



PNNL-ACT-10097

# Power-to-Gas Tool: User's Guide

June 2020

T Ramachandran  
P Balducci  
D Wu

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY  
*operated by*  
BATTELLE  
*for the*  
UNITED STATES DEPARTMENT OF ENERGY  
*under Contract DE-AC05-76RL01830*

Printed in the United States of America

Available to DOE and DOE contractors from the  
Office of Scientific and Technical Information,  
P.O. Box 62, Oak Ridge, TN 37831-0062;  
ph: (865) 576-8401  
fax: (865) 576-5728  
email: [reports@adonis.osti.gov](mailto:reports@adonis.osti.gov)

Available to the public from the National Technical Information Service  
5301 Shawnee Rd., Alexandria, VA 22312  
ph: (800) 553-NTIS (6847)  
email: [orders@ntis.gov](mailto:orders@ntis.gov) <<https://www.ntis.gov/about>>  
Online ordering: <http://www.ntis.gov>

# **Power-to-Gas Tool: User's Guide**

June 2020

T Ramachandran  
P Balducci  
D Wu

Prepared for  
the Massachusetts Clean Energy Center

Pacific Northwest National Laboratory  
Richland, Washington 99354

## Summary

For the development and evaluation of alternative power-to-gas (P2G) control and dispatch algorithms, energy storage evaluation tools previously developed by Pacific Northwest National Laboratory (PNNL) were modified to simulate P2G operations and evaluate the services provided by an ITM Power P2G unit sited in the Holyoke Gas and Electric (HG&E) service territory. P2G supports a web of potential assets that could be used to transform electrical energy into hydrogen either for use as transportation fuel or industrial gas, or as a source of clean fuel for injection into the natural gas grid. When P2G operates independently, it can also provide wholesale grid services (e.g., frequency regulation) through load modification. The developed evaluation tool allows the user to evaluate the financial benefits of a P2G system under various scenarios with varying parameters associated with prices, technology cost and performance, and incentives. This user's guide accompanies the tool and provides useful instructions, guiding users on how to input data and interpret results.

## Acknowledgments

We are grateful to the Massachusetts Clean Energy Center for its financial support and leadership, without which this project would not have been possible. We are also grateful to our project partners, Stephen Jones and Callum Smith of ITM Power and Brian Beauregard and Jonathan Zwirko of Holyoke Gas and Electric, who provided data and guidance throughout this study. Finally, we are grateful to Dr. Imre Gyuk, who is the Energy Storage Program Manager in the Office of Electricity at the U.S. Department of Energy, for providing financial support and leadership on this and other related work at Pacific Northwest National Laboratory.

## Acronyms and Abbreviations

|      |                                       |
|------|---------------------------------------|
| HG&E | Holyoke Gas & Electric                |
| LMP  | locational marginal prices            |
| O&M  | operations and maintenance            |
| P2G  | power-to-gas                          |
| PNNL | Pacific Northwest National Laboratory |
| PV   | present value                         |
| ROI  | return on investment                  |

## Contents

|   |     |
|---|-----|
| Summary .....   | ii  |
| Acknowledgments .....   | iii |
| Acronyms and Abbreviations .....  | iv  |
| Contents .....  | v   |
| 1.0 Introduction .....  | 1   |
| 2.0 Evaluating P2G Benefits .....                                       | 2   |
| 3.0 Instructions for Using the P2G Evaluation Tool .....                | 3   |
| 3.1 Creating a user account .....                                       | 3   |
| 3.2 Creating a new model .....  | 3   |
| 3.3 Input Panels .....  | 5   |
| 3.3.1 Setting Panel .....   | 5   |
| 3.3.2 Financial Analysis Panel .....                                    | 5   |
| 3.3.3 Insurance and Tax Rates Panel .....                               | 5   |
| 3.3.4 Wholesale Energy Prices and Charges Panel .....                   | 5   |
| 3.3.5 End-user Utility Rates Panel .....                                | 6   |
| 3.3.6 Services and Value Streams Panel .....                            | 6   |
| 3.3.7 Grid Services Panel .....   | 6   |
| 3.3.8 Electrolyzer, Compressor and Storage Tanks Parameters Panel ..... | 6   |
| 3.3.9 Hydrogen Sale Panel .....   | 6   |
| 3.3.10 Pipeline Injection Panel .....                                   | 6   |
| 3.3.11 Methanation Panel .....  | 7   |
| 3.4 Running a Simulation .....  | 7   |
| 3.5 Simulation Results .....  | 7   |
| 4.0 Conclusions .....   | 10  |
| 5.0 References .....  | 11  |

Figures

Figure 1: P2G system scope .....2

Figure 2: P2G Evaluation Tool - User Home Guide.....3

Figure 3: Model parameters page .....4

Figure 4: Editing Saved Models.....4

Figure 5: Downloading Default Files .....5

Figure 6: Output Page .....8

Figure 7: Hourly P2G Load and Hydrogen Flow Rate .....9



## 1.0 Introduction

For the development and evaluation of alternative power-to-gas (P2G) control and dispatch algorithms, energy storage evaluation tools previously developed by Pacific Northwest National Laboratory (PNNL) were modified to simulate P2G operations and evaluate the services provided by an ITM Power P2G unit sited in the Holyoke Gas and Electric (HG&E) service territory. P2G supports a web of potential assets that could be used to transform electrical energy into hydrogen either for use as transportation fuel or industrial gas, or as a source of clean fuel for injection into the natural gas grid. When P2G operates independently, it can also provide wholesale grid services (e.g., frequency regulation) through load modification. The developed evaluation tool allows the user to evaluate the financial benefits of a P2G system under various scenarios with varying parameters associated with prices, technology cost and performance, and incentives. This user's guide accompanies the tool and provides useful instructions, guiding users on how to input data and interpret results.

## 2.0 Evaluating P2G Benefits

In order to perform the financial analysis, the operating schedule for a single year is determined using a model-based optimization approach. This schedule is then used to determine the revenue/cost associated with operating the P2G system for that year and will serve as the basis for the financial analysis. The P2G system scope for this analysis includes an electrolyzer and two pathways for sale of the end-product: bulk sale in the form of transportation fuel or industrial gas, and injection into the natural gas grid. The technology components (see Figure 1) necessary for sale to transportation and industrial users include compression and modular storage tanks. For direct injection into natural gas pipelines, technology components include a methanation reactor (optional) and cavern storage (optional). The tool also allows for short-term storage of hydrogen in compressed hydrogen storage tanks, which may be accessible to inject into the natural gas pipeline, and for longer term storage in underground caverns.

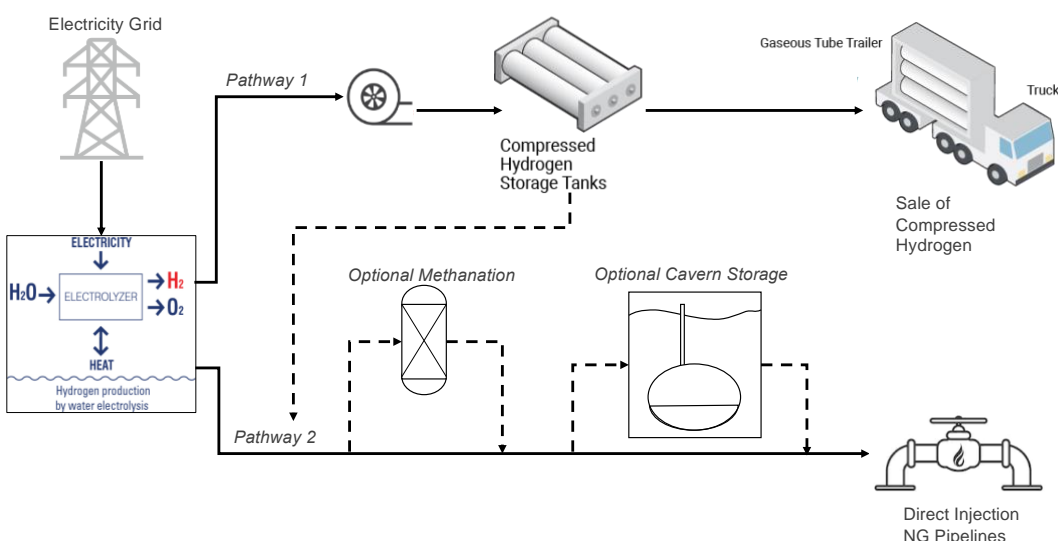


Figure 1: P2G system scope

PNNL has developed a web-based tool that allows the user to input the different parameters and the capital cost associated with the various equipment components that are found along pathway 1 and 2 alongside the electrolyzer. The tool also allows the user to determine the various grid services that can be provided by the P2G system along with the corresponding prices. Once these inputs are provided, the tool uses an optimization based approach to determine optimal operating schedule of the P2G plant for a year and compute the financial benefits and return on investment or ROI, over the entire lifetime of the P2G system, associated with constructing such a plant.

## 3.0 Instructions for Using the P2G Evaluation Tool

The web-tool can be accessed using any standard browser in the following location: <http://eset.pnnl.gov>. As it is a web-tool, there are no system requirements.

### 3.1 Creating a user account

In order to access the tool, a user account needs to be created.

- Go to <http://eset.pnnl.gov>
- Click on 'Create Account' and enter a username, a valid e-mail address, first and last name, and the name of your institution.
- A confirmation e-mail will be sent to the provided e-mail id. Follow the instructions in the e-mail to complete the account creation process.

Once the account has been created, you can access the dashboard to the P2G analysis tool (see Figure 2) Clicking on the *Account* tab will allow the user to change the default details and the password provided during the account creation process.

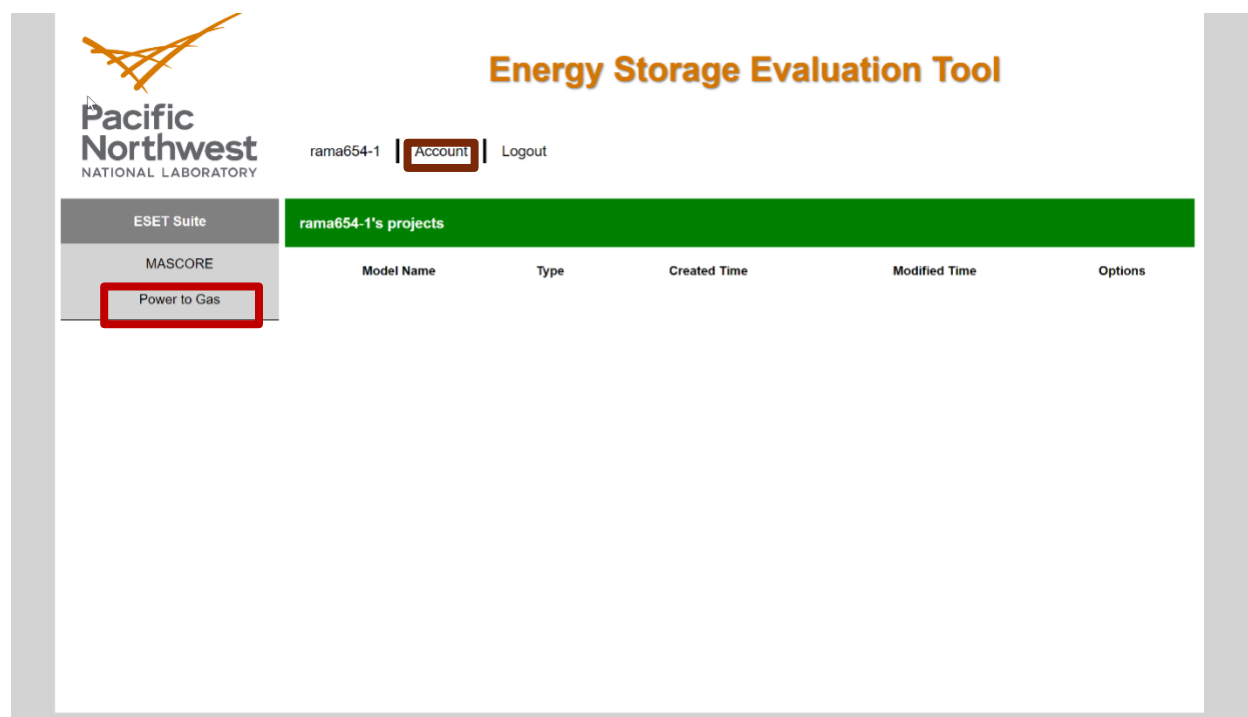


Figure 2: P2G Evaluation Tool - User Home Guide

### 3.2 Creating a new model

The user can create a new model by clicking on the Power to Gas (highlighted in red in Figure 3) link on the left-hand side of the dashboard. This will result in a text box asking for the model name.

Once an appropriate model name has been provided, the user will be taken to a page (see Figure 3) in which the model parameters can be modified. A brief description of all the input panels is provided in the following section. Note that the input tab (highlighted in red in Figure 3) is selected by default and the output cannot be accessed until the simulation model has been run.

Note: All parameters have pre-specified default values. If the user does not modify those values, the defaults will be used. The rationale for each default value is specified in the P2G System Valuation Final Report, which also accompanied the P2G Tool (Balducci et al. 2020).

Figure 3: Model parameters page

Once the model has been created, the user can also edit the model at any time from the dashboard by clicking on the edit button (as seen in Figure 4).

Figure 4: Editing Saved Models

### 3.3 Input Panels

#### 3.3.1 Setting Panel

The setting panels allows the user to input the year and indicate whether present value (PV) analysis over the system's economic life is desired. It also allows for the selection of P2G deployment options:

- Operation by municipal utility
- Operation as a transmission asset
- Operation in a distribution system, served by a distribution utility
- Operation in a distribution system, served by a municipal utility.

The first two options require the user to upload wholesale energy prices and the last two require an end-user utility rate. Provisions for uploading these files are provided in the wholesale energy prices and charges panel and end-user utility rates panel.

#### 3.3.2 Financial Analysis Panel

In order to compute the PV benefits, different rate parameters, including discount and annual benefit escalation rates, are required. The financial analysis panel allows the user to specify those rates. These data are not used if the PV analysis flag is not checked in the settings panel.

#### 3.3.3 Insurance and Tax Rates Panel

The user can specify various tax and insurance rates. These data are not used if the PV analysis flag is not checked in the settings panel. The formulas used to calculate PV and annualized costs are presented in the P2G System Valuation Final Report, which also accompanied the P2G Tool (Balducci et al. 2020).

#### 3.3.4 Wholesale Energy Prices and Charges Panel

The user can upload a file containing the hourly locational marginal prices (LMP) for the year that is specified in the settings panel. The capacity rate and the regional network service fee can also be provided by the user. Note that a default price profile has already been included in the simulation. The default profile can be downloaded by clicking on the default button highlighted (in red) in Figure 5. The same is true for all the other files that the user can potentially upload.

##### Wholesale Energy Prices and Charges

| Energy Price [\$/MWh]   | Capacity Rate [\$/kW-year] | RNS Rate [\$/kW-month] |
|---|----------------------------|------------------------|
| <div>Default</div> <div>Upload</div> <div>LMP_default.csv</div> | <div>9.55</div>            | <div>9.17</div>        |

Figure 5: Downloading Default Files

### 3.3.5 End-user Utility Rates Panel

The user can upload the hourly end-user utility prices for the year specified in the settings panel. The demand charge and a nominal load profile, which will be used to compute the change in the demand charge, can also be provided by the user.

### 3.3.6 Services and Value Streams Panel

The services and value streams panel consists of the list of services (regulation, demand response, and emission benefits) in which the user can choose to participate.

### 3.3.7 Grid Services Panel

The P2G plant can provide two type services to the grid: frequency regulation and demand response. In order to participate in the frequency regulation service, the user needs to provide the hourly regulation prices for the desired year. In order to participate in the demand response service, the user needs to specify the hours during which load reduction would be required and the price for providing demand response.

### 3.3.8 Electrolyzer, Compressor and Storage Tanks Parameters Panel

The user can easily specify the different parameters and the capital cost associated with the different equipment:

- The electrolyzer's operation is characterized by its rated capacity, production rate, and minimum operating level.
- The compressor's rated capacity, energy consumption (in kw/kg of hydrogen compressed) and % loss in hydrogen as it undergoes compression needs to be specified.
- The overall capacity of the tube-storage tanks that is deployed near the P2G plant can also be specified.
- The capital cost associated with the different equipment also needs to be provided by the user.

As in all cases, there are default values provided for each parameter.

### 3.3.9 Hydrogen Sale Panel

The hydrogen stored in the tube-storage is picked up on a weekly schedule to meet the transportation fuel demand. The user can specify the price of the hydrogen used as transportation fuel and the corresponding weekly demand. The user can also specify the price and weekly demand for industrial gas.

### 3.3.10 Pipeline Injection Panel

The natural gas pipelines have constraints on the volume of hydrogen that can be injected into the pipeline. The maximum admixture percentage specifies the maximum volume of hydrogen that can be injected as a function of the volume of the gas flowing through the pipeline. The density of the hydrogen, the hourly volume of gas flowing through the pipeline, and price for injecting gas into the pipeline can also be specified by the user.

### 3.3.11 Methanation Panel

The hydrogen injected into the pipeline/reservoir can undergo an optional methanation process which converts hydrogen + CO<sub>2</sub> into synthetic methane. The price of the CO<sub>2</sub> used for this process along with the rated power and the maximum hydrogen intake of the biologic reactor can be specified by the user. The operations and maintenance (O&M) costs (variable and fixed) and the capital cost can also be modified in this panel.

## 3.4 Running a Simulation

Once the data entry is complete, the user first needs to click on the save button (located on the top-left of the model parameters page) in order to save the model. Once the model is saved, the simulation can be run by clicking on the run button (located on the top-right of the model parameters page).

## 3.5 Simulation Results

Once the simulation is complete, the output can be accessed by clicking on the output tab (as seen in Figure 6) in the model parameters page. The output page provides numerical details regarding the operation (e.g., hours of operation, hydrogen production, operating schedule) and finance (ROI, PV benefits if requested in the model input page) of the P2G system and a visual breakdown of the revenue streams and costs. The PV analysis integrates all the capital, O&M, and benefit estimates over the economic life of the unit and compresses them into single lump-sum cost and benefit estimates using a defined discount rate, and presents them in PV terms.

P2G hourly operation results (see Figure 7) through a year also are provided, including both the power consumption from different P2G components and hydrogen flow along the two pathways.

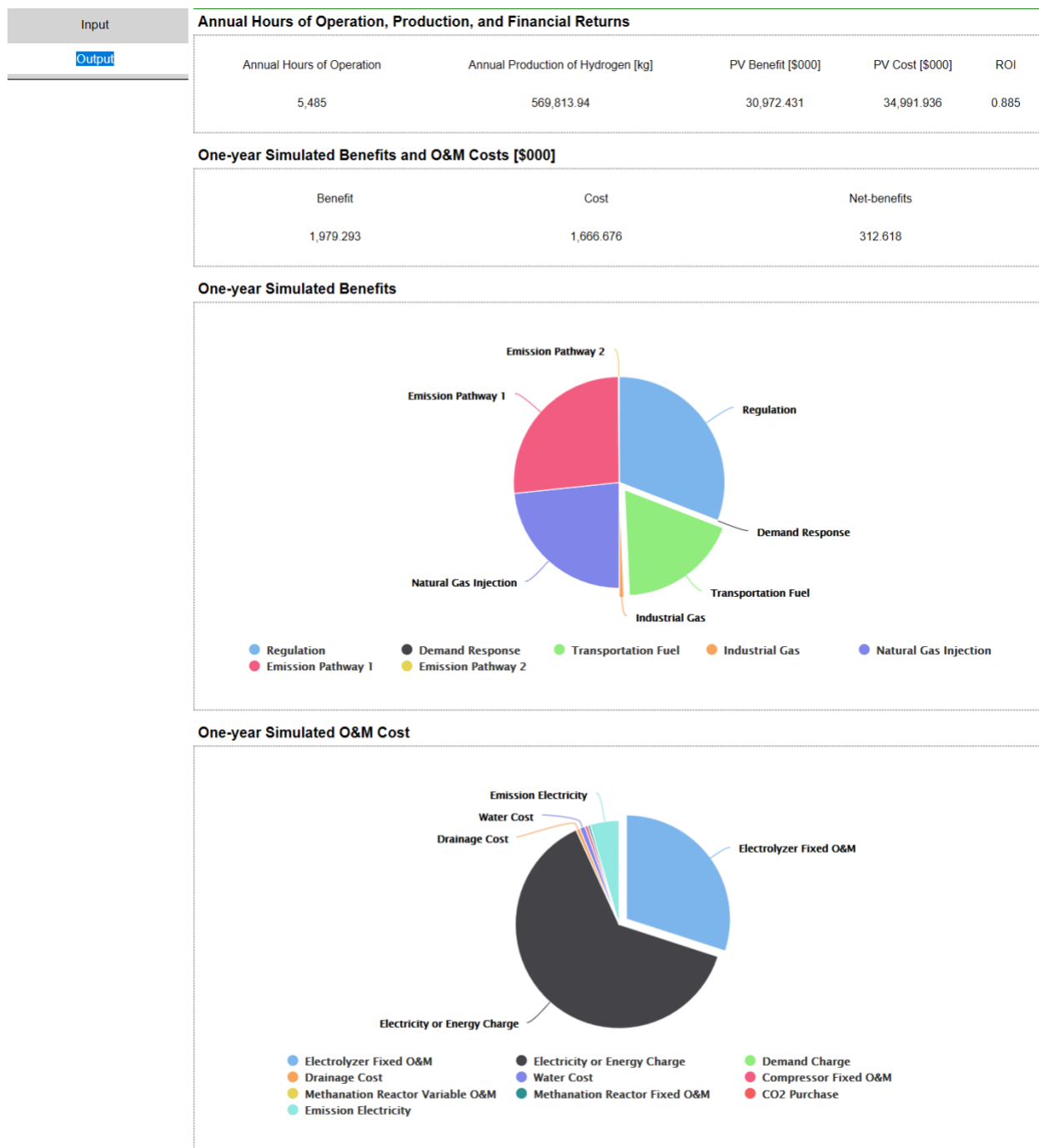
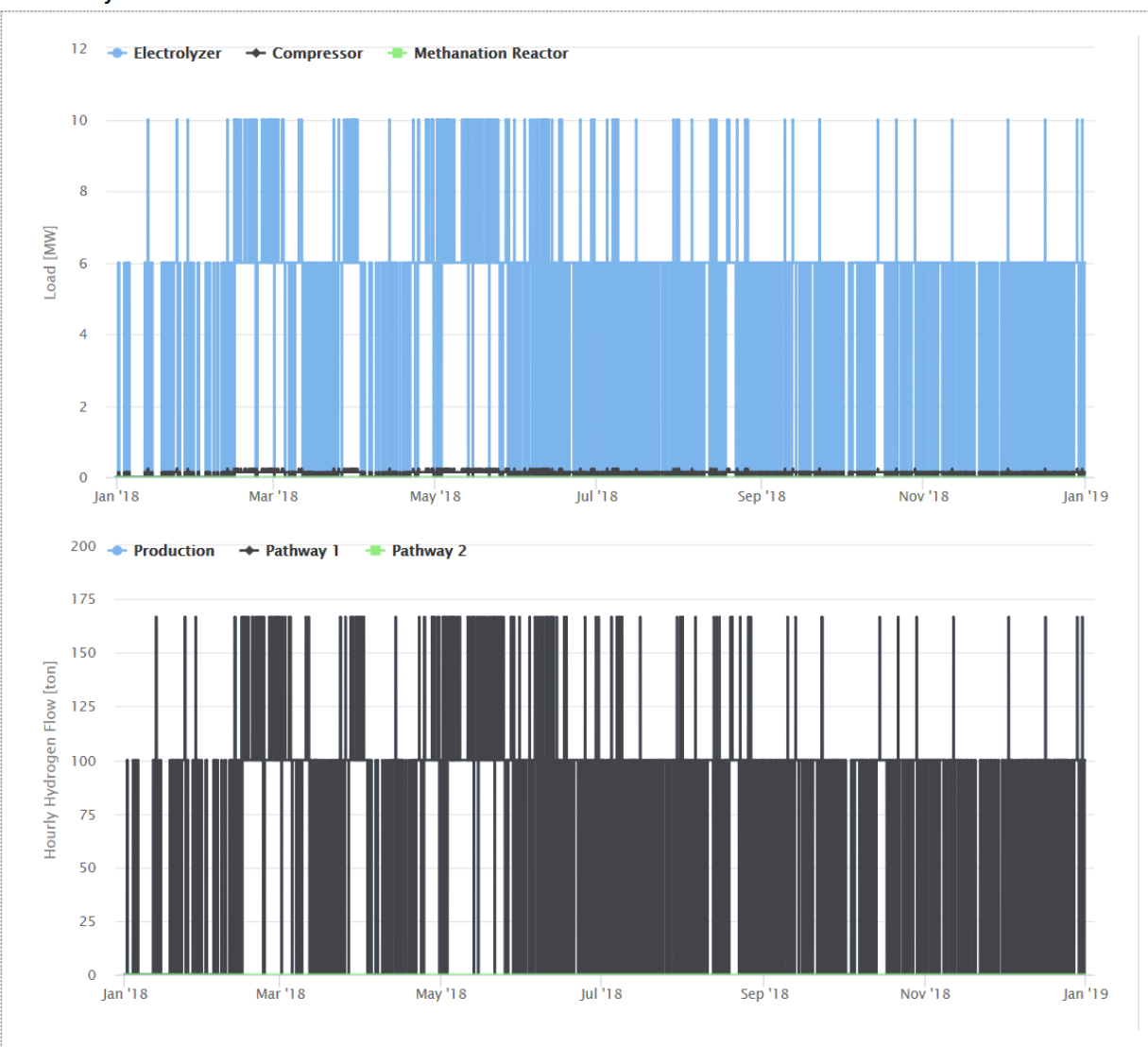


Figure 6: Output Page



**P2G Hourly Load**



**Figure 7: Hourly P2G Load and Hydrogen Flow Rate**

## 4.0 Conclusions

PNNL, working in collaboration with ITM Power and HG&E, have developed a suite of products to support analysis of P2G in Massachusetts. These products include:

- P2G model that can be accessed at [eset.pnnl.gov](http://eset.pnnl.gov);
- P2G system valuation report that describes in detail the methodology underpinning the P2G model and presents the results of 82 scenarios run using the model; and
- This P2G model user's guide.

This user's guide accompanies the other products and is designed to simplify the experience of each user, providing useful instructions while guiding users as they input data and interpret results.

## 5.0 References

Balducci P.J., D. Wu, T. Ramachandran, A.M. Campbell, V. Fotedar, K. Mongird, and S. Huang, et al. 2020. *Power-to-Gas System Valuation – Final Report*. PNNL-ACT-10095. Richland, WA: Pacific Northwest National Laboratory.

# **Pacific Northwest National Laboratory**

902 Battelle Boulevard  
P.O. Box 999  
Richland, WA 99354  
1-888-375-PNNL (7665)

***[www.pnnl.gov](http://www.pnnl.gov)***