Hydrogen Station Capacity Tool (HyCap) Documentation/Users Manual

Sam Sprik, Taichi Kuroki, Kazunori Nagasawa

National Renewable Energy Laboratory

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Acknowledgments

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And through multiple reviews with partners in the hydrogen industry

List of Acronyms

HP	High pressure
HyCap	Hydrogen Station Capacity tool
LP	Low pressure
MP	Medium pressure
NREL	National Renewable Energy Laboratory
SOC	State of charge

Executive Summary

The Hydrogen Station Capacity tool (HyCap), first developed by the National Renewable Energy Laboratory (NREL) in 2024, is used to estimate hydrogen station dispensing capacity for light-, medium- and heavy-duty vehicles. The tool can handle multiple station configurations such as liquid delivered, gaseous delivered, onsite production, gaseous trailer swap and pipeline delivered. The tool runs calculations at a time step of one second. Required spreadsheet inputs define characteristics of major station components and fueling demand profiles. Results come in multiple formats including graphs showing achievable dispensing capacity of the station. This document outlines the applications for this tool, the underlying operating algorithm, available user inputs, simulation outputs, assumptions made and sample hydrogen station calculations.

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1 Introduction

The Hydrogen Station Capacity tool (HyCap) is designed to estimate a fueling station's daily dispensing capacity based on station equipment and pre-defined fueling demand profiles for light-, medium-, and heavy-duty hydrogen vehicles. HyCap is software either distributed and run on a user's computer or potentially run by submitting input files to an NREL website to be determined at a future date. It uses an input spreadsheet with parameters describing the station components along with a fueling demand profile and outputs information including mass dispensed into vehicles, daily dispensing capacity, and station storage changes. HyCap calculates and tracks pressures, flows and temperatures of hydrogen in station components. Multiple station configurations are accommodated including gaseous delivered, liquid delivered, onsite production, trailer swap and pipeline delivered. This model is not meant to be a design tool, but rather an evaluation tool based on station components and fueling standards with limits on items such as maximum pressure ramp rates.

HyCap reads the external user inputs and calculates pressures, temperatures and flows every second based on the predefined fueling demand scenario. The capacity calculation utilizes CSA HGV 4.9 [1] as the basis to determine one fill. The model has algorithms for dispensing, compression, delivery, and production, see Figure 1 for an example station configuration. HyCap outputs the number of kilograms (kg) dispensed in total and for full fills. A full fill is assumed to be greater than or equal to 95% state-of-charge (SOC). The output also includes more details on fill count, amount, duration, ending SOC, and station storage pressures and masses for the user to see how the algorithms were applied.

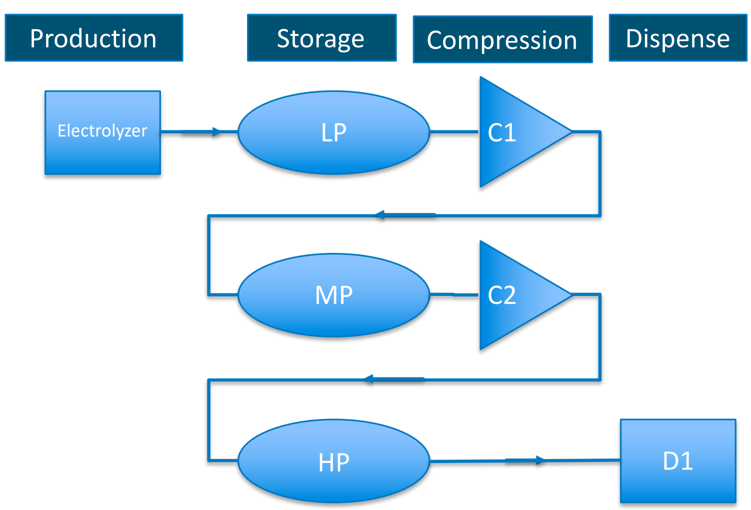

Figure 1. Sample station configuration.

HyCap is currently an executable. The details in this report are all based on the executable user interface. An online user interface is in development, expected towards the end of 2024, with no planned changes to the model algorithms.

2 HyCap Inputs, Assumptions, and Outputs

HyCap accepts user inputs for the following:

- Hydrogen source – how the hydrogen is delivered or produced onsite
- Station components – details the characteristics of major station components
- Fueling demand profile – details how much hydrogen is needed for the vehicles

The spreadsheet for station details is shown in the following figures. Figure 2 defines the hydrogen source and corresponding parameters. There are five options: 1) Gas delivery; 2) Liquid storage & delivery; 3) Trailer swap delivery; 4) Pipeline delivery; and 5) On-site production. Based on which source/scenario is selected, the corresponding fields become available to modify. For example, in the case of trailer swap delivery, the non-grayed out section shows that a selection is needed to define the pressure level for the banks swapped, max number of trailer swaps per day, number of banks swapped, time required to swap the trailer, the pressure that triggers a trailer swap, and whether station banks are used for trailer swap.

Delivery/Production				
Scenario	select	Trailer swap delivery	-	Scenario: 1) Gas delivery; 2) Liquid storage & delivery; 3) Trailer swap delivery; 4) Pipeline delivery; and 5) On-site production
Gas delivery to station	input	200	kg	Mass per delivery
	input	1	#/day	Number of deliveries per day
	input	6	#	Number of banks delivering hydrogen
	input	35	MPa	Pressure of delivery truck
	input	1	kg/s	Delivery flow rate
	input	3600	s	Delivery truck dwell time
	input	80	%	Storage level trigger for delivery (ratio of remaining mass in gaseous storage system to initial mass)
Liquid delivery to station	input	5	kg/s	Liquid truck delivery rate to storage
	input	80	%	Storage level trigger for delivery (ratio of remaining mass in liquid storage system to initial mass)
Trailer swap delivery to station	select	Medium-pressure	-	Type of banks swapped: 1) High-pressure; 2) Medium-pressure; and 3) Low-pressure
	input	3	#/day	Number of swaps per day
	input	6	#	Number of banks swapped
	input	1800	s	Time required to swap banks
	input	25	MPa	Storage level trigger for swapping trailers
	input	Yes	-	Station banks used for trailer swap. Yes: Use all the banks in the station; No: Use the same number of the trailer banks and station banks
Pipeline delivery to station	input	10	MPa	Output max pressure of pipeline
	input	5	kg/h	Flow rate from pipeline to bank(s)
	input	80	%	Storage level trigger for delivery (ratio of remaining mass in gaseous storage system to initial mass)
On-site production at station	input	15	kg/h	Flow/production rate
	input	3	MPa	Output max pressure
	input	75	%	Storage level trigger for production (ratio of remaining mass in gaseous storage system to initial mass)

Figure 2. Station Input Data – Hydrogen Source

Station storage parameters are defined in the gaseous/liquid storage section as seen in Figure 3. Here the inputs include number of banks, min and max pressures for banks, volume of banks, and if banks are to be used for filling of vehicles as is done in cascade filling. For liquid storage parameters include cryopump and vaporizer max flow rates as well as vaporizer output pressure.

Gaseous/Liquid Storage

High-pressure (HP) gaseous storage	select	Yes	-	High-pressure (HP) bank eligible for fill?
	input	3	-	Number of HP banks
	input	0.33	m3	Volume of HP bank
	input	45	MPa	Minimum HP bank pressure
	input	90	MPa	Maximum HP bank pressure
Medium-pressure (MP) gaseous storage	select	Yes	-	Medium-pressure (MP) bank eligible for fill?
	input	12	-	Number of MP banks
	input	1	m3	Volume of MP bank
	input	0	MPa	Minimum MP bank pressure
	input	41	MPa	Maximum MP bank pressure
Low-pressure (LP) gaseous storage	select	Yes	-	Low-pressure (LP) bank eligible for fill?
	input	0	-	Number of LP banks
	input	2.6	m3	Volume of LP bank
	input	0	MPa	Minimum LP bank pressure
	input	24	MPa	Maximum LP bank pressure
Liquid storage	input	0	-	Number of liquid banks
	input	0	m3	Volume of liquid bank
	input	0	kg/h	Liquid pump maximum flowrate
	input	0	kg/h	Vaporizer maximum flowrate
	input	0	MPa	Vaporizer output pressure (must be greater than MP compressor minimum)

Figure 3. Station Input Data – Storage

Figure 4 shows where the user enters in information for the compressor, chiller, and dispenser. For the compressor, there are inputs for number of medium- and high-pressure compressors, the minimum suction pressures, maximum output pressures, maximum flowrates, reference pressure and temperature for maximum flowrate parameter, and if compressor and liquid system can fill the same bank that is filling vehicle for a direct path from compression to vehicle.

The chiller is assumed to be sized properly and only asks for the pre-cooling setpoint which is what the hydrogen temperature needs to be when leaving the chiller.

The dispenser section covers the demand profile to use, which can be a custom profile defined in the same file but in a different worksheet. The target fueling pressure, vehicle storage size and arriving pressure are used with the demand profile in the calculations. The selection of "Custom Profile 1" allows the user to specify how many kilograms demanded per hour but leaves the vehicles identical. The "Chevron Friday Profile" is typically used for light-duty stations as it represents what a typical gas station would see on a Friday. All the profiles have the demand defined by the hour of the day.

The control subsection includes the time between vehicle fills, average pressure ramp rate, maximum number of fueling positions, target SOC, and the required differential pressure between dispenser and vehicle storage.

The environment subsection sets the ambient temperature which is assumed to be constant during the simulation.

Compressor					
High-pressure compressor (HPC)	input	1	-	Number of high pressure compressors (HPCs)
	input	5	MPa	Minimum HPC suction pressure
	input	90	MPa	Maximum HPC outlet pressure
	input	75	kg/h	HPC maximum flowrate
	input	10	MPa	HPC reference pressure for maximum flowrate
	input	15	degC	HPC reference temperature for maximum flowrate
Medium-pressure compressor (MPC)	input	0	-	Number of medium pressure compressors (MPCs)
	input	3.5	MPa	Minimum MPC pressure
	input	42	MPa	Maximum MPC pressure
	input	1	kg/h	MPC maximum flowrate
	input	0.1	MPa	MPC reference pressure for maximum flowrate
	input	15	degC	MPC reference temperature for maximum flowrate
Algorithm	select	Yes	-	Allow compressor & liquid storage system to fill bank which are used for dispensing?
	select	No	-	Direct fueling without high-pressure (HP) storage banks. Eligible for this control if HP storage banks are NOT eligible to fill (row 37)
Chiller					
	input	-40	degC	Pre-cooling setpoint
Dispenser					
Demand	select	Chevron Friday Profile	-	Vehicle demand profile: 1) Custom Profile 1; 2) Chevron Friday Profile
Vehicle on-board storage	select	H70	-	Target fueling pressure: 1) H70; 2) H50; and 3) H35
	input	5	kg	Vehicle on-board storage size
	input	10	MPa	Arrival vehicle tank pressure
Control	input	255	s	Time between the end of a vehicle fill to the beginning of the next fill
	input	20	MPa/min	Average pressure ramp rate
	input	1	-	Maximum number fueling positions capable of simultaneous fill

Figure 4. Station Input Data – Compressor, Chiller, Dispenser

	A	B
1	Hour	Demand [kg]
2	0	70
3	1	70
4	2	70
5	3	70
6	4	70
7	5	70
8	6	70
9	7	100
10	8	100
11	9	100
12	10	100
13	11	100
14	12	100

Figure 5. Station Input Data – Custom Demand Profile-1, Specified by kg per hour

A fill is predefined in amount and profile. For light duty, a typical vehicle storage volume is 126 liters (or 5 kg at 20^{o}C), with a starting pressure of 10 MPa (approximately 1 kg). The ending fill pressure is 70 MPa. The fill demand profile for typical light duty stations is over 24 hours and follows the "Friday" profile from the Figure 2-16, page 2-39) the "Hydrogen Delivery Infrastructure Options Analysis"[2]. The number of fills varies for each hour per this profile and keeps the starting conditions consistent, except for partial fills based on the demand profile. A partial fill increases the starting pressure linearly. For example, the profile has 1.2 fills so the model will try one full fill (4 kg) and then another fill of only approximately 0.9 kg. Heavy-duty profiles follow the same way of setting up the fills but may make more sense to use a more constant demand during the day since trucks don't follow the same filling patterns as light duty. This is where the custom profile can be defined as needed.

Once the input data is defined in the spreadsheet, the user runs the compiled software which brings up a user interface as seen in Figure 6. Here the user specifies where the input file is located as well as where the output files should be saved. Pushing the "OK" button starts the simulation which, when completed, results in multiple files saved to the selected directory as seen in Figure 7. The output files contain .csv files with summarized vehicle fueling results and the values for simulation parameters for each second during the 24-hour run. Many of these parameters are plotted in the resulting figures. The first result figure contains information about the daily dispensing capacity of the station. It will summarize dispensed mass and dispensed mass at SOC limit. It includes a graph showing the demand by hour of the day with the actual dispensed by vehicle along with summary numbers for initial and ending mass of hydrogen at station along with how much was delivered/produced at station.

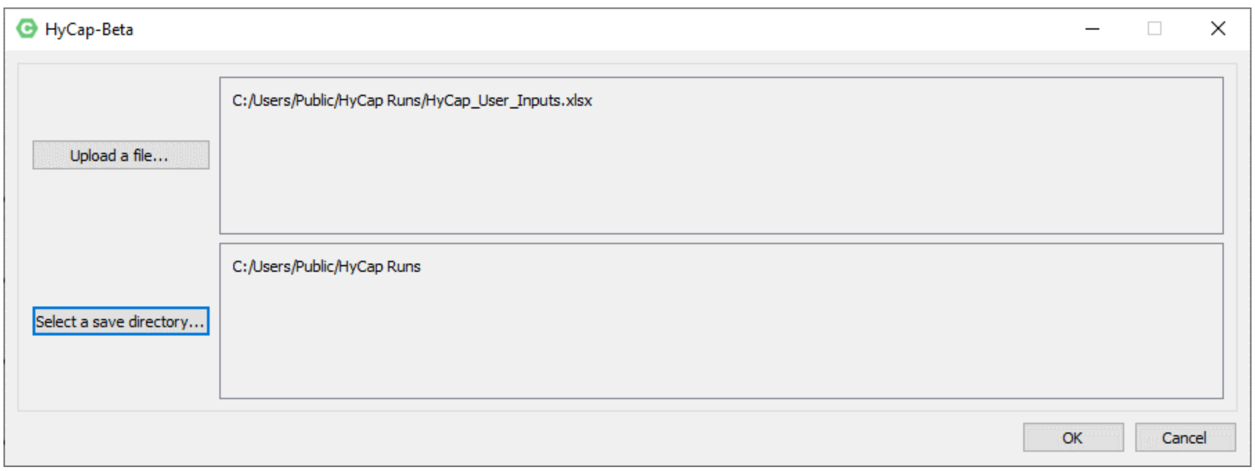

Figure 6. HyCap User Interface

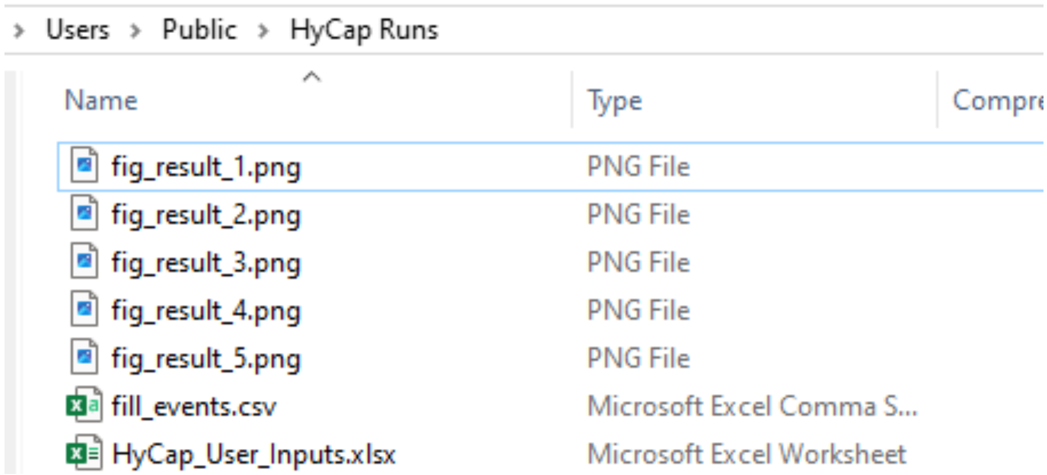

Figure 7. HyCap Output Files

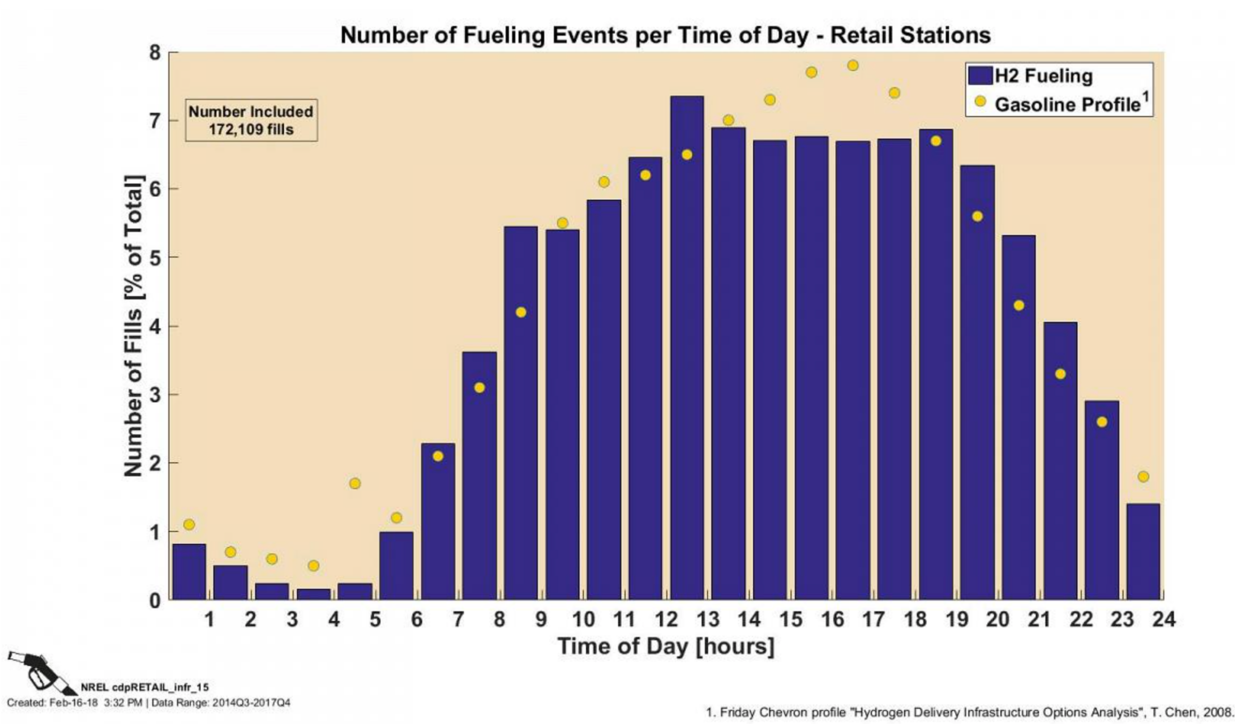

Figure 8. Data from real light-duty hydrogen stations compared with the "Friday" profile used for the capacity calculations for a light-duty station

The model makes several assumptions to replicate a possible real-world fueling scenario and be consistent for capacity calculations even though actual fueling may vary from these assumptions.

- The model assumes a constant ambient temperature defined in input file. Default is 20^{o}C
- The demand profile and fill conditions are predetermined by input files
- The dispenser operates to keep a constant pressure ramp rate defined in input file. It may adjust that down if station can't keep up if there is time for a particular vehicle fill.
- The maximum time between fills is 4 minutes, 15 seconds and the minimum is 1 minute

- The station begins with 100% SOC
- Pressure banks are eligible for cascade fueling if allowed in input file
- Compression is scaled linearly based on suction pressure
- Delivery is allowed, based on user input for amount delivered and a station SOC trigger for when the delivery happens
- All equipment works as specified without failures
- The model does not consider dynamics shorter than one second
- All equipment begins operation at the specified time (no priming or warm up times are included)
- The station has no leaks
- No hydrogen is vented during normal operation (e.g., compressor or dispenser unloading)
- On-site production and pipeline have a flow-rate input
- Multiple fueling positions multiplies the demand profile, offsets the fill start time by 1 second
- Partial fills are allowed if the station is not able to complete a full fill

The model completed external user beta testing prior to HyCap version 1.0 release.

3 Sample Station Capacity Estimates

3.1 Sample Station – Gas Delivered, 1200 kg storage

This sample station has LP and HP storage banks with a HP compressor and 1 dispensing position. See Figure 9 for the calculated fill data, with the predetermined fueling demand.

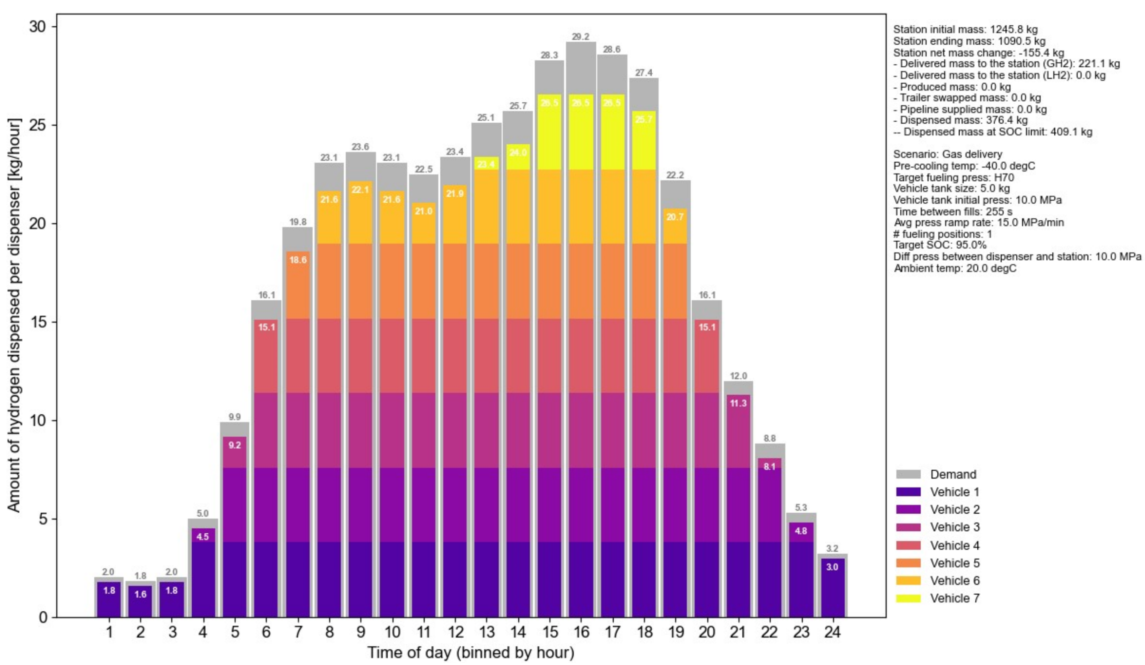

Figure 9. Gas delivered light-duty, 1 dispenser, ~1200 kg storage

4 Conclusions

The HyCap model is a consistent and transparent model to calculate the capacity of a hydrogen fueling station based on user inputs for the station configuration. HyCap station configurations include delivered (gas or liquid), trailer swap, pipeline, and on-site production. HyCap will have a publicly available online user interface developed later before the end of 2024. HyCap is not representative of all possible station configurations, or a design tool for station build or operation. It provides a reasonable estimation of station capacity based on station and demand parameters while considering the limitations imposed by pressure, temperature and flow rate of dispensing gaseous hydrogen.

References

[1] CSA Group, “Hydrogen Fueling Stations CSA HGV 4.9:2016.” CSA Group, Apr-2016.
[2] T.-P. Chen, “Hydrogen Delivery Infrastructure Options Analysis,” DOE Report, Mar. 2014.