NREL
NATIONAL RENEWABLE ENERGY LABORATORY

40
1977 – 2017





# Modeling Fuel Cells in SAM

Nicholas DiOrio, Janine Freeman

September 19, 2019

# SAM Events 2019

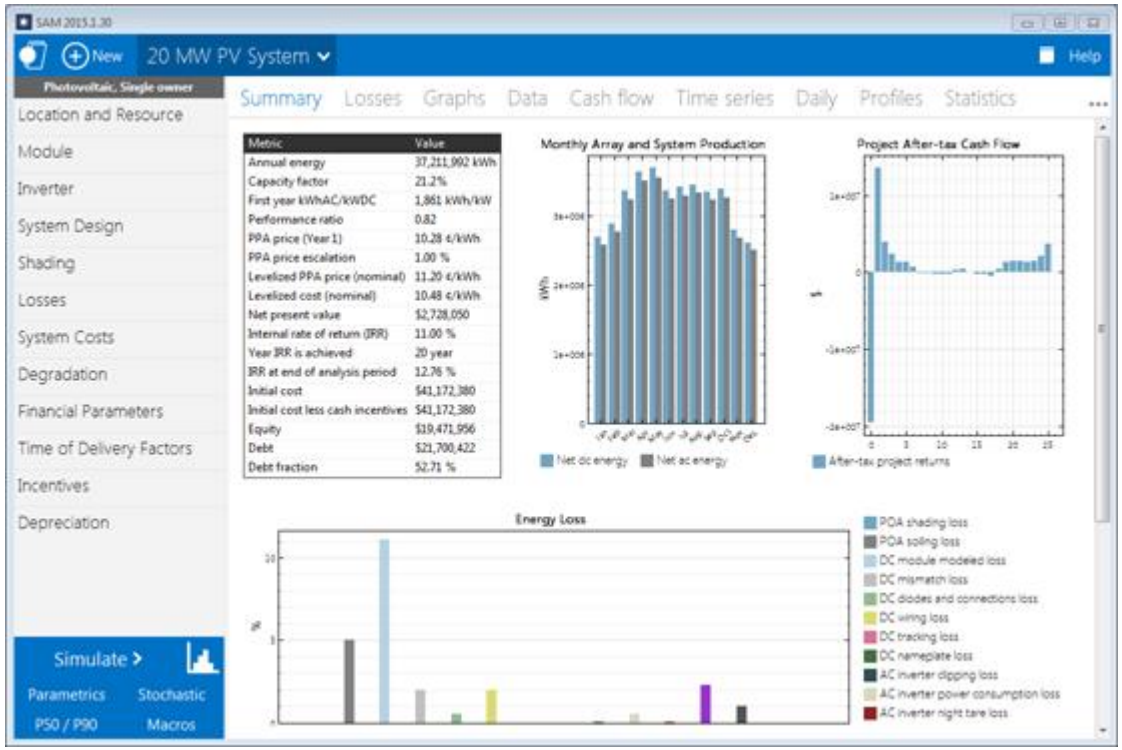
- Introduction to PySAM, August 1, 2019
- Modeling Wind Systems in SAM, August 22, 2019
- **SAM Virtual Conference, August 28, 2019**
- Modeling Fuel Cells in SAM, September 19, 2019

Learn about upcoming events here:

https://sam.nrel.gov/events.html

# System Advisor Model (SAM)

SAM is free software for modeling the performance and economics of renewable energy projects.




http://sam.nrel.gov
github.com/NREL/SAM

- Developed by NREL with funding from DOE
- Windows, OSX, and Linux
- One or two new versions per year
- Software Development Kit (SDK)
- Support

**Download Beta version**

http://samrepo.nrelcloud.org/beta-releases/sam-beta-windows-2019-7-15.exe

## Technologies

- Photovoltaics
  - Detailed & PVWatts
  - Battery Storage
- Wind
- Concentrating solar power
- Geothermal
- Biomass
- Solar water heating
- Fuel Cell

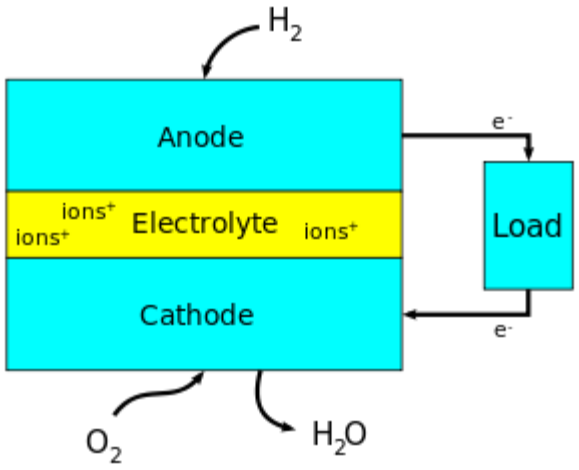
## Financial Models

- Behind-the-meter
  - residential
  - commercial
  - third-party ownership
- Power purchase agreements
  - single owner
  - equity flips
  - sale-leaseback
- Simple LCOE calculator

# Outline

- Fuel cells
- SAM modeling of PV + Fuel Cell + Storage
- Demo

# Fuel Cells




NREL Transforming ENERGY

Hydrogen & Fuel Cells

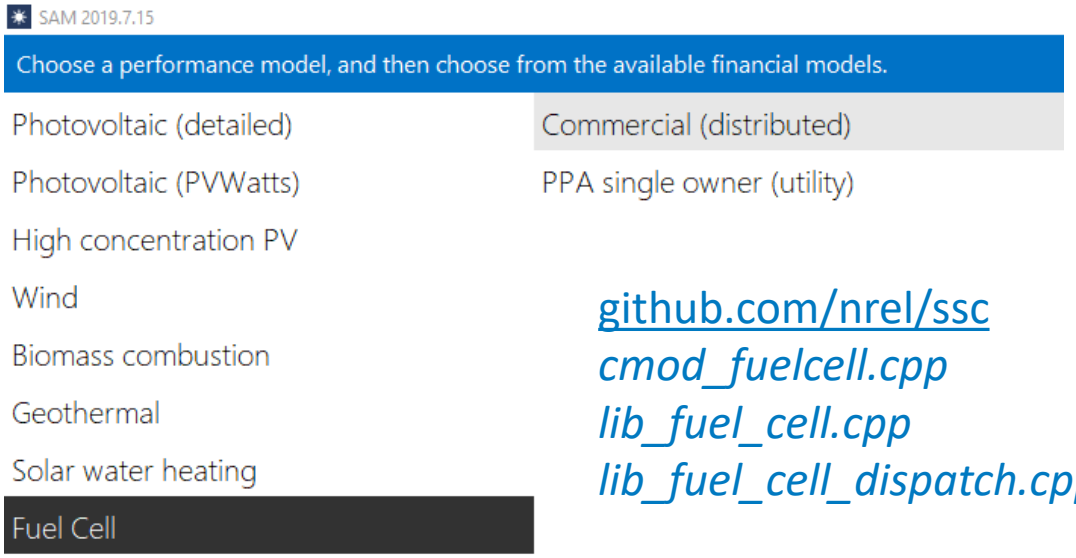
https://www.nrel.gov/hydrogen/fuel-cells.html

- An electrochemical cell that converts the chemical energy of a fuel and oxidizing agent into electricity through a pair of redox reactions.
- A single cell consists of electrolyte sandwiched between two electrodes.
- A fuel cell stack may contain a few to hundreds of individual cells layered together. This scalability enables multiple applications

- A variety of NREL data and tools are available specifically focused on fuel cells
- https://www.nrel.gov/hydrogen/data-tools.html

**We'd like to thank the fuel cell modeling team at NREL for help developing SAM's model**

# SAM fuel cell model




[github.com/nrel/ssc](github.com/nrel/ssc)
*cmod_fuelcell.cpp*
*lib_fuel_cell.cpp*
*lib_fuel_cell_dispatch.cpp*


- We introduce a fuel cell technology with two financial options
  - Commercial – intended for commercial or industrial applications where fuel cell will be offsetting a load for a behind-the-meter customer
  - PPA single owner – intended for a utility scale site generating power to sell through a PPA

# Fuel cell properties

**Fuel Cell Type**

SOFC

MCFC
PAFC
SOFC
Custom

Modifying the fuel cell type changes default information about the system size, dynamic response, degradation and efficiency. SAM models all fuel cell types the same way, by applying an electrical efficiency based upon the percent of max power at each timestep and limiting operation based upon dynamic response limits.

**Syste**

**Size**

| | | |
|---|---|---|
| Unit nameplate | 200 | kW |
| Minimum unit output | 30 | % of nameplate |
| Number of units | 1 | |
| Total system nameplate | 200 | kW |
| Minimum system output | 60 | kW |

**Dynamic Response**

| | | | |
|---|---|---|---|
| ☐ Started up | Startup time | 24 | hours |
| | Shutdown time | 24 | hours |
| | Ramp rate up limit (per unit) | 20 | kW/hr |
| | Ramp rate down limit (per unit) | 20 | kW/hr |
| | Calculated ramp up limit (per unit) | 20 | kW/h |
| | Calculated ramp down limit (per unit) | 20 | kW/h |

**Degradation**

| | | |
|---|---|---|
| Degradation | 20 | %/year |
| Restart degradation | 1 | kW |

Fuel cell degradation is assumed to degrade the max power output

**Shutdown schedule**

Import...
Export...
Copy
Paste
Rows: 1

| Shutdown hour of year | Hours shutdown |
|---|---|
| 0 | 0 |

*Default values populated from FCPower and correspondence with modeling experts*

# Fuel cell model

**Efficiency**

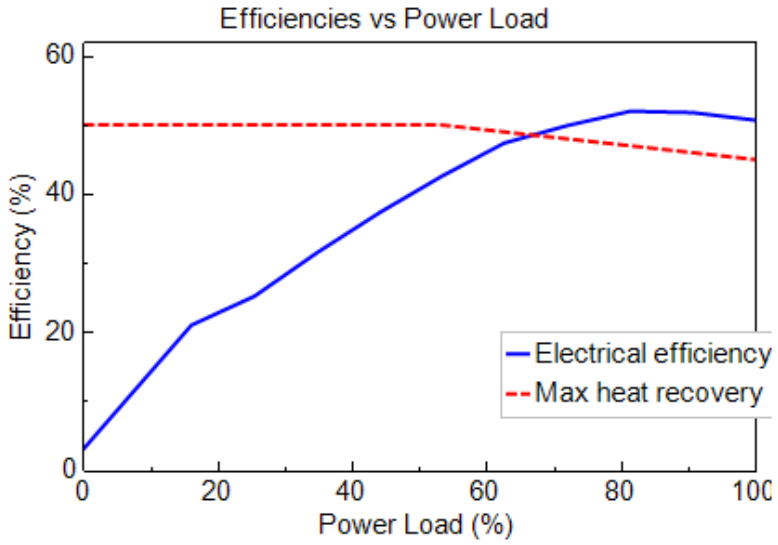
Choose power percentage definition: Power percent function of nameplate power

The electrical efficiency is applied to the power generated to calculate fuel consumption, while heat recovery percent determines heat generation. These efficiencies are calculated from the percent power output, which can be defined relative the original nameplate power, or to the degraded max power.

Import... | Export... | Copy | Paste

Rows: 11

| % Power | Electrical Efficiency LHV (%) | Max Heat Recovery (%) |
|---|---|---|
| 0 | 3 | 50 |
| 16.1 | 21 | 50 |
| 25.5 | 25.2 | 50 |
| 34.8 | 31.5 | 50 |
| 44.1 | 37.3 | 50 |
| 53.4 | 42.6 | 50 |
| 62.7 | 47.4 | 49 |
| 72 | 49.9 | 48 |
| 81.4 | 52 | 47 |
| 90.7 | 51.8 | 46 |
| 100 | 50.7 | 45 |




**Fuel Properties**

Fuel Type: Natural Gas

Lower Heating Value: 983 Btu/ft3

Fuel limited on site: ☐

Fuel available: 1e+10 Liters

Different fuel types may not be compatible will all fuel cell technologies or may require additional system components to convert the fuel into usable hydrogen. Selecting a fuel type in SAM simply modifies default values for the lower heating value and price, making the assumption that the user understands the fuel input limitations for their system.

# Fuel cell operation

**Fuel Cell Operation**

**Dispatch options**

- (●) Fixed output
- ( ) Follow electric load
- ( ) Manual dispatch
- ( ) Input dispatch

**Fixed output**

Fixed output percentage: 95 %

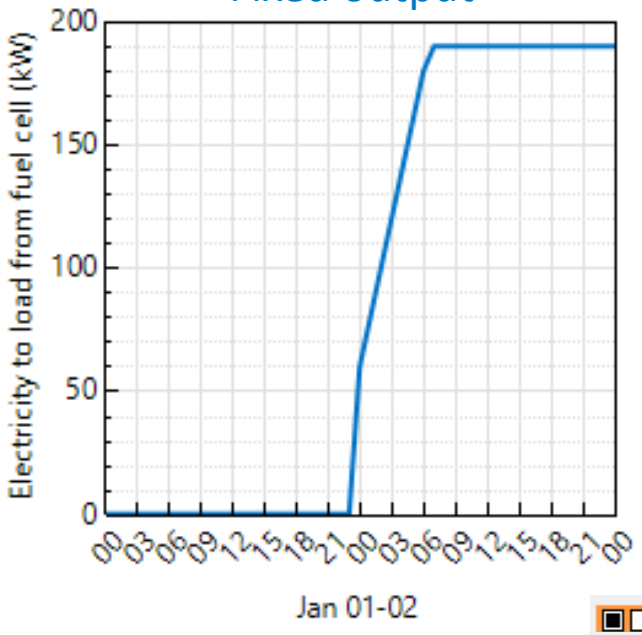
**Input dispatch**

Input dispatch: Edit data... kW

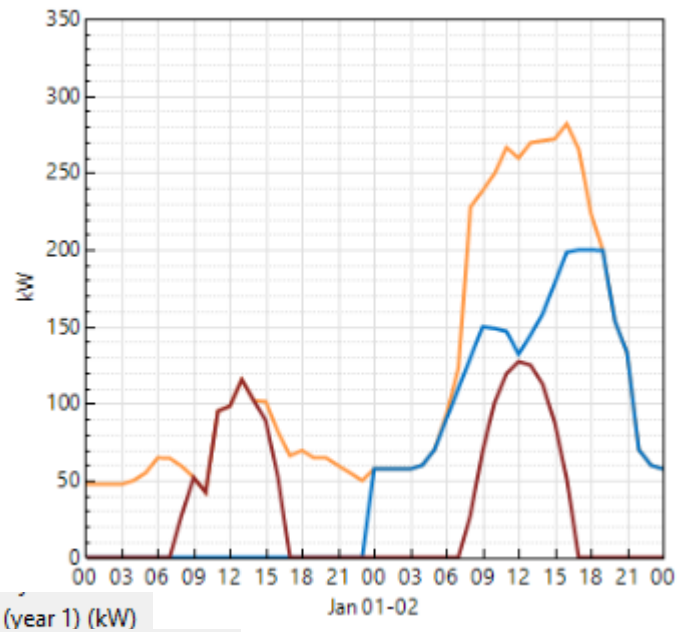
**Operation options**

- ( ) Allowed to shutdown
- (●) Idle at min power

## Fixed output




## Load following



# Fuel cell degradation and replacement

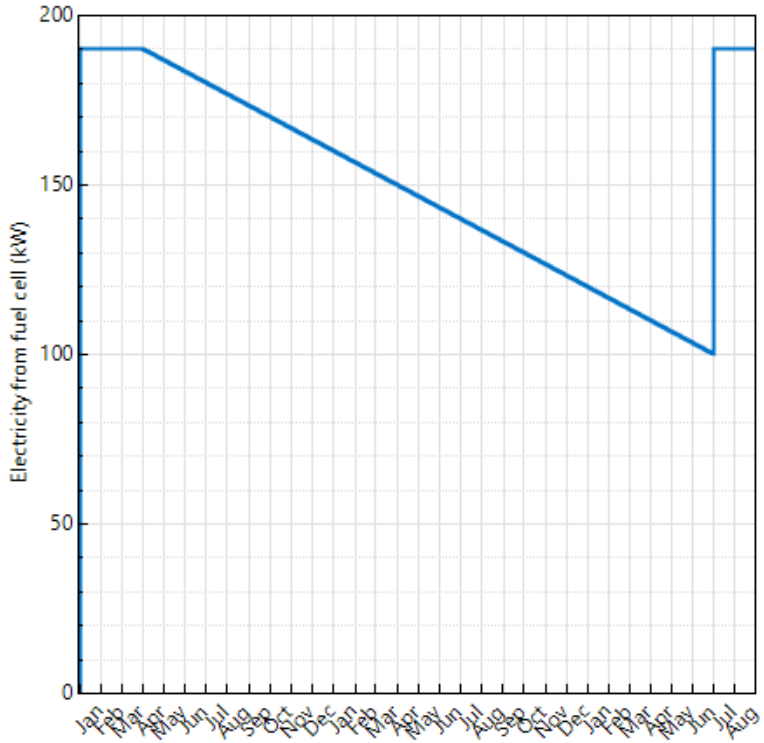
**Stack Replacement**

- ○ No replacements
- ◉ Replace at specified capacity
- ○ Replace at specified schedule

Fuel cell stack replacement threshold: 50 %

Fuel cell replacement schedule: Edit data...

Enter a 1 to replace fuel cell stack in each year desired




**Degradation**

Degradation: 20 %/year

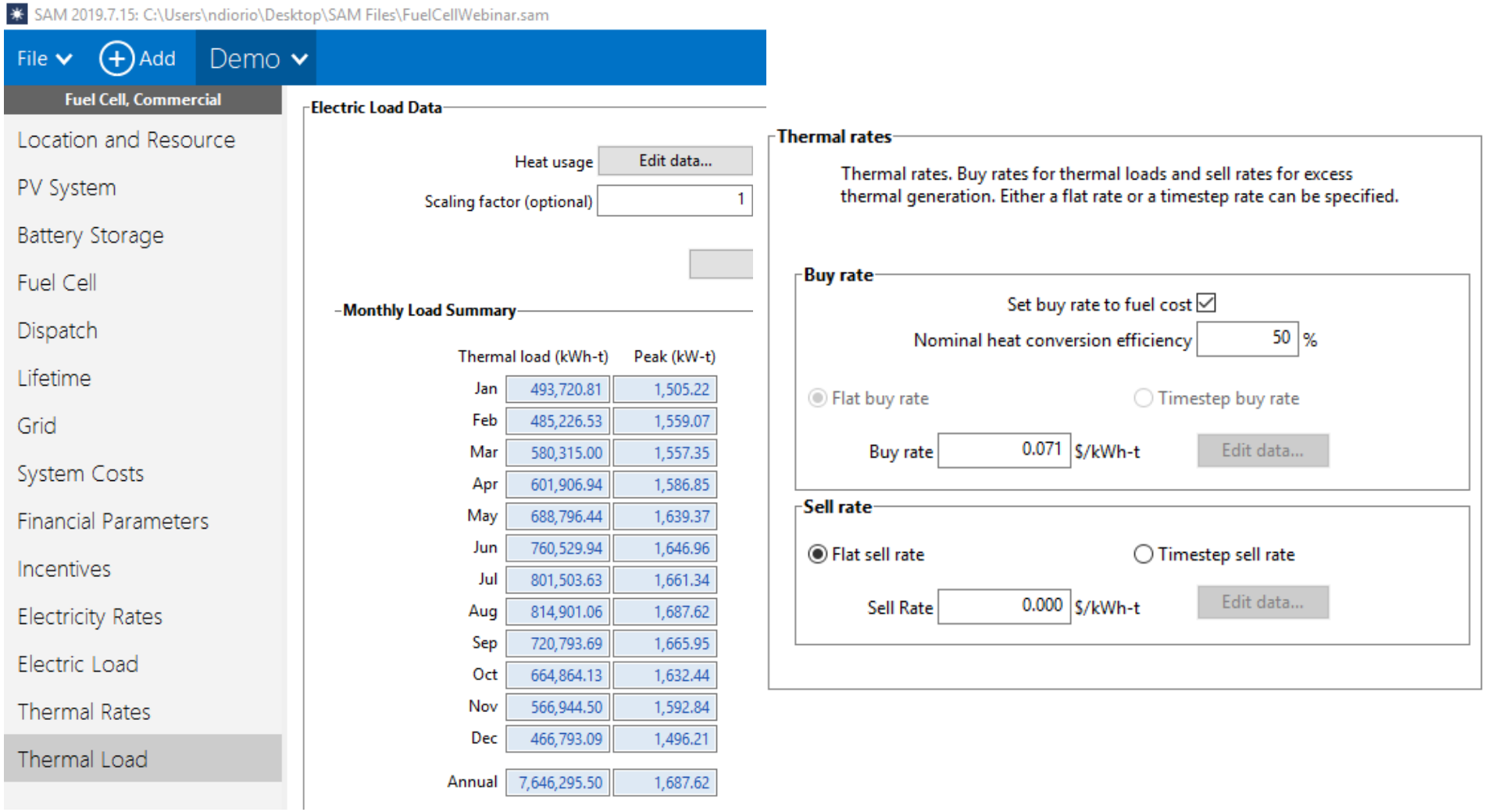
Restart degradation: 1 kW

Fuel cell degradation is assumed to degrade the max power output

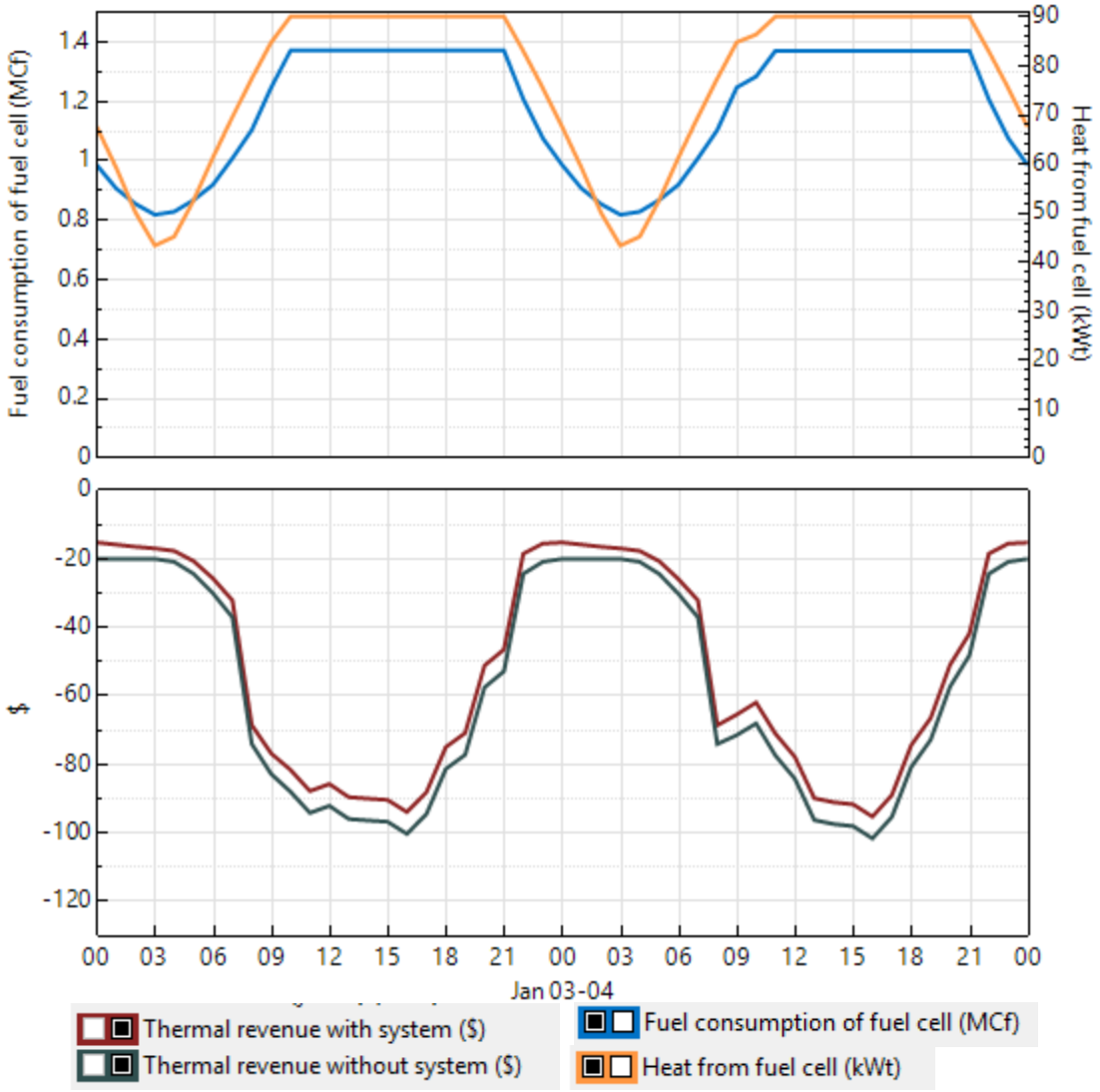
**Operation and Maintenance Costs**

| First year cost | PV | Battery | Fuel Cell |
|---|---|---|---|
| Fixed annual cost | 0 | 0 | 0 |
| Fixed cost by capacity | 50 | 0 | 0 |
| Variable cost by generation | 0 | | |
| Replacement cost | | 300 $/kWh | 10000 $/kW |
| Fuel cost | | | 10 $/MCf |

# Heating loads and rates



# Fuel cell thermal generation

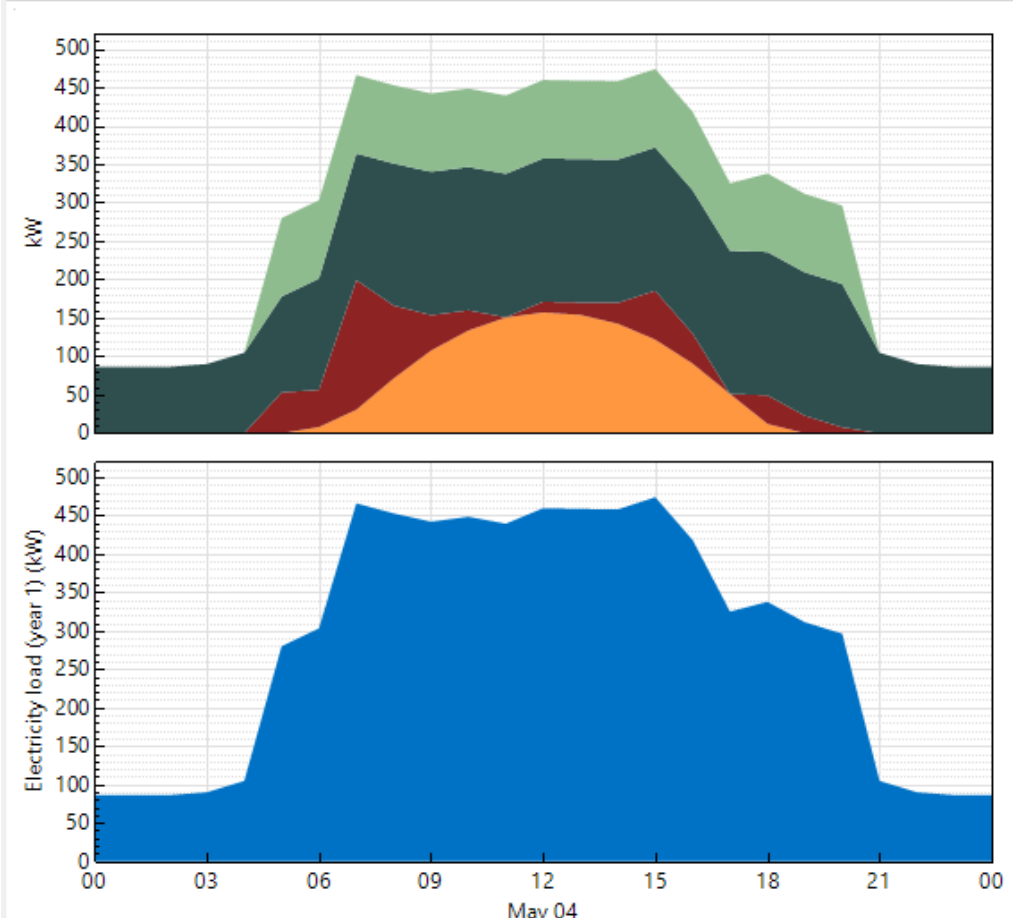



SAM outputs:

- Heat produced by fuel cell
- Fuel consumption
- Thermal revenue

# PV plus fuel cell plus storage

PV → Fuel cell → Battery → Financial

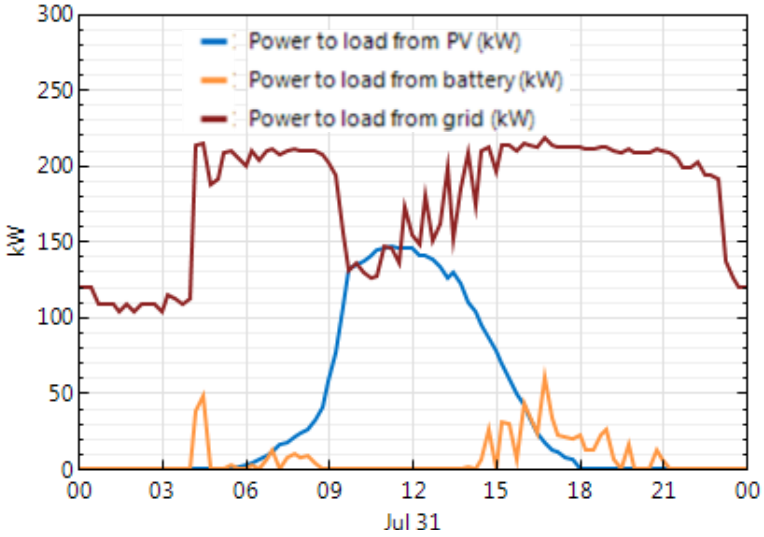


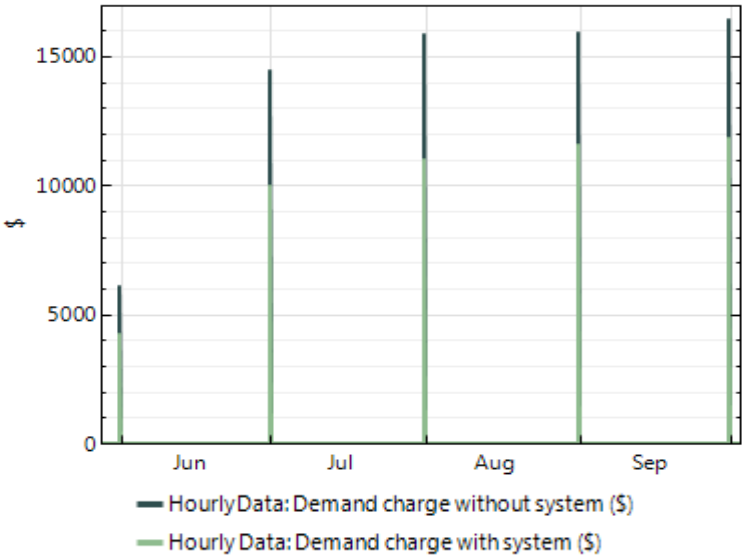

Electricity to load from PV (kW)
Electricity to load from battery (kW)
Electricity to load from fuel cell (kW)
Electricity to load from grid (kW)
Electricity load (year 1) (kW)

- First, PV model offsets load
- Then, fuel cell operates on resulting net load
- Then, battery controller dispatches on resulting net load.
- Grid makes up the remainder

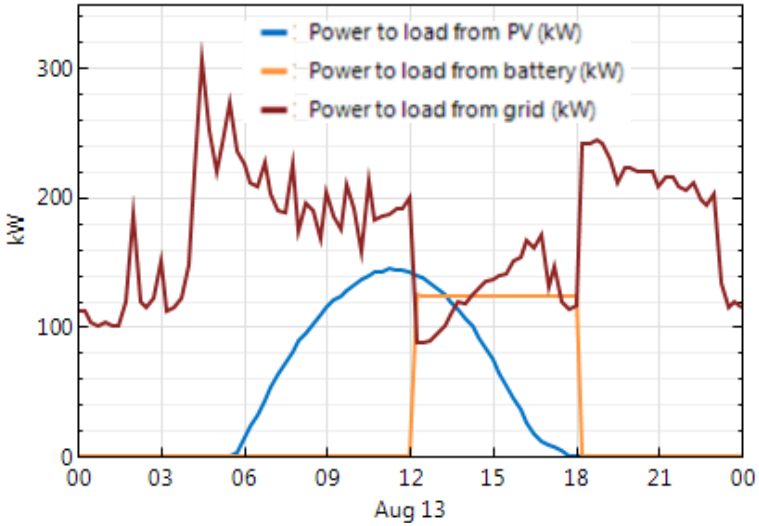
# Battery Dispatch Visualization (behind-the-meter)

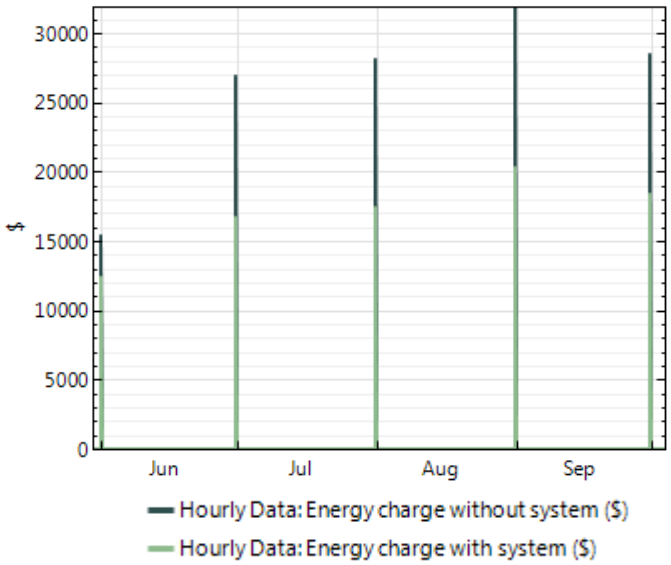
## Peak shaving for demand charge reduction



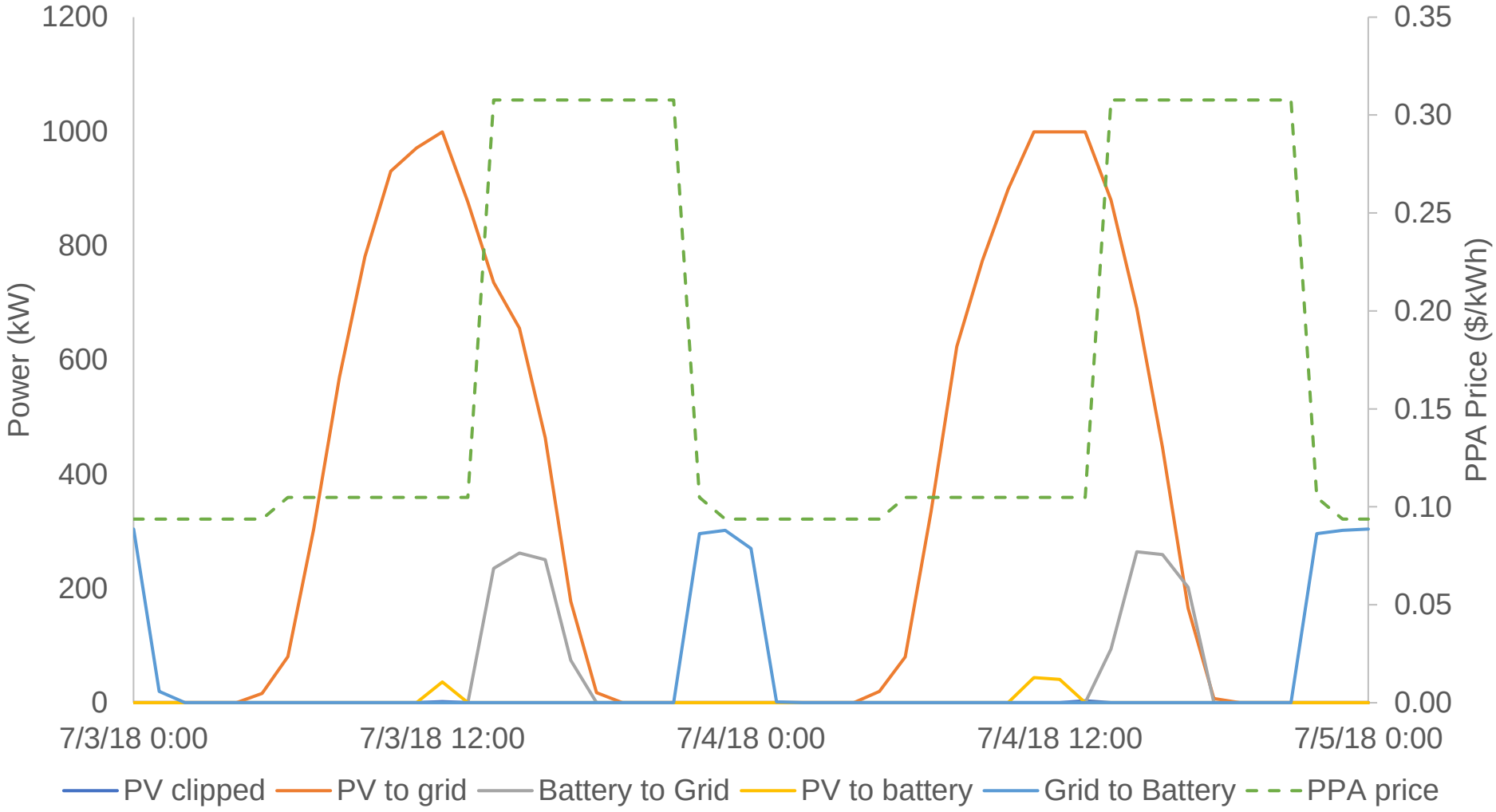




## Manual dispatch for energy arbitrage



# Battery Dispatch (utility scale)




Battery charges from PV minimally during peak operation to reduce clipping, otherwise charges mostly from grid.

# Demo

# Thank you! Questions?

Janine Freeman - project lead, photovoltaic and wind models
Nick DiOrio - code architecture, battery storage models
Nate Blair - emeritus lead, financials, costs, systems
Steve Janzou - programming, utility rate structures (subcontractor)
Paul Gilman - user support and documentation (subcontractor)
Ty Neises - concentrating solar power models
Mike Wagner - concentrating solar power models
Matt Boyd- concentrating solar power models

www.nrel.gov
http://sam.nrel.gov