies. [7] Outside of the technology readiness list provided in Table 1, the technology assumptions for the 2011 and 2013 scenarios have been captured in the hydrogen delivery chapter of the MYRD&D Plan. [7] The assumptions are also included in the delivery scenario runs referenced in Records 12022a, 12022b, and 12022c available at www.hydrogen.energy.gov/program_records.html.

B. Scenario Definitions

Three 350-bar delivery scenarios were developed for the purpose of evaluating the impacts of technology advancements in delivery and dispensing equipment on the levelized cost of hydrogen delivery. The cases developed are hydrogen transmission and distribution[d] via pipeline, hydrogen transmission via pipeline and distribution via tube trailer, and hydrogen transmission and distribution via tube trailer. [9] These are denoted in Table 2 (p. 10) as: "pipeline," "pipeline – tube trailer," and "tube trailer," respectively.

Likewise five 700-bar hydrogen delivery scenarios were developed for the purpose of projecting the impacts of technology advancements in delivery and dispensing on levelized cost. These

---

[d] "Transmission" refers to delivery of hydrogen from centralized production to the city gate, and "distribution" refers to delivery from the city gate to a refueling station.

include pipeline transmission and distribution, pipeline transmission and tube trailer distribution, tube trailer transmission and distribution, pipeline transmission and liquid tanker distribution, and liquid tanker transmission and distribution. These cases are described schematically in the Appendix (Figure 4 and Figure 5). These cases are labeled as “pipeline,” “pipeline-tube trailer,” “tube trailer,” “pipeline-liquid tanker,” and “liquid tanker” respectively in Table 2 (p. 10).

The three cases developed for delivery pathways with 350-bar dispensing and five cases developed for pathways with 700-bar dispensing have the following common assumptions:

1. A city (based on Indianapolis) with a population of 1.4 M was chosen because it represents an average city for the U.S., allows for informative large scale deployment projections, and is consistent with previous DOE analyses[e].
2. A mature fuel cell electric vehicle (FCEV) market penetration of 10%-15% that is served by the hydrogen delivery infrastructure under study. It was found in previous studies that when delivery cost is plotted as a function of FCEV market penetration for a city with a population of about 1 million, the resulting curve begins to level off around 10%–15%; i.e., progressively smaller cost reduction is gained by assuming market penetration above this level. [10]
3. For consistency with the latest hydrogen cost target analysis and other H2A models, all costs were expressed in 2007$.
4. A refueling station capacity with average dispensing rate of 750–1,000 kg of H_2/day at 100% utilization.[f]
5. All components were assumed to be manufactured at high volume[g]. Cost reductions that are likely to take place due to economies of scale have been incorporated in HDSAM 3.0 based on input from industry experts.
6. Unless otherwise specified, the hydrogen production plant is sited 100 km from the edge of the city, or city gate.
7. In 2005, 2011, and 2013, the analysis period over which the levelized cost was calculated was 30 years. In 2015 and 2020, this period was changed to 40 years for consistency with other DOE offices.

---

[e] The 2010 population density of Indianapolis was within 25% of the national average for urban areas. [12]

[f] For the 2005 analysis, a market penetration of 15% and a station size of a 1,000 kg/day were assumed. For the 2011 analysis and beyond, a market penetration of 10% and a station size of 750 kg/day were assumed for a more accurate cost comparison across pathways. In 2015, the definition of “capacity” in HDSAM changed from characterizing a station’s average dispensing rate to its peak dispensing ability. A 750 kg/day station in 2011 and 2013 (HDSAM V2.3) had a peak capacity of 888 kg/day, while a 750 kg/day station in 2015 and 2020 (HDSAM 3.0) has a peak capacity of 750 kg/day. For reference, the average size of stations currently being installed in California is 180 kg/day. [11]

[g] The assumption of “high volume” does not correspond to a specific number of units produced. The impact of economies of scale on a unit’s cost is expected to plateau with the number of units manufactured. “High volume” corresponds to the manufacturing volume that results in that plateau.

C. Cost Estimates and Projections

As described above, for each set of scenarios, delivery costs were calculated assuming technology readiness in the respective time period. The “2020 projection” cases were based on the lowest cost of each technology that appears achievable today based on input from technical experts. The levelized cost estimates and projections for 350-bar and 700-bar dispensing pathways in each of the years analyzed are shown in Table 2. Key conclusions include:

- For the assumed transport distance (100 km), high-pressure tube trailer transport offers the lowest delivery cost option, largely because it reduces the compression necessary at the forecourt when the tube trailer consolidation strategy is implemented. The logistics of frequent deliveries to large capacity stations may, however, inhibit the practicality of the tube trailer pathway [13, 14]; stations will likely be unable to accept more than one tube trailer delivery per day.
- Pipeline infrastructure requires high expense, largely because of right-of-way and installation costs. Pipeline pathways may become competitive with longer transport distances, and a mature nationwide FCEV market.

Table 1: Key technologies assumed in projections of hydrogen delivery costs, based on technology readiness for commercial use and cost

Delivery Component	**Technology Year**				
	2005	**2011**	**2013**	**2015**	**2020**
Refueling station compressors	Diaphragm (HDSAM v2.2)	Reciprocating and diaphragm (HDSAM v2.3)	Average of available technologies and adjusted requirements for tube trailer delivery	Diaphragm (HDSAM 3.0)	Diaphragm (HDSAM 3.0)
Refueling station gas storage	Steel vessels (HDSAM v2.2)	Steel and carbon fiber composite vessels (HDSAM v2.3)	Steel and carbon fiber composite vessels (HDSAM v2.3)	Steel and carbon fiber composite vessels (HDSAM 3.0)	Lower cost steel vessels with composite over-wrap (MYRD&D)
Refueling station cryopumps	Liquid pumps (HDSAM v2.2)	High-pressure cryopumps (HDSAM v2.3)	High-pressure cryopumps (HDSAM v2.3)	High-pressure cryopumps (HDSAM 3.0)	High-pressure cryopumps (HDSAM 3.0)
Cryogenic storage at station	Cryogenic vessels (HDSAM v2.2)	Cryogenic vessels (HDSAM v2.3)	Cryogenic vessels (HDSAM v2.3)	Cryogenic vessels (HDSAM 3.0)	Cryogenic vessels (HDSAM 3.0)
Refueling station dispenser (gaseous)	Based on CNG dispenser (HDSAM v2.2)	H_2 dispensers (HDSAM v2.3)	H_2 dispensers (HDSAM v2.3)	H_2 dispensers (HDSAM 3.0)	H_2 dispensers (HDSAM 3.0)
Precooling equipment	No data*	Chiller sized to meet refueling demand at -40°C**	Chiller sized to meet refueling demand at -40°C**	Chiller and heat exchanger sized to meet refueling demand at -40°C**	Chiller and heat exchanger sized to meet refueling demand at -40°C**
Tube trailers	180-bar (300 kg payload) steel tubes (HDSAM v2.2)	250-bar (616 kg payload) carbon fiber composite tubes (HDSAM v2.3)	350-bar (809 kg payload) carbon fiber composite tubes	540-bar (1127 kg payload) composite tubes (HDSAM 3.0)	540-bar (1127 kg payload) composite tubes (HDSAM 3.0)
Tube trailer terminals	Steel vessels and reciprocating compression (HDSAM v2.2)	Steel vessels and reciprocating compression (HDSAM v2.2)	Steel vessels and reciprocating compression (HDSAM v2.2)	Steel concrete composite vessels (MYRD&D) Diaphragm compression (HDSAM 3.0)	Lower cost storage vessels (MYRD&D) Diaphragm compression (HDSAM 3.0)
Liquid tanker	17,000 gallon cryogenic tank (4,000 kg payload)	17,000 gallon cryogenic tank (4,000 kg payload)	17,000 gallon cryogenic tank (4,000 kg payload)	17,000 gallon cryogenic tank (4,000 kg payload)	17,000 gallon cryogenic tank (4,000 kg payload)

	(HDSAM v2.2)	(HDSAM v2.2)	(HDSAM v2.2)	(HDSAM 3.0)	(HDSAM 3.0)
Liquefiers	Conventional liquefaction (HDSAM v2.2)	Conventional liquefaction (HDSAM v2.3)	Conventional liquefaction (same as HDSAM v2.3)	Conventional liquefaction (HDSAM 3.0)	Conventional liquefaction (HDSAM 3.0)
Pipelines	Steel pipelines (HDSAM v2.2)	Steel pipelines (HDSAM v2.3)	Steel pipeline to city gate and FRP pipeline for distribution	100-bar steel pipeline to city gate (HDSAM 3.0) FRP for distribution	100-bar steel pipeline to city gate (HDSAM 3.0) Lower cost FRP for distribution*** (MYRD&D)
Pipeline compressors	Reciprocating (HDSAM v2.2)	Centrifugal (HDSAM v2.3)	Centrifugal (HDSAM v2.3)	Centrifugal (HDSAM 3.0)	Centrifugal (HDSAM 3.0)
Geologic Storage	Caverns (HDSAM v2.2)	Caverns (HDSAM v2.3)	Caverns (HDSAM v2.3)	Caverns (HDSAM v2.3)	Lower cost caverns (MYRD&D)

*Precooling is required for fast fills to 700 bar. A 700-bar refueling option was not available in 2005.

** Per SAE J2601 refueling protocol.

*** Assumed that labor and miscellaneous costs of FRP decrease by 10%.

Table 2: Hydrogen cost estimates as a function of dispensed gas pressure, delivery pathway, and year

	Delivery and Dispensing Costs†* (\$/kg H_2)					
350-bar gas dispensing pathways	**2005**	**2011**	**2013**	**2015**	**2020 Projection**	**2020 Target**
Pipeline	3.71	4.59††	4.44	3.69††	3.65	2.00
Pipeline-tube trailer	4.62	3.22	3.16	2.92	2.92	
Tube trailer	5.26	3.24	3.00	2.69	2.69	
700-bar dispensing pathways	**Delivery and Dispensing Costs†* (\$/kg H_2)**					
Pipeline	No data**	5.00††	4.84	4.03††	3.98	2.00
Pipeline-tube trailer	No data**	3.59	3.21	3.31	3.26	
Tube trailer	No data**	3.61	3.29	3.02	2.97	
Pipeline – liquid tanker	No data**	3.73	3.73	5.03	5.03	
Liquid tanker	No data**	3.23	3.23	3.84	3.84	

† Cost results are estimates and are reported directly from HDSAM Model.

* Assumes geologic hydrogen storage with the exception of those pathways that use liquid tankers for delivery.

†† Steel pipeline cost estimates were updated in 2011 for improved accuracy [16], and modified slightly in 2015 based on improved analysis of the original cost data and improved understanding of material costs. [3]

** A 700-bar refueling option was not available in 2005.

Note that data in Table 2 cannot be directly compared with cost projections calculated previously (before 2011) because: (1) the baseline economic year has changed from 2005 (i.e., \$2005) to 2007 (i.e. \$2007) in analyses conducted for 2011 and beyond; (2) analyses before 2011 assumed 350-bar dispensing at the station, whereas current technology is now focused on 700-bar dispensing; (3) the assumed market penetration changed from 15% to 10% in 2011 for a better representation of mid-term costs; and (4) the station size changed from 1,000 kg/day to 750 kg/day in 2011. As mentioned above, the data in Table 2 reflects current knowledge of past and present technologies for transmission, distribution, terminal operations, and station operations and makes assumptions regarding future technologies utilizing information from current R&D projects and input from industry experts.

Appendix: Delivery and Dispensing Scenario Definitions

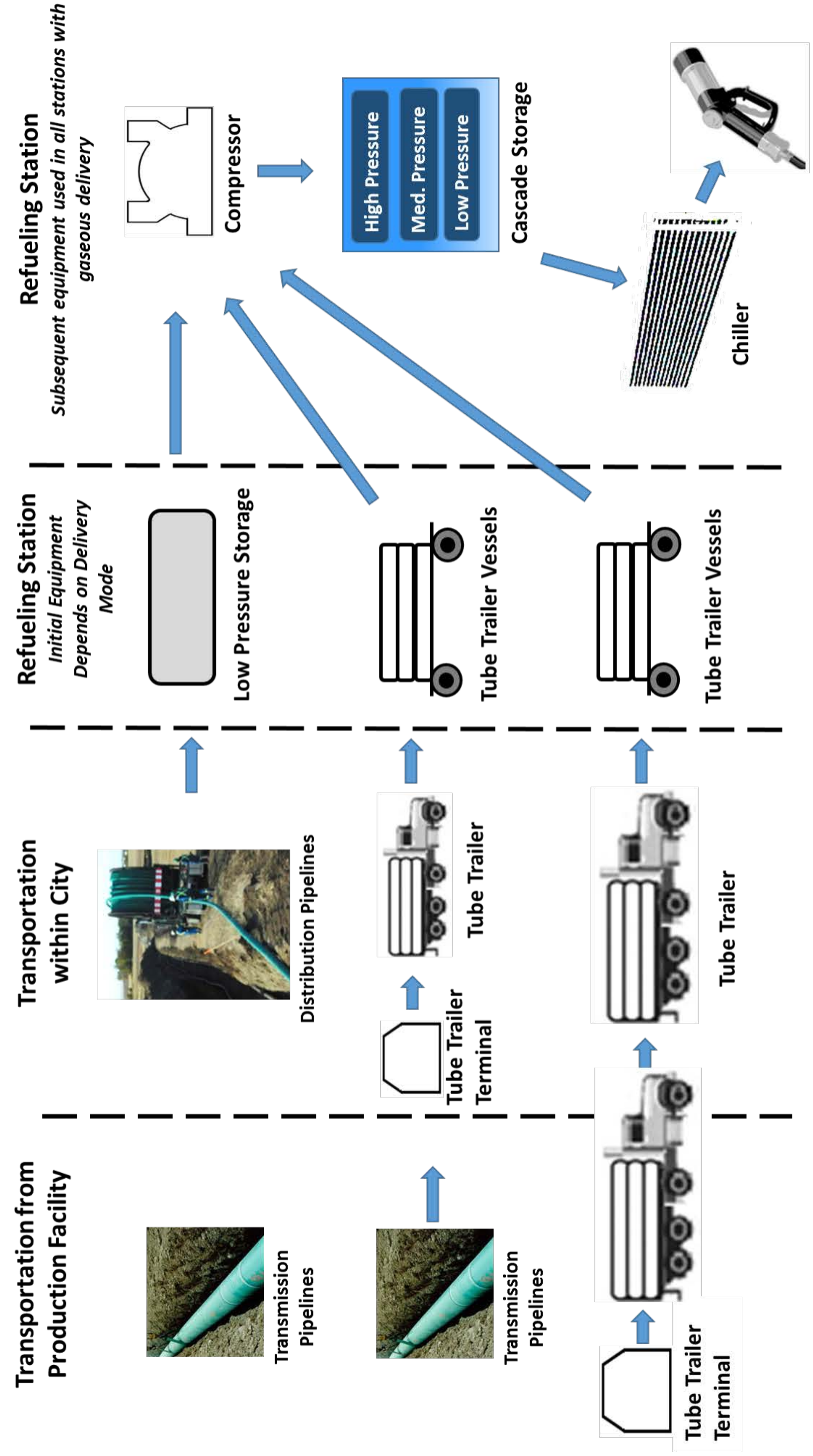

Figure 4 Gaseous Delivery Scenario Definitions. All scenarios begin with centralized production facility.

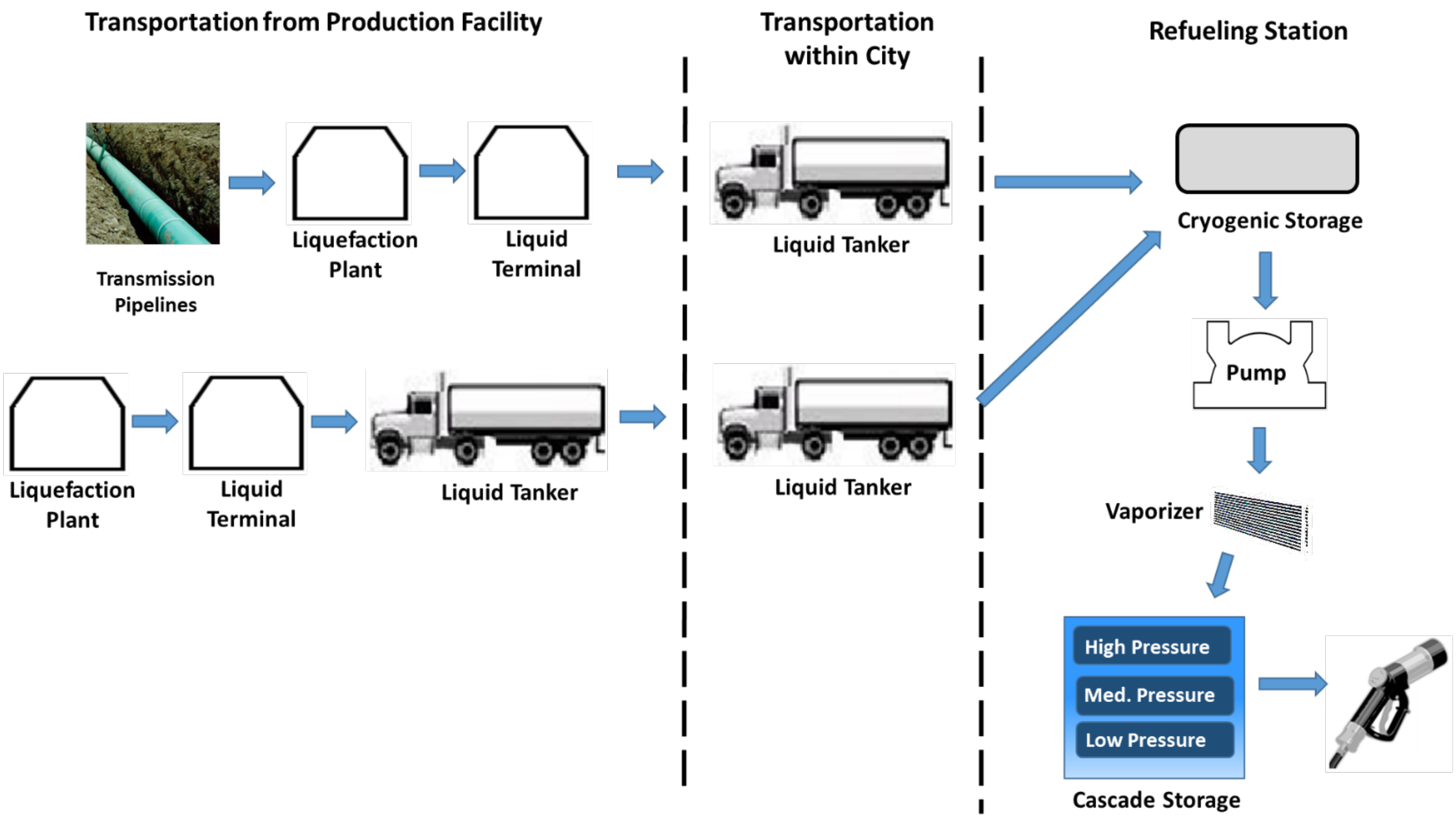

Figure 5 Liquid Delivery Scenario Definitions

References

1. Elgowainy, A., et al. Argonne National Laboratory. (December, 2014). *Tube-trailer consolidation strategy for reducing hydrogen refueling station costs.* International Journal of Hydrogen Energy, 39, 35, pp. 20197-20206.
2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office. (December, 2013). *Hydrogen Delivery Cost Projections – 2013* (Record 13013). Washington, DC: Sutherland, Elgowainy, and Dillich. https://www.hydrogen.energy.gov/pdfs/13013_h2_delivery_cost_central.pdf
3. Fekete, J., et al. National Institute of Standards and Technology. (2015). *Economic impact of applying high strength steels in hydrogen gas pipelines.* International Journal of Hydrogen Energy, 40, pp. 10547-10558.
4. Ronevich, J., et al. Sandia National Laboratory. (2016). *Effects of microstructure banding on hydrogen assisted fatigue crack growth in X65 pipeline steels.* International Journal of Fatigue, 82, 3, pp. 497-504
5. Rawls, George. Savannah River National Laboratory. (June 2015). *Fiber Reinforced Composite Pipelines.* Presented at the 2015 Annual Merit Review, Washington, DC. https://www.hydrogen.energy.gov/pdfs/review15/pd022_rawls_2015_o.pdf
6. Gilette, J.L. and Kolpa, R.L. Argonne National Laboratory. (November 2007). *Overview of Interstate Hydrogen Pipeline Systems*. http://corridoreis.anl.gov/documents/docs/technical/APT_61012_EVS_TM_08_2.pdf
7. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office. (August, 2015). *Multi-Year Research, Development and Demonstration Plan: Planned Program Activities for 2011–2020*, Section 3.2. Washington, DC. http://energy.gov/sites/prod/files/2015/08/f25/fcto_myrdd_delivery.pdf
8. Zhang, Wei, et al. Oak Ridge National Laboratory. (September 2012). *Manufacturing Cost Analysis of Novel Steel/Concrete Composite Vessel for Stationary Storage of High-Pressure Hydrogen.* http://info.ornl.gov/sites/publications/files/Pub41882.pdf
9. Nexant. (May, 2008). *Hydrogen Delivery Infrastructure Options Analysis* (DOE Award #DE-FG36-05GO15032). T-P. Chen. Appendix B.
10. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office. (2006). *Hydrogen Delivery Options and Issues.* Washington, DC: Mark Paster. http://www1.eere.energy.gov/hydrogenandfuelcells/analysis/pdfs/paster_h2_delivery.pdf
11. California Energy Commission. (December 2015). *Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*. CEC-600-2015-016. http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf
12. “2010 Census Urban Lists Record Layouts”. (2010). U.S. Census Bureau. Washington, DC: https://www.census.gov/geo/reference/ua/ualists_layout.html

13. Parks, G., et al. National Renewable Energy Laboratory. (May 2014). *Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs.* Technical Report NREL/BK-6A10-58564. Golden, CO. http://www.nrel.gov/docs/fy14osti/58564.pdf

14. Elgowainy, Amgad. Argonne National Laboratory. (June 2015). *Hydrogen Delivery Infrastructure Analysis*. Presented at the 2015 Annual Merit review, Washington, DC. https://www.hydrogen.energy.gov/pdfs/review15/pd014_elgowainy_2015_o.pdf

15. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office. (November, 2012). *H_2 Production and Delivery Cost Apportionment* (Record 12001). Washington, DC: Weil, Dillich, Joseck, and Ruth. http://www.hydrogen.energy.gov/pdfs/12001_h2_pd_cost_apportionment.pdf

16. Brown, Daryl. Pacific Northwest National Laboratory. (November 2010). *National Lab uses OGJ data to develop cost equations*. Oil & Gas Journal, issue 109, page 102. http://www.ogj.com/articles/print/volume-109/issue-1/transportation/national-lab-uses-ogj-data-to-develop-cost-equations.html