Next Generation Hydrogen Station Composite Data Products: Retail Stations

Summer 2020: Data through Quarter 2 of 2020

Genevieve Saur, Spencer Gilleon, and Sam Sprik
February 2021
Hydrogen Station Project Partners

- Air Liquide
- Air Products
- California Air Resources Board
- California Energy Commission
- California State University Los Angeles
- Equilon
- FirstElement Fuel
- Gas Technology Institute
- ITM Power
- Iwatani
- Linde
- H2 Frontier
- Messer
- Proton OnSite
- Shell
- IPHE and HySUT
Analysis Categories

- Deploy
- Cost
- Performance
- Reliability
- Utilization
- Safety
- Quality
- Energy
Deployment
CDP-INFR-27
Hydrogen Station Timeline

Hydrogen Station Timeline - Retail Stations

Stations Sorted by Opening Date

Duration [days]

Design
Permit
Construction
Commission
Hydrogen Station Timeline Trend - Retail Stations

Days for Design

Days for Permitting

Days for Construction

Days for Commissioning

[1] 42 projects with timelines included
Safety
An Incident is an event that results in:
- a lost time accident and/or injury to personnel
- damage/unplanned downtime for project equipment, facilities or property
- impact to the public or environment
- any hydrogen release that unintentionally ignites
- release of any volatile, hydrogen containing compound (including the hydrocarbons used as common fuels)

A Near Miss is:
- an event that under slightly different circumstances could have become an incident
- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite
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CDP-INFR-48
Mean Fills per Hydrogen Leak

Mean Fills per H\textsubscript{2} Leak - Retail Stations

Station Average: 1012 Fills per H\textsubscript{2} Leak.
13 of 42 stations did not report leaks.
Mean Hydrogen Dispensed per Hydrogen Leak

Station Average: 2822 kg H\textsubscript{2} Dispensed per H\textsubscript{2} Leak.

13 of 42 stations did not report leaks.
Maintenance and Reliability
Maintenance by Known Equipment Type - Retail Stations

Total Events $^1 = 13,137$
- 62% unscheduled

- classified events: 9025
- multiple systems: 2119
- entire system: 783

Classified Events
- dispenser: 24%
- compressor: 13%
- chiller: 51%
- gas mgmt panel: 7%
- storage: 5%

Total Hours $^1 = 33,442$
- 71% unscheduled

- dispenser: 40%
- compressor: 11%
- chiller: 7%
- gas mgmt panel: 22%
- storage: 20%

MISC includes the following failure modes: veh other, aux, electrolyzer, feedwater, purifier, fuel, reformer, safety, thermal management, electrical, air, other

1. Total includes classified events (plotted) and unclassified events.
2. Maintenance events with unknown equipment type excluded from plot.
CDP-INFR-94
Maintenance by Equipment Type by Quarter

Maintenance by Equipment Type by Quarter - Retail Stations

Number of Maintenance Events

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Number at bottom of bars is number of stations reporting for that quarter.
*"OTHER" includes items for which equipment type could not be determined from the data.
Infrastructure Maintenance Labor Hours per Event - Retail Stations

68% of repairs require less than the mean of 3.5 hours of labor.
Median labor hours: 2.3
Failure Modes for Top Equipment Categories - Retail Stations

GAS MGMT PANEL
- COMMUNICATION ERROR: 7%
- FAILED PART: 13%
- OVERTEMPERATURE: 24%
- UNDETERMINED: 51%

COMPRESSOR
- MATERIAL DEFORM/DEGRADD/FATIGUE: 40%
- FAILED PART: 20%
- OVERTEMPERATURE: 22%
- UNDETERMINED: 7%

DISPENSER
- COMMUNICATION ERROR: 7%
- FAILED PART: 24%
- OVERTEMPERATURE: 20%
- UNDETERMINED: 40%

MISC includes the following failure modes: collision, communication error, contamination, debris, design flaw, electrical breaker, end of life, environmental factors, fluid leak, freezing, installation error, level low, loose electrical, loose mechanical, lost signal, maintenance error, manufacturing defect, material deform/grade/fatigue, metal fatigue, moisture, na, operator error, out of calibration, overtemperature, power outage/quality, pressure loss, software bug, stress outside design limit, tight, vandalism, vibration, other.

* Percentage of total events or hours.
**Compressor Monthly Maintenance - Retail Stations**

**Overall Averages**
- 5.9 hours per station per month.
- 2169.9 kg dispensed per maintenance hour.

**Overall Averages**
- 2.7 events per station per month.
- 2025.7 kg dispensed per maintenance event.

* Trendlines connect continuous months of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.
Overall Average:
89 hours per station per quarter.
Average last 8 quarters:
94 hours per station per quarter.
Average last 4 quarters:
121 hours per station per quarter.

Stars represent individual station maintenance hours in a given quarter.
Overall Average: $9,955 per station per quarter.
Average: $8,782 per station per last 8 quarters.
Average: $10,731 per station per last 4 quarters.
CDP-INFR-49
Mean Fills Between Failures

Mean Fills Between Failures - Retail Stations

- Median Site
- Lowest Site

Mean Fills Between Failures

0 500 1000 1500 2000 2500 3000

AIR  CHILLER  COMPRESSOR  DISPENSER  ELECTRICAL  FUEL  GAS MGMT PANEL  SAFETY  STORAGE  THERMAL MANAGEMENT

Created: Jan-08-21 9:56 AM | Data Range: 2014Q3-2020Q2
CDP-INFR-50
Reliability Growth by Fills

Overall Site Reliability Growth By Fills - Retail Stations

Instantaneous MTBF improved for 21 of 42 sites for the last 20% of events.

Sites sorted by Increasing Age
Fills


2. % change in instantaneous mean Fills between failures
CDP-INFR-51
Mean Amount Dispensed Between Failures

Mean $H_2$ Dispensed Between Failures (kg) - Retail Stations

Median Site

Lowest Site

AIR
CHILLER
COMPRESSOR
DISPENSER
ELECTRICAL
FUEL
GAS MGMT PANEL
SAFETY
STORAGE
THERMAL MANAGEMENT

Created: Jan-08-21  9:34 AM | Data Range: 2014Q3-2020Q2
Reliability Growth by Amount Dispensed

Overall Site Reliability Growth By \( H_2 \) Dispensed (kg) - Retail Stations

Instantaneous MTBF improved for 19 of 42 sites for the last 20% of events.

Sites sorted by Increasing Age
\( H_2 \) Dispensed (kg)


2. % change in instantaneous mean \( H_2 \) Dispensed (kg) between failures
Historical Failure Rate (bathtub curve) by Fills - Retail Stations

\[ \rho = \frac{\lambda}{\beta} (\beta - 1) \]

\[ \lambda = 1.746 \]

\[ \beta = 0.573 \]

19 Mean Fills per Failure at 1000 Fills
Historical Failure Rate (bathtub curve) by kg H$_2$ Dispensed - Retail Stations

\[ \rho = \frac{\lambda}{\beta^{2}} \]  
\[ \lambda = 1.215 \]  
\[ \beta = 0.585 \]  

48 Mean kg H$_2$ Dispensed per Failure at 5000 kg H$_2$ Dispensed
Maintenance Causes and Effects - Retail Stations

Subsystem: CHILLER
Component: ENTIRE

Preventative Maintenance accounted for 12% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: CHILLER
Component: HEAT EXCHANGER

Preventative Maintenance accounted for 10% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects

Subsystem: CHILLER
Component: VALVE

Preventative Maintenance accounted for 2% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER
Component: ENTIRE

Preventative Maintenance accounted for 24% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER
Component: NOZZLE

Preventative Maintenance accounted for 5% of all events.
Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER
Component: VALVE

Preventative Maintenance accounted for 6% of all events.
Suppressed in the plot to show detail for other causes.

Causes

Effects
Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR
Component: ENTIRE

Preventative Maintenance accounted for 30% of all events. Suppressed in the plot to show detail for other causes.

Causes

Effects

CDP-INFR-70
Maintenance Causes and Effects: Compressor (Entire)
Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR
Component: PISTON

Preventative Maintenance accounted for 5% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR
Component: VALVE

Preventative Maintenance accounted for 3% of all events. Suppressed in the plot to show detail for other causes.
Performance
CDP-INFR-01
Hydrogen Dispensed by Quarter

Hydrogen Dispensed By Quarter - Retail Stations

Cumulative Hydrogen Dispensed = 2,751,018 kg
Avg H2 Dispensed in 2020Q2 per station = 3,549 kg
Number of stations operating in 2020Q2 = 44

Note: Colors represent individual stations. Station count is number at bottom of bar.
Hydrogen Fills by Quarter

By Year

Cumulative Fuelings = 970,598

Note: Colors represent individual stations. Station count is number at bottom of bar.
Hydrogen Dispensed By Region - Retail Stations

Cumulative Hydrogen Dispensed
Northern California = 961,542 kg
Southern California = 1,671,131 kg
Connector California = 118,345 kg

Note: Station count is number at bottom of bar.
Cumulative Hydrogen Dispensed = 2,751,018 kg
Avg H2 Dispensed in 2020Q2 per station = 3,549 kg
Number of stations operating in 2020Q2 = 44

Note: Stations reporting data count is number at bottom of bar.
[1] Other includes pipeline and stations with multiple hydrogen sources.
Histogram of Fueling Rates

- 861,336 Events
- Average = 0.9 kg/min
- 1.0% > 1.51 kg/min
- 0.2% > 2 kg/min

2.5 minute fill of 5 kg

2020 MYRDD Target
Ultimate MYRDD Target
Average
Histogram of Fueling Times

- 861,336 Events
- Average = 3.39 min
- 48% < 3.3 min
- 21% < 2.5 min

- 2020 MYRDD Target for 5 kg
- Ultimate MYRDD Target (5 kg in 2.5 min)
- Average
Histogram of Fueling Amounts

Average = 3.01 kg
Time Between Fueling

Histogram of Time Between Fuelings - Retail Stations

- 26% of fills are within 0-5 minutes of each other
- 45% of fills have more than 20 minutes between them
- 863,266 Total Fills

Final Pressures for Fills with <5 Minutes in Between

- 45,634 fills removed from lowest bar with both Previous and Next Final Fill Pressure 0

*Time is from end of fill to start of next fill.
Fueling Final Pressures - Retail Stations

- Avg Final Pressure = 349 bar
- % of Fills > 350 bar = 52%
- Number of Fills = 24437

- Avg Final Pressure = 758 bar
- % of Fills > 700 bar = 87%
- Number of Fills = 723095

*The line at 450 bar separates 350 bar fills from 700 bar fills. It is slightly over the allowable 125% of nominal pressure (437.5 bar) from SAE J2601.
Histogram of Fueling Rates
350 vs 700 bar Fills

Fill Type | Avg | %>1.51 | %>2  | Count  
----------|-----|--------|------|--------
350 bar   | 0.89| 1.8%   | 0.5% | 85273  
700 bar   | 0.93| 0.6%   | 0.3% | 777332 

2.5 minute fill of 5 kg
Hydrogen Dispensed by Quarter and Pressure - Retail Stations
CDP-INFR-14
Hydrogen Dispensed per Hour
Number of Fills by Time of Day

Number of Fueling Events per Time of Day - Retail Stations

Number Included
905,726 fills

Fueling Amounts per Time of Day

- **Total [%]**
- **Max [kg]**
- **Average [kg]**

Amount Included
2,738,553 kg

Graph showing fueling amounts per time of day with time of day in hours on the x-axis and amount dispensed [% of Total] on the y-axis. The graph includes a bar chart for total, max, and average fueling amounts.
Fueling Profile by Day and Hour

Fueling Amounts by Day and Hour - Retail Stations - Connector/Destination California

Fueling Profile by Day and Hour

Fueling Amounts by Day and Hour - Retail Stations - Northern California

sun

mon

tue

wed

thu

fri

sat

Fueling Amounts by Day and Hour - Retail Stations - Southern California

CDP-INFR-91
Missed Fuel Opportunity

Missed Fuel Opportunity during Q1 of 2020 for 35 stations (29,109 kg)

*The minute fill profile was taken as an average from an hourly total.*
Missed Fuel Opportunity during Q2 of 2020 for 35 stations (10,357 kg)

*The minute fill profile was taken as an average from an hourly total.*
Missed Fuel Opportunity during Q3 of 2020 for 35 stations (14,885 kg)

*The minute fill profile was taken as an average from an hourly total.*
Missed Fuel Opportunity during Q4 of 2020 for 35 stations (33,150 kg)

*The minute fill profile was taken as an average from an hourly total.*
Missed Fuel Opportunity during 2020 for 35 stations (87,189 kg)

The minute fill profile was taken as an average from an hourly total.
2020 Station Unavailability for 43 stations

Day of the Year

Time of Day

# of Stations Unavailable

* y-axis resolution - minutes | x-axis resolution - days

Created: Jan-08-21 9:24 AM | Data Range: 2012Q1-2020Q2
2020 Station Unavailability for 19 stations
Northern California

# of Stations Unavailable

Day of the Year

Time of Day

* y-axis resolution - minutes | x-axis resolution - days
CDP-INFR-95
Station Unavailability

2020 Station Unavailability for 24 stations
Southern California

Day of the Year

# of Stations Unavailable

* y-axis resolution - minutes | x-axis resolution - days
Histogram of Fueling Rates by Amounts - Retail Stations

- 0 to 0.5 kg
- 0.5 to 1 kg
- 1 to 2 kg
- 2 to 4 kg
- 4 to 6 kg
- 2020 MYRDD Target
- Ultimate MYRDD Target
Histogram of Fueling Amount Vs Time - Retail Stations

- 01/01/2015 Through 07/01/2015
- 07/01/2015 Through 01/01/2016
- 01/01/2016 Through 07/01/2016
- 07/01/2016 Through 01/01/2017
- 01/01/2017 Through 07/01/2017
- 07/01/2017 Through 01/01/2018
- 01/01/2018 Through 07/01/2018
- 07/01/2018 Through 01/01/2019
- 01/01/2019 Through 07/01/2019
- 07/01/2019 Through 01/01/2020
- 01/01/2020 Through 07/01/2020

Number of Fills

Amount [kg]

Fill Time [min]

Fueling Amount vs. Time to Fill
CDP-INFR-56
Fueling Rates by Year

Histogram of Fueling Rates
By Year

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<th>Avg (kg/min)</th>
<th>%&gt;1.51</th>
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3.3 minute fill of 5 kg

2.5 minute fill of 5 kg
CDP-INFR-55
Monthly Averages: All Fills

Monthly Averages for All Fills - Retail Stations

- Rate [kg/min]
  - Avg: 0.93
  - Overall Avg
  - Individual Station Avg

- Time [min]
  - Avg: 3.6
  - Overall Avg
  - Individual Station Avg

- Amount [kg]
  - Avg: 3.2
  - Overall Avg
  - Individual Station Avg

Data Range: 2014Q3-2020Q2
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -40°C

- **Avg Rate [kg/min]**: 0.93
- **Avg Time [min]**: 3.6
- **Avg Amount [kg]**: 3.2
Cost
Compressor Operation Cost - Retail Stations

Average = 1.92 [$/kg]
Maintenance Costs Per kg Dispensed Over Time - Retail Stations

Overall Average: $16 per kg.

*Each color represents a unique station. 0 data points excluded that were over $1000/kg
CDP-INFR-73
Histogram of Monthly Maintenance Costs

Histogram of Monthly Maintenance Costs - Retail Stations

Total Quarterly Maintenance Cost
Mean Quarterly Maintenance Cost

Frequency of Quarterly Cost

Total Quarterly Cost [$1,000s]
Hydrogen Price by Quarter - Retail Stations

H2 Price [$/kg]

H70 Price Range
H35 Price Range
H70 Weighted Price (by kg)
H35 Weighted Price (by kg)

Note: Data points above $20/kg have been filtered due to a data reporting error.
Utilization
CDP-INFR-05
Dispensed Hydrogen per Day of Week

Dispensed Hydrogen per Day of Week - Retail Stations

- H2 Stations [%]
- Gasoline Station [%]
- Individual Stations [kg/day]
- Average of Stations [kg/day]

max station avg: 142 kg/day

Dispensed Fuel [% of total]

Sun Mon Tues Wed Thur Fri Sat

Dispensed Hydrogen per Day of Week

1. Chevron weekly demand profile "Hydrogen Delivery Infrastructure Options Analysis", T. Chen.
Station Capacity Utilization - Retail Stations

1. Station nameplate capacity reflects a variety of system design considerations including system capacity, throughput, system reliability and durability, and maintenance. Actual daily usage may exceed nameplate capacity.

2. Maximum quarterly utilization considers all days; average daily utilization considers only days when at least one filling occurred.
Station Usage - Retail Stations

Maximum Daily Fills
Average Daily Fills

Note: The focus for early stations is geographic coverage

1 Excludes hydrogen fills of < 0.5 kg
2 Average daily fills considers only days when at least one fill occurred
Hydrogen Dispensed by Month - Retail Stations

- Individual station
- Average of all stations

Monthly Amount [kg]

Created: Dec-03-20  4:14 PM | Data Range: 2014Q3-2020Q2
Number of Fills by Month
Station Capacity Utilization Trends by Quarter - Retail Stations

Number of Stations = 42 Total
Total H2 Dispensed = 2,751,008 kg

Range of Station Capacities

Maximum Daily Fueling Capacity (kg)

Average Utilization (%) vs. Quarters

1 Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

2 Average quarterly utilization only considers quarters when at least one fill occurred.

3 Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.
Station Amount Dispensed by Quarter - Retail Stations

Number of Stations = 42 Total
Total H2 Dispensed = 2,751,008 kg

1. Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station was offline or missing data. Each station is represented by a unique color.

2. Average quarterly amount only considers quarters when at least one fill occurred.
Trendlines connect continuous quarters of operation for a single station. Gaps in trendlines represent quarters in which a station had no fills or was missing data. Each station is represented by a unique color.

The average percent of days with fills only considers quarters in which at least one fill occurred. Stations with no filing days in a quarter are excluded from the average for that quarter. All stations with at least one fill in a quarter are given equal weight when calculating the average for the quarter.
1 Station nameplate capacity is as reported to NREL and reflects a variety of system design considerations including: system capacity, throughput, system reliability, and maintenance. Actual daily usage may exceed nameplate capacity.

2 Average quarterly utilization only considers days when at least one fill occurred.

3 Utilization is calculated by dividing the quarterly amount dispensed by the stations nameplate capacity.

4 Only quarters with fills are included.
Daily Fueling Amounts by Station

Daily Fueling Amounts - Retail Stations

- Daily Avg. 64.0 kg
- Daily Avg. 13.6 kg
- Daily Avg. 66.6 kg

Stations

NREL cdpRETAIL_infr_80
Created: Nov-13-20  6:02 PM | Data Range: 2014Q3-2020Q2
Daily Fueling Amounts Over Time - Retail Stations

*Daily Average per Month

*Daily average only includes days with fills.
Hydrogen Quality
Impurities (Retail Stations) - Ammonia

- SAEJ2719 Limit = 100 ppb
- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

Measured Impurity [ppb]

Number of Samples

- Delivered Compressed 336 Sample(s)
- Delivered Liquid 18 Sample(s)
- Delivered Pipeline 1 Sample(s)
- Onsite Electrolysis 36 Sample(s)
- Delivered Compressed; Onsite Electrolysis 3 Sample(s)
- Onsite SMR 9 Sample(s)

- Not Detected Summary-
- Delivered Compressed 336 Sample(s)
- Delivered Liquid 18 Sample(s)
- Delivered Pipeline 1 Sample(s)
- Onsite Electrolysis 36 Sample(s)
- Delivered Compressed; Onsite Electrolysis 3 Sample(s)
- Onsite SMR 9 Sample(s)
Impurities (Retail Stations) - Argon

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

SAEJ2719 Limit = 100 ppm

Measured Impurity [ppm]

Number of Samples

--Not Detected Summary--
- Delivered Compressed 330 Sample(s)
- Delivered Liquid 18 Sample(s)
- Onsite Electrolysis 36 Sample(s)
- Delivered Compressed; Onsite Electrolysis 4 Sample(s)
- Onsite SMR 8 Sample(s)

--Not Measured Summary--
- Delivered Compressed 8 Sample(s)
- Delivered Compressed; Onsite Electrolysis 1 Sample(s)

Impurity limits:
- nd det. lim = 0.4 ppm
- nd det. lim = 0.5 ppm
- nd det. lim = 1 ppm
- nd det. lim = 4 ppm
- nd det. lim = 25 ppm
- SAEJ2719 Limit = 100 ppm
Impurities (Retail Stations) - Carbon Dioxide

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

- Not Detected Summary:
  - Delivered Compressed 332 Sample(s)
  - Delivered Liquid 18 Sample(s)
  - Delivered Pipeline 1 Sample(s)
  - Onsite Electrolysis 36 Sample(s)
  - Delivered Compressed; Onsite Electrolysis 3 Sample(s)
  - Onsite SMR 9 Sample(s)

- Not Measured Summary:
  - Delivered Compressed 8 Sample(s)
  - Delivered Compressed; Onsite Electrolysis 1 Sample(s)

SAEJ2719 Limit = 2 ppm
Impurities (Retail Stations) - Carbon Monoxide

<table>
<thead>
<tr>
<th>Measured Impurity [ppb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
</tr>
<tr>
<td>0.5-2</td>
</tr>
<tr>
<td>2-10</td>
</tr>
<tr>
<td>10-50</td>
</tr>
<tr>
<td>50-100</td>
</tr>
<tr>
<td>100-150</td>
</tr>
<tr>
<td>150-200</td>
</tr>
<tr>
<td>&gt; 200</td>
</tr>
</tbody>
</table>

- **Delivered Compressed**
- **Delivered Liquid**
- **Delivered Pipeline**
- **Onsite Electrolysis**
- **Delivered Compressed; Onsite Electrolysis**
- **Onsite SMR**

**Not Detected Summary**
- Delivered Compressed: 329 Sample(s)
- Delivered Liquid: 18 Sample(s)
- Delivered Pipeline: 1 Sample(s)
- Onsite Electrolysis: 36 Sample(s)
- Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
- Onsite SMR: 8 Sample(s)

**Not Measured Summary**
- Delivered Compressed: 5 Sample(s)
- Delivered Compressed; Onsite Electrolysis: 2 Sample(s)

ND det. lim = 50 ppb
ND det. lim = 80 ppb
ND det. lim = 100 ppb
SAEJ2719 Limit = 200 ppb

411 Total Samples

Created: Nov-13-20  6:24 PM | Data Range: 2015Q4-2020Q2
Impurities—Formaldehyde

- Not Detected Summary:
  - Delivered Compressed: 271 Sample(s)
  - Delivered Liquid: 13 Sample(s)
  - Delivered Pipeline: 1 Sample(s)
  - Onsite Electrolysis: 2 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)
  - Onsite SMR: 9 Sample(s)

- Not Measured Summary:
  - Delivered Compressed: 1 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)

SAEJ2719 Limit = 10 ppb

Measured Impurity [ppb]
- nd det. lim = 1 ppb
- nd det. lim = 2 ppb
- nd det. lim = 5 ppb

Number of Samples
- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR
Impurities (Retail Stations) - Formic Acid

Measured Impurity [ppb]

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

SAE J2719 Limit = 200 ppb

nd det. lim = 1 ppb
nd det. lim = 5 ppb
nd det. lim = 15 ppb
nd det. lim = 20 ppb
nd det. lim = 100 ppb

Number of Samples

0-1 1-2 2-10 10-50 50-100 100-150 150-200 > 200

411 Total Samples

- Not Detected Summary:--
  Delivered Compressed: 223 Sample(s)
  Delivered Liquid: 16 Sample(s)
  Delivered Pipeline: 1 Sample(s)
  Onsite Electrolysis: 1 Sample(s)
  Delivered Compressed, Onsite Electrolysis: 1 Sample(s)
  Onsite SMR: 1 Sample(s)

- Not Measured Summary:--
  Delivered Compressed: 119 Sample(s)
  Delivered Liquid: 2 Sample(s)
  Onsite Electrolysis: 20 Sample(s)
  Delivered Compressed, Onsite Electrolysis: 4 Sample(s)
  Onsite SMR: 2 Sample(s)
Impurities (Retail Stations) - Helium

NREL cd/RETAL_infr_79
Created: Nov-13-20  6:20 PM | Data Range: 2015Q4-2020Q2

411 Total Samples

- Not Detected Summary:
  - Delivered Compressed: 304 Sample(s)
  - Delivered Liquid: 18 Sample(s)
  - Delivered Pipeline: 1 Sample(s)
  - Onsite Electrolysis: 34 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
  - Onsite SMR: 8 Sample(s)

- Not Measured Summary:
  - Delivered Compressed: 17 Sample(s)
  - Onsite Electrolysis: 2 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)

SAEJ2719 Limit = 300 ppm

Measured Impurity [ppm]

Delivered Compressed
Delivered Liquid
Delivered Pipeline
Onsite Electrolysis
Delivered Compressed; Onsite Electrolysis
Onsite SMR

Number of Samples

0 50 100 150 200 250 300 350 400
0-5 5-10 10-25 25-50 50-100 100-150 150-200 200-250 250-300 > 300

nd det. lim = 10 ppm
nd det. lim = 40 ppm

NREL cdp/RETAIL_infr_79
Impurities (Retail Stations) - Nitrogen

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

Notes for exceeding SAE J2719 Limits:
Commissioning
Impurities (Retail Stations) - Oxygen

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Onsite SMR
- Delivered Compressed; Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis

Number of Samples:
- Delivered Compressed: 16 Sample(s)
- Onsite SMR: 1 Sample(s)

Not Measured Samples:
- Delivered Compressed: 325 Sample(s)
- Delivered Liquid: 18 Sample(s)
- Onsite Electrolysis: 36 Sample(s)
- Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
- Onsite SMR: 8 Sample(s)

SAE J2719 Limit = 5 ppm

Measured Impurity [ppm]:
- nd det. lim = 1 ppm
- nd det. lim = 2 ppm

NDL = Not Detected Summary

Total Samples: 411
Impurities—Particulate Concentration

Measured Impurity [mg/kgH2]

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

SAE J2719 Limit = 1 mg/kgH2

nd det. lim = 0.05 mg/kgH2

Number of Samples

Delivered Compressed 334 Sample(s)
Delivered Liquid 18 Sample(s)
Delivered Pipeline 1 Sample(s)
Onsite Electrolysis 36 Sample(s)
Delivered Compressed; Onsite Electrolysis 5 Sample(s)
Onsite SMR 8 Sample(s)

411 Total Samples

Not Detected Summary—
- Delivered Compressed 1 Sample(s)
- Delivered Liquid 1 Sample(s)
- Delivered Pipeline 1 Sample(s)
- Onsite Electrolysis 1 Sample(s)
- Delivered Compressed; Onsite Electrolysis 1 Sample(s)
- Onsite SMR 0 Sample(s)
Impurities—Total Halogenates

- Not Detected Summary:
  - Delivered Compressed: 239 Sample(s)
  - Delivered Liquid: 17 Sample(s)
  - Delivered Pipeline: 1 Sample(s)
  - Onsite Electrolysis: 26 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
  - Onsite SMR: 8 Sample(s)

- Not Measured Summary:
  - Delivered Compressed: 40 Sample(s)
  - Onsite Electrolysis: 4 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)

- SAEJ2719 Limit: 50 ppb

- Measured Impurities [ppb]:
  - 0-1
  - 1-10
  - 10-20
  - 20-30
  - 30-40
  - > 50

- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

411 Total Samples
Impurities—Total Hydrocarbons

**ND det. lim = 0.1 ppm**
**ND det. lim = 0.25 ppm**

**SAEJ2719 Limit = 2 ppm**

Notes for exceeding SAE J2719 Limits:
Ok for Total HC = 3.2 (Methane = 3.2 ok per SAEJ2719)

Delivered Compressed
Delivered Liquid
Delivered Pipeline
Onsite Electrolysis
Delivered Compressed; Onsite Electrolysis
Onsite SMR

**411 Total Samples**

**Not Detected Summary**
- Delivered Compressed: 325 Sample(s)
- Delivered Liquid: 18 Sample(s)
- Onsite Electrolysis: 32 Sample(s)
- Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
- Onsite SMR: 8 Sample(s)

**Not Measured Summary**
- Delivered Compressed: 1 Sample(s)
- Delivered Compressed; Onsite Electrolysis: 2 Sample(s)
Impurities (Retail Stations) - Total Sulfur

- Not Detected Summary:
  - Delivered Compressed: 298 Sample(s)
  - Delivered Liquid: 18 Sample(s)
  - Onsite Electrolysis: 32 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 3 Sample(s)
  - Onsite SMR: 8 Sample(s)

- Not Measured Summary:
  - Delivered Compressed: 34 Sample(s)
  - Onsite Electrolysis: 2 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)

Measured Impurity [ppb]:
- 0
- 0.001-0.25
- 0.25-0.5
- 0.5-1
- 1-2
- 2-3
- 3-4
- > 4

Delivered Compressed
Delivered Liquid
Delivered Pipeline
Onsite Electrolysis
Delivered Compressed; Onsite Electrolysis
Onsite SMR

SAEJ2719 Limit = 4 ppb
nd det. lim = 1 ppb
nd det. lim = 3 ppb
nd det. lim = 3 ppb

411 Total Samples
411 Total Samples
Impurities (Retail Stations) - Water

411 Total Samples

- Not Detected Summary:
  - Delivered Compressed: 2 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 1 Sample(s)

- Not Measured Summary:
  - Delivered Liquid
  - Delivered Pipeline
  - Onsite Electrolysis
  - Delivered Compressed; Onsite Electrolysis
  - Onsite SMR

Impurities—Water

Delivered Compressed
Delivered Liquid
Delivered Pipeline
Onsite Electrolysis
Delivered Compressed; Onsite Electrolysis
Onsite SMR

Number of Samples

Measured Impurity [ppm]

nd det. lim = 0.5 ppm
nd det. lim = 1 ppm

SAE J2719 Limit = 5 ppm

nd 0-1 1-1.5 1.5-2 2-3 3-4 4-5 > 5

Number of Samples

0 20 40 60 80 100 120 140 160 180

Measurements:

- Delivered Compressed Sample(s)
- Delivered Liquid Sample(s)
- Delivered Pipeline Sample(s)
- Onsite Electrolysis Sample(s)
- Delivered Compressed; Onsite Electrolysis Sample(s)
- Onsite SMR Sample(s)

Data Range: 2015Q4-2020Q2

Created: Nov-13-20  6:16 PM
Component Energy
Compressor Energy

Average = 1.38 [kWh/kg]

Energy Consumed Only in Start Up and Shut Down

NREL cdpRETAIL_infr_35
Created: Dec-02-20 12:51 PM | Data Range: 2014Q3-2020Q2
Dispenser Efficiency - Retail Stations

Average (for >500kg) = 1.71 [kWh/kg]

Chiller Energy for 700bar

Average (for >500kg) = 1.39 [kWh/kg]
CDP-INFR-78
Station Energy per kg Dispensed
CDP-INFR-83
Station Energy Cost per kg Dispensed

Electricity Cost per kg - Retail Stations

- Compressed Delivery
- Delivered Pipeline
- Liquid Delivery
- Onsite Electrolysis; Compressed Delivery
- Onsite SMR; Compressed Delivery

Monthly Amount of Hydrogen Dispensed [kg]

Monthly Electricity Cost [$/kg]
Electricity Cost per kWh - Retail Stations

- Compressed Delivery, Average: 0.28 $/kWh
- Delivered Pipeline, Average: 0.21 $/kWh
- Liquid Delivery, Average: 0.24 $/kWh
- Onsite Electrolysis; Compressed Delivery, Average: 0.13 $/kWh
- Onsite SMR; Compressed Delivery, Average: 0.19 $/kWh

*Some data has been filtered due to station reporting errors.*
CDP-INFR-86
Station Electricity Cost per kWh by Region

Electricity Cost per kWh by Region - Retail Stations

- Connector California, Average: 0.34 $/kWh
- Northern California, Average: 0.26 $/kWh

*Some data has been filtered due to station reporting errors.*
Electricity Cost per kWh by Utility - Retail Stations

- **PG&E**, Average: 0.29 $/kWh
- **SCE**, Average: 0.24 $/kWh
- **SDG&E**, Average: 0.38 $/kWh
- **unknown**, Average: 0.24 $/kWh

*Some data has been filtered due to station reporting errors.*