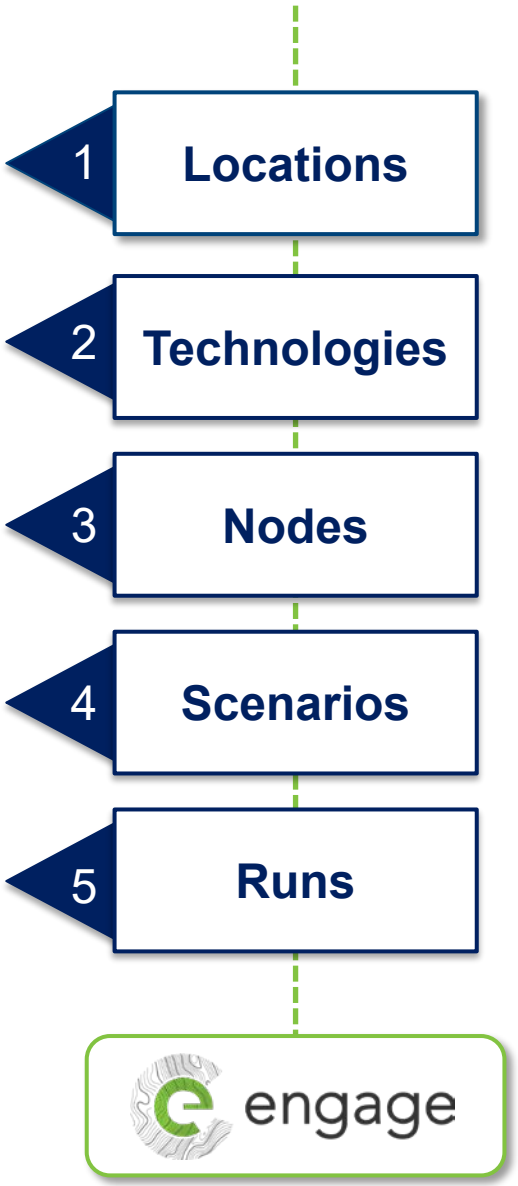
USAID Haiti Training Session #3: Capacity Expansion

Cameron Weiner, National Renewable Energy Laboratory

Training Session #2 Exercise



1. **How much capacity did the model build?**
2. **Was there unmet demand?**
3. **How much did it cost to operate the solar farm for one year?**

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Training Session #2 Exercise

1 **Locations**

2 **Technologies**

3 **Nodes**

4 **Scenarios**

5 **Runs**

engage

1. **How much capacity did the model build?**

   1,000 kW or 1 MW, in line with what was configured for the solar PV technology

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   Yes, during the hospital's daily peaks indicating that solar was not enough to meet demand

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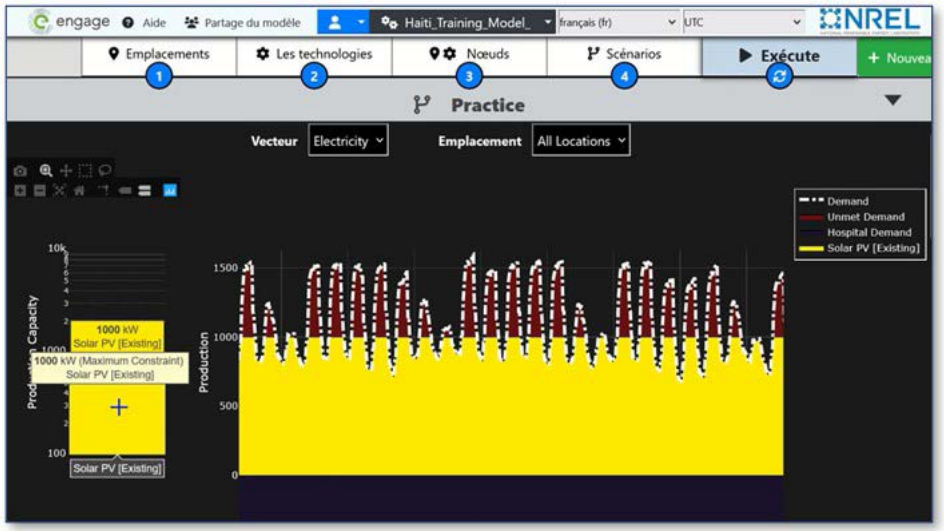

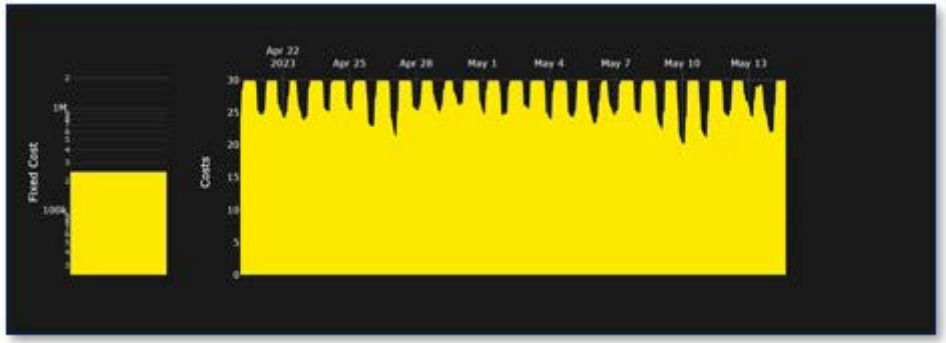

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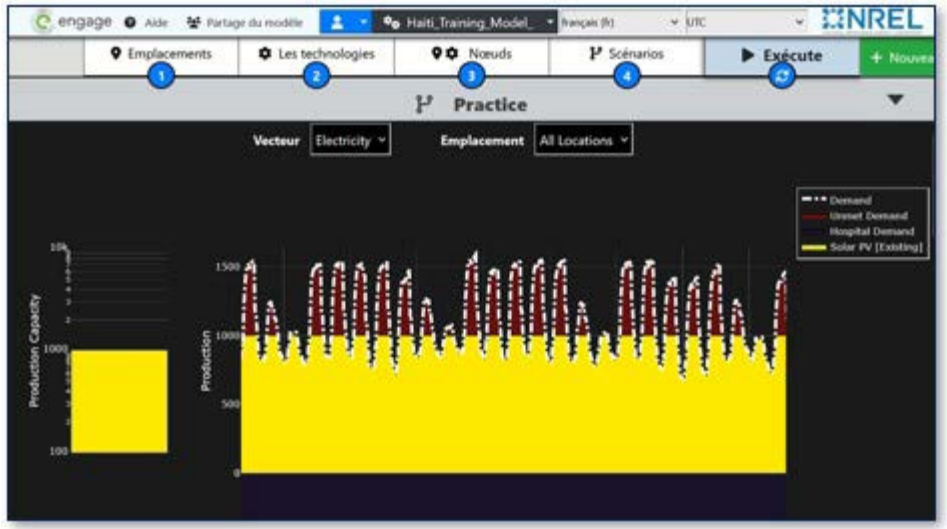

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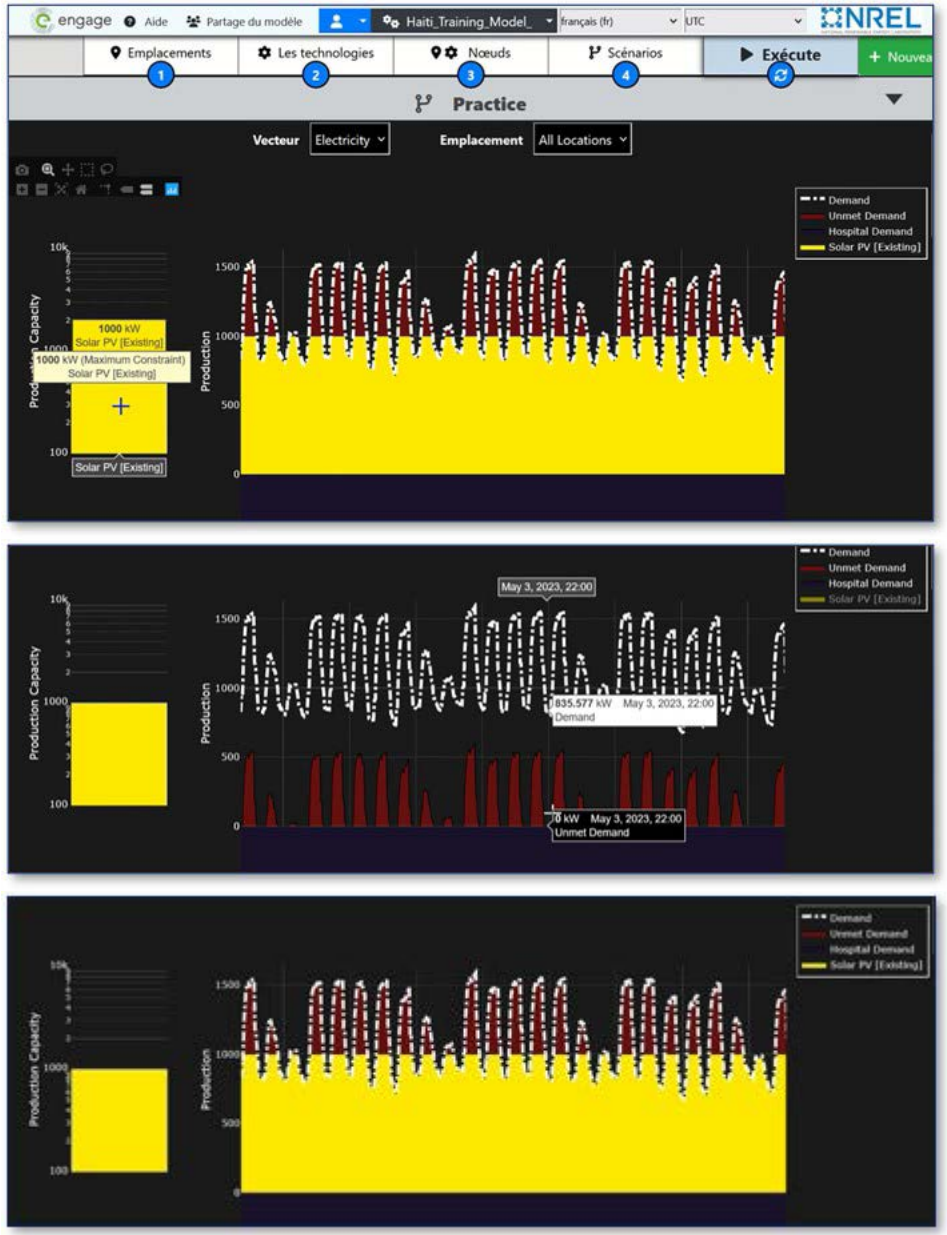
3. **How much did it cost to operate the solar farm for one year?**

   $242,000



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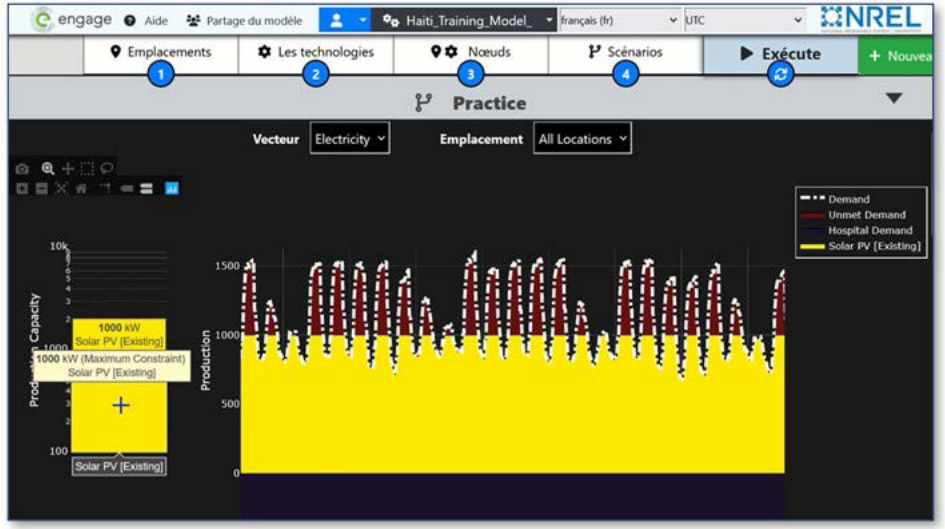
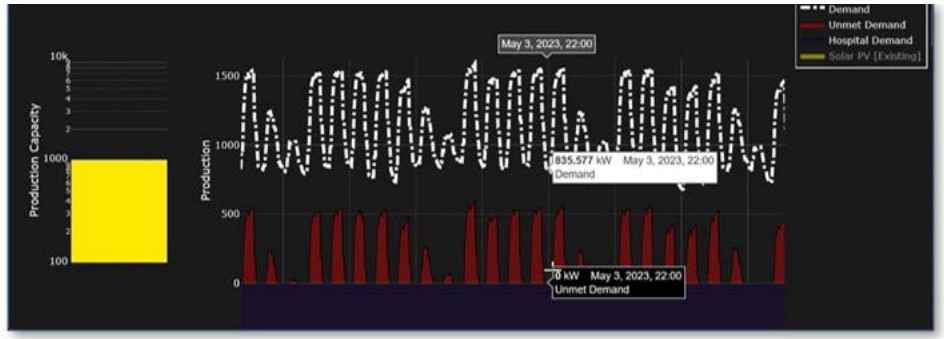
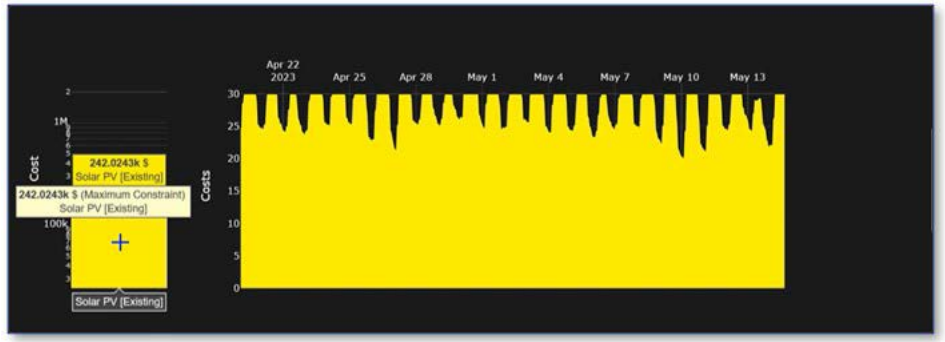
   How can we **cost optimally** meet the hospital's remaining demand using **capacity expansion** modeling?







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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*

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** 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*

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Capacity Expansion Modeling

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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

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Capacity Expansion Modeling

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

- 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

- Future electricity demand
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Capacity Expansion Modeling

Calliope can run a model in "operation" mode to simulate limited foresight.

https://www.callio.pe/

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

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Capacity Expansion Limitations

Future electricity demand

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Capacity Expansion Modeling

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

- Capacity expansion models often represent **power plants as one aggregate generator** even though they are commonly made up of individual units
  - **Example:** Individual generators at a power plant that have may have different operational parameters from another
  - **Benefit:** Less complex, shorter runtimes
  - **Implication:** Engage may overvalue or undervalue a power plant, which can lead to suboptimal investment decisions

Capacity Expansion Limitations

Future electricity demand

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Capacity Expansion Modeling

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

- **Verify** Engage results and **think critically** about the model's outputs
- Use capacity expansion models to **guide insight into energy sector planning**, such as identifying competitive technologies

Capacity Expansion Limitations

Future electricity demand

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Capacity Expansion Modeling

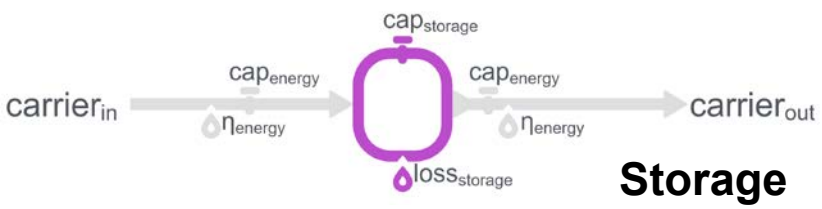
engage

Simulates how energy or commodities moves through a given system

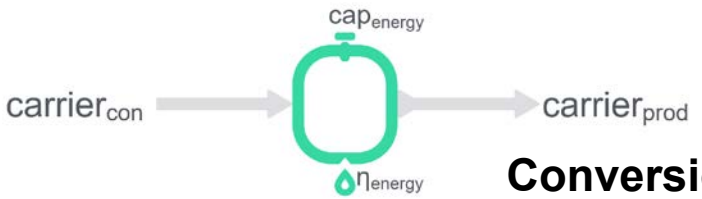
carriers

archetypes

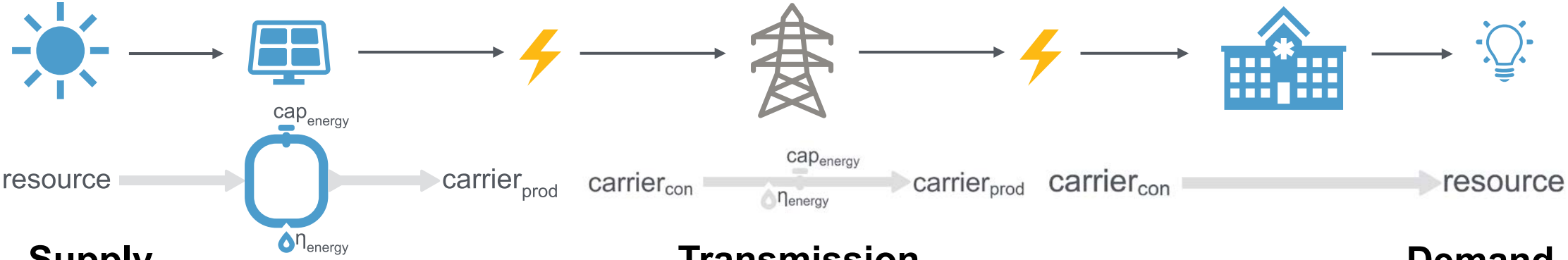
- Supply
- Transmission
- Demand
- Storage
- Conversion



Storage



Conversion



Supply **Transmission** **Demand**

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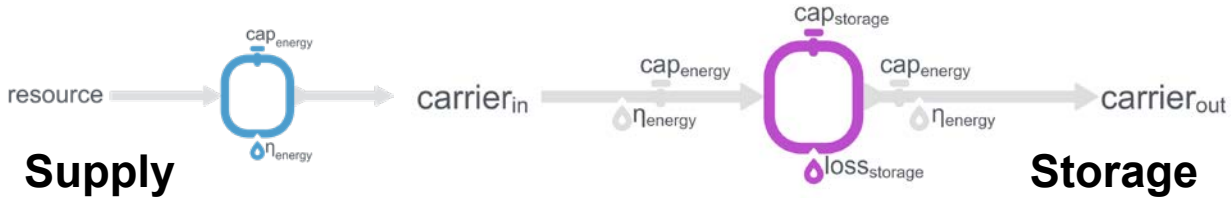
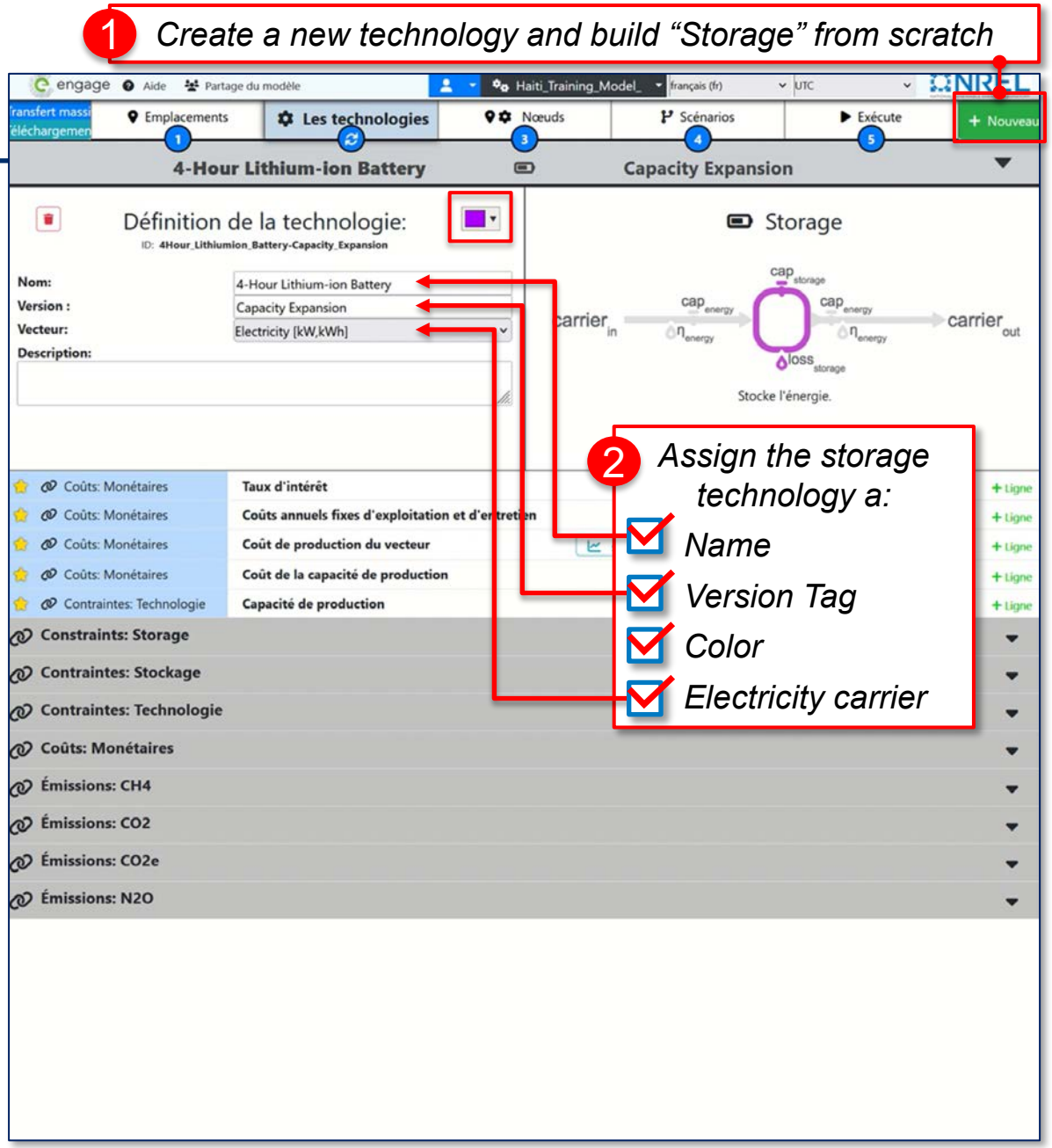
Storage Archetype



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



Electric batteries

Potential (kinetic) energy (ex:water at a height)

Electrochemical

Fuel (natural gas, diesel)

Storage Examples

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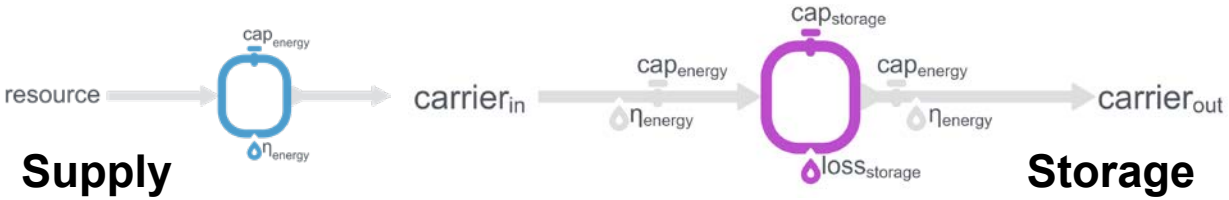
Storage Archetype



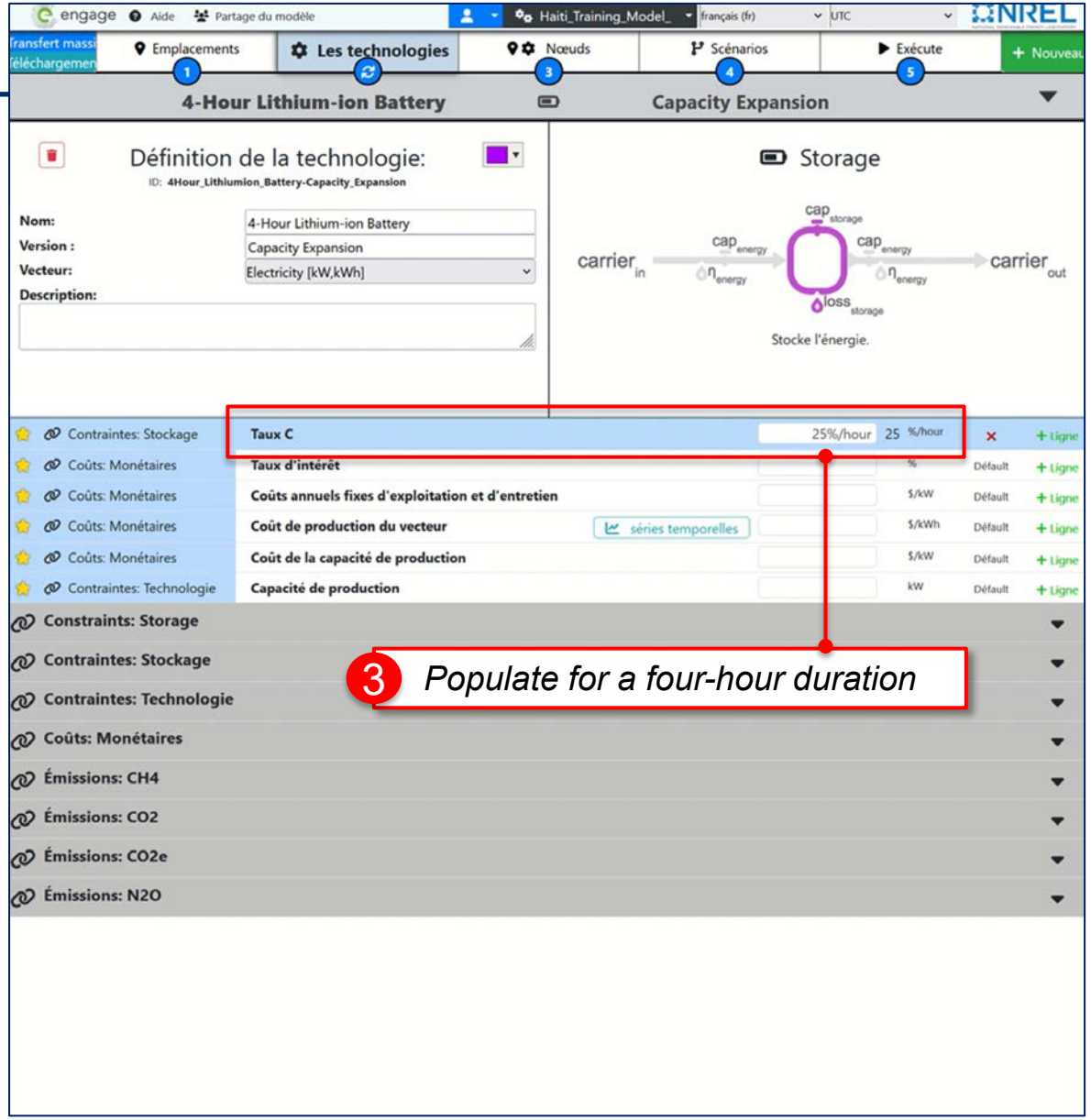
- ☑ C-rate

Indicates **storage duration** by describing the rate the technology can be discharged relative to its maximum capacity

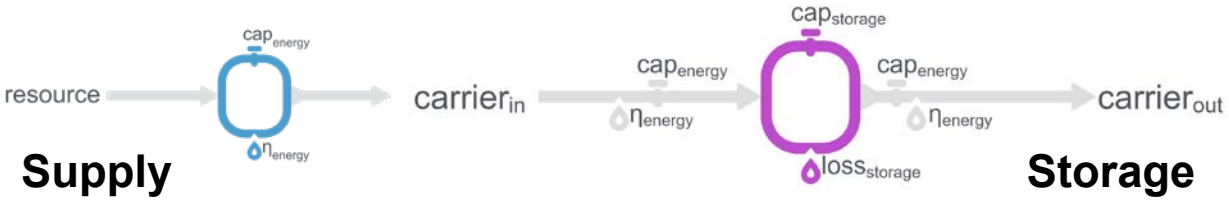
2-Hour Battery	=	50% / hour	(1/2)
4-Hour Battery	=	25% / hour	(1/4)
6-Hour Battery	=	~17% / hour	(1/6)
10-Hour Battery	=	10% / hour	(1/10)

Storage Examples

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



Storage Archetype



- ☑ C-rate — Indicates **storage duration** by describing the rate the technology can be discharged relative to its maximum capacity
- ☑ Storage capacity — Represents **total amount of carrier** the technology can store (ex: kWh)

Storage Examples

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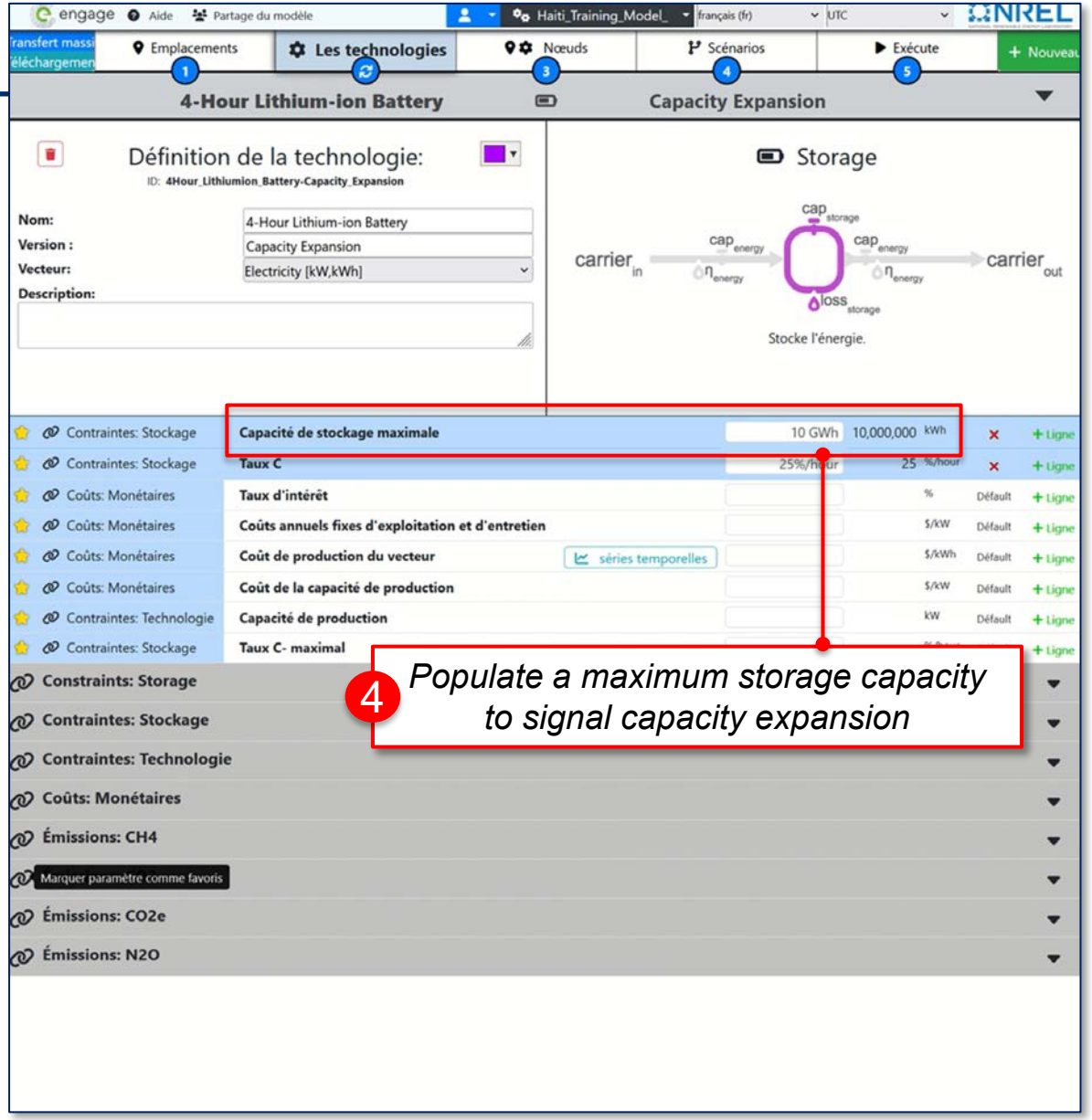

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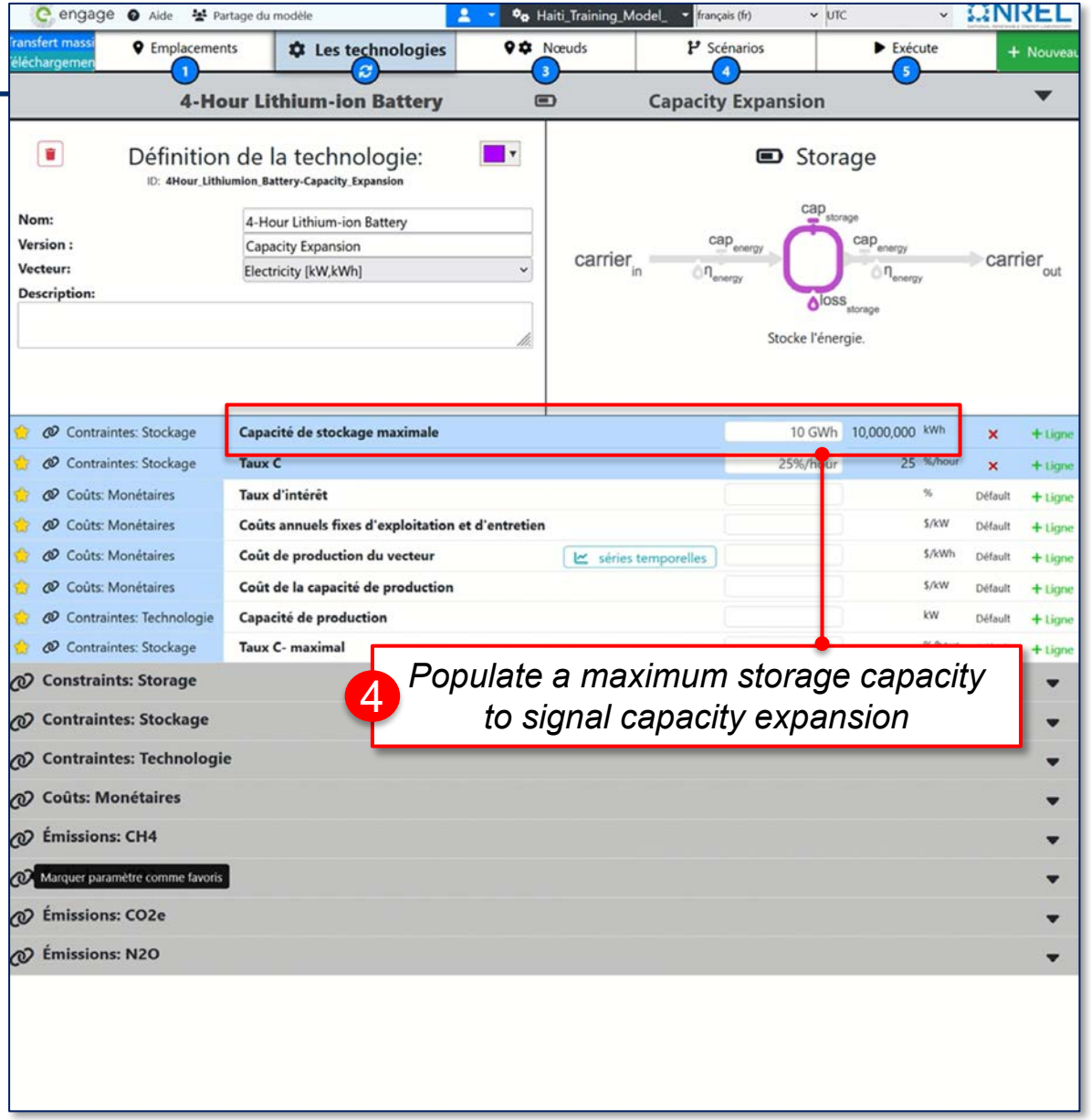
Linear Capacity Expansion

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



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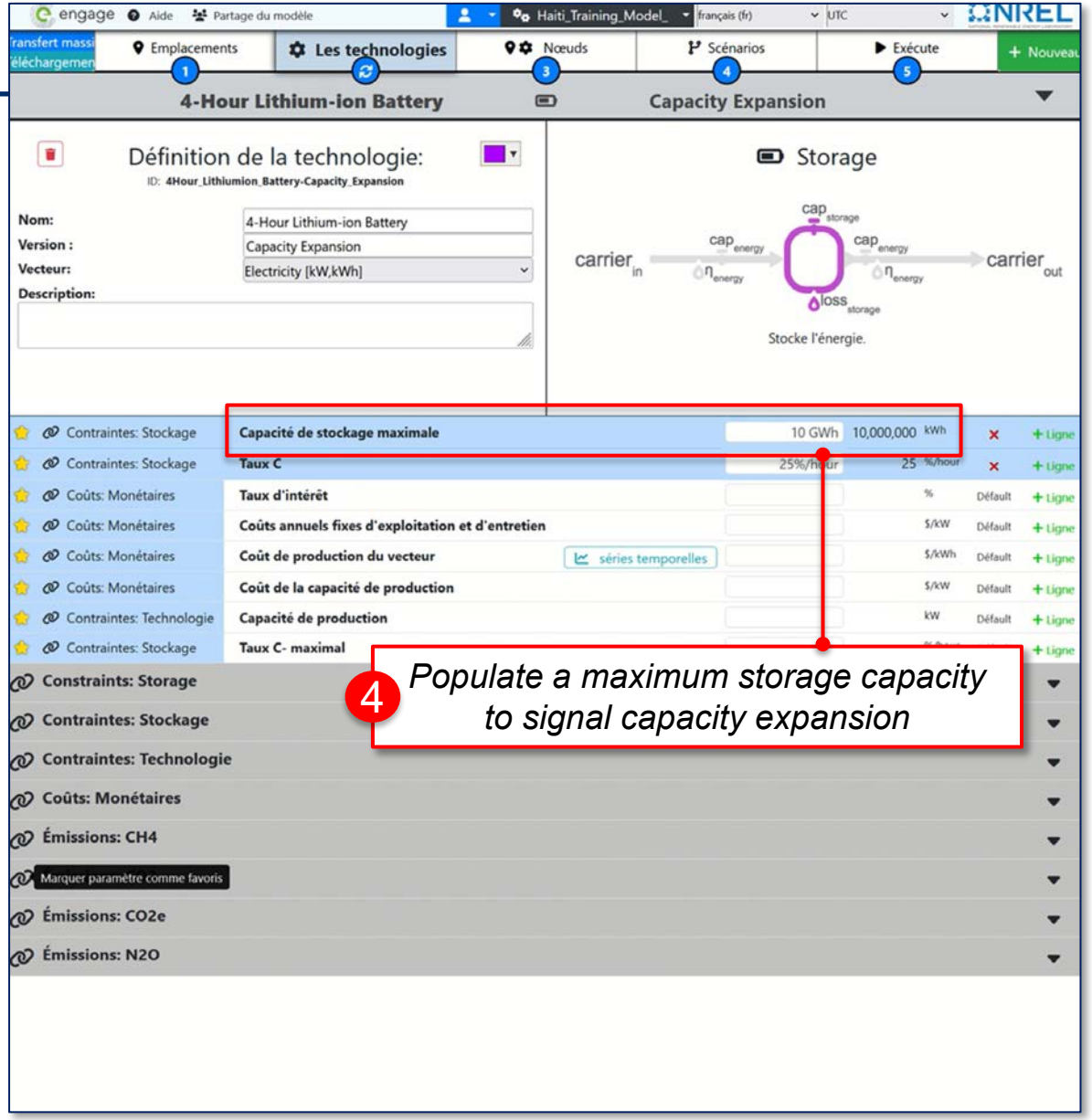
Storage	Maximum storage capacity	Storage capacity
Storage*	Maximum c-rate	C-rate

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



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Linear Capacity Expansion

- Maximum function

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

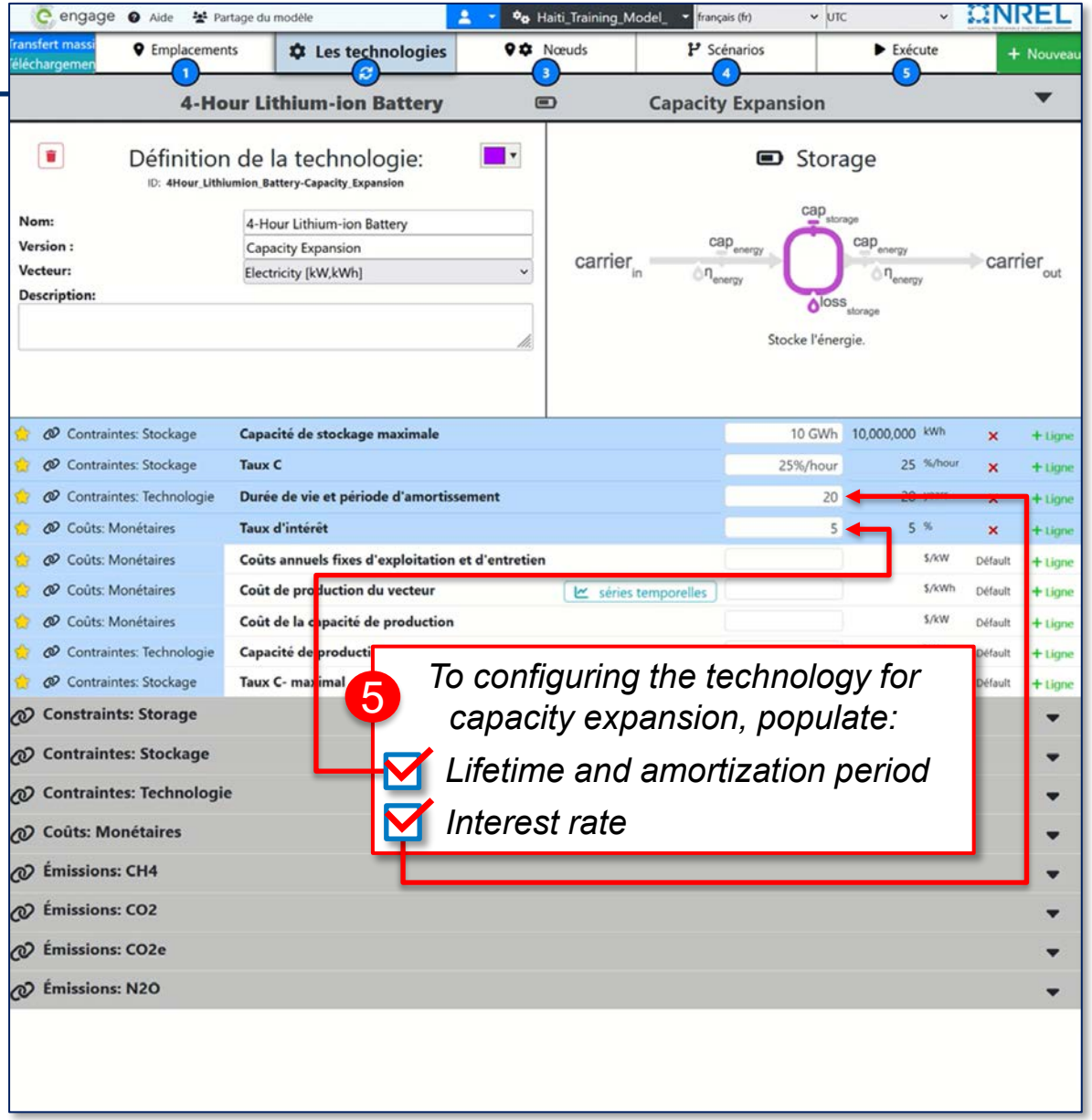
- Lifetime and amortization period

- Interest rate

Relates to how Engage treats **cashflows**

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

0101
1100
0010



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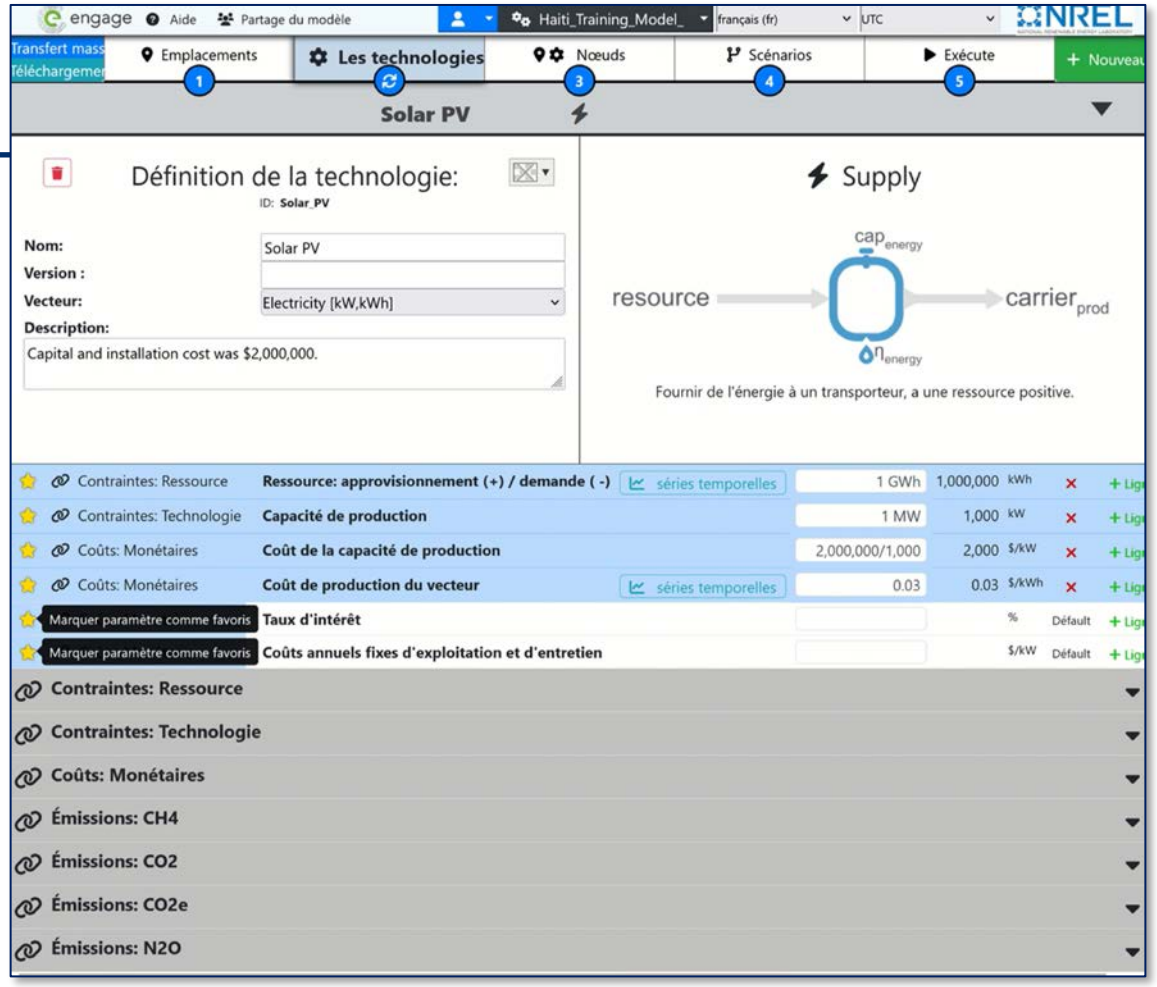

$**2,000,000** for a 1 MW solar farm

20-year technological lifespan

≈ $**100,000**

≈ $**160,000***

** With 5% interest rate*

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Linear Capacity Expansion

Maximum function

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

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

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

Annual Technology Baseline

Populated framework that identifies **technology-specific costs** as they relate to:

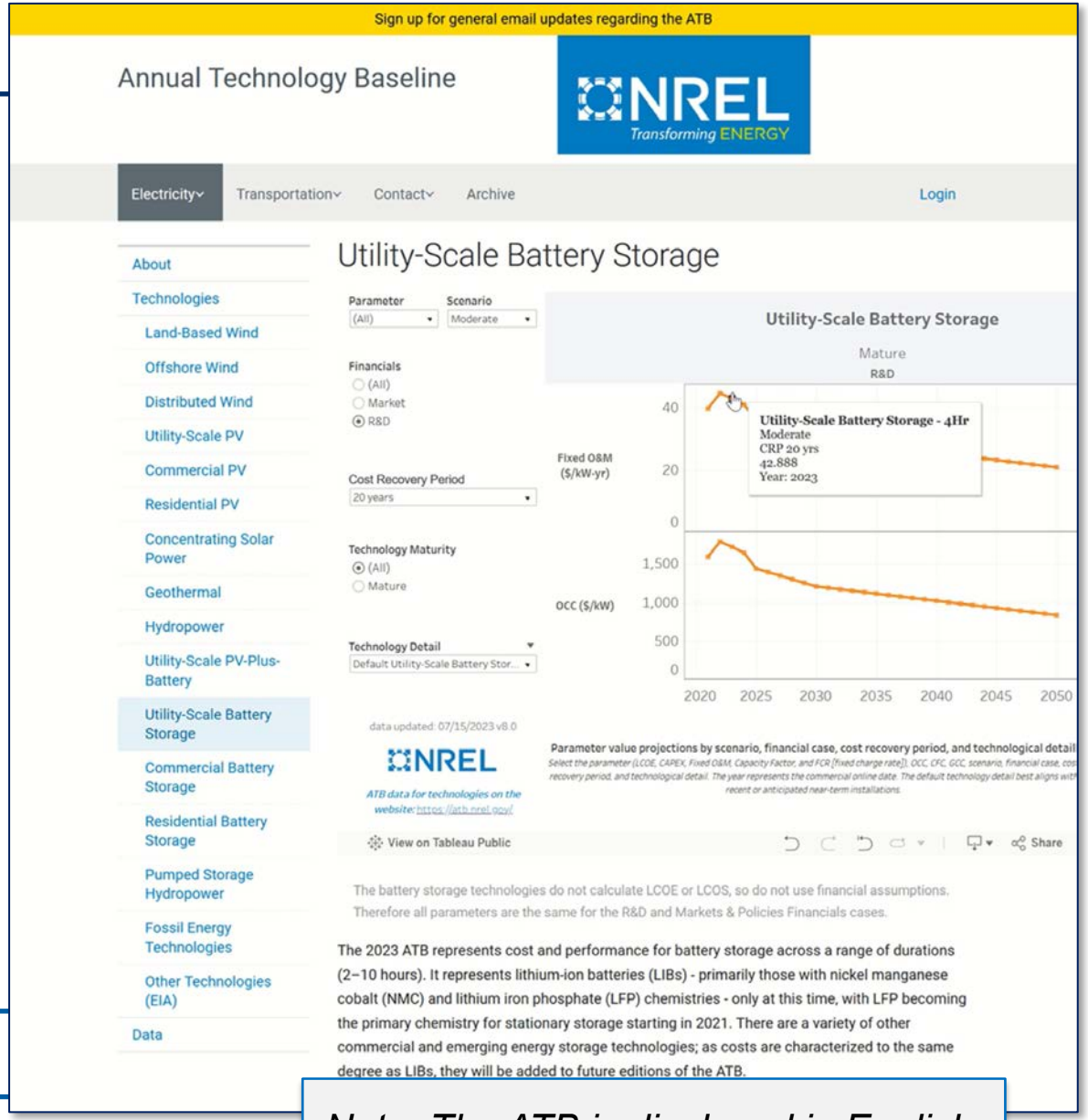
- Performance parameters under a robust set of modeling inputs that consider:
  - Electricity generation futures
  - Financial modeling scenarios

ATB uses assumption primarily focused within the United States market

Historical cost data for projects is always preferrable since it considers **local conditions**

Overnight capital cost (OCC): $1,715.50 / kW

Fixed operation and maintenance (O&M): $42.88 / kW



atb.nrel.gov

Note: The ATB is displayed in English.

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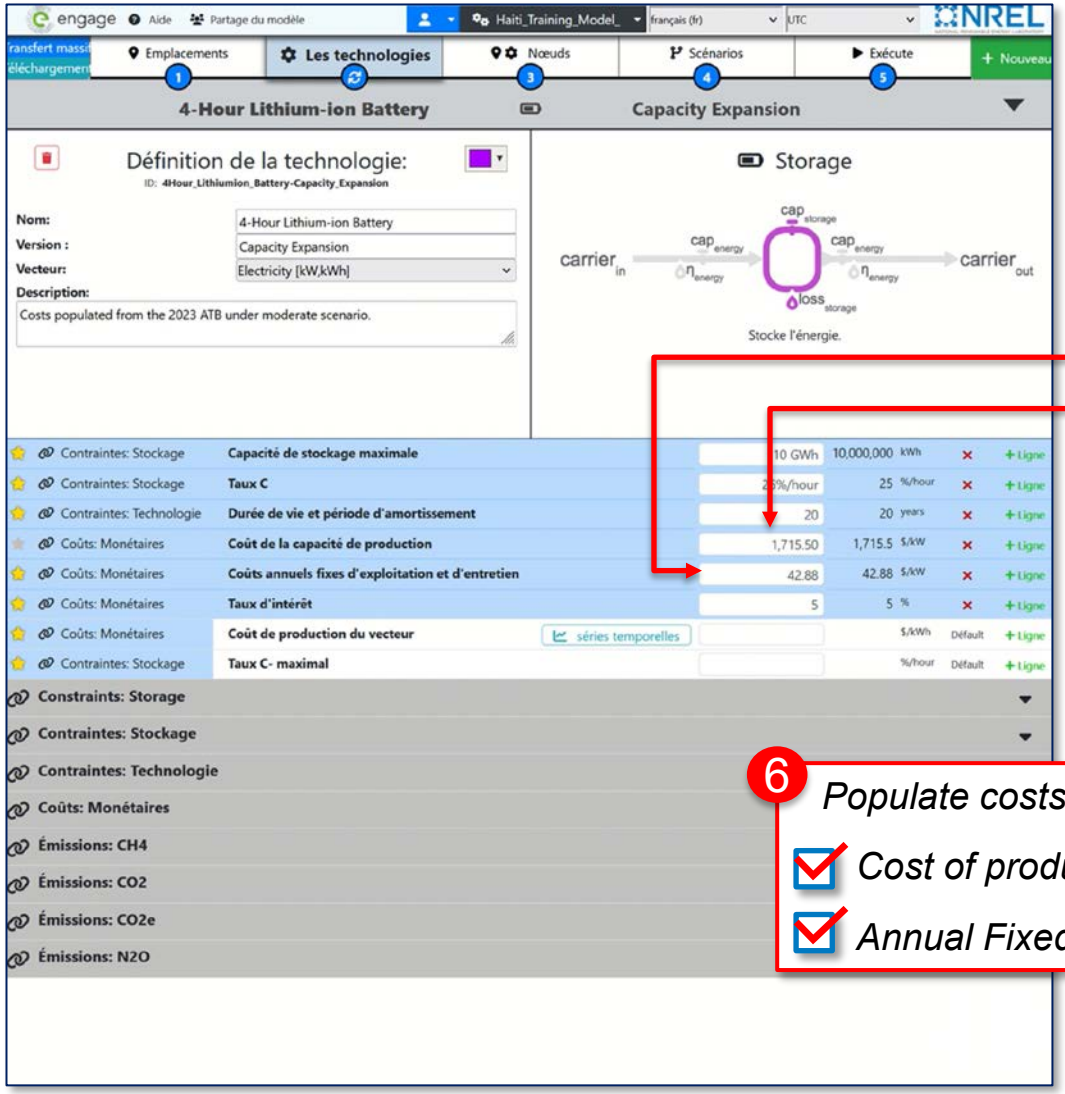
Annual Technology Baseline



6 *Populate costs from the ATB for:*

- ☑ *Cost of production capacity*
- ☑ *Annual Fixed O&M Costs*

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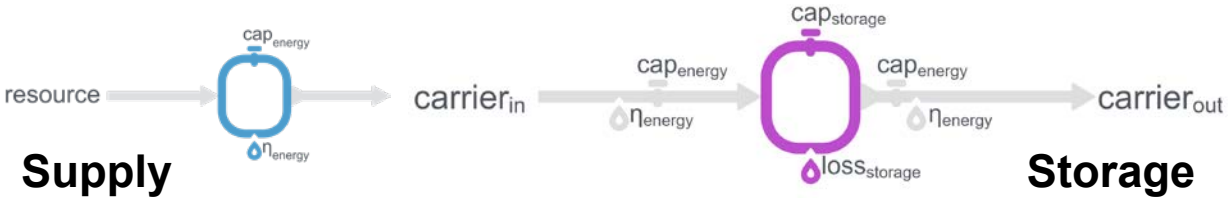
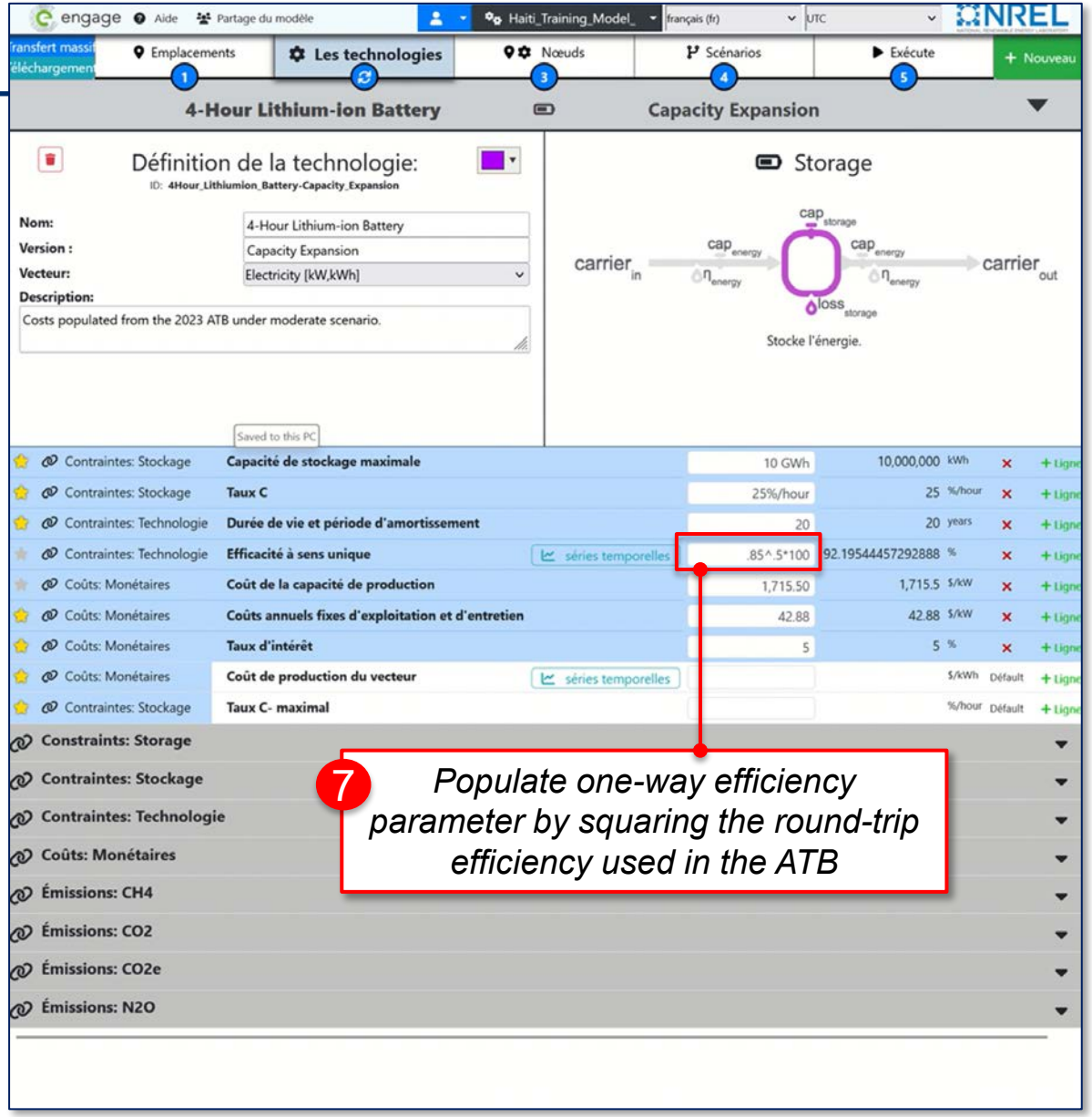
Storage Archetype



- **C-rate** — Indicates **storage duration** by describing the rate the technology can be discharged relative to its maximum capacity
- **Storage capacity** — Represents **total amount of carrier** the technology can store (ex: kWh)
- **One-way efficiency** — Measures the **loss in storing a carrier**, whether on the charging or discharging side

Storage Examples

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



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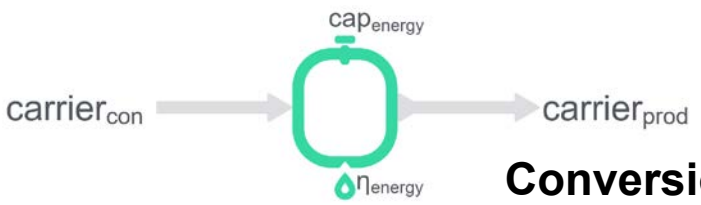
Conversion Archetype



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

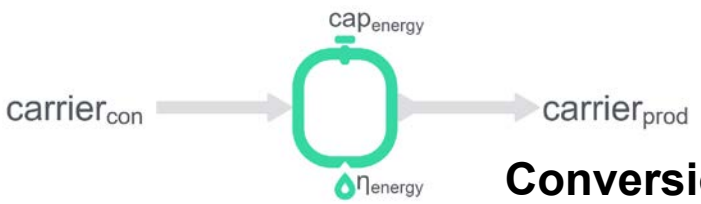
Conversion Examples

- Combined cycle gas turbine (CCGT)
- Coal power plant
- Natural gas boiler
- Electric transformer

Conversion Archetype

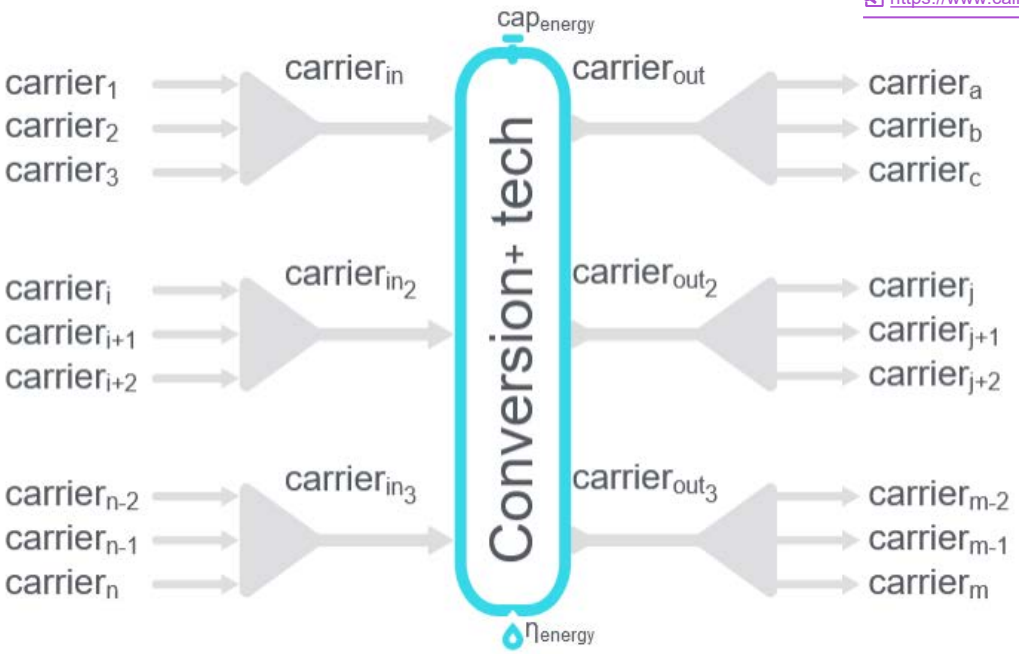
Read more about Conversion Plus under the Calliope Documentation in Engage.

https://www.callio.pe/



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
- Conversion Plus archetype is ideal for modeling complex technologies with **multiple input** and **output carriers**



Conversion Plus

Conversion Examples

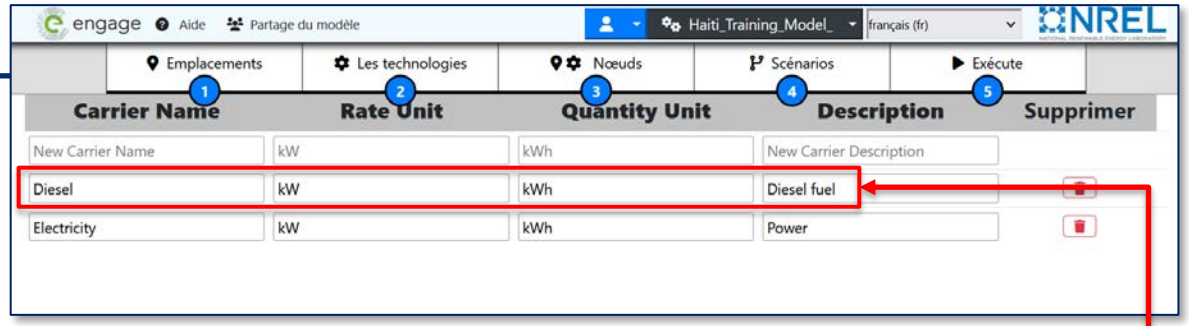
- Combined cycle gas turbine (CCGT)
- Coal power plant
- Natural gas boiler
- Electric transformer

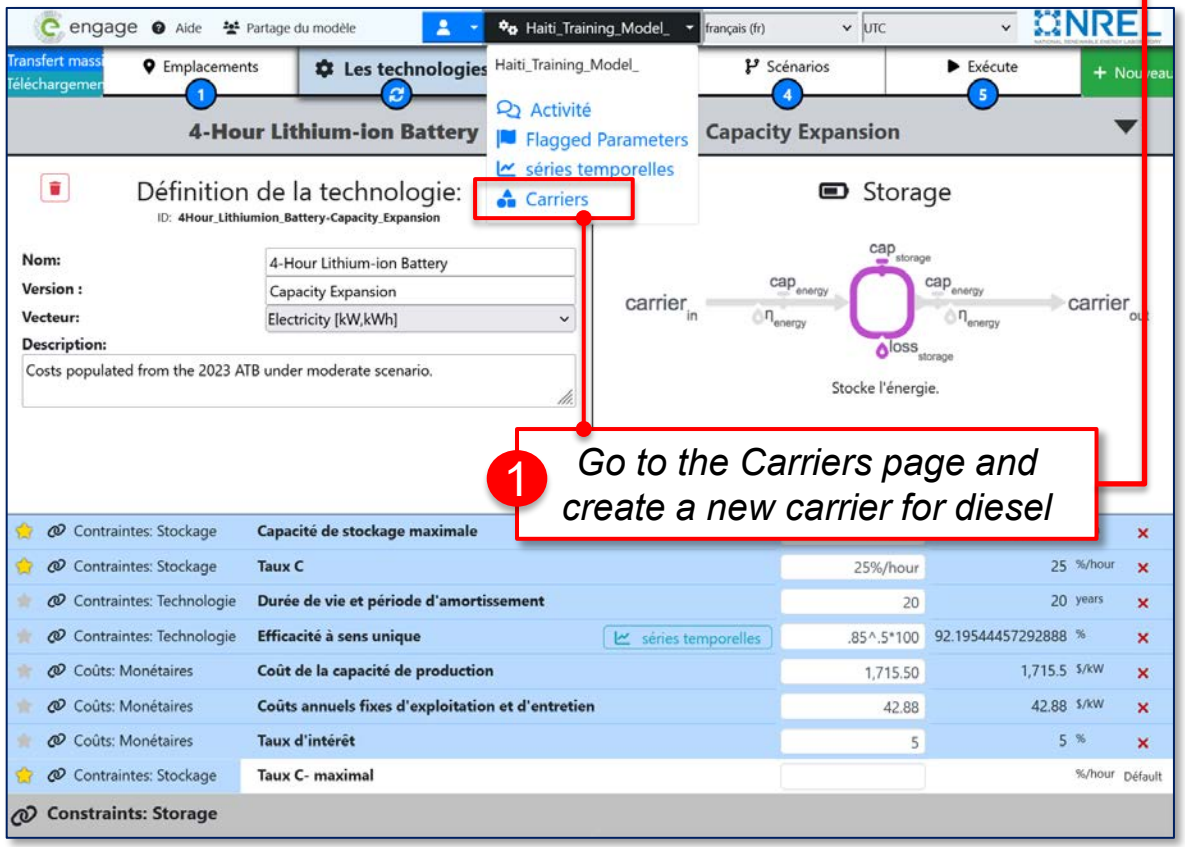
Conversion Plus Examples

- Advanced gas turbines
- Combined heat and power (CHP)
- Air source heat pumps

Diesel Supply

- Resource: Supply/Demand — Represents **fuel availability** of diesel for backup generator
- Carrier Production Cost — Represents **fuel price** for diesel





Diesel Supply

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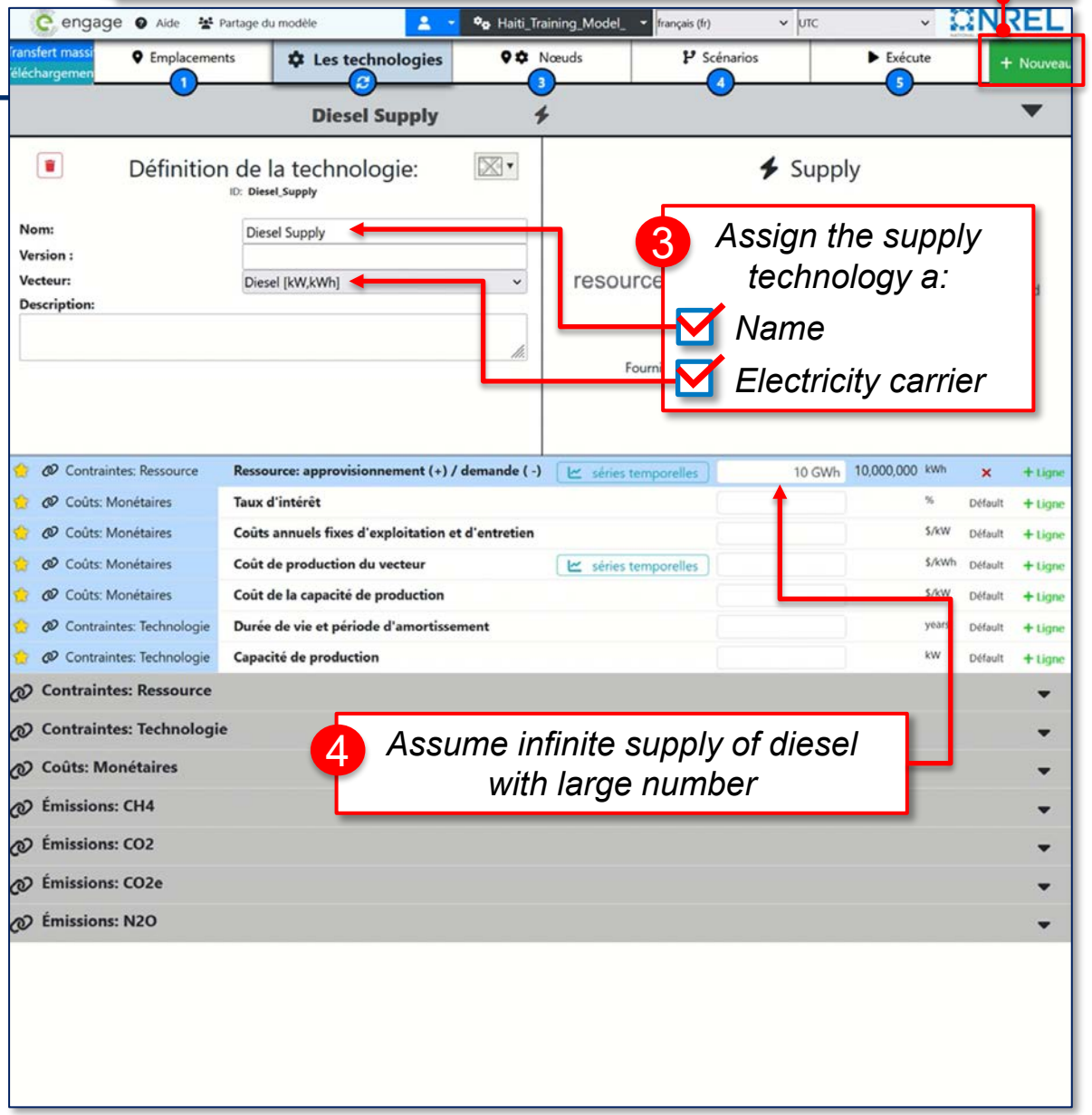
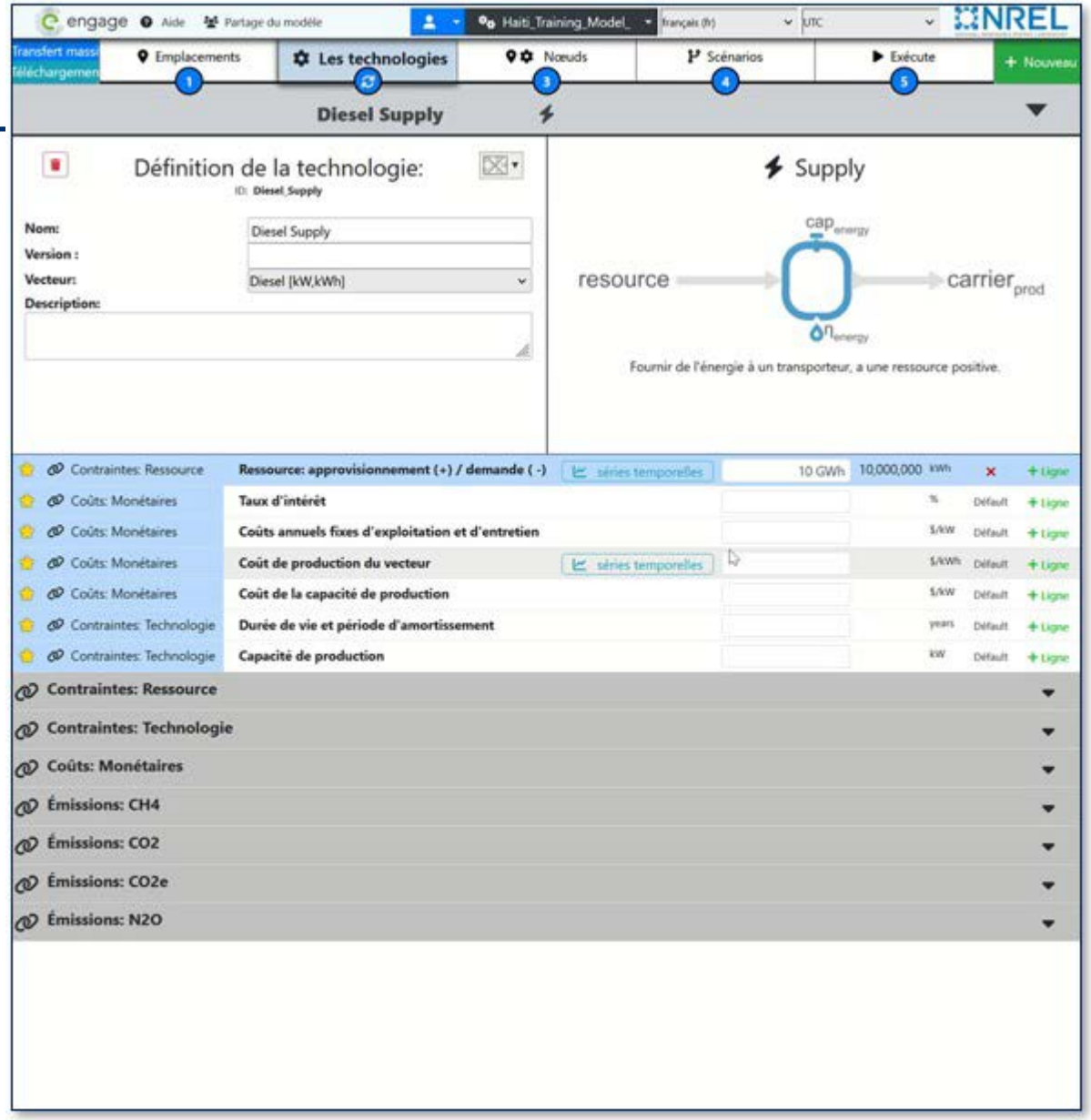
- Carrier Production Cost — Represents **fuel price** for diesel

2 *Create a new technology and build "Supply" from scratch*



Diesel Supply

- Resource: Supply/Demand — Represents **fuel availability** of diesel for backup generator
- Carrier Production Cost — Represents **fuel price** for diesel
  - → $3 per **gallon**



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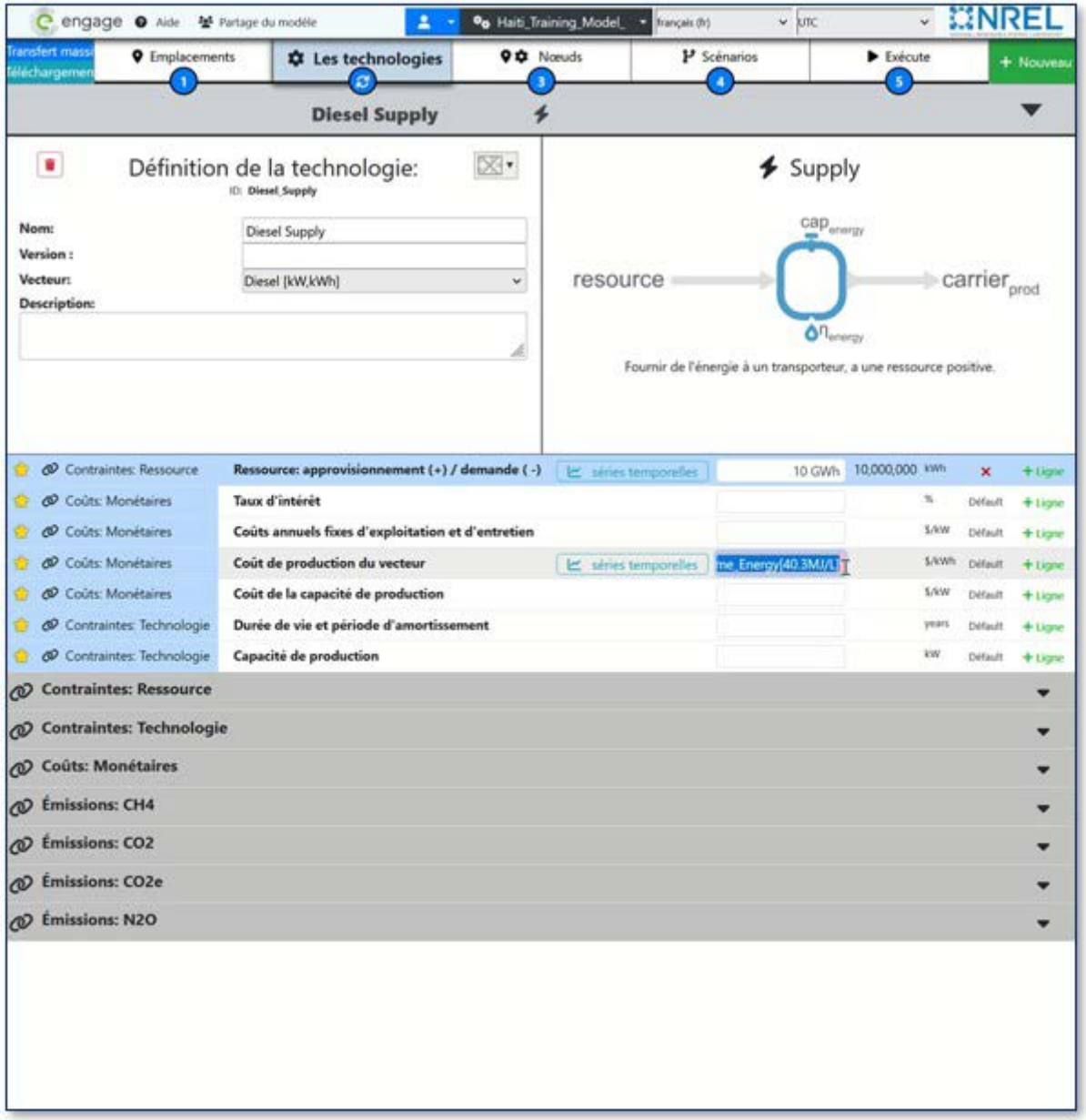
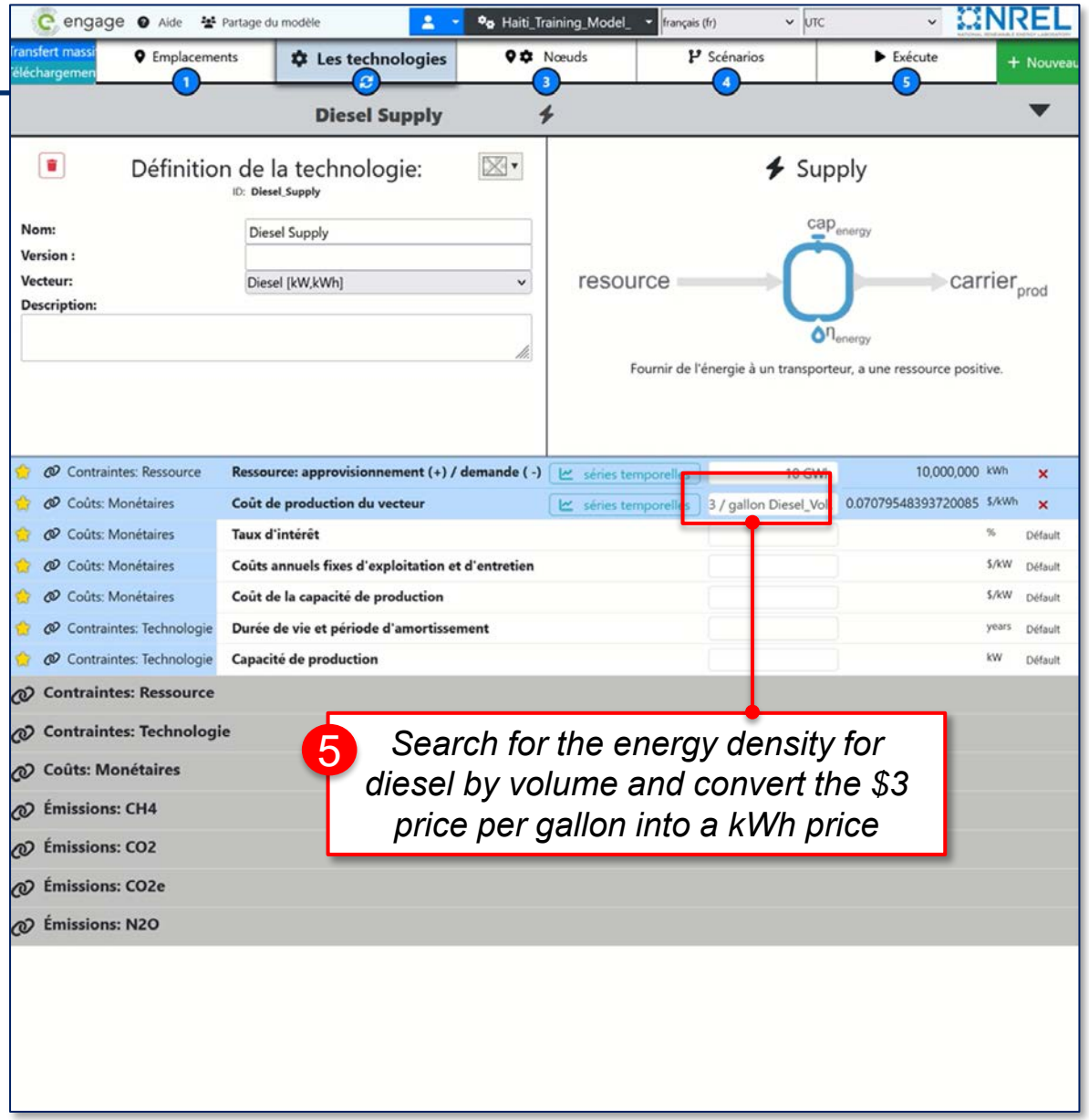


Diesel Supply

- ☑ Resource: Supply/Demand — Represents **fuel availability** of diesel for backup generator
- ☑ Carrier Production Cost — Represents **fuel price** for diesel
  - ↳ $3 per **gallon**

- Structure inputs in **compatible or equivalent** units 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



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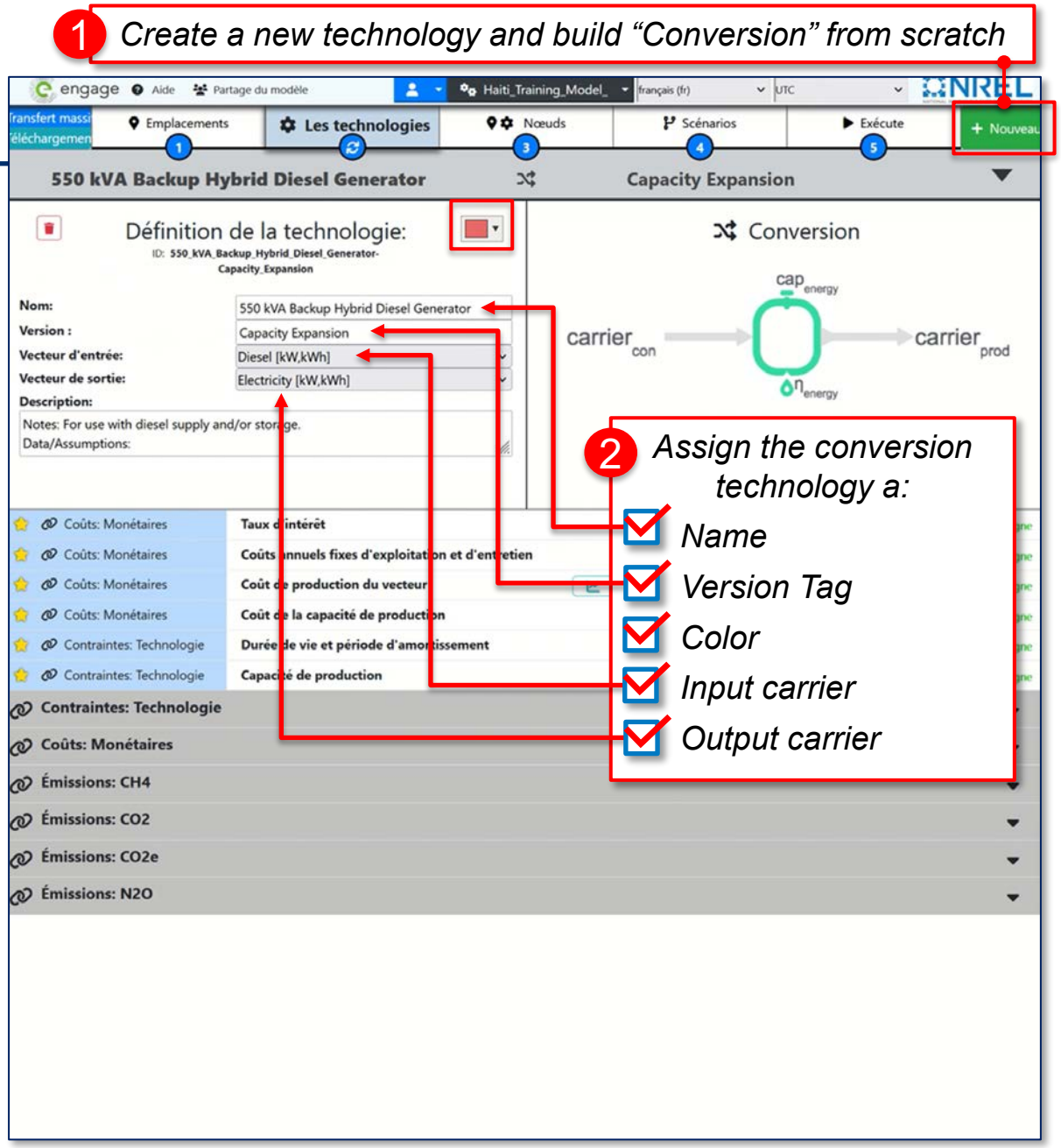
Backup Diesel Generator



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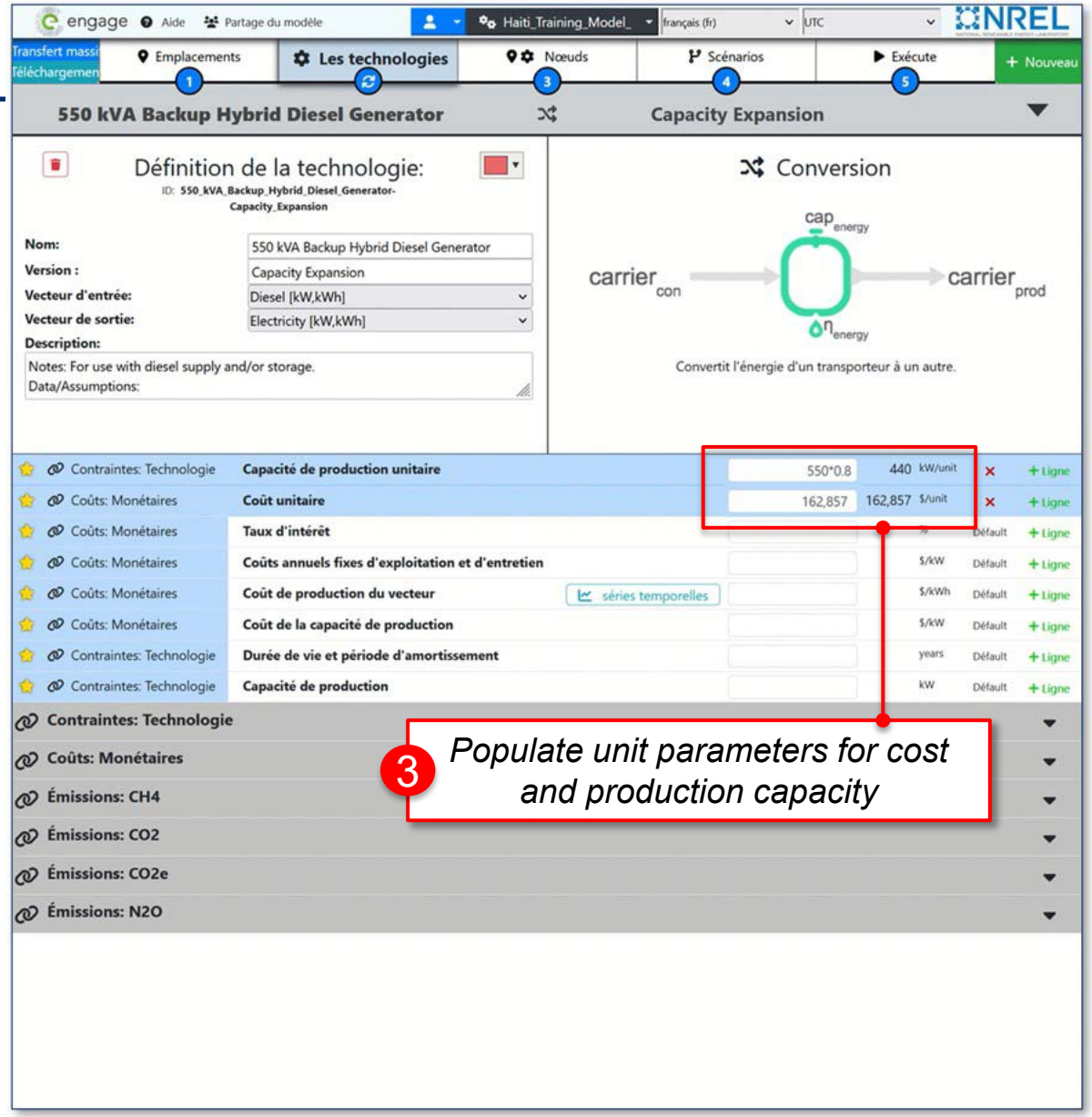
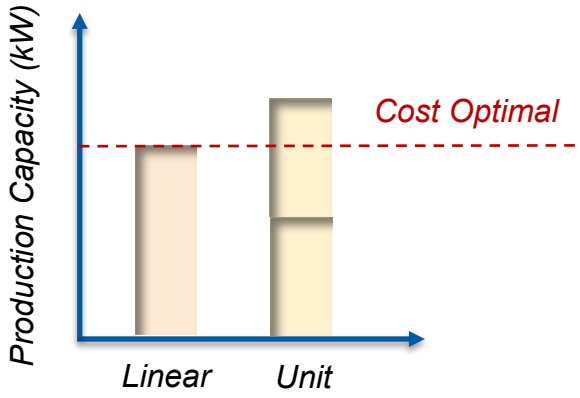
550 kVA × 80% = 440 kW

Apparent Power × **Power Factor**



Unit Capacity Expansion

Maximum number of units

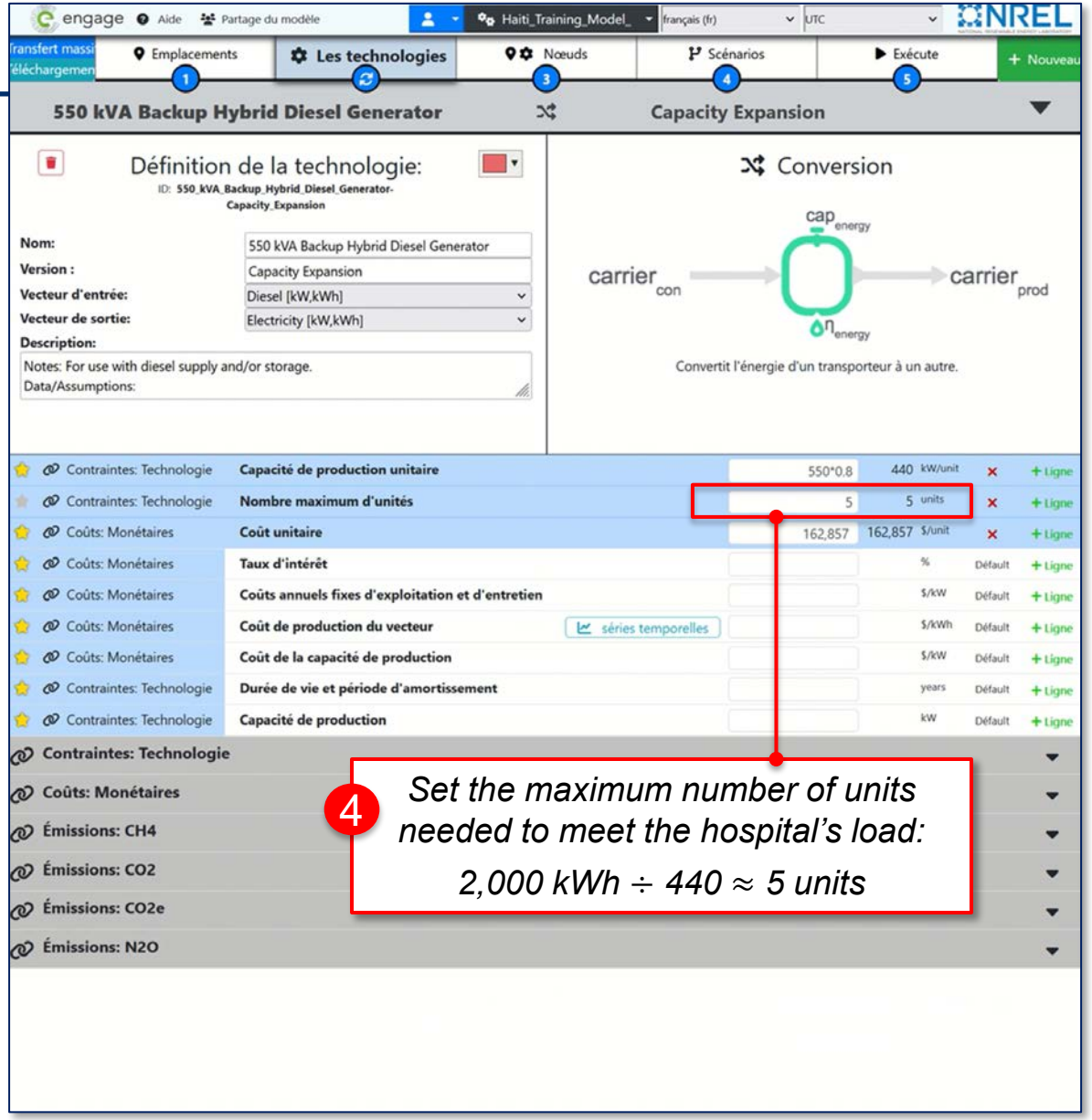


Model **linearly expands** resource to the cost optimal point

Linear Expansion

Model determines cost optimal **number of units**

Unit Expansion



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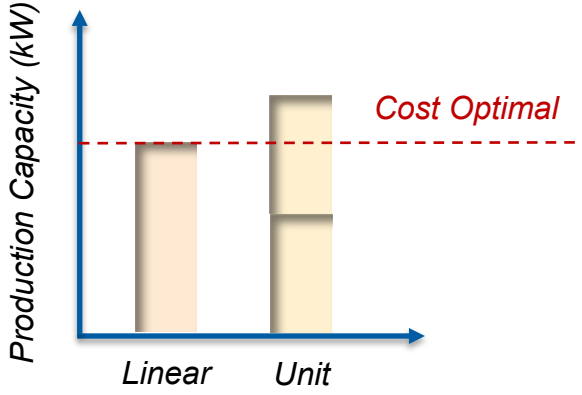

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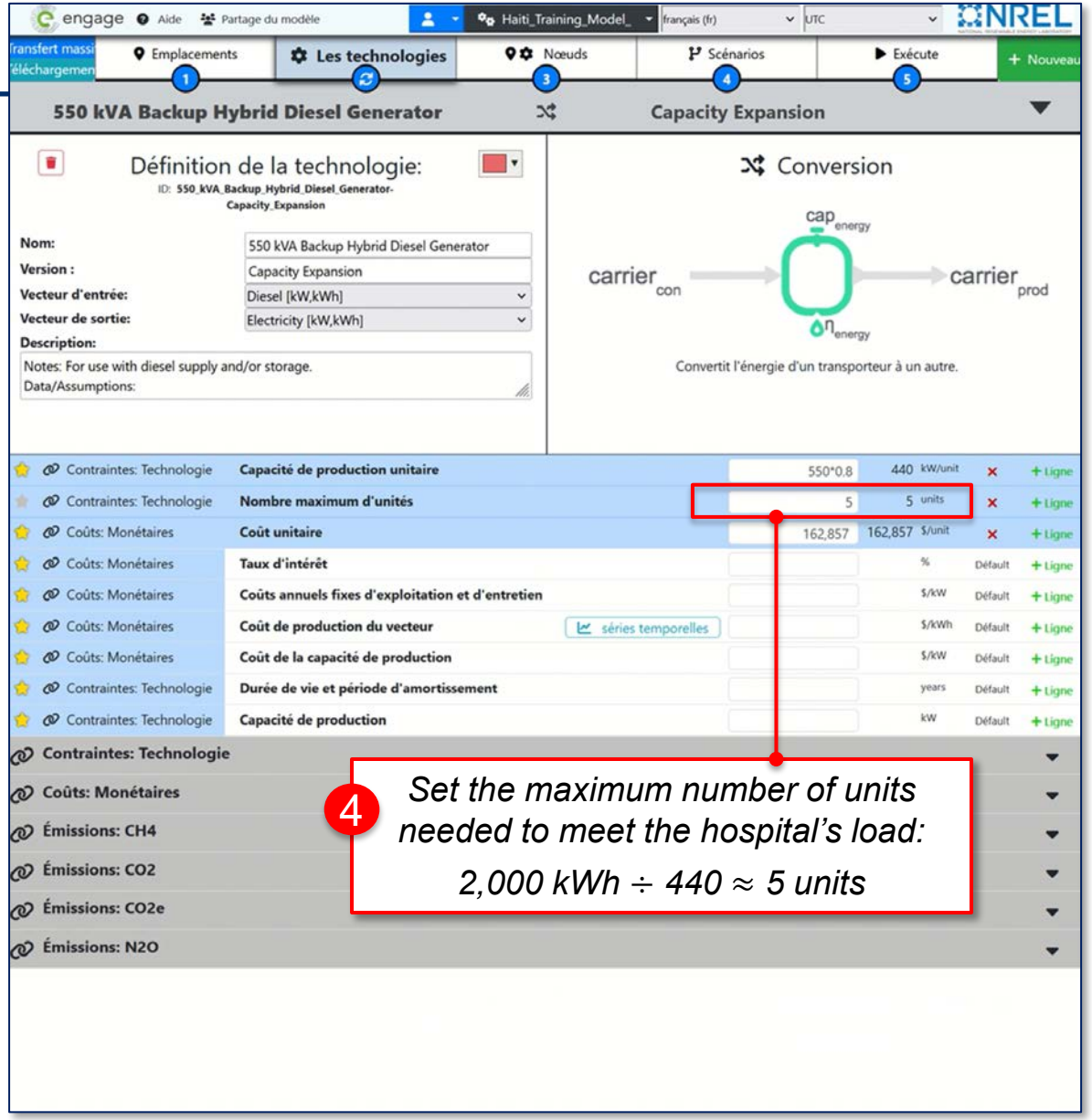
- **Challenge**: More algorithmically complex to the point of becoming computationally unsolvable



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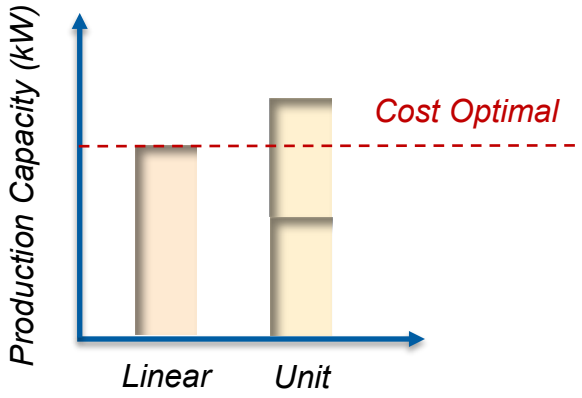

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Linear Expansion

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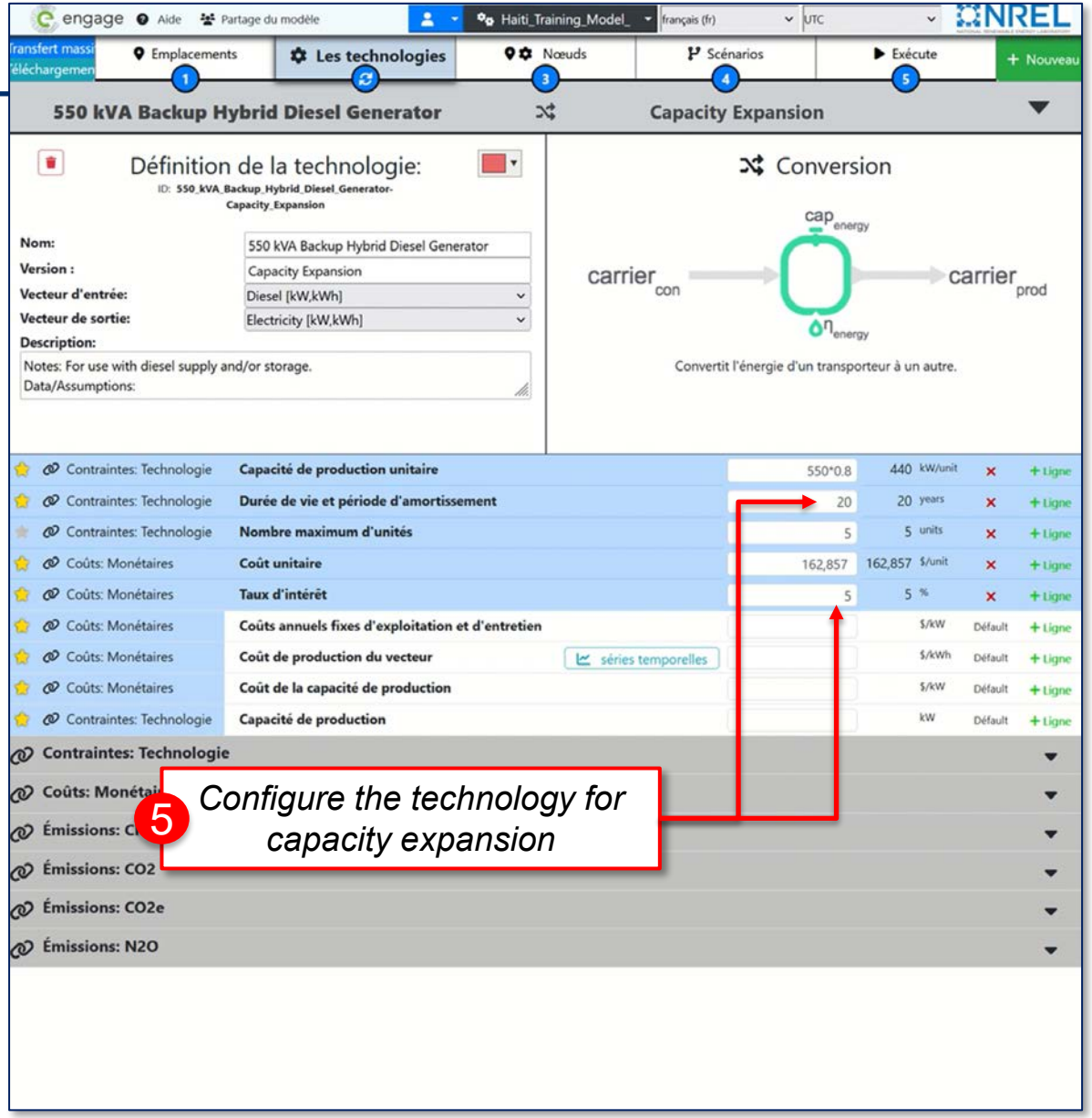
Unit Expansion

- **Advantage**: Closer to real-world investment decisions with limited foresight
- **Challenge**: More algorithmically complex to the point of becoming computationally unsolvable

- Lifetime and amortization period
- Interest rate



Backup Diesel Generator

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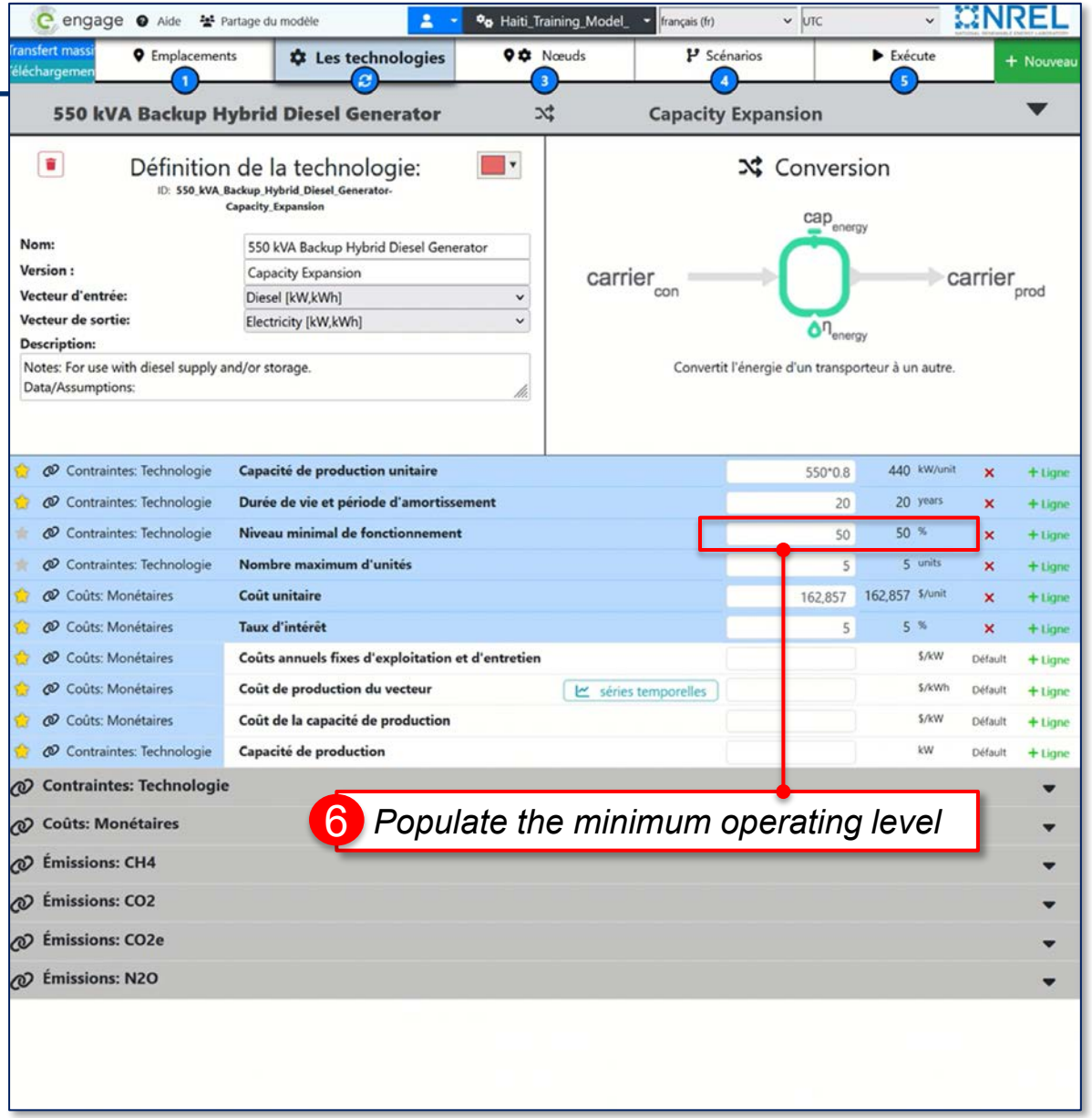
  550 kVA × 80% = 440 kW

  Apparent Power × **Power Factor**
- **Minimum operating level** — Requires a **minimum fraction** of the maximum production capacity to operate – 50%



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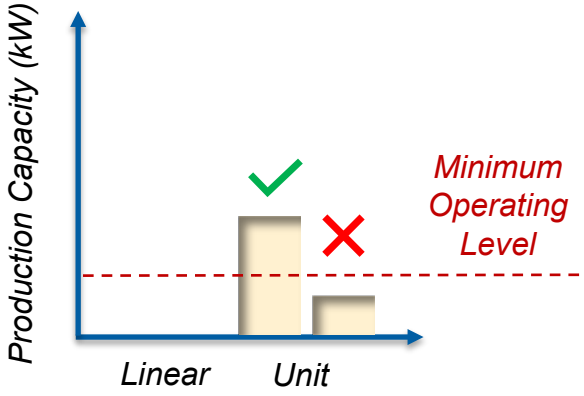
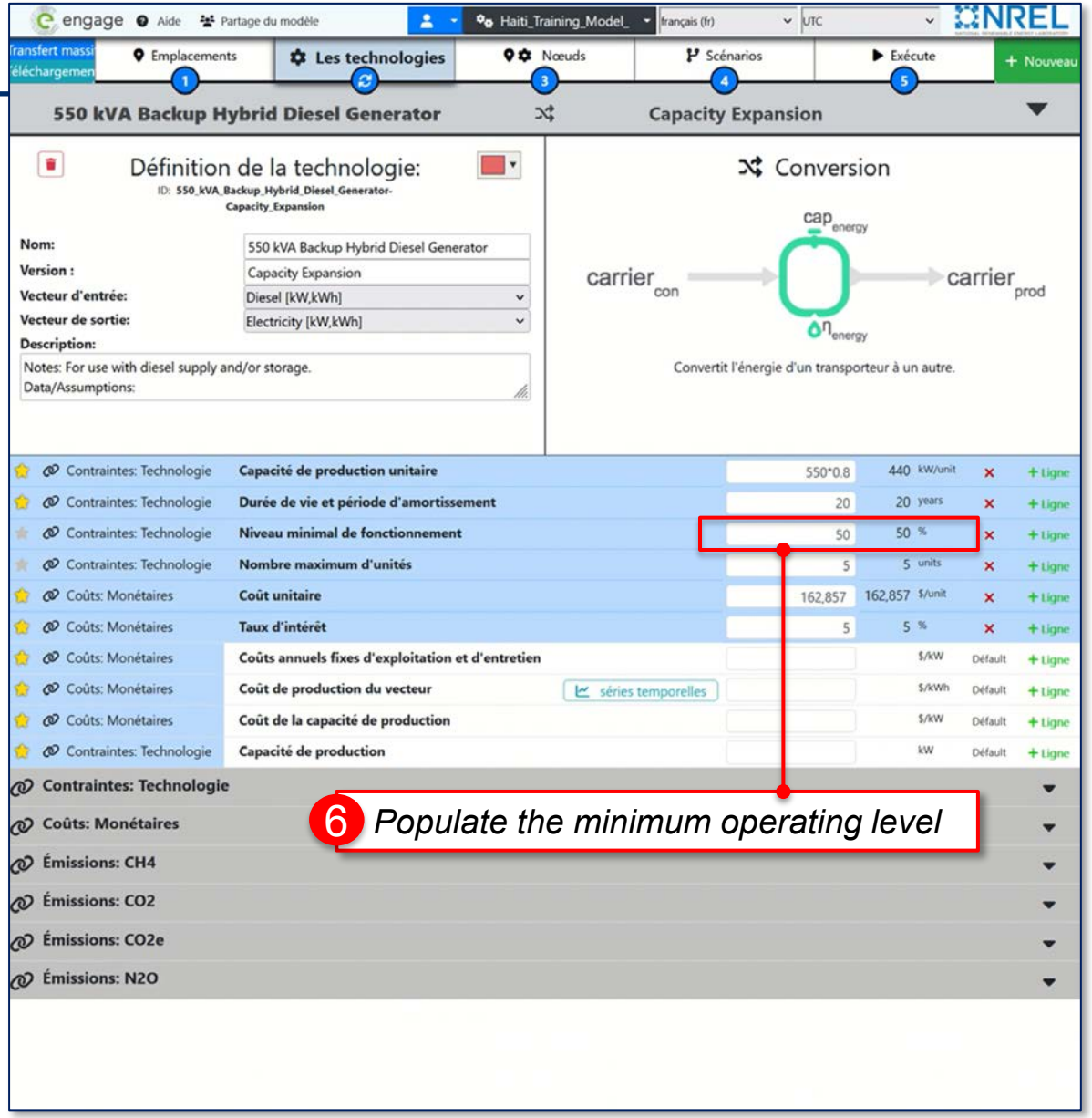


Unit Advantage:

Capable of modeling real-world minimum operating conditions where **technology is shut down** if it cannot operate above a certain capacity



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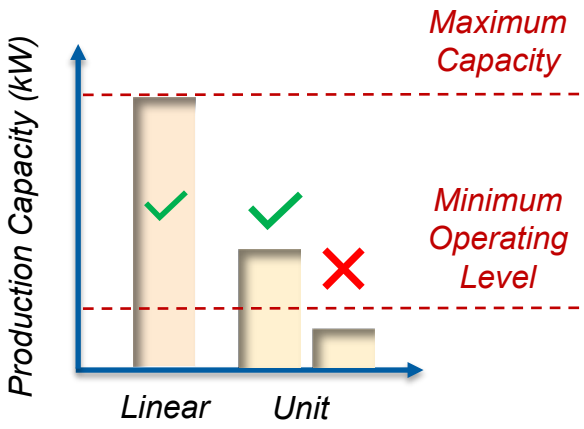
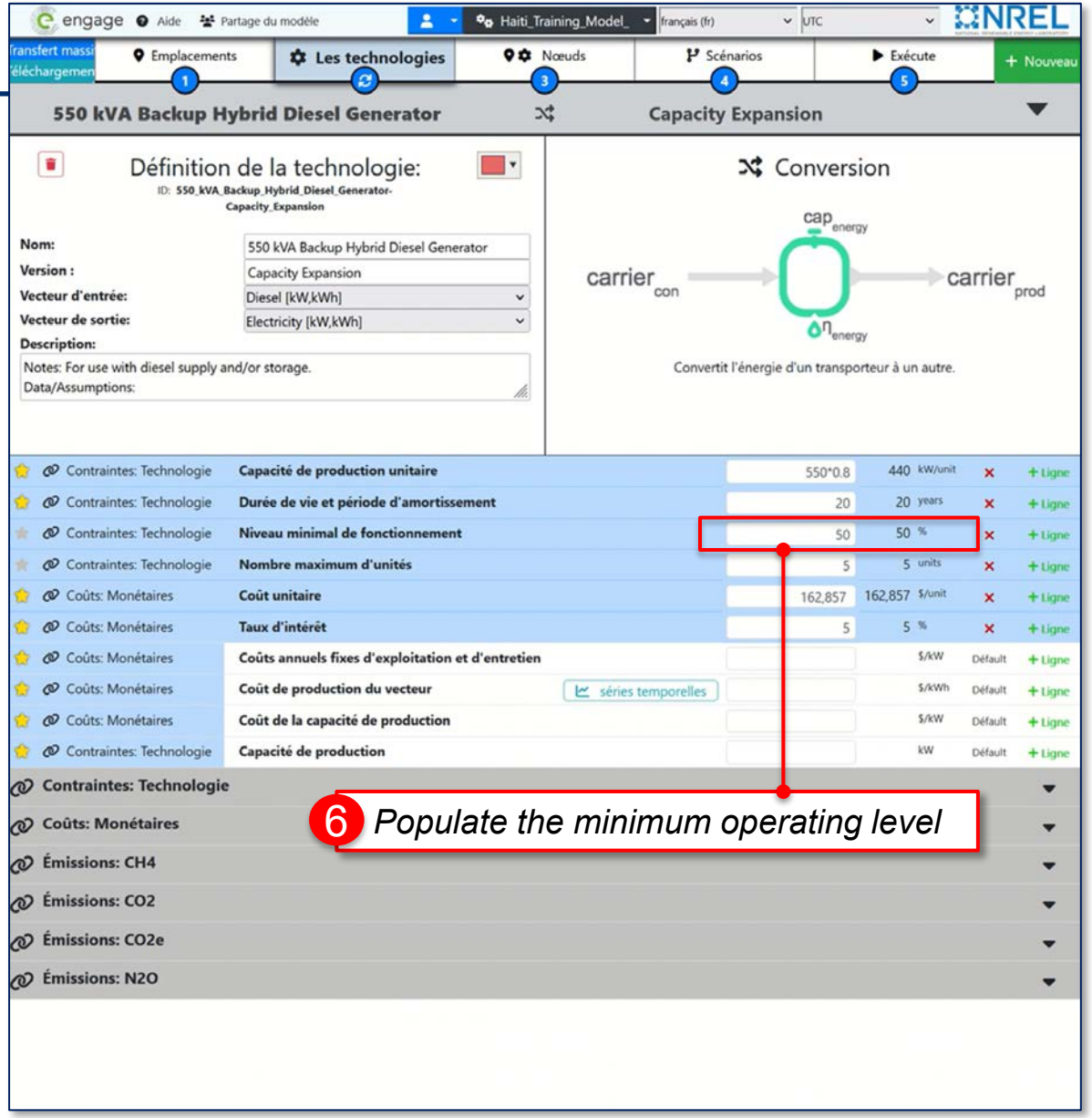


Linear Challenge:

Interprets minimum operating levels as the **required minimum** operating capacity



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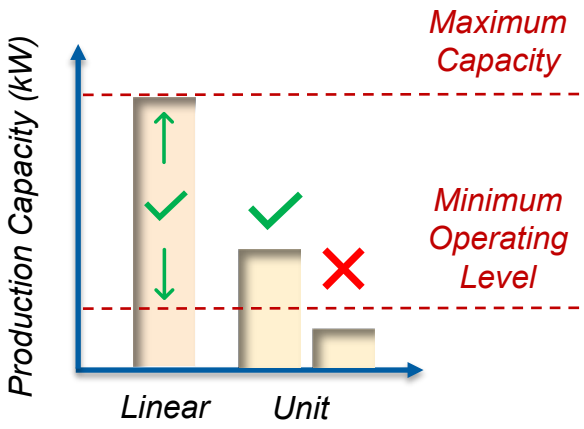
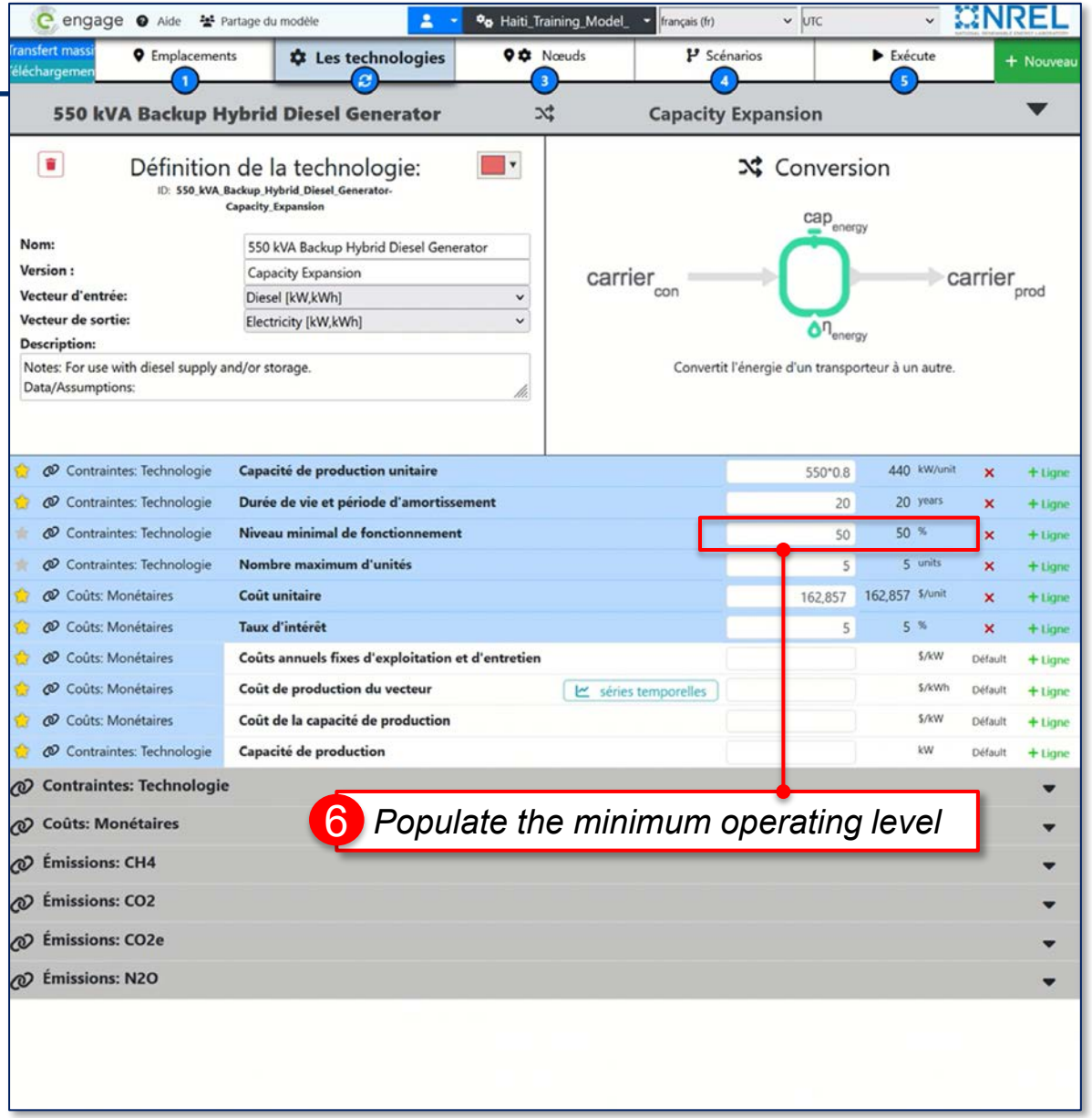


Linear Challenge:

Creates **operating floor** where technology operates between maximum and minimum level and **never shuts off**



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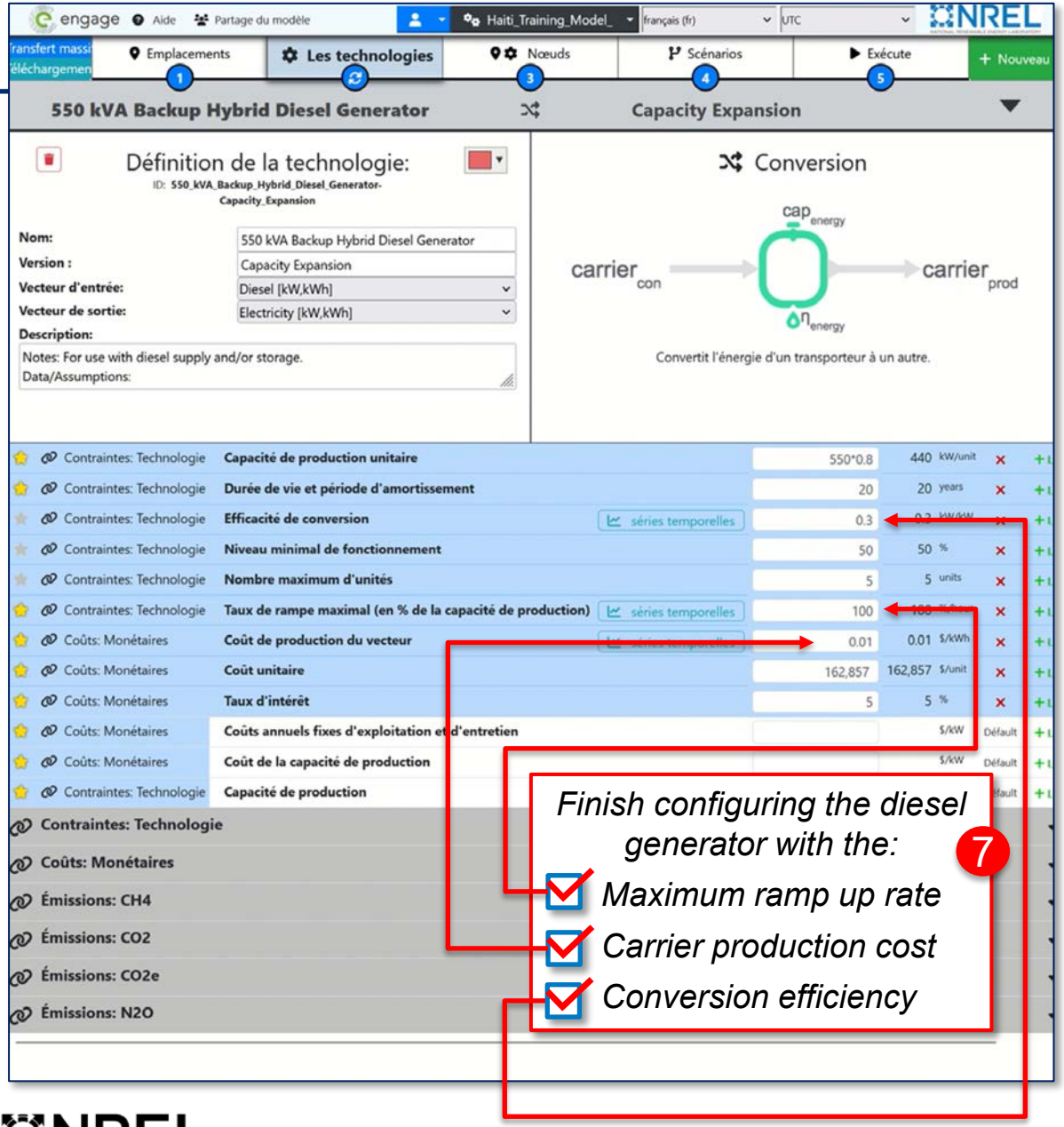
- **Minimum operating level** — Requires a **minimum fraction** of the maximum production capacity to operate – 50%
- **Maximum ramp up rate** — Describes **time needed** before technology is at maximum capacity – 100% / hour
- **Conversion efficiency** — Measures the **conversion rate** between input and output carriers – 30% for diesel to electricity
- **Carrier production cost** — Represents **variable** operation and maintenance cost - $0.01 / kWh



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Model Building Process

1 Locations

2 Technologies

3 Nodes

4 Scenarios

5 Runs

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Model Building Process

1 **Locations**

2 **Technologies**

Nodes

Scenarios

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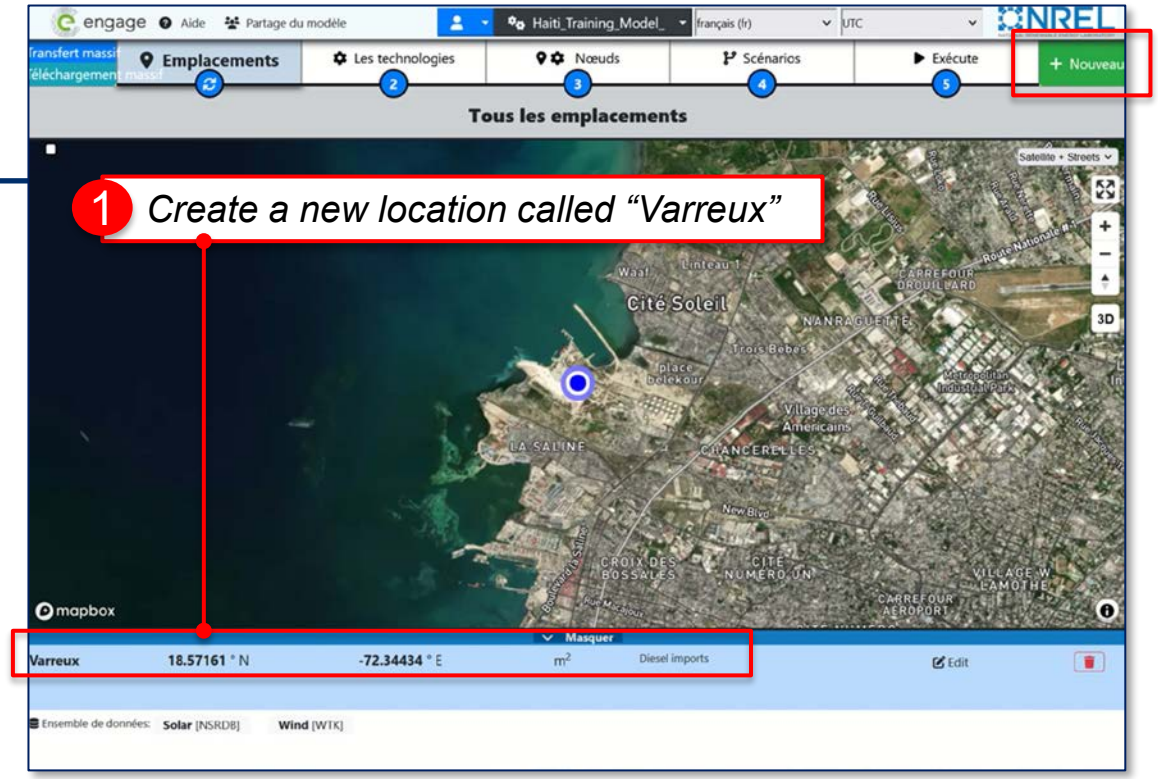
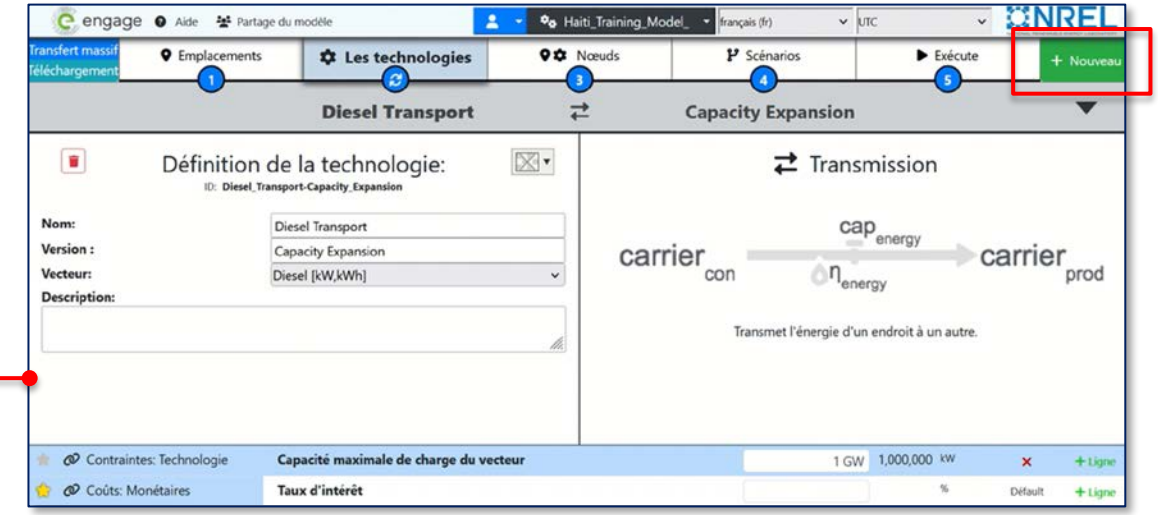
engage

1. Create **a new location** called “Varreux”
2. Create **new transmission technology** called “Diesel Transport”



1 *Create a new location called “Varreux”*



2 *Create a new transmission technology for “Diesel Transport”*

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Model Building Process

1 **Locations**

2 **Technologies**

3 **Nodes**

Scenarios

Runs

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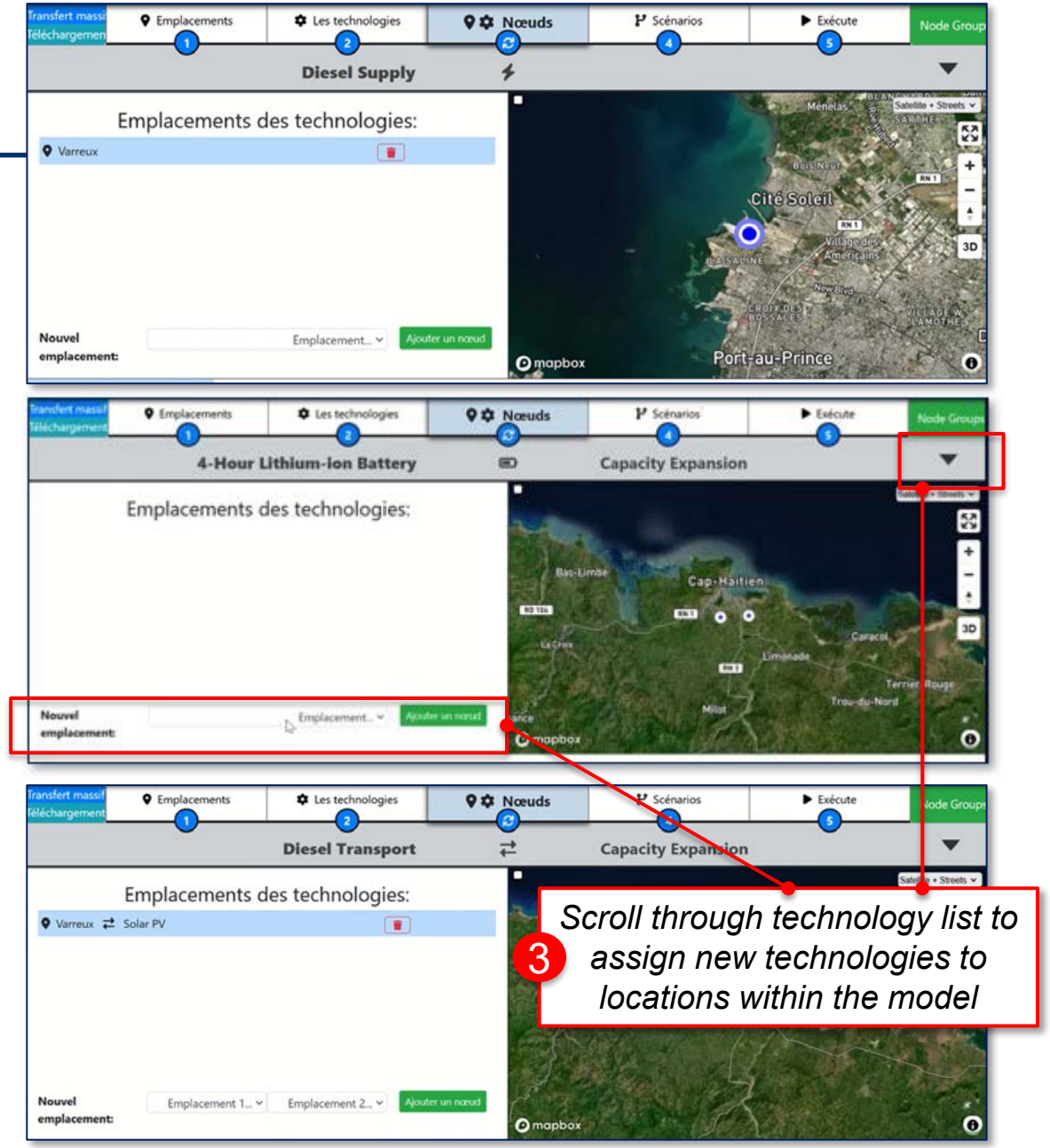
1. Create **a new location** called “Varreux”
2. Create **new transmission technology** called “Diesel Transport”
3. Under Nodes tab, **assign**:
   - Diesel Supply to Varreux
   - Diesel generator to Solar PV and battery to Hospital
   - Diesel Transport to Varreux and Solar PV



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Model Building Process

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3. Under Nodes tab, **assign**:
   - Diesel Supply to Varreux
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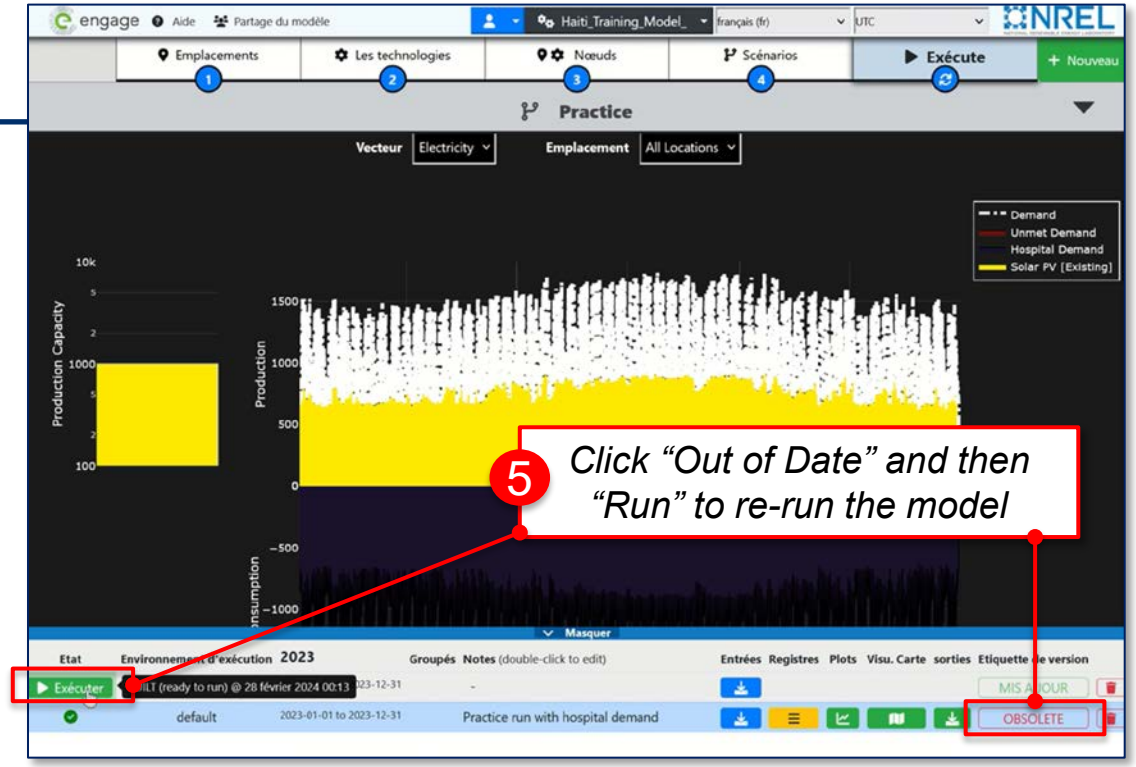
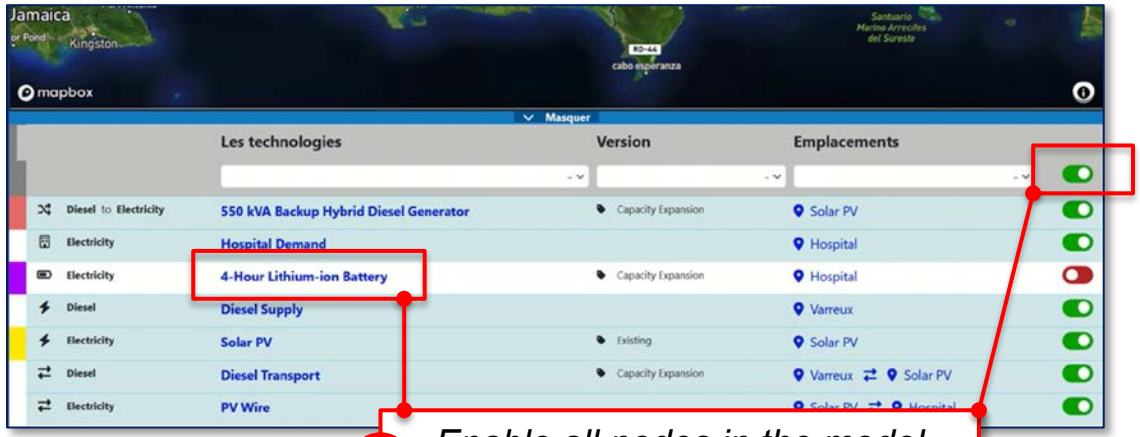
   - Diesel Transport to Varreux and Solar PV
4. Enable **all nodes** under the Scenarios page except for the **lithium-ion battery**
5. Click **“Out of Date”** under the Runs page



5 *Click “Out of Date” and then “Run” to re-run the model*



4 *Enable all nodes in the model except for the lithium-ion battery*

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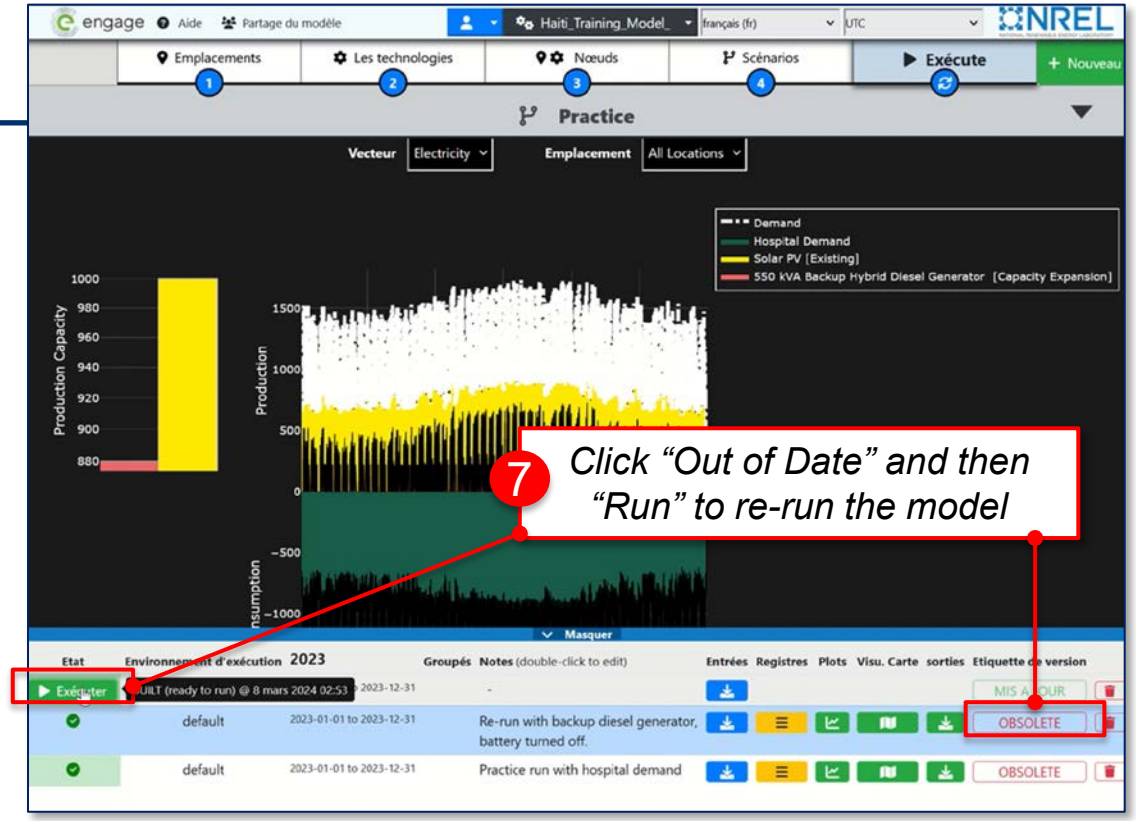
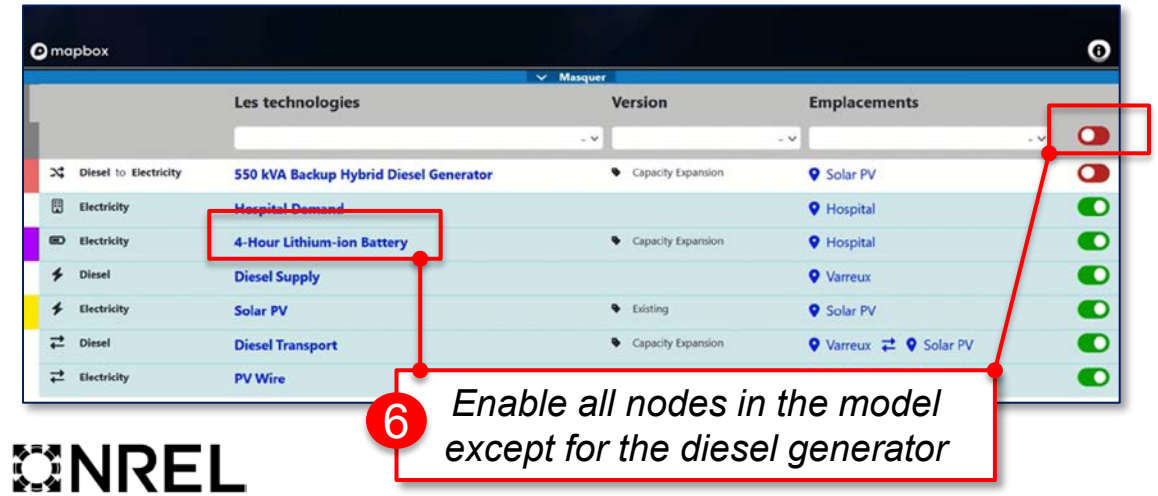
5. Click **“Out of Date”** under the Runs page





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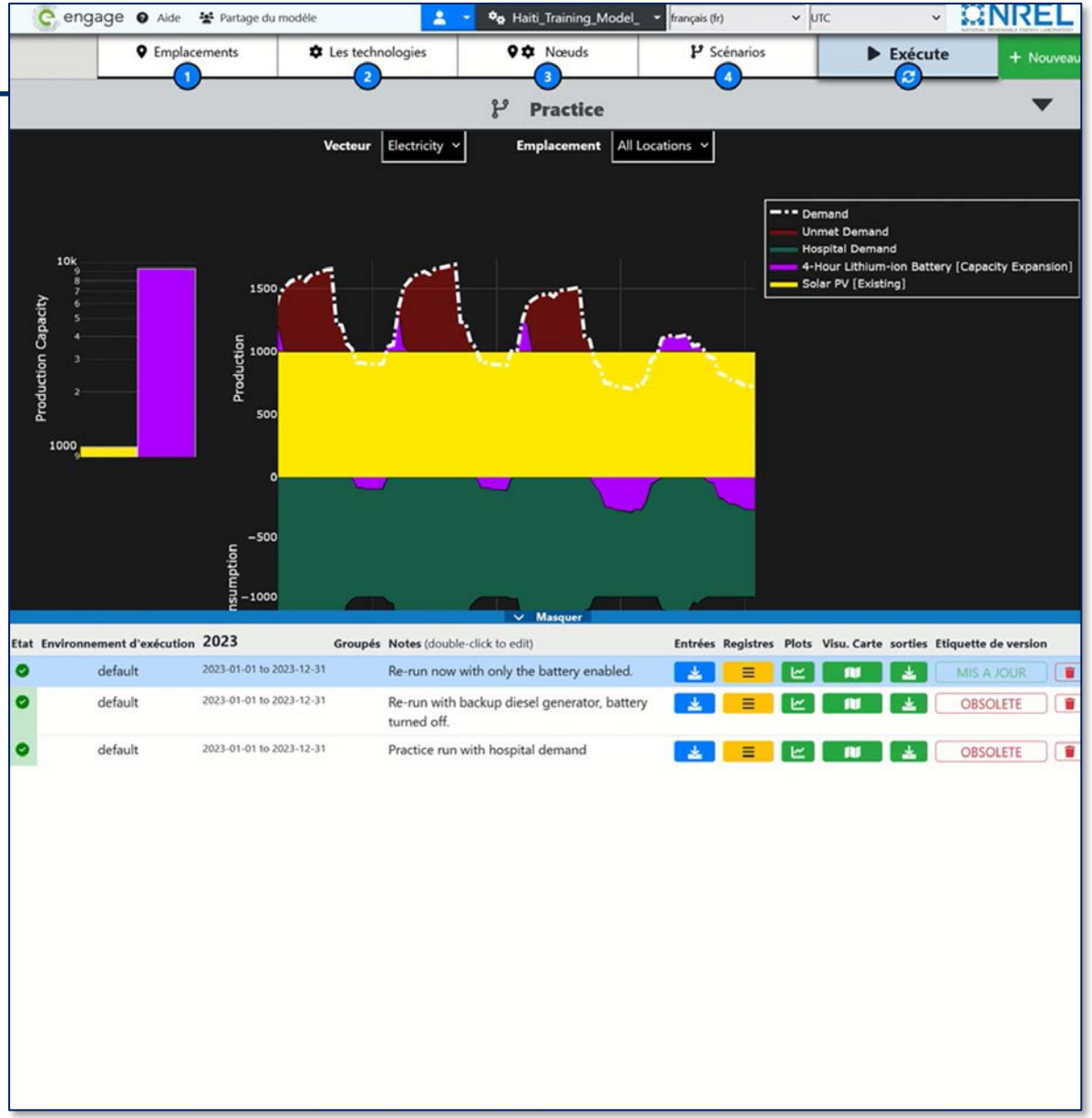
Next Training Session

1. What was the cost optimal build of each technology?

2. How did the annual costs change under each technology?

3. Was there any unmet demand? If so, why?



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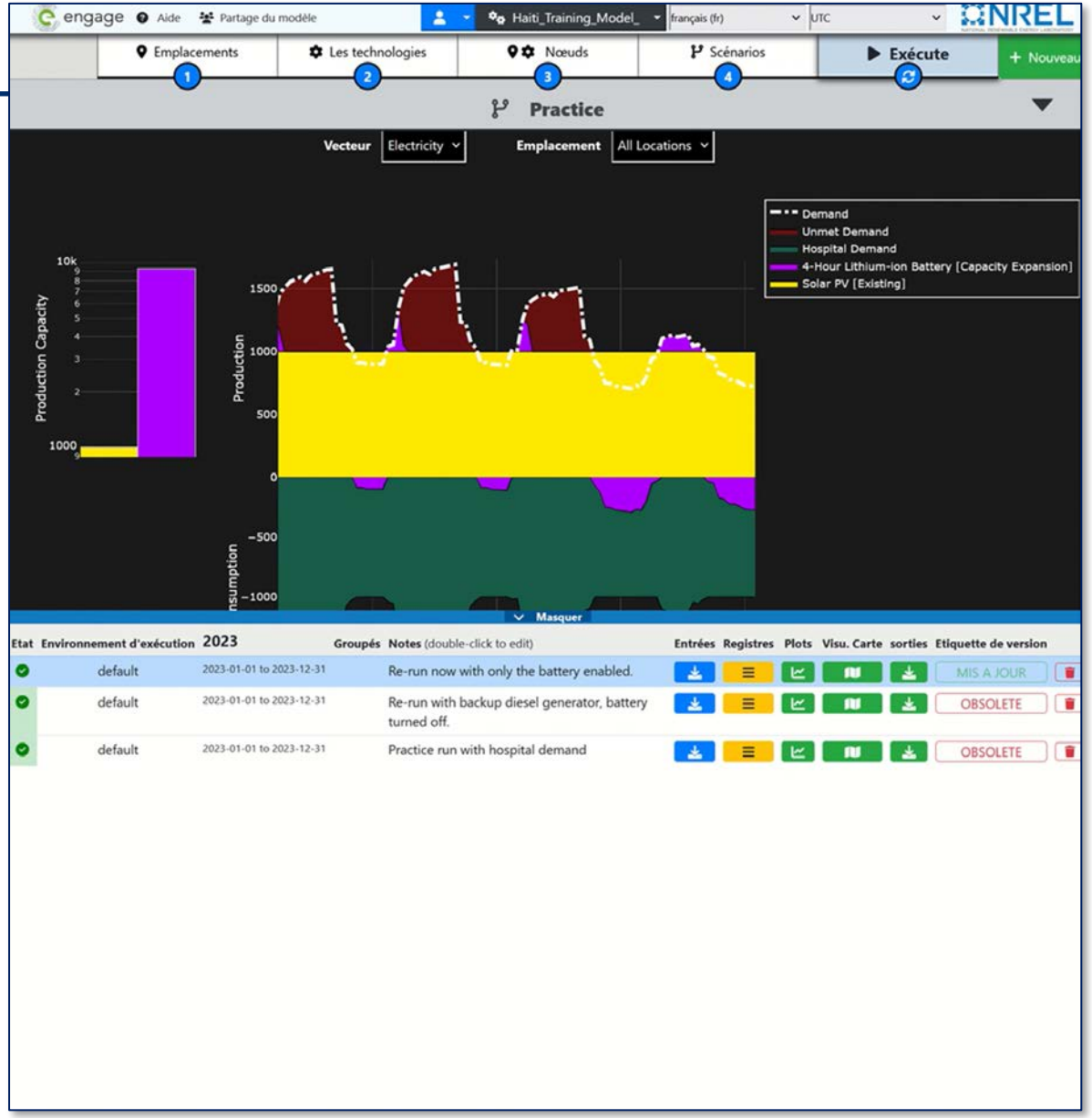
Next Training Session

- Modeling renewable energy systems
- Resilience and power sector modeling scenarios



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Thank you!

Contact engage@nrel.gov with any issues or questions.

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