# TECHTEST:

## An Excel-Based Tool for Evaluating Techno-Economic, Energy, and Carbon Impacts of Early-Stage Technologies

A Tutorial from the U.S. Department of Energy (DOE)

energetics | U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | NREL

TECHTEST: An Excel-Based Tool for Evaluating Techno-Economic, Energy, and Carbon Impacts of Early-Stage Technologies
A Tutorial from the U.S. Department of Energy

Welcome to the DOE's video tutorial series on energy and cost analysis!

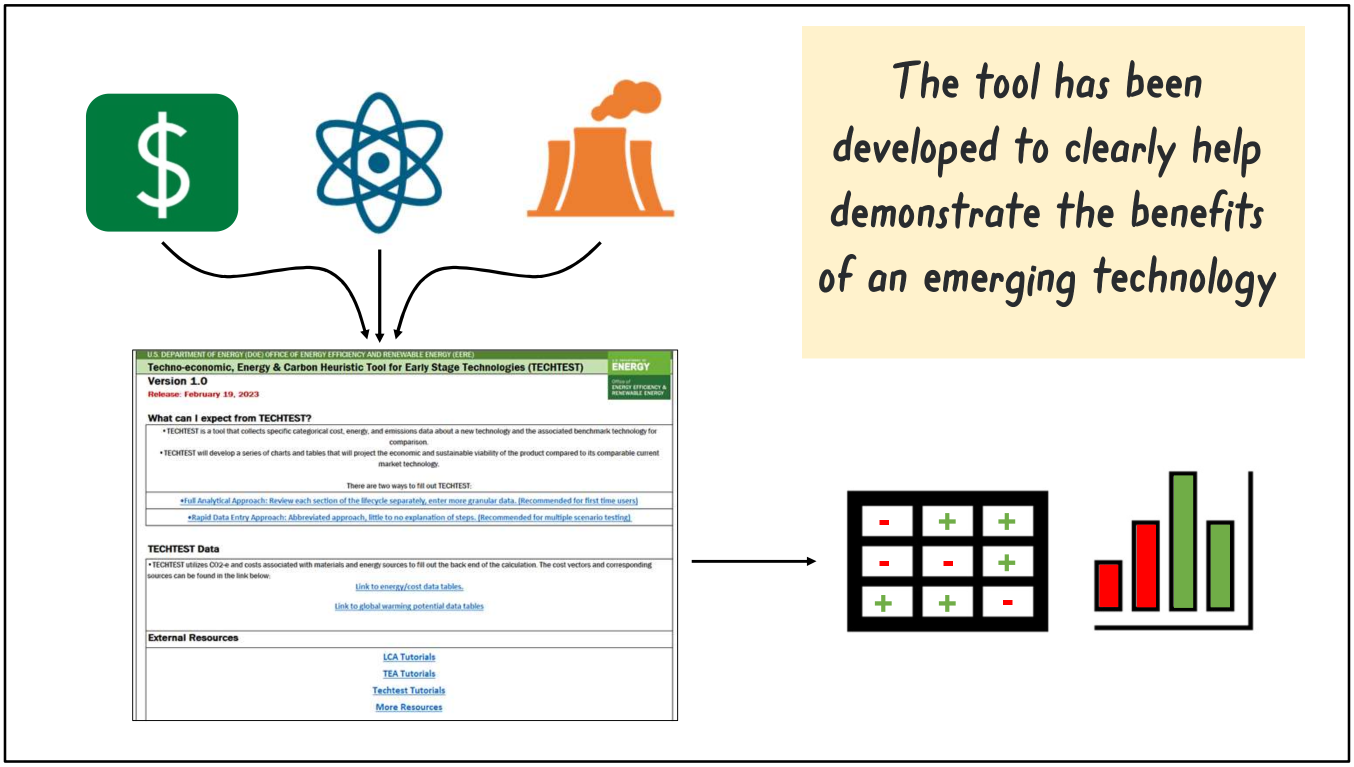
Jordan

In this module, we will:

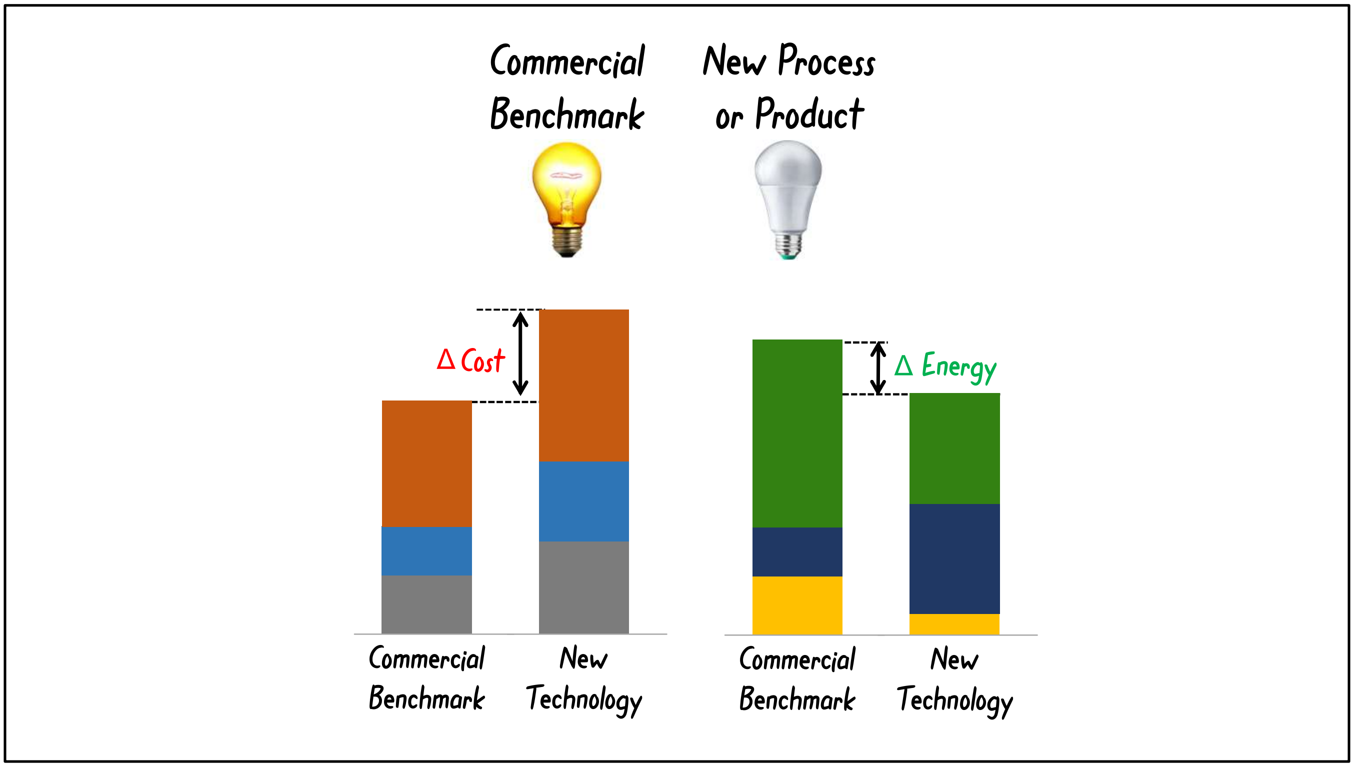
- Describe TECHTEST, an Excel-based tool that offers a framework for conducting an abbreviated Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) of an emerging technology compared to its industry benchmark
- Go through an example scenario to explore the tool's features

Welcome to the DOE video tutorial series on energy and cost analysis. In this module, we will:

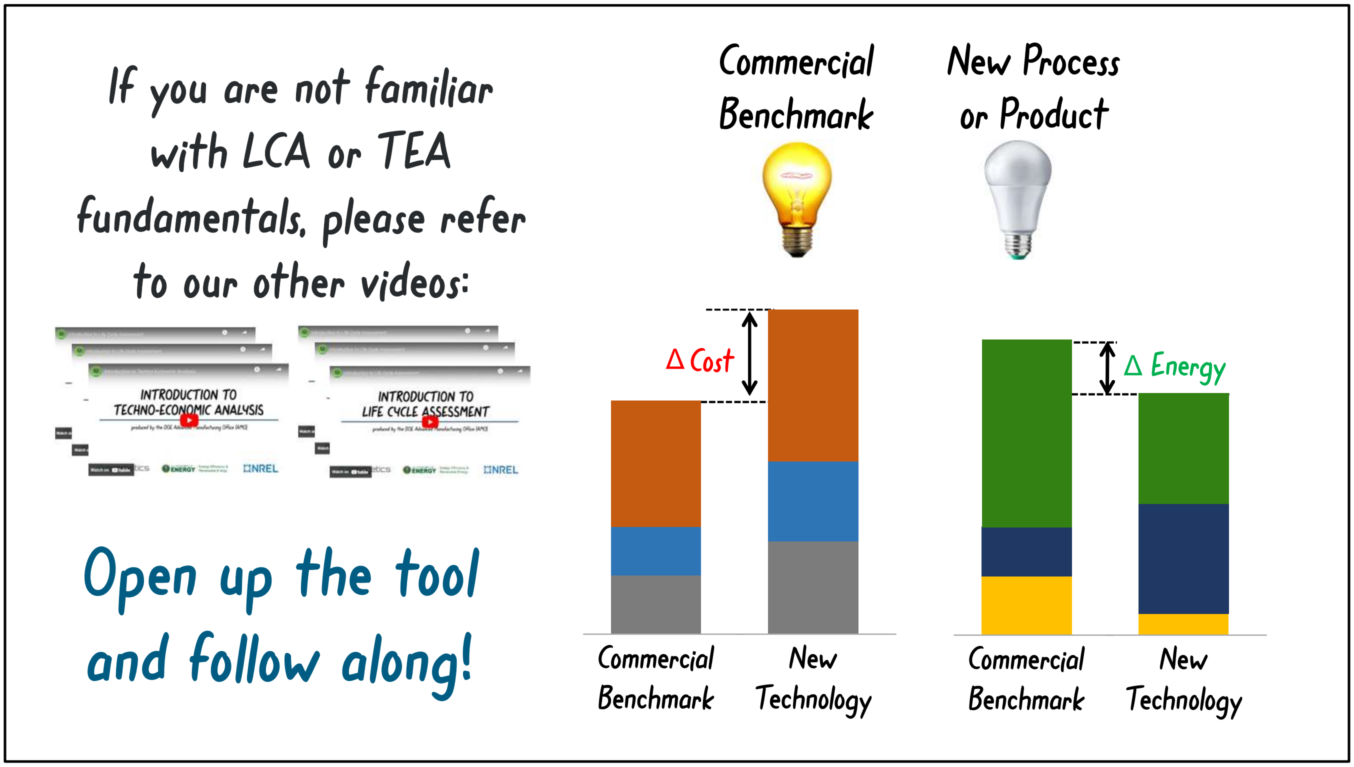
- Describe TECHTEST, an Excel-based tool that offers a framework for conducting an abbreviated Life Cycle Assessment and Techno-Economic Analysis of an emerging technology compared to its industry benchmark.
- We will also go through an example scenario to explore the tool's features.



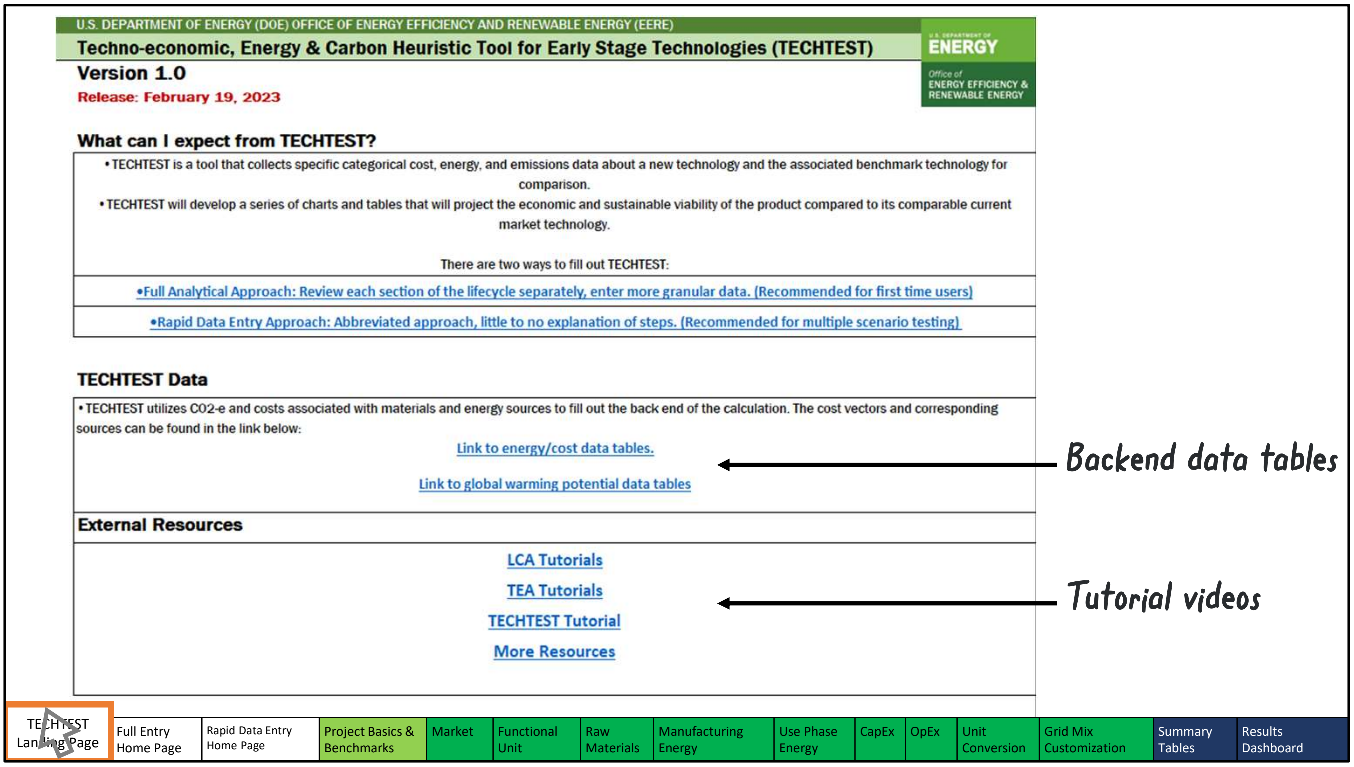

When provided with cost, energy, and emissions data for new and benchmark technologies, TECHTEST will generate summary tables and visualizations detailing the potential benefits and drawbacks resulting from deployment of the new technology. The tool has been developed to help clearly demonstrate the benefits of an emerging technology to potential investors as well as to state and federal funding agencies.



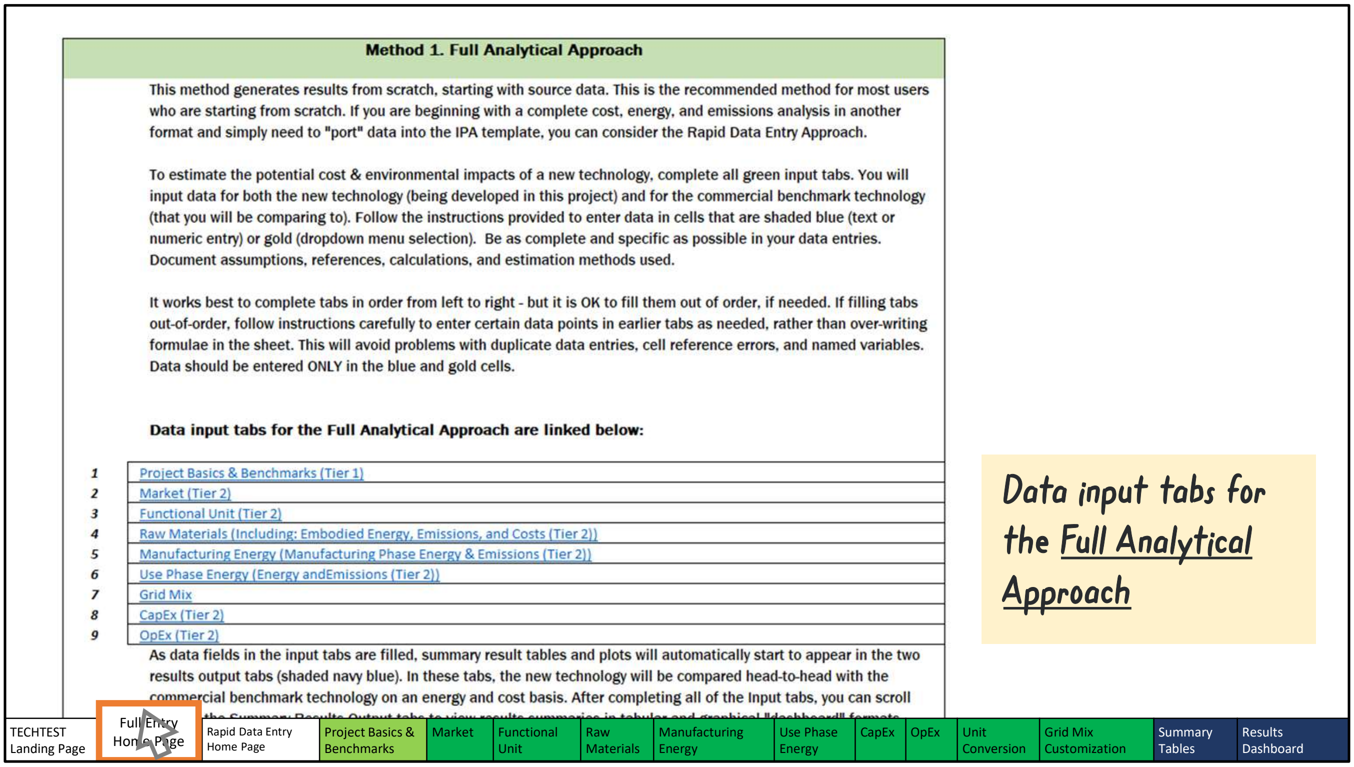

While working with TECHTEST, you will input data for a new process or product as well as for its analogous industry benchmark technology. TECHTEST will then generate comparative insights about the economic and environmental impacts of both technologies.



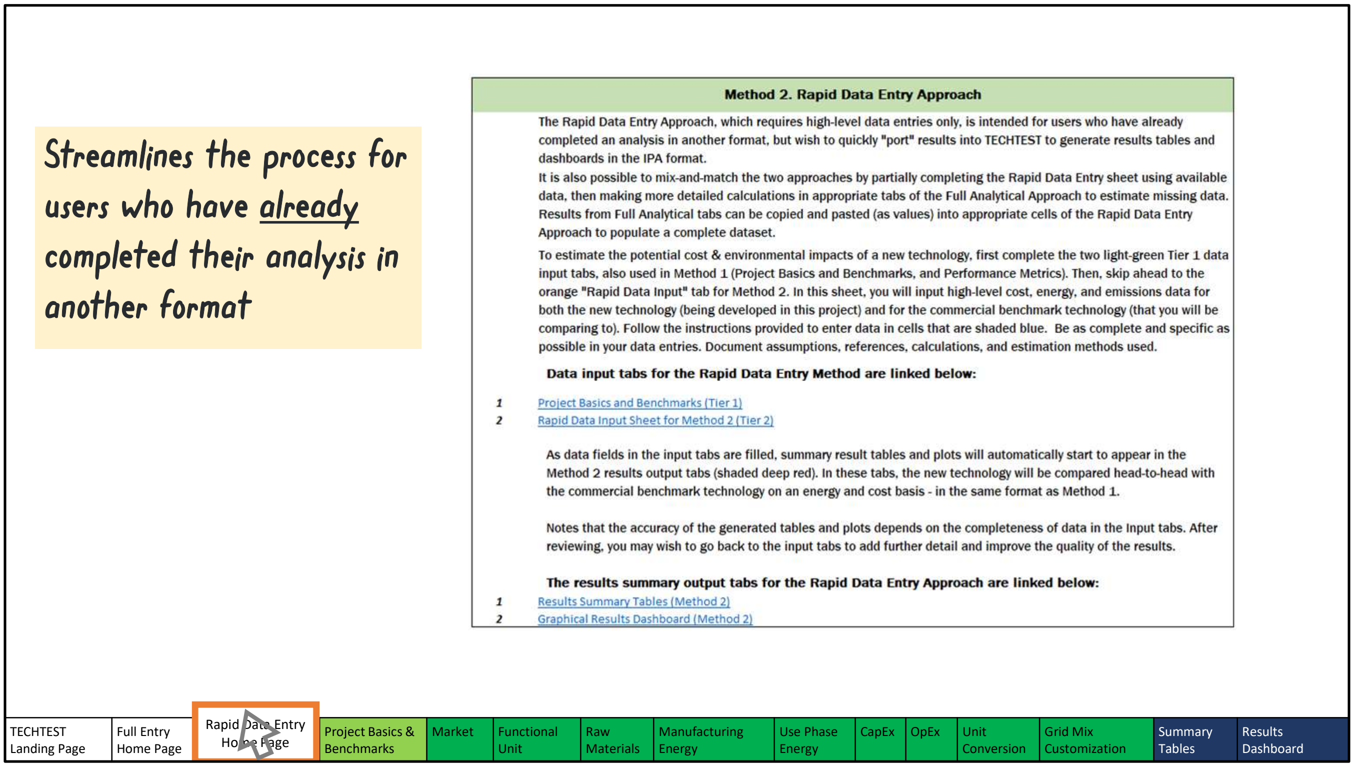

Note that if you are not yet familiar with Life Cycle Assessment and Techno-Economic Analysis fundamentals, please refer to our other tutorial videos in this series. Also, please note that TECHTEST only examines the Global Warming Potential impacts of the new product or process and does not incorporate other environmental factors. Before continuing, we encourage you to open up the tool itself and follow along to get a hands-on understanding of its required inputs and overall functionality.



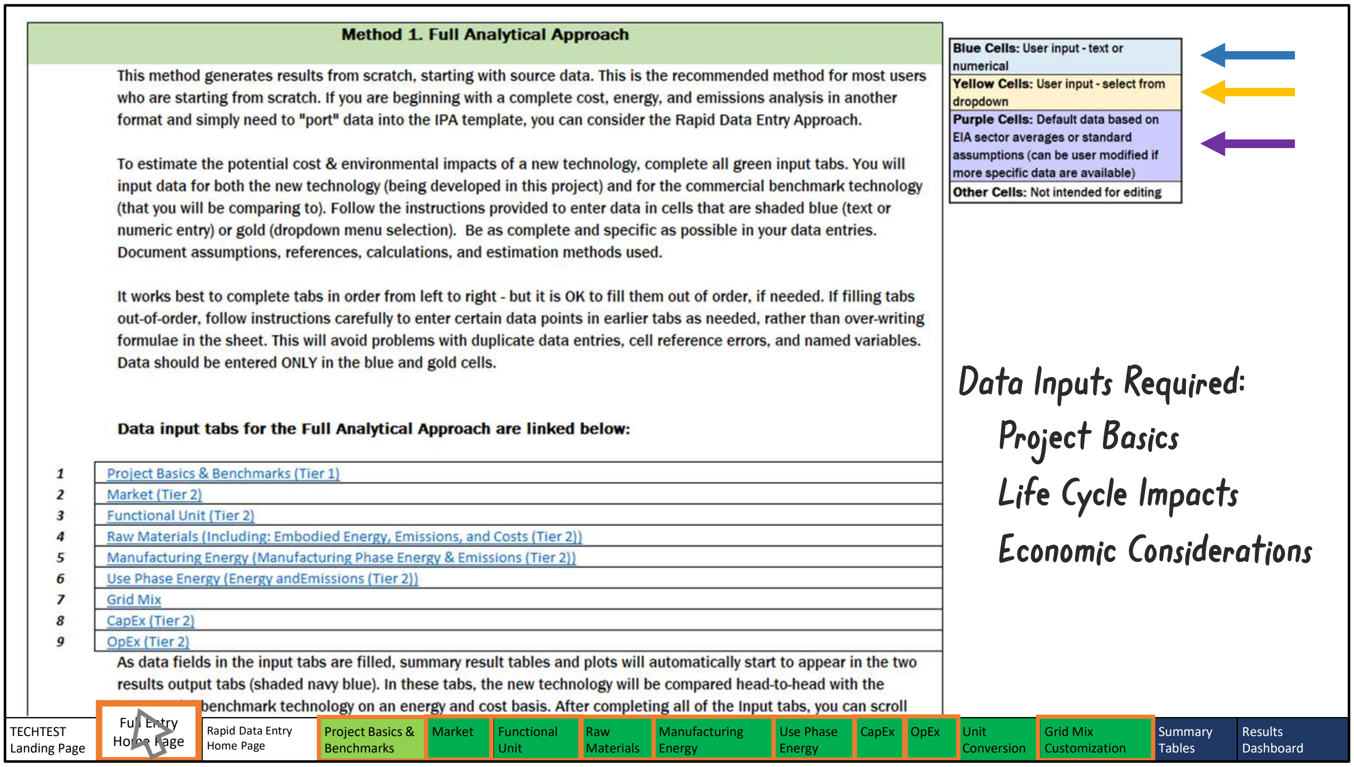

The TECHTEST tool starts with a few introductory tabs that contain helpful information. The TECHTEST Landing Page contains links to tutorial videos, and back-end data tables.




On the Full Entry Home Page tab, you will find a list of data input tabs for the Full Analytical Approach, which we'll be going through today.

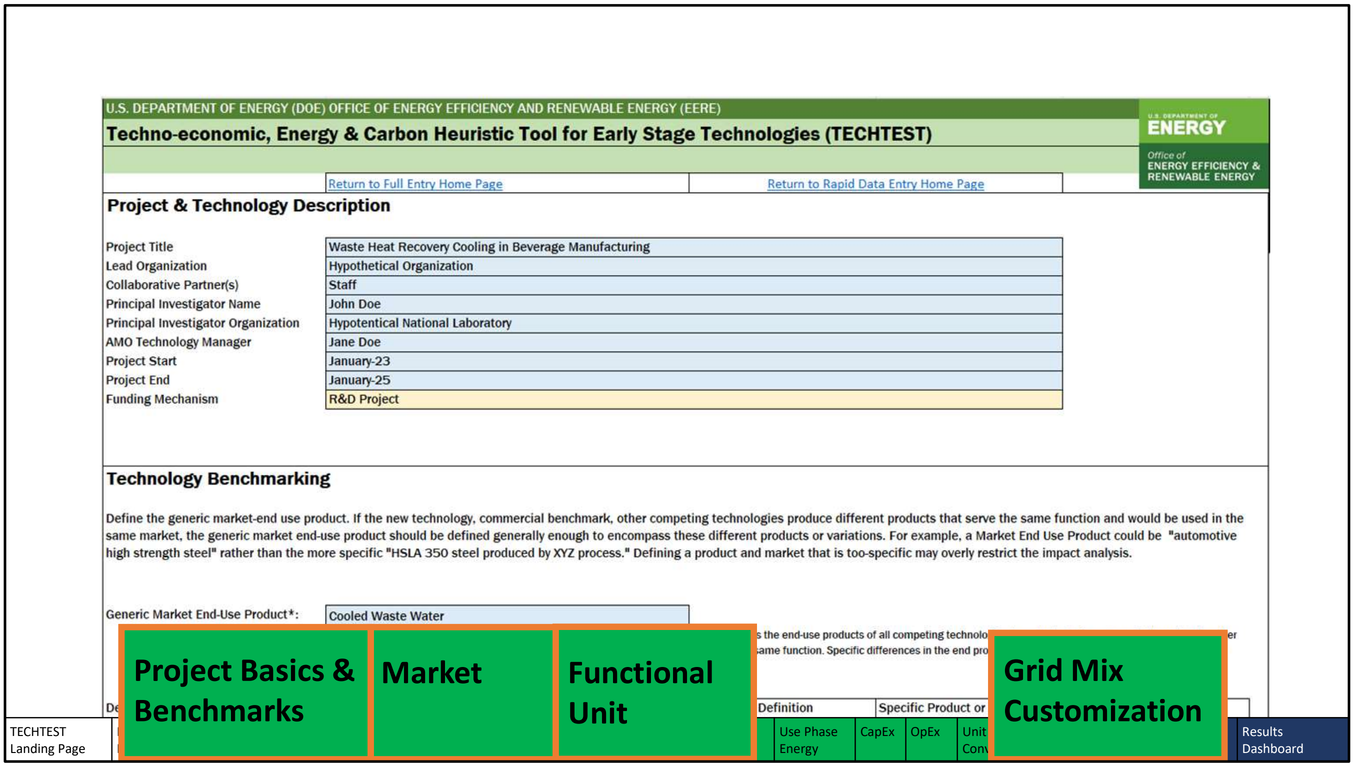



There’s also a Rapid Data Entry Home Page, which streamlines the process for users who have already completed their analysis in another format and are using TECHTEST to quickly generate results tables and visualizations.

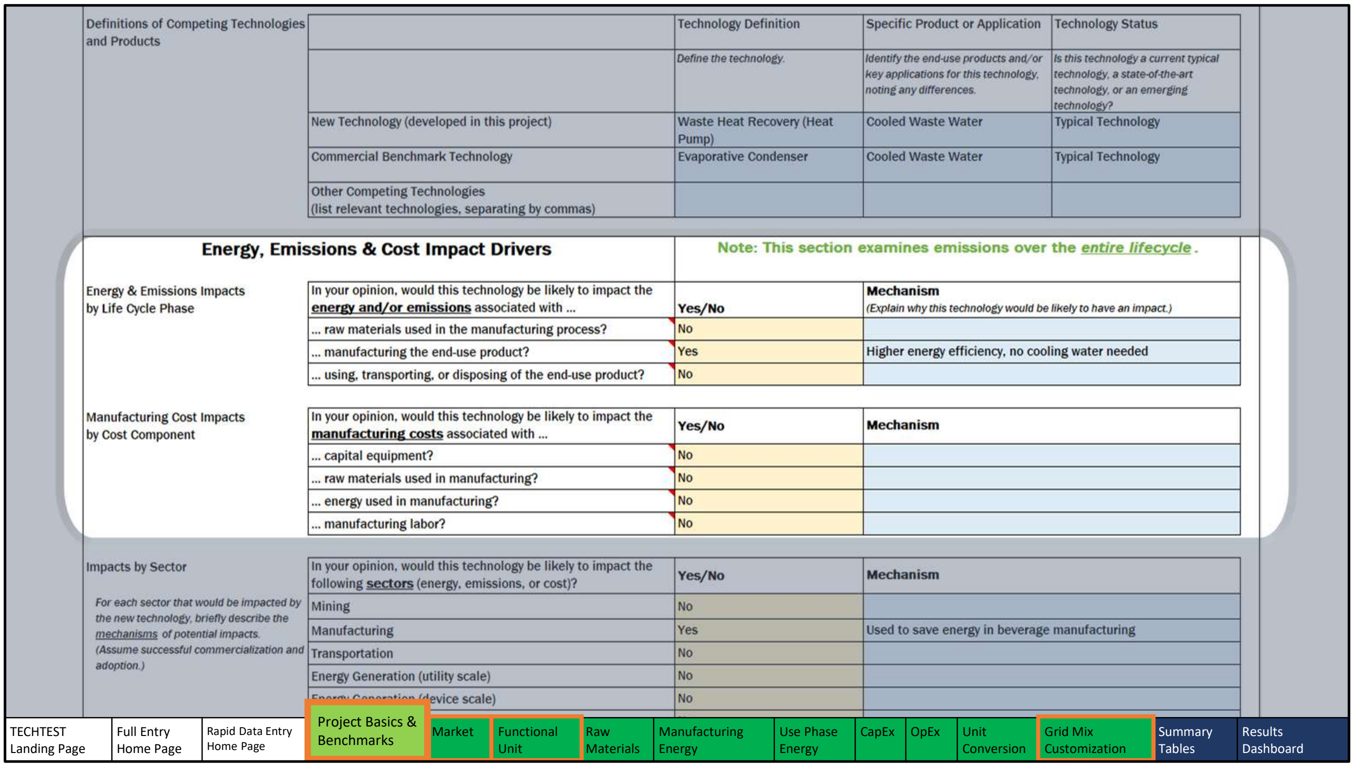



We'll be focusing on the Full Analytical Approach in this video. Throughout the tool, you will see blue, yellow, and purple cells: blue cells take text or numerical user input data; yellow cells will have you choose from a dropdown menu of options; and purple cells are filled with default data based on sector averages or standard assumptions (though these can be modified if more specific data are available). In this Full Analytical Approach, the data inputs required to generate results by TECHTEST fall into three categories: Project Basics, Life Cycle Impacts and Economic Considerations.

We'll start with a general overview of what's contained in each of these sections.




There are four tabs that fall into the Project Basics category. These tabs help the user get started by describing the associated industry and fundamentals of the project.



| Definitions of Competing Technologies and Products | | Technology Definition | Specific Product or Application | Technology Status |
|---|---|---|---|---|
| | | *Define the technology.* | *Identify the end-use products and/or key applications for this technology, noting any differences.* | *Is this technology a current typical technology, a state-of-the-art technology, or an emerging technology?* |
| | New Technology (developed in this project) | Waste Heat Recovery (Heat Pump) | Cooled Waste Water | Typical Technology |
| | Commercial Benchmark Technology | Evaporative Condenser | Cooled Waste Water | Typical Technology |
| | Other Competing Technologies (list relevant technologies, separating by commas) | | | |

**Energy, Emissions & Cost Impact Drivers**

Note: This section examines emissions over the ***entire lifecycle***.

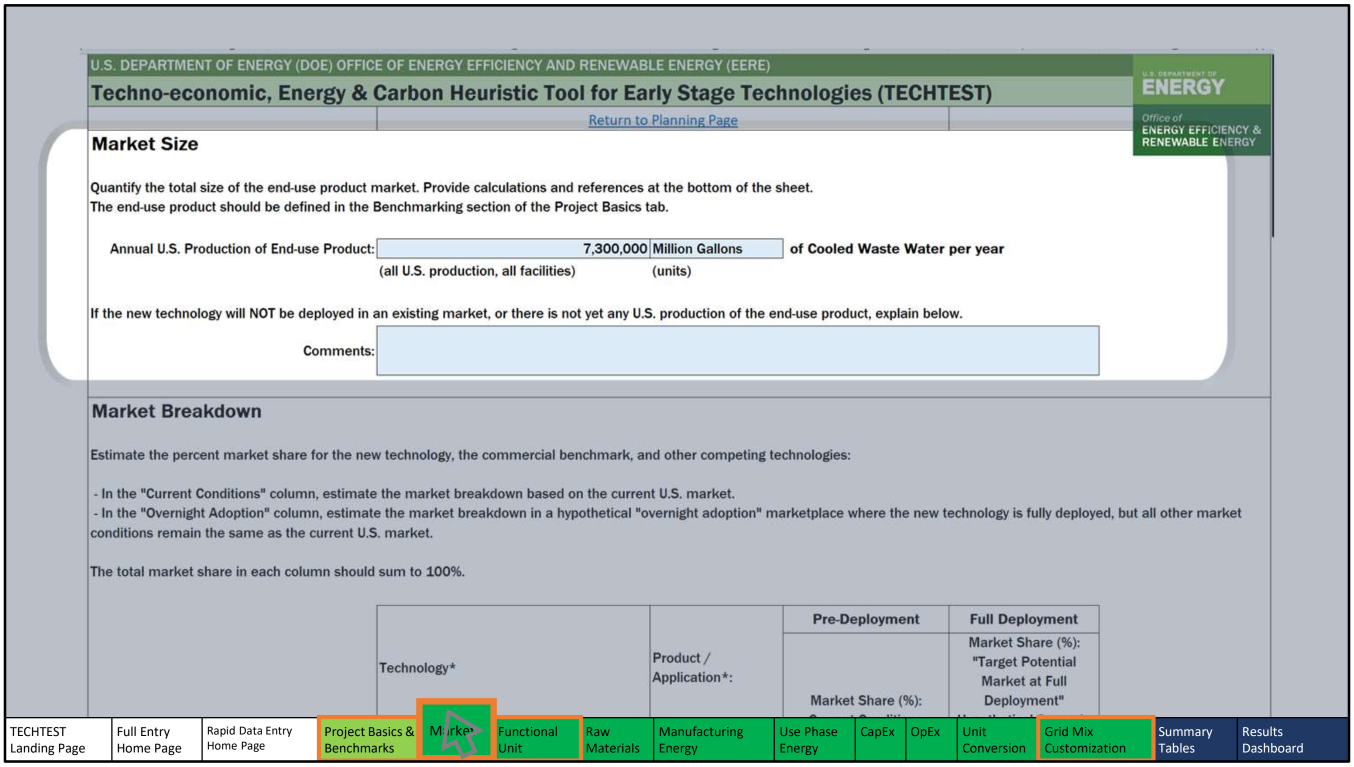
| Energy & Emissions Impacts by Life Cycle Phase | In your opinion, would this technology be likely to impact the **energy and/or emissions** associated with ... | Yes/No | **Mechanism** *(Explain why this technology would be likely to have an impact.)* |
|---|---|---|---|
| | ... raw materials used in the manufacturing process? | No | |
| | ... manufacturing the end-use product? | Yes | Higher energy efficiency, no cooling water needed |
| | ... using, transporting, or disposing of the end-use product? | No | |

| Manufacturing Cost Impacts by Cost Component | In your opinion, would this technology be likely to impact the **manufacturing costs** associated with ... | Yes/No | Mechanism |
|---|---|---|---|
| | ... capital equipment? | No | |
| | ... raw materials used in manufacturing? | No | |
| | ... energy used in manufacturing? | No | |
| | ... manufacturing labor? | No | |

| Impacts by Sector | In your opinion, would this technology be likely to impact the following **sectors** (energy, emissions, or cost)? | Yes/No | Mechanism |
|---|---|---|---|
| *For each sector that would be impacted by the new technology, briefly describe the mechanisms of potential impacts. (Assume successful commercialization and adoption.)* | Mining | No | |
| | Manufacturing | Yes | Used to save energy in beverage manufacturing |
| | Transportation | No | |
| | Energy Generation (utility scale) | No | |
| | Energy Generation (device scale) | No | |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

In the Project Basics & Benchmarks tab, the user identifies where energy, emissions, and cost improvements may occur with respect to the new technology.




The Market tab collects information on the projected market size…

Annual U.S. Production of End-use Product: 7,300,000 Million Gallons of Cooled Waste Water per year

(all U.S. production, all facilities) (units)

If the new technology will NOT be deployed in an existing market, or there is not yet any U.S. production of the end-use product, explain below.

Comments:

## Market Breakdown

Estimate the percent market share for the new technology, the commercial benchmark, and other competing technologies:

- In the "Current Conditions" column, estimate the market breakdown based on the current U.S. market.
- In the "Overnight Adoption" column, estimate the market breakdown in a hypothetical "overnight adoption" marketplace where the new technology is fully deployed, but all other market conditions remain the same as the current U.S. market.

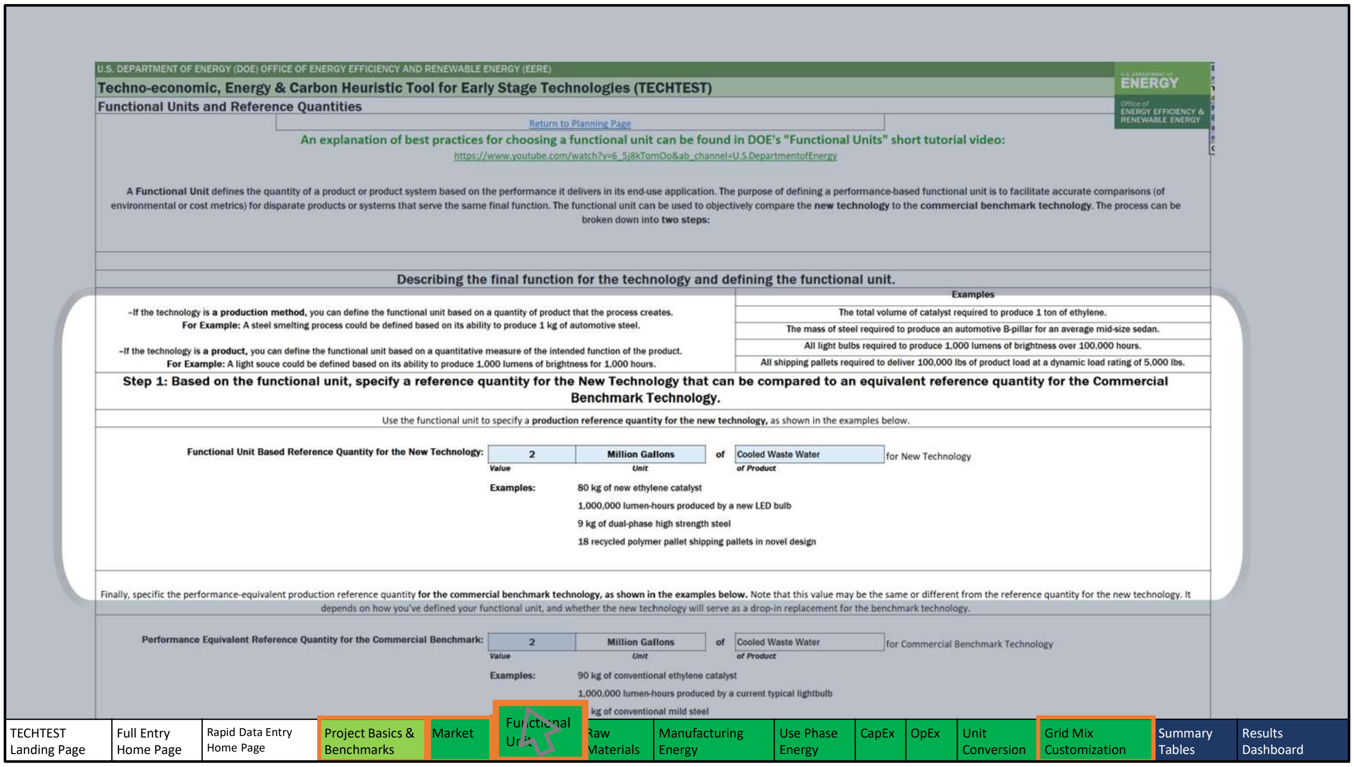
The total market share in each column should sum to 100%.

| | Technology* | Product / Application*: | Pre-Deployment<br>Market Share (%): Current Conditions | Full Deployment<br>Market Share (%): "Target Potential Market at Full Deployment" Hypothetical Scenario |
|---|---|---|---|---|
| New Technology: | Waste Heat Recovery (Heat Pump) | Cooled Waste Water | 0% | 100% |
| Commercial Benchmark: | Evaporative Condenser | Cooled Waste Water | 100% | 0% |
| Other Competing Technologies: | 0 | 0 | | |
| | | Sum: | 100% | 100% |

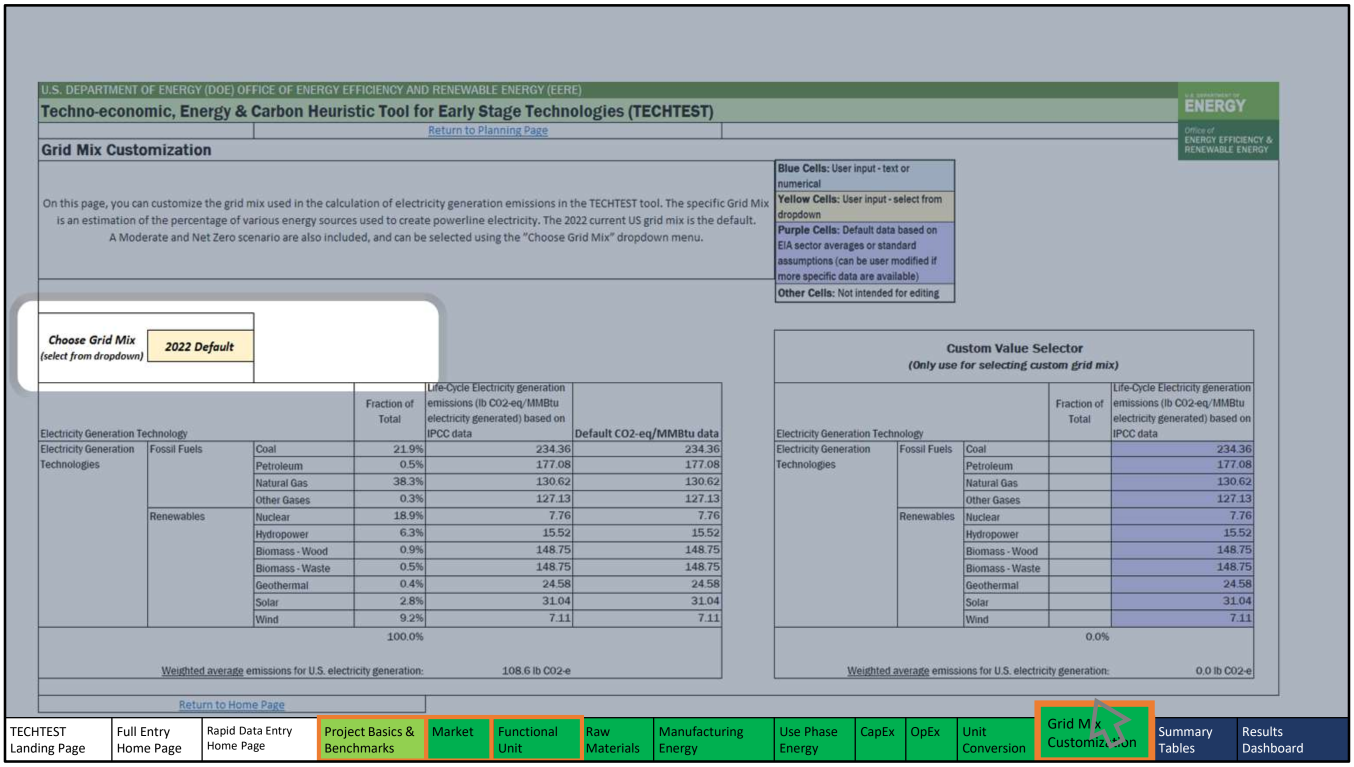
*Note that the technology and product definitions are imported from the Benchmarking section of the "Project Basics" tab. If any edits to these definitions are needed, please modify the definitions in that tab.

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

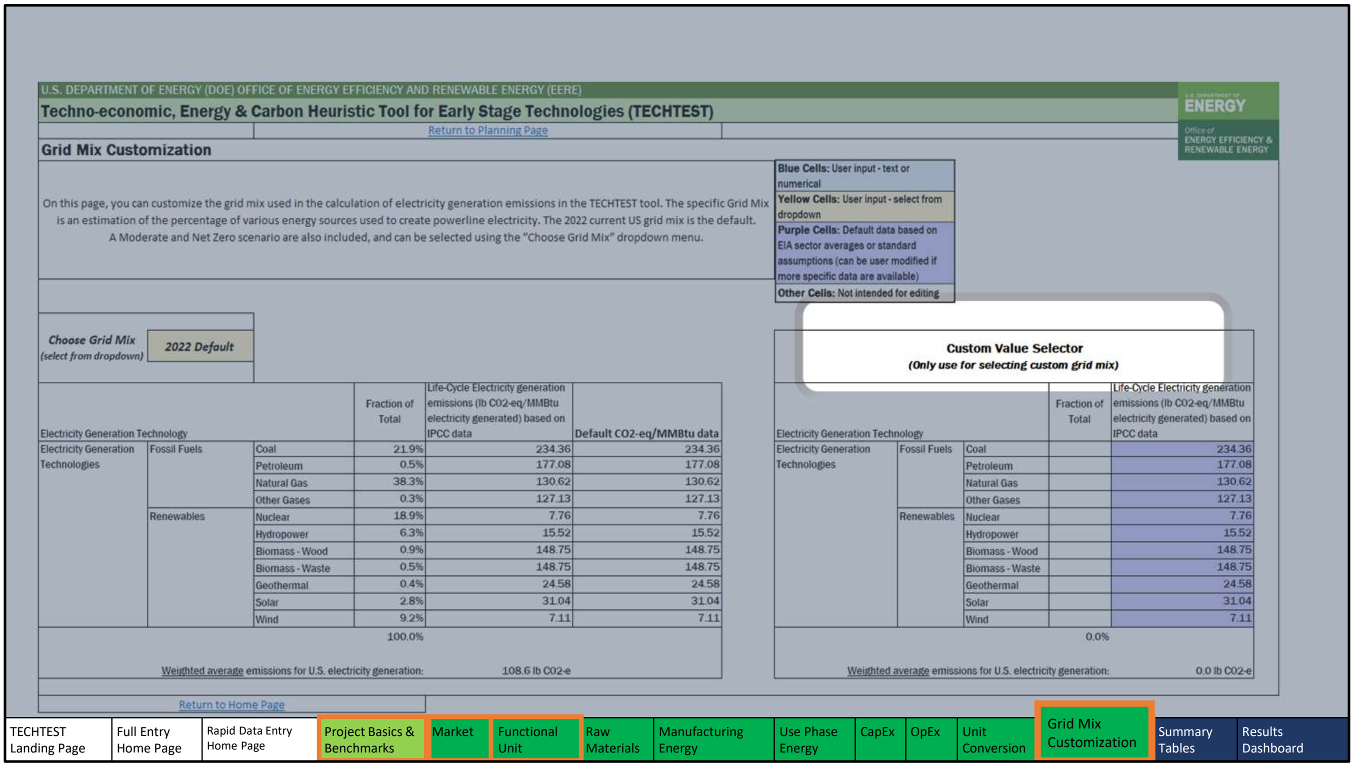
…and market share of the two technologies.



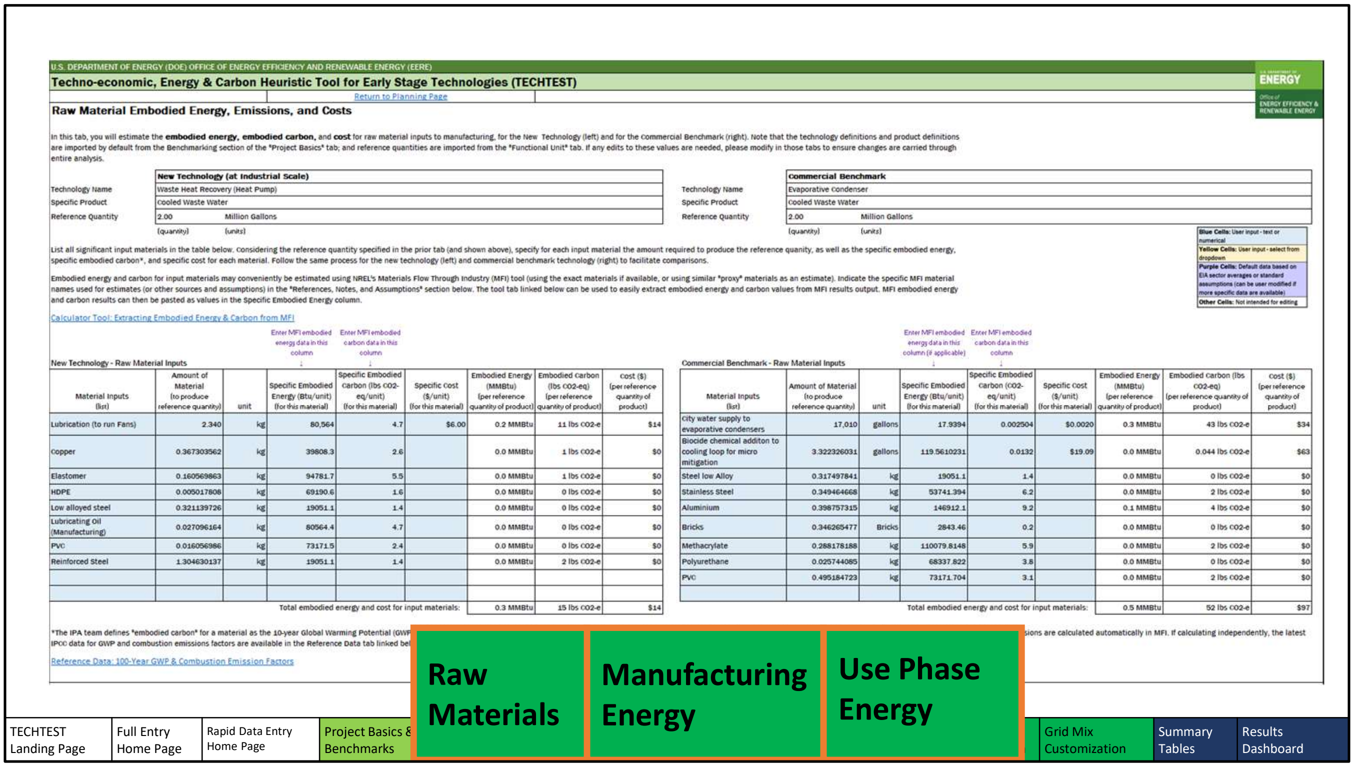

The Functional Unit tab specifies the reference quantity for the new technology as well as a performance-equivalent reference quantity for the benchmark technology. The reference quantity specifies the amount of product delivered based on the performance of each technology.



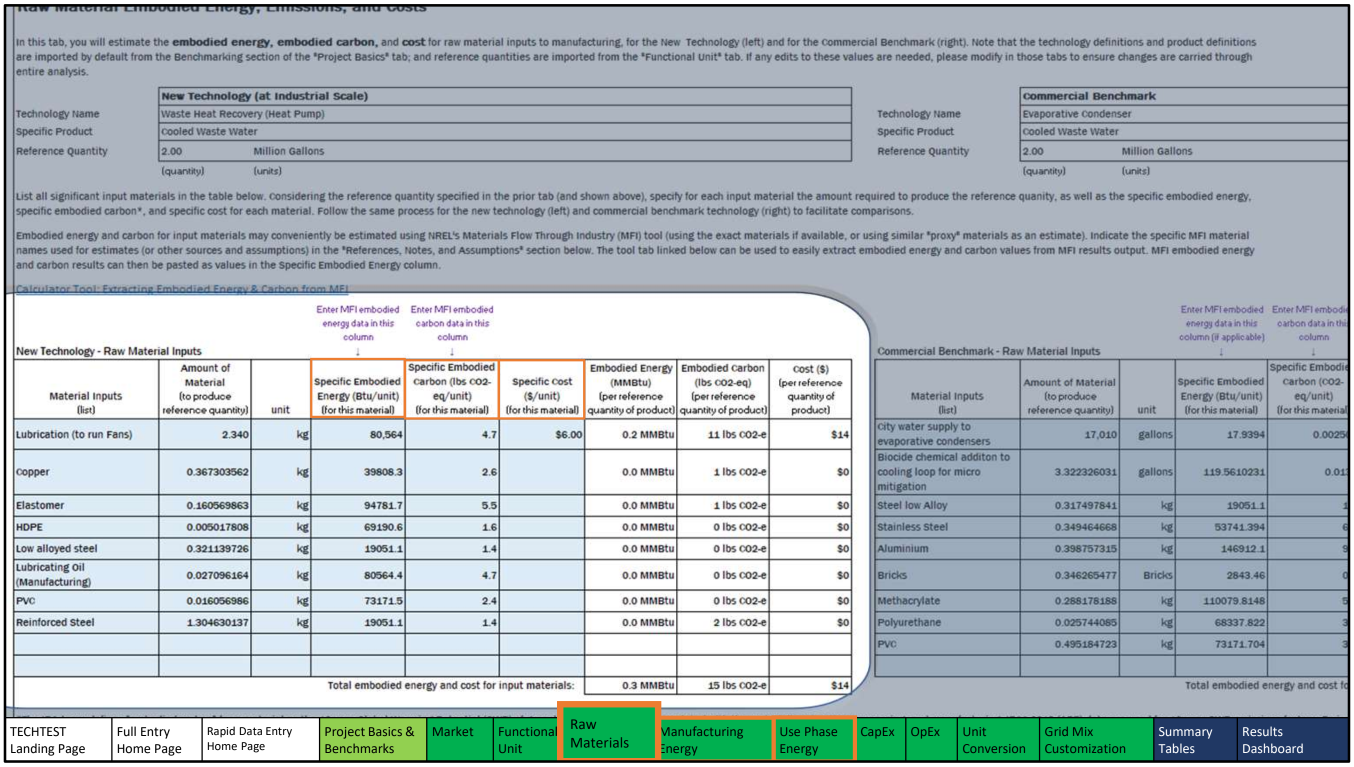

Additionally, further to the right in the tab menu is the Grid Mix Customization tab, which allows you to choose between various default scenarios for the mix of electricity generation technologies…




…or input a custom mix of fossil-fuel and renewable sources.




Moving on, the Life Cycle Impacts category, is composed of three tabs make up the bulk of the environmental and economic assessments of the technologies.



Raw Material Embodied Energy, Emissions, and Costs

In this tab, you will estimate the **embodied energy, embodied carbon,** and **cost** for raw material inputs to manufacturing, for the New Technology (left) and for the Commercial Benchmark (right). Note that the technology definitions and product definitions are imported by default from the Benchmarking section of the "Project Basics" tab; and reference quantities are imported from the "Functional Unit" tab. If any edits to these values are needed, please modify in those tabs to ensure changes are carried through entire analysis.

| | New Technology (at Industrial Scale) | |
|---|---|---|
| Technology Name | Waste Heat Recovery (Heat Pump) | |
| Specific Product | Cooled Waste Water | |
| Reference Quantity | 2.00 | Million Gallons |
| | (quantity) | (units) |

| | Commercial Benchmark | |
|---|---|---|
| Technology Name | Evaporative Condenser | |
| Specific Product | Cooled Waste Water | |
| Reference Quantity | 2.00 | Million Gallons |
| | (quantity) | (units) |

List all significant input materials in the table below. Considering the reference quantity specified in the prior tab (and shown above), specify for each input material the amount required to produce the reference quanity, as well as the specific embodied energy, specific embodied carbon*, and specific cost for each material. Follow the same process for the new technology (left) and commercial benchmark technology (right) to facilitate comparisons.

Embodied energy and carbon for input materials may conveniently be estimated using NREL's Materials Flow Through Industry (MFI) tool (using the exact materials if available, or using similar "proxy" materials as an estimate). Indicate the specific MFI material names used for estimates (or other sources and assumptions) in the "References, Notes, and Assumptions" section below. The tool tab linked below can be used to easily extract embodied energy and carbon values from MFI results output. MFI embodied energy and carbon results can then be pasted as values in the Specific Embodied Energy column.

Calculator Tool: Extracting Embodied Energy & Carbon from MFI

New Technology - Raw Material Inputs

| Material Inputs (list) | Amount of Material (to produce reference quantity) | unit | Specific Embodied Energy (Btu/unit) (for this material) | Specific Embodied Carbon (lbs CO2-eq/unit) (for this material) | Specific Cost ($/unit) (for this material) | Embodied Energy (MMBtu) (per reference quantity of product) | Embodied Carbon (lbs CO2-eq) (per reference quantity of product) | Cost ($) (per reference quantity of product) |
|---|---|---|---|---|---|---|---|---|
| | | | Enter MFI embodied energy data in this column ↓ | Enter MFI embodied carbon data in this column ↓ | | | | |
| Lubrication (to run Fans) | 2.340 | kg | 80,564 | 4.7 | $6.00 | 0.2 MMBtu | 11 lbs CO2-e | $14 |
| Copper | 0.367303562 | kg | 39808.3 | 2.6 | | 0.0 MMBtu | 1 lbs CO2-e | $0 |
| Elastomer | 0.160569863 | kg | 94781.7 | 5.5 | | 0.0 MMBtu | 1 lbs CO2-e | $0 |
| HDPE | 0.005017808 | kg | 69190.6 | 1.6 | | 0.0 MMBtu | 0 lbs CO2-e | $0 |
| Low alloyed steel | 0.321139726 | kg | 19051.1 | 1.4 | | 0.0 MMBtu | 0 lbs CO2-e | $0 |
| Lubricating Oil (Manufacturing) | 0.027096164 | kg | 80564.4 | 4.7 | | 0.0 MMBtu | 0 lbs CO2-e | $0 |
| PVC | 0.016056986 | kg | 73171.5 | 2.4 | | 0.0 MMBtu | 0 lbs CO2-e | $0 |
| Reinforced Steel | 1.304630137 | kg | 19051.1 | 1.4 | | 0.0 MMBtu | 2 lbs CO2-e | $0 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | Total embodied energy and cost for input materials: | 0.3 MMBtu | 15 lbs CO2-e | $14 |

Commercial Benchmark - Raw Material Inputs

| Material Inputs (list) | Amount of Material (to produce reference quantity) | unit | Specific Embodied Energy (Btu/unit) (for this material) | Specific Embodie Carbon (CO2-eq/unit) (for this material |
|---|---|---|---|---|
| | | | Enter MFI embodied energy data in this column (if applicable) ↓ | Enter MFI embodi carbon data in thi column ↓ |
| City water supply to evaporative condensers | 17,010 | gallons | 17.9394 | 0.0025 |
| Biocide chemical additon to cooling loop for micro mitigation | 3.322326031 | gallons | 119.5610231 | 0.01 |
| Steel low Alloy | 0.317497841 | kg | 19051.1 | 1 |
| Stainless Steel | 0.349464668 | kg | 53741.394 | 6 |
| Aluminium | 0.398757315 | kg | 146912.1 | 9 |
| Bricks | 0.346265477 | Bricks | 2843.46 | 0 |
| Methacrylate | 0.288178188 | kg | 110079.8148 | 5 |
| Polyurethane | 0.025744085 | kg | 68337.822 | 3 |
| PVC | 0.495184723 | kg | 73171.704 | 3 |
| | | | | |
| | | | Total embodied energy and cost fo | |

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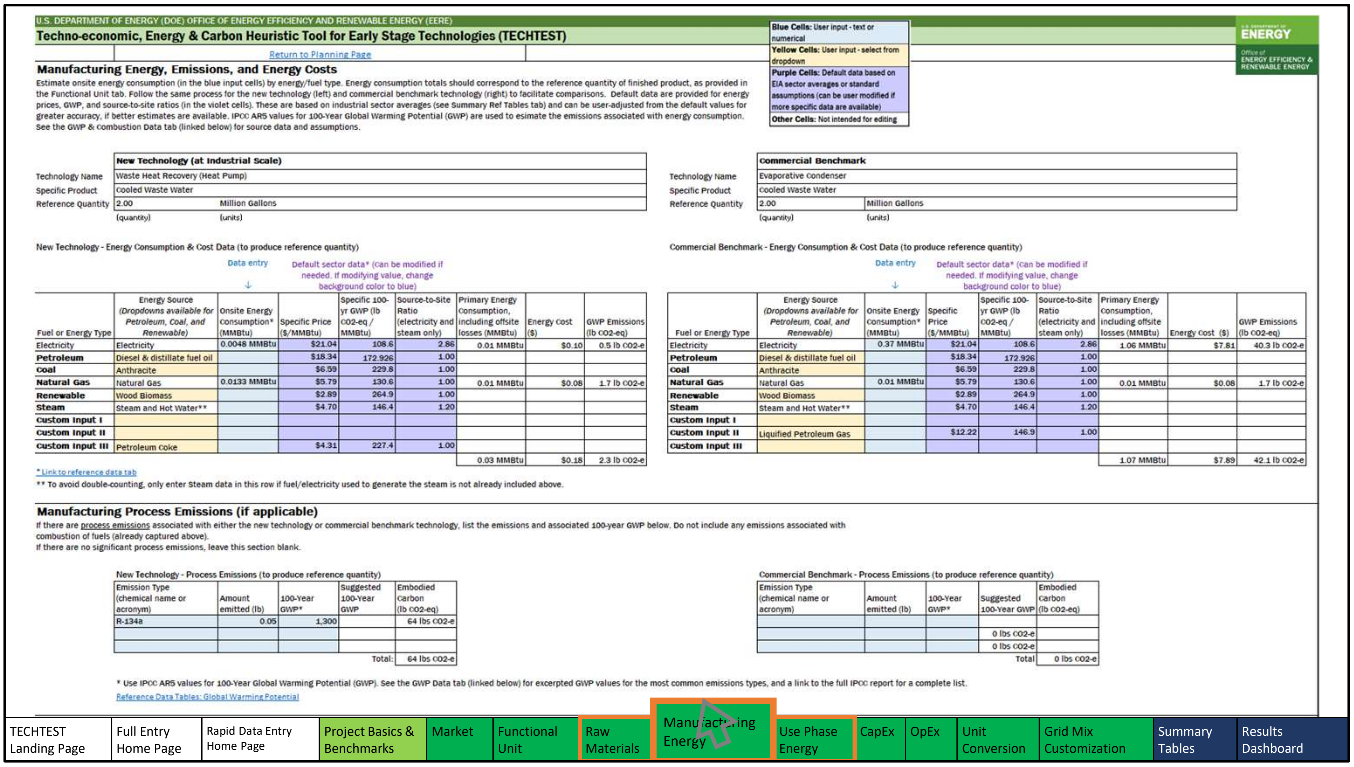
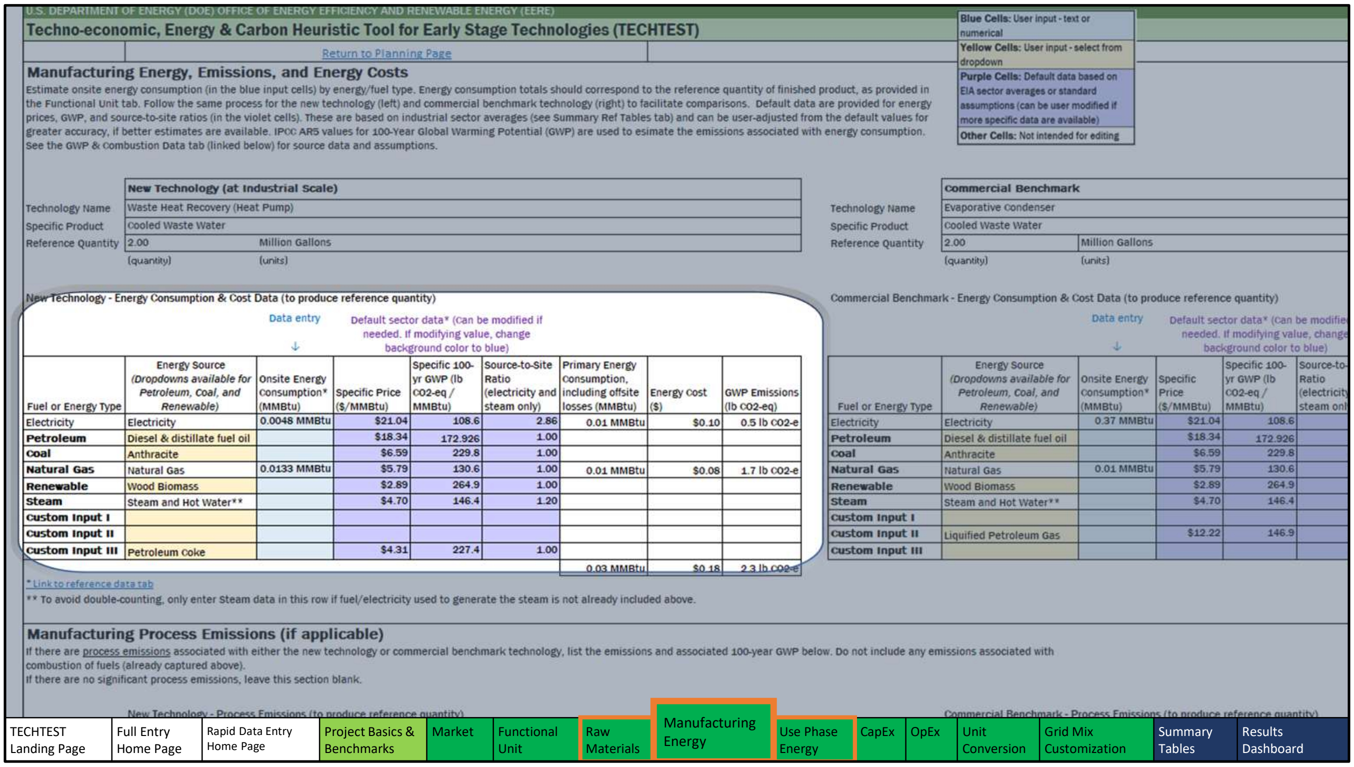
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

The Raw Materials tab incorporates data on the materials required to produce the identified reference quantity for both technologies. This data includes, embodied energy, CO2 and cost.




The Manufacturing Energy tab calculates the energy required to manufacture the reference quantity…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**Techno-economic, Energy & Carbon Heuristic Tool for Early Stage Technologies (TECHTEST)**

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**Blue Cells:** User input - text or numerical
**Yellow Cells:** User input - select from dropdown
**Purple Cells:** Default data based on EIA sector averages or standard assumptions (can be user modified if more specific data are available)
**Other Cells:** Not intended for editing

**Manufacturing Energy, Emissions, and Energy Costs**

Estimate onsite energy consumption (in the blue input cells) by energy/fuel type. Energy consumption totals should correspond to the reference quantity of finished product, as provided in the Functional Unit tab. Follow the same process for the new technology (left) and commercial benchmark technology (right) to facilitate comparisons. Default data are provided for energy prices, GWP, and source-to-site ratios (in the violet cells). These are based on industrial sector averages (see Summary Ref Tables tab) and can be user-adjusted from the default values for greater accuracy, if better estimates are available. IPCC AR5 values for 100-Year Global Warming Potential (GWP) are used to esimate the emissions associated with energy consumption. See the GWP & Combustion Data tab (linked below) for source data and assumptions.

| | New Technology (at Industrial Scale) | |
|---|---|---|
| Technology Name | Waste Heat Recovery (Heat Pump) | |
| Specific Product | Cooled Waste Water | |
| Reference Quantity | 2.00 | Million Gallons |
| | (quantity) | (units) |

| | Commercial Benchmark | |
|---|---|---|
| Technology Name | Evaporative Condenser | |
| Specific Product | Cooled Waste Water | |
| Reference Quantity | 2.00 | Million Gallons |
| | (quantity) | (units) |

New Technology - Energy Consumption & Cost Data (to produce reference quantity)

Data entry ↓ | Default sector data* (Can be modified if needed. If modifying value, change background color to blue)

| Fuel or Energy Type | Energy Source (Dropdowns available for Petroleum, Coal, and Renewable) | Onsite Energy Consumption* (MMBtu) | Specific Price ($/MMBtu) | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (electricity and steam only) | Primary Energy Consumption, including offsite losses (MMBtu) | Energy Cost ($) | GWP Emissions (lb CO2-eq) |
|---|---|---|---|---|---|---|---|---|
| Electricity | Electricity | 0.0048 MMBtu | $21.04 | 108.6 | 2.86 | 0.01 MMBtu | $0.10 | 0.5 lb CO2-e |
| **Petroleum** | Diesel & distillate fuel oil | | $18.34 | 172.926 | 1.00 | | | |
| **Coal** | Anthracite | | $6.59 | 229.8 | 1.00 | | | |
| **Natural Gas** | Natural Gas | 0.0133 MMBtu | $5.79 | 130.6 | 1.00 | 0.01 MMBtu | $0.08 | 1.7 lb CO2-e |
| **Renewable** | Wood Biomass | | $2.89 | 264.9 | 1.00 | | | |
| **Steam** | Steam and Hot Water** | | $4.70 | 146.4 | 1.20 | | | |
| **Custom Input I** | | | | | | | | |
| **Custom Input II** | | | | | | | | |
| **Custom Input III** | Petroleum Coke | | $4.31 | 227.4 | 1.00 | | | |
| | | | | | | 0.03 MMBtu | $0.18 | 2.3 lb CO2-e |

Commercial Benchmark - Energy Consumption & Cost Data (to produce reference quantity)

Data entry ↓ | Default sector data* (Can be modifie needed. If modifying value, change background color to blue)

| Fuel or Energy Type | Energy Source (Dropdowns available for Petroleum, Coal, and Renewable) | Onsite Energy Consumption* (MMBtu) | Specific Price ($/MMBtu) | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Ratio (electricity steam onl |
|---|---|---|---|---|---|
| Electricity | Electricity | 0.37 MMBtu | $21.04 | 108.6 | |
| **Petroleum** | Diesel & distillate fuel oil | | $18.34 | 172.926 | |
| **Coal** | Anthracite | | $6.59 | 229.8 | |
| **Natural Gas** | Natural Gas | 0.01 MMBtu | $5.79 | 130.6 | |
| **Renewable** | Wood Biomass | | $2.89 | 264.9 | |
| **Steam** | Steam and Hot Water** | | $4.70 | 146.4 | |
| **Custom Input I** | | | | | |
| **Custom Input II** | Liquified Petroleum Gas | | $12.22 | 146.9 | |
| **Custom Input III** | | | | | |

* Link to reference data tab

** To avoid double-counting, only enter Steam data in this row if fuel/electricity used to generate the steam is not already included above.

**Manufacturing Process Emissions (if applicable)**

If there are process emissions associated with either the new technology or commercial benchmark technology, list the emissions and associated 100-year GWP below. Do not include any emissions associated with combustion of fuels (already captured above).
If there are no significant process emissions, leave this section blank.

New Technology - Process Emissions (to produce reference quantity) | Commercial Benchmark - Process Emissions (to produce reference quantity)

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

…broken down by fuel type.

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### Use Phase Energy and Emissions

Complete this tab for any technology expected to have an energy impact during final use of the finished product in its end-use sector. Technologies for which the Use Phase is important include energy-consuming devices or systems, energy-producing devices or systems, or material/component inputs to such systems. For example, a lightweight material may provide fuel savings (compared to typical materials) when used in a vehicle; and an energy-efficient device may provide electricity savings (compared to typical devices) when used in a consumer application. If the technology is not expected to have use phase impacts, leave this section blank. Technologies for which the Use Phase is not expected to be important include technologies where the end-use product is identical to that produced using current typical technologies. For example, a new production route for a commodity chemical would not be expected to have use phase impacts because the end-use product (the commodity chemical) is identical.

To evaluate the use phase energy impact, estimate the total U.S. annual energy consumption (for the end-use market impacted by the technology) based on two scenarios:

1. Current Annual Energy Consumption
2. Hypothetical Annual Energy Consumption, Based on "Overnight Replacement" with New Technology

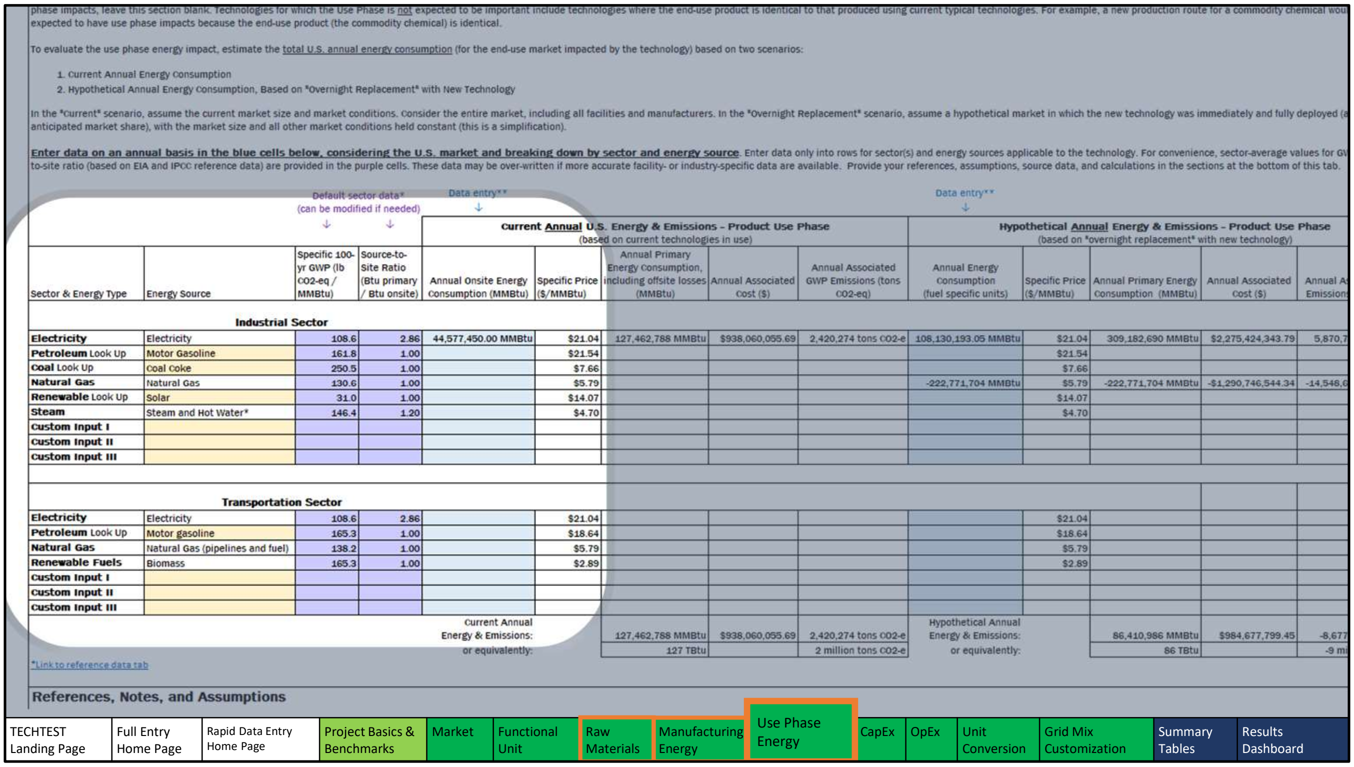
In the "Current" scenario, assume the current market size and market conditions. Consider the entire market, including all facilities and manufacturers. In the "Overnight Replacement" scenario, assume a hypothetical market in which the new technology was immediately and fully deployed (at its maximum anticipated market share), with the market size and all other market conditions held constant (this is a simplification).

**Enter data on an annual basis in the blue cells below, considering the U.S. market and breaking down by sector and energy source**. Enter data only into rows for sector(s) and energy sources applicable to the technology. For convenience, sector-average values for GWP and source-to-site ratio (based on EIA and IPCC reference data) are provided in the purple cells. These data may be over-written if more accurate facility- or industry-specific data are available. Provide your references, assumptions, source data, and calculations in the sections at the bottom of this tab.

| | | Default sector data* (can be modified if needed) | | Data entry** | | | | | Data entry** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Current Annual U.S. Energy & Emissions - Product Use Phase (based on current technologies in use) | | | | | Hypothetical Annual Energy & Emissions - Product Use Phase (based on "overnight replacement" with new technology) | | | | |
| Sector & Energy Type | Energy Source | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (Btu primary / Btu onsite) | Annual Onsite Energy Consumption (MMBtu) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption, including offsite losses (MMBtu) | Annual Associated Cost ($) | Annual Associated GWP Emissions (tons CO2-eq) | Annual Energy Consumption (fuel specific units) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption (MMBtu) | Annual Associated Cost ($) | Annual Associated GWP Emissions (tons CO2-eq) |
| **Industrial Sector** | | | | | | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | 44,577,450.00 MMBtu | $21.04 | 127,462,788 MMBtu | $938,060,055.69 | 2,420,274 tons CO2-e | 108,130,193.05 MMBtu | $21.04 | 309,182,690 MMBtu | $2,275,424,343.79 | 5,870,785.4 tons CO2-e |
| **Petroleum** Look Up | Motor Gasoline | 161.8 | 1.00 | | $21.54 | | | | | $21.54 | | | |
| **Coal** Look Up | Coal Coke | 250.5 | 1.00 | | $7.66 | | | | | $7.66 | | | |
| **Natural Gas** | Natural Gas | 130.6 | 1.00 | | $5.79 | | | | -222,771,704 MMBtu | $5.79 | -222,771,704 MMBtu | -$1,290,746,544.34 | -14,548,652.1 tons CO2-e |
| **Renewable** Look Up | Solar | 31.0 | 1.00 | | $14.07 | | | | | $14.07 | | | |
| **Steam** | Steam and Hot Water* | 146.4 | 1.20 | | $4.70 | | | | | $4.70 | | | |
| **Custom Input I** | | | | | | | | | | | | | |
| **Custom Input II** | | | | | | | | | | | | | |
| **Custom Input III** | | | | | | | | | | | | | |
| **Transportation Sector** | | | | | | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | | $21.04 | | | | | $21.04 | | | |
| **Petroleum** Look Up | Motor gasoline | 165.3 | 1.00 | | $18.64 | | | | | $18.64 | | | |
| **Natural Gas** | Natural Gas (pipelines and fuel) | 138.2 | 1.00 | | $5.79 | | | | | $5.79 | | | |
| **Renewable Fuels** | Biomass | 165.3 | 1.00 | | $2.89 | | | | | $2.89 | | | |
| **Custom Input I** | | | | | | | | | | | | | |
| **Custom Input II** | | | | | | | | | | | | | |
| **Custom Input III** | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |

And the Use Phase Energy tab quantifies the expected energy impacts from the product's final use.



phase impacts, leave this section blank. Technologies for which the Use Phase is not expected to be important include technologies where the end-use product is identical to that produced using current typical technologies. For example, a new production route for a commodity chemical wou expected to have use phase impacts because the end-use product (the commodity chemical) is identical.

To evaluate the use phase energy impact, estimate the total U.S. annual energy consumption (for the end-use market impacted by the technology) based on two scenarios:

1. Current Annual Energy Consumption
2. Hypothetical Annual Energy Consumption, Based on "Overnight Replacement" with New Technology

In the "Current" scenario, assume the current market size and market conditions. Consider the entire market, including all facilities and manufacturers. In the "Overnight Replacement" scenario, assume a hypothetical market in which the new technology was immediately and fully deployed (a anticipated market share), with the market size and all other market conditions held constant (this is a simplification).

**Enter data on an annual basis in the blue cells below, considering the U.S. market and breaking down by sector and energy source**. Enter data only into rows for sector(s) and energy sources applicable to the technology. For convenience, sector-average values for GV to-site ratio (based on EIA and IPCC reference data) are provided in the purple cells. These data may be over-written if more accurate facility- or industry-specific data are available. Provide your references, assumptions, source data, and calculations in the sections at the bottom of this tab.

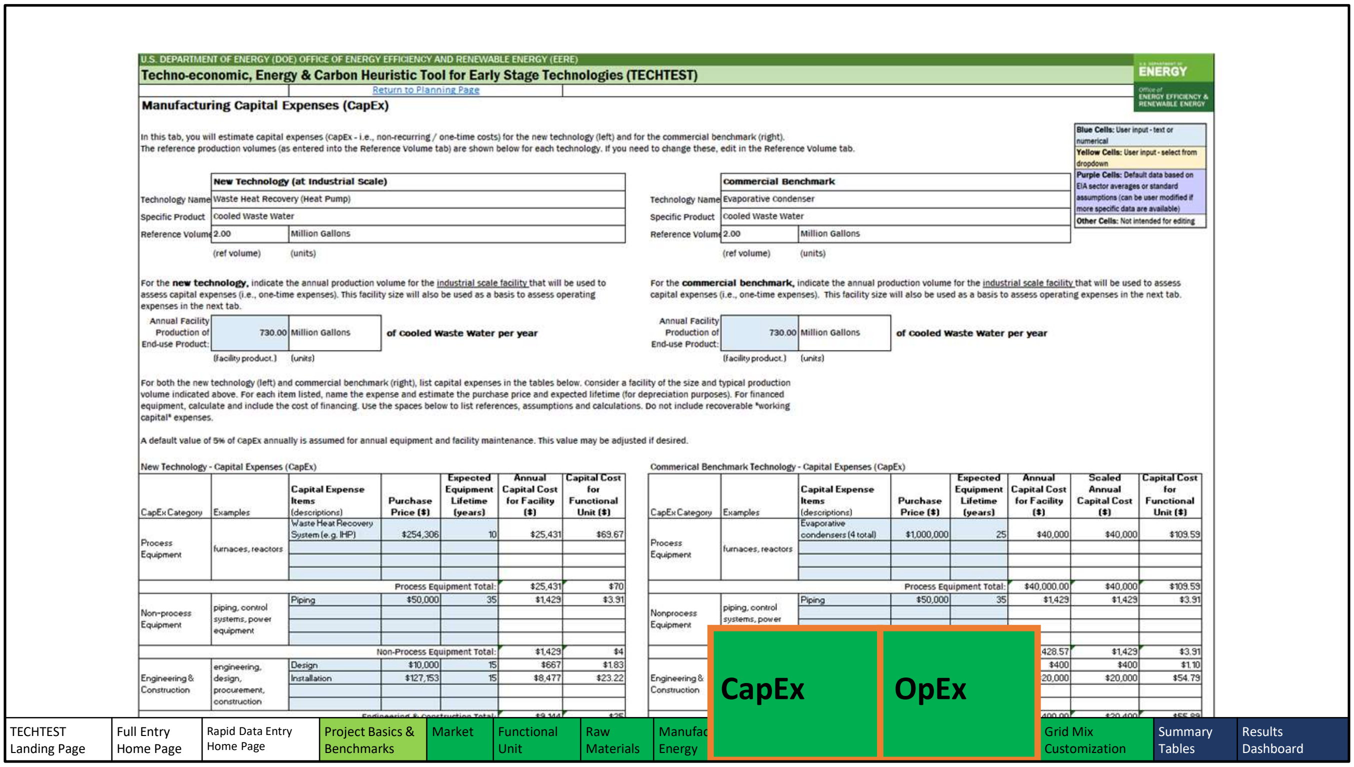
| | | Default sector data* (can be modified if needed) | | Data entry** | | | | | Data entry** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Current Annual U.S. Energy & Emissions – Product Use Phase (based on current technologies in use) | | | | | Hypothetical Annual Energy & Emissions – Product Use Phase (based on "overnight replacement" with new technology) | | | | |
| Sector & Energy Type | Energy Source | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (Btu primary / Btu onsite) | Annual Onsite Energy Consumption (MMBtu) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption, including offsite losses (MMBtu) | Annual Associated Cost ($) | Annual Associated GWP Emissions (tons CO2-eq) | Annual Energy Consumption (fuel specific units) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption (MMBtu) | Annual Associated Cost ($) | Annual A Emissions |
| **Industrial Sector** | | | | | | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | 44,577,450.00 MMBtu | $21.04 | 127,462,788 MMBtu | $938,060,055.69 | 2,420,274 tons CO2-e | 108,130,193.05 MMBtu | $21.04 | 309,182,690 MMBtu | $2,275,424,343.79 | 5,870,7 |
| **Petroleum** Look Up | Motor Gasoline | 161.8 | 1.00 | | $21.54 | | | | | $21.54 | | | |
| **Coal** Look Up | Coal Coke | 250.5 | 1.00 | | $7.66 | | | | | $7.66 | | | |
| **Natural Gas** | Natural Gas | 130.6 | 1.00 | | $5.79 | | | | -222,771,704 MMBtu | $5.79 | -222,771,704 MMBtu | -$1,290,746,544.34 | -14,546,6 |
| **Renewable** Look Up | Solar | 31.0 | 1.00 | | $14.07 | | | | | $14.07 | | | |
| **Steam** | Steam and Hot Water* | 146.4 | 1.20 | | $4.70 | | | | | $4.70 | | | |
| **Custom Input I** | | | | | | | | | | | | | |
| **Custom Input II** | | | | | | | | | | | | | |
| **Custom Input III** | | | | | | | | | | | | | |
| **Transportation Sector** | | | | | | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | | $21.04 | | | | | $21.04 | | | |
| **Petroleum** Look Up | Motor gasoline | 165.3 | 1.00 | | $18.64 | | | | | $18.64 | | | |
| **Natural Gas** | Natural Gas (pipelines and fuel) | 138.2 | 1.00 | | $5.79 | | | | | $5.79 | | | |
| **Renewable Fuels** | Biomass | 165.3 | 1.00 | | $2.89 | | | | | $2.89 | | | |
| **Custom Input I** | | | | | | | | | | | | | |
| **Custom Input II** | | | | | | | | | | | | | |
| **Custom Input III** | | | | | | | | | | | | | |
| | | | | Current Annual Energy & Emissions: | | 127,462,788 MMBtu | $938,060,055.69 | 2,420,274 tons CO2-e | Hypothetical Annual Energy & Emissions: | | 86,410,986 MMBtu | $984,677,799.45 | -8,677 |
| | | | | or equivalently: | | 127 TBtu | | 2 million tons CO2-e | or equivalently: | | 86 TBtu | | -9 mi |

*Link to reference data tab

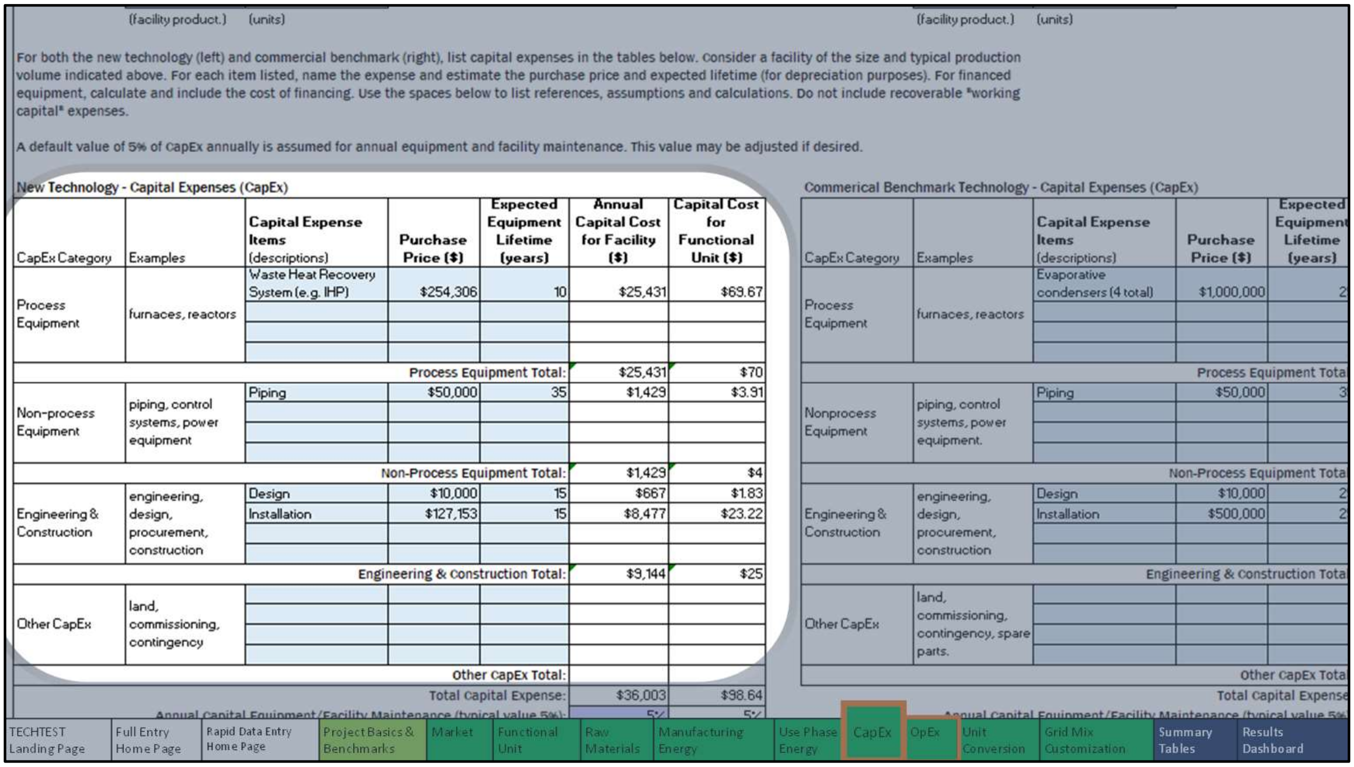
**References, Notes, and Assumptions**

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

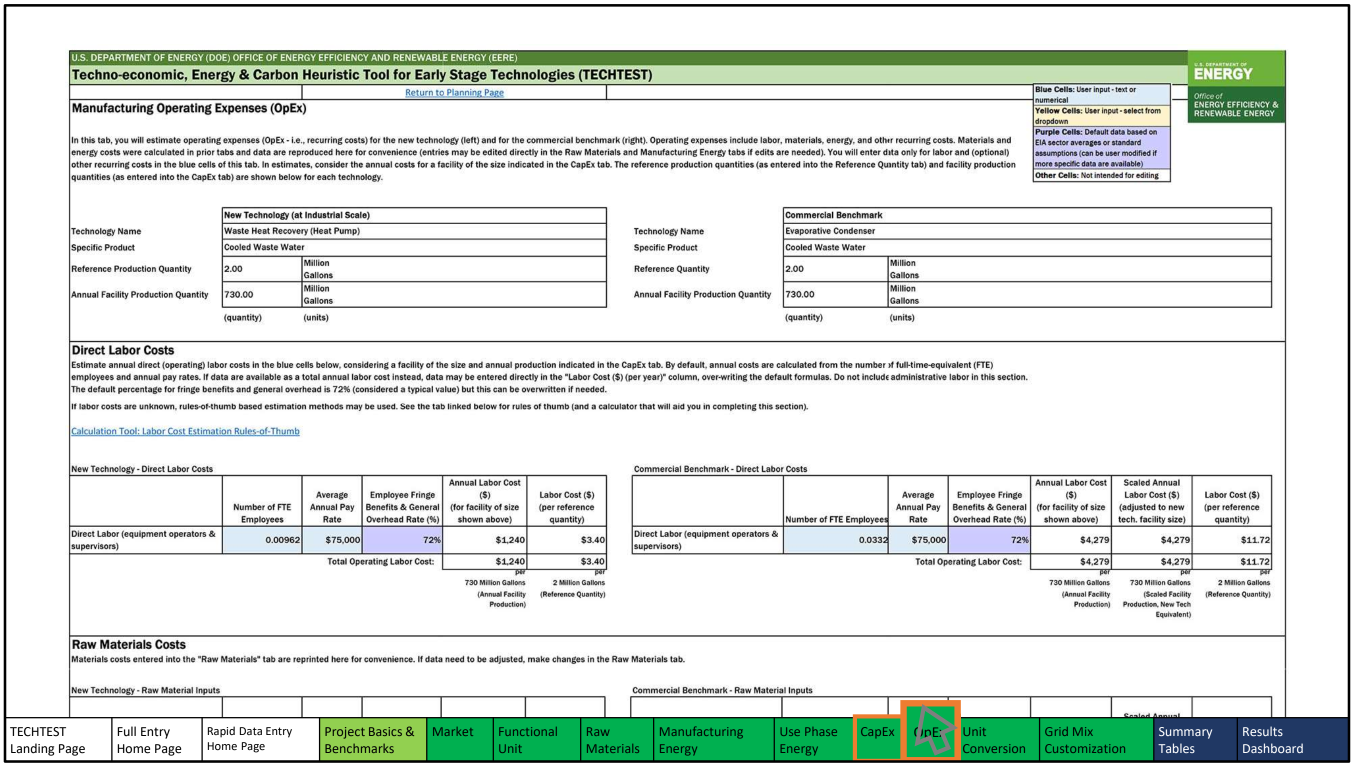
And the Use Phase Energy tab quantifies the expected energy impacts from the product's final use.




The two tabs in the Economic Considerations category house economic operations data on the project.




The CapEx (or capital expenses) tab captures the expenses for manufacturing equipment along with other purchase costs required to produce these technologies at the established scale.

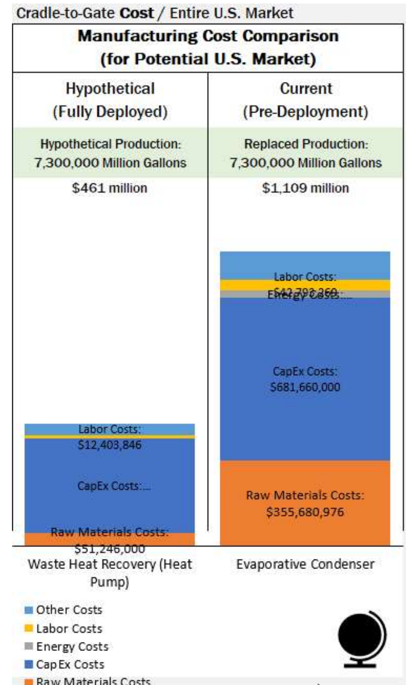



The OpEx (or operating expenses) tab models the ongoing cost of operating the manufacturing equipment, through a measure of labor costs and other dynamic cost considerations.

## Manufacturing Cost Results

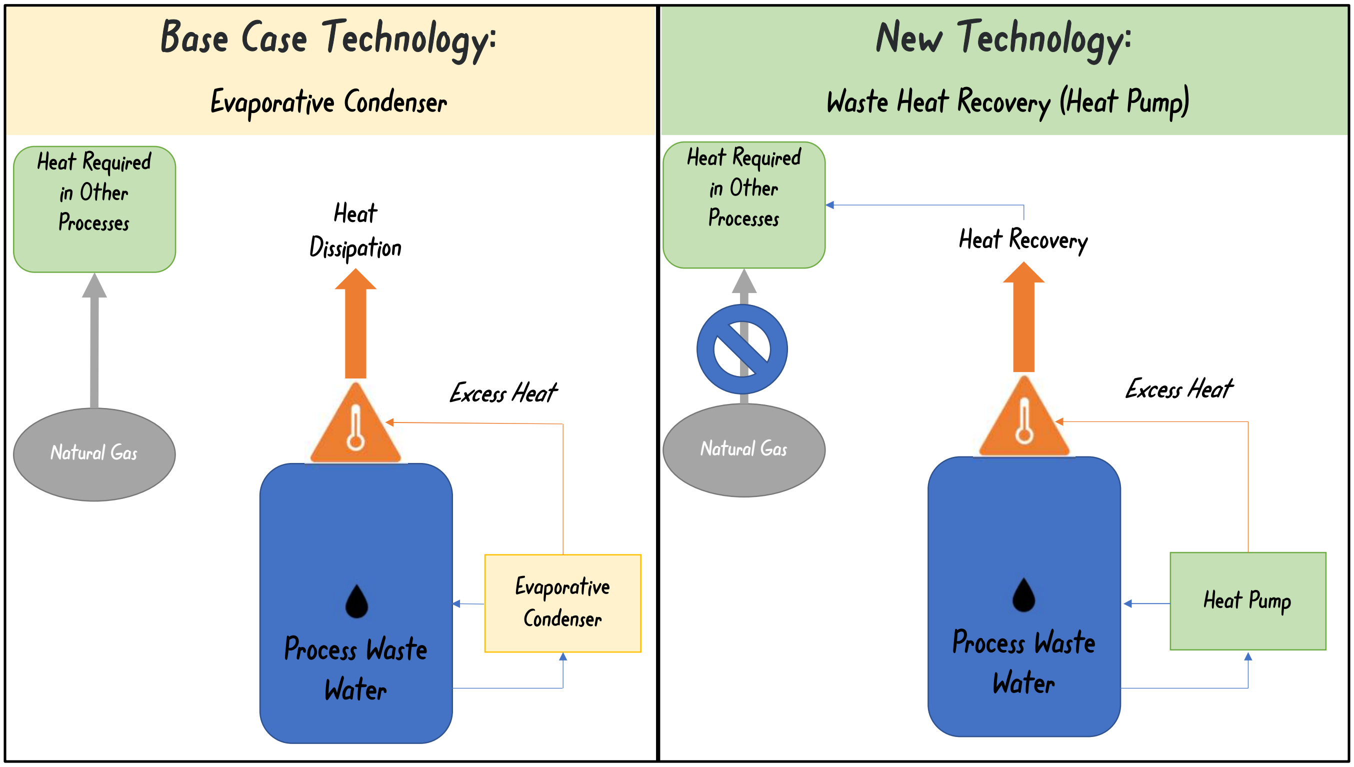
**Manufacturing Cost Comparison**
Based on Equivalent Reference Quantity

| | | New Technology, at Industrial Scale | Commercial Benchmark |
|---|---|---|---|
| | Technology Name | Waste Heat Recovery (Heat Pump) | Evaporative Condenser |
| | Reference Quantity | 2 Million Gallons of Cooled Waste Water | 2 Million Gallons of Cooled Waste Water |
| | | Manufacturing Cost ($) for Functional Unit | |
| Capital Expenses (CapEx) | Process Equipment | $69.67 | $109.59 |
| | Non-process Equipment | $3.91 | $3.91 |
| | Engineering & Construction | $25.05 | $55.89 |
| | Other Capital Expenses | | |
| | Facility & Equipment Maintenance | $4.93 | $8.47 |
| Operating Expenses (OpEx) | Raw Materials | $14.04 | $97.45 |
| | Energy | $0.18 | $7.89 |
| | Direct Labor | $3.40 | $11.72 |
| | Other Recurring Costs | $13.70 | $32.88 |
| Total Manufacturing Cost | CapEx Subtotal | $108.75 | $186.76 |
| | OpEx Subtotal | $31.32 | $149.94 |
| | **Total Cost (CapEx + OpEx)** | **$140.06** | **$336.69** |

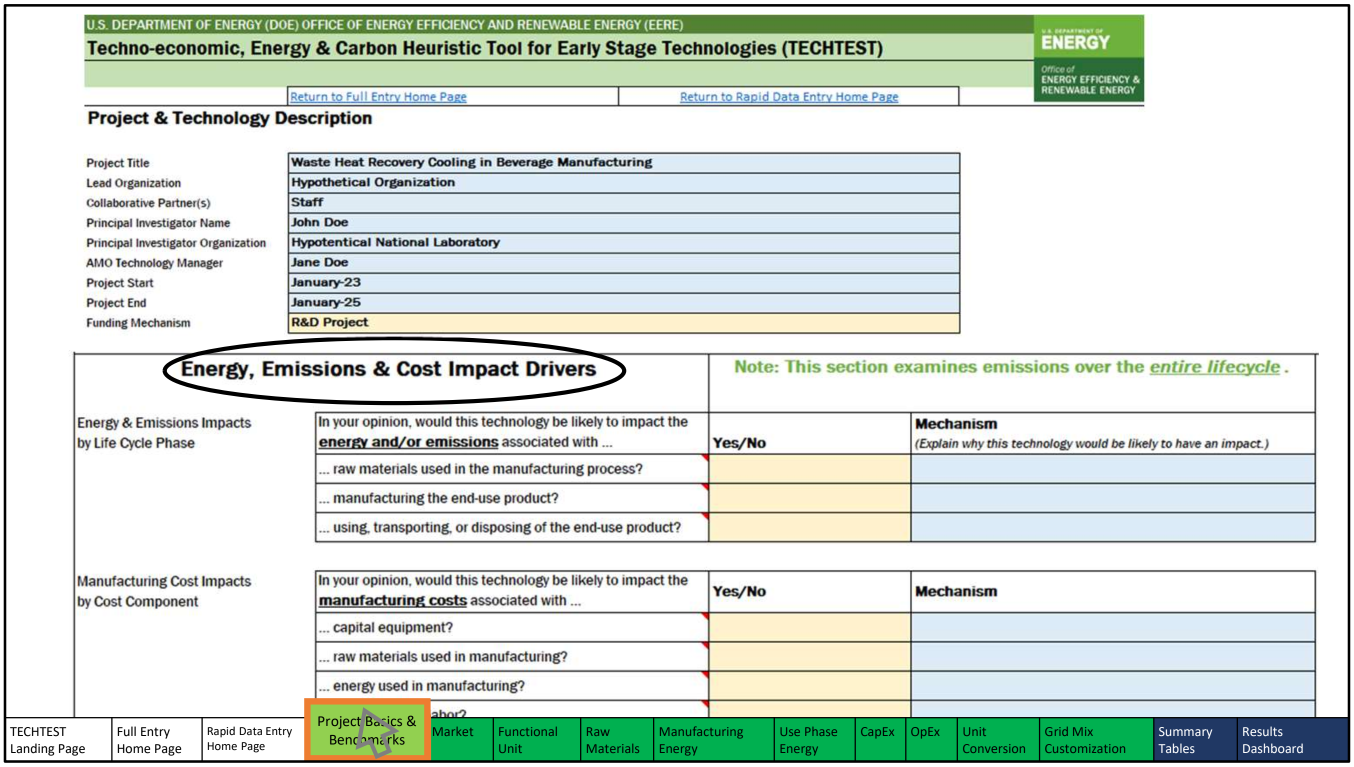



TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard

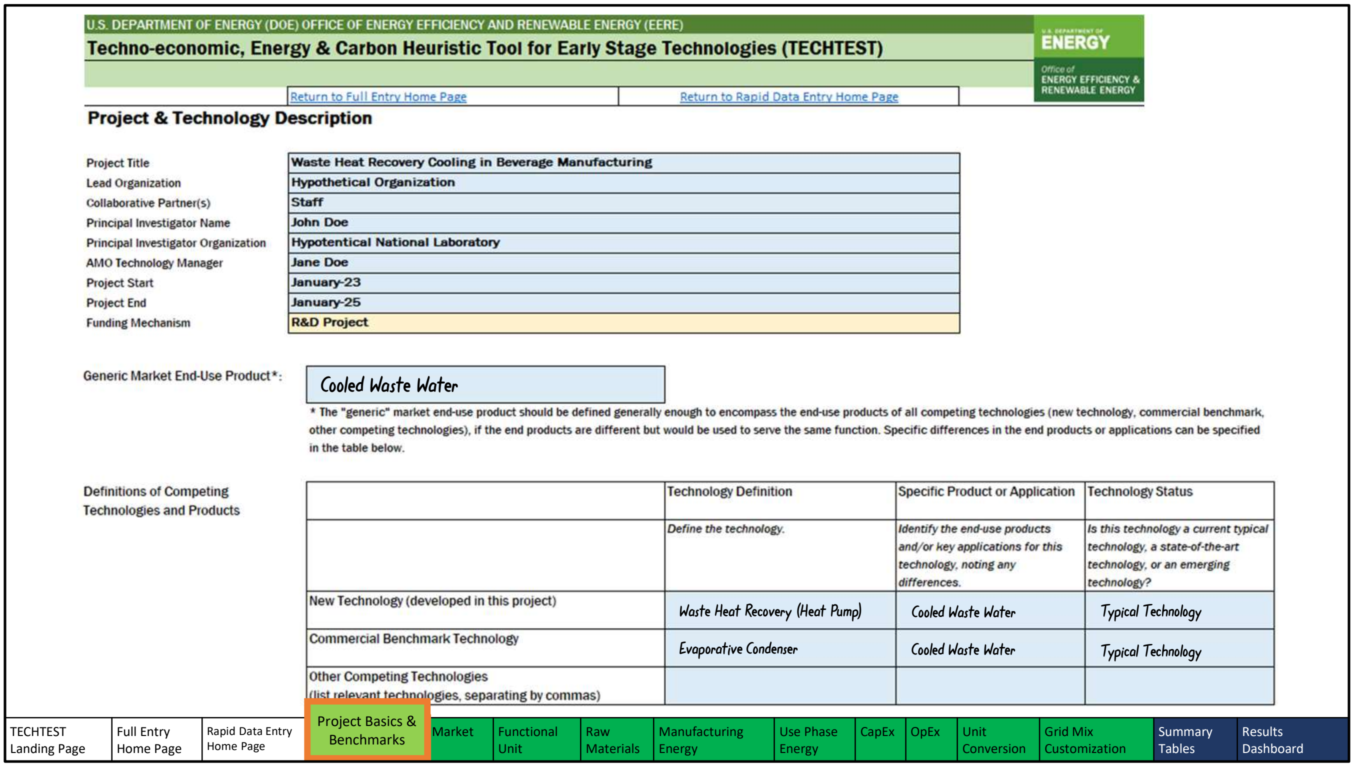
Finally, the two Results tabs will showcase the results of your TECHTEST analysis, in table form in the Summary Tables tab and graphically in the Results Dashboard tab. Now that the general TECHTEST framework has been established, let’s get started with our example scenario.




For this example, we will use the Full Analytical Approach to analyze a new waste heat recovery technology involving a heat pump being used to cool process wastewater and compare it to the benchmark technology of using evaporative coolers to achieve the required heat removal. The heat recovered by the heat pump can be utilized upstream for process heating needs, offsetting natural gas purchases that would otherwise be required.




In the Project Basics & Benchmarks tab, we will identify where improvements may occur with respect to the new technology. The data input sections of this tab include: general project information; the generic market end-use product; definitions of competing technologies and products; and the energy, emissions, and cost impact drivers.


U.S. DEPARTMENT OF ENERGY (DOE) OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY (EERE)

**Techno-economic, Energy & Carbon Heuristic Tool for Early Stage Technologies (TECHTEST)**

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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**Project & Technology Description**

| | |
|---|---|
| Project Title | Waste Heat Recovery Cooling in Beverage Manufacturing |
| Lead Organization | Hypothetical Organization |
| Collaborative Partner(s) | Staff |
| Principal Investigator Name | John Doe |
| Principal Investigator Organization | Hypotentical National Laboratory |
| AMO Technology Manager | Jane Doe |
| Project Start | January-23 |
| Project End | January-25 |
| Funding Mechanism | R&D Project |

Generic Market End-Use Product*: Cooled Waste Water

* The "generic" market end-use product should be defined generally enough to encompass the end-use products of all competing technologies (new technology, commercial benchmark, other competing technologies), if the end products are different but would be used to serve the same function. Specific differences in the end products or applications can be specified in the table below.

Definitions of Competing Technologies and Products

| | Technology Definition | Specific Product or Application | Technology Status |
|---|---|---|---|
| | *Define the technology.* | *Identify the end-use products and/or key applications for this technology, noting any differences.* | *Is this technology a current typical technology, a state-of-the-art technology, or an emerging technology?* |
| New Technology (developed in this project) | Waste Heat Recovery (Heat Pump) | Cooled Waste Water | Typical Technology |
| Commercial Benchmark Technology | Evaporative Condenser | Cooled Waste Water | Typical Technology |
| Other Competing Technologies (list relevant technologies, separating by commas) | | | |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

We will enter the end-use product as “cooled waste water,” defining the new and commercial benchmark technologies as “Waste Heat Recovery (Heat Pump)” and “Evaporative Condenser,” respectively.

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**Techno-economic, Energy & Carbon Heuristic Tool for Early Stage Technologies (TECHTEST)**

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**Project & Technology Description**

Project Title: **Waste Heat Recovery Cooling in Beverage Manufacturing**

**Energy, Emissions & Cost Impact Drivers**

**Note: This section examines emissions over the *entire lifecycle*.**

Energy & Emissions Impacts by Life Cycle Phase

| In your opinion, would this technology be likely to impact the **energy and/or emissions** associated with ... | **Yes/No** | **Mechanism** *(Explain why this technology would be likely to have an impact.)* |
|---|---|---|
| ... raw materials used in the manufacturing process? | Yes | Higher energy efficiency, no cooling water needed |
| ... manufacturing the end-use product? | | |
| ... using, transporting, or disposing of the end-use product? | | |

Manufacturing Cost Impacts by Cost Component

| In your opinion, would this technology be likely to impact the **manufacturing costs** associated with ... | **Yes/No** | **Mechanism** |
|---|---|---|
| ... capital equipment? | | |
| ... raw materials used in manufacturing? | | |
| ... energy used in manufacturing? | | |
| ... manufacturing labor? | | |

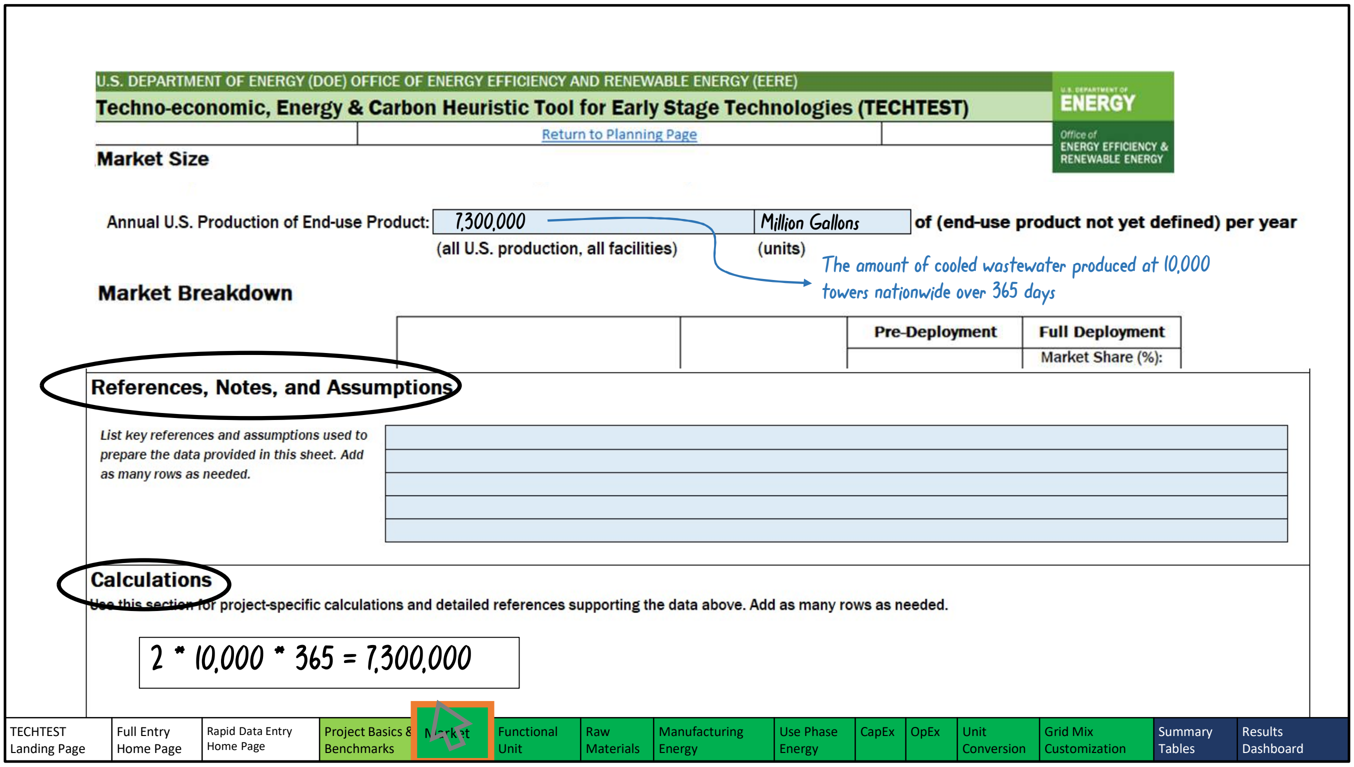
Impacts by Sector

*For each sector that would be impacted by the new technology, briefly describe the mechanisms of potential impacts. (Assume successful commercialization and adoption.)*

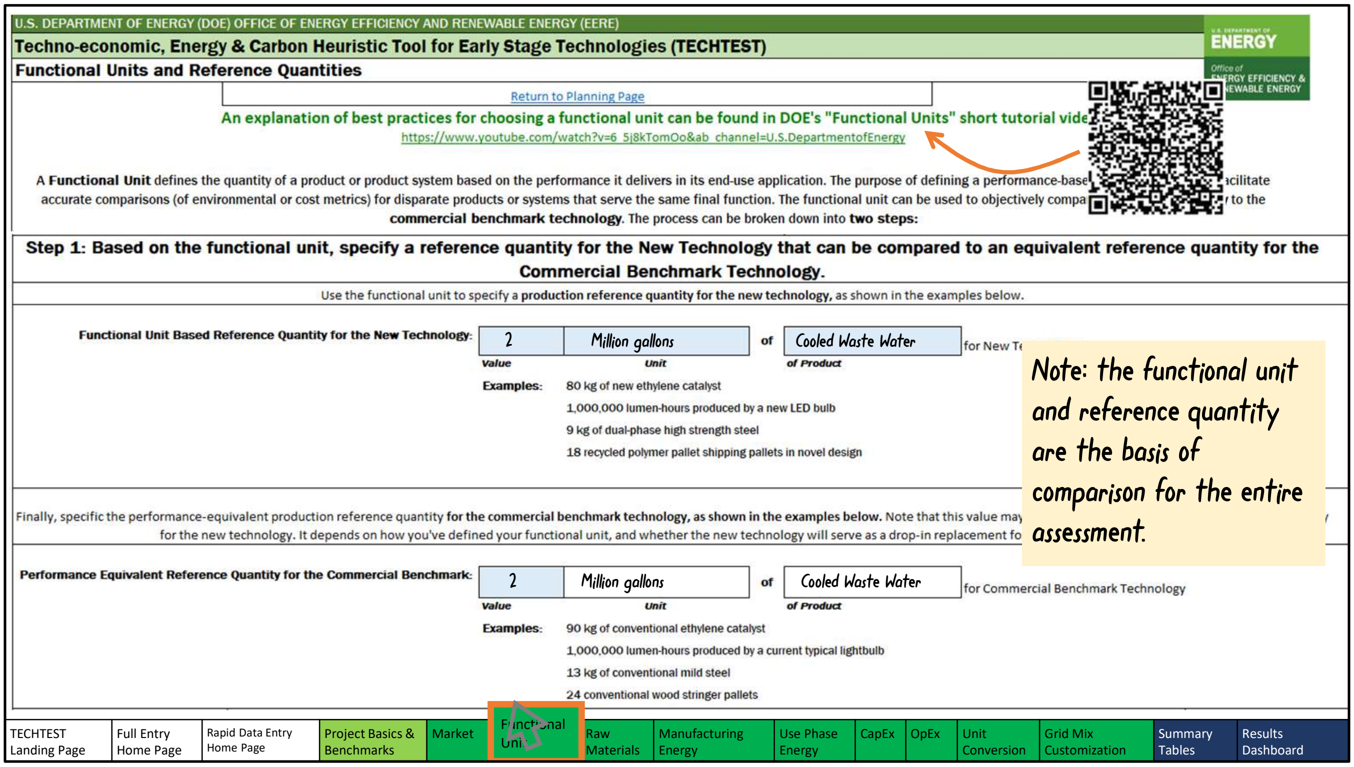
| In your opinion, would this technology be likely to impact the following **sectors** (energy, emissions, or cost)? | **Yes/No** | **Mechanism** |
|---|---|---|
| Mining | Yes | Used to save energy in beverage manufacturing |
| Manufacturing | | |
| Transportation | | |
| Energy Generation (utility scale) | | |
| Energy Generation (device scale) | | |

TECHTEST Landing P

We then identify the areas where the new technology could see improvements over the benchmark.

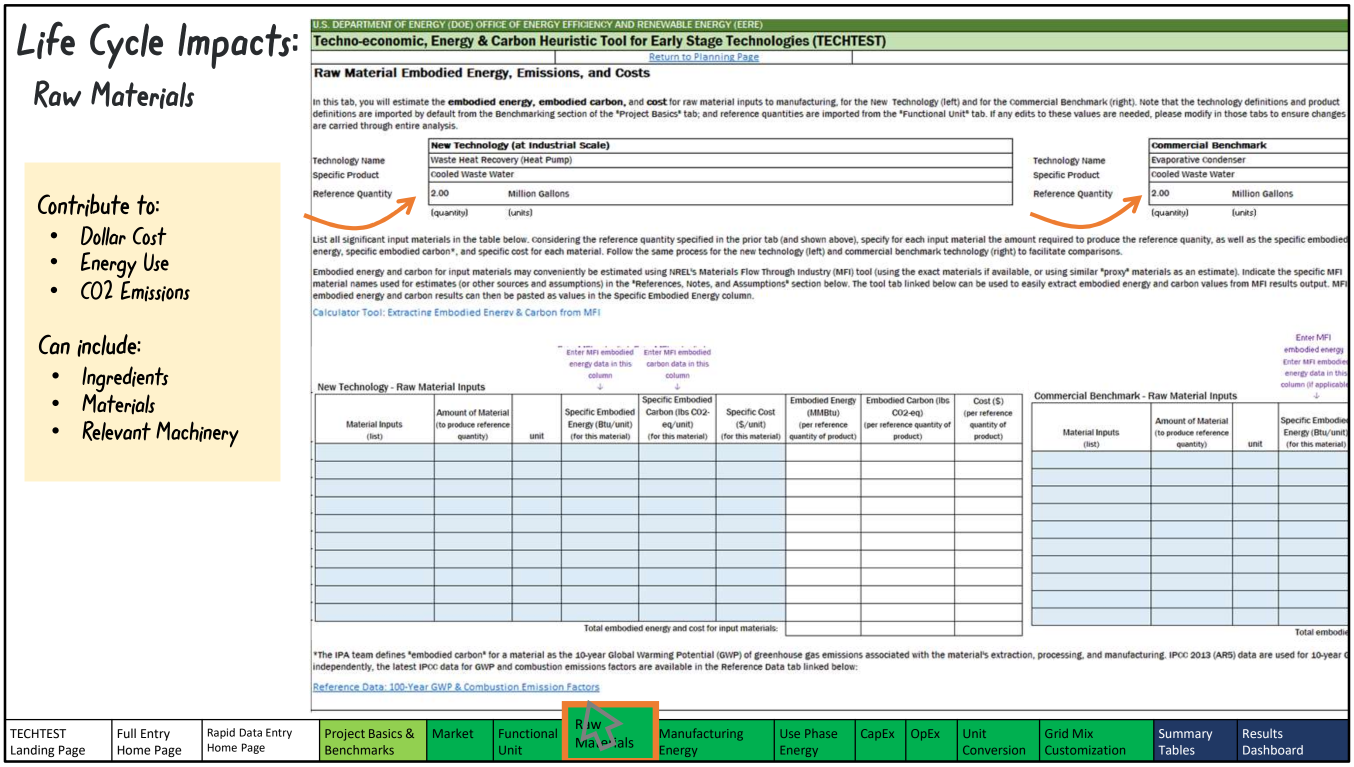



On the Market tab, we input the total annual production of the end-use product at all U.S. facilities (in this case, the amount of cooled waste water produced at 10,000 towers nationwide over 365 days), as well as the hypothetical use percentages for each technology. There is also space to add references, notes, assumptions, and calculations; this space appears at the bottom of each data input tab.

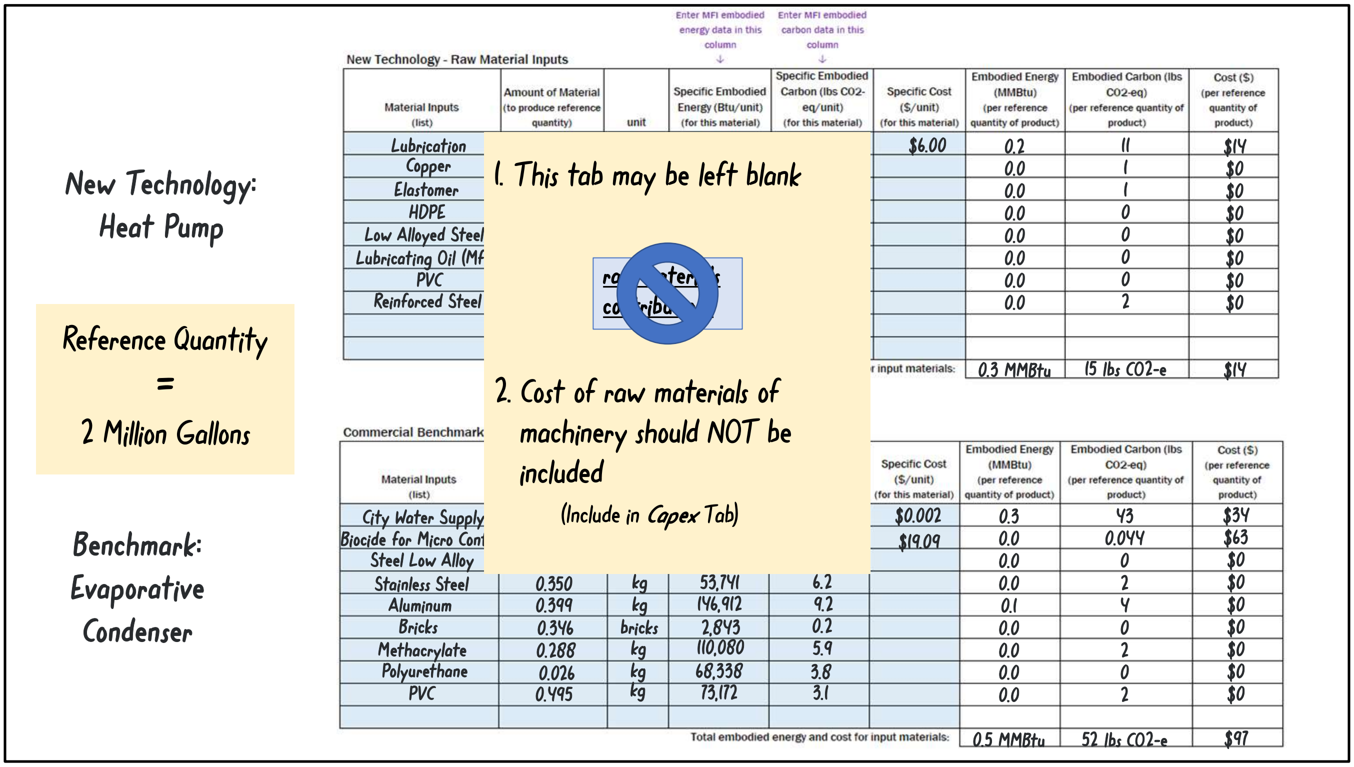



On the Functional Unit tab, we establish 2 million gallons of cooled waste water (the typical daily output of a water tower) as our reference quantity. Despite differences in the process, both technologies will produce the same amount of water, so our equivalent reference quantity stays the same.

Note that the functional unit, and reference quantity, are the basis of comparison for the entire assessment, so it is important to ensure consistency between the new and benchmark technologies. If you are unfamiliar with establishing a functional unit, we recommend viewing the “Defining Functional Units” tutorial video, linked at the top of the Functional Unit tab.




Next, we'll work through the Life Cycle Impacts category, starting with raw materials. The Raw Materials tab compiles data on the materials required to produce the identified reference quantity of each technology. These materials contribute to the overall dollar cost, energy use, and emissions. Raw materials can include product ingredients, materials, and relevant machinery, but will vary significantly based on technology and project scope.



New Technology - Raw Material Inputs

| Material Inputs (list) | Amount of Material (to produce reference quantity) | unit | Specific Embodied Energy (Btu/unit) (for this material) | Specific Embodied Carbon (lbs CO2-eq/unit) (for this material) | Specific Cost ($/unit) (for this material) | Embodied Energy (MMBtu) (per reference quantity of product) | Embodied Carbon (lbs CO2-eq) (per reference quantity of product) | Cost ($) (per reference quantity of product) |
|---|---|---|---|---|---|---|---|---|
| Lubrication | | | | | $6.00 | 0.2 | 11 | $14 |
| Copper | | | | | | 0.0 | 1 | $0 |
| Elastomer | | | | | | 0.0 | 1 | $0 |
| HDPE | | | | | | 0.0 | 0 | $0 |
| Low Alloyed Steel | | | | | | 0.0 | 0 | $0 |
| Lubricating Oil (MF | | | | | | 0.0 | 0 | $0 |
| PVC | | | | | | 0.0 | 0 | $0 |
| Reinforced Steel | | | | | | 0.0 | 2 | $0 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | r input materials: | 0.3 MMBtu | 15 lbs CO2-e | $14 |

Commercial Benchmark

| Material Inputs (list) | | | | | Specific Cost ($/unit) (for this material) | Embodied Energy (MMBtu) (per reference quantity of product) | Embodied Carbon (lbs CO2-eq) (per reference quantity of product) | Cost ($) (per reference quantity of product) |
|---|---|---|---|---|---|---|---|---|
| City Water Supply | | | | | $0.002 | 0.3 | 43 | $34 |
| Biocide for Micro Cont | | | | | $19.09 | 0.0 | 0.044 | $63 |
| Steel Low Alloy | | | | | | 0.0 | 0 | $0 |
| Stainless Steel | 0.350 | kg | 53,741 | 6.2 | | 0.0 | 2 | $0 |
| Aluminum | 0.399 | kg | 146,912 | 9.2 | | 0.1 | 4 | $0 |
| Bricks | 0.346 | bricks | 2,843 | 0.2 | | 0.0 | 0 | $0 |
| Methacrylate | 0.288 | kg | 110,080 | 5.9 | | 0.0 | 2 | $0 |
| Polyurethane | 0.026 | kg | 68,338 | 3.8 | | 0.0 | 0 | $0 |
| PVC | 0.495 | kg | 73,172 | 3.1 | | 0.0 | 2 | $0 |
| | | | | | | | | |
| | | | | | Total embodied energy and cost for input materials: | 0.5 MMBtu | 52 lbs CO2-e | $97 |



For this example, we have assembled a list of the materials required to build the technology in question, along with materials that are consumed when running these machines. The machine-part materials are amortized across the lifetime of the machine (with their costs included later in the capital expenses tab), and all inputs are calculated on a per reference quantity basis. Next, embodied energy and embodied carbon values are entered for each raw material, as well as the monetary cost of the materials consumed when running these machines.

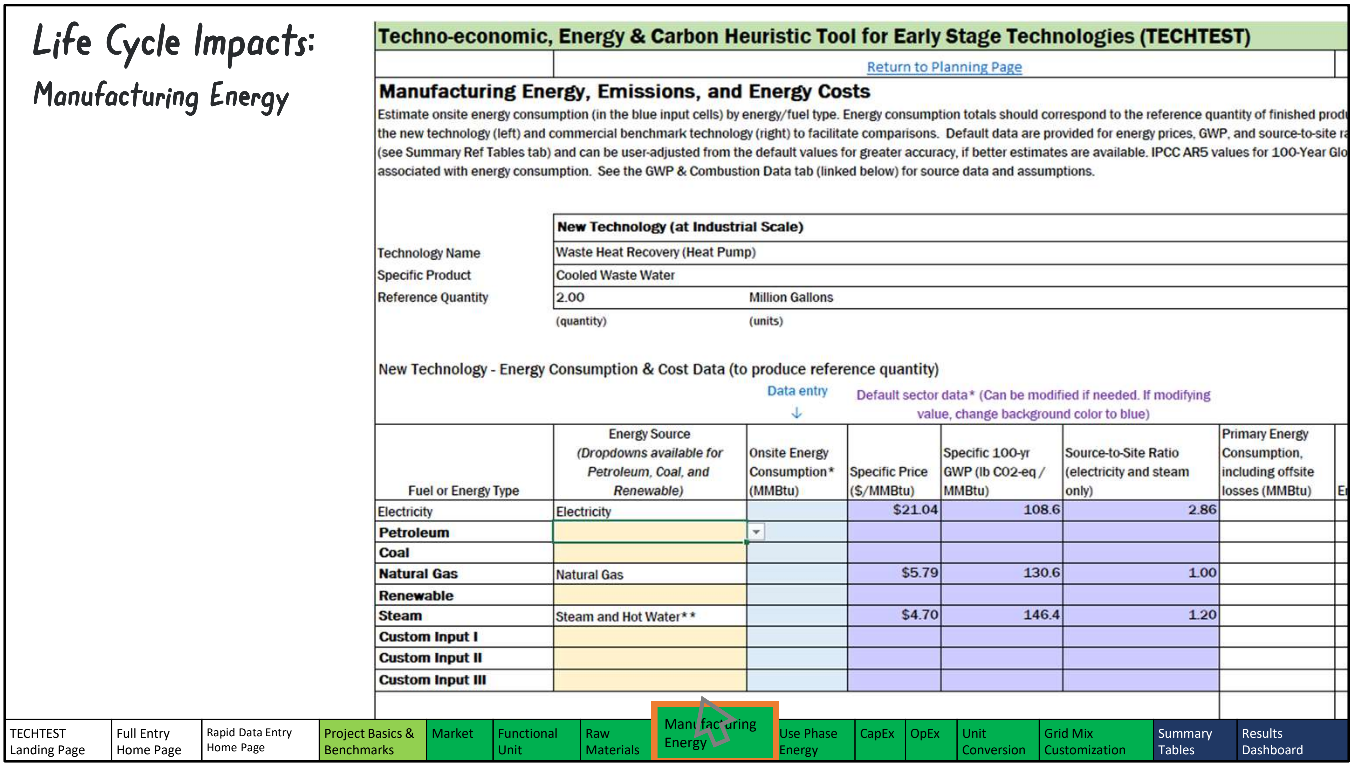
There are a few important points to keep in mind for this section:

First, this tab may be left blank for a technology that is process-focused, as raw materials contributions may not be significant in such cases.

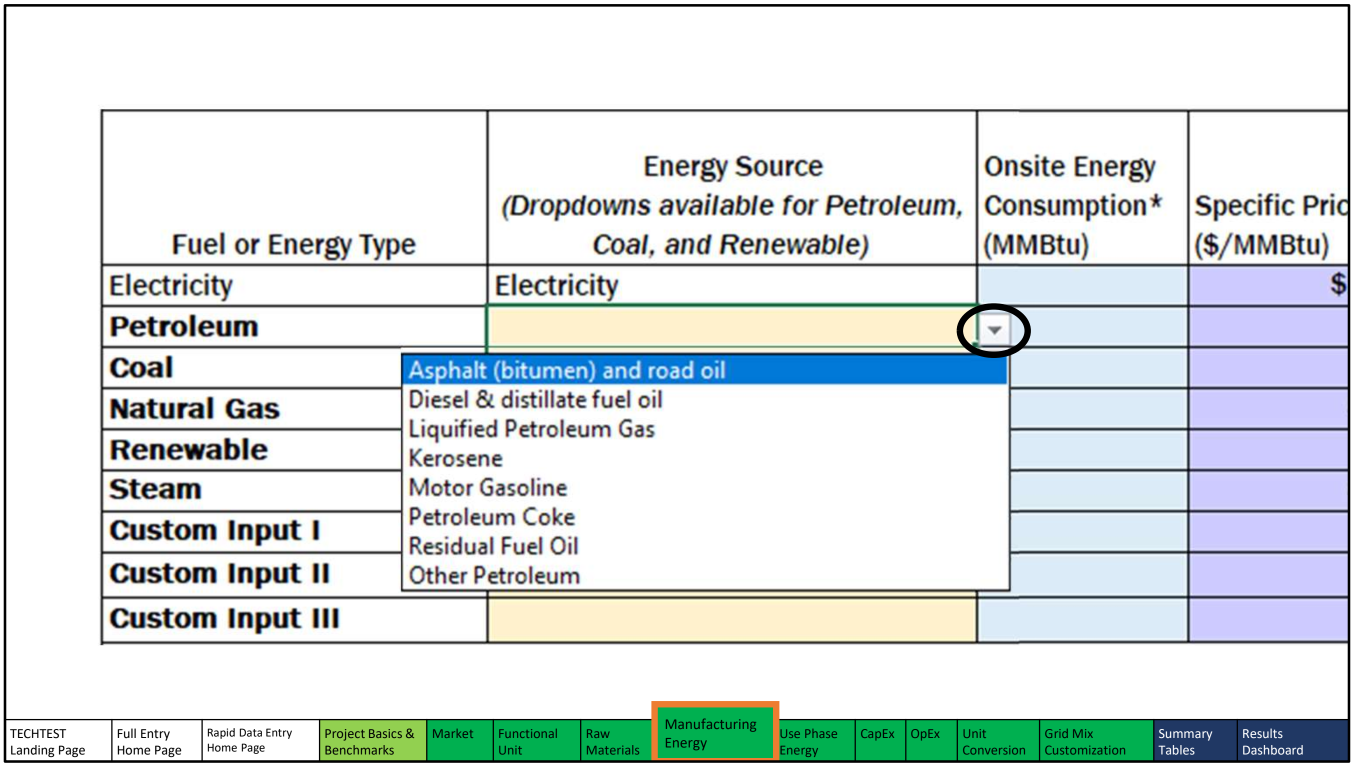
Second, the cost of raw materials of machinery should NOT be included, as the total machinery cost will be identified later in the CapEx tab.

# Life Cycle Impacts:

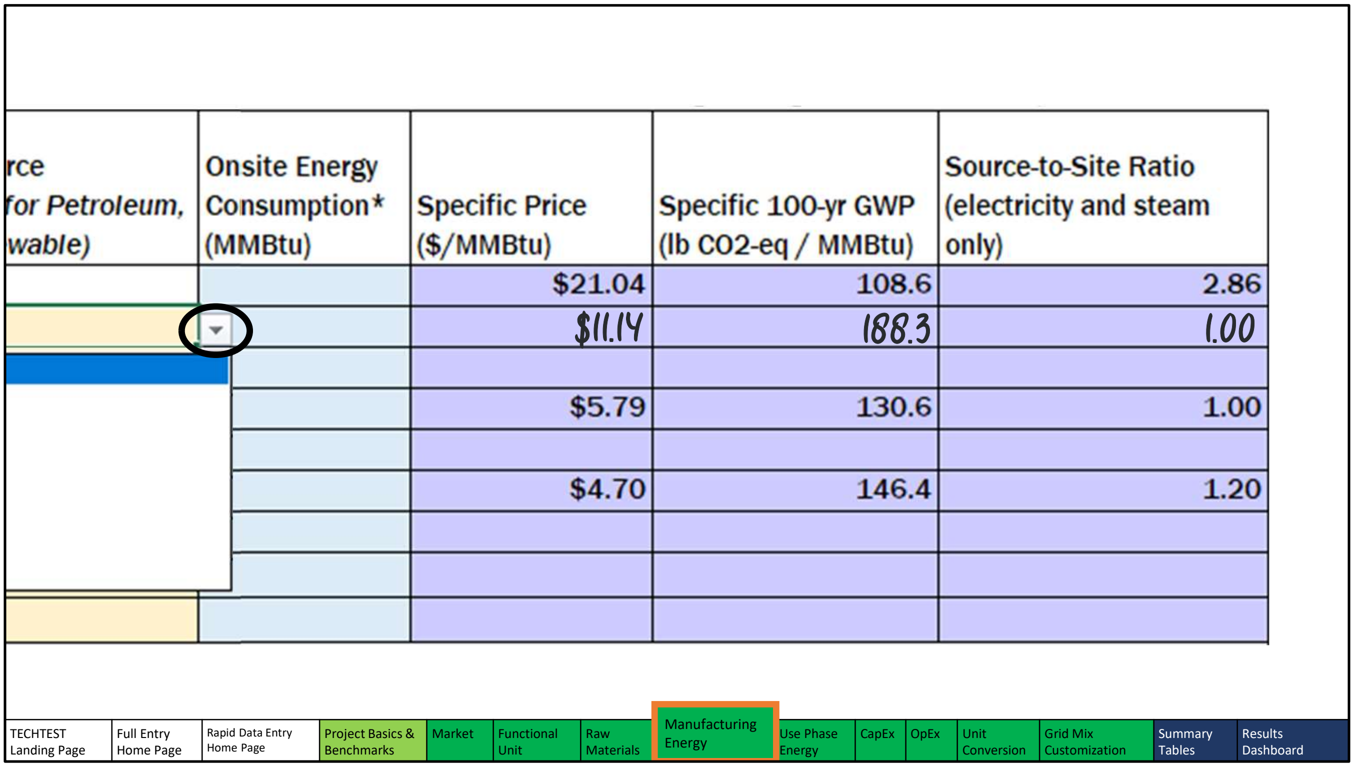
## Manufacturing Energy




The Manufacturing Energy tab calculates the energy required to "manufacture" the reference quantity.




Energy sources can be selected from dropdown lists within the yellow cells.



| rce for Petroleum, wable) | Onsite Energy Consumption* (MMBtu) | Specific Price ($/MMBtu) | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (electricity and steam only) |
|---|---|---|---|---|
| | | $21.04 | 108.6 | 2.86 |
| | | $11.14 | 188.3 | 1.00 |
| | | | | |
| | | $5.79 | 130.6 | 1.00 |
| | | | | |
| | | $4.70 | 146.4 | 1.20 |
| | | | | |
| | | | | |
| | | | | |



Notice that the values in the purple cells automatically populate after you identify the energy sources in the dropdown.

## All energy cost inputs should be on a per-functional-unit basis

| Category | Energy Source | CO2 Emissions Factor (kg of GHG per TJ) | CH4 Emissions Factor (kg of GHG per TJ) | N2O Emissions Factor (kg of GHG per TJ) | Calculated 100-Year GWP Emissions (kg CO2-eq per TJ) | Calculated 100-Year GWP Emissions (lbs CO2-eq per MMBtu)* |
|---|---|---|---|---|---|---|
| Petroleum | Bitumen (asphalt) | 80,700 | 3 | 0.6 | 80,945 | 188.3 |
| | Gas / Diesel Oil (distillate fuel oil) | 74,100 | 3 | 0.6 | 74,345 | 172.9 |
| | Liquified Petroleum Gas | 63,100 | 1 | 0.1 | 63,154 | 146.9 |
| | Kerosene | 71,900 | 3 | 0.6 | 72,145 | 167.8 |
| | Motor Gasoline | 69,300 | 3 | 0.6 | 69,545 | 161.8 |
| | Petroleum Coke | 97,500 | 3 | 0.6 | 97,745 | 227.4 |
| | Residual Fuel Oil | 77,400 | 3 | 0.6 | 77,645 | 180.6 |
| | Other Petroleum | 73,300 | 3 | 0.6 | 73,545 | 171.1 |
| Coal | Coke Oven Coke and Lignite Coke | 107,000 | 10 | 1.5 | 107,680 | 250.5 |
| | Bituminous Coal | 94,600 | 3 | 1.5 | 95,091 | 221.2 |
| | Anthracite | 98,300 | 3 | 1.5 | 98,791 | 229.8 |
| | Lignite | 101,000 | 3 | 1.5 | 101,491 | 236.1 |
| Natural Gas | Natural Gas | 56,100 | 1 | 0.1 | 56,154 | 130.6 |
| Renewable Fuels | Municipal Waste (biomass) | 100,000 | 30 | 4.0 | 101,902 | 237.0 |
| | Industrial Wastes | 143,000 | 30 | 4.0 | 144,902 | 337.0 |
| | Wood / Wood Waste | 112,000 | 30 | 4.0 | 113,902 | 264.9 |
| | Biogasoline & Biodiesel | 70,800 | 3 | 0.6 | 71,045 | 165.3 |
| Steam | Steam and Hot Water** | 62,872 | 1 | 0.1 | 62,936 | 146.4 |

ini-Tool | MFI Embodied Energy Mini-Tool | Labor Estimation Mini-Tool | GWP Ref Tables | EIA Ref Tables | Summary Ref Tables

If necessary, you can customize the specific prices, global warming potentials, and source-to-site ratios by modifying these values in the GWP Ref Tables and EIA Ref Tables tabs. And remember, all energy cost inputs should be on a per-functional-unit basis.

New Technology - Energy Consumption & Cost Data (to produce reference quantity)

**New Technology: Heat Pump**

Data entry ↓ | Default sector data* (Can be modified if needed. If modifying value, change background color to blue)

| Fuel or Energy Type | Energy Source (Dropdowns available for Petroleum, Coal, and Renewable) | Onsite Energy Consumption* (MMBtu) | Specific Price ($/MMBtu) | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (electricity and steam only) | Primary Energy Consumption, including offsite losses (MMBtu) | Energy Cost ($) | GWP Emissions (lb CO2-eq) |
|---|---|---|---|---|---|---|---|---|
| Electricity | Electricity | 0.0048 | $21.04 | 108.6 | 2.86 | 0.01 MMBtu | $0.10 | 0.5 lb CO2-e |
| **Petroleum** | | | | | | | | |
| **Coal** | | | | | | | | |
| **Natural Gas** | Natural Gas | 0.0133 | $5.79 | 130.6 | 1.00 | 0.01 MMBtu | $0.08 | 1.7 lb CO2-e |
| **Renewable** | | | | | | | | |
| **Steam** | Steam and Hot Water** | | $4.70 | 146.4 | 1.20 | | | |
| **Custom Input I** | | | | | | | | |
| **Custom Input II** | | | | | | | | |
| **Custom Input III** | | | | | | | | |
| | | | | | | 0.03 MMBtu | $0.18 | 2.3 lb CO2-e |

Commercial Benchmark - Energy Consumption & Cost Data (to produce reference quantity)

**Benchmark: Evaporative Condenser**

Data entry ↓ | Default sector data* (Can be modified if needed. If modifying value, change background color to blue)

| Fuel or Energy Type | Energy Source (Dropdowns available for Petroleum, Coal, and Renewable) | Onsite Energy Consumption* (MMBtu) | Specific Price ($/MMBtu) | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (electricity and steam only) | Primary Energy Consumption, including offsite losses (MMBtu) | Energy Cost ($) | GWP Emissions (lb CO2-eq) |
|---|---|---|---|---|---|---|---|---|
| Electricity | Electricity | 0.370 | $21.04 | 108.6 | 2.86 | 1.06 MMBtu | $7.81 | 40.3 lb CO2-e |
| **Petroleum** | | | | | | | | |
| **Coal** | | | | | | | | |
| **Natural Gas** | Natural Gas | 0.010 | $5.79 | 130.6 | 1.00 | 0.01 MMBtu | $0.08 | 1.7 lb CO2-e |
| **Renewable** | | | | | | | | |
| **Steam** | Steam and Hot Water** | | $4.70 | 146.4 | 1.20 | | | |
| **Custom Input I** | | | | | | | | |
| **Custom Input II** | | | | | | | | |
| **Custom Input III** | | | | | | | | |
| | | | | | | 1.07 MMBtu | $7.89 | 42.1 lb CO2-e |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |

For our example scenario, we enter the associated electricity and natural gas onsite energy consumptions for manufacturing both technologies, based on the 2-million-gallon reference quantity.

## Manufacturing Process Emissions (if applicable)

If there are process emissions associated with either the new technology or commercial benchmark technology, list the emissions and associated 100-year GWP below. Do not incl

If there are no significant process emissions, leave this section blank.

New Technology: Heat Pump

New Technology - Process Emissions (to produce reference volume)

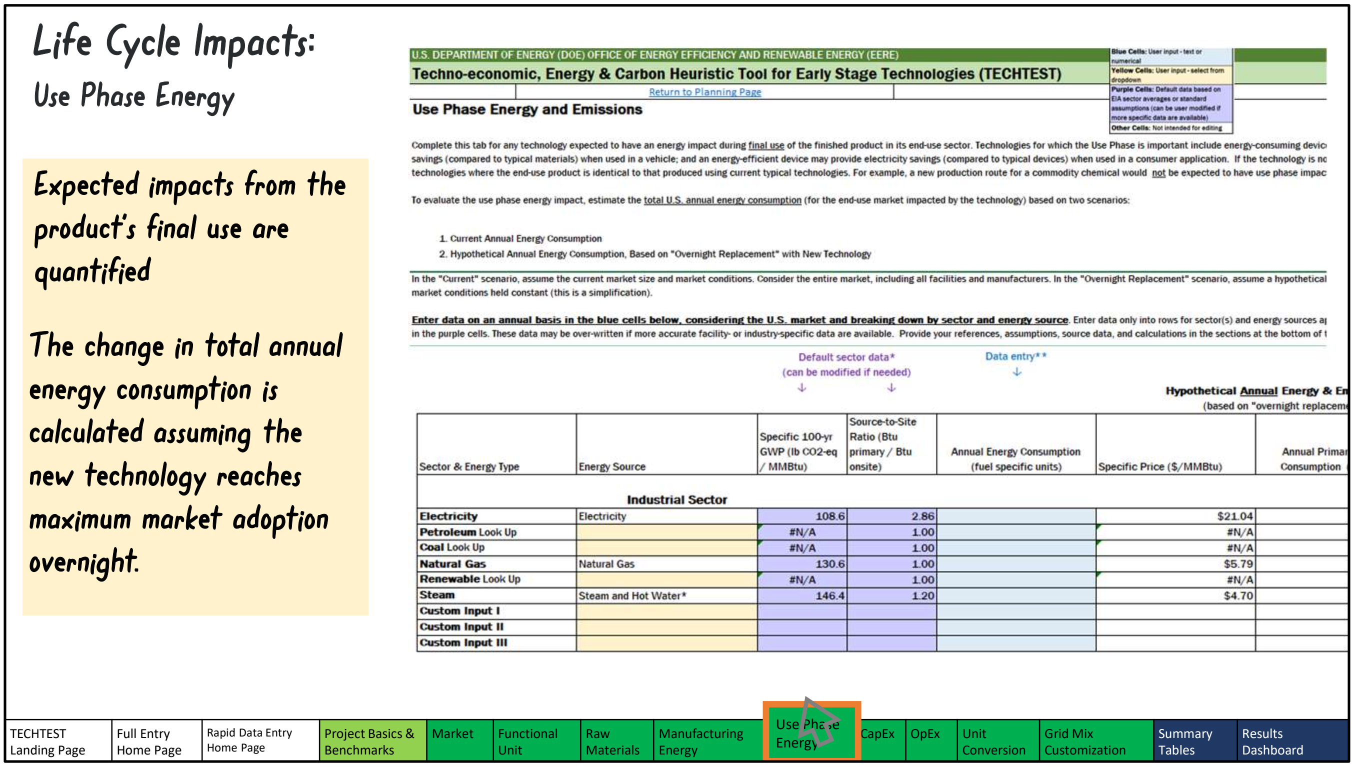
| Emission Type (chemical name or acronym) | Amount emitted (lb) | 100-Year GWP* | Suggested 100-Year GWP | Embodied Carbon (lb CO2-eq) |
|---|---|---|---|---|
| R-134a | 0.05 | 1,300 | | 64 lbs CO2-e |
| | | | | |
| | | | | |
| | | | Total: | 64 lbs CO2-e |

* Use IPCC AR5 values for 100-Year Global Warming Potential (GWP). See the GWP Data tab (linked below) for excerpted GWP values for the mos

Reference Data Tables: Global Warming Potential

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

In this tab, we will also enter the manufacturing process emissions (if applicable) that result from manufacturing the reference quantity. In this case, emissions associated with the refrigerant used in the new waste heat recovery technology are entered.




The Use Phase Energy tab is where expected energy impacts from the product's final use are quantified for both the new and benchmark technologies. Because the use phase energy depends on the size of the end-use market, the change in total U.S. annual energy consumption is calculated assuming the new technology reaches maximum market adoption overnight.

New Technology: Heat Pump

Default sector data* (can be modified if needed) ↓ ↓

Data entry** ↓

**Hypothetical Annual Energy & Emissions - Product Use Phase**
(based on "overnight replacement" with new technology)

| Sector & Energy Type | Energy Source | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (Btu primary / Btu onsite) | Annual Energy Consumption (fuel specific units) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption (MMBtu) | Annual Associated Cost ($) | Annual Associated GWP Emissions (tons CO2-eq) |
|---|---|---|---|---|---|---|---|---|
| **Industrial Sector** | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | 108,130,193 MMBtu | $21.04 | 309,182,690 MMBTU | $2,275,424,343.79 | 5,870,785 tons CO2-e |
| **Petroleum** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Coal** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Natural Gas** | Natural Gas | 130.6 | 1.00 | -222,771,704 MMBtu | $5.79 | -222,771,704 MMBtu | -$1,290,746,544.34 | -14,548,652 tons CO2-e |
| **Renewable** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Steam** | Steam and Hot Water* | 146.4 | 1.20 | | $4.70 | | | |
| **Custom Input I** | | | | | | | | |
| **Custom Input II** | | | | | | | | |
| **Custom Input III** | | | | | | | | |

Benchmark: Evaporative Condenser

Default sector data* (can be modified if needed) ↓ ↓

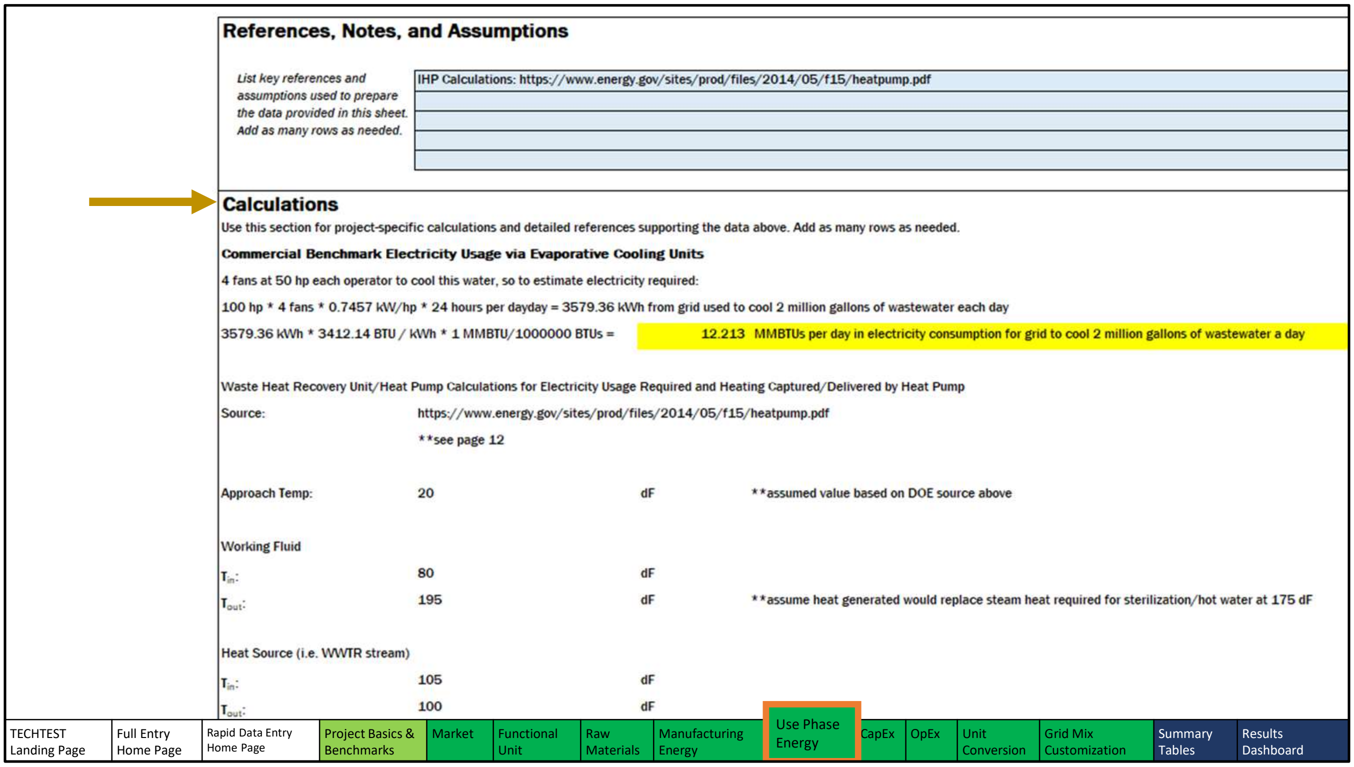
Data entry** ↓

**Current Annual U.S. Energy & Emissions - Product Use Phase**
(based on current technologies in use)

| Sector & Energy Type | Energy Source | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (Btu primary / Btu onsite) | Annual Onsite Energy Consumption (MMBtu) | Specific Price ($/MMBtu) | Annual Primary Energy Consumption, including offsite losses (MMBtu) | Annual Associated Cost ($) | Annual Associated GWP Emissions (tons CO2-eq) |
|---|---|---|---|---|---|---|---|---|
| **Industrial Sector** | | | | | | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | 44,577,450 MMBtu | $21.04 | 127,462,788 MMBtu | $938,060,055.69 | 2,420,274 tons CO2-e |
| **Petroleum** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Coal** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Natural Gas** | Natural Gas | 130.6 | 1.00 | | $5.79 | | | |
| **Renewable** Look Up | | #N/A | 1.00 | | #N/A | | | |
| **Steam** | Steam and Hot Water* | 146.4 | 1.20 | | $4.70 | | | |
| **Custom Input I** | | | | | | | | |
| **Custom Input II** | | | | | | | | |
| **Custom Input III** | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |

Here we will calculate the electricity costs, scaled up to annual usage, for both technologies. Additionally, the heat pump reduces natural gas usage by transporting heat for process use elsewhere in the system. We can account for this by adding a negative input for natural gas. Note that negative inputs can be used throughout TECHTEST to show avoided emissions.


## References, Notes, and Assumptions

*List key references and assumptions used to prepare the data provided in this sheet. Add as many rows as needed.*

IHP Calculations: https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf

## Calculations

Use this section for project-specific calculations and detailed references supporting the data above. Add as many rows as needed.

**Commercial Benchmark Electricity Usage via Evaporative Cooling Units**

4 fans at 50 hp each operator to cool this water, so to estimate electricity required:

100 hp * 4 fans * 0.7457 kW/hp * 24 hours per dayday = 3579.36 kWh from grid used to cool 2 million gallons of wastewater each day

3579.36 kWh * 3412.14 BTU / kWh * 1 MMBTU/1000000 BTUs = 12.213 MMBTUs per day in electricity consumption for grid to cool 2 million gallons of wastewater a day

Waste Heat Recovery Unit/Heat Pump Calculations for Electricity Usage Required and Heating Captured/Delivered by Heat Pump

Source: https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf

**see page 12

Approach Temp: 20 dF **assumed value based on DOE source above

Working Fluid

$T_{in}$: 80 dF

$T_{out}$: 195 dF **assume heat generated would replace steam heat required for sterilization/hot water at 175 dF

Heat Source (i.e. WWTR stream)

$T_{in}$: 105 dF

$T_{out}$: 100 dF

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |

The entered values are determined in the Calculations section at the bottom of this tab.

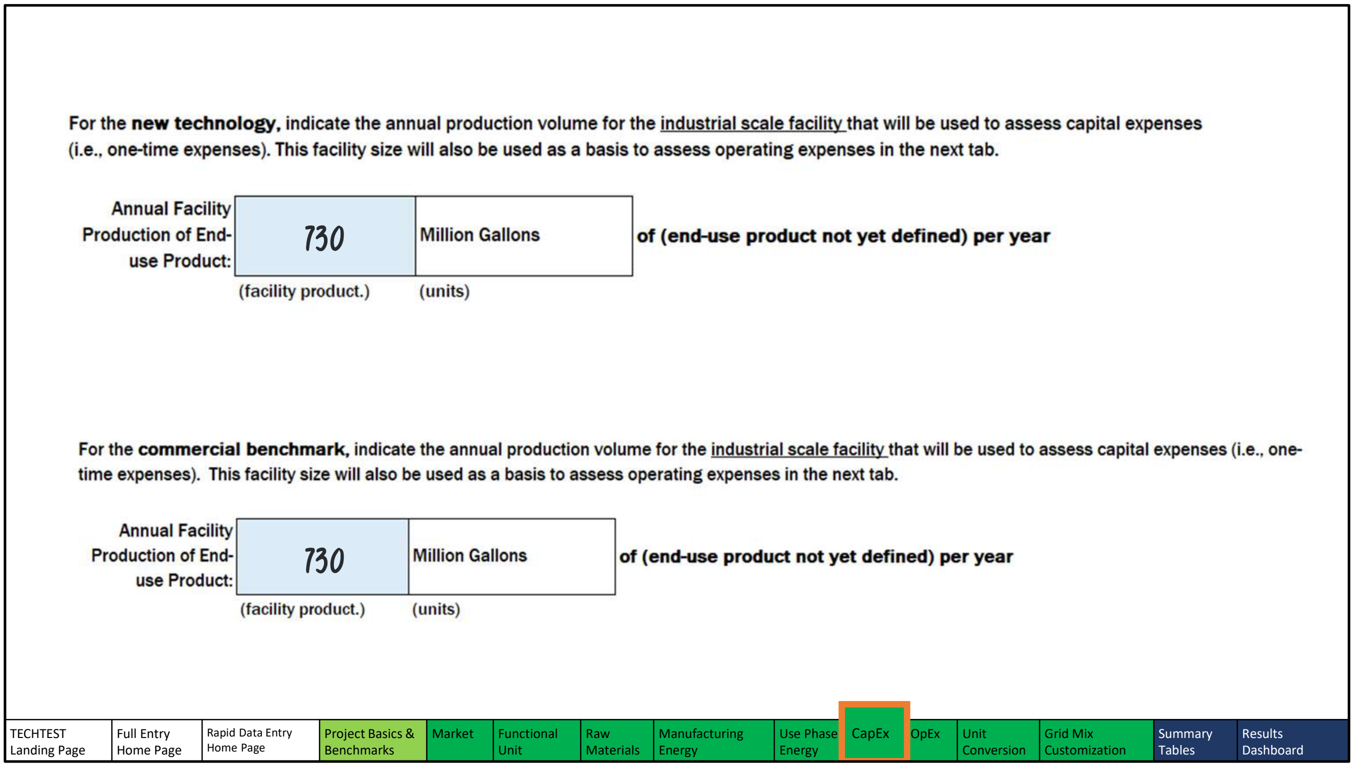
| Sector & Energy Type | Energy Source | Specific 100-yr GWP (lb CO2-eq / MMBtu) | Source-to-Site Ratio (Btu primary / Btu onsite) | Annual Energy Consumption (fuel specific units) |
|---|---|---|---|---|
| | ~~Transportation Sector~~ | | | |
| **Electricity** | Electricity | 108.6 | 2.86 | |
| **Petroleum** Look Up | | #N/A | 1.00 | |
| **Natural Gas** | Natural Gas (pipelines and fuel) | 138.2 | 1.00 | |
| **Renewable Fuels** | Biomass | 165.3 | 1.00 | |
| **Custom Input I** | | | | |
| **Custom Input II** | | | | |
| **Custom Input III** | | | | |

Hypothetical Annual Energy & Emissions:
or equivalently:

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

The transportation sector does not apply to our waste heat recovery scenario, so only energy impacts in the industrial sector are entered.


Moving on to the Economic Considerations category, the CapEx (or capital expenses) tab captures the expenses for machinery and other one-time purchases required to manufacture the established functional unit. However, note that these costs are often independent of the volume of product produced. Data inputs here include process and non-process equipment, engineering, construction, and any other one-time costs required to commission the referenced technology.



For the **new technology,** indicate the annual production volume for the industrial scale facility that will be used to assess capital expenses (i.e., one-time expenses). This facility size will also be used as a basis to assess operating expenses in the next tab.

| Annual Facility Production of End-use Product: | 730 | Million Gallons | **of (end-use product not yet defined) per year** |
|---|---|---|---|
| | (facility product.) | (units) | |

For the **commercial benchmark,** indicate the annual production volume for the industrial scale facility that will be used to assess capital expenses (i.e., one-time expenses). This facility size will also be used as a basis to assess operating expenses in the next tab.

| Annual Facility Production of End-use Product: | 730 | Million Gallons | **of (end-use product not yet defined) per year** |
|---|---|---|---|
| | (facility product.) | (units) | |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

We start by entering the annual facility output of the functional unit (not the reference quantity) for both technologies.

## New Technology: Heat Pump

New Technology - Capital Expenses (CapEx)

| CapEx Category | Examples | Capital Expense Items (descriptions) | Purchase Price ($) | Expected Equipment Lifetime (years) | Annual Capital Cost for Facility ($) | Capital Cost for Functional Unit ($) |
|---|---|---|---|---|---|---|
| Process Equipment | furnaces, reactors | WHR – Heat Pump | $254,306 | 10 | $25,431 | $69.67 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | Process Equipment Total: | $25,431 | $69.67 |
| Non-process Equipment | piping, control systems, power equipment | Piping | $50,000 | 35 | $1,429 | $3.91 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | Non-Process Equipment Total: | $1,429 | $3.91 |
| Engineering & Construction | engineering, design, procurement, construction | Design | $10,000 | 15 | $667 | $1.83 |
| | | Installation | $127,153 | 15 | $8,477 | $23.22 |
| | | | | | | |
| | | | | | | |
| | | | | Engineering & Construction Total: | | $25.05 |
| Other CapEx | land, commissioning, contingency | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | Other CapEx Total: | $36,003 | $98.64 |
| | | | | Total Capital Expense: | | |
| | | | | Annual Capital Equipment/Facility Maintenance (typical value 5%): | 5% | 5% |
| | | | | Total Capital Expense, Including Maintenance: | $37,803 | $98.64 |
| | | | | | per | per |
| | | | | | per 730 mil gals (Annual Facility Production) | per 2 mil gals (Reference Quantity) |

## Benchmark: Evaporative Condenser

Commerical Benchmark Technology - Capital Expenses (CapEx)

| CapEx Category | Examples | Capital Expense Items (descriptions) | Purchase Price ($) | Expected Equipment Lifetime (years) | Annual Capital Cost for Facility ($) | Scaled Annual Capital Cost ($) (Adjusted to new tech. facility size) | Capital Cost for Functional Unit ($) |
|---|---|---|---|---|---|---|---|
| Process Equipment | furnaces, reactors | Evap. Condensers | $1,000,000 | 25 | $40,000 | $40,000 | $109.59 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | Process Equipment Total: | $40,000 | $40,000 | $109.59 |
| Nonprocess Equipment | piping, control systems, power equipment. | Piping | $50,000 | 35 | $1,429 | $1,429 | $3.91 |
| | | | | | | | |
| | | | | | | | |
| | | | | | $1,429 | $1,429 | $3.91 |
| | | | | Non-Process Equipment Total: | | | |
| Engineering & Construction | engineering, design, procurement, construction | Design | $10,000 | 25 | $400 | $400 | $1.10 |
| | | Installation | $500,000 | 25 | $20,000 | $20,000 | $54.79 |
| | | | | | | | |
| | | | | | | | |
| | | | | Engineering & Construction Total: | $20,400 | $20,400 | $55.89 |
| Other CapEx | land, commissioning, contingency, spare parts. | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | Other CapEx Total: | $61,829 | $61,829 | $169.39 |
| | | | | Total Capital Expense: | | | |
| | | | | Annual Capital Equipment/Facility Maintenance (typical value 5%): | 5% | 5% | 5% |
| | | | | Total Capital Expense, Including Maintenance: | $64,920 | $64,920 | $169.39 |
| | | | | | per | per | per |
| | | | | | per 730 mil gals (Annual Facility Production) | per 730 mil gals (Scaled Facility Production, New Tech Equivalent) | per 2 mil gals (Reference Quantity) |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Next, the costs and associated expected lifetime for the necessary system components are added.

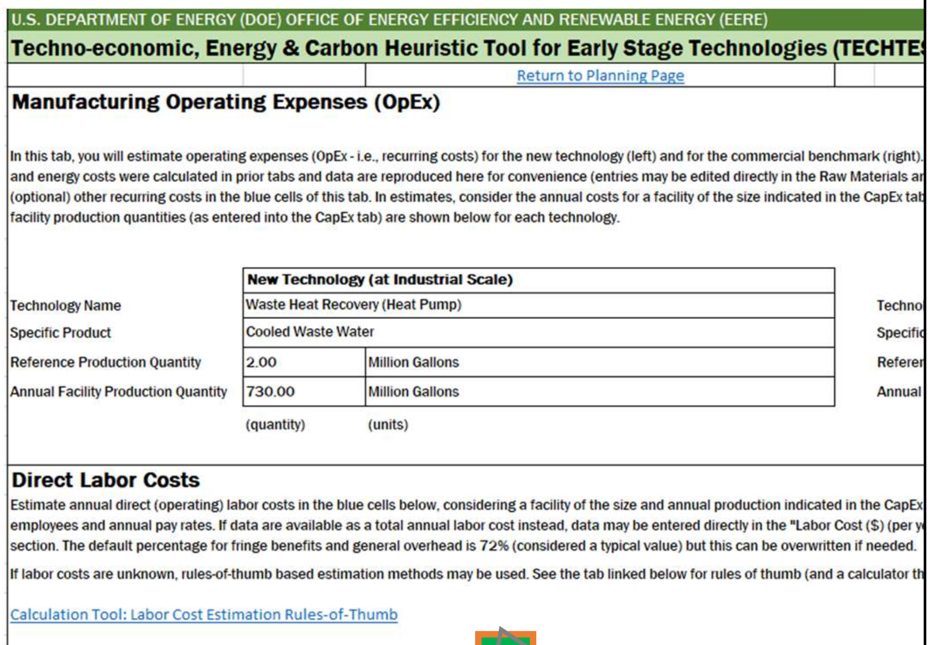
Keep in mind that the level of granularity of the capital expenses for the new technology must be equal to that of the benchmark to ensure a fair cost comparison.

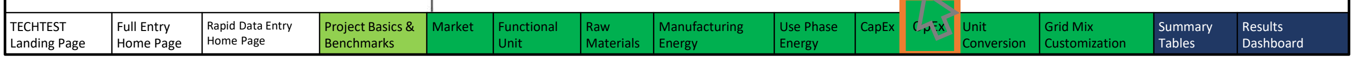
# Economic Considerations:

OpEx

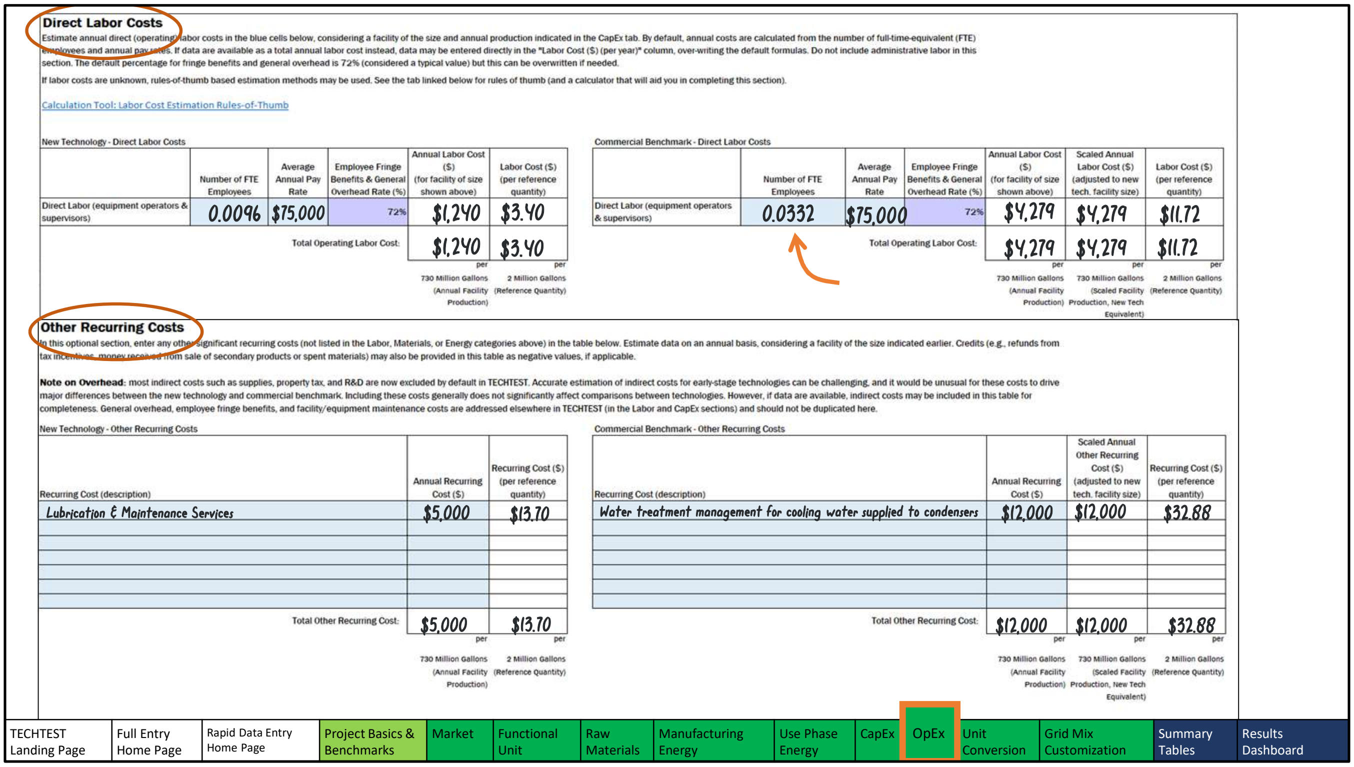
Models the cost of operating the technology required to produce the established functional unit.

Some inputs in this tab may not be applicable.




The OpEx (or operating expenses) tab models the cost of operating the technology required to produce the established functional unit. Depending on your project scope, some inputs in this tab may not be applicable.



**Direct Labor Costs**

Estimate annual direct (operating) labor costs in the blue cells below, considering a facility of the size and annual production indicated in the CapEx tab. By default, annual costs are calculated from the number of full-time-equivalent (FTE) employees and annual pay rates. If data are available as a total annual labor cost instead, data may be entered directly in the "Labor Cost ($) (per year)" column, over-writing the default formulas. Do not include administrative labor in this section. The default percentage for fringe benefits and general overhead is 72% (considered a typical value) but this can be overwritten if needed.

If labor costs are unknown, rules-of-thumb based estimation methods may be used. See the tab linked below for rules of thumb (and a calculator that will aid you in completing this section).

Calculation Tool: Labor Cost Estimation Rules-of-Thumb

New Technology - Direct Labor Costs

| | Number of FTE Employees | Average Annual Pay Rate | Employee Fringe Benefits & General Overhead Rate (%) | Annual Labor Cost ($) (for facility of size shown above) | Labor Cost ($) (per reference quantity) |
|---|---|---|---|---|---|
| Direct Labor (equipment operators & supervisors) | 0.0096 | $75,000 | 72% | $1,240 | $3.40 |
| | | | Total Operating Labor Cost: | $1,240 | $3.40 |
| | | | | per 730 Million Gallons (Annual Facility Production) | per 2 Million Gallons (Reference Quantity) |

Commercial Benchmark - Direct Labor Costs

| | Number of FTE Employees | Average Annual Pay Rate | Employee Fringe Benefits & General Overhead Rate (%) | Annual Labor Cost ($) (for facility of size shown above) | Scaled Annual Labor Cost ($) (adjusted to new tech. facility size) | Labor Cost ($) (per reference quantity) |
|---|---|---|---|---|---|---|
| Direct Labor (equipment operators & supervisors) | 0.0332 | $75,000 | 72% | $4,279 | $4,279 | $11.72 |
| | | | Total Operating Labor Cost: | $4,279 | $4,279 | $11.72 |
| | | | | per 730 Million Gallons (Annual Facility Production) | per 730 Million Gallons (Scaled Facility Production, New Tech Equivalent) | per 2 Million Gallons (Reference Quantity) |

**Other Recurring Costs**

In this optional section, enter any other significant recurring costs (not listed in the Labor, Materials, or Energy categories above) in the table below. Estimate data on an annual basis, considering a facility of the size indicated earlier. Credits (e.g., refunds from tax incentives, money received from sale of secondary products or spent materials) may also be provided in this table as negative values, if applicable.

**Note on Overhead:** most indirect costs such as supplies, property tax, and R&D are now excluded by default in TECHTEST. Accurate estimation of indirect costs for early-stage technologies can be challenging, and it would be unusual for these costs to drive major differences between the new technology and commercial benchmark. Including these costs generally does not significantly affect comparisons between technologies. However, if data are available, indirect costs may be included in this table for completeness. General overhead, employee fringe benefits, and facility/equipment maintenance costs are addressed elsewhere in TECHTEST (in the Labor and CapEx sections) and should not be duplicated here.

New Technology - Other Recurring Costs

| Recurring Cost (description) | Annual Recurring Cost ($) | Recurring Cost ($) (per reference quantity) |
|---|---|---|
| Lubrication & Maintenance Services | $5,000 | $13.70 |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| Total Other Recurring Cost: | $5,000 | $13.70 |
| | per 730 Million Gallons (Annual Facility Production) | per 2 Million Gallons (Reference Quantity) |

Commercial Benchmark - Other Recurring Costs

| Recurring Cost (description) | Annual Recurring Cost ($) | Scaled Annual Other Recurring Cost ($) (adjusted to new tech. facility size) | Recurring Cost ($) (per reference quantity) |
|---|---|---|---|
| Water treatment management for cooling water supplied to condensers | $12,000 | $12,000 | $32.88 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Total Other Recurring Cost: | $12,000 | $12,000 | $32.88 |
| | per 730 Million Gallons (Annual Facility Production) | per 730 Million Gallons (Scaled Facility Production, New Tech Equivalent) | per 2 Million Gallons (Reference Quantity) |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Data inputs include the direct labor costs, along with any other recurring costs required to operate or create the technology.

In our example, there are more system aspects to manage with the benchmark technology, so the number of full-time employees will be higher.

## Raw Materials Costs

Materials costs entered into the "Raw Materials" tab are reprinted here for convenience. If data need to be adjusted, make changes in the Raw Materials tab.

New Technology - Raw Material Inputs

| Material Inputs (list) | Amount of Material (to produce reference quantity) | unit | Specific Cost ($/unit) (for this material) | Annual Materials Cost ($) (per year) | Materials Cost ($) (per reference quantity) |
|---|---|---|---|---|---|
| Lubrication (to run Fans) | 2.34 | kg | $6.00 | $5,125 | $14.04 |
| Copper | 0.367303562 | kg | | $0 | $0.00 |
| Elastomer | 0.160569863 | kg | | $0 | $0.00 |
| HDPE | 0.005017808 | kg | | $0 | $0.00 |
| Low alloyed steel | 0.321139726 | kg | | $0 | $0.00 |
| Lubricating Oil (Manufacturing) | 0.027096164 | kg | | $0 | $0.00 |
| PVC | 0.016056986 | kg | | $0 | $0.00 |
| Reinforced Steel | 1.304630137 | kg | | $0 | $0.00 |
| | | | | | |
| | | | Total Materials Cost: | $5,125 | $14.04 |
| | | | | per 730 Million Gallons (Annual Facility Production) | per 2 Million Gallons (Reference Quantity) |

Commercial Benchmark - Raw Material Inputs

| Material Inputs (list) | Amount of Material (to produce reference quantity) | unit | Specific Cost ($/unit) (for this material) | Annual Materials Cost ($) (per year) | Scaled Annual Materials Cost ($) (adjusted to new tech. facility size) | Materials Cost ($) (per reference quantity) |
|---|---|---|---|---|---|---|
| City water supply to evaporative condensers | 17010.30928 | gallons | $0.002 | $12,417.53 | $12,418 | $34.02 |
| Biocide chemical additon to cooling loop for micro mitigation | 3.322326031 | gallons | $19.09 | $23,150.57 | $23,151 | $63.43 |
| Steel low Alloy | 0.317497841 | kg | | $0.00 | $0 | $0.00 |
| Stainless Steel | 0.349464668 | kg | | $0.00 | $0 | $0.00 |
| Aluminium | 0.398757315 | kg | | $0.00 | $0 | $0.00 |
| Bricks | 0.346265477 | Bricks | | $0.00 | $0 | $0.00 |
| Methacrylate | 0.288178188 | kg | | $0.00 | $0 | $0.00 |
| Polyurethane | 0.025744085 | kg | | $0.00 | $0 | $0.00 |
| PVC | 0.495184723 | kg | | $0.00 | $0 | $0.00 |
| | | | Total Materials Cost: | $35,568 | $35,568 | $97.45 |
| | | | | per 730 Million Gallons (Annual Facility Production) | per 730 Million Gallons (Scaled Facility Production, New Tech Equivalent) | per 2 Million Gallons (Reference Quantity) |

Will auto-populate

## Energy Costs

Energy costs entered into the "Manufacturing Energy" tab are reprinted here for convenience. If data need to be adjusted, make changes in the Manufacturing Energy tab.

New Technology - Energy Cost Data

| Energy Source | Onsite Energy Consumption (MMBtu) (to produce reference quantity) | unit | Annual Energy Cost ($) | Energy Cost ($) (per reference quantity) |
|---|---|---|---|---|
| Electricity | 0.00 | MMBtu | $37 | $0.10 |
| Petroleum | 0.01 | MMBtu | | $0.00 |
| Coal | 0.01 | MMBtu | | $0.00 |
| Natural Gas | 0.01 | MMBtu | $28 | $0.08 |
| Renewable Sources | 0.00 | MMBtu | | $0.00 |
| Steam | 0.00 | MMBtu | | $0.00 |
| Custom Inputs | 0.00 | MMBtu | | $0.00 |
| | | Total Energy Cost: | $65 | $0.18 |
| | | | per 730 Million Gallons (Annual Facility Production) | per 2 Million Gallons (Reference Quantity) |

Commercial Benchmark - Energy Cost Data

| Energy Source | Onsite Energy Consumption (MMBtu) (to produce reference quantity) | unit | Annual Energy Cost ($) | Scaled Annual Energy Cost ($) (adjusted to new tech. facility size) | Energy Cost ($) (per reference quantity) |
|---|---|---|---|---|---|
| Electricity | 0.37 | MMBtu | $2,851 | $2,851.15 | $7.81 |
| Petroleum | 0.01 | MMBtu | | | $0.00 |
| Coal | 0.01 | MMBtu | | | $0.00 |
| Natural Gas | 0.01 | MMBtu | $28 | $28.23 | $0.08 |
| Renewable Sources | 0.00 | MMBtu | | | $0.00 |
| Steam | 0.00 | MMBtu | | | $0.00 |
| Custom Inputs | 0.00 | MMBtu | | | $0.00 |
| | | Total Energy Cost: | $2,879 | $2,879.38 | $7.89 |
| | | | per 730 Million Gallons (Annual Facility Production) | per 730 Million Gallons (Scaled Facility Production, New Tech Equivalent) | per 2 Million Gallons (Reference Quantity) |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |

Costs that we entered earlier on the raw materials and manufacturing energy tabs will auto-populate the lower tables to give a full cradle-to-gate picture. And note that these data inputs are to be entered based on a facility's annual production basis.

# OpEx Summary

## New Technology: Heat Pump

New Technology - OpEx Summary

| Waste Heat Recovery (Heat Pump) | | |
|---|---|---|
| OpEx Category | Annual Recurring Cost ($) | Recurring Cost ($) (per reference quantity) |
| Direct Labor Cost | $1,240 | $3.40 |
| Raw Materials Cost | $5,125 | $14.04 |
| Energy Cost | $65 | $0.18 |
| Other Recurring Costs | $5,000 | $13.70 |
| Total Operating Expense: | $11,430 | $31.32 |
| | per 730 Million Gallons (Annual Facility Production) | per 2 Million Gallons (Reference Quantity) |

## Benchmark: Evaporative Condenser

Commercial Benchmark - OpEx Summary

| Evaporative Condenser | | | |
|---|---|---|---|
| OpEx Category | Annual Recurring Cost ($) | Scaled Annual Recurring Cost ($) (adjusted to new tech. facility size) | Recurring Cost ($) (per reference quantity) |
| Direct Labor Costs | $4,279 | $4,279 | $11.72 |
| Raw Materials Costs | $35,568 | $35,568 | $97.45 |
| Energy Costs | $2,879 | $2,879 | $7.89 |
| Other Recurring Costs | $14,738 | $14,738 | $40.38 |
| Total Operating Expense: | $57,464 | $57,464 | $157.44 |
| | per 730 Million Gallons (Annual Facility Production) | per 730 Million Gallons (Scaled Facility Production, New Tech Equivalent) | per 2 Million Gallons (Reference Quantity) |

| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

We can now see a full summary of the operating expenses for the two technologies in the OpEx Summary section, with a significant improvement anticipated for the new heat pump technology.

# Project Basics

## Grid Mix Customization

Allows customization of the electricity grid mix based on the generation technologies used.

U.S. DEPARTMENT OF ENERGY (DOE) OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY (EERE)

**Techno-economic, Energy & Carbon Heuristic Tool for Early Stage Technologies (TECHTEST)**

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**Grid Mix Customization**

On this page, you can customize the grid mix used in the calculation of electricity generation emissions in the TECHTEST tool. The specific Grid Mix is an estimation of of various energy sources used to create powerline electricity. The 2022 current US grid mix is the default. A Moderate and Net Zero scenario are also included, and using the "Choose Grid Mix" dropdown menu.

*Choose Grid Mix (select from dropdown)*: *2022 Default*

| Electricity Generation Technology | | | Fraction of Total | Life-Cycle Electricity generation emissions (lb CO2-eq/MMBtu electricity generated) based on IPCC data | Default CO2-eq/MMBtu data |
|---|---|---|---|---|---|
| Electricity Generation Technologies | Fossil Fuels | Coal | 21.9% | 234.36 | 234.36 |
| | | Petroleum | 0.5% | 177.08 | 177.08 |
| | | Natural Gas | 38.3% | 130.62 | 130.62 |
| | | Other Gases | 0.3% | 127.13 | 127.13 |
| | Renewables | Nuclear | 18.9% | 7.76 | 7.76 |
| | | Hydropower | 6.3% | 15.52 | 15.52 |
| | | Biomass - Wood | 0.9% | 148.75 | 148.75 |
| | | Biomass - Waste | 0.5% | 148.75 | 148.75 |
| | | Geothermal | 0.4% | 24.58 | 24.58 |
| | | Solar | 2.8% | 31.04 | 31.04 |
| | | Wind | 9.2% | 7.11 | 7.11 |
| | | | 100.0% | | |

Weighted average emissions for U.S. electricity generation: 108.6 lb CO2-e

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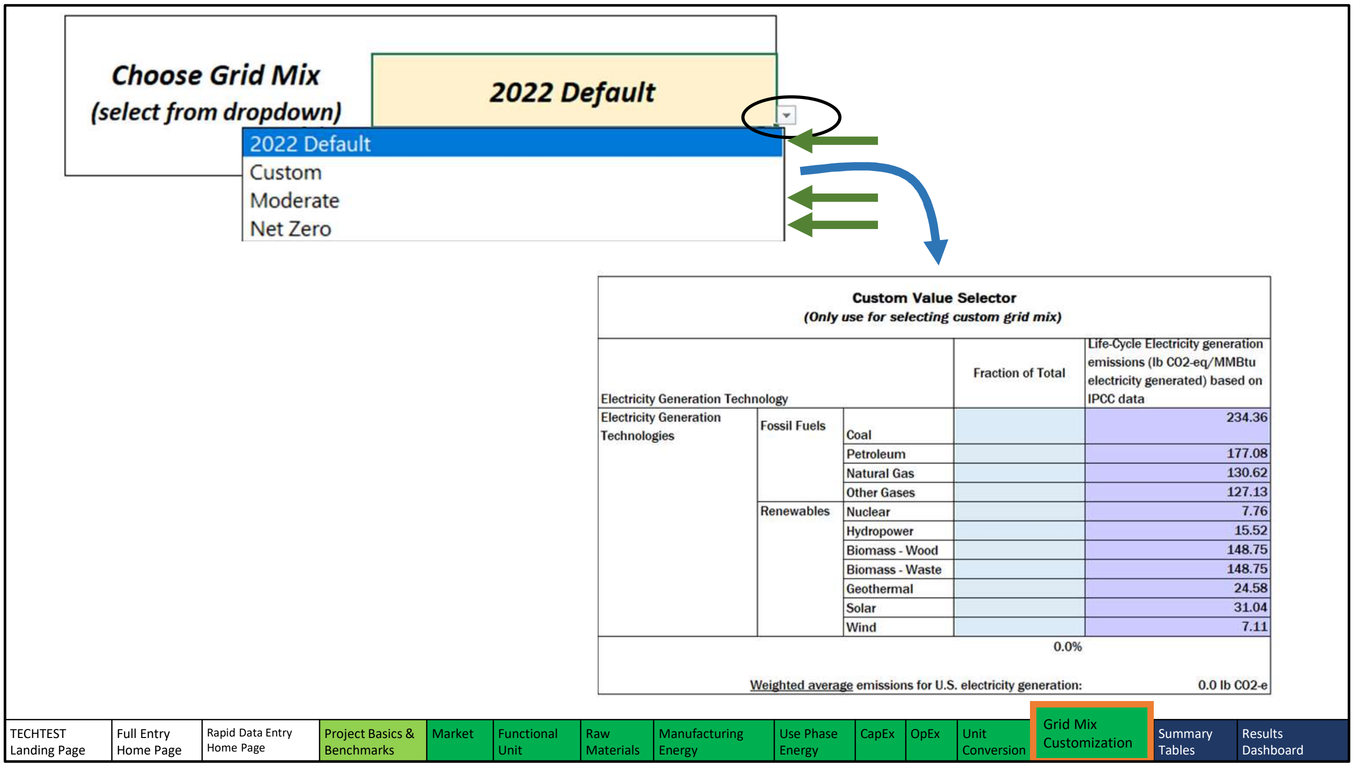
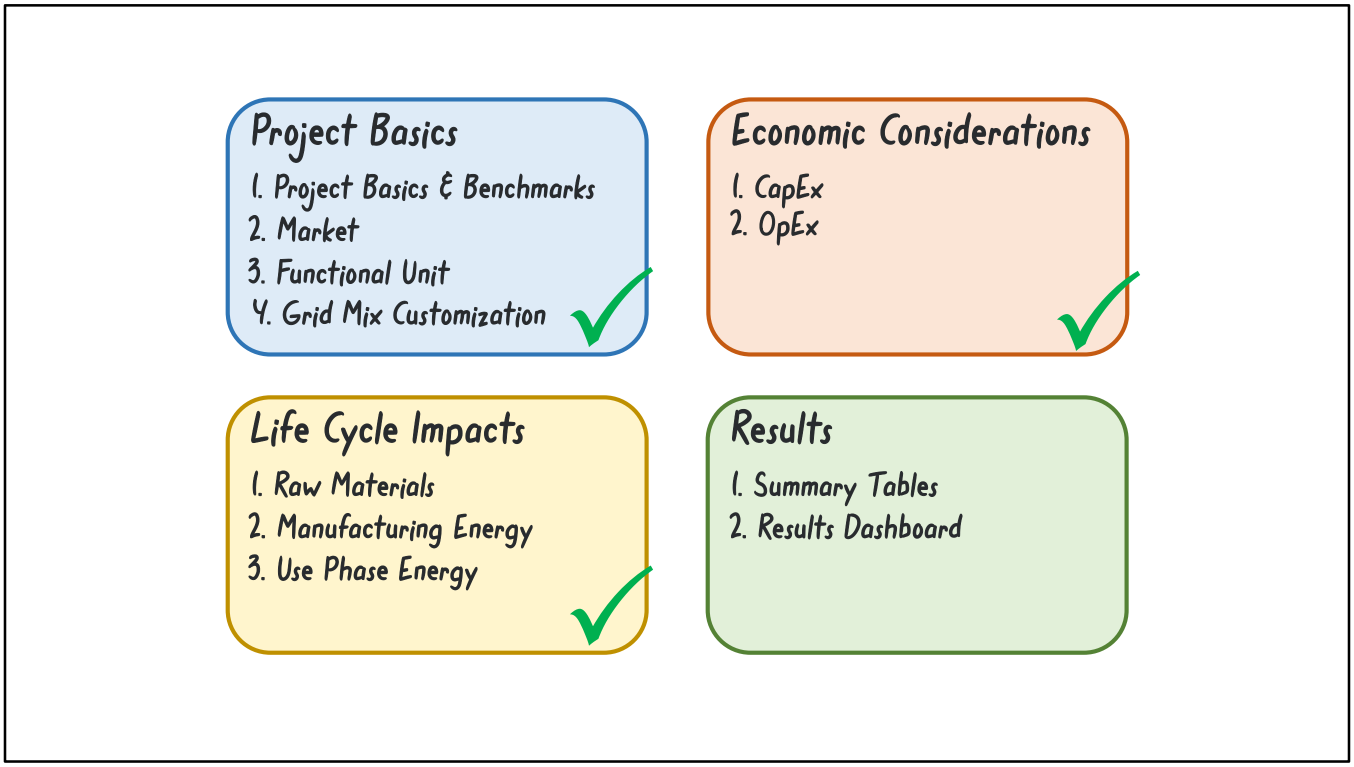
| TECHTEST Landing Page | Full Entry Home Page | Rapid Data Entry Home Page | Project Basics & Benchmarks | Market | Functional Unit | Raw Materials | Manufacturing Energy | Use Phase Energy | CapEx | OpEx | Unit Conversion | Grid Mix Customization | Summary Tables | Results Dashboard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

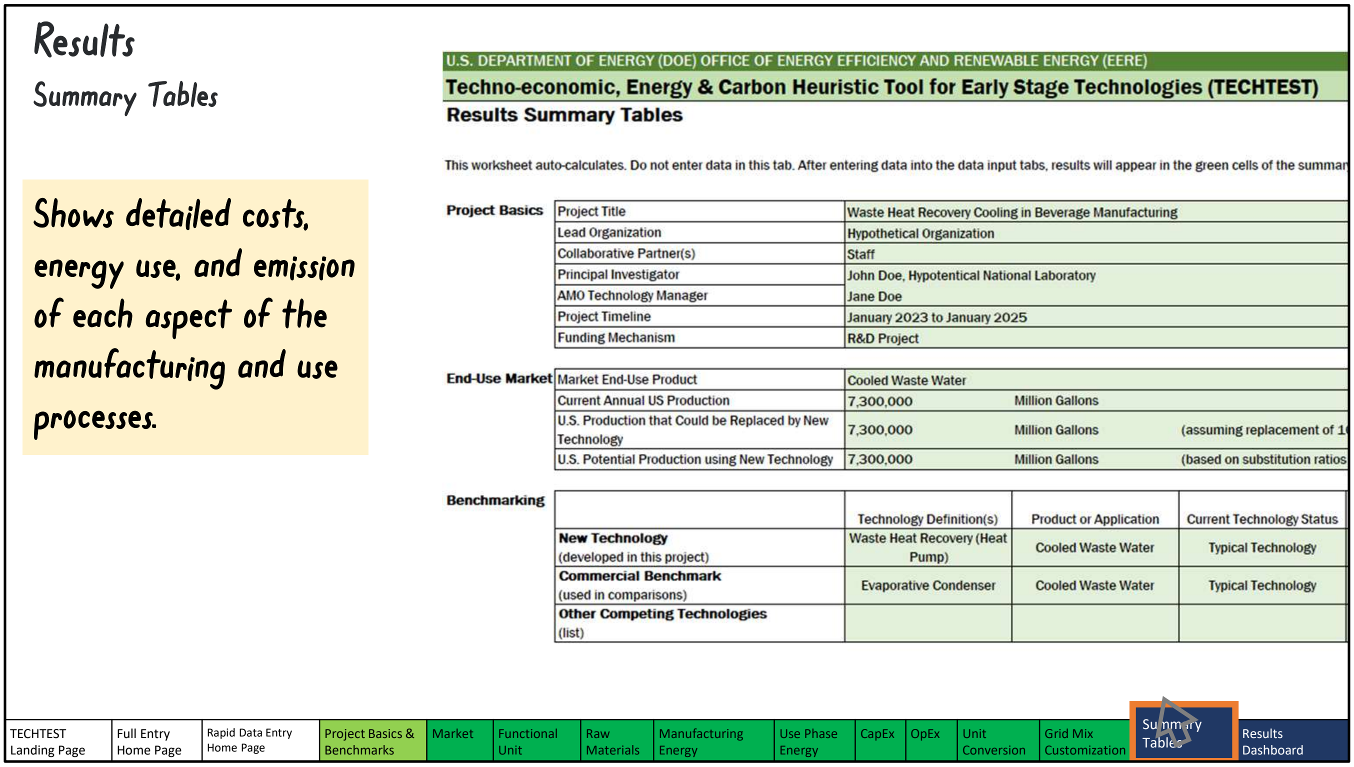
One final tab before heading into our results is the Grid Mix Customization tab, which allows customization of the electricity grid mix based on the generation technologies used, including fossil fuels and renewable sources.



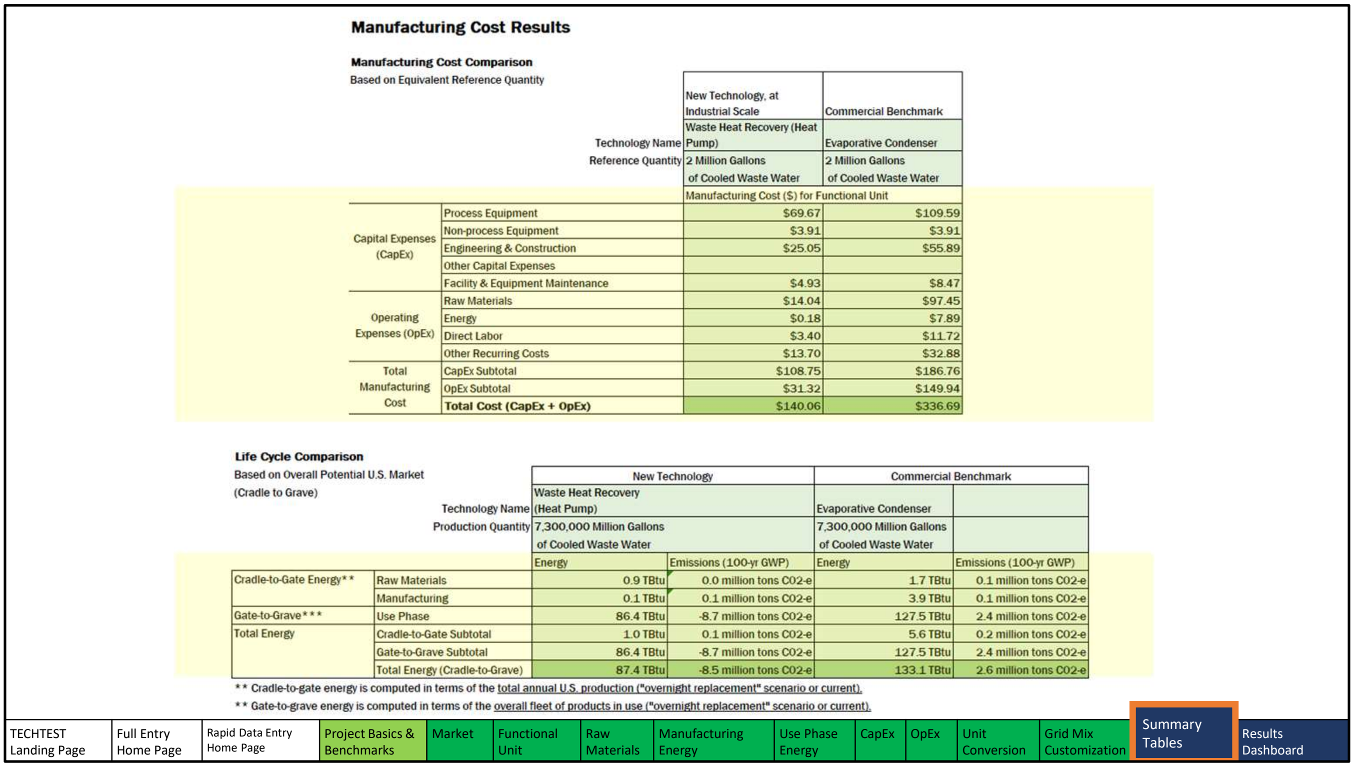

The Choose Grid Mix dropdown menu allows you to choose between three preset scenarios: a 2022 U.S. Default scenario, a hypothetical Moderate scenario (on the way to Net Zero), and a Net Zero scenario that consists almost entirely of renewables. There is also a Custom option, which can be used to manually edit the mix of energy generation technologies and emissions.




Once all the previous sections have been completed, the results from our TECHTEST analysis can be viewed in table and graph form.




The Summary Tables tab shows the detailed costs, energy use, and emissions of each aspect of the manufacturing and use processes.



## Manufacturing Cost Results

**Manufacturing Cost Comparison**
Based on Equivalent Reference Quantity

| | | New Technology, at Industrial Scale | Commercial Benchmark |
|---|---|---|---|
| Technology Name | | Waste Heat Recovery (Heat Pump) | Evaporative Condenser |
| Reference Quantity | | 2 Million Gallons of Cooled Waste Water | 2 Million Gallons of Cooled Waste Water |
| | | Manufacturing Cost ($) for Functional Unit | |
| Capital Expenses (CapEx) | Process Equipment | $69.67 | $109.59 |
| | Non-process Equipment | $3.91 | $3.91 |
| | Engineering & Construction | $25.05 | $55.89 |
| | Other Capital Expenses | | |
| Operating Expenses (OpEx) | Facility & Equipment Maintenance | $4.93 | $8.47 |
| | Raw Materials | $14.04 | $97.45 |
| | Energy | $0.18 | $7.89 |
| | Direct Labor | $3.40 | $11.72 |
| | Other Recurring Costs | $13.70 | $32.88 |
| Total Manufacturing Cost | CapEx Subtotal | $108.75 | $186.76 |
| | OpEx Subtotal | $31.32 | $149.94 |
| | **Total Cost (CapEx + OpEx)** | $140.06 | $336.69 |

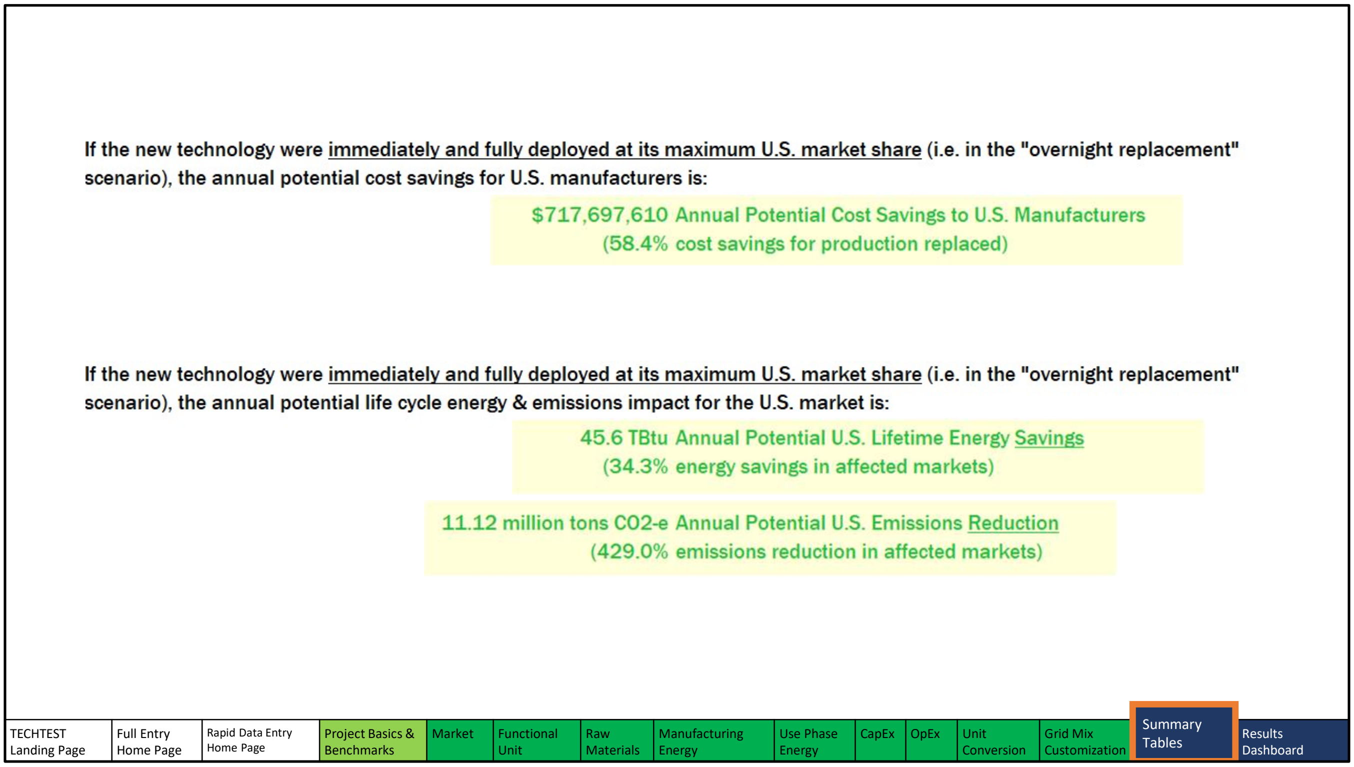
**Life Cycle Comparison**
Based on Overall Potential U.S. Market
(Cradle to Grave)

| | | New Technology | | Commercial Benchmark | |
|---|---|---|---|---|---|
| Technology Name | | Waste Heat Recovery (Heat Pump) | | Evaporative Condenser | |
| Production Quantity | | 7,300,000 Million Gallons of Cooled Waste Water | | 7,300,000 Million Gallons of Cooled Waste Water | |
| | | Energy | Emissions (100-yr GWP) | Energy | Emissions (100-yr GWP) |
| Cradle-to-Gate Energy** | Raw Materials | 0.9 TBtu | 0.0 million tons C02-e | 1.7 TBtu | 0.1 million tons C02-e |
| | Manufacturing | 0.1 TBtu | 0.1 million tons C02-e | 3.9 TBtu | 0.1 million tons C02-e |
| Gate-to-Grave*** | Use Phase | 86.4 TBtu | -8.7 million tons C02-e | 127.5 TBtu | 2.4 million tons C02-e |
| Total Energy | Cradle-to-Gate Subtotal | 1.0 TBtu | 0.1 million tons C02-e | 5.6 TBtu | 0.2 million tons C02-e |
| | Gate-to-Grave Subtotal | 86.4 TBtu | -8.7 million tons C02-e | 127.5 TBtu | 2.4 million tons C02-e |
| | Total Energy (Cradle-to-Grave) | 87.4 TBtu | -8.5 million tons C02-e | 133.1 TBtu | 2.6 million tons C02-e |

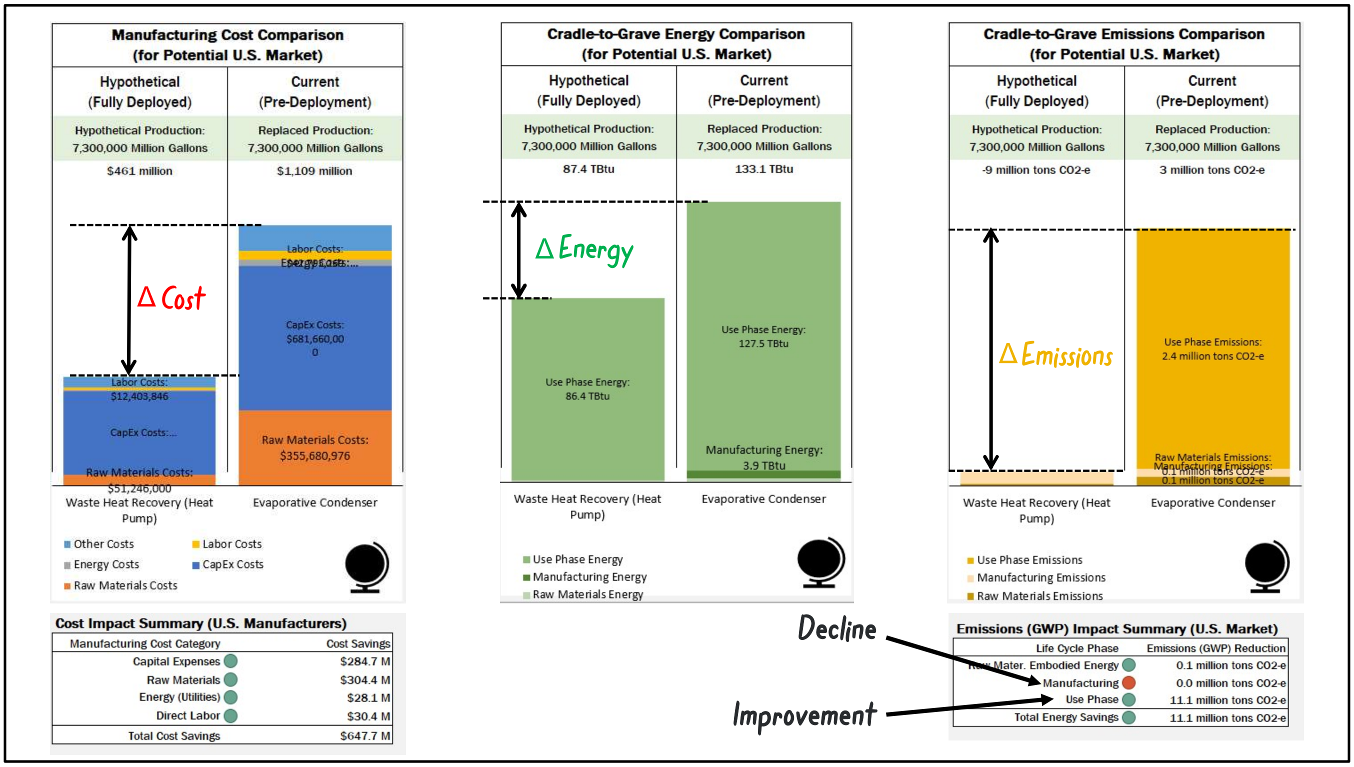
** Cradle-to-gate energy is computed in terms of the total annual U.S. production ("overnight replacement" scenario or current).
** Gate-to-grave energy is computed in terms of the overall fleet of products in use ("overnight replacement" scenario or current).



This tab is great for examining how the contributions from each section contribute to the overall picture, and for directly comparing lifecycle steps.




Looking at the results presented in bolded green text, we can see that our proposed technology offers the potential for significant cost savings, energy savings, and emissions reduction.




| Cost Impact Summary (U.S. Manufacturers) | |
|---|---|
| Manufacturing Cost Category | Cost Savings |
| Capital Expenses | $284.7 M |
| Raw Materials | $304.4 M |
| Energy (Utilities) | $28.1 M |
| Direct Labor | $30.4 M |
| Total Cost Savings | $647.7 M |

| Emissions (GWP) Impact Summary (U.S. Market) | |
|---|---|
| Life Cycle Phase | Emissions (GWP) Reduction |
| Raw Mater. Embodied Energy | 0.1 million tons CO2-e |
| Manufacturing | 0.0 million tons CO2-e |
| Use Phase | 11.1 million tons CO2-e |
| Total Energy Savings | 11.1 million tons CO2-e |

The Results Dashboard tab presents the big-picture results of our TECHTEST analysis in graphical form, displaying charts of cost, energy, and emissions for both the reference volume and the overall U.S. market. Results are broken down by contribution, and improvements and declines can be seen as green and red circles, respectively, in the lower tables.

**Cost Impact Summary (U.S. Manufacturers)**

| Manufacturing Cost Category | Cost Savings |
|---|---|
| Capital Expenses | $284.7 M |
| Raw Materials | $304.4 M |
| Energy (Utilities) | $28.1 M |
| Direct Labor | $30.4 M |
| Total Cost Savings | $647.7 M |

**Energy Impact Summary (U.S. Market)**

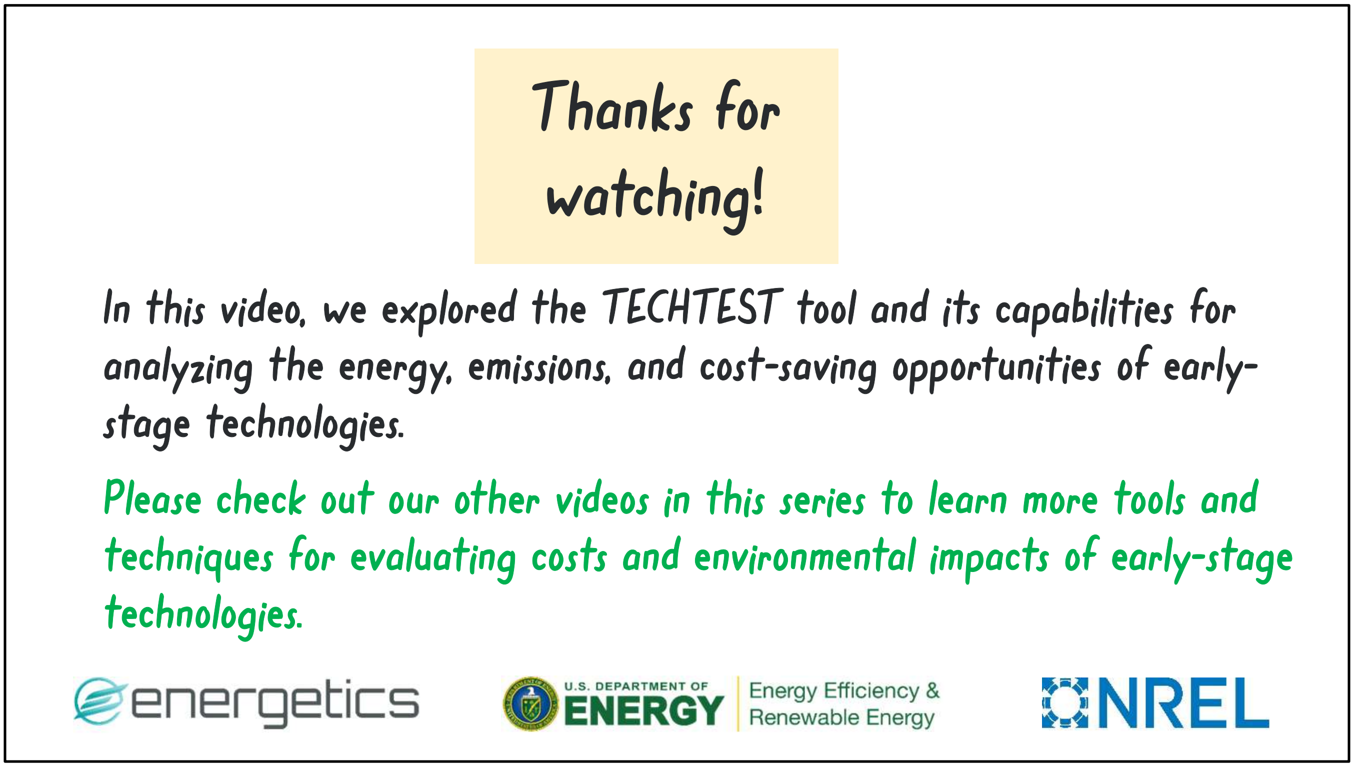
| Life Cycle Phase | Energy Savings |
|---|---|
| Raw Mater. Embodied Energy | 0.8 TBtu |
| Manufacturing | 3.8 TBtu |
| Use Phase | 41.1 TBtu |
| Total Energy Savings | 45.6 TBtu |

**Emissions (GWP) Impact Summary (U.S. Market)**

| Life Cycle Phase | Emissions (GWP) Reduction |
|---|---|
| Raw Mater. Embodied Energy | 0.1 million tons CO2-e |
| Manufacturing | 0.0 million tons CO2-e |
| Use Phase | 11.1 million tons CO2-e |
| Total Energy Savings | 11.1 million tons CO2-e |



In our example, we can see a consistent improvement with the new technology. The only area in which the heat pump underperforms is the manufacturing phase, where released refrigerants weaken its performance. Luckily, the manufacturing phase is a tiny contribution to the whole picture, and the heat pump ends up being a much better performer in the long run.




In this video, we explored the TECHTEST tool and its capabilities for analyzing the energy, emissions, and cost-saving opportunities of early-stage technologies. This tool was designed to offer a flexible degree of granularity when comparing new and benchmark technologies, while providing clear, detailed results about the opportunities presented by these new approaches.

We hope you've found this video helpful in orienting yourself with the TECHTEST tool. Check out our other videos in this series to learn more tools and techniques for evaluating costs and environmental impacts of early-stage technologies. Thanks for watching!