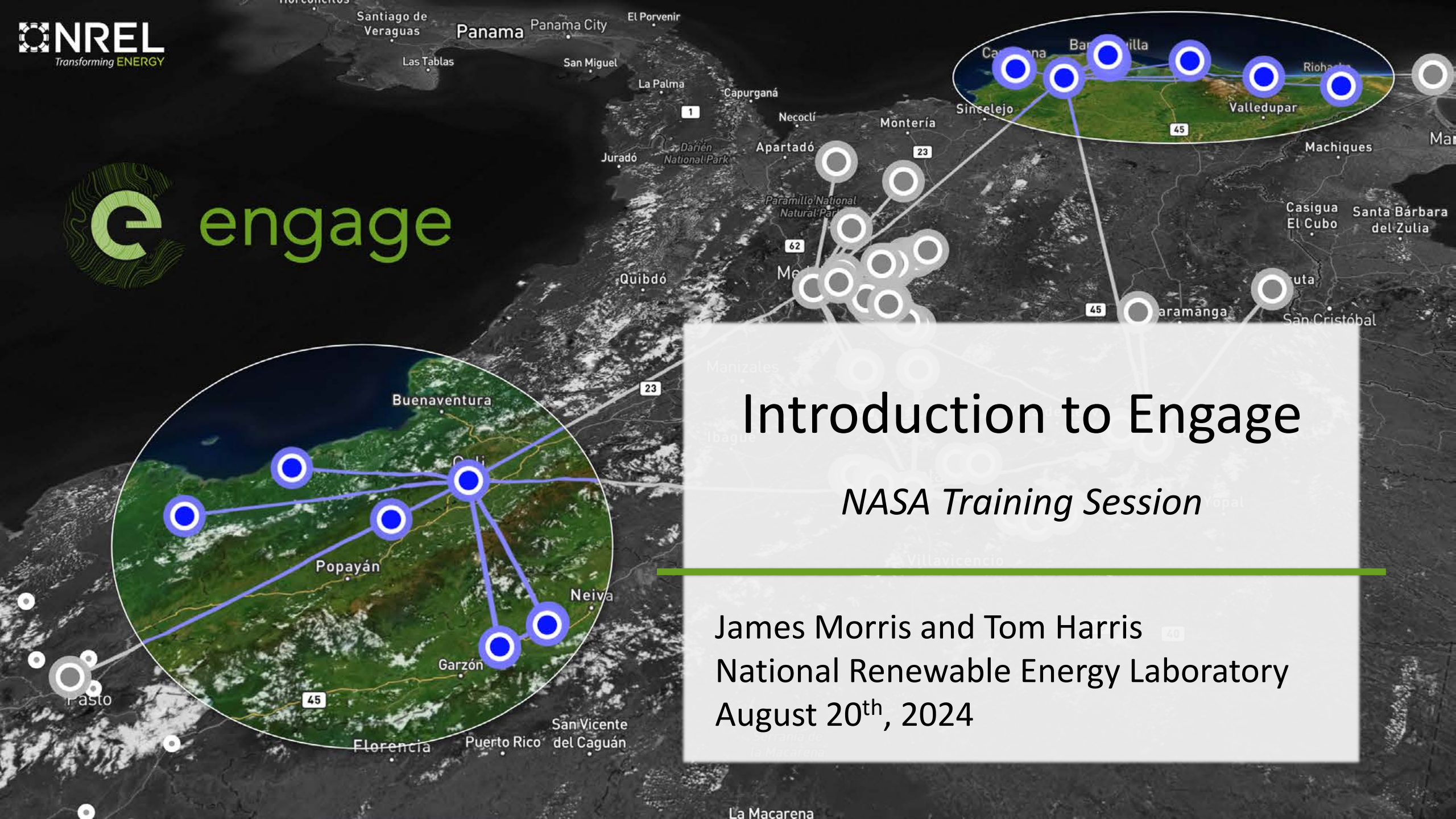

NREL
Transforming ENERGY
engage
Introduction to Engage
NASA Training Session
James Morris and Tom Harris
National Renewable Energy Laboratory
August 20th, 2024

What is Engage?

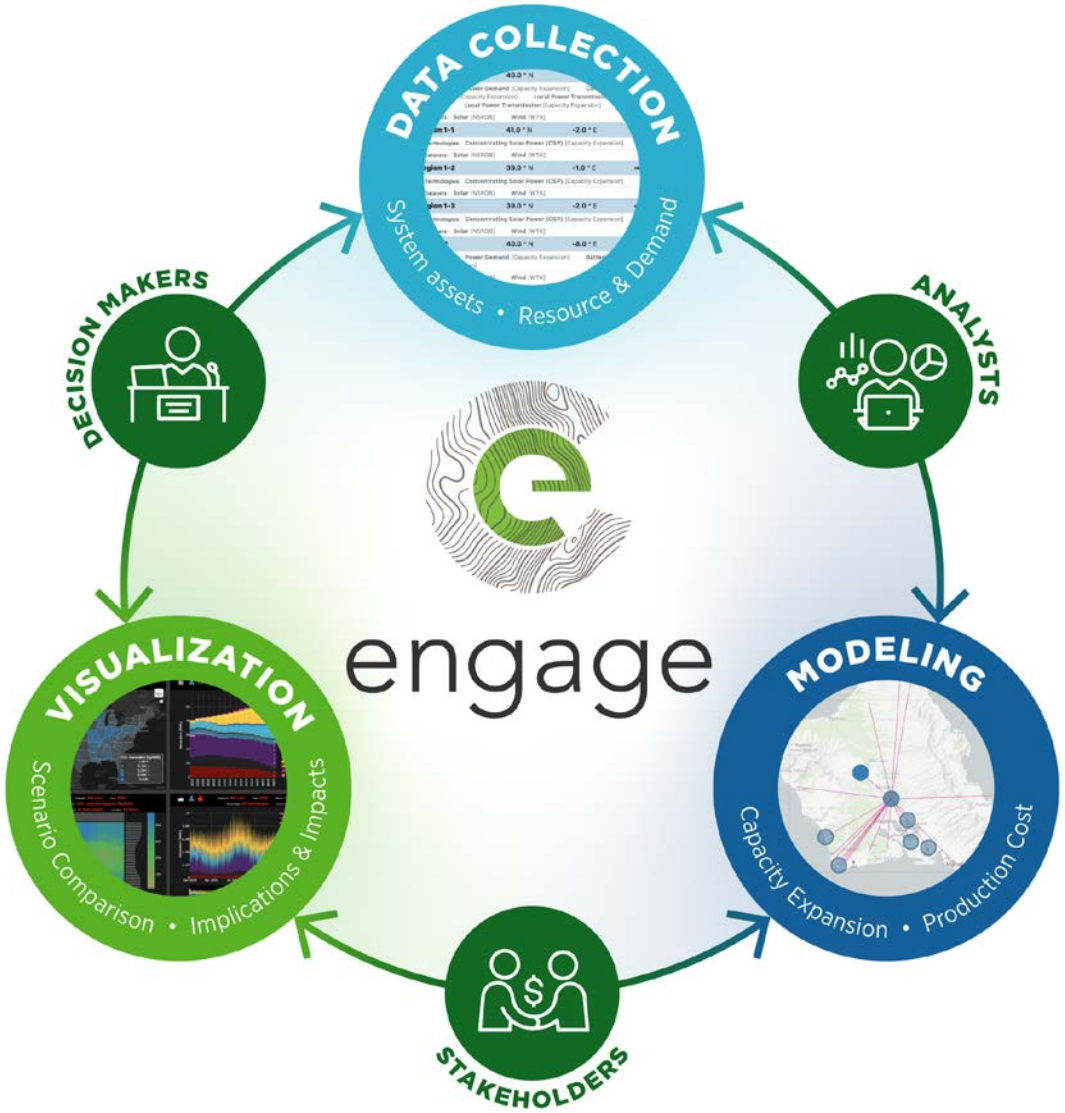
Engage is a **capacity expansion modeling web application**, developed by the National Renewable Energy Laboratory (NREL).

First developed in collaboration with the Hawaii State Energy Office, sponsored by the U.S. Department of Energy's Energy Transitions Initiative.

Engage™ **empowers diverse stakeholders** to participate in **energy ecosystem decisions**, enabling multi-system optimization and simulation via an accessible, collaborative, communicative web application.

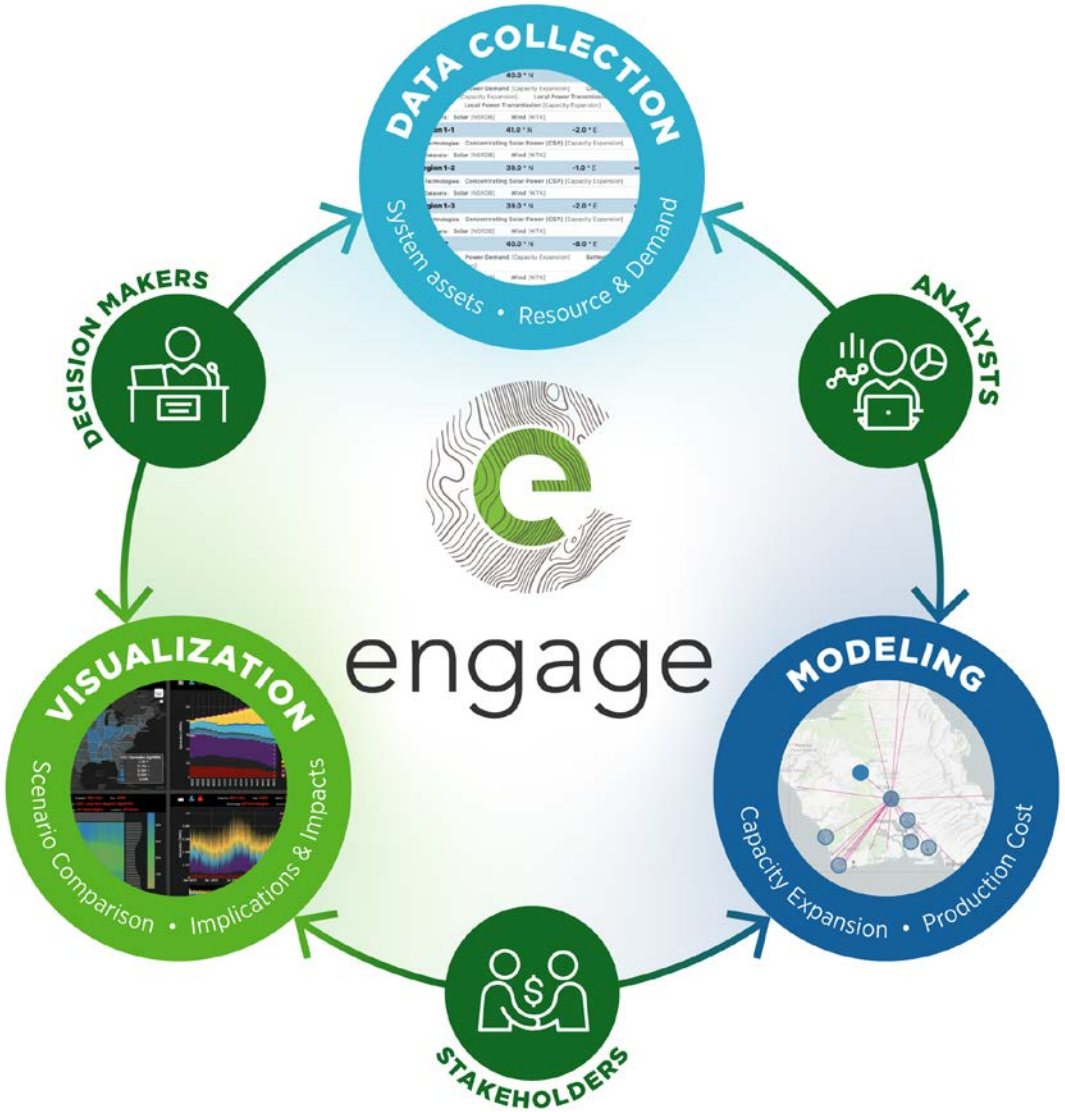
Engage can **co-optimize** electrical, fuel, water, transport and other systems with various technologies at any scale from district energy/microgrid to continental.

Visit Engage at https://engage.nrel.gov.



What questions can Engage answer?

1. What should be our **future generation and transmission** portfolio(s)?
2. What **operational and capital costs/savings** can be anticipated after switching from one portfolio of technologies to another?
3. How does the **cost optimal system vary with constraints** on emissions, land use, or local economic development goals?
4. How significantly will **policy measures in energy efficiency and electrification** impact installed capacity?
5. How can distributed energy resources be **effectively integrated** with bulk power systems?
6. What is the most **cost-competitive pathway** for achieving **net-zero emissions** by 2050?
7. What are the **high-level cost, rate, and welfare implications** of alternative power sector regulations?



The People: Who can benefit from using Engage?

Engage can empower stakeholders to **understand the impacts** of different energy decisions in their community.

Engage can aid decision makers in need of **capable and transparent analysis tools** to effectively navigate energy developments.

Engage can assist analysts from government, academia, and NGOs to **innovate and challenge the status quo** of traditional energy systems and policies.

The People: What is their role in the modeling process?

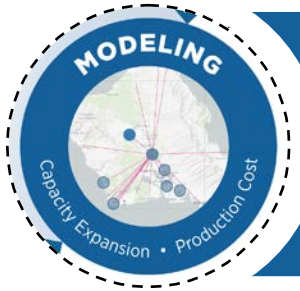
Stakeholders **contribute perspective** to the Engage model on any community-specific inputs and **voice community needs and objectives** during scenario development.

Decision makers **bring together representatives** from government, industry, and communities to **collaborate** on models and **communicate** model implications.

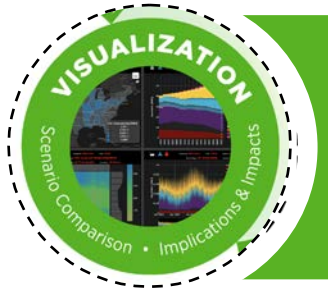
Analysts support stakeholders and decision markers in **model training and capacity building**, executing heavy-lift tasks like data preparation.

The Process: How do I use Engage?

First, collect **performance and cost data** on existing and/or future generation and transmission assets in addition to timeseries data on **available resources** and **demand**.



Second, develop capacity expansion models that **optimize investment and retirement decisions** on assets by minimizing total system costs.



Finally, visualize scenarios and **compare their costs and asset buildouts** across planning years to understand energy system implications.

And reiterate as needed!

Capacity Planning Modeling Data Flow

Least-cost system modeling that meets forecasted load, respecting all constraints.

Modeling inputs

Modeling outputs

Existing System Representation
The baseline system

Future System Technology Options
Technologies the model can build to meet projected demand

Technologies
Generators: thermal generators, renewable energy, fuel production
Transmission: electric lines, fuel pipelines & transport, water lines and flows
Storage: fuel storage, batteries, pumped storage, water storage

Technology Attributes
Efficiencies, renewable resource potential, available land, emissions and pollution profiles, and costs

Additional Requirements/Limits
- Spatial/land-use limitations
- Renewable portfolio requirements
- Other emissions/externalities limits
- Resilience requirements

engage

Generation and Transmission Capacity Planning via Economic Optimization

Demand and End-use Projections / Value Streams
- Electricity demand & value
- Heating demand & value
- Cooling demand & value
- Fuel demand & value
- Water demand/uses & value
- Other demands & values

Cost-optimized techs
Generation, transmission, and storage capacities

Resulting costs
- Investment (capital) costs
- Fixed and variable operating costs
- Levelized cost of energy (LCOE) for each carrier in the system

Other
- Production, consumption, storage, and export profiles
- Land use and locations of technologies
- Resources used, emissions, pollution, etc.

Big Picture: Key Design Themes

Accessibility

Flexibility

Communication

Collaboration

Accessibility

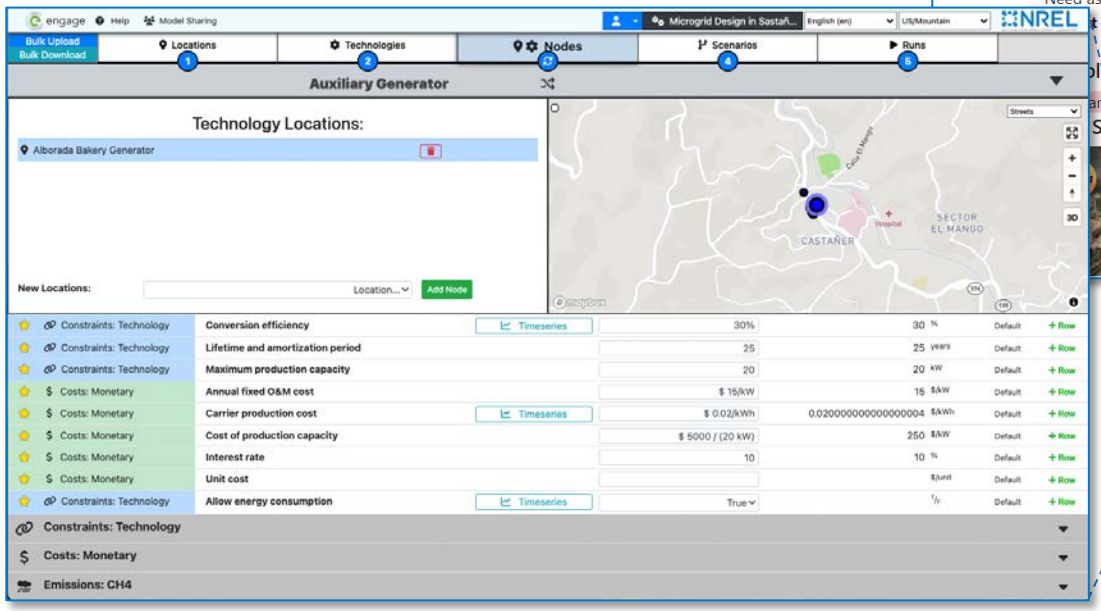
Register your account today!

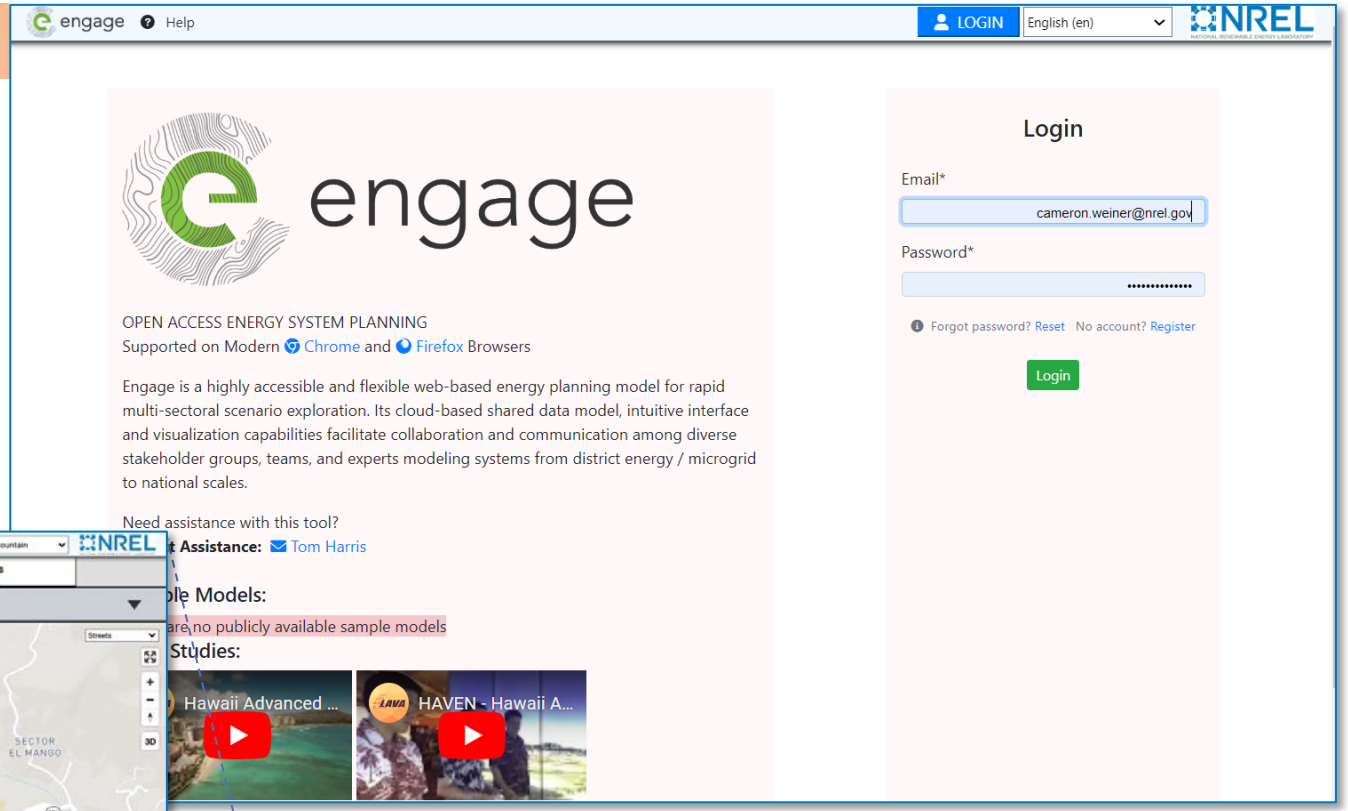
Free

All users have to do to access Engage is register an account; there are no fees to run models

Cloud-based

Web-based application so that users do not have to download or locally install software to use Engage





User-friendly

No deep knowledge of programming or computer science required to use Engage; Engage interface designed so that there is minimal to zero coding involved to build and run a model

Flexibility

Engage models are adaptable to real-world…

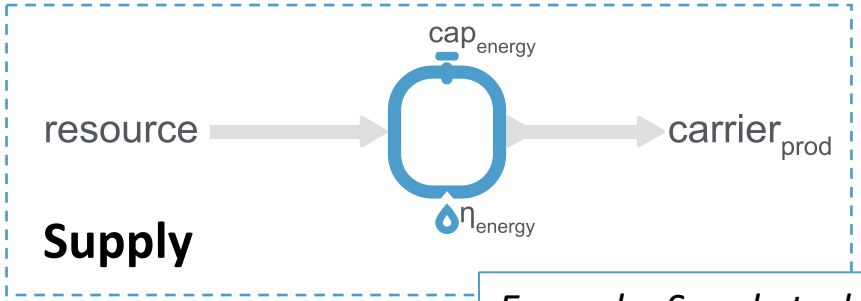
engage

Technologies

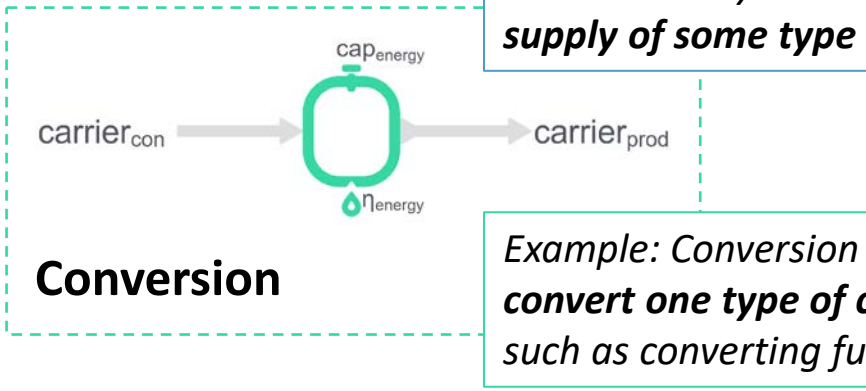
Conditions

Timelines

…through the use of Engage building blocks.



*Example: Supply technologies introduce carriers to a system and represent the **supply of some type of resource***



*Example: Conversion technologies **convert one type of carrier to another**, such as converting fuel to electricity*

Engage has two building blocks:

☑ Archetypes

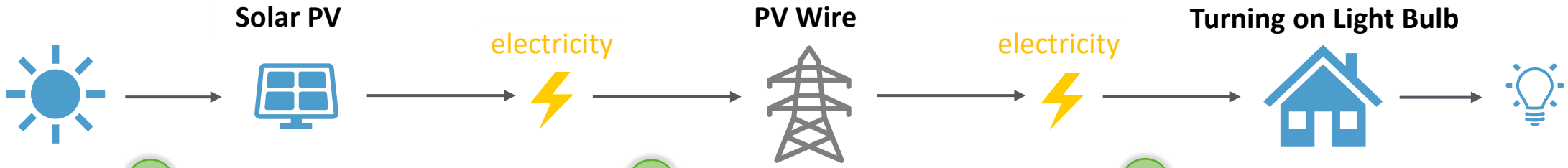
General-purpose archetype **technology representations** of system relationships that can be altered by users to model most type of technologies and systems (electrical, fuel, water systems, etc)

☑ Carriers

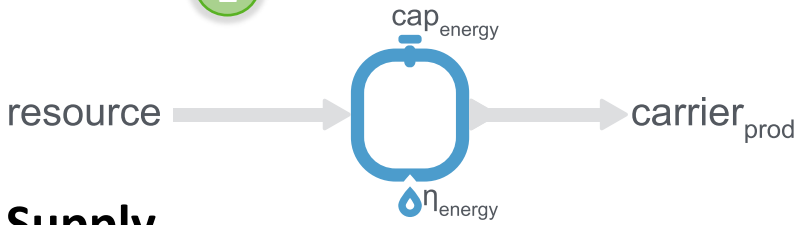
Carriers represent **energy or commodities** that move through Engage, defined according to what the user is interested in measuring (power, water, diesel, hydrogen, etc.)

Flexibility

*Customize and link the **five technology archetypes in Engage** to represent real-world technologies for generation, transmission, and storage assets in an energy system*



1



Supply

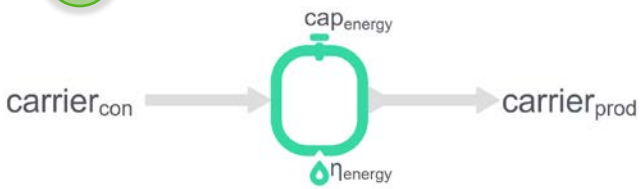
2

Transmission

3

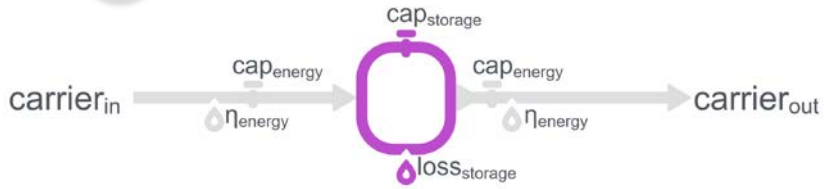
Demand

4



Conversion

5



Storage

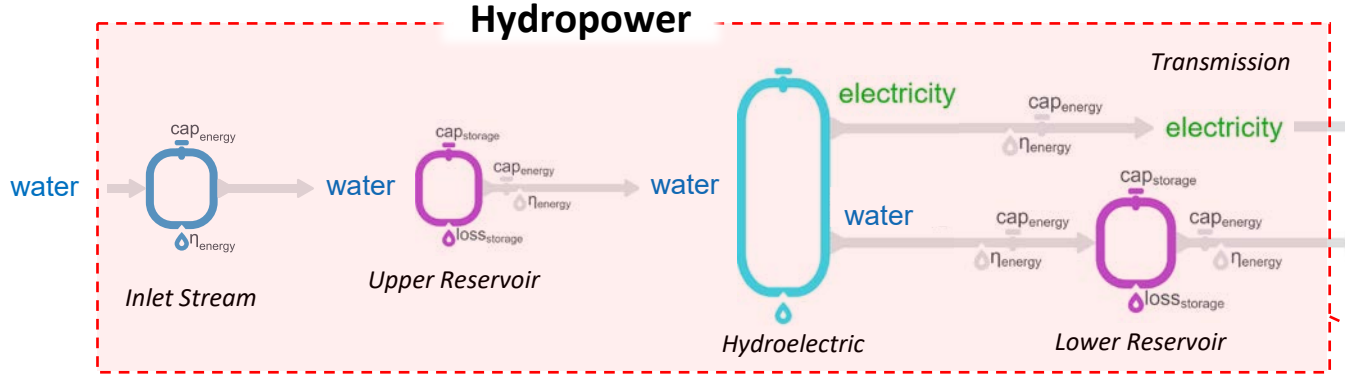
https://www.callio.pe/

Engage relies on the open-source modeling framework **Calliope** to develop base models and execute runs.

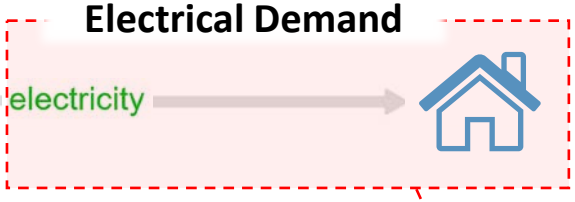
Flexibility

Build complex technologies and assign them real-world geographic locations to indicate nodal relationships in the mathematical model

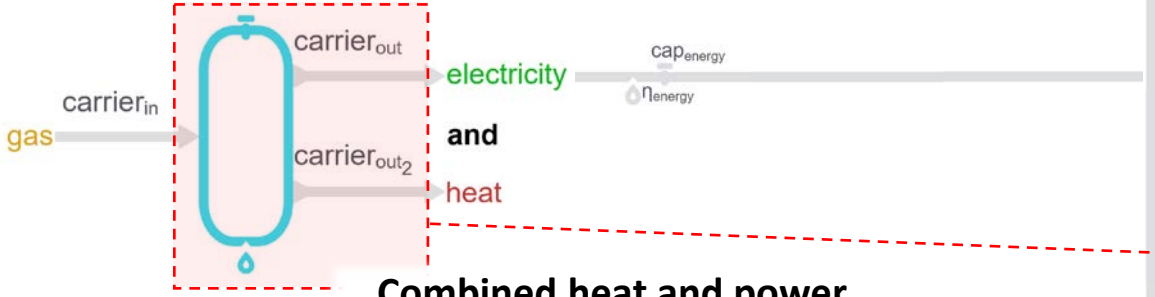
Hydropower



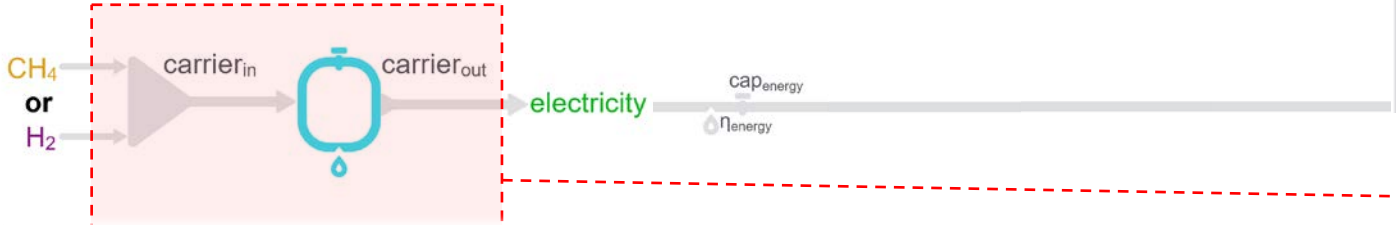
Electrical Demand



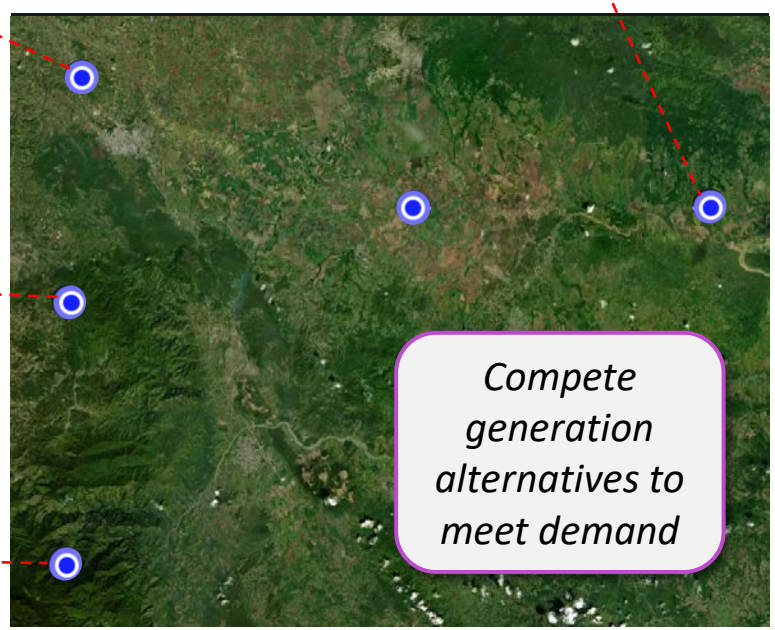
Create carriers to represent real-world commodities



Combined heat and power

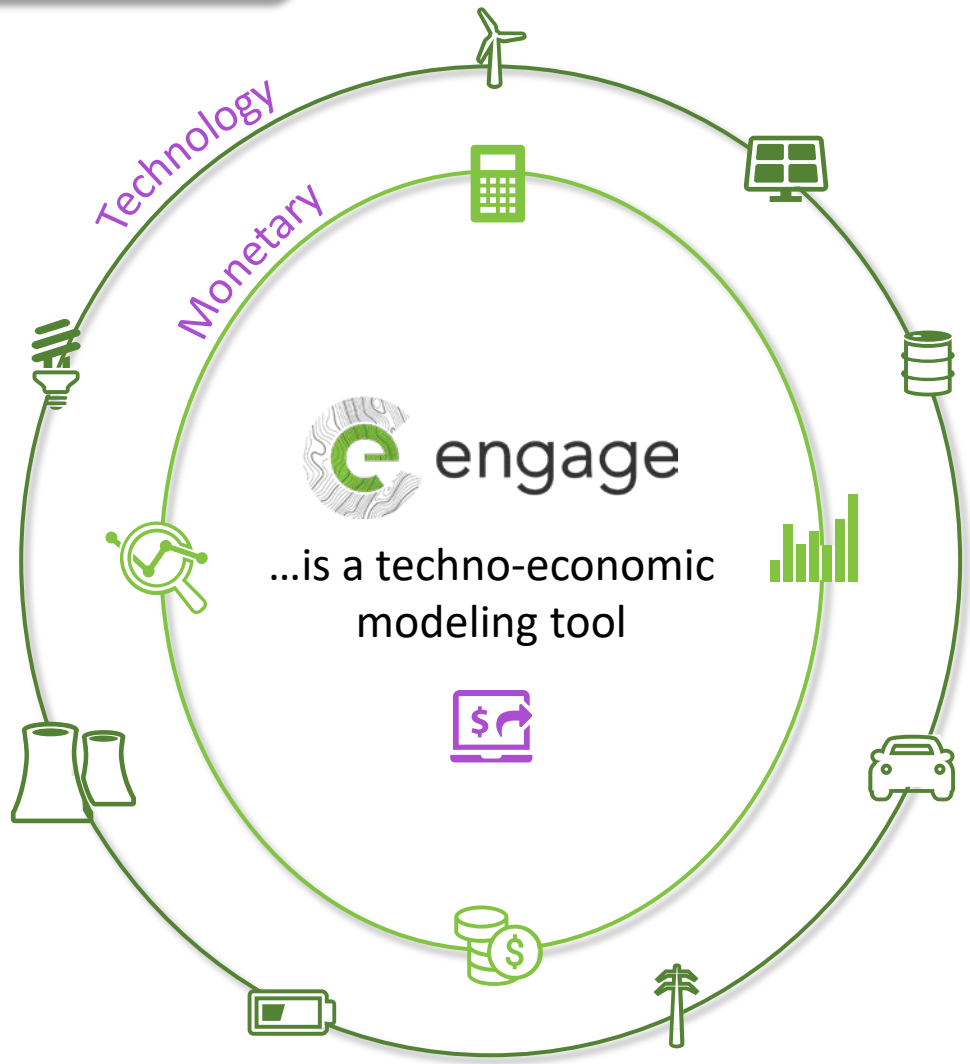


Advanced gas turbine



Compete generation alternatives to meet demand

Flexibility

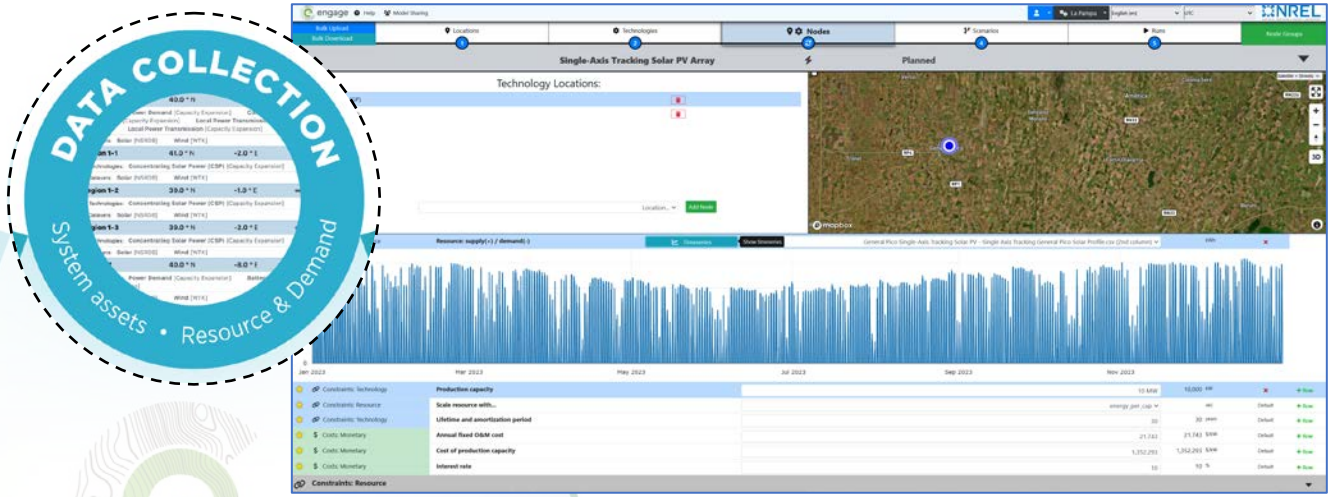


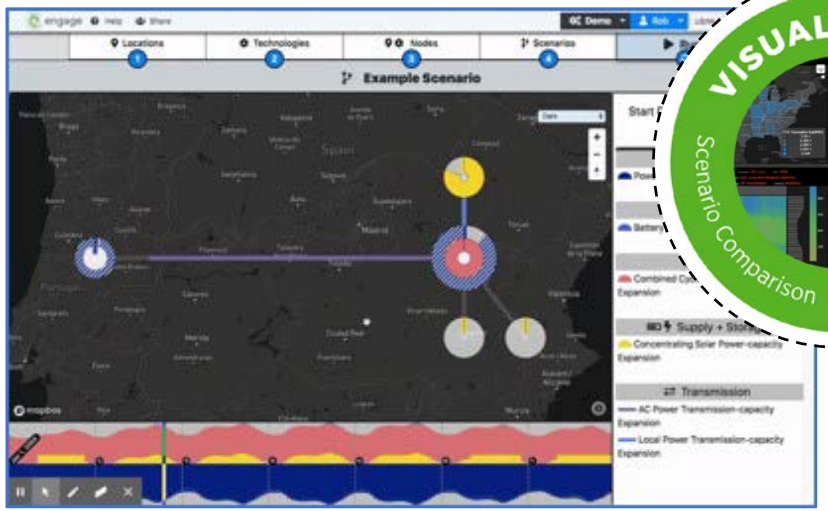
What Engage Can Do	What Engage Cannot Do
☑ Capacity expansion	☒ Complex production cost modeling
☑ Arbitrary technologies	☒ A/C or D/C Power Flow (ex: voltage and frequency regulation)
☑ Arbitrary carriers	☒ System dynamics modeling
☑ Resilience*	

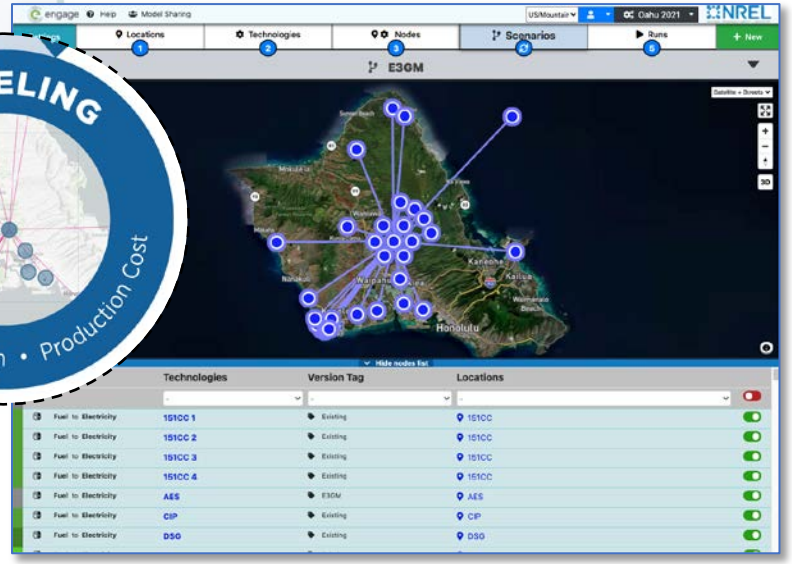
** Limited applications*

Communication

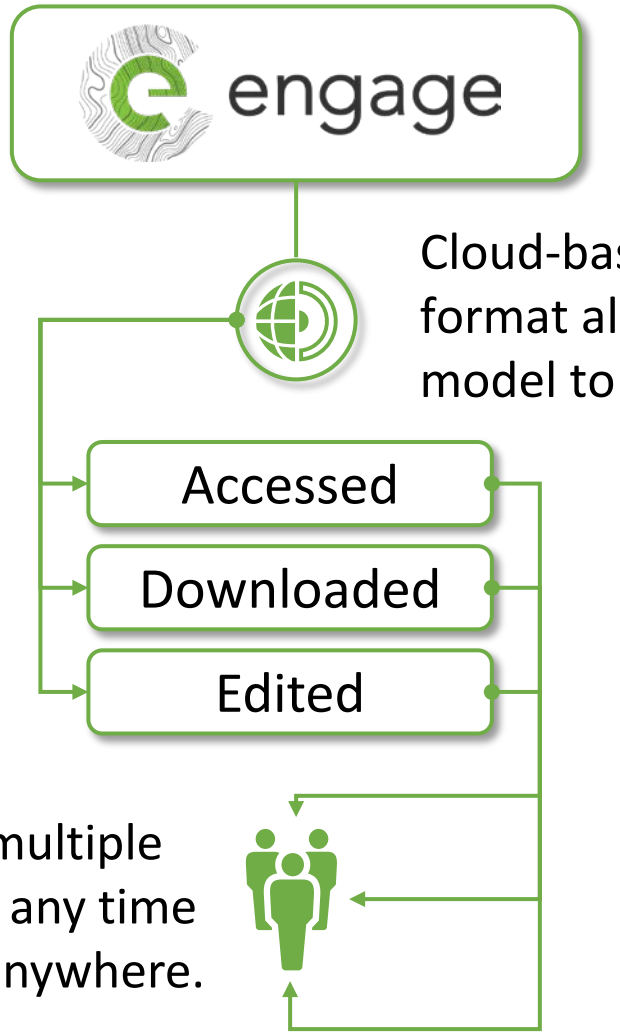
Engage comes with a variety of **visualization capabilities** to enhance user understanding throughout the modeling process and **communicate model impacts and implications**.







Collaboration

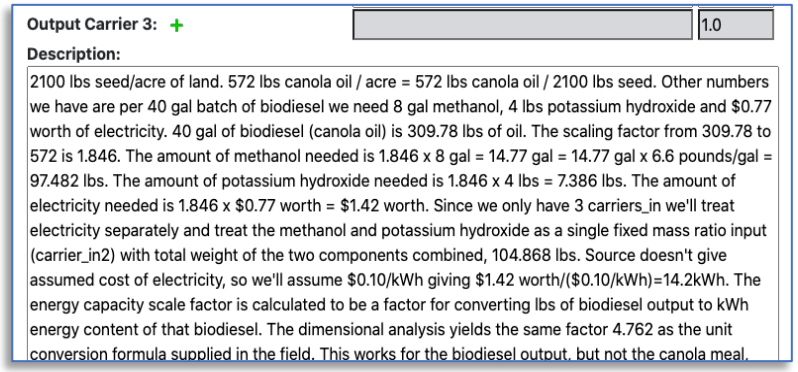


Cloud-based format allows a model to be…

…by multiple users any time and anywhere.

Description Boxes

Engage has text boxes throughout the model where users can **document their work** for each step of the modeling process

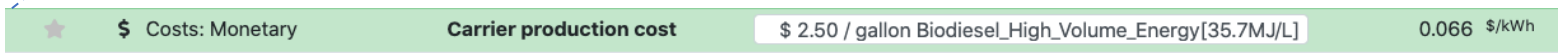


Activity Page

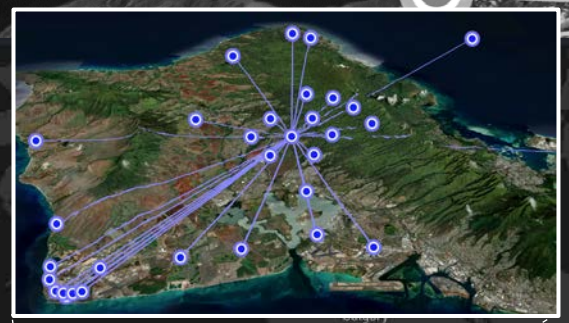
Engage has an Activity page to **update other users** on edits and changes

Unit Conversions

Engage enables unit conversions in parameter fields to **streamline calculations and record assumptions**



Places of engagement



NASA/FAA

NREL

Hawaii

Haiti

Puerto Rico

Calliope

Colombia

Indonesia

Argentina

Read Engage case studies at:

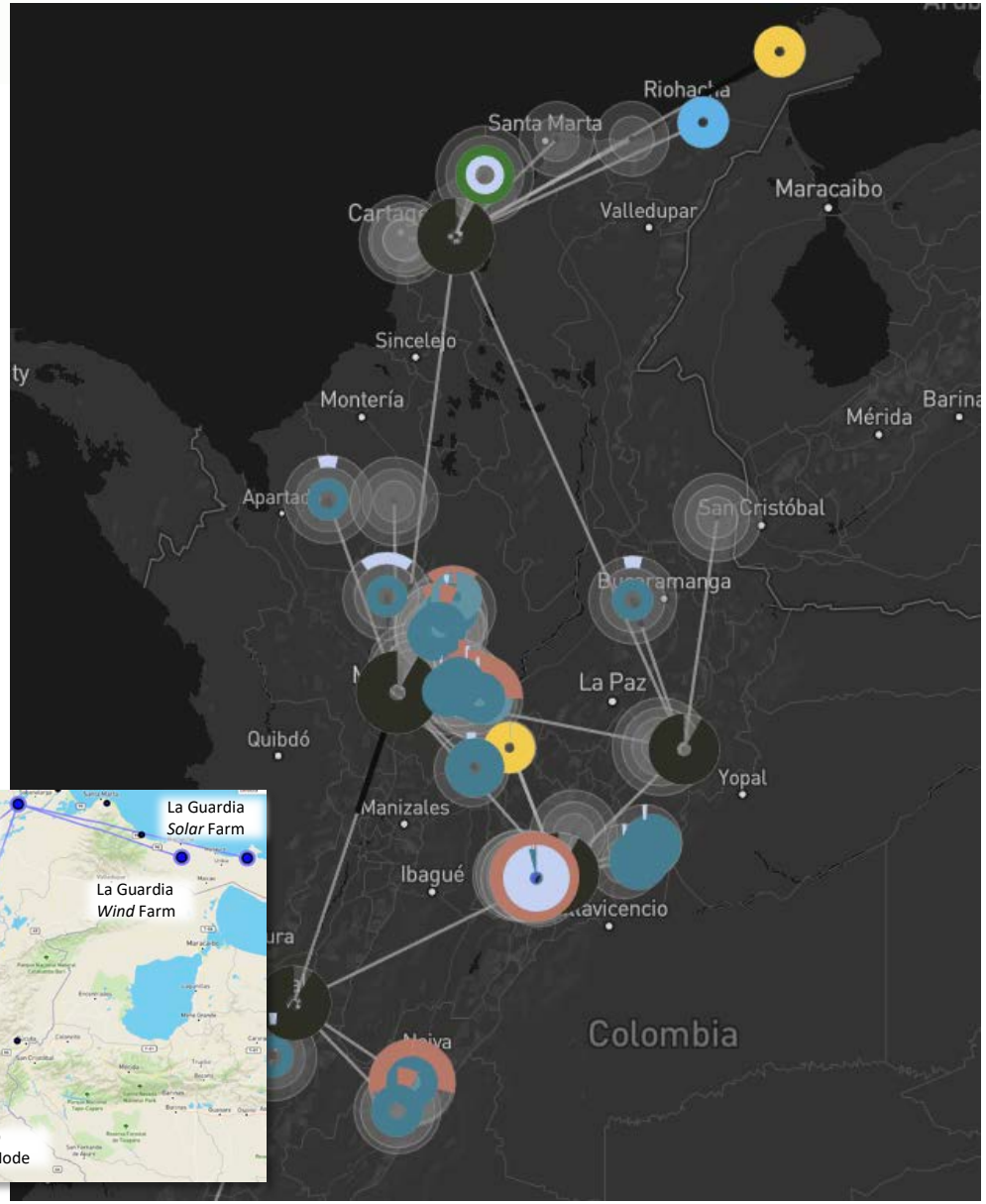
https://www.nrel.gov/research/publications.html

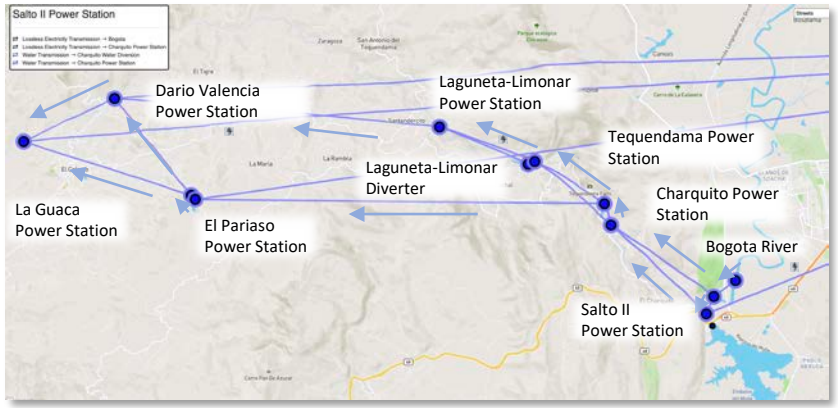
engage NREL Transforming ENERGY

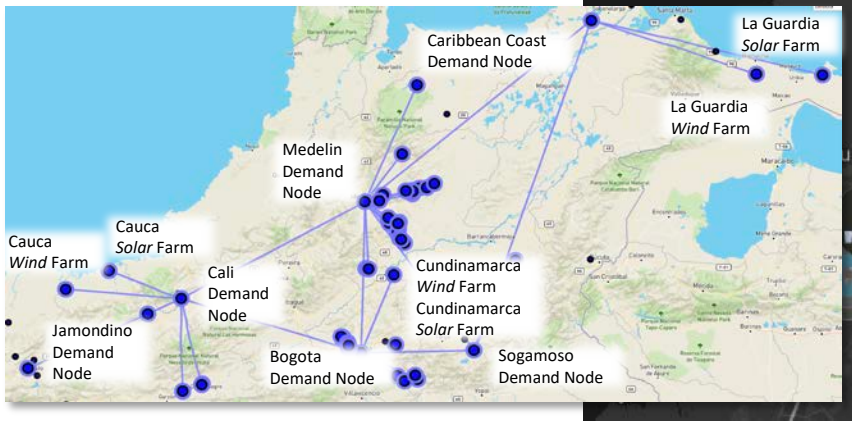
Case Study: Colombia Hydroelectric Model

Model incorporated:

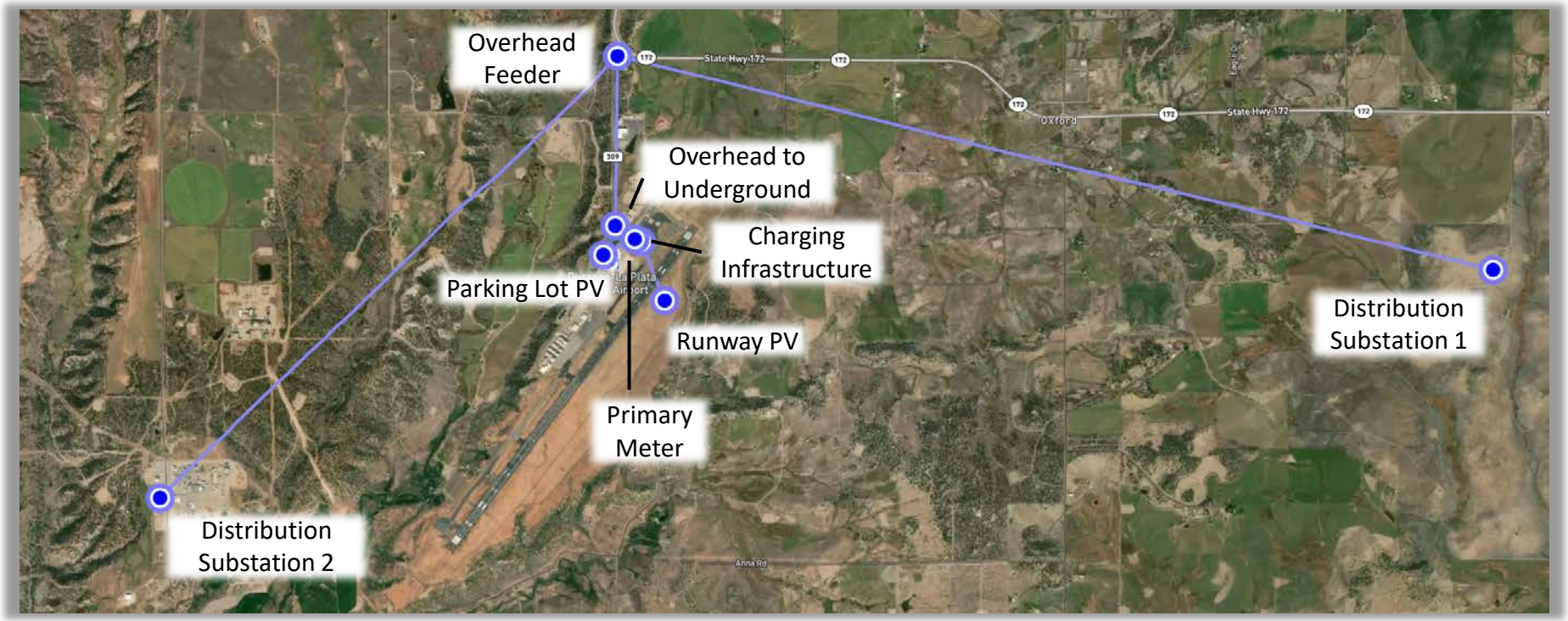
- Water flows and hydroelectric generation
- Coal generation
- Natural gas generation, and
- Capacity expansion of:
  - Wind generation (ERA5 data)
  - Solar PV generation (NSRDB data)
  - High voltage electric transmission







Case Study: Airport Models



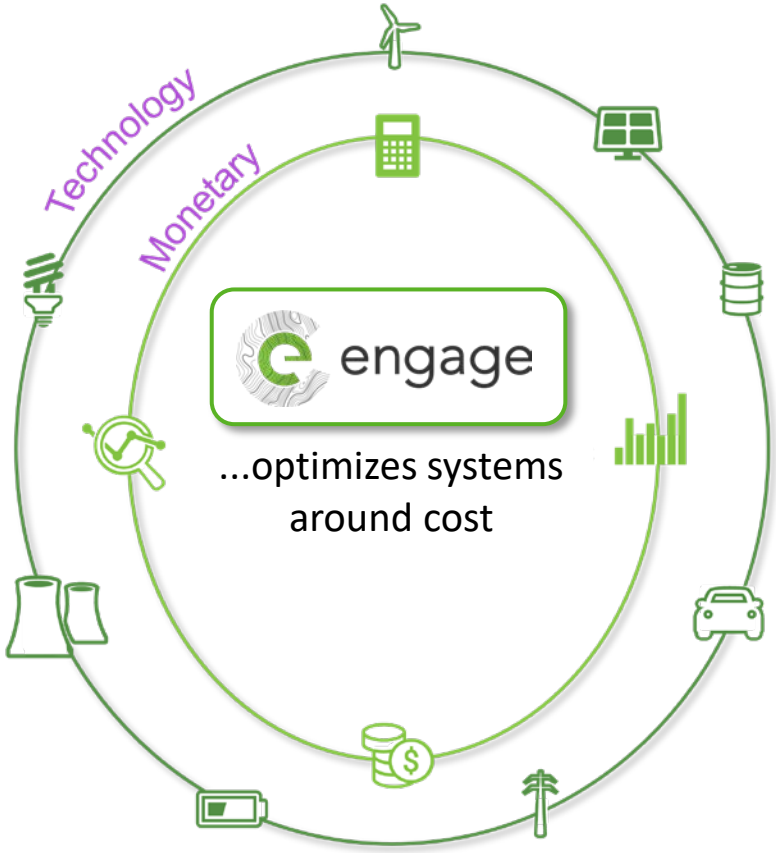
Models incorporate:

- EV charging loads for electrified aircraft
- Existing and proposed utility rates
- Optimizes for the lowest cost to the airports

- **Capacity expansion of:**
  - On-site PV and battery buildout
  - Charging infrastructure
  - Distribution system upgrades
  - On-site electrical infrastructure (cables, transformers, ect.)

Capacity Expansion Modeling

Models that simulate **investment into new generation and transmission capacity**, given assumptions about…



- Future electricity demand
- Fuel Prices
- Technology cost and performance
- Policy and regulation*

** Definition borrowed from Department of Energy presentation by Erin Boyd at https://www.energy.gov/sites/prod/files/2016/02/f30/EPSA_Power_Sector_Modeling_FINAL_021816_0.pdf*

Capacity Expansion Modeling

Models that simulate **investment into new generation and transmission capacity**, given assumptions about…

1. What **operational and energy cost savings** could be anticipated by transitioning from a decentralized energy portfolio to a centralized one?
2. How does the **cost optimal system vary with constraints** on emissions, land use, and economic development goals?
3. What are the **high-level cost impacts** of alternative power sector policies?

Questions for Capacity Expansion

- Future electricity demand
- Fuel Prices
- Technology cost and performance
- Policy and regulation*

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Capacity Expansion Modeling

Models that simulate **investment into new generation and transmission capacity**, given assumptions about…

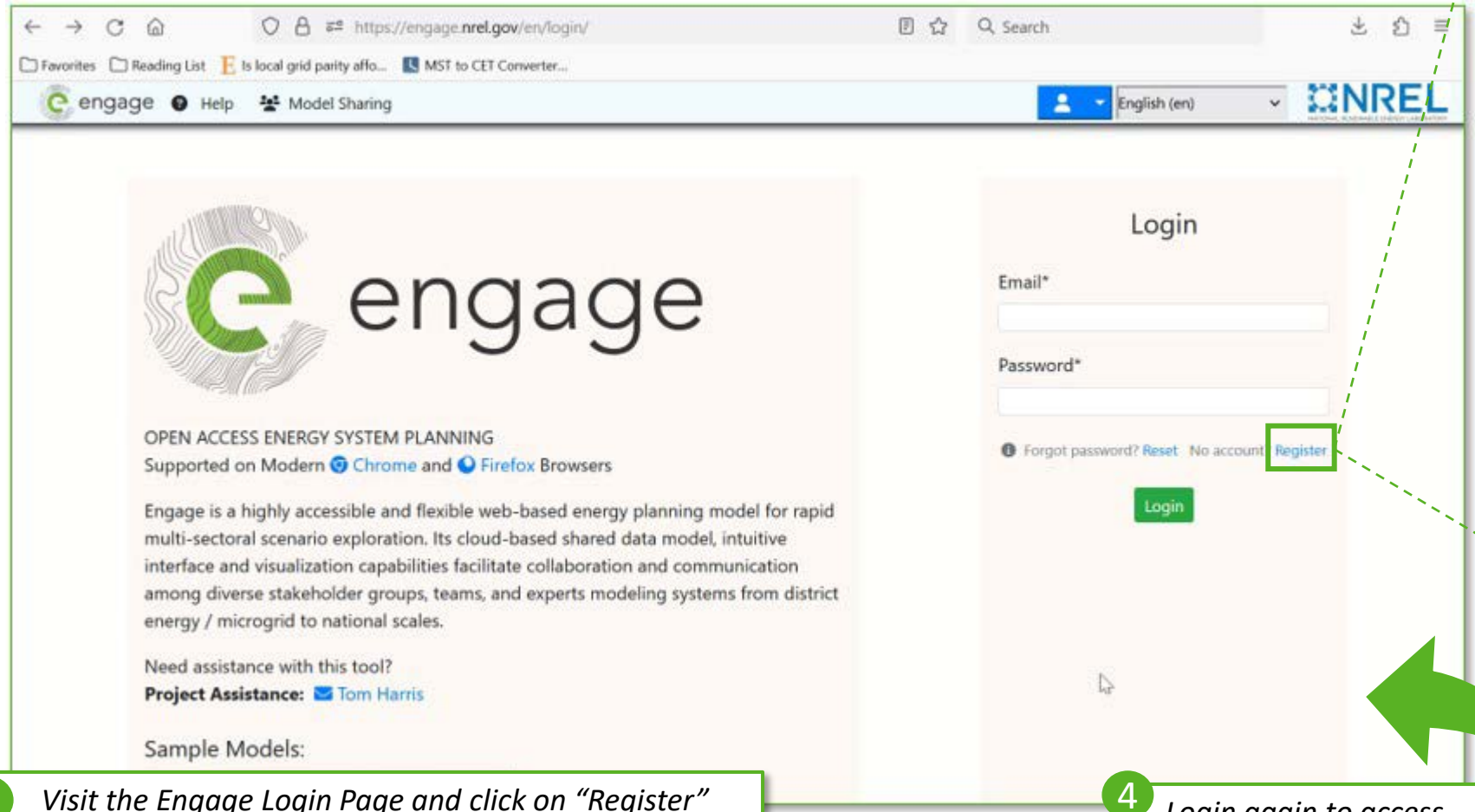
- Future electricity demand
- Fuel Prices
- Technology cost and performance
- Policy and regulation*

- Capacity expansion models are not **operational models**
  - Engage has **perfect foresight** when optimizing an energy portfolio
  - **Example:** Keeping batteries charged when it is sunny to meet demand when it will be cloudy in place of solar
  - **Implication:** Engage may build and dispatch technologies in ways that are operationally unrealistic

Capacity Expansion Limitations

** Definition borrowed from Department of Energy presentation by Erin Boyd at https://www.energy.gov/sites/prod/files/2016/02/f30/EPSA_Power_Sector_Modeling_FINAL_021816_0.pdf*

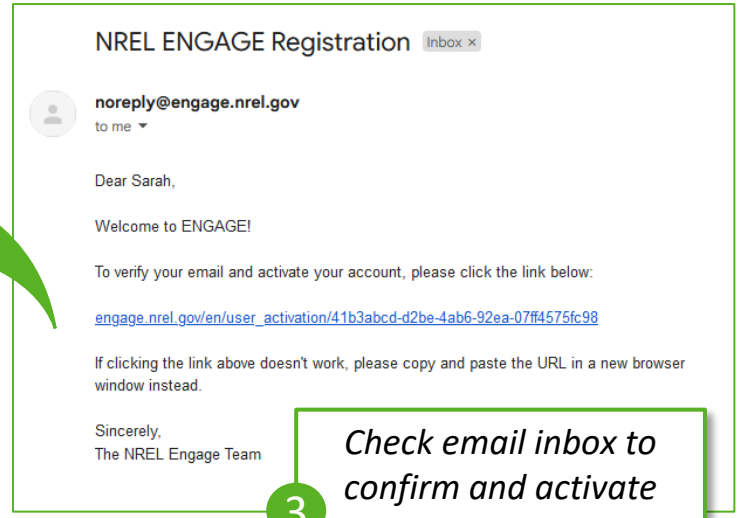
Exercise #1: Create an Engage Account



1 *Visit the Engage Login Page and click on "Register"*

engage.nrel.gov

2 *Fill out your information and click "Submit Registration"*



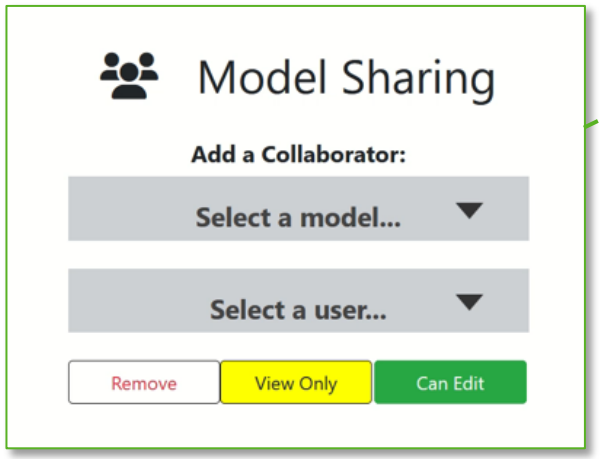
3 *Check email inbox to confirm and activate account*

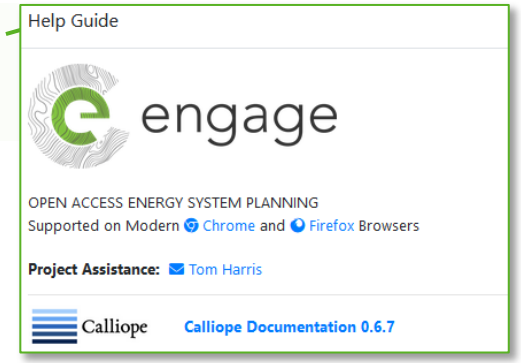
4 *Login again to access the Models Page*

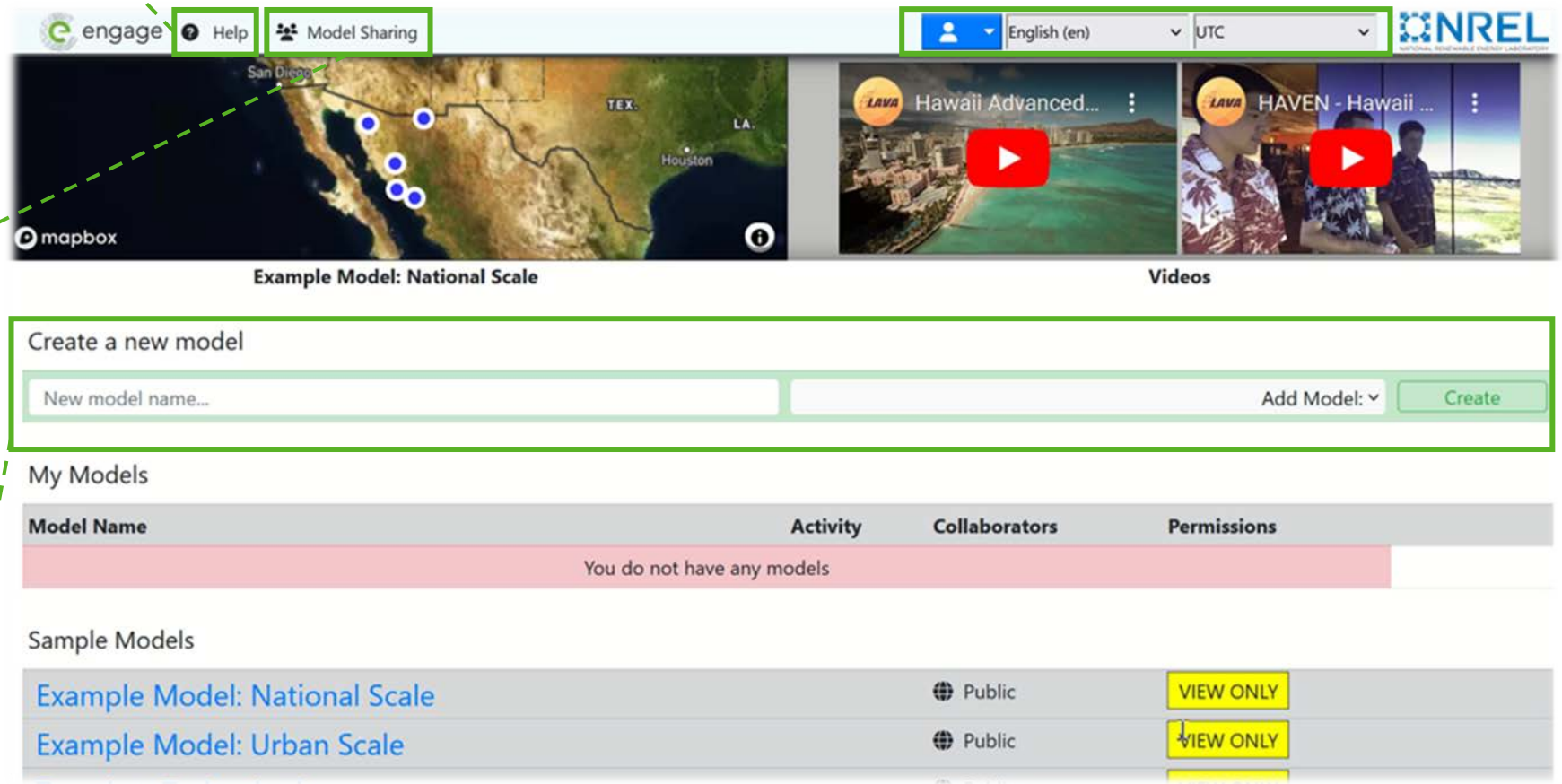
Exercise #2: Create a Model

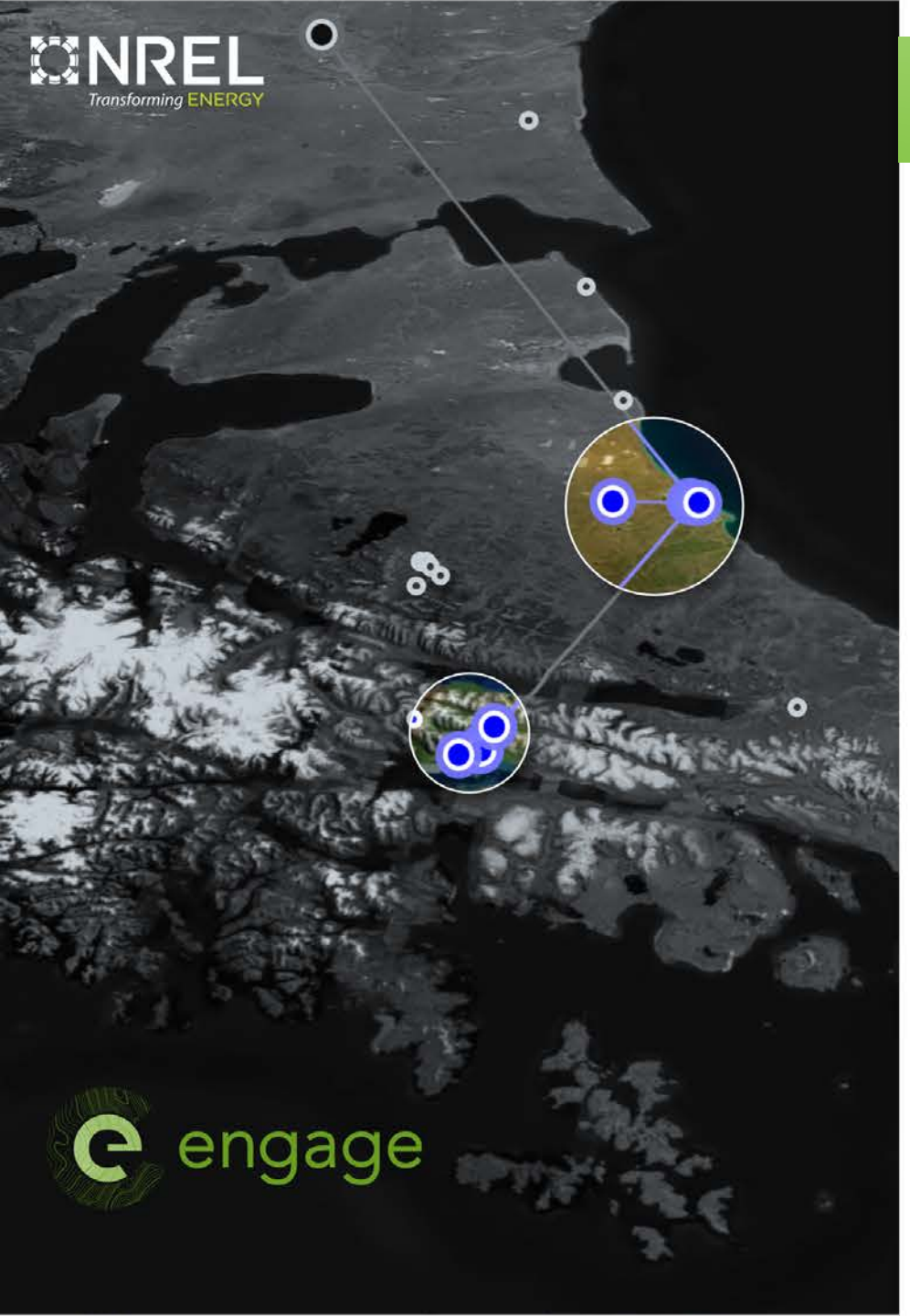
The Engage Models Page allows users to…

- **Share models** with other users and permission levels
- **Access help** including Calliope documentation
- **Adjust settings** to preferred language and time zone
- **Create models** (either blank or from prior models)



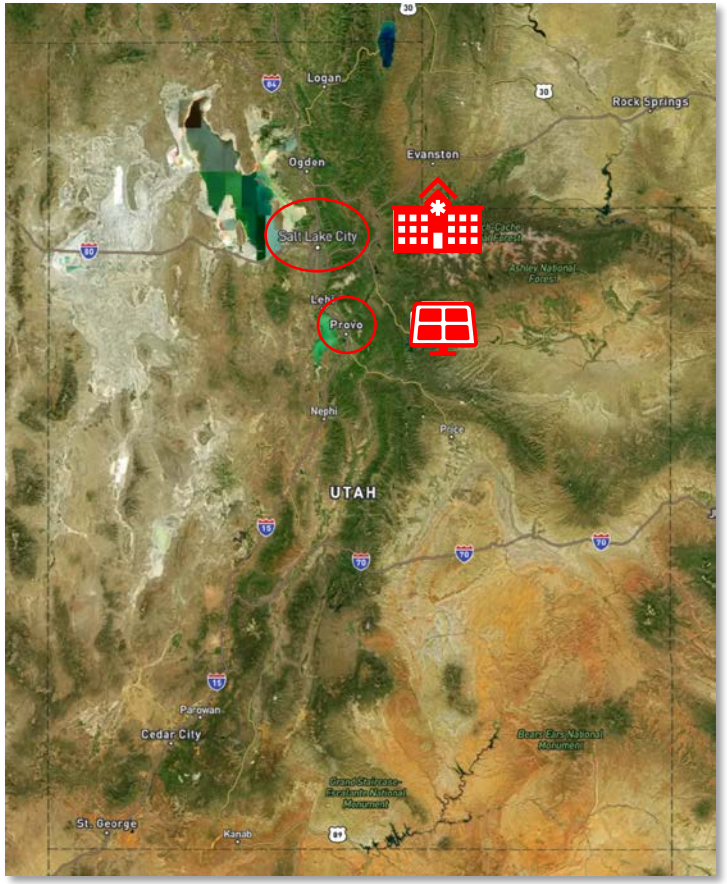






Exercise #3: Build an Existing Solar PV System

Imagine a scenario where you have a hospital near Salt Lake City, Utah and its only energy source is a 5 MW solar photovoltaic (PV) farm in Provo.



What technologies would you need to model this contained energy system?

What would be the model's primary carrier?

What type of data would you need to collect to build the model?

Create a Carrier and Technology

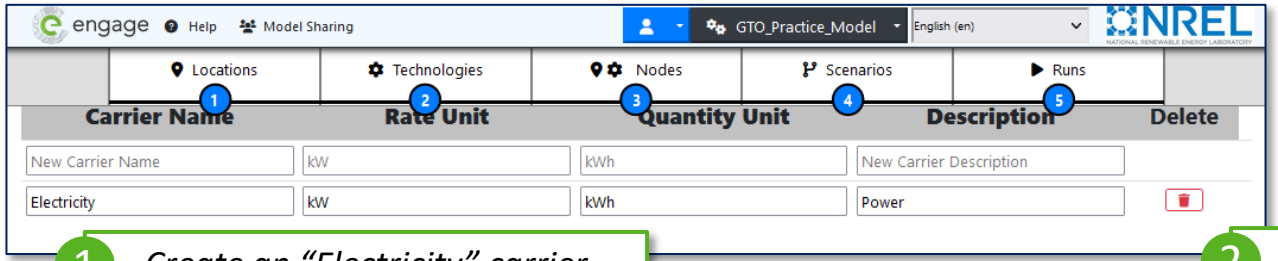
Don't forget to assign a carrier, color, and version tag!

engage

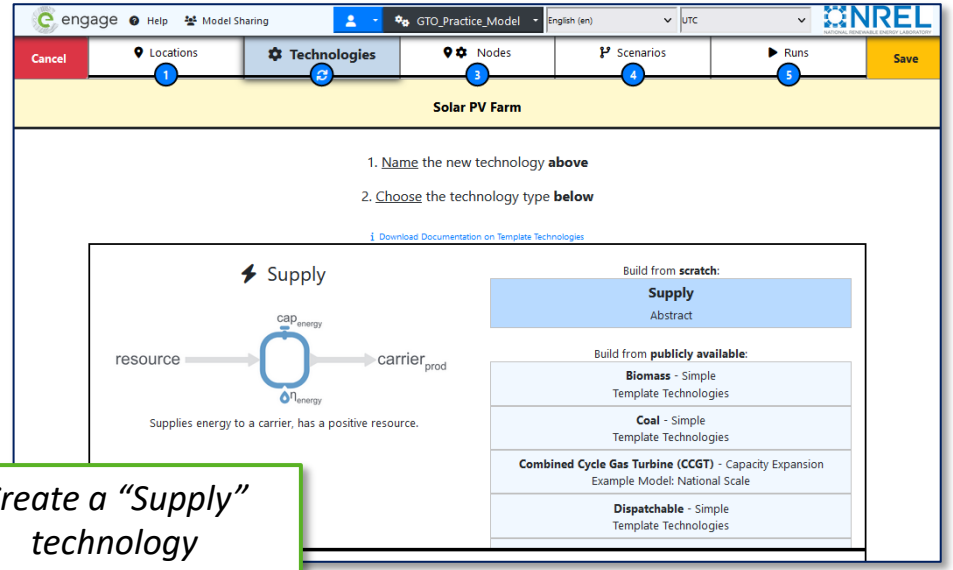
Simulates how energy or commodities move through a given system

carriers

archetypes

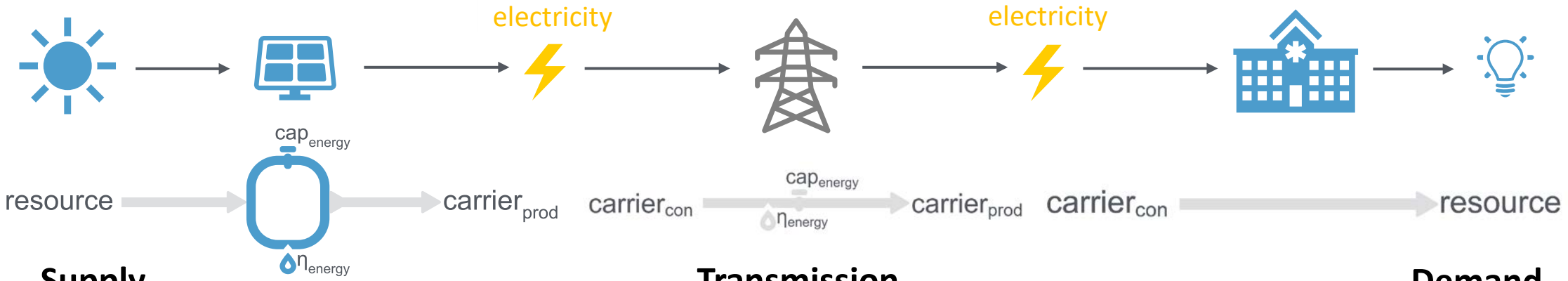


1 *Create an "Electricity" carrier*



2 *Create a "Supply" technology*

Solar PV **PV Wire** **Hospital**



Supply **Transmission** **Demand**

Supply Technology Archetype

engage

Simulates how energy or commodities moves through a given system

carriers

archetypes

- Supply
-
-
-
-
-

- Takes a **resource** and produces a **defined carrier** (power, water, diesel, natural gas, etc.)
- Appropriate for simple technologies with an **infinite supply** or a **capacity factor**

3

Production capacity	5 MW	5,000	kW
Scale resource with...	energy		ABC
Resource: supply(+) / demand(-)	Timeseries		kWh

Leave blank for now

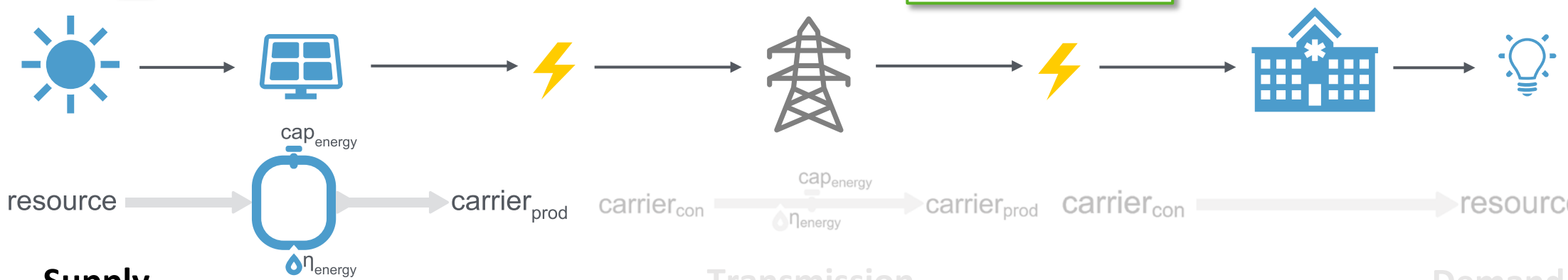
Wind
Nuclear
CCGT*
Coal
Biomass

Electric Supply

* Combined cycle gas turbine

Natural gas imports
Thermal energy (steam)
Water from reservoirs

Commodity Supply



Supply Transmission Demand

Modeling Technology Costs

engage

Simulates how energy or commodities moves through a given system

carriers

archetypes

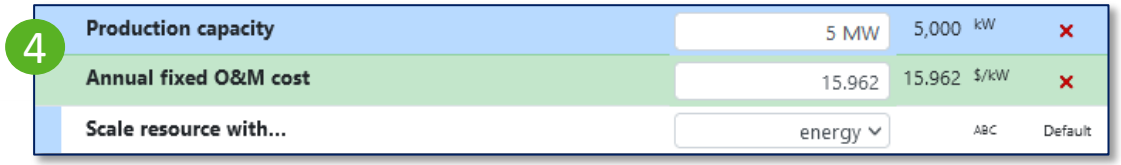
Supply

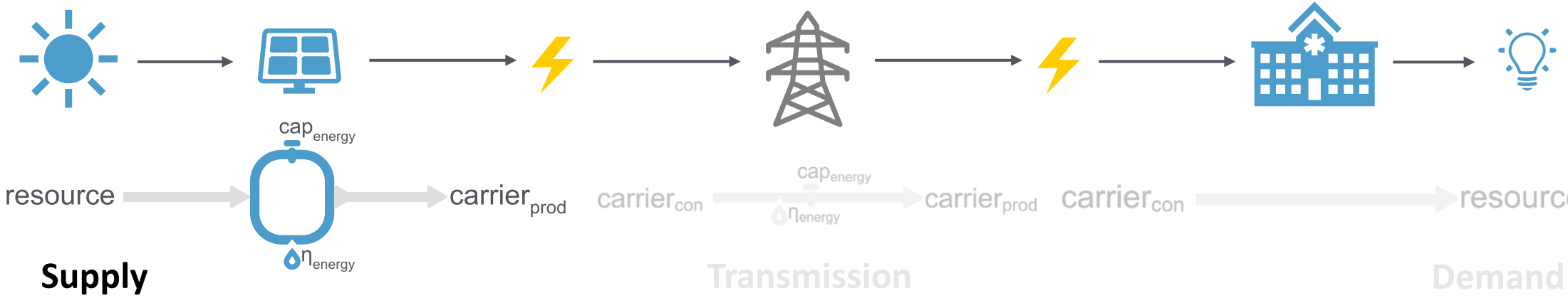
- Power purchase agreements (PPAs)
- Fuel and variable costs ($/kWh)
- Capital and fixed costs ($/kW)
- Interest rates (%)
- Annual operation and maintenance costs (O&M)

Costs Engage Can Model

1. Coax the model into generating **cash flows** that will have the desired **modeling impact**.
   - Critical for capacity expansion modeling
2. Be **consistent** in representations.
   - Ex: consistent treatment of sunk costs, interest rates

Modeling Reminders





Transmission Technology Archetype

engage

Simulates how energy or commodities moves through a given system

carriers

archetypes

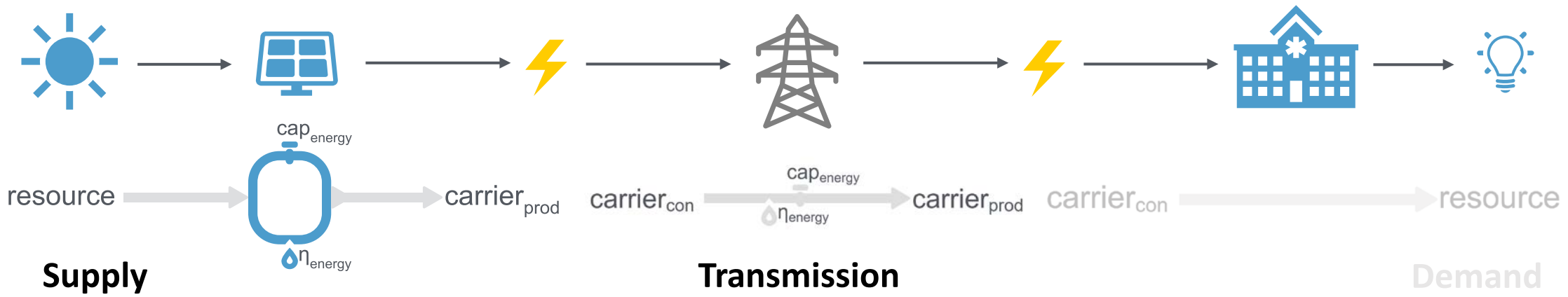
- Supply
- Transmission

- Carries a carrier from one location to another
- Copper plate transmission is a modeling approach that assumes energy can flow without issues; ideal when focusing on a model's generation capabilities

5				
	Carrying capacity		1 GW	1,000,000 kW
	Carrying efficiency	Timeseries	100	100 %

- Distribution Lines
- Natural gas pipelines
- Rivers
- Steam pipes
- Freight trains

Transmission Examples



Demand Technology Archetype

engage

Simulates how energy or commodities moves through a given system

carriers

archetypes

- [x] Supply
- [x] Transmission
- [x] Demand
- [ ]
- [ ]

- Consumes and **removes carriers** from a system through a resource with a negative value
- The **scale** of negative resources can vary, from **individual apartments** to **cities** to entire markets

6 Demand

$carrier_{con}$ → resource

Demands energy from a carrier, has a negative resource.

Build from **publicly available**:

Electrical Demand Example Model: Urban Scale
Flat Load - Simple Template Technologies
Heat Demand Example Model: Urban Scale
Hospital - Simple Template Technologies

A timeseries is a **set of data** that tracks a specific **variable overtime**

Calliope can process any type of data at **any timestep** in a csv file like:

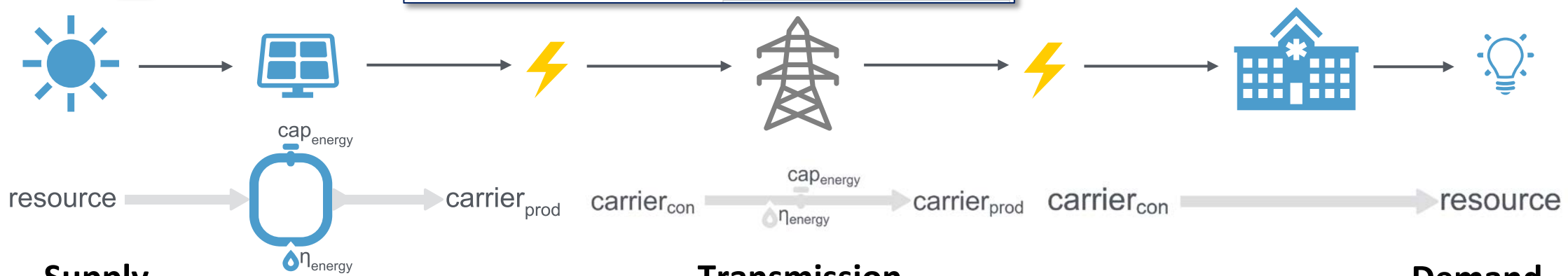
- 15-minute intervals
- 1-hour intervals*
- 1-month intervals

Recommend uploading timeseries at intervals that **match the model's desired temporal resolution and planning horizon**

Increased granularity will **improve model precision** but can also lead to **longer runtimes**

Timeseries

* Engage default run time



Supply **Transmission** **Demand**

Model Building Process: Create a Location

1. **Locations**
2. Technologies
3. Nodes
4. Scenarios
5. Runs

engage

Function: Create representative locations for technologies within the model

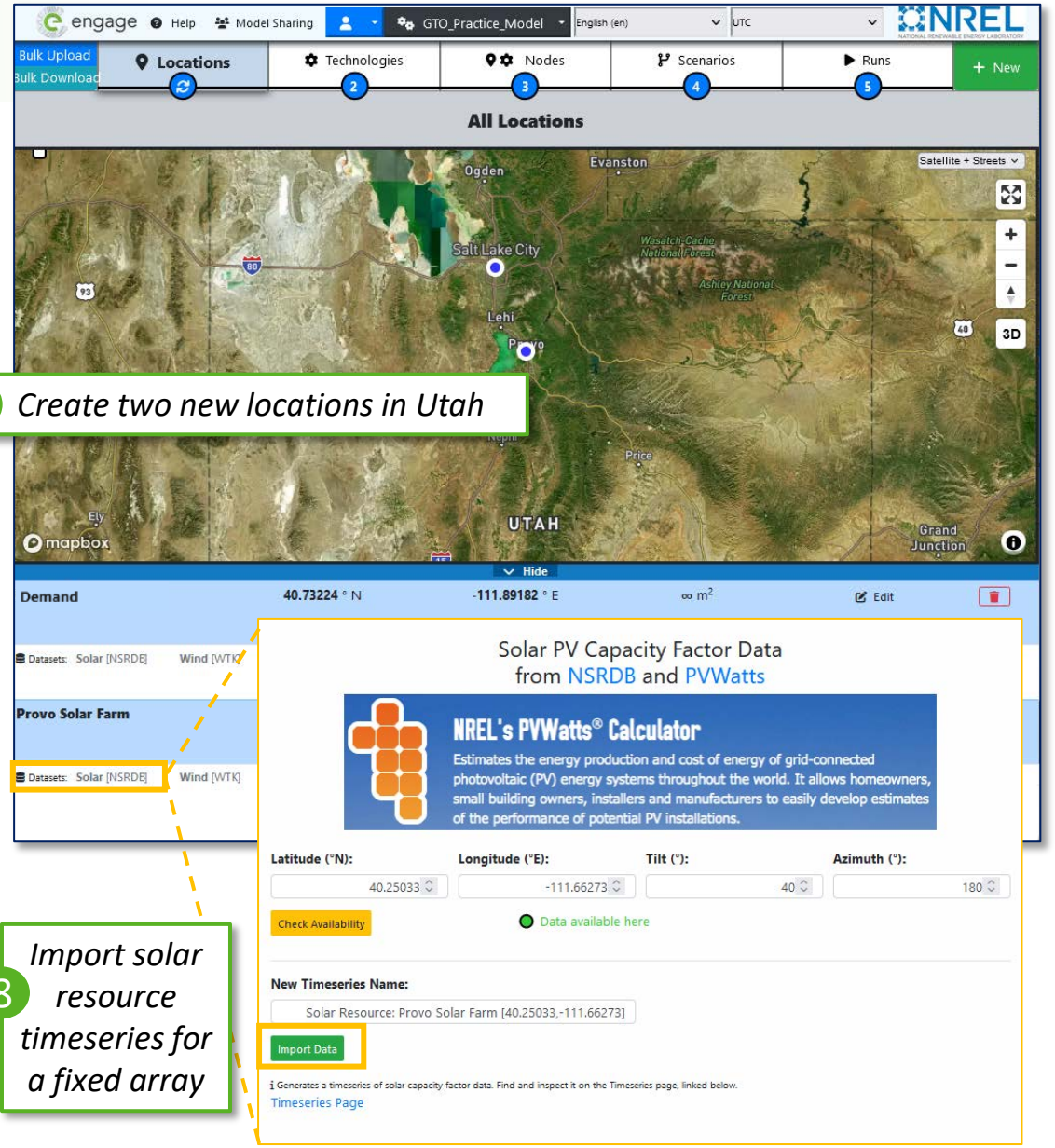
Mapbox features allow users to:

- **Zoom** in on specific locations
- **Examine** street maps
- **View** satellite imaging

Every technology in Engage must have an **assigned location,** which is critical for creating and enabling nodes

Multiple technologies can be assigned to a location, but a **transmission technology** must have **two assigned** locations.

Directly **interfaces** with PVWatts and the Wind Toolkit to **pull capacity factor time series** into the model.



Model Building Process: Build a Technology

1. **Locations**
2. **Technologies**
3. Nodes
4. Scenarios
5. Runs

engage

☑ Scale resource with…

Sets the **scaling of the resource timeseries** by:

Energy (ex: kWh, Btu)

Resource is defined by timeseries and scaling factor

Energy by land area (ex: kWh/m^2)

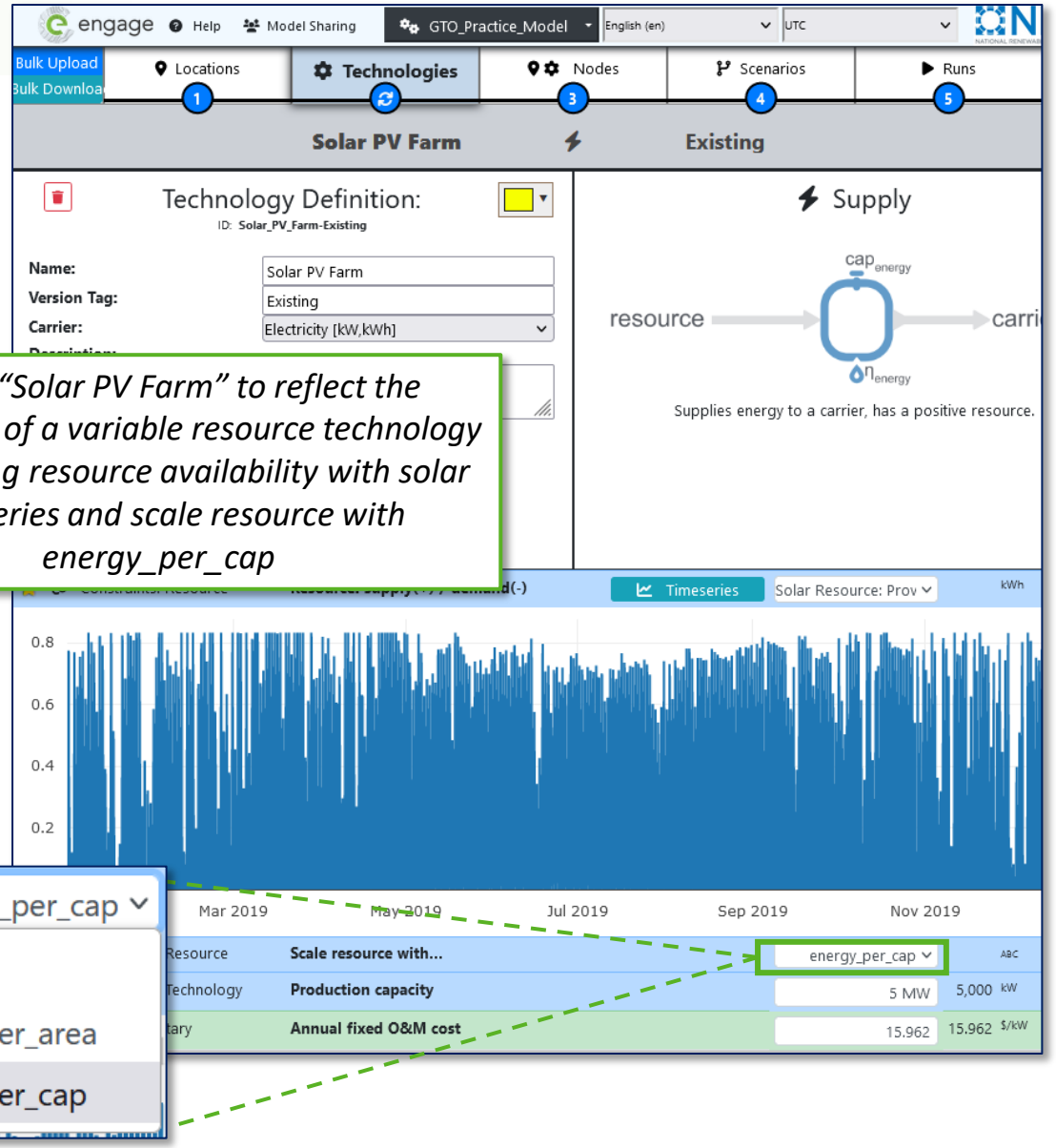
Resource time series is scaled by land/collector area utilized (a decision variable)

Energy by production capacity (ex: kWh/kW)

Resource time series is scaled by capacity of technology during capacity expansion

☑ Resource: Supply/Demand

9 *Adjust "Solar PV Farm" to reflect the constraints of a variable resource technology by updating resource availability with solar timeseries and scale resource with energy_per_cap*



Model Building Process: Configure a Node

1. **Locations**
2. **Technologies**
3. **Nodes**
4. Scenarios
5. Runs

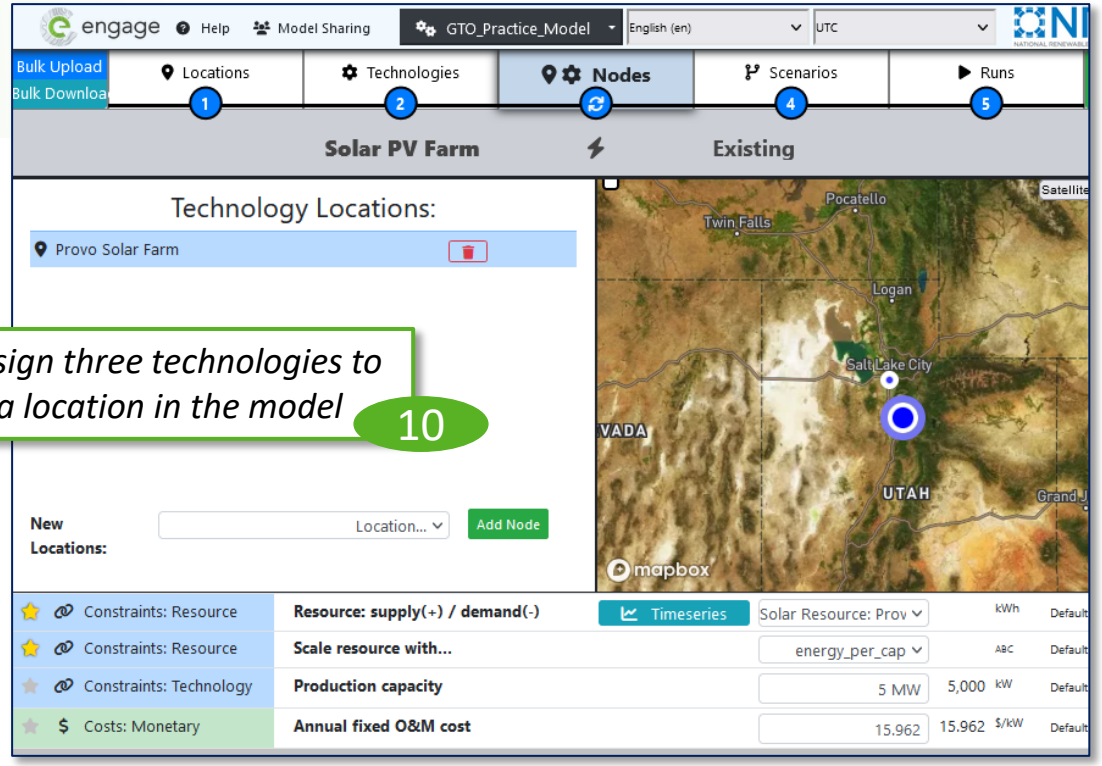
engage

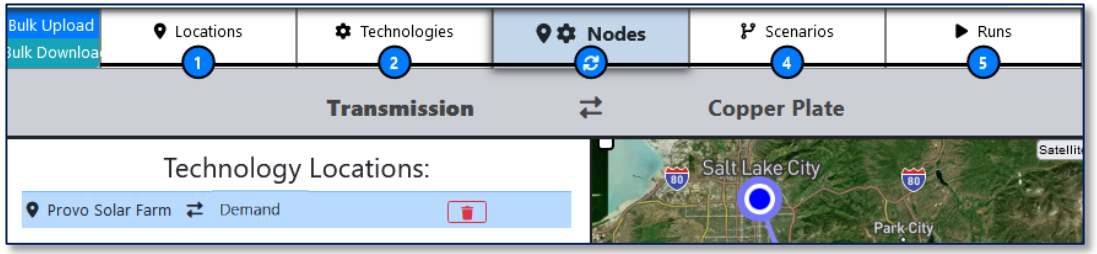
Function: Assign technologies to locations in the model to measure, control, and analyze energy/commodity flows

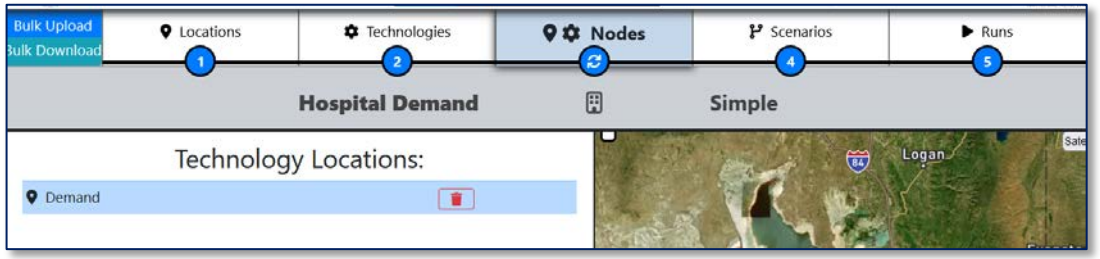
Automatically populates parameters listed under the Technologies page so that users can:

- Create **multiple versions** of the same technologies
- Customize technology parameters to be **locationally-specific**

All technologies will require the assignment of **at least one location**, while **transmission technologies** require **two locations**







Model Building Process: Design a Scenario

Create a new scenario and enable all three nodes

11

1. **Locations**
2. **Technologies**
3. **Nodes**
4. **Scenarios**
5. Runs

engage

Function: Build scenarios by enabling nodes and setting overarching model constraints

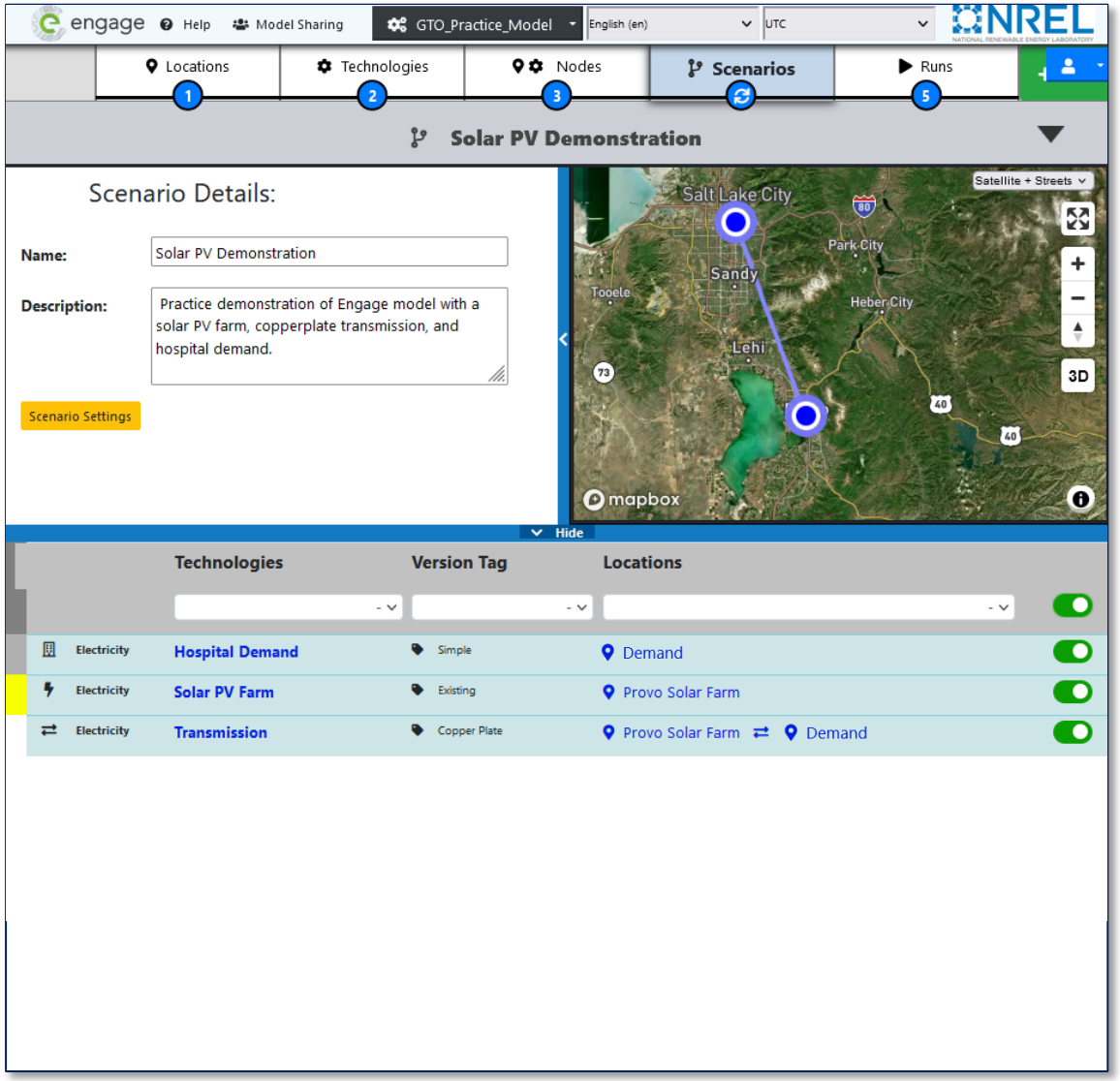
Activate technologies at specific locations by turning on their **corresponding nodes**

Organize nodes by their:

- Technology
- Technology version tag
- Location

Create constraints on groups of techs or the overall model such as:

- A carbon cap
- A reserve margin



Model Building Process: Run the Model

1. Locations
2. Technologies
3. Nodes
4. Scenarios
5. Runs

engage

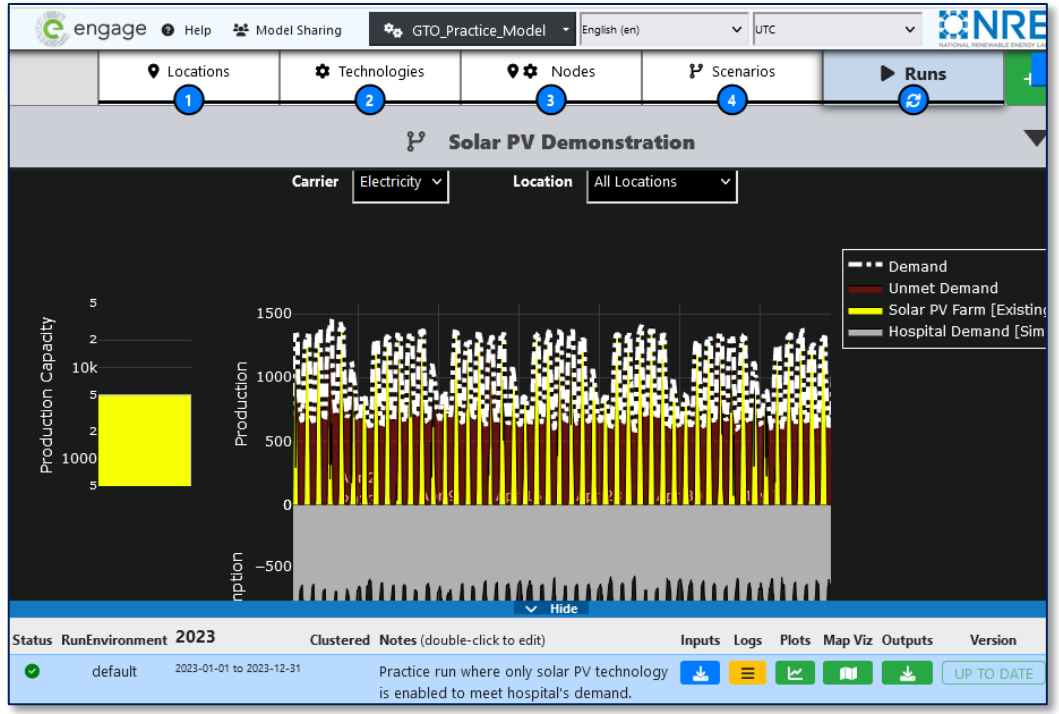
Function: Renders configured scenario into a Calliope problem and runs scenario for evaluation

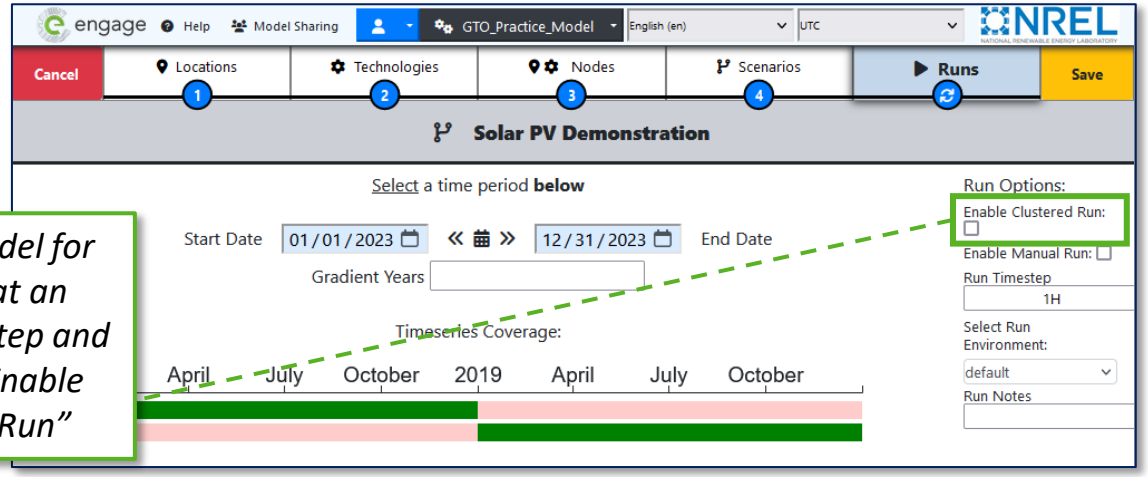
Engage **limits runs to one year**, which means Engage runs can…

- ✗ Over one year (ex: 1/2023 to 1/2025)
- ✗ Beyond one year (ex: 5/2023 to 1/2024)
- ✓ Within a year (ex: 4/2023 to 8/2023)
- ✓ Up to one year (ex: 1/2023 to 12/2023)

Engage can collect **run timesteps at any interval**, including:

- 15-minute
- 30-minute
- 1-hour (default)
- 2-hour

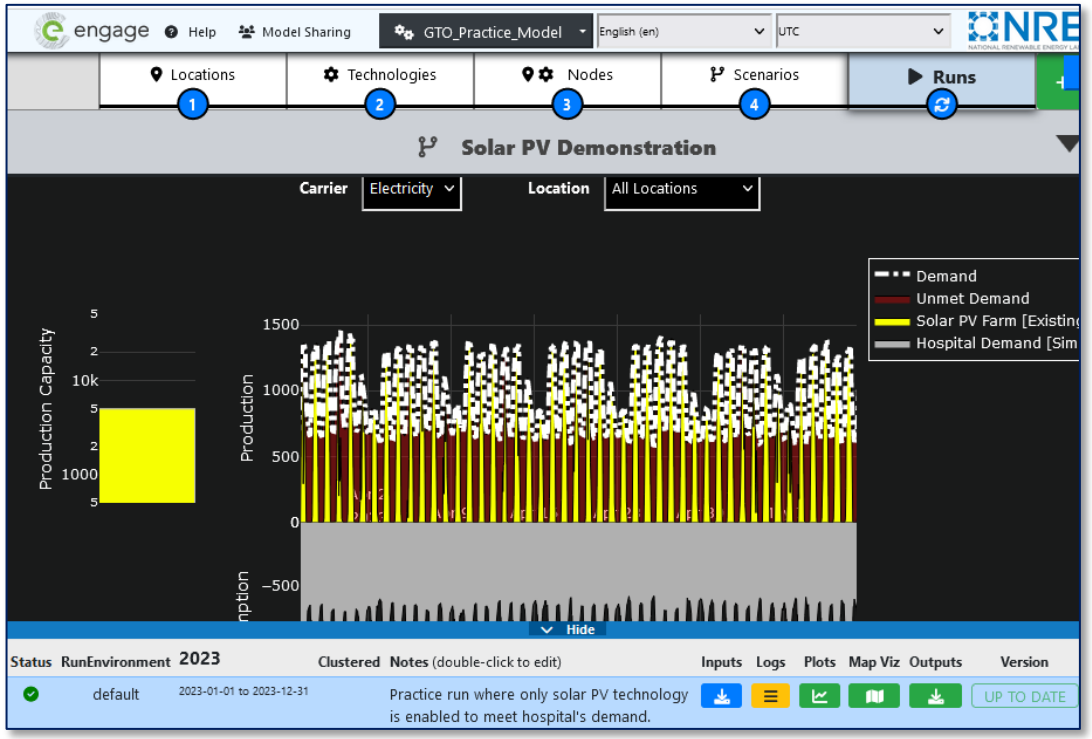


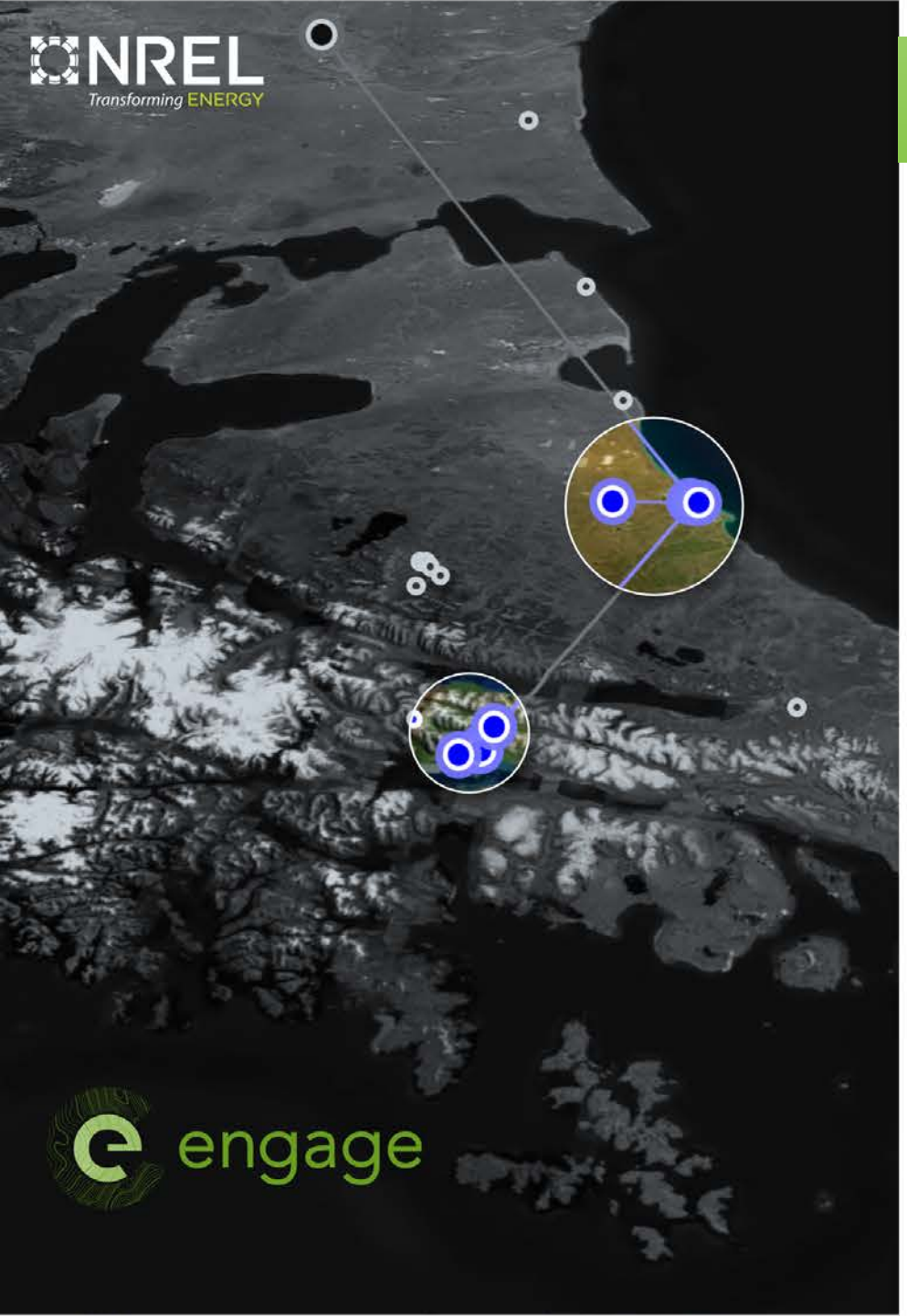


12 *Run the model for one year at an hourly timestep and uncheck "Enable Clustered Run"*

Exercise Questions:

1. Was there unmet demand in the model? If so, why? Is this surprising?
2. How much solar capacity did the model build? Is this in line with what we would expect?
3. How much did it cost to operate our solar PV farm for one year?





Exercise #4: Capacity Expansion for Unmet Demand

Now imagine you have two choices to meet the hospital's remaining demand: a backup diesel generator or a lithium-ion battery. You want to make the decision based on what's cost optimal.

NREL Image 88842

NREL Image 88841

What types of cost data would you need to collect to compete these technologies?

What operational constraints should you consider modeling for each technology?

Storage Technology Archetype

engage

Simulates how energy or commodities moves through a given system

carriers

- Electric batteries
- Electrochemical
- Potential energy (water at a height)
- Fuel (natural gas, diesel, hydrogen)

Storage Examples

archetypes

- [x] Supply
- [x] Transmission
- [x] Demand
- [x] Storage
- [ ]

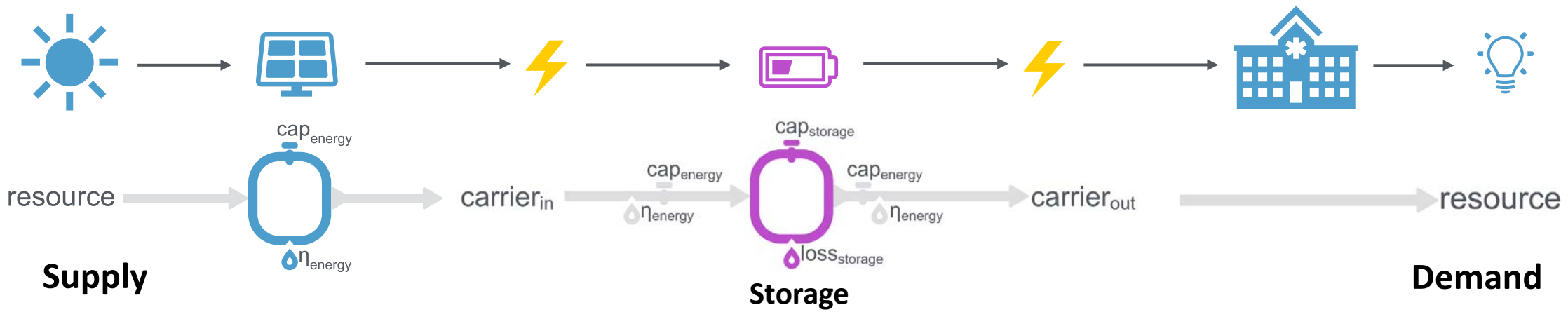
- Takes **carriers in and stores** them until later time intervals
- Serves system load but still **requires a supply** archetype

C-Rate indicates **storage duration** by describing the rate the technology can be discharged relative to its maximum capacity

2-Hour = **50**% / hour (1/**2**)
4-Hour = **25**% / hour (1/**4**)
10-Hour = **10**% / hour (1/**10**)

1	C-rate		25%/hour	25 %/hour
	Maximum storage capacity		10 GWh	10,000,000 kWh
	One-way efficiency	Timeseries	.85^.5*100	92.19544457292888 %

Square root round-trip efficiency to convert to one-way efficiency



Linear Capacity Expansion

Maximum function

Model **linearly expands** resource to the cost optimal point

Parameter

Technology	*Capacity Expansion*	*Fixed*
Supply	Maximum production capacity	Production capacity
Transmission	Maximum carrying capacity	Carrying capacity
Storage	Maximum storage capacity	Storage capacity
Storage*	Maximum c-rate	C-rate

* Assumes that the cost of storage is also linear, which is often not the case

Lifetime and amortization period

- Technological lifespan
- Contract period
- Maturity date of loan

Interest rate

- Cost of debt on loan
- Required rate of return
- Weighted average cost of capital (WACC)

Relates to how Engage treats **cashflows**

Processes fixed and operating costs on an **annualized** basis

0101
1100
0010

$**2,000,000** for a 1 MW solar farm

20-year technological lifespan

≈ $**100,000**/year

≈ $**160,000**/year*

** With 5% interest rate*

Final Technology Configuration

engage Help Model Sharing GTO_Practice_Model English (en) UTC NREL

Bulk Upload Bulk Download | Locations 1 | Technologies | Nodes 3 | Scenarios 4 | Runs 5 | + New

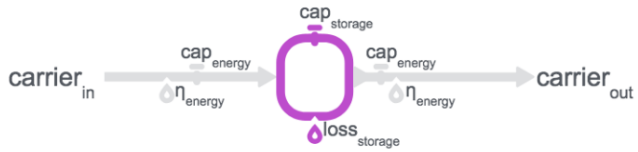
4-Hour Lithium-ion Battery **Capacity Expansion**

Technology Definition:

ID: 4Hour_Lithiumion_Battery-Capacity_Expansion

Name: 4-Hour Lithium-ion Battery
Version Tag: 2 Capacity Expansion
Carrier: Electricity [kW,kWh]
Description:

Storage



Stores energy.

Constraints: Storage	**C-rate**		25%/hour	25 %/hour	×	+ Row
Constraints: Storage	**Maximum storage capacity**		10 GWh	10,000,000 kWh	×	+ Row
Constraints: Technology	**Lifetime and amortization period**		20	20 years	×	+ Row
Constraints: Technology	**One-way efficiency**	Timeseries	.85^.5*100	92.19544457292888 %	×	+ Row
Costs: Monetary	**Annual fixed O&M cost**		42.88	42.88 $/kW	×	+ Row
Costs: Monetary	**Cost of production capacity**		1,715.50	1,715.5 $/kW	×	+ Row
Costs: Monetary	**Interest rate**		5	5 %	×	+ Row

Constraints: Storage

Constraints: Technology

Costs: Monetary

Emissions: CH4

Conversion Technology Archetype

engage

Simulates how energy or commodities moves through a given system

carriers

archetypes

- Supply
- Transmission
- Demand
- Storage
- Conversion

- **Converts** one type of a carrier to another
- Appropriate for technologies where we would want to **track input carriers** used in the production of another carrier

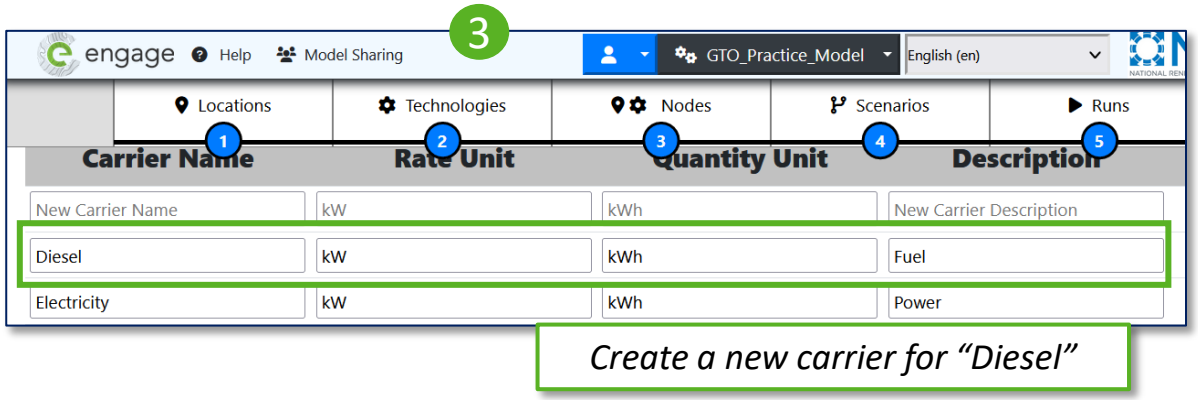
Combined cycle gas turbine (CCGT)

Natural gas boiler

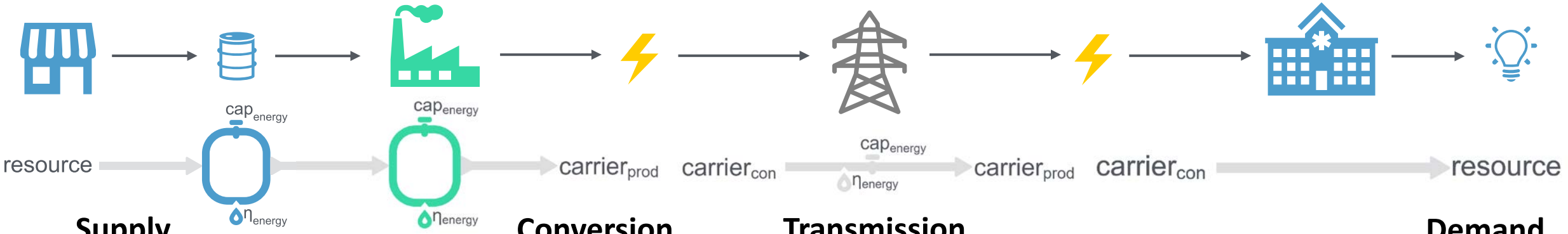
Coal power plant

Electric transformer

Conversion Examples



Create a new carrier for "Diesel"



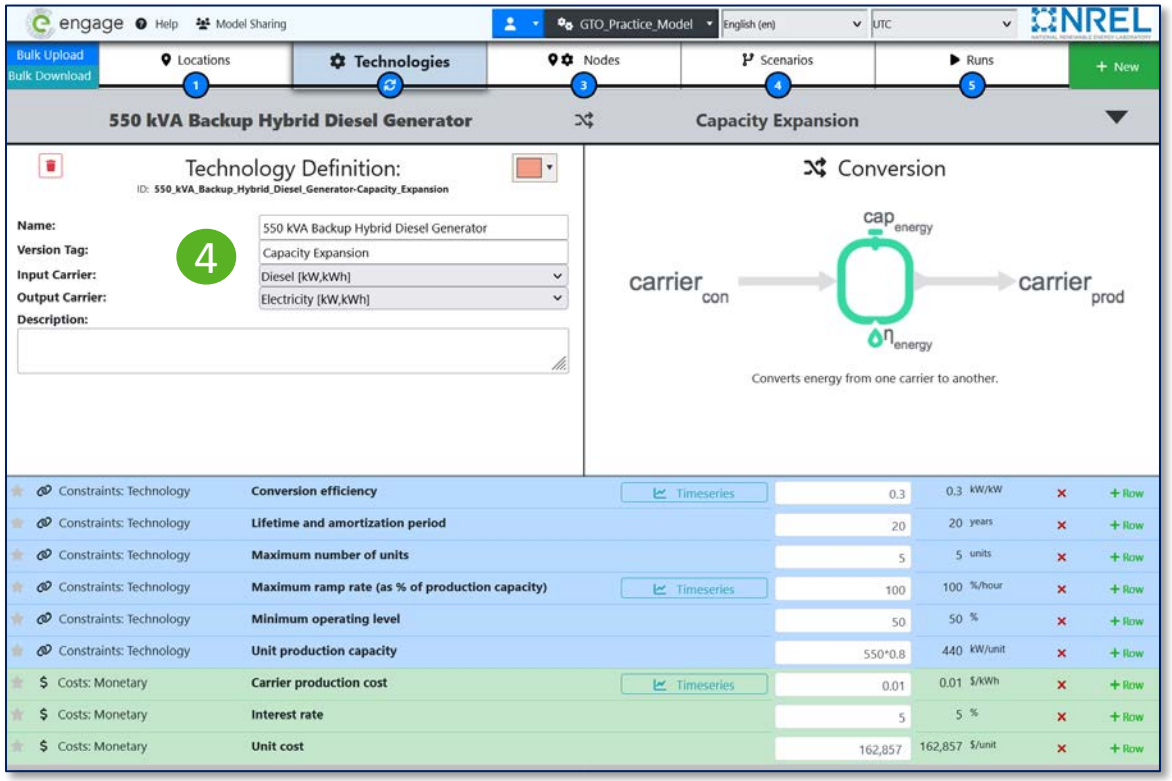
Linear vs. Unit Capacity Expansion

Model **linearly expands** resource to the cost optimal build out

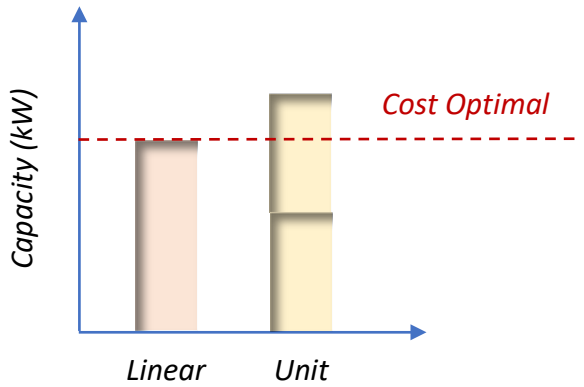
Linear Expansion

Model determines cost optimal **number of units**

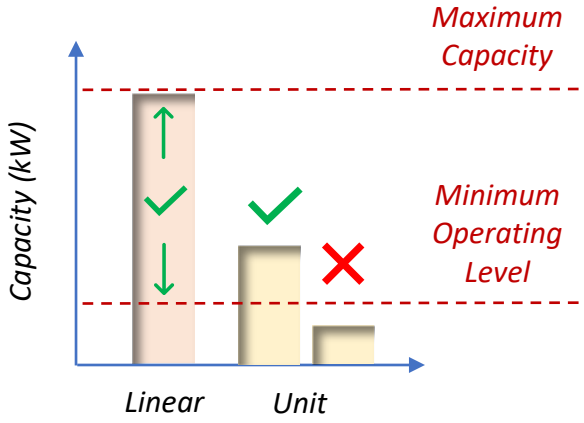
Unit Expansion



Build Differences

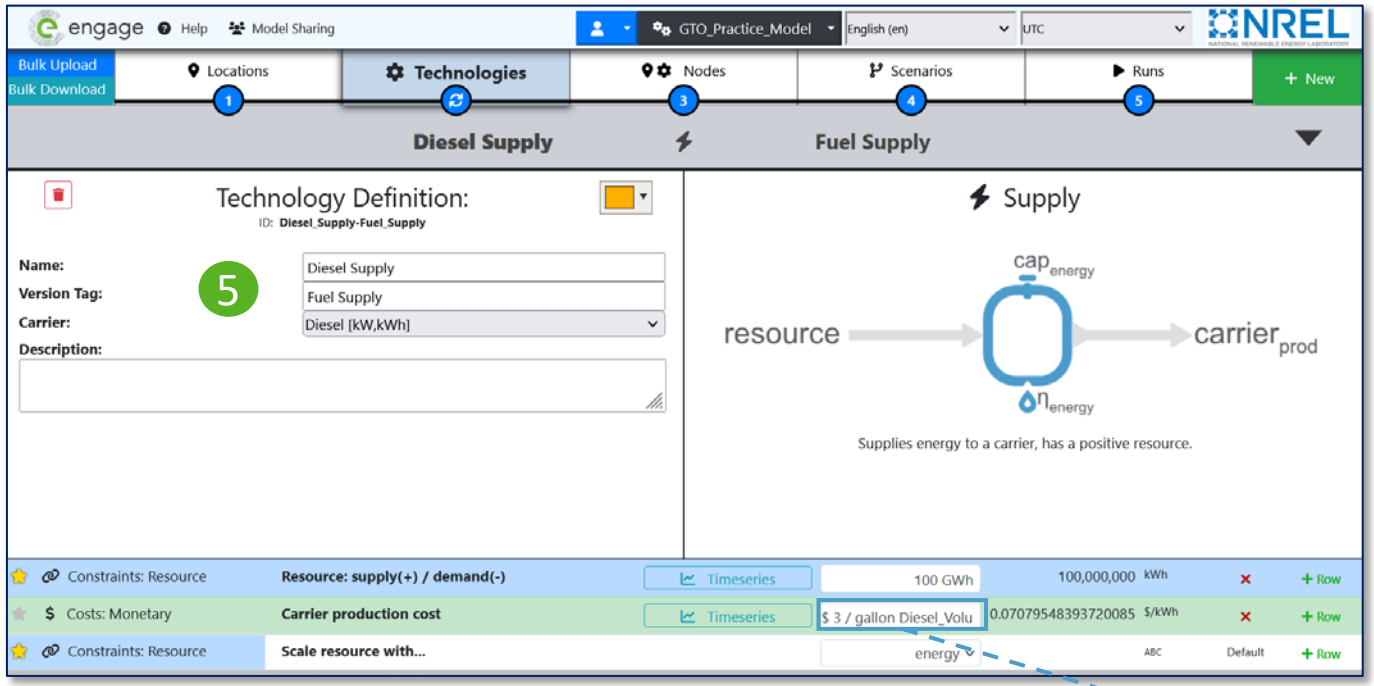


Operational Differences



Linear Expansion	Unit Expansion
Advantages	
Easier to configure technologies and run the model, particularly if the models are large-scale and multi-carrier	Closer to real-world investment decisions with limited foresight
	Capable of modeling real-world minimum operating conditions
Challenges	
Interprets any minimum operating conditions as an operating floor	More algorithmically complex to the point of becoming computationally unsolvable

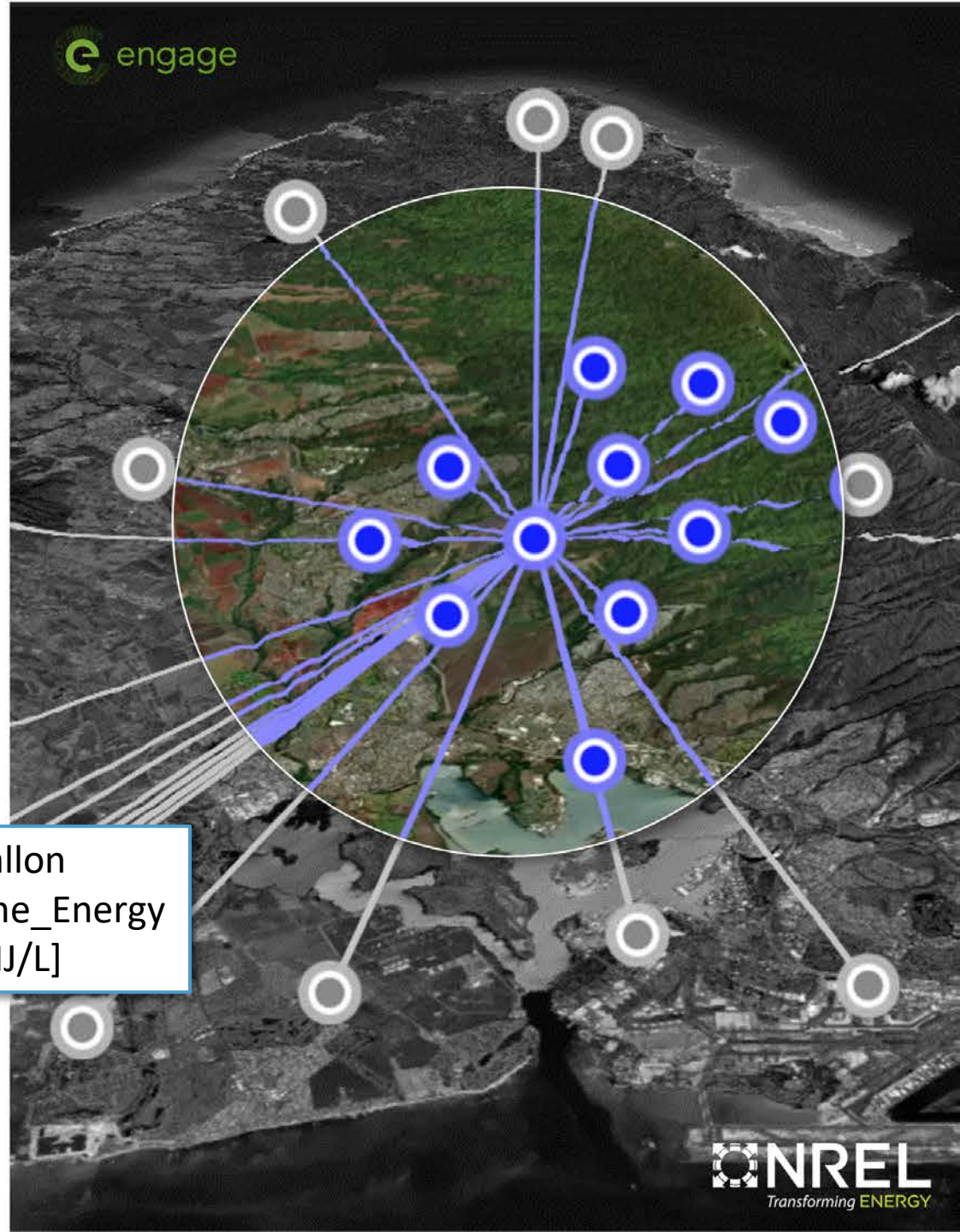
Unit of Measure Conversions



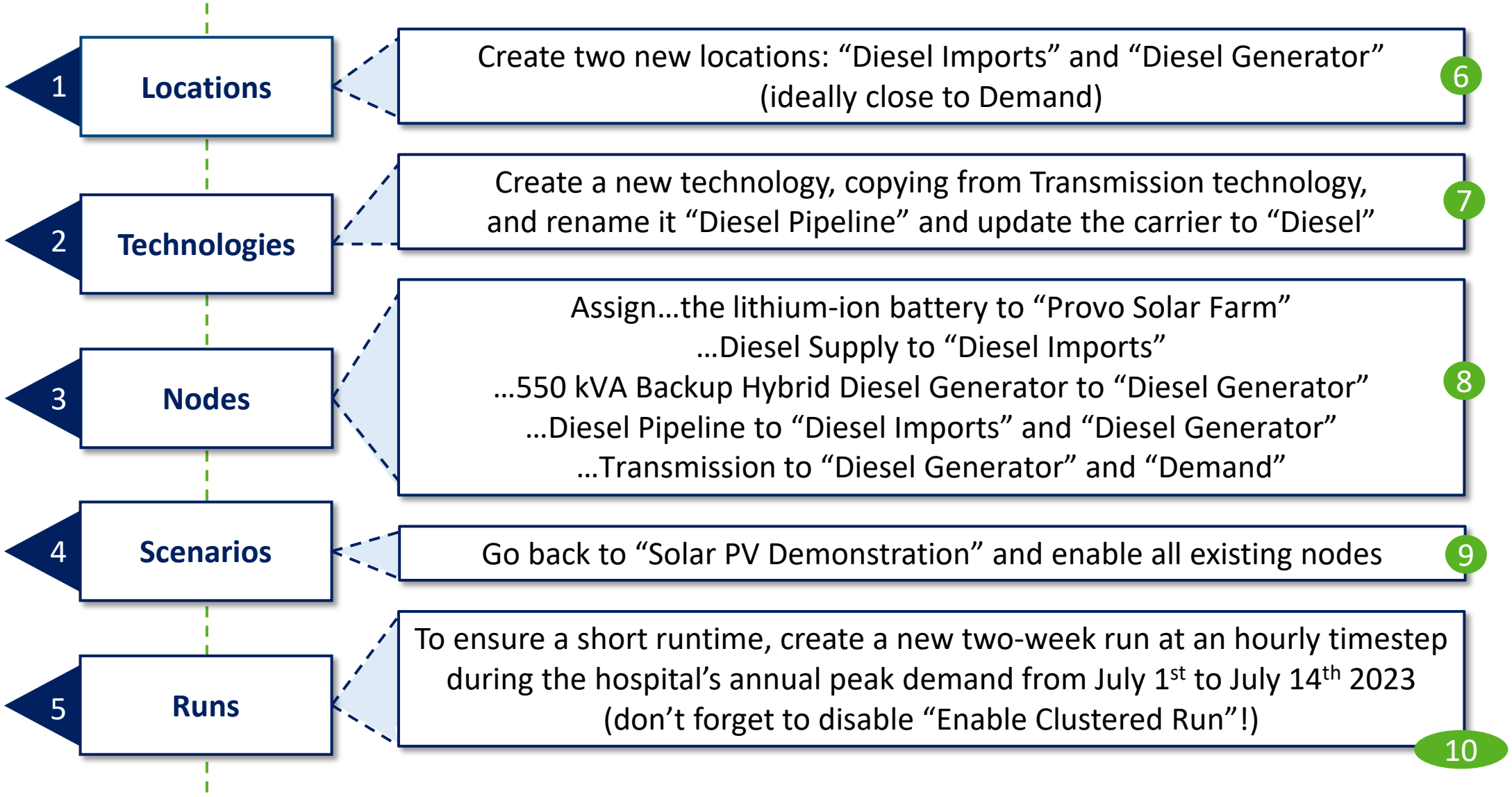
- Structure inputs in **compatible or equivalent** units of measure to achieve target units
- Separate terms by **spaces**
- Use **parentheses** to indicate order of operations
- Search for **existing unit conversions** in Engage
- Converter does not handle **currency conversions**

Tips on Unit Conversion

$ 3 / gallon Diesel_Volume_Energy [40.3MJ/L]

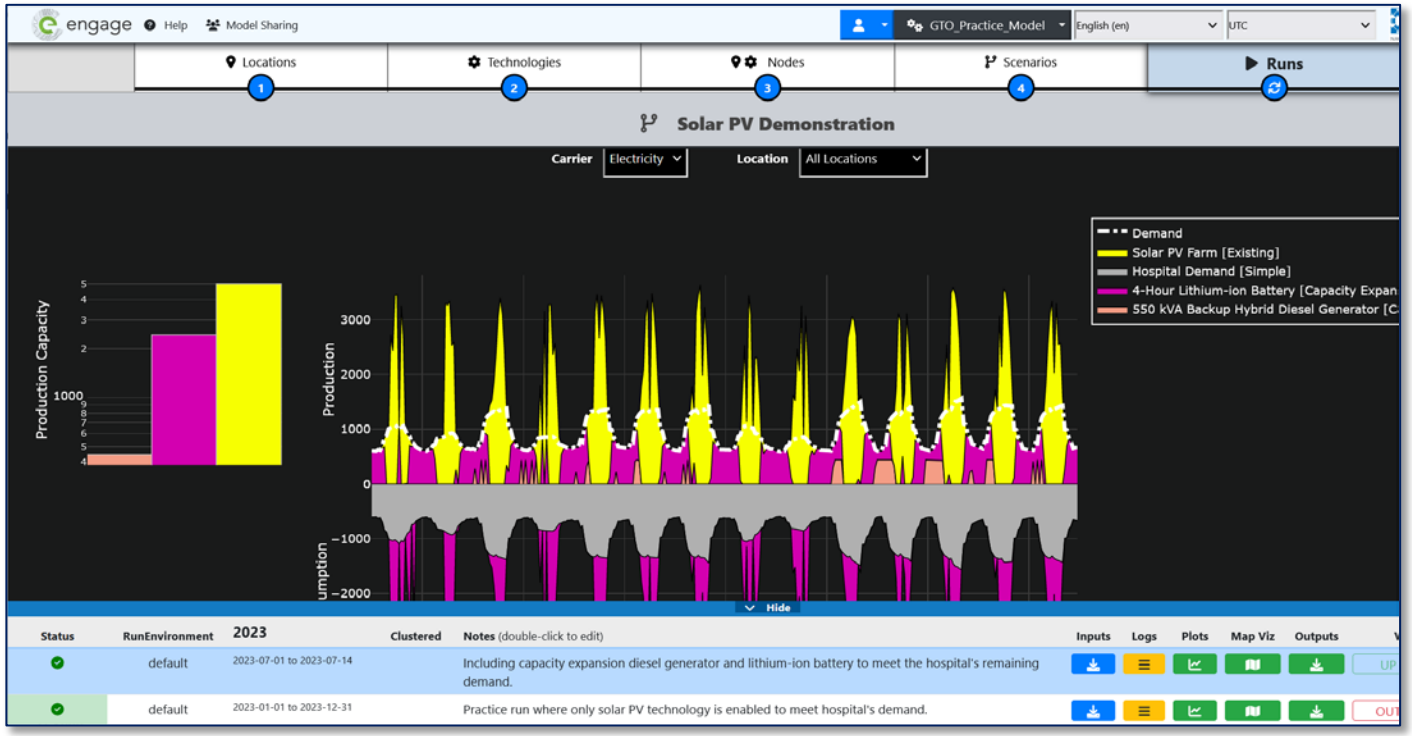


Model Building Process: Do it Yourself!



Exercise Questions:

1. Did the model successfully satisfy the remaining demand?
2. How much storage capacity (kWh) did the model build for the lithium-ion battery? How many units of the diesel generator did the model?
3. How did the solar PV, battery, and diesel generator technologies interact with each other?



NREL/PR-7A40-90959

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Engage Trainings

USAID Haiti Engage Training Series

Year: 2024

Total Length: ~4 hours (5 total training sessions)

Target Audience: Beginner modelers

Topics Covered:

- **Engage Orientation**
  - Click here to access the recording (French version)
  - Click here to access the slide decks (French version)
- **Introduction to Engage: Simple Technology Archetypes and Carriers**
  - Click here to access the recording (French version)
  - Click here to access the slide decks (French version)
- **Capacity Expansion: Advanced Technology Archetypes and Carriers**
  - Click here to access the recording (French version)
  - Click here to access the slide decks (French version)
- **Resilience Planning and Renewables**
  - Click here to access the recording (French version)
  - Click here to access the slide decks (French version)
- **Traditional Power Sector Modeling**
  - Click here to access the recording (French version)
  - Click here to access the slide decks (French version)

Contact us to access the Haiti_Training_Model at engage@nrel.gov