Next Generation Hydrogen Station
Composite Data Products: Retail Stations

Data through Quarter 4 of 2018

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April 2019
Hydrogen Station Project Partners

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

- Deploy
- Cost
- Performance
- Reliability
- Utilization
- Safety
- Energy
- Quality
Deployment
CDP-INFR-10
Cumulative Number of Stations
CDP-INFR-11
Hydrogen Stations by Type

Hydrogen Station Type - Retail Stations

- Delivered
- On-Site
- Other Projects

Number of Stations

Delivered Pipeline | Liquid Delivery | Compressed Delivery | Onsite SMR | Onsite Electrolysis | Mobile Fueler | Trailers

- Retired
- Future
- Open

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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A Near Miss is:
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- any hydrogen release sufficient to sustain a flame if ignited

A Minor H2 Leak is:
Safety Reports by Event Description - Retail Stations

- Incident
- Near Miss
- Minor H2 Leak

Number of Reports

Severity

Equipment Malfunction
H2 Release - No Accumulation
Other
User error

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
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- any hydrogen release that unintentionally ignites
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A Near Miss is:
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A Minor H2 Leak is:
- an unplanned hydrogen release insufficient to sustain a flame, and does not accumulate in sufficient quantity to ignite
Station Average: 1091 Fills per H₂ Leak.

10 of 32 stations did not report leaks.
Station Average: 3600 kg H₂ Dispensed per H₂ Leak.

10 of 32 stations did not report leaks.
Maintenance and Reliability
Maintenance by Known Equipment Type - Retail Stations

- Dispenser: 24%
- Compressor: 22%
- Chiller: 7%
- Gas Mgmt Panel: 6%
- Other: 12%
- Unknown: 25%

Event Count:
- Classified events: 5604
- Multiple systems: 1143
- Entire station: 923
- Entire system: 294

MISC includes the following failure modes: feedwater, electrolyzer, thermal management, safety, storage, 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 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.
CDP-INFR-22
Maintenance Labor Hours per Event

Infrastructure Maintenance Labor Hours per Event - Retail Stations

Maximum and Mean Event Labor Hours for each site.

66% of repairs require less than the mean of 3.6 hours of labor.
Median labor hours: 2.5
CDP-INFR-23
Equipment Category Repair Time

Equipment Category Repair Time - Retail Stations

Repair Labor Time (Hours)

AIR
CHILLER
COMPRESSOR
DISPENSER
ELECTRICAL
ELECTROLYZER
ENTIRE
FEEDWATER
GAS MGMT PANEL
SAFETY
STATION OTHER
STORAGE
THERMAL MANAGEMENT

75th Percentile
Mean
Median
25th Percentile
Failure Modes for Top Equipment Categories - Retail Stations

- GAS MGMT PANEL: 6%*
- CHILLER: 12%*
- COMPRESSOR: 25%*
- DISPENSER: 57%*

- GAS MGMT PANEL: 7%*
- CHILLER: 24%*
- COMPRESSOR: 22%*
- DISPENSER: 47%*

MISC includes the following failure modes: communication error, contamination, debris, design flaw, electrical breaker, end of life, environmental factors, fluid leak, freezing, installation error, level low, loose electrical, loose mechanical, maintenance error, manufacturing defect, material defect/misrun, fatigue, moisture, mis-operation error, out of calibration, over-temperature, power outage/quality, pressure loss, software bug, stress outside design limit, light, vandalism, vibration, other.

* Percentage of total events or hours.
Overall Averages
5 hours per station per month.
2569 kg dispensed per maintenance hour.

Overall Averages
3 events per station per month.
Inf 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:
83 hours per station per quarter.

Stars represent individual station maintenance hours in a given quarter.
Maintenance Costs Over Time - Retail Stations

Overall Average: $10,230 per station per quarter.

*Each color represents a unique station.
CDP-INFR-49
Mean Fills Between Failures

Mean Fills Between Failures - Retail Stations

Median Site
Lowest Site

Mean Fills Between Failures

AIR
CHILLER
COMPRESSOR
DISPENSER
ELECTRICAL
GAS MGMT PANEL
SAFETY
STORAGE
THERMAL MANAGEMENT
CDP-INFR-50
Reliability Growth by Fills

Overall Site Reliability Growth By Fills - Retail Stations

Instantaneous MTBF improved for 17 of 32 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 $\text{H}_2$ Dispensed Between Failures (kg) - Retail Stations

- Median Site
- Lowest Site

<table>
<thead>
<tr>
<th>Component</th>
<th>Mean $\text{H}_2$ Dispensed Between Failures (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR</td>
<td>5000</td>
</tr>
<tr>
<td>CHILLER</td>
<td>4000</td>
</tr>
<tr>
<td>COMPRESSOR</td>
<td>3000</td>
</tr>
<tr>
<td>DISPENSER</td>
<td>2000</td>
</tr>
<tr>
<td>ELECTRICAL</td>
<td>1000</td>
</tr>
<tr>
<td>ENTIRE</td>
<td>6000</td>
</tr>
<tr>
<td>GAS MGMT PANEL</td>
<td>7000</td>
</tr>
<tr>
<td>SAFETY</td>
<td>8000</td>
</tr>
<tr>
<td>STATION OTHER</td>
<td>7000</td>
</tr>
<tr>
<td>STORAGE</td>
<td>9000</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>6000</td>
</tr>
<tr>
<td>THERMAL MANAGEMENT</td>
<td>8000</td>
</tr>
</tbody>
</table>
CDP-INFR-52
Reliability Growth by Amount Dispensed

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

Instantaneous MTBF improved for 14 of 32 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

\[ \rho = \lambda \beta \text{Fills}^{(\beta-1)} \]

\[ \lambda = 1.763 \]

\[ \beta = 0.578 \]

18 Mean Fills per Failure at 1000 Fills
Historical Failure Rate (bathtub curve) by kg H₂ Dispensed - Retail Stations

\[
\rho = \lambda \beta \text{ kg H}_2 \text{ Dispensed}^{(\beta-1)}
\]

\[
\lambda = 1.208
\]

\[
\beta = 0.592
\]

45 Mean kg H₂ Dispensed per Failure at 5000 kg H₂ Dispensed
Maintenance Causes and Effects - Retail Stations

Subsystem: CHILLER
Component: ENTIRE

Causes

Effects
CDP-INFR-65
Maintenance Causes and Effects: Chiller (Other)

Maintenance Causes and Effects - Retail Stations
Subsystem: CHILLER
Component: OTHER

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

Causes

Effects

NREL cdpRETAIL_infr_65
Created: Apr-01-19 11:32 AM | Data Range: 2014Q3-2018Q4
Maintenance Causes and Effects

Subsystem: CHILLER
Component: REFRIGERANT

CAUSES

- FAILED PART
- LEVEL LOW
- LOOSE MECHANICAL
- OUT OF CALIBRATION
- UNDETERMINED
- WARNING LOW

EFFECTS

- FLUID LEAK NON-H2
- NA
- UNDETERMINED
Maintenance Causes and Effects - Retail Stations
Subsystem: DISPENSER
Component: ENTIRE

Causes

Effects

Preventative Maintenance accounted for 25% of all events. Suppressed in the plot to show detail for other causes.
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER
Component: NOZZLE
Maintenance Causes and Effects - Retail Stations

Subsystem: DISPENSER
Component: FITTING

Causes

Effects
Maintenance Causes and Effects - Retail Stations

Subsystem: COMPRESSOR
Component: ENTIRE

Causes

Effects

Preventative Maintenance accounted for 28% 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.

Causes

Effects
Maintenance Causes and Effects - Retail Stations
Subsystem: COMPRESSOR
Component: FITTING

Causes

Effects
Performance
Hydrogen Dispensed By Quarter - Retail Stations

Cumulative Hydrogen Dispensed = 1,470,151 kg

By Year

2018: 913,194 kg
2017: 449,725 kg
2016: 104,891 kg
2015: 2,341 kg

H2 Dispensed [1,000 kg]

0 50 100 150 200 250


Note: Colors represent individual stations. Station count is number at bottom of bar.
CDP-INFR-58
Hydrogen Fills by Quarter

Hydrogen Fills By Quarter - Retail Stations

Cumulative Fuelings = 495,256

By Year

2018 [306,543]
2017 [150,196]
2016 [37,313]
2015 [1,204]

H2 Fills [1,000]

Number of Fills [1,000]

Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
2015 1 1 3 10 17 20 23 25 26 27 30 30 31 32 32 34
2016
2017
2018

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

Hydrogen Dispensed By Region - Retail Stations

- Northern California
- Southern California
- Connector California

By Year

Cumulative Hydrogen Dispensed
Northern California = 497,283 kg
Southern California = 919,928 kg
Connector California = 52,941 kg
Histogram of Fueling Rates

- 440,919 Events
- Average = 0.9 kg/min
- 1.0% > 1.51 kg/min
- 0.2% > 2 kg/min

2.5 minute fill of 5 kg
Histogram of Fueling Times

- 440,919 Events
- Average = 3.52 min
- 42% <3.3 min
- 17% <2.5 min

- 2020 MYRDD Target for 5kg
- Ultimate MYRDD Target (5 kg in 2.5 min)
Histogram of Time Between Fuelings - Retail Stations

- Back-to-Back Fills
- 22% of fills are within 0-5 minutes of each other
- 52% of fills have more than 20 minutes between them
- 442,191 Total Fills

Final Pressures for Fills with <5 Minutes in Between

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

- **350 bar Fills (200 to 450 bar)**
  - Avg Final Pressure = 351 bar
  - % of Fills > 350 bar = 52%
  - Number of Fills = 15156

- **700 bar Fills (> 450 bar)**
  - Avg Final Pressure = 768 bar
  - % of Fills > 700 bar = 90%
  - Number of Fills = 400531

*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   | 0.85| 2.4%   | 0.7% | 15774
700 bar   | 0.93| 0.6%   | 0.3% | 425971

2.5 minute fill of 5 kg
CDP-INFR-90
Hydrogen Dispensed by Quarter and Pressure

Hydrogen Dispensed by Quarter and Pressure - Retail Stations

H2 Amount Dispensed [1000 kg]

Amount Dispensed (H70)
Amount Dispensed (H35)
Number of Fuelings Per Hour - Retail Stations

- Average: 3.6 per hour
- Median: 3.0 per hour
- Max: 31.0 per hour
CDP-INFR-14
Hydrogen Dispensed per Hour

Hydrogen Dispensed Per Hour - Retail Stations

Average: 11.0 kgs per hour
Median: 10.0 kgs per hour
Max: 115.2 kgs per hour
Number of Fills by Time of Day

Number of Fueling Events per Time of Day - Retail Stations

Number Included
465,794 fills

H2 Fueling
Gasoline Profile

CDP-INFR-16
Fueling Amounts per Time of Day

Fueling Amounts per Time of Day - Retail Stations

Amount Included
1,464,895 kg

Max and Avg Dispensed [kg]
CDP-INFR-88a Fueling Profile by Day and Hour Connector/Destination Stations

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

Sun

Mon

Tue

Wed

Thu

Fri

Sat

% Hydrogen
% Gasoline*

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

CDP-INFR-88c Fueling Profile by Day and Hour
Southern California

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

sun

mon

tue

wed

thu

fri

sat

Hydrogen
Gasoline*

Missed Fuel Opportunity during Q4 of 2018 for 26 stations (12,342 kg)

*The minute fill profile was taken as an average from an hourly total.*
CDP-INFR-93
Station Unavailability

2018 Station Unavailability for 38 stations

Time of Day

Day of the Year

# of Stations Unavailable

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

Created: Mar-21-19 1:27 PM | Data Range: 2012Q1-2018Q4

NREL cdpRETAIL_infra_93
CDP-INFR-17
Fueling Rates by Amount Filled
Histogram of Fueling Rates By Year

- 3.3 minute fill of 5 kg
- 2.5 minute fill of 5 kg
- Avg Fuel Rate (kg/min)
- Number of Fueling Events

<table>
<thead>
<tr>
<th>Year</th>
<th>Avg (kg/min)</th>
<th>% &gt; 1.51</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>0.69</td>
<td>0.2%</td>
</tr>
<tr>
<td>2016</td>
<td>0.83</td>
<td>0.9%</td>
</tr>
<tr>
<td>2017</td>
<td>0.88</td>
<td>0.5%</td>
</tr>
<tr>
<td>2018</td>
<td>0.96</td>
<td>1.4%</td>
</tr>
</tbody>
</table>
CDP-INFR-55
Monthly Averages: All Fills

Monthly Averages for All Fills - Retail Stations

- **Rate [kg/min]**: Avg: 0.92
- **Time [min]**: Avg: 3.5
- **Amount [kg]**: Avg: 3.1

Created: Apr 01, 2019 2:59 PM | Data Range: 2014Q3-2018Q4
CDP-INFR-57
Monthly Averages: 700 bar Fills >1 kg with Pre-Cool of -40°C
Cost
Compressor Operation Cost - Retail Stations

Average = 2.36 [$/kg]

Data Points Reported

Electrical Energy Cost per kg [$/kg]
Maintenance Costs Per kg Dispensed Over Time - Retail Stations

Overall Average: $19 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]
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: 163 kg/day

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

- Maximum Daily Utilization
- Maximum Quarterly Utilization
- Average Daily Utilization

Note: The focus for early stations is geographic coverage.

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
CDP-INFR-19
Hydrogen Dispensed by Month

Hydrogen Dispensed By Month - Retail Stations

- Individual station
- Average of all stations
CDP-INFR-20
Number of Fills by Month
Station Capacity Utilization Trends by Quarter - Retail Stations

Number of Stations = 34 Total
Total H2 Dispensed = 1,470,147 kg

Range of Station Capacities

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 = 34 Total
Total H2 Dispensed = 1,470,147 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.
Days with Fills by Quarter - Retail Stations

% Of Days With At Least One Fill

Quarters


1 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.

2 The average percent of days with fills only considers quarters in which at least one fill occurred. Stations with no filling 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.
Summary of Station Usage Statistics - Retail Stations

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.

Created: Apr 01 19 2:49 PM | Data Range: 2014Q3-2015Q4
CDP-INFR-80
Daily Fueling Amounts by Station

Daily Fueling Amounts - Retail Stations

- Daily Average
  - Daily Avg. 54.2 kg

kg [at 70MPa]

kg [at 35MPa]

kg [All]

Daily Avg. 5.5 kg

Daily Avg. 55.4 kg

Stations
Daily Fueling Amounts by Month

Daily Fueling Amounts Over Time - Retail Stations

- Daily Average per Month

*Daily average only includes days with fills.
Hydrogen Quality
Impurities—Argon

Impurities (Retail Stations) - Argon

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

261 Total Samples

Not Detected Summary:
- Delivered Compressed: 214 Sample(s)
- Delivered Liquid: 8 Sample(s)
- Onsite Electrolysis: 24 Sample(s)
- Delivered Compressed, Onsite Electrolysis: 4 Sample(s)
- Onsite SMR: 4 Sample(s)

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

Number of Samples

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
SAE J2719 Limit = 100 ppm

Measured Impurity [ppm]
Impurities—Carbon Dioxide

261 Total Samples
- Not Detected Summary
  - Delivered Compressed: 218 Sample(s)
  - Delivered Liquid: 8 Sample(s)
  - Onsite Electrolysis: 24 Sample(s)
  - Delivered Compressed, Onsite Electrolysis: 3 Sample(s)
  - Onsite SMR: 4 Sample(s)

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

Delivered Compressed
Delivered Liquid
Delivered Pipeline
Onsite Electrolysis
Delivered Compressed, Onsite Electrolysis
Onsite SMR

SAE J2719 Limit = 2 ppm

Number of Samples

Measured Impurity [ppm]

nd det. lim = 0.05 ppm
nd det. lim = 0.1 ppm
nd det. lim = 0.5 ppm
nd

0 50 100 150 200 250 300
Impurities—Carbon Monoxide

Impurities (Retail Stations) - Carbon Monoxide

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

Number of Samples

Measured Impurity [ppb]

nd det. lim = 80 ppb
nd det. lim = 100 ppb
SAE J2719 Limit = 200 ppb
Impurities (Retail Stations) - Formaldehyde

251 Total Samples
- Not Detected Summary:
  - Delivered Compressed: 121 Sample(s)
  - Delivered Liquid: 7 Sample(s)
  - Onsite Electrolysis: 7 Sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 Sample(s)
  - Onsite SMR: 4 Sample(s)

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

Number of Samples

Measured Impurity [ppb]

nd det. lim = 1 ppb
nd det. lim = 2 ppb

SAE J2719 Limit = 10 ppb
Impurities—Formic Acid

261 Total Samples
Not Detected Summary:
Delivered Compressed:
107 Sample(s)
Delivered Liquid:
6 Sample(s)
Onsite Electrolysis:
4 Sample(s)
Onsite Electrolysis 1 Sample(s)
Onsite SMR 2 Sample(s)
Not Measured Summary:
Delivered Compressed:
113 Sample(s)
Delivered Liquid:
2 Sample(s)
Onsite Electrolysis:
20 Sample(s)
Onsite Electrolysis 4 Sample(s)
Onsite SMR 2 Sample(s)

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

Measured Impurity [ppb]

Number of Samples

NREL cdpRETAIL_inf_79
Created: Mar-19-19 11:56 AM | Data Range: 2015Q4-2018Q4

SAE J2719 Limit = 200 ppb
nd det. lim = 1 ppb
nd det. lim = 5 ppb
nd det. lim = 15 ppb
nd det. lim = 100 ppb
nd
Impurities—Helium

The graph shows the distribution of impurities in Helium samples from retail stations, categorized by delivery method:
- Delivered Compressed
- Delivered Liquid
- Delivered Pipeline
- Onsite Electrolysis
- Delivered Compressed; Onsite Electrolysis
- Onsite SMR

251 Total Samples
- Not Detected Summary
  - Delivered Compressed: 169 sample(s)
  - Delivered Liquid: 8 sample(s)
  - Onsite Electrolysis: 22 sample(s)
  - Delivered Compressed; Onsite Electrolysis: 3 sample(s)
  - Onsite SMR: 4 sample(s)
- Not Measured Summary
  - Delivered Compressed: 11 sample(s)
  - Onsite Electrolysis: 2 sample(s)
  - Delivered Compressed; Onsite Electrolysis: 2 sample(s)

The graph includes the number of samples and measured impurity levels in parts per million (ppm).

SAE J2719 Limit = 300 ppm
Impurities—Nitrogen

Impurities (Retail Stations) - Nitrogen

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

Number of Samples

Measured Impurity [ppm]

nd det. lim. = 2 ppm
nd det. lim. = 5 ppm
nd det. lim. = 25 ppm

Notes for exceeding SAE J2719 Limits:
Commissioning

SAE J2719 Limit = 100 ppm
Impurities—Oxygen

Impurities (Retail Stations) - Oxygen

- 251 Total Samples
- Not Detected Summary:
  - Delivered Compressed 7 Sample(s)
- Not Measured Summary:
  - Delivered Compressed 213 Sample(s)
  - Delivered Liquid 8 Sample(s)
  - Onsite Electrolysis 24 Sample(s)
  - Delivered Compressed; Onsite Electrolysis 3 Sample(s)
  - Onsite SMR 4 Sample(s)

Number of Samples

Measured Impurity [ppm]

nd det. lim = 1 ppm

SAE J2719 Limit = 5 ppm

nd
Impurities—Particulate Concentration

Impurities (Retail Stations) - Particulate Concentration

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

nd det. lim. = 0.05 mg/kgH2

SAE J2719 Limit = 1 mg/kgH2

Measured Impurity [mg/kgH2]

Number of Samples

nd  0  0.05  0.2  0.4  0.6  0.8  1

1  2  3  4  5

251 Total Samples
- Not Detected Summary
  - Delivered Compressed 1 Sample(s)
  - Not Measured Summary
  - Delivered Compressed 213 Sample(s)
  - Delivered Liquid 8 Sample(s)
  - Onsite Electrolysis 24 Sample(s)
  - Delivered Compressed; Onsite Electrolysis 5 Sample(s)
  - Onsite SMR 4 Sample(s)
CDP-INFR-79
Impurities—Total Halogenates

![Impurities (Retail Stations) - Total Halogenates](chart)

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

NREL cdpRETAIL_infr_79
Created: Mar-19-19 11:50 AM | Data Range: 2015Q4-2018Q4
Impurities—Total Hydrocarbons

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

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

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

Number of Samples

Measured Impurity [ppb]

nd det. lim = 3 ppb
SAE J2719 Limit = 4 ppb
Impurities—Water

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

SAE J2719 Limit = 5 ppm

251 Total Samples

- Not Detected Summary
  - Delivered Compressed: Onsite Electrolysis
  - Not Measured Summary
  - Delivered Compressed: Onsite Electrolysis

nd det. lim = 1 ppm

Number of Samples

Measured Impurity [ppm]

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

Created: Mar-18-19 11:53 AM | Data Range: 2015Q4-2018Q4
Component Energy
Compressor Energy

Average = 1.53 [kWh/kg]

Energy Consumed Only in Start Up and Shut Down
CDP-INFR-92
Dispenser Energy

Dispenser Efficiency - Retail Stations

Average (for >500kg) = 2.62 [kWh/kg]

Chiller Energy for 700bar

Average (for >500kg) = 2.59 [kWh/kg]
Electricity Usage - Retail Stations

- Compressed Delivery
- Liquid Delivery
- Onsite Electrolysis; Compressed Delivery

Monthly Electricity Usage per kg vs. Monthly Amount of Hydrogen Dispensed [kg]

Station Energy per kg Dispensed
CDP-INFR-83
Station Energy Cost per kg Dispensed

Electricity Cost per kg - Retail Stations

- Compressed Delivery
- Liquid Delivery
- Onsite Electrolysis; Compressed Delivery

Monthly Electricity Cost [$/kg]

Monthly Amount of Hydrogen Dispensed [kg]
CDP-INFR-84
Station Electricity Cost per kWh

Electricity Cost per kWh - Retail Stations

- Compressed Delivery, Average: 0.31 $/kWh
- Compressed Delivery Average
- Liquid Delivery, Average: 0.23 $/kWh
- Liquid Delivery Average
- Onsite Electrolysis; Compressed Delivery, Average: 0.13 $/kWh
- Onsite Electrolysis; Compressed Delivery Average
Station Electricity Cost per kWh by Region

Electricity Cost per kWh by Region - Retail Stations

- Connector California, Average: 0.38 $/kWh
- Connector California Average
- Northern California, Average: 0.27 $/kWh
- Northern California Average
- Southern California, Average: 0.29 $/kWh
- Southern California Average