Project Neptune – GFO-19-602 Hydrogen Refueling Infrastructure

Shell – Equilon Enterprises

Background

At the request of the California Energy Commission (CEC), members of the Hydrogen Safety Panel (HSP) performed a review of design documents for the Shell Equilon Enterprises (Shell) Project Neptune installation of hydrogen fueling stations in California, per the general funding opportunity, GFO-19-602. The project entails design and construction of hydrogen gas storage and light-duty vehicle fueling stations in existing Shell gasoline stations. The initial effort being reviewed involves design for implementation at seven stations, which will increase to a total of 50 stations by 2025.

The initial seven stations are located in the following cities:

- Torrance
- Newport Beach
- Monrovia
- Carlsbad
- Los Angeles
- Long Beach
- City of Industry

The HSP design review was conducted virtually during the spring of 2021. It involved multiple teleconferences with Shell and their design and basic equipment supplier, Maximator GmbH (Maximator), with offline HSP evaluation of design, safety, and technical documents, including site overhead pictures obtained from Google Earth. Principal design documents included a general piping and instrument diagram (P&ID), site layout drawings, and a process control narrative. A desktop safety review/risk binning analysis was reviewed; additional comments on this document will be provided during future review of the Shell general safety plan. Design completion during review was approximately 30%.

Key Design Review Focus Areas

The HSP review included evaluation of siting issues, comparison to codes and standards, and examination of technical applications per HSP expertise. The main focus areas were:

- General safety impact to the public and property from planned station operation
- Impact to safety from specific technology applications (e.g., pipe venting)
- System conformance with U.S. codes and standards, especially NFPA 2

Results

Shell is to be commended for thoroughly covering hydrogen safety as part of its design planning, and sharing its safety information. Shell and Maximator were diligent in providing design and technical documentation, and were extremely supportive during the many online discussions.

The design by Shell and Maximator is sound and is typical of hydrogen fueling stations with unique Maximator applications. The overall system design basically addresses NFPA 2-2020 requirements.

General comments from the webinar discussions, and detailed safety observations and recommendations from the HSP review, are offered below. There is some overlap with general discussion notes and offline review comments, but both are included here for completeness. Consideration of further safety aspects identified by the HSP will enhance the safe operation of Shell's design, construction, and operation.

The HSP is honored to be involved in Shell's Project Neptune and looks forward to future involvement with Shell and the CEC to ensure all hydrogen-related hazards are safely managed. Please provide questions for clarifications or requests for additional specific review to the HSP.

Comments and Suggested Improvements

1. General/Summary Comments
    a. Major potential accident and normal operational releases, especially from a system pipe, vent stack, or delivery vehicle, should be addressed to show impacts on the neighbors and the public for each specific location. There is a large amount of hydrogen storage on site and within the delivery vehicle. There could be multiple daily deliveries. The project team should review the impact on the public of release scenarios from the vent stack, hose, or a piping rupture for each specific site.
    b. One possible gap is that the on-site hydrogen storage "module" is provided by a separate supplier who was not involved in the HSP review process, so information about that system element was presented in less detail than the other systems and the HSP is unclear on the supplier's involvement in the overall safety planning and review process.
    c. The stack is an innovative, unique design and combines several station functions into a single unit. The HSP could not determine if pressure drops, flows, and potential impacts of various upstream issues (particularly if multiple issues were to occur at the same time), and stack damage were adequately considered and calculated. The project should ensure stack design accounts for all maximum flows and pressures.
    d. Delivery of hydrogen via high-pressure tube trailers to the sites was identified as potentially having several risks. Although the transfer system and its safety systems appear robust, with multiple layers of shutdown and isolation capability, pedestrian safety is a concern due to the proximity of unloading operations to sidewalks and other on-site pedestrian traffic. Another concern is the potential congestion and dangerous interactions at some of the sites related to the pathway for the delivery trucks (especially gasoline/diesel), the potential need to move parked cars upon the arrival of the hydrogen delivery trailer, and contention between hydrogen and other deliveries to the sites from the long time required to complete a hydrogen transfer (~2 hours per transfer). The desktop safety review (DSR) states, "There were no scenarios impacting

Community or Environment that required further analysis in the DSR." The basis for that statement is not clear.

e. The ground storage element, "Supply Storage," consists of many hydrogen storage cylinders that are grouped into three banks and interconnected via manifolds, which then connect to the "Max Flowtech Supply" module via individual piping runs, which vary from site to site. There is a concern that there is no mechanism for isolating the storage cylinders or banks until the piping runs enter the Max Flowtech Supply module. It appears that any leak in the Supply Storage module or piping runs could not be isolated and could potentially result in one of the banks being completely vented. This scenario could result in a hydrogen release that is not directed to the vent stack (similar to the Norway incident) or a release due to a failure in the Max Flowtech Supply module (similar to the incident in White Plains, NY). The current design would also necessitate the emptying and purging of an entire bank if service is needed.

   This risk is compounded by the Storage Supply piping to the Max Flowtech Supply being different at each site and therefore dependent on the contractor, construction techniques, and other site-specific factors. If that piping is breached, with no way to isolate the cylinders/banks, it becomes very hard to predict the consequences of a potential release.

2. Siting
   a. The design should show the setback distances to exposures (NFPA 2-2020, per Chapter 7, or Chapter 5 for performance-based) and include these distances in the analysis of the effect of a release for those exposures.
   b. Site-specific review comments are shown in Table 1.

Table 1. Shell Station Site-Specific Review Comments

#	Site Address	Comments & Recommendations
1	2051 West 190th St Torrance, CA 90501	a. Address the potential for parked cars to be blocked by or hinder the hydrogen delivery.
2	1600 Jamboree Rd Newport Beach, CA 92660	b. The system has two sets of supply storage tubes (~800 kg of hydrogen). It is one of the best sites for deliveries to minimize public and property interactions.
3	705 West Huntington Dr Monrovia, CA 91016	c. The delivery fill system and dispensers are very remote from the hydrogen system. It appears the truck could be blocked by other vehicles being filled. d. The hydrogen system is located between two buildings. The interaction between the hydrogen system and the adjacent building and rooftop devices should be reviewed for possible rerouting to avoid public intake.

Table 1. Shell Station Site-Specific Review Comments		
#	Site Address	Comments & Recommendations
4	7170 Avenida Encinas Carlsbad, CA 92011	e. The delivery fill system and dispensers are very remote from the hydrogen system. Access for the larger truck is very tight and it appears the truck could be blocked by other vehicles being filled. The project team should assess the interaction between cars being fueled and the hydrogen delivery vehicle, and potential interaction between the gasoline/diesel fuel tank vents and delivery vehicles and the hydrogen delivery vehicle. f. The interaction between the hydrogen system and the adjacent building and rooftop devices should be reviewed for possible rerouting to avoid public intake.
5	5164 W. Washington Blvd Los Angeles, CA 90022	g. The delivery fill system and dispensers are very remote from the hydrogen system. The hydrogen delivery truck will block some parking spaces and one of the entrances during a delivery. Maneuvering of the hydrogen delivery vehicle has a larger potential for accident due to the small area. Access for the larger truck is very tight and it appears the truck could be blocked by other vehicles being filled. It also appears that the larger truck would need to back up to exit the site. h. Address the potential interaction between the gasoline/ diesel fuel tank vents and delivery vehicles and the hydrogen delivery vehicle. i. The interaction between the hydrogen system and the adjacent building and rooftop devices should be reviewed for possible rerouting to avoid public intake.
6	2589 N. Lakewood Blvd Long Beach, CA 90815	j. The delivery fill system and dispensers are remote from the hydrogen system. The supply systems are on the lot line with retail stores and their parking areas. In the offload position, the trailer, especially the longer delivery vehicle, blocks the sidewalks and two of the four inlet/outlets. The offload is very close to the road and sidewalk. k. Address the potential interaction between the gasoline/ diesel fuel tank vents and delivery vehicles and the hydrogen delivery vehicle. l. The interaction between the hydrogen system and the adjacent building and rooftop devices should be reviewed for possible rerouting to avoid public intake.

Table 1. Shell Station Site-Specific Review Comments		
#	Site Address	Comments & Recommendations
7	2600 Pellissier Place City of Industry, CA 90601	m. The dispensers are remote from the hydrogen system. The carwash entrance will be blocked during a delivery. For the larger delivery vehicle, the space would be restricted at the gasoline dispensers, the car wash entrance, and potentially egress from the building through the front doors. n. Address the potential interaction between the gasoline/ diesel fuel tank vents and delivery vehicles and the hydrogen delivery vehicle. o. The interaction between the hydrogen system and the adjacent building and rooftop devices should be reviewed for possible rerouting to avoid public intake.

3. Codes and Standards
    a. The project team indicated that an NFPA 2 performance-based approach was used for code compliance rather than NFPA 2 prescriptive distances to site equipment and hydrogen systems. This requires additional modeling and requirements per NFPA 2, Chapter 5. The following are examples of issues that should be addressed in a performance-based approach:
        i. Independent review of results. (NFPA 2-2020, 5.1.5)
        ii. The degree of the conservatism…shall be specified and a justification for the source shall be provided. (NFPA 2-2020, 5.1.6)
        iii. Copies of all references relied upon by the performance-based design to support assumptions design features or any other part of the design shall be made available to the AHJ. (NFPA 2-2020, 5.6.2)
        iv. The facility shall be maintained in accordance with all documented assumptions and design specifications. (NFPA 2-2020, 5.1.10.2)
        v. Annually certify design features and systems are as installed. (NFPA 2-2020, 5.1.11)
        vi. Minimize the potential exposure of people or property to unsafe conditions or events involving an unintended reaction or release of hazardous materials. (NFPA 2-2020, 5.1.12.1(3))
        vii. Provide appropriate safeguards to minimize the risk of and limit the damage and injury that could result from an explosion. (NFPA 2-2020, 5.1.12.1(6))
        viii. Fire Conditions – No occupant who is not intimate with ignition shall be exposed to instantaneous or cumulative untenable conditions. (NFPA 2-2020, 5.2.2.1)

   ix. Explosion conditions. The facility design shall provide an acceptable level of safety for the occupants and for individuals immediately adjacent to the property form the effects of unintentional deflagration or detonation. (NFPA 2-2020, 5.2.2.2)
   x. Design scenarios must be analyzed. (NFPA 2-2020, 5.4)
   xi. Specific fire input data for computer fire models shall be in accordance with ASTM E1591.

b. ATEX was the standard used for the electrical design, and it is uncertain if this design meets NFPA 2/70 code requirements. It is recommended that the system adhere to NFPA 70, the National Electric Code.
c. A design review is required to meet the NFPA 2, Chapter 5 requirement to review the effects of fire, explosion, or a release for the public and the surrounding property (customers, neighbors, residences, retail stores, and gasoline delivery vehicles around the system). The HSP found no analysis by Shell or Maximator for this requirement. This should be reviewed for a major release from the vent stack, major pipe leaks, or a hose from the trailer. The project team should follow this recommendation for all station configurations rather than assuming a single worst-case location.
d. The design review recommended in (c) should provide an understanding of the impact of a credible large release on the surrounding properties/population. It is recommended that the hydrogen venting effects for the public and surrounding buildings be modeled and understood in the case of a large release and potential deflagration per the NFPA 2 code requirements.
e. The frequency of deliveries and the historical incident rate for this activity should be well understood and steps should be taken to reduce the severity to an acceptable level. For hydrogen delivery, there appears to be a lot of emphasis on operator dependency, especially related to station congestion and delivery of gas or diesel fuel. There might be contention between a hydrogen delivery and a gasoline/diesel delivery at the same station, as it is not apparent how these would be coordinated.
f. The hydrogen system and fill connection distances to the public (e.g., customers, pedestrians, surrounding buildings) should be carefully examined with results of a credible release from the tube trailer or the hydrogen system. As many of these cannot meet the prescriptive-based approach (especially for lot lines, wall opening, and exposure to the public), using a performance-based approach for each site is possible but, as noted above, the approach must meet Chapter 5 of NFPA 2-2020. Again, this recommendation applies to all Neptune configurations; the analysis should not assume a single worst-case location.

4. <u>Piping and Instrumentation</u>
   a. There is potential for fire or deflagration at the dispensers, piping to/from the dispensers, and within the confined hydrogen system area. In many instances, the systems are surrounded by walls. The project team should assess the impacts of a release and ignition within these confined areas.

b. The addition of more safeguards (from pressure transients to physical impacts) should be assessed for the piping from the hydrogen storage system to the dispensers and the storage tubes (with no individual isolation) to the isolation valves in the Flowtech equipment.
c. Hydrogen quick connects are used for the connection of hydrogen to the tube trailer. Consider a secondary device to ensure the quick connect cannot release during fueling.
d. There are no individual valves to isolate the supply of high-pressure storage tubes. A break in the pipe line between the tubes and the three bank isolation valves would require the tubes to fully vent down before the leak could be fixed or isolated. A breach of the three lines to each bank of tubes could cause an uncontrollable release.

5. Vent Systems
   a. The vent line design is critical to containing the hydrogen. The remote delivery supply panels and dispensers vent line pressures and pressure drops should be specifically analyzed to ensure the pipe lines are not over-pressured or the relief devices are not damaged by chattering form the high-flow conditions.
   b. The design of the vent stack was approved by Intertek and Shell according to CGA 5.5. Teleconference discussions included performance testing of the vent stack at high pressure and flow to verify mechanical integrity and stability. It is also unclear whether the vent stack complies with CGA 5.5 requirements related to discharge of multiple sources, and design for deflagration or detonation.
   c. All vent lines have a much lower pressure rating than the safety valves to which they are connected. [redacted] With up to 1000 barg at the safety relief valves, the pressure rating of the vent piping is in question. This confirms what was noted in the risk assessment item #2/consequence #10.1.2.1. (The first two items in Appendix A of the DSR Recommendations directly address the questions raised by the HSP regarding the design of the vent stack. The items refer to specific sections of Appendix C, Technical DSR Worksheets, but it is unclear whether the recommendations were completed and what the results were.)
   d. The flow calculations for the inlet lines to the safety valves and the outlet vent lines showing pressure and pressure drop were not provided for review. The safety valve inlet and outlet lines were simulated using the calculated case flow rate shown in the data under Section 2.6.4, "Back pressure in Vent line," of the extract safety memorandum. The safety valve flow rates required were shown to be much lower than the safety valve capacity (7.5% up to a maximum of 30.4% of the safety valve flow rate). Of concern is that the vent line not only carries the flow for AW.C2-Q103-FL1, but also for the two dispenser safety relief valves.

HSP comments from the review of the five potential maximum flow cases are as follows:

- Case 1: Overpressure the Max Flowtech Supply from supply trailer (550-barg max pressure). The project team indicated this is not an issue as the delivery trailer maximum pressure is less than the Max Flowtech Supply safety valve set point. This case seems to be correct, as long as no delivery of hydrogen can occur over 500 barg.
- Case 2: Overpressure the Max Flowtech Supply from the second stage of compressor (975-barg max) during active offloading. The flow rate to the relief device is restricted by the compressor piping to [redacted]. The vent piping inlet and outlet design must use the actual safety valve flow rate, not the flow rates for the safety sizing case. This should be completed for each specific site, as the lengths of the vent pipe runs vary among sites.
- Case 3: Overpressure the Max Flowtech Supply from active trailer offloading, through inadvertent opening of the active offloading valves. The flow rate to the relief device is restricted by the piping to [redacted] The vent piping inlet and outlet design must use the actual safety valve flow rate, not the flow rates for the safety sizing case. This should be completed for each specific site, as the lengths of the vent pipe runs vary among sites.
- Case 4: Overpressure storage from high-pressure storage. Per the project team, this can't be an issue due to the small volume of high-pressure storage. As long as the components between the high-pressure storage and the Supply Storage module are all rated at over 975 barg, this conclusion seems to be correct.
- Case 5: Thermal expansion in storage tubes by external fire. This was not considered by Maximator. Consider smaller safety relief valves to reduce the potential for unsafe safety relief valve chattering.

e. The following considerations should be assessed for all vent lines/stacks, including the noted single safety valve (AW.C2-Q103-FL1):

   i. The flow rates of the relief devices should be reviewed in every vent line for pressure and pressure drop where safety relief chattering may occur. For instance, for the provided case, the flow rate of [redacted] is not the flow rate that should be used for modeling pressure and pressure drop in the inlet to the safety valve and the vent line calculation. The flow rate that should be used is the actual safety valve flow rate [redacted]. The current design has the potential of causing a chattering safety valve problem. Oversized relief devices have caused chattering, which can cause major safety issues.[1] Additional information from ASME requirements can be found in ASME Section VIII UG-135 (b).

[1] https://epsc.be/epsc_media/Learning+Sheets/2020/20_04+EPSC+Learning+Sheet+_+Chattering+PSV-p-1309.pdf

ii. Multiple safety valve flow rates should be reviewed when in a common vent line. No relief device cases provided reviewed the potential for multiple pressure relief devices to open simultaneously.
iii. There is a muffler on the end of two smaller vent lines. Pressure drop through the muffler is a concern at the large design flow rates of the safety valves. This will add to the chattering and the high pressures in the vent line that are larger than the design pressures. Consider eliminating the mufflers.
iv. All vent lines should be pressure rated at the relief device set point or to the safety valve flow rate vent line pressure so that the line pressure will not exceed the pressure rating (maximum allowable working pressure).
v. The following failure causes of the vent stack (which is acting in the role of a chimney) and the support system should be evaluated for credibility and safety improvement:
    - Damage from external forces (earthquake, wind, etc.)
    - Deflagration within the large vent stack from the smaller stack releases; should an ignition occur, there is likely a propagation of failures from the deflagration overpressure and/or heat from the resulting flame
    - Damage or excess oxygen in a large hydrogen flame from the hydrogen cooling heat exchanger air affecting a large hydrogen stack fire
    - Prolonged release, where air will be ingested with the venting hydrogen either because the fan remains on (Aside - is the fan classified?) or because of the Bernoulli effect caused by the venting hydrogen

f. It is not clear to the HSP members that the worst-case loads for the back pressure and burst pressure of the vent stack are well understood. One suggested option is that various parameters be tested (e.g., large volume release, ignition of gas inside vent stack, prolonged release inside the vent).
g. Assess the value of a redundant vent stack in case of failure of the main stack.

6. Other Comments, Questions, and Suggested Improvements
   a. Involve the supplier of the Supply Storage module in a review of the DSR and HAZOP with particular attention to any risks associated with the absence of individual cylinder isolation capability.
   b. The DSR appears to evaluate only the risks associated with the gases/fluids involved in the system. Consider a review of high-pressure-related hazards (hydrogen plus hydraulic fluids) and any appropriate electrical hazards.
   c. The HAZOP document was not fully available for the HSP review because of Maximator confidentiality requirements. This complicates the process of a third-party independent review.
   d. Section 5.1.7.2 in Appendix C of the DSR recommends installation of physical barriers to prevent damage to the supply panel, which could result in loss of containment of the Supply Storage module. Consider isolating the banks or individual cylinders directly within the Supply Storage module as a better option.

e. As with the Supply Storage module, the delivery trailer is part of the system even though it is not Maximator's responsibility. Consider providing at least an overview of the trailer P&ID and function.
f. Consider including a list of all applicable design standards in any design review report. Reviewing this list would have been valuable. For example, the HSP assumes that the plumbing between the various modules must confirm the appropriate ASME piping standards – should that be stipulated somewhere? HGV 4.9 (Hydrogen Fueling Stations) may also be appropriate, and the Panel has seen this requested for hydrogen stations in other projects.

Listing of Formal Documents Reviewed

Table 2. Documents Supplied by Shell and Maximator Used for Review

#	Document Identifier
1	SOP.30131-P-TRUCK-101920.pdf, "Preliminary Truck Exhibit," Sheet C-2, Torrance site
2	SOP.30132-P-Site-C-1 102820.pdf, "Site Plan," Sheet C-1, Newport Beach site
3	SOP.30544-P-Site-C-1 Site Plan after mtg 2-2-21.pdf, "Preliminary Site Plan" Sheet C-1, Long Beach site
4	SOP-30544-P-TRUCK-CARLSBAD-2021.01.27.pdf, "Preliminary Truck Exhibit," Sheet C-2, Carlsbad site
5	SOP-30543-P-SITE (City of Industry) 02-01-21.pdf, "Preliminary Site Plan" Sheet C-1.0, City of Industry site
6	SOP-30545-P-SITE 1-25-21.pdf, "Preliminary Site Plan" Sheet C-1.0, Los Angeles site
7	SOP-30546-P-SITE-MONROVIA-2021.02.08.pdf, "Preliminary Site Plan" Sheet C-300, Monrovia site
8	SHYD-01-R-01 DSR Hydrogen Refueling Station Rev 1.0.pdf, "Report, DSR [Desktop Safety Review] Hydrogen Refueling Station, December 16, 2020, Risktec Solutions B.V.
9	FPLAN_4321.0003__20201008_EN.pdf, Native P&Ds, "&MFSI "Connection Diagram," 16 pages
10	FPLAN_4321.0003_P&ID_rev2.docx, P&IDs, "&MFSI "Connection Diagram," 16 pages
11	Tab_Legende_Fluidsymbole_H2_ISO1219.2012.pdf, "Shell Project Neptune P&ID Legend Sheet," 10 pages
12	BES_4321.0003_Process Control Narrative_rev2.docx, Process Control Narrative, 26 pages
13	BES_4321.0003_Safeguard Memorandum_rev3.pdf, [Extract] – pressure and flowrate tables

Acknowledgements

The HSP appreciates the very helpful and consistent support of James Jessup of Shell for providing technical information, coordinating the many online meetings, and providing answers to technical queries.