Micro-power System Modeling using HOMER - Tutorial 1

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www.mwftr.com
Homer (Hybrid Optimization Model for Electric Renewables)

HOMER models micropower systems with single or multiple power sources:
- Photovoltaics
- Wind turbines
- Biomass power
- Run-of-river hydro
- Diesel and other reciprocating engines
- Cogeneration
- Microturbines
- Batteries
- Grid
- Fuel cells
- Electrolyzers
Homer – a tool

- A tool for designing micropower systems
  - Village power systems
  - Stand-alone applications and Hybrid Systems

- Wind turbines
- PV
- Batteries
- Diesels
- Microturbines
- Fuel cells
- Small hydro
- Small modular biomass
- Grid connection
“HOMER Legacy” software

HOMER® Legacy was created at the National Renewable Energy Laboratory as a tool to find affordable energy solutions for village power. HOMER Legacy set the standard for early stage microgrid design and assessment, but HOMER Pro is our supported and developed product. Most people who have landed on this page should be using HOMER Pro.

HOMER Energy continues to make HOMER Legacy available to the following people:
- Classroom and thesis use
- Small non-profit organizations that are working to improve access to energy in developing countries.

If you do not fit one of the above profiles, please use HOMER Pro instead. We may have to discontinue this charity if we continue to get too many inappropriate requests.

Support and training: No support or training is available for HOMER Legacy, and HOMER Legacy will never be updated. HOMER Legacy users can receive and provide mutual support via the HOMER Users Group. There is no cost to join or participate.

Part One: Download HOMER Legacy

Step 1 - Sign in to your HOMER account at users.homerenergy.com, navigate to DOWNLOAD/PURCHASE > Retired Products > HOMER Legacy.

Note: If you do not have a user account, please refer to instructions for creating a new user account.
Homer - capabilities

*Finds combination components that can service a load at the lowest cost with answering the following questions:

- Should I buy a wind turbine, PV array, or both?
- Will my design meet growing demand?
- How big should my battery bank be?
- What if the fuel price changes?
- How should I operate my system?
- And many others…*
**Homer - Features**

- **Simulation**—Estimate the cost and determine the feasibility of a system design over the 8760 hours in a year.
- **Optimization**—Simulate each system configuration and display a list of systems sorted by net present cost (NPC).
  - **Life-Cycle Cost:**
    - Initial cost – purchases and installation
    - Cost of owning and O&M and replacement
  - **NPC:** Life-cycle cost expressed as a lump sum in “today’s dollars”
- **Sensitivity Analysis**—Perform an optimization for each sensitivity variable.
Features

- Homer can accept max 3 generators
  - Fossil Fuels
  - Biofuels
  - Cogeneration
- Renewable Technologies
  - Solar PV
  - Wind
  - Biomass and biofuels
  - Hydro
Features

Emerging Technologies
- Fuel Cells
- Microturbines
- Small Modular biomass

Grid Connected System
- Rate Schedule, Net metering, and Demand Charges

Grid Extension
- Breakeven grid extension distance: minimum distance between system and grid that is economically feasible
Features

- Loads
  - Electrical
  - Thermal
  - Hydrogen

- Resources
  - Wind speed (m/s)
  - Solar radiation (kWh/m²/day)
  - Stream Flow (L/s)
  - Fuel price ($/L)
Optimization

- Best possible system configuration that satisfies the user-specified constraints at the **lowest total NPC (net present cost)**.
- Decide on the mix of components that the system should contain, the **size** or **quantity** of each component,
- Ranks the feasible ones according to total net present cost
Optimization Example

- Configuration and 140 (5x1x7x4=140) search spaces

Overall Optimization results

<table>
<thead>
<tr>
<th>FL30 (Quantity)</th>
<th>Gen (kW)</th>
<th>Batt. (kW)</th>
<th>Conv.</th>
<th>Initial Capital</th>
<th>Total NPC</th>
<th>COE ($/kW)</th>
<th>Diesel (L)</th>
<th>Gen (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$216,500</td>
<td>$849,905</td>
<td>0.273</td>
<td>75,107</td>
<td>4,528</td>
</tr>
<tr>
<td>2</td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$346,500</td>
<td>$854,650</td>
<td>0.274</td>
<td>54,434</td>
<td>3,350</td>
</tr>
<tr>
<td>1</td>
<td>135</td>
<td>48</td>
<td>30</td>
<td>$200,500</td>
<td>$855,733</td>
<td>0.275</td>
<td>78,061</td>
<td>4,910</td>
</tr>
<tr>
<td>2</td>
<td>135</td>
<td>48</td>
<td>30</td>
<td>$330,500</td>
<td>$856,335</td>
<td>0.275</td>
<td>57,654</td>
<td>3,685</td>
</tr>
</tbody>
</table>

Categorized optimization result

<table>
<thead>
<tr>
<th>FL30 (Quantity)</th>
<th>Gen (kW)</th>
<th>Batt. (kW)</th>
<th>Conv.</th>
<th>Initial Capital</th>
<th>Total NPC</th>
<th>COE ($/kW)</th>
<th>Diesel (L)</th>
<th>Gen (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$216,500</td>
<td>$849,905</td>
<td>0.273</td>
<td>75,107</td>
<td>4,528</td>
</tr>
<tr>
<td>135</td>
<td>64</td>
<td>30</td>
<td></td>
<td>$86,500</td>
<td>$885,175</td>
<td>0.284</td>
<td>101,290</td>
<td>5,528</td>
</tr>
<tr>
<td>135</td>
<td>0</td>
<td>30</td>
<td></td>
<td>$0</td>
<td>$996,273</td>
<td>0.320</td>
<td>132,357</td>
<td>8,760</td>
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<tr>
<td>1</td>
<td>135</td>
<td></td>
<td></td>
<td>$130,000</td>
<td>$1,130,637</td>
<td>0.363</td>
<td>127,679</td>
<td>8,740</td>
</tr>
</tbody>
</table>
Sensitivity Analysis

- Optimization: best configuration under a particular set of input assumptions
- Sensitivity Analysis: Multiple optimizations each using a different set of input assumptions
- “How sensitive the outputs are to changes in the inputs” – results in various tabular and graphic formats
- User enters a range of values for a single input variable:
  - Grid power price
  - Fuel price,
  - Interest rate
  - Lifetime of PV array
  - Solar Radiation
  - Wind Speed
Why Sensitivity Analysis? Uncertainty!

- When unsure of a particular variable, enter several values covering the likely range and see how the results vary across the range.
- Diesel Generator – Wind Configuration: Uncertainty in diesel fuel price with $0.6 per liter in the planning stage and 30 year generator lifetime
- Example: **Spider Graph**

**Tabular Format**

<table>
<thead>
<tr>
<th>Diesel Price ($/L)</th>
<th>FL30 Life</th>
<th>Gen O&amp;M Multiplier</th>
<th>Gen (kW)</th>
<th>Batt. (kW)</th>
<th>Conv. (kW)</th>
<th>Total NPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.420</td>
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<td>30</td>
<td>$688,579</td>
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<td></td>
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<td>30</td>
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<td>0.480</td>
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<td>64</td>
<td>753,695</td>
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<td></td>
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<tr>
<td>0.510</td>
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<td>135</td>
<td>64</td>
<td>777,748</td>
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<td></td>
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<tr>
<td>0.540</td>
<td>1</td>
<td>135</td>
<td>64</td>
<td>801,800</td>
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<td>0.570</td>
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<td>135</td>
<td>64</td>
<td>825,852</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.600</td>
<td>1</td>
<td>135</td>
<td>64</td>
<td>849,905</td>
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<td></td>
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<tr>
<td>0.630</td>
<td>2</td>
<td>135</td>
<td>64</td>
<td>872,093</td>
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<td></td>
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<td>0.660</td>
<td>2</td>
<td>135</td>
<td>64</td>
<td>889,525</td>
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<td></td>
</tr>
<tr>
<td>0.690</td>
<td>2</td>
<td>135</td>
<td>64</td>
<td>906,957</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.720</td>
<td>2</td>
<td>135</td>
<td>64</td>
<td>924,389</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sensitivity Analysis on Hourly Data Sets

- Sensitivity analysis on hourly data sets such as primary electric load, solar/wind resource
- 8760 values that have a certain average value with scaling variables
- Example: Graphical Illustration
  - Hourly primary load data with an annual average of 22 kWh/day with average wind speed of 4 m/s
  - Primary load scaling variables of 20, 40, ---, 120 kWh/day & 3, 4, ---, 7 m/s wind speeds.
Resources Modeling

- **Solar Resources**: average global solar radiation on horizontal surface (kWh/m² or kWh/m²-day) or monthly average clearness index (atmosphere vs. earth surface). **Inputs** – solar radiation values and the latitude and the longitude. **Output** – 8760 hour data set

- **Wind Resources**: Hourly or 12 monthly average wind speeds. Anemometer height. Wind turbine hub height. Elevation of the site.

- **Hydro Resources**: Run-of-river hydro turbine. Hourly (or monthly average) stream flow data.

- **Biomass Resources**: wood waste, agricultural residue, animal waste, energy crops. Liquid or gaseous fuel.

- **Fuel**: density, lower heating value, carbon content, sulfur content. Price and consumption limits
Component Modeling—See Appendix for details

- HOMER models 10 types of parts that generates, delivers, converts, or stores energy

- 3 intermittent renewable resources:
  - PV modules (dc)
  - wind turbines (dc or ac)
  - run-of-river hydro turbines (dc or ac)

- 3 dispatchable energy sources: [control them as needed]
  - Generators
  - the grid
  - boilers

- 2 energy converters:
  - Converters (dc $\leftrightarrow$ ac)
  - Electrolyzers (ac, dc $\rightarrow$ electrolysis $\rightarrow$ Hydrogen)

- 2 types of energy storage:
  - batteries (dc)
  - hydrogen storage tanks
How to build a HOMER project

1. Collect Information
   - Electric demand (load)
   - Energy resources
2. Define Options (Gen, Grid, etc)
3. Enter Load Data
4. Enter Resource Data
5. Enter Component Sizes and Costs
6. Enter Sensitivity Variable Values
7. Calculate Results
8. Examine Results

Caveat: HOMER is only a model. HOMER does not provide "the right answer" to questions. It does help you consider important factors, and evaluate and compare options.
Example Case – Micro Grid in Sri Lanka

Load profile:
- Base load of 5W, small peaks of 20 W, peak load of 40W; total daily average load = 350 Wh
- Sensitivity analysis range: [0.3kWh, 16kWh/d]

Solar Resource
- 7.30 Latitude & 81.30 longitude
- NASA Surface Meteorology and Solar Energy Web: average solar radiation = 5.43 kWh/m²/d.

Diesel Fuel Price
- $0.4/L – $0.7/L
- Sensitivity analysis range: [$0.3, 0.8] with increment of $0.1/L

- Economics:
  - Real annual interest rate at 6%
- Reliability Constraints
  - 0% annual capacity shortage
    Sensitivity Analysis range: [0.5 – 5]%
Example Case – Micro Grid in Sri Lanka

- PV: de-rating factor at 90%
- Battery: T-105 or L-16
- Converters: efficiency at 90% for inversion and 85% for rectification
- Generator: not allowed to operate at less than 30% capacity

<table>
<thead>
<tr>
<th>Component</th>
<th>Size</th>
<th>Capital Cost ($)</th>
<th>Replacement Cost ($)</th>
<th>O&amp;M Cost ($)</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Panels</td>
<td>0.05 – 5.0 kW</td>
<td>$7,500/kW</td>
<td>$7,500/kW</td>
<td>0.00</td>
<td>20 years</td>
</tr>
<tr>
<td>Trojan T-105</td>
<td>225 Ah / 6 volt (bank size: 1 – 54 batteries)</td>
<td>$75/battery</td>
<td>$75/battery</td>
<td>$2.00/year</td>
<td>845 kWh of throughput per battery</td>
</tr>
<tr>
<td>Converter</td>
<td>0.1 – 4.0 kW</td>
<td>$1,000/kW</td>
<td>$1,000/kW</td>
<td>$100/year</td>
<td>15 years</td>
</tr>
<tr>
<td>Generator</td>
<td>4.25 kW</td>
<td>$2,550</td>
<td>$2,550</td>
<td>$0.15/hour</td>
<td>5000 hours</td>
</tr>
</tbody>
</table>
Analysis Result

- Diesel price $0.3/L
- Diesel Price $0.8/L
1. “ExampleProject.hmr”
2. Open the Example Project File: ExampleProject.hmr
3. Click the Primary Load
4. Exit out of HOMER – We have things to do
Find the Site [Location]

- Latitude and Longitude
- Your dorm room
- Your home
- Your favorite place

[Image of a map with latitude and longitude coordinates]
LAT and LONG --- Conversion

Degrees Minutes Seconds to Decimal Degrees

Decimal Degrees to Degrees Minutes Seconds

- Decimal Latitude: 38.901792
- Decimal Longitude: -77.036871

Results: Latitude: 38° 54' 6.4512"
           Longitude: -77° 2' 12.7356"
Resources – Average Monthly Irradiation and Wind Speed

Surface meteorology and Solar Energy
A renewable energy resource web site (release 6.0)
sponsored by NASA’s Applied Science Program in the Science Mission Directorate
developed by POWER: Prediction of Worldwide Energy Resource Project

- over 200 satellite-derived meteorology and solar energy parameters
- monthly averaged from 22 years of data
- data tables for a particular location
- GIS Web Mapping Application & Services

Join the SSE mailing list to receive updates about the SSE data archive.

Data Retrieval:
- Meteorology and Solar Energy
- GIS Web Mapping Application & Services
- Renewable Software Application Inputs

Supporting Documentation:
- Acknowledgement for data usage
- Horizontal Grid for Input and Output
Surface meteorology and Solar Energy

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Data Retrieval:

- Meteorology and Solar Energy
  - Data tables for a particular location
    - Tables of all SSE data set parameters for a single site.
  - Regional data subsets
    - Subsets of data by region.
  - Daily data
    - Time series plots and data lists of Insolation and Air Temperature for a single site.
  - Global data sets
    - Text files of monthly averaged data for the entire globe. Some annual averages or annual sums are included.
A new POWER home page with enhanced responsive GIS-enabled web data services and mapping capabilities will soon replace the current SSE home page with a target date of May 1, 2018. This current set of SSE web applications and website will no longer be accessible after that date. The new POWER will include improved solar and meteorological data with all parameters available on a 0.5-degree global grid. The beta version of the new home page, featuring the updated parameters, schedule updates and FAQ, can be accessed at POWER. Please direct any questions to POWER Project Team.

### NASA Surface meteorology and Solar Energy - Location

Enter BOTH latitude and longitude either in decimal degrees or degrees and minutes separated by a space.

<table>
<thead>
<tr>
<th>Example:</th>
<th>Latitude 33.5</th>
<th>OR</th>
<th>Latitude 33 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude -80.75</td>
<td>South: -90 to 0</td>
<td>North: 0 to 90</td>
<td></td>
</tr>
<tr>
<td>West: -180 to 0</td>
<td>East: 0 to 180</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Submit | Reset

This form is "Reset" if the input is out of range.

Back to SSE Data Set Home Page
Select Parameters – Just 2 below are enough

Latitude 38.9 / Longitude -77.03 was chosen.

### Geometry

- **Latitude and longitude (center and boundaries)**

### Parameters for Solar Cooking

- **Average insolation**
  - Midday insolation
  - Clear sky insolation
  - Clear sky days

### Meteorology (Wind)

- **Wind Speed at 50 m (Average, Min, Max)**
  - Percent of time for ranges of Wind Speed at 50 m
  - Wind Speed at 50 m for 3-hourly intervals
  - Wind Direction at 50 m
  - Wind Direction at 50 m for 3-hourly intervals
  - Wind Speed at 10 m for terrain similar to airports
Monthly Data for Insolation and Wind Speed

Northern boundary
39
Western boundary
Center
Latitude 38.5
Longitude -77.5
38
Eastern boundary
-77
Southern boundary
-77

**Parameters for Solar:**

<table>
<thead>
<tr>
<th>Lat 38.9</th>
<th>Lon -77.03</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>22-year Average</td>
<td>2.12</td>
<td>2.87</td>
<td>3.91</td>
<td>4.86</td>
<td>5.40</td>
<td>5.80</td>
<td>5.67</td>
<td>5.00</td>
<td>4.38</td>
<td>3.51</td>
<td>2.36</td>
<td>1.89</td>
<td></td>
</tr>
</tbody>
</table>

**Meteorology (Wind):**

<table>
<thead>
<tr>
<th>Lat 38.9</th>
<th>Lon -77.03</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-year Average</td>
<td>5.28</td>
<td>5.35</td>
<td>5.40</td>
<td>4.96</td>
<td>4.09</td>
<td>3.97</td>
<td>3.46</td>
<td>3.41</td>
<td>3.88</td>
<td>4.33</td>
<td>5.09</td>
<td>5.33</td>
<td>4.54</td>
<td></td>
</tr>
</tbody>
</table>

**Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%):**

<table>
<thead>
<tr>
<th>Lat 38.9</th>
<th>Lon -77.03</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-10</td>
<td>-12</td>
<td>-12</td>
<td>-9</td>
<td>-11</td>
<td>-9</td>
<td>-12</td>
<td>-11</td>
<td>-6</td>
<td>-14</td>
<td>-8</td>
<td>-7</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>14</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sources for Wind Data

- www.windfinder.com
- www.wunderground.com

1 mph = 0.44704 ms$^{-1}$
1 knot = 0.5144444444 meters / second
HOMER: Open the file again

- Click the generator

- 25 kW $10,000
- Minimum running at 30%

Choose a fuel, and enter at least one size, capital cost and operation and maintenance (O&M) value in the Costs table. Note that the capital cost includes installation costs, and that the O&M cost is expressed in dollars per operating hour. Enter a nonzero heat recovery ratio if heat will be recovered from this generator to serve thermal load. As it searches for the optimal system, HOMER will consider each generator size in the Sizes to Consider table.

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Equipment

- Click Wind Turbine
  - From the drop down list click through the wind turbines and look at the power curve. Try to find a Wind Turbine that would best maximize Average Wind Speed (m/s): 3.27
Equipment

- Click PV

- Lifetime, De-rating factor, slope, No-tracking
Resource Information

- Select Solar Resources, Wind Resources, and Diesel
- Type in Solar Radiation
- Type in Wind Speed
- Diesel Fuel Price
Equipment

- Click Converter icon
- 5kW $4,000

A converter is required for systems in which DC components serve an AC load or vice versa. A converter can be an inverter (DC to AC), rectifier (AC to DC), or both.

Enter at least one size and capital cost value in the Costs table. Include all costs associated with the converter, such as hardware and labor. As it searches for the optimal system, HOMER considers each converter capacity in the Sizes to Consider table. Note that all references to converter size or capacity refer to inverter capacity.

Hold the pointer over an element or click Help for more information.

<table>
<thead>
<tr>
<th>Sizes to consider</th>
<th>Size (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>5.000</td>
</tr>
<tr>
<td></td>
<td>10.000</td>
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<tr>
<td></td>
<td>15.000</td>
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</tbody>
</table>

Costs

<table>
<thead>
<tr>
<th>Size (kW)</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M ($/Ayr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.000</td>
<td>4000</td>
<td>4000</td>
<td>0</td>
</tr>
</tbody>
</table>

Inverter inputs

- Lifetime (years): 15
- Efficiency (%): 90
- Inverter can operate simultaneously with an AC generator

Rectifier inputs

- Capacity relative to inverter (%): 100
- Efficiency (%): 85
Other Information

- **Economics**
  - Real interest 6%
  - Lifetime 25 years

- **System Control**
  - Cycle-charging
### Other Information

- **Emission:** all 0
- **Constraints**
  - Operating reserve 10%
- **Capacity shortage:** 0%

#### Constraints

| Maximum annual capacity shortage (%) | 0 |
| Minimum renewable fraction (%)      | 0 |
| Operating reserve                   |
| As percent of load                  |
| Hourly load (%)                     | 10 |
| Annual peak load (%)                | 0  |
| As percent of renewable output      |
| Solar power output (%)              | 25 |
| Wind power output (%)               | 50 |
| Primary energy savings              |
| Minimum primary energy savings (%)  | 10 |
| Reference electrical efficiency (%) | 33 |
| Reference thermal efficiency (%)    | 75 |
Emission Calculation in HOMER

- Carbon content of fuel
- If CO₂ is only interest
  - Set 0 to CO

How does HOMER calculate emission, especially carbon dioxide?

If the system you are modeling consumes fuel, HOMER calculates the total annual carbon input by multiplying the fuel consumption by the carbon content of the fuel. It assumes that all that carbon gets emitted as either unburned hydrocarbons, CO, or CO₂. You enter the emissions factors for unburned hydrocarbons and CO, so HOMER can calculate how much of the total carbon gets emitted in those two forms. The rest gets emitted as CO₂.

Typically only a tiny fraction of the carbon gets emitted as hydrocarbon and CO₂, so nearly all of it gets emitted as CO₂. If you are interested only in CO₂, you should set the UHC and CO emissions factors to zero. Note that 3.67 g of CO₂ contains 1 g of carbon. So ignoring UHC and CO emissions, the system will emit 3.67 g of CO₂ for every g of carbon in the consumed fuel.
Fuel Carbon Content

- **Diesel**
  - Lower heating value: 43.2 MJ/kg
  - Density: 820 kg/m³
  - Carbon content: 88%
  - Sulfur content: 0.33%

- **Natural Gas**
  - Lower heating value: 45 MJ/kg
  - Density: 0.79 kg/m³
  - Carbon content: 67%
  - Sulfur content: 0.33%

- **Gasoline**
  - Lower heating value: 44 MJ/kg
  - Density: 740 kg/m³
  - Carbon content: 86%
  - Sulfur content: 0.33%
The best way to use HOMER and Carbon? Two scenarios suppose you are carbon capped would you just put in a fuel cap. If you are carbon taxed would you just add cost to fuel.

You can limit or penalize emissions if you click the Emissions button just below the schematic.

- Carbon penalty will appear as "Other" O&M Cost.

To cap carbon dioxide emissions, click the CO2 checkbox in the lower half of the Emissions window and enter the maximum allowable emissions in kg/yr. To apply a carbon tax enter the penalty in $/tonne in the top half of the window. Just be sure to enter it in terms of $/tonne of CO2, not per tonne of carbon.

You can limit fuel consumption if you click on the fuel button below the schematic. That would have the same effect as limiting emissions, but you would have to calculate the amount of fuel corresponding to your emission cap. It’s easier to just enter the emission cap. Same with the carbon tax – you could calculate the equivalent cost per litre of fuel and increase the fuel price accordingly, but it’s easier to just enter the emission penalty.
Example

3 Generators only to meet a load
- Diesel generator – Carbon 88% of 820 kg per 1000 L
- Gasoline generator – Carbon 86% of 740 kg per 1000L
- Natural Gas generator – Carbon 67% of 0.79 kg per 1 m³

Total fuel consumption for each
- Diesel – 10,996 L
- Gasoline – 1,762 L
- Natural Gas – 2,613 m³

Carbon Content
- Diesel: 820 * 10.996 * 0.88 = 7974 kg/yr
- Gasoline: 740 * 1.762 * 0.86 = 1,121 kg/yr
- Natural Gas: 0.79 * 2,613 * 0.67 = 1,383 kg/yr
- Total = 10,478 kg/yr

Total CO₂
- 10,478 kg * 3.67 = 38,454 kg CO₂/year

Added O&M Cost per year with $2 per ton of CO₂
- $2*38,454 = $76.9/yr
**System Report - Example**

**Project Period = 25 years**

### Net Present Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital</th>
<th>Replacement</th>
<th>O&amp;M</th>
<th>Fuel</th>
<th>Salvage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($ )</td>
<td>($ )</td>
<td>($ )</td>
<td>($ )</td>
<td>($ )</td>
<td>($ )</td>
</tr>
<tr>
<td>Generator 1</td>
<td>2,000</td>
<td>14,307</td>
<td>22,294,186</td>
<td>112,453</td>
<td>-217</td>
<td>22,422,726</td>
</tr>
<tr>
<td>Generator 2</td>
<td>2,000</td>
<td>7,693</td>
<td>6,151,354</td>
<td>33,794</td>
<td>-457</td>
<td>6,194,385</td>
</tr>
<tr>
<td>Generator 3</td>
<td>4,000</td>
<td>8,125</td>
<td>7,649,564</td>
<td>33,470</td>
<td>-12</td>
<td>7,695,147</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>974</td>
<td>0</td>
<td>0</td>
<td>974</td>
</tr>
<tr>
<td>System</td>
<td>8,000</td>
<td>30,126</td>
<td>36,096,072</td>
<td>179,718</td>
<td>-687</td>
<td>36,313,236</td>
</tr>
</tbody>
</table>

**Annualized Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital</th>
<th>Replacement</th>
<th>O&amp;M</th>
<th>Fuel</th>
<th>Salvage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($/yr)</td>
<td>($/yr)</td>
<td>($/yr)</td>
<td>($/yr)</td>
<td>($/yr)</td>
<td>($/yr)</td>
</tr>
<tr>
<td>Generator 1</td>
<td>156</td>
<td>1,119</td>
<td>1,744,001</td>
<td>8,797</td>
<td>-17</td>
<td>1,754,056</td>
</tr>
<tr>
<td>Generator 2</td>
<td>156</td>
<td>602</td>
<td>481,200</td>
<td>2,644</td>
<td>-36</td>
<td>484,566</td>
</tr>
<tr>
<td>Generator 3</td>
<td>313</td>
<td>636</td>
<td>598,400</td>
<td>2,618</td>
<td>-1</td>
<td>601,966</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>76</td>
<td>0</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td>System</td>
<td>626</td>
<td>2,357</td>
<td>2,823,677</td>
<td>14,059</td>
<td>-54</td>
<td>2,840,665</td>
</tr>
</tbody>
</table>

36,095,104 for no carbon penalty

2,823,602 for no carbon penalty

Changed O&M with $2 per ton of CO2 penalty, for the 38 ton emission per year. $2 \times 38 = $76/year
Emission Input – Emission Penalty

Costs resulting from emissions penalties appear as 'Other O&M cost'. HOMER discards systems that exceed the specified emissions limits.

Emissions penalties:
- Carbon dioxide ($/t): 2.0
- Carbon monoxide ($/t): 0
- Unburned hydrocarbons ($/t): 0
- Particulate matter ($/t): 0
- Sulfur dioxide ($/t): 0
- Nitrogen oxides ($/t): 0
Analysis of the System

1. Click “Calculate” to start the analysis

Click Overall: view all possible combinations
Analysis of the System

- Click “Categorized”

- Now back to “Overall”, and choose any system of interest by clicking/ double clicking
Analysis

Simulation Results
PV Output

Simulation Results

System Architecture: 10 kW PV, 25 kW Generator 1, 10 kW Inverter
10 kW Rectifier

Cost Summary | Cash Flow | Electrical | PV | Gen1 | Converter | Emissions | Hourly Data

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated capacity</td>
<td>10.0</td>
<td>kW</td>
</tr>
<tr>
<td>Mean output</td>
<td>11.3</td>
<td>kW</td>
</tr>
<tr>
<td>Mean output</td>
<td>27.2</td>
<td>kWh/d</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>11.3</td>
<td>%</td>
</tr>
<tr>
<td>Total production</td>
<td>9.811</td>
<td>kWh/yr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum output</td>
<td>0.00</td>
<td>kW</td>
</tr>
<tr>
<td>Maximum output</td>
<td>35.84</td>
<td>kW</td>
</tr>
<tr>
<td>PV penetration</td>
<td>16.0</td>
<td>%</td>
</tr>
<tr>
<td>Hours of operation</td>
<td>4380</td>
<td>h/yr</td>
</tr>
<tr>
<td>Levelized cost</td>
<td>0.303</td>
<td>$/kWh</td>
</tr>
</tbody>
</table>

Total NPC: $365,558
Levelized COE: $0.521/kWh
Operating Cost: $24,460/yr
Electrical Output

Simulation Results

System Architecture:
- 10 kW PV
- 25 kW Generator 1
- 10 kW Inverter

Cost Summary

<table>
<thead>
<tr>
<th>Production</th>
<th>kW/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV array</td>
<td>9,481</td>
<td>12</td>
</tr>
<tr>
<td>Generator 1</td>
<td>76,057</td>
<td>88</td>
</tr>
<tr>
<td>Total</td>
<td>85,538</td>
<td>100</td>
</tr>
</tbody>
</table>

Cost Flow

<table>
<thead>
<tr>
<th>Production</th>
<th>kW/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC primary load</td>
<td>94,533</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>94,533</td>
<td>100</td>
</tr>
</tbody>
</table>

Simulation Results Summary

- Total NPC: $365,558
- Levelized CCE: $0.521/kWh
- Operating Cost: $24,450/yr

Monthly Average Electric Production

- PV
- Generator 1

Other Costs

- Excess electricity: 30,254 kWh, 35.2%
- Unmet electric load: 0.00635 kWh, 0.0%
- Capacity shortage: 0.442 kWh, 0.0%

Renewable Fraction: 0.115
Sensitivity Analysis on Wind Power

- Click Wind resource
- Click “Edit Sensitivity Values” >> Do so for Load, Solar, and Diesel
- Wind Resources
- Primary Load
- Solar Resources

- Diesel Fuel
Sensitivity Analysis

- Save and Calculate
- New we see the tab for “Sensitivity Results”
HOMER Produces An Input Summary Report:

- Click HTML Input Summary from the File menu, or click the toolbar button:
- HOMER will create an HTML-format report summarizing all the relevant inputs, and display it in a browser. From the browser, you can save or print the report, or copy it to the clipboard so that you can paste it into a word processor or spreadsheet program.
Input summary Report - Example

HOMER Input Summary
File name: Practice2 hmr
File version: 2.68 beta
Author: Charles

AC Load: Primary Load 1
Data source: Synthetic
Daily noise: 15%
Hourly noise: 20%
Scaled annual average: 43.4 kWh/d
Scaled peak load: 4.38 kW
Load factor: 0.414

PV
<table>
<thead>
<tr>
<th>Size (kW)</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M ($/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>7,000</td>
<td>7,000</td>
<td>0</td>
</tr>
</tbody>
</table>

Sizes to consider: 0, 2, 4, 6 kW
Lifetime: 20 yr
Derating factor: 80%
Tracking system: No Tracking
Slope: 0 deg
Azimuth: 0 deg
Ground reflectance: 20%

Wind Resource (Synthesized Data)

Load Profile (Synthesized Data)

Weibull k: 2.00
Autocorrelation factor: 0.850
Diurnal pattern strength: 0.250
Hour of peak wind speed: 15
Scaled annual average: 3.04 m/s
Anemometer height: 10 m
Altitude: 0 m
Wind shear profile: Logarithmic
Surface roughness length: 0.01 m
HOMER – Simulation Result System Report

HOMER Produces A Report Summarizing The Simulation Results

Just click the HTML Report button in the Simulation Results window:
Example System Report

System Report - Practice2.hmr

Sensitivity case
Diesel Price: 2.4 $/L

System architecture
PV Array 2 kW
Generator 1.5 kW
Inverter 1 kW
Rectifier 1 kW

Cost summary
Total net present cost $254,738
Levelized cost of energy $1.258/kWh
Operating cost $19,098/yr

Net Present Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M ($)</th>
<th>Fuel ($)</th>
<th>Salvage ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>7,000</td>
<td>2,183</td>
<td>0</td>
<td>0</td>
<td>-1,223</td>
<td>7,969</td>
</tr>
<tr>
<td>Generator 1</td>
<td>2,000</td>
<td>14,940</td>
<td>2,298</td>
<td>225,506</td>
<td>-191</td>
<td>243,893</td>
</tr>
<tr>
<td>Converter</td>
<td>1,600</td>
<td>668</td>
<td>0</td>
<td>0</td>
<td>-124</td>
<td>2,143</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>742</td>
<td>0</td>
<td>0</td>
<td>742</td>
</tr>
<tr>
<td>System</td>
<td>10,600</td>
<td>17,191</td>
<td>2,900</td>
<td>225,506</td>
<td>-1,539</td>
<td>254,736</td>
</tr>
</tbody>
</table>

Electrical

<table>
<thead>
<tr>
<th>Component</th>
<th>Production</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV array</td>
<td>2,341</td>
<td>13%</td>
</tr>
<tr>
<td>Generator 1</td>
<td>15,396</td>
<td>87%</td>
</tr>
<tr>
<td>Total</td>
<td>17,737</td>
<td>100%</td>
</tr>
</tbody>
</table>
System Report

**Emissions**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>19,356</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>47.8</td>
</tr>
<tr>
<td>Unburned hydrocarbons</td>
<td>5.29</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>3.6</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>38.9</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>426</td>
</tr>
</tbody>
</table>
HOMER displays a message suggesting that we add more generator quantities to the sizes to consider.
Those messages mean that:

- you need to expand your search space to be sure you have found the cheapest system configuration.
- If the total net present cost varied with the PV size in this way, and you simulated 10, 20, 30, and 40 kW sizes, HOMER would notice that the optimal number of turbines is 40 kW, but since that was as far as you let it look, it would give you the "search space may be insufficient" warning because 50 kW may be better yet.
- It doesn't know that until you let it try 50kW and 60kW.
- If you expanded the search space, HOMER would no longer give you that warning, since the price started to go up so you have probably identified the true least-cost point.
Report Submission for Lab 9

- Using the Homer Tutorial Part 1
- Follow every step from slide page 21
  - With your own location → Resources are determined
  - With your own loading condition

- Write your report describing
  - Location,
  - Load,
  - Solar Resources
  - Wind Resources
  - Optimum result (the Price of energy. $/kWh)?
  - Comment and Opinion
  - Appendix 1: Input report from HOMER
  - Appendix 2: Output Report from HOMER
HOMER models 10 types of part that generates, delivers, converts, or stores energy

- 3 intermittent renewable resources:
  - PV modules (dc)
  - wind turbines (dc or ac)
  - run-of-river hydro turbines (dc or ac)

- 3 dispatchable energy sources: [control them as needed]
  - Generators
  - the grid
  - boilers

- 2 energy converters:
  - Converters (dc ↔ ac)
  - Electrolyzers (ac,dc → electrolysis → Hydrogen)

- 2 types of energy storage:
  - batteries (dc)
  - hydrogen storage tanks
Physical Modeling - load

Load: a demand for electric or thermal energy

3 types of loads

- **Primary load**: electric demand that must be served according to a particular schedule
  - When a customer switches on, the system must supply electricity
  - kW for each hour of the load
  - Lights, radio, TV, appliances, computers,

- **Deferrable load**: electric demand that can be served at any time within a certain time span
  - Tank – drain concept
  - Water pumps, ice makers, battery-charging station

- **Thermal load**: demand for heat
  - Supply from boiler or waste heat recovered from a generator
  - Resistive heating using excess electricity
Physical Modeling - Resources

- **Solar Resources**: average global solar radiation on horizontal surface (kWh/m² or kWh/m²-day) or monthly average clearness index (atmosphere vs. earth surface). **Inputs** – solar radiation values and the latitude and the longitude. **Output** – 8760 hour data set

- **Wind Resources**: Hourly or 12 monthly average wind speeds. Anemometer height. Wind turbine hub height. Elevation of the site.

- **Hydro Resources**: Run-of-river hydro turbine. Hourly (or monthly average) stream flow data.

- **Biomass Resources**: wood waste, agricultural residue, animal waste, energy crops. Liquid or gaseous fuel.

- **Fuel**: density, lower heating value, carbon content, sulfur content. Price and consumption limits
Components - PV, Wind, and Hydro

- **PV Array**
  - $P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$
  - $f_{PV}$: PV de-rating factor
  - $Y_{PV}$: Rated Capacity [kW]
  - $I_T$: Global Solar Radiation incidence on the surface of the PV array [kW/m²]
  - $I_S$: Standard amount of radiation, 1 kW/m².

- **Wind Turbine**
  - Wind turbine power curve

- **Hydro Turbine**
  - Power Output Eqn = Turbine efficiency, density of water, gravitational acceleration, net head, flow rate through the turbine

  $$P_{hyd} = \eta_{hyd} \rho_{water} gh_{net} \dot{Q}_{turbine}$$
Components - Generator

Generators

- Principal properties: max and min electrical power output, expected lifetime, type of fuel, fuel curve

- **Fuel curve**: quantity of fuel consumed to produce certain amount of electrical power. Straight line is assumed.

- Fuel Consumption ($F$) [L/h], [m$^3$/h], or [kg/h]:
  - $F_o$ - fuel curve intercept coefficient [L/h-kW];
  - $F_1$ - fuel curve slope [L/h-kW];
  - $Y_{gen}$ - rated capacity [kW];
  - $P_{gen}$ - electrical output [kW]

\[
F = F_o Y_{gen} + F_1 P_{gen}
\]
Components - Generator

- Generator costs: initial capital cost, replacement cost, and annual O&M cost per operating hour (not including fuel cost)
- **Fixed cost:** cost per hour of simply running the generator without producing any electricity

\[ c_{\text{gen,fixed}} = c_{\text{om,gen}} + \frac{C_{\text{rep,gen}}}{R_{\text{gen}}} + F_0 Y_{\text{gen}} c_{\text{fuel,eff}} \]

- \( c_{\text{om,gen}} \) is the O&M cost per hour,
- \( C_{\text{rep,gen}} \) the replacement cost
- \( R_{\text{gen}} \) the generator lifetime in hours.
- \( F_0 \) the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt.
- \( Y_{\text{gen}} \) the capacity of the generator (kW).
- \( c_{\text{fuel,eff}} \) the effective price of fuel in dollars per quantity of fuel.

- **Marginal cost:** additional cost per kWh of producing electricity from the generator

\[ c_{\text{gen,mar}} = F_1 c_{\text{fuel,eff}} \]

- \( F_1 \) is the fuel curve slope in quantity of fuel per hour per kilowatthour.
Components – Battery Bank

Battery Bank

- Principal properties:
  - nominal voltage
  - capacity curve: discharge capacity in AH vs. discharge current in A
  - lifetime curve: number of discharge-charge cycles vs. cycle depth
  - minimum state of charge: State of charge below which must not be discharged to avoid permanent damage
  - round-trip efficiency: percentage of energy going in to that can be drawn back out

- Example capacity curve for a deep-cycle US-250 battery (Left)
Components - Grid

- **Grid and Grid Power Cost**
  - Grid power price [$/kWh]: charges for energy purchase from grid
  - Demand rate [$/kW/month]: peak grid demand
  - Sellback rate [$/kWh]: price the utility pays for the power sold to grid

- **Net Metering**: a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period.
  - Purchase > sales: consumer pays the utility an amount equal to the net grid purchases times the grid power cost.
  - sales > purchases: the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is typically less than the grid power price, and often zero.

- **Grid fixed cost**: $0

- **Grid marginal cost**: current grid power price plus any cost resulting from emissions penalties.
Components - Boiler

- **Boiler**
  - Assumed to provide unlimited amount of thermal energy on demand
  - Input: type of fuel, boiler efficiency, emission
  - Fixed cost: $0
  - Marginal cost:

\[
c_{\text{boiler, mar}} = \frac{3.6c_{\text{fuel, eff}}}{\eta_{\text{boiler}}LHV_{\text{fuel}}}
\]

- \(c_{\text{fuel, eff}}\) is the effective price of the fuel (including the cost of any penalties on emissions) in dollars per kilogram
- \(\eta_{\text{boiler}}\) is the boiler efficiency
- \(LHV_{\text{fuel}}\) is the lower heating value of the fuel in MJ/kg
Converter

- Inversion and Rectification
- Size: max amount of power it delivers
- Synchronization ability: parallel run with grid
- Efficiency
- Cost: capital, replacement, o&m, lifetime
Components – Fuel Cell

Electrolyzer:
- Size: max electrical input
- Min load ratio: the minimum power input at which it can operate, expressed as a percentage of its maximum power input.
- Cost: capital, replacement, o&m, lifetime

Hydrogen Tank
- Size: mass of hydrogen it can contain
- Cost: capital, replacement, o&m, lifetime
System Dispatch

- Dispatchable and non-dispatchable power sources
  - Dispatchable source: provides operating capacity in an amount equal to the maximum amount of power it could produce at a moment’s notice.
    - **Generator**
      - In operation: dispatchable opr capacity = rated capacity
      - non-operation: dispatchable opr capacity = 0
    - **Grid**: dispatchable opr capacity = max grid demand
    - **Battery**: dispatchable opr capacity = current max discharge power
  - Non-dispatchable source
    - Operating capacity (PV, Wind, or Hydro) = the amount the source is currently producing (Not the max amount it can produce)

- **NOTE**: If a system is ever unable to supply the required amount of load plus operating reserve, HOMER records the shortfall as “capacity shortage”.
  - HOMER calculates the total amount of such shortages over the year and divides the total annual capacity shortage by the total annual electric load.
Dispatch Strategy for a system with Gen and Battery

**Dispatch Strategy**

- **Whether and how the generator should charge the battery bank?**
- **HOMER** provides 2 simple strategies and lets user model them both to see which is better in any particular situation.
  - **Load-following**: a generator produces only enough power to serve the load, and does not charge the battery bank.
  - **Cycle-Charging**: whenever a generator operates, it runs at its maximum rated capacity and charges the battery bank with the excess.
  - It was found that over a wide range of conditions, the better of these two simple strategies is virtually as cost-effective as the ideal predictive strategy.

- **“Set-point state charge”**: in the cycle-charging strategy, generator charges until the battery reaches the set-point state of charge.
Control of Dispatchable System Components

- Fundamental principle: cost minimization – fixed cost and marginal cost
- Example: Hydro-Diesel-Battery System

- Dispatchable sources: diesel generator [80kW] and battery [40kW]
- If net load is negative: excess power charges battery
- If net load is positive: operate diesel OR discharge battery
Dispatch Control Example

Hydro-Diesel-Battery System

- Net load < 20kW: Discharge the battery
- Net load > 20kW: Operate the diesel generator
Load Priority

- Decisions on allocating electricity
- Presence of ac and dc buses
- Electricity produced on one bus will serve:
  - First, primary load on the same bus
  - Then, primary load on the opposite bus
  - Then, deferrable load on the same bus
  - Then, charge battery bank
  - Then, sells to grid
  - Then, electrolyzer
  - Then, dump load
Economic Modeling

- Conventional sources: low capital and high operating costs
- Renewable sources: high initial capital and low operating costs
- Life-cycle costs = capital + operating costs
- HOMER uses NPC for life-cycle cost
  - NPC is the opposite of NPV (Net present value)
- NPC includes: initial construction, component replacements, maintenance, fuel, cost of buying grid, penalties, and revenues (selling power to grid + salvage value at the end of the project lifetime)

\[ S = C_{\text{rep}} \frac{R_{\text{rem}}}{R_{\text{comp}}} \]

- \( S \) is the salvage value.
- \( C_{\text{rep}} \) the replacement cost of the component
- \( R_{\text{rem}} \) the remaining life
- \( R_{\text{comp}} \) the lifetime of the component.
Real Cost

- All price escalates at the same rate over the lifetime
- Inflation can be factored out of analysis by using the real (inflation-adjusted) interest rate (rather than nominal interest rate) when discounting the future cash flows to the present
- Real interest rate = nominal interest rate – inflation rate
- Real cost \(\rightarrow\) in terms of constant dollars
NPC and COE

- **Total NPC**

\[
C_{\text{NPC}} = \frac{C_{\text{ann,tot}}}{\text{CRF}(i, N)}
\]

- **Levelized Cost of Energy (COE): average cost/kWh**

\[
\text{COE} = \frac{C_{\text{ann,tot}}}{E_{\text{prim}} + E_{\text{def}} + E_{\text{grid,sales}}}
\]