ESTIMATING MANUFACTURING ENERGY CONSUMPTION AND EMISSIONS

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

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Estimating Manufacturing Energy Consumption and Emissions

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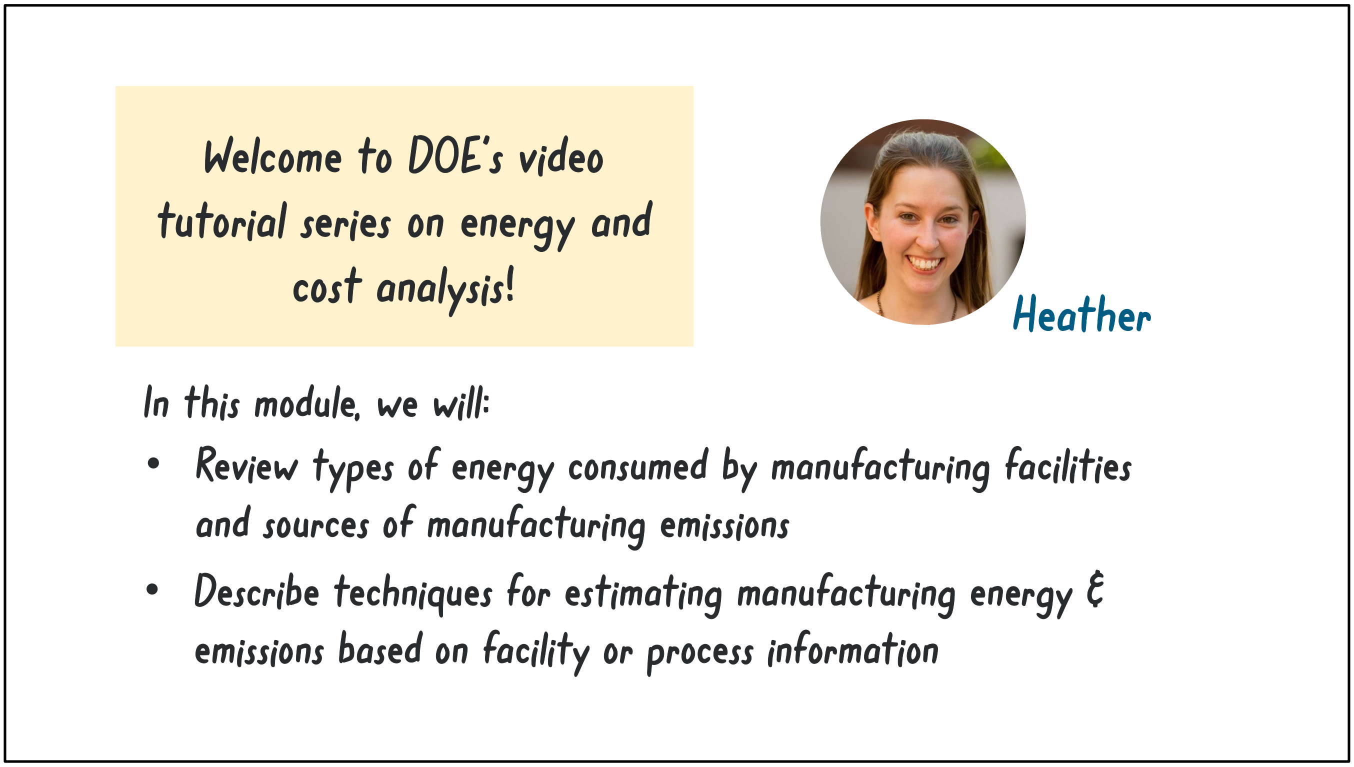
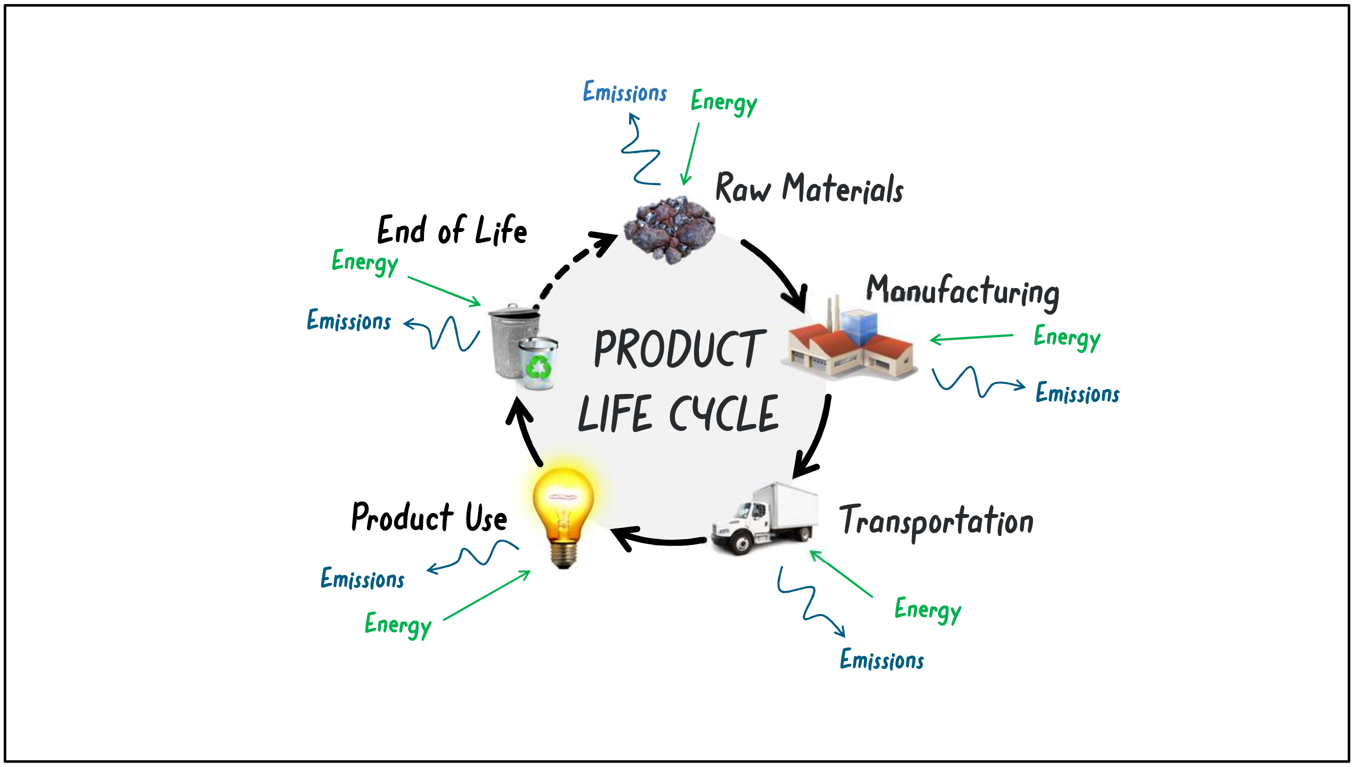


Welcome to DOE's video tutorial series on energy and cost analysis. I'm Heather.

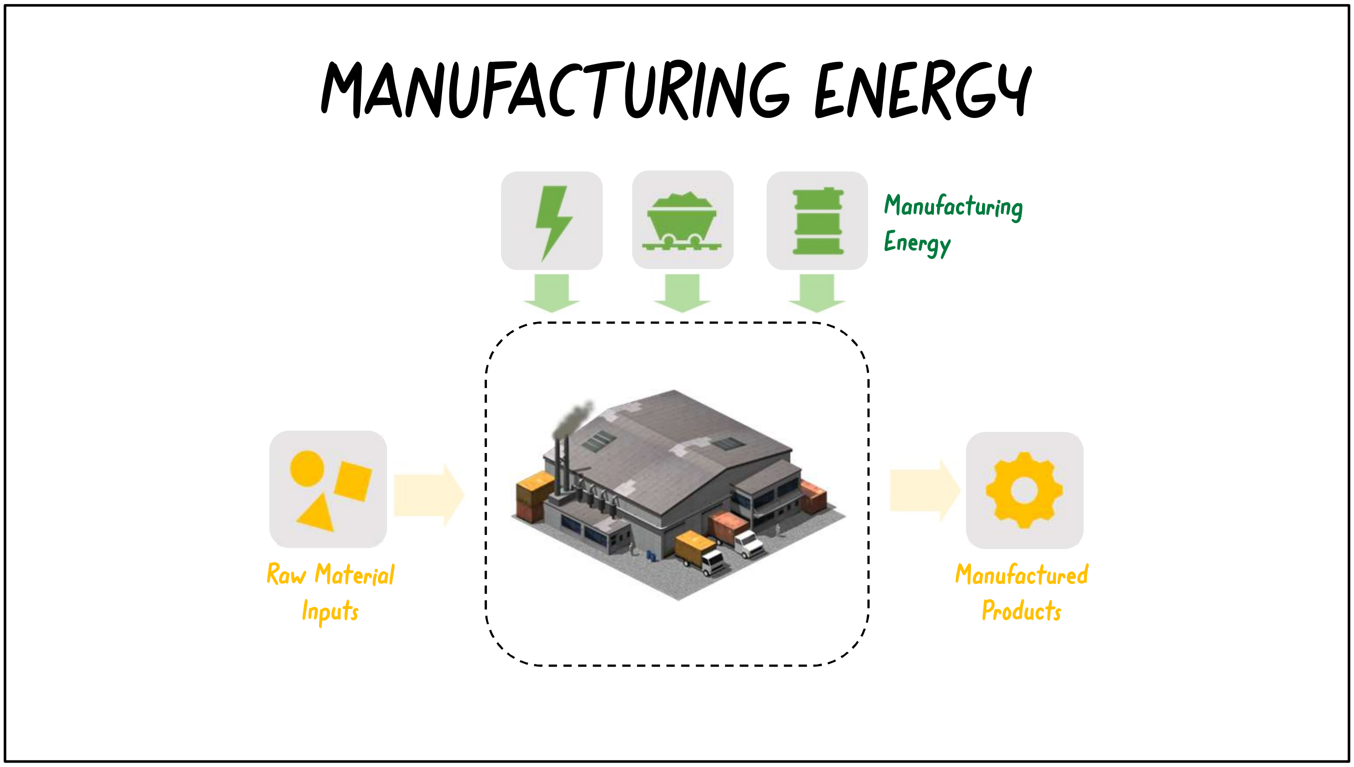
In this module, we will:

- Review types of energy consumed by manufacturing facilities and sources of manufacturing emissions
- Describe techniques for estimating manufacturing energy & emissions based on facility or process information.

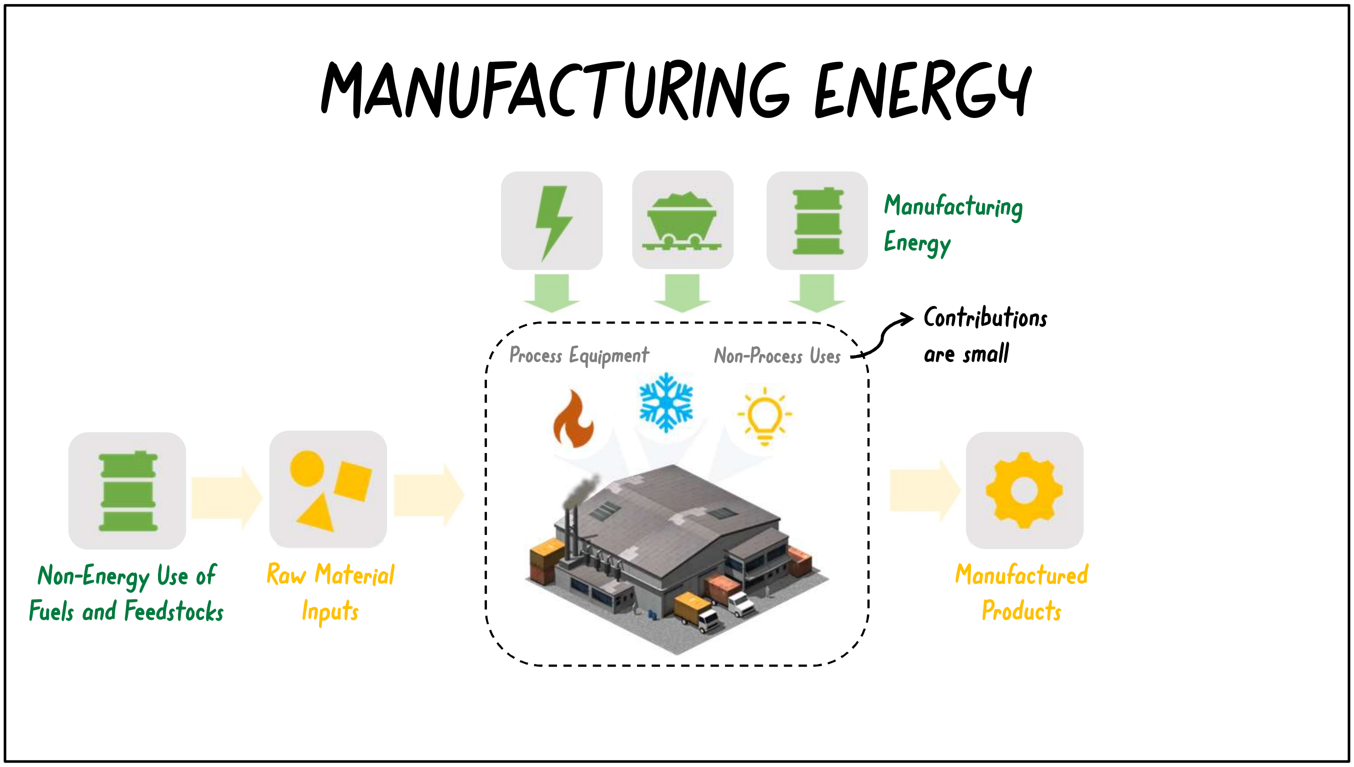


Every manufactured product has a life cycle, starting with the initial extraction of raw materials, continuing through product manufacturing, transportation, and use; and ending with final disposal, deconstruction, or recycling at the end of the product's useful life.

Energy and emissions impacts can be incurred throughout the product life cycle. In this video, we'll focus on the second phase in the product life cycle: product manufacturing.

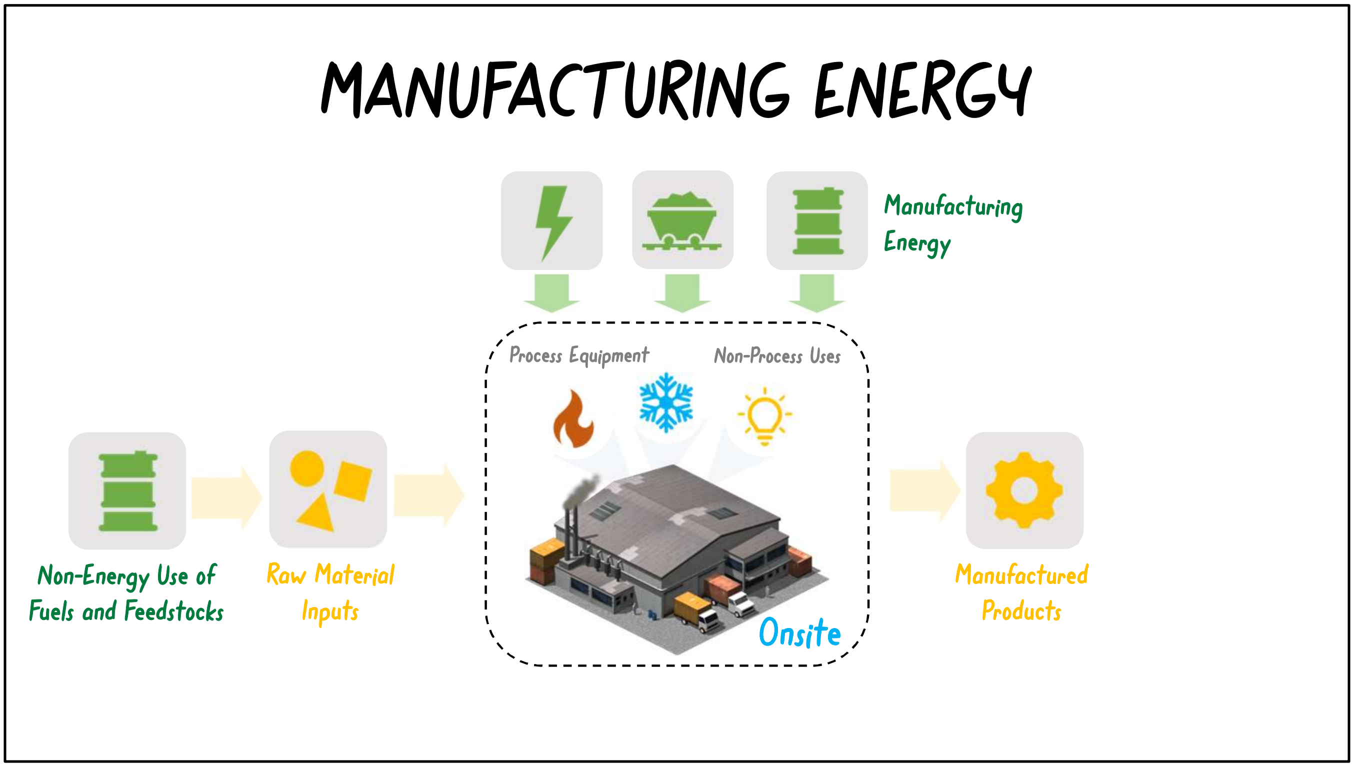


Manufacturing processes consume fuels and electricity as energy to transform raw materials inputs into final manufactured products.

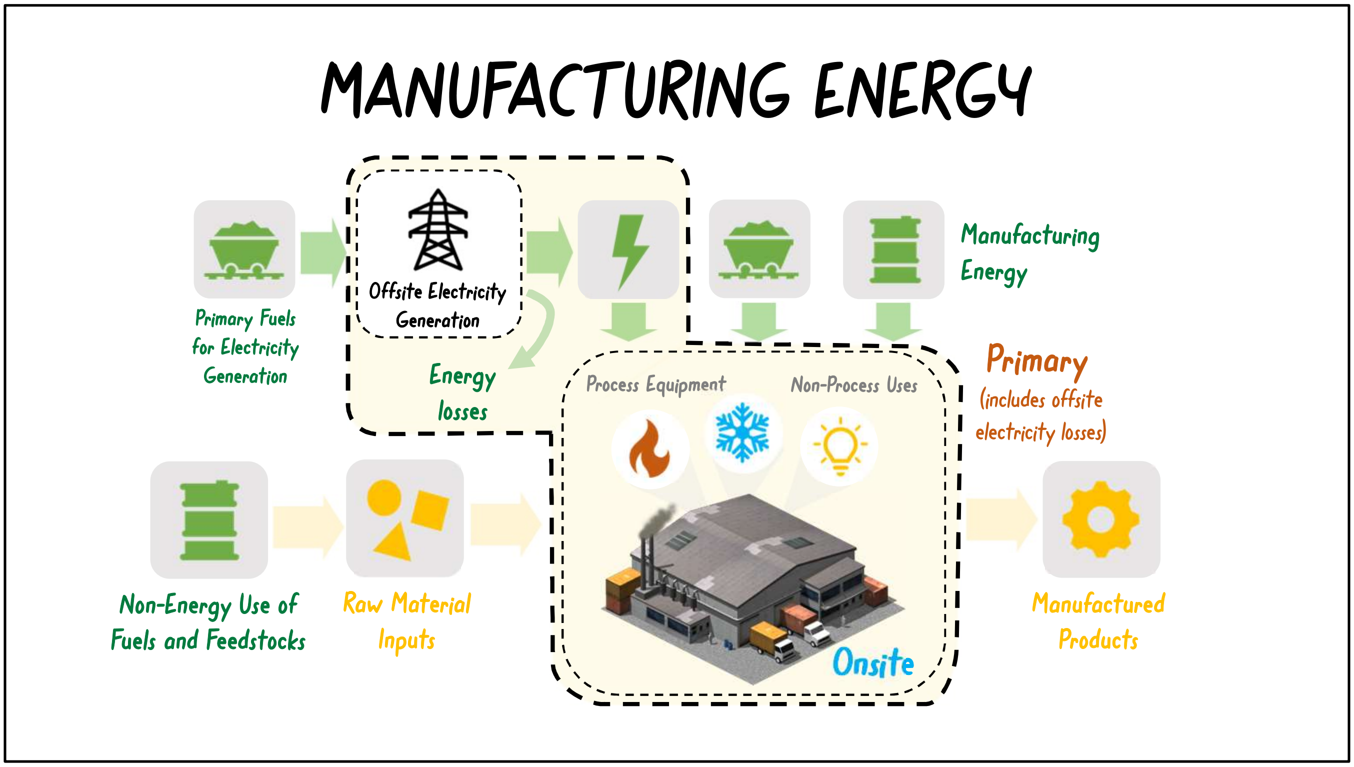


This includes energy consumed by manufacturing process equipment, such as furnaces and chillers; as well as energy consumed in non-process uses such as HVAC and lighting. Typically, the contributions of non-process energy to the total energy consumption of a manufacturing facility are small.

Another form of fuel consumption at manufacturing facilities is the non-energy use of fuels as feedstocks, such as the petroleum used to produce plastics. The embodied energy and emissions of fuels used as chemical feedstocks can be captured as part of the Raw Materials phase of the life cycle. This is discussed as part of our tutorial on Estimating Raw Material Energy and Emissions.

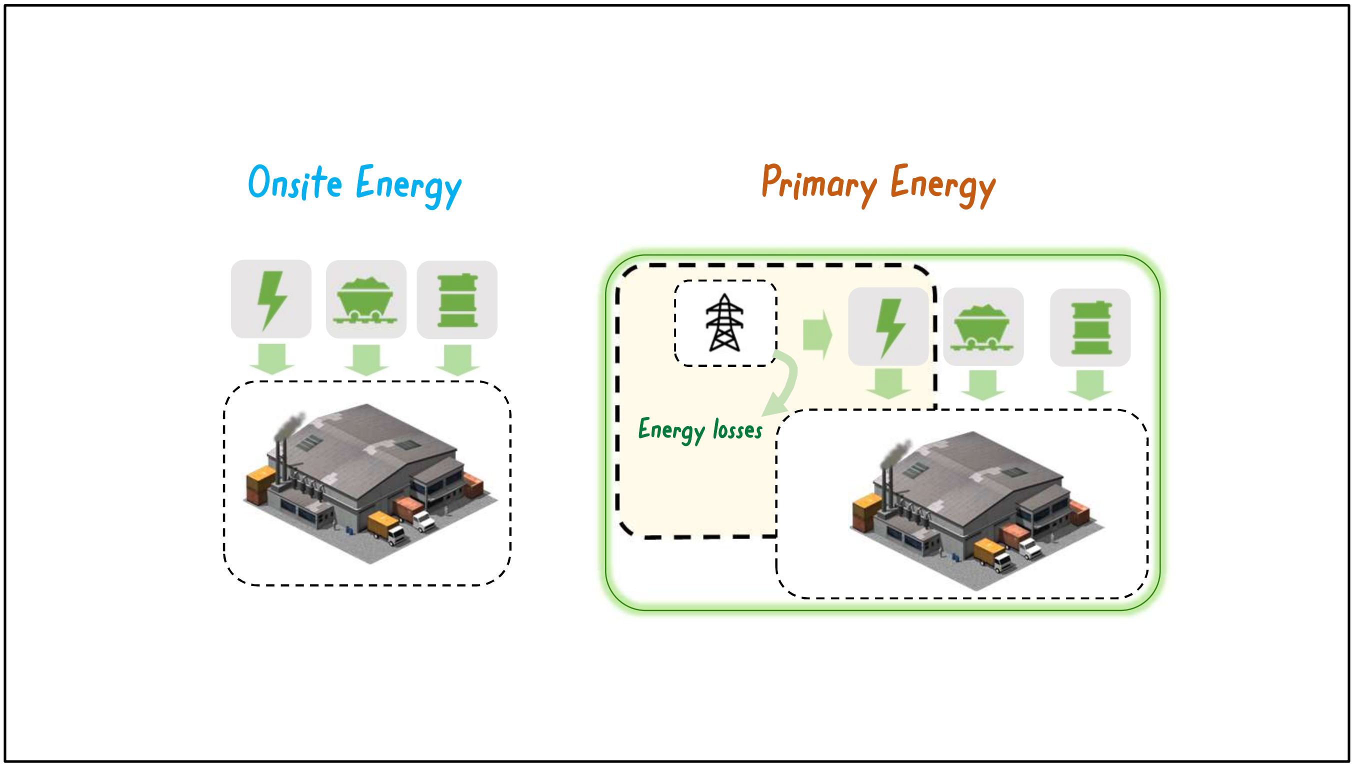


We describe manufacturing energy consumed within the plant boundaries, whether for process or non-process uses, as “onsite” manufacturing energy consumption.



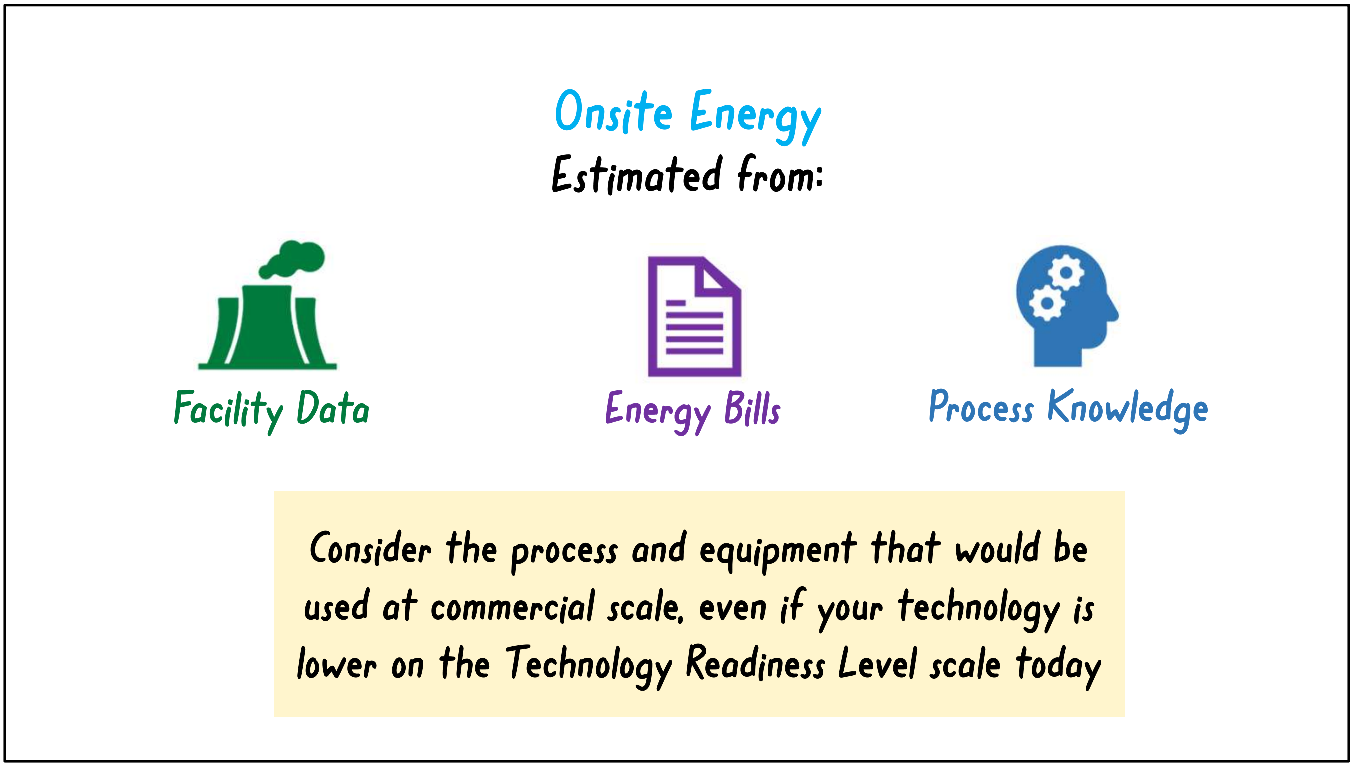
Manufacturing energy can also include an offsite component as a result of the energy losses associated with electricity generation at power plants. Electricity is not a primary energy source in itself – but rather a convenient, converted form of energy that is generated from fossil fuels as well as renewable sources.

Energy losses associated with electricity generation can be significant. Considering typical grid efficiencies today, nearly 2/3 of the energy consumed to generate electric power is lost. Therefore, when we think about manufacturing energy consumption, it's important to consider the energy content of the original fuels that were used to produce that electricity. This is called primary energy. Primary energy is the basis for calculations of cumulative energy demand, or "CED," which is the energy metric used in this tutorial series.



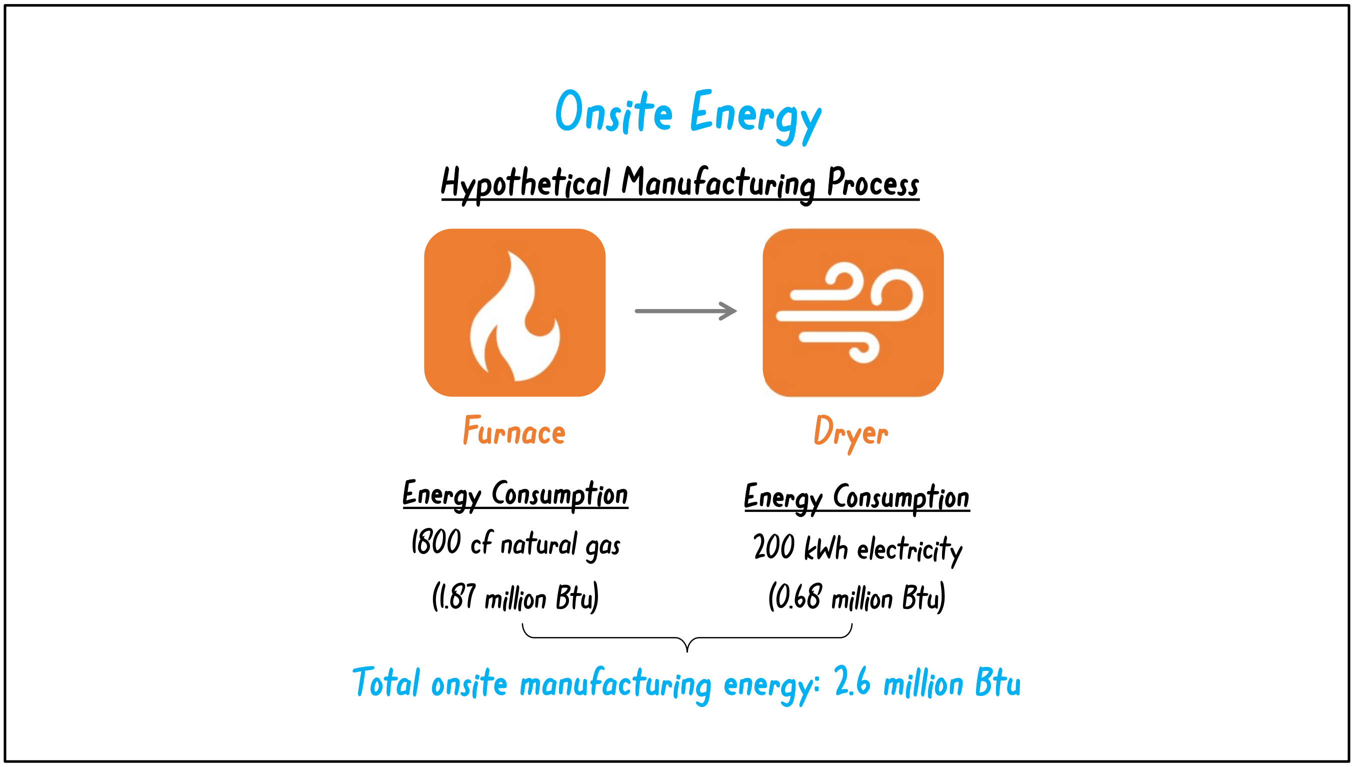
First, we'll walk through the details of calculating the on-site energy, which includes consumption of direct combustion fuels and electricity.

Then we'll calculate Primary Energy, focusing on how to account for energy lost through grid inefficiencies using the source-to-site ratio.



We'll start by determining onsite energy.

Onsite energy consumption could be estimated from facility data, energy bills, or knowledge of manufacturing equipment. When estimating manufacturing energy requirements for an early stage technology, consider the process and equipment that would be used at commercial scale, even if your technology is lower on the technology readiness level scale today. This is important for accurate estimations of potential impact—and for objective comparisons to the commercial benchmark.



As an example, let's consider a hypothetical manufacturing process that involves two pieces of equipment – a furnace and a dryer. To produce a certain reference volume of final product, the furnace consumes 1800 cubic feet of natural gas and the dryer consumes 200 kilowatt-hours of electricity. Converting these values to common units of million Btu based on their heat content, the total onsite manufacturing energy for this process is 2.6 million Btu.

To calculate primary energy, we'll need to know the prevailing <u>grid efficiency</u>.

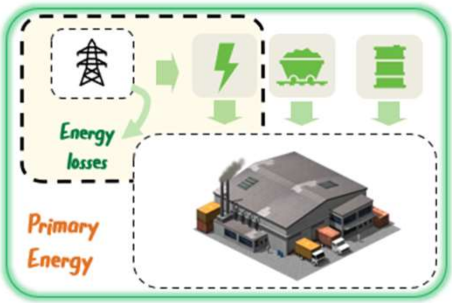
The primary energy content of a unit of electricity depends on the specific energy mix for the grid (or onsite generation system) serving that facility.

To calculate primary energy from this onsite consumption, we'll need to know the prevailing grid efficiency to determine the electricity losses.

Electric grid efficiencies vary regionally, depending on the energy mix used by power plants supplying energy to the local grid. Power plants may generate power from a combination of fossil fuels, nuclear, and renewable sources – and the primary energy content of a unit of electricity depends on the specific energy mix for the grid, or onsite generation system, serving that facility.

CALCULATING PRIMARY ENERGY

$$\text{Primary Energy} = \text{Onsite Energy} \times \text{Source-to-Site Ratio}$$



$$\text{Source-to-Site Ratio} = \frac{\text{Heat content of raw fuels consumed}}{\text{Heat content of generated electricity}}$$

Primary energy consumption is calculated by multiplying the onsite energy consumption by a ratio called the “source-to-site” ratio. For electric energy, the source-to-site ratio is determined by dividing the total heat content of raw fuels by the heat content of the generated electricity.

CALCULATING PRIMARY ENERGY

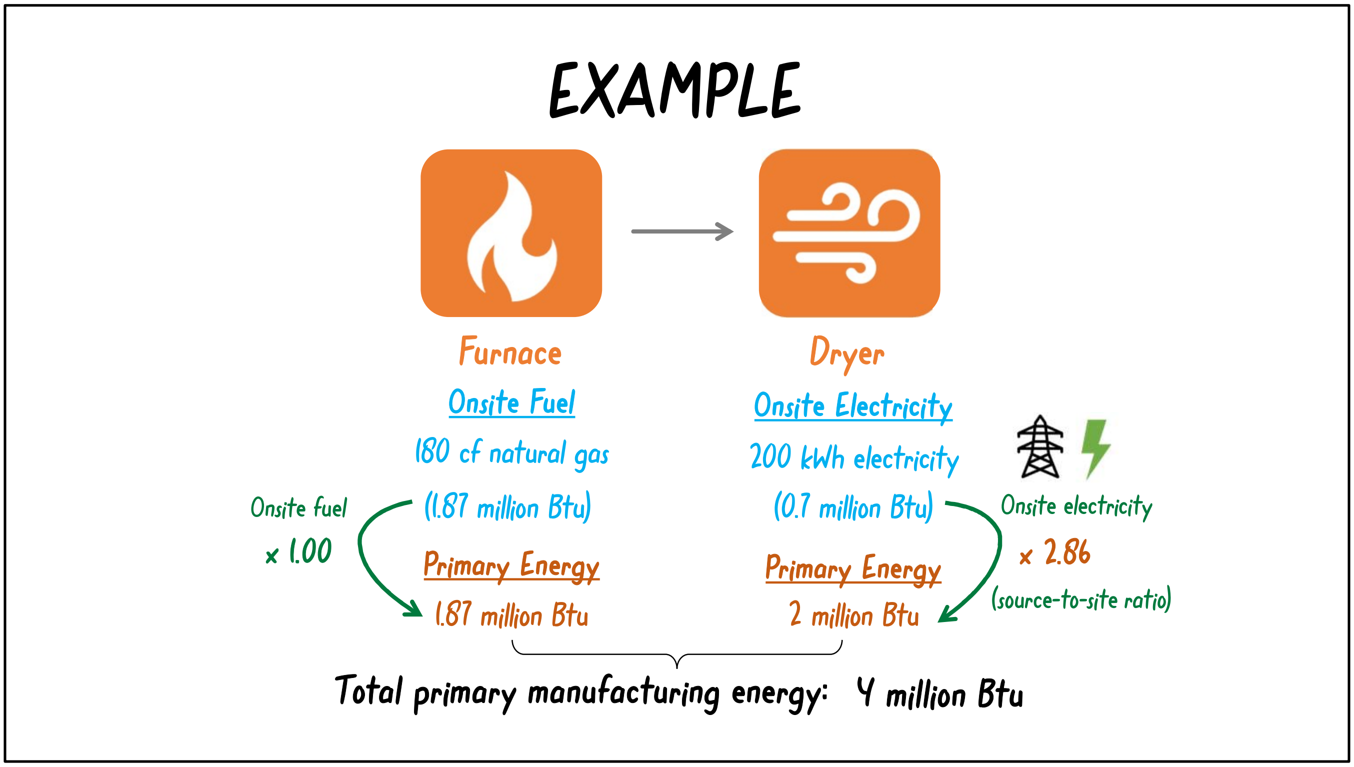
$$\text{Primary Energy} = \text{Onsite Energy} \times \text{Source-to-Site Ratio}$$

- If source-to-site ratio is known based on facility- or location-specific grid mix, the known value should be used
- Otherwise, the source-to-site ratio can be approximated using an average value for the U.S. or regional electric grid

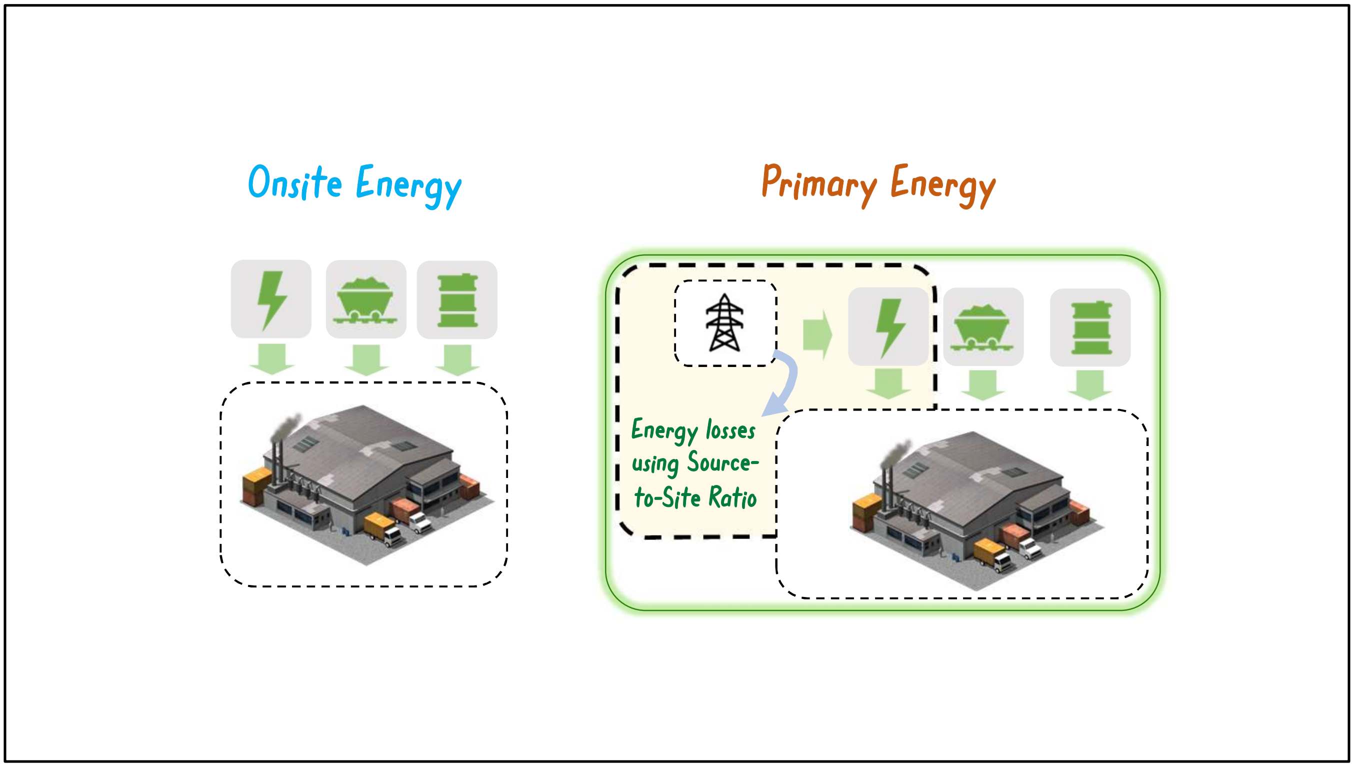
$$\text{Source-to-Site Ratio} = \frac{\text{Heat content of raw fuels consumed}}{\text{Heat content of generated electricity}}$$

If the source-to-site ratio is known based on an identified facility- or location-specific grid mix, the known value should be used in calculations.

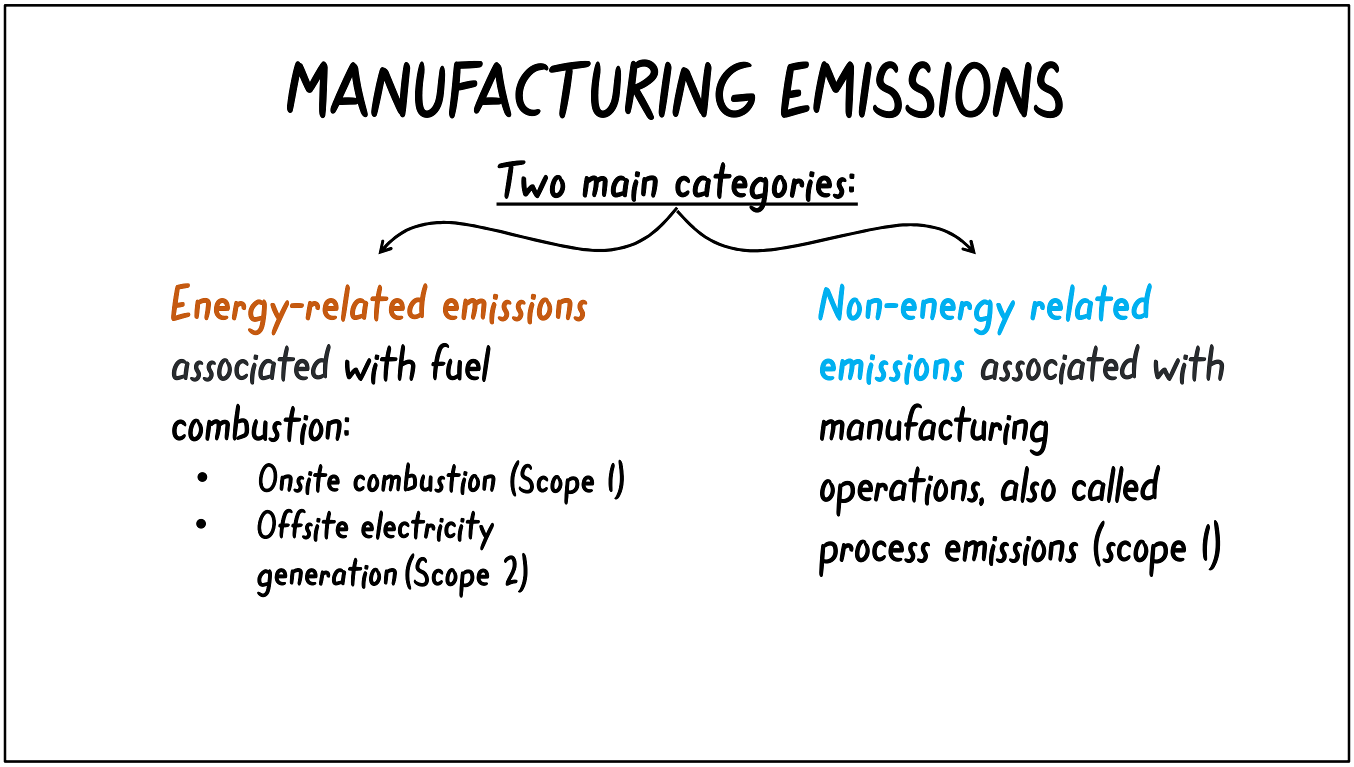
Otherwise, the source-to-site ratio can be approximated using an average value for the U.S. or regional electric grid.



Returning to our example, our manufacturing process consumed 200 kWh of electricity – corresponding to 0.7 million Btu of onsite electric energy. To convert this to a primary value, we need to multiply by the source-to-site ratio. Multiplying by the 2020 average U.S. source-to-site value of 2.86, the primary energy demand for the electricity used in this manufacturing process is 2 million Btu. We can add this to the 2 million Btu of fuel energy (from natural gas) to compute the total primary energy consumption for this process: 4 million Btu.



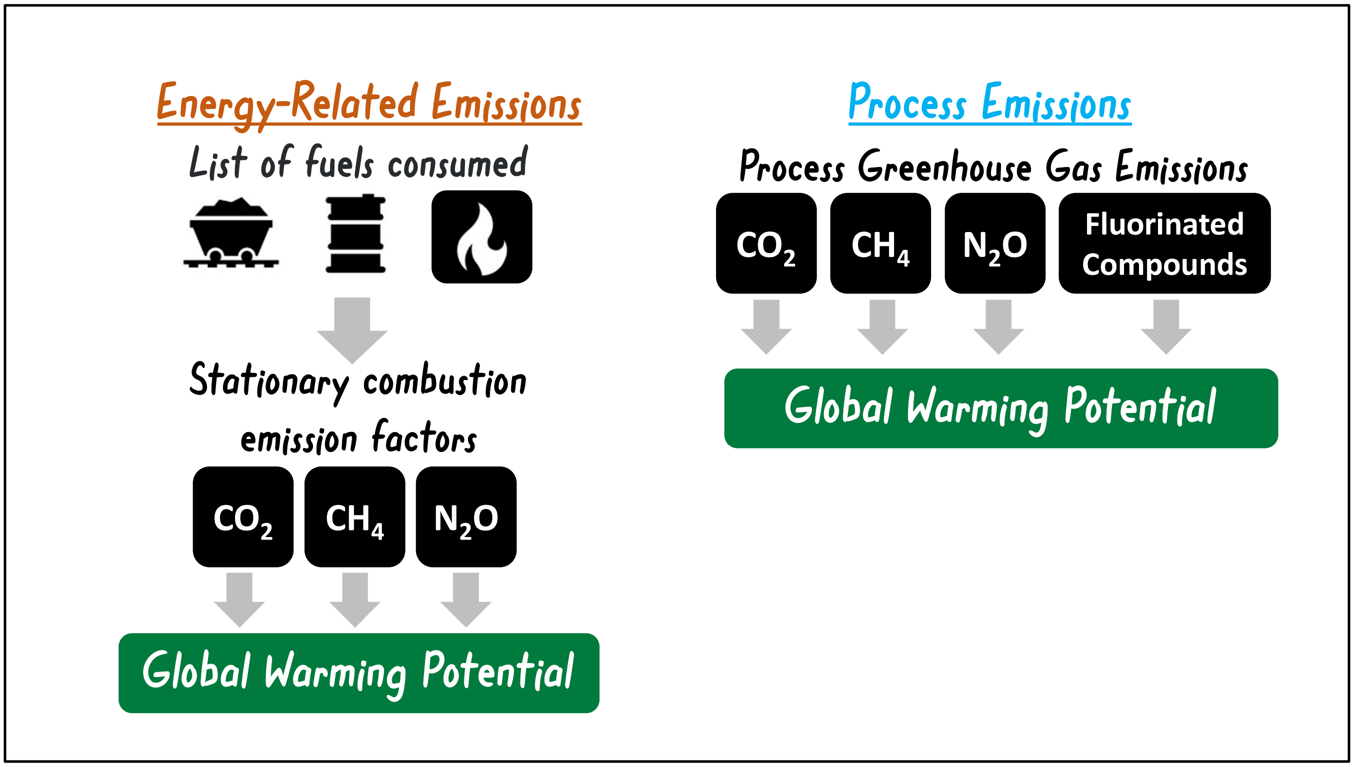
Now that we've calculated manufacturing energy on an onsite and primary basis, let's take a look at manufacturing emissions.



Manufacturing emissions come in two main categories:

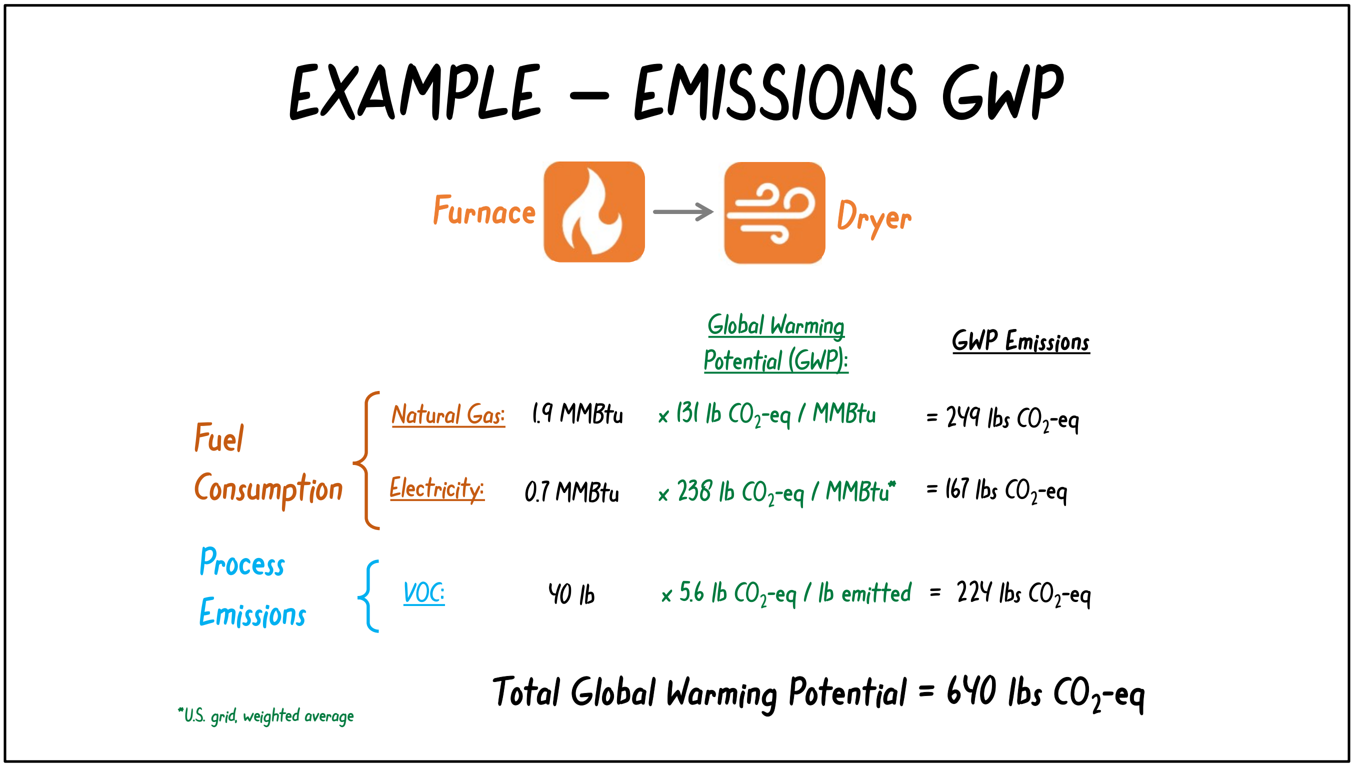
1. Energy-related emissions associated with fuel combustion. This includes emissions associated with onsite combustion at manufacturing facilities, sometimes called Scope 1 emissions, plus emissions associated with offsite electricity generation, called Scope 2; and

2. non-energy related emissions associated with manufacturing operations, also called process emissions.



For energy-related emissions, our starting point will be a list of the fuels consumed. To convert these to combustion emissions, we can first consult tables of stationary combustion emissions factors to assess the volumetric quantities of greenhouse gases emitted during combustion of each fuel. For electricity, these calculations will be based on the prevailing grid mix. Then, we'll assess the global warming potential, or GWP, by using GWP tables to assess the CO2-equivalent emissions value of each greenhouse gas.

For process emissions, our starting point would typically be a volume of a specific greenhouse gas, so we will simply assess the GWP value for that greenhouse gas to assess the CO2-equivalent emissions value.

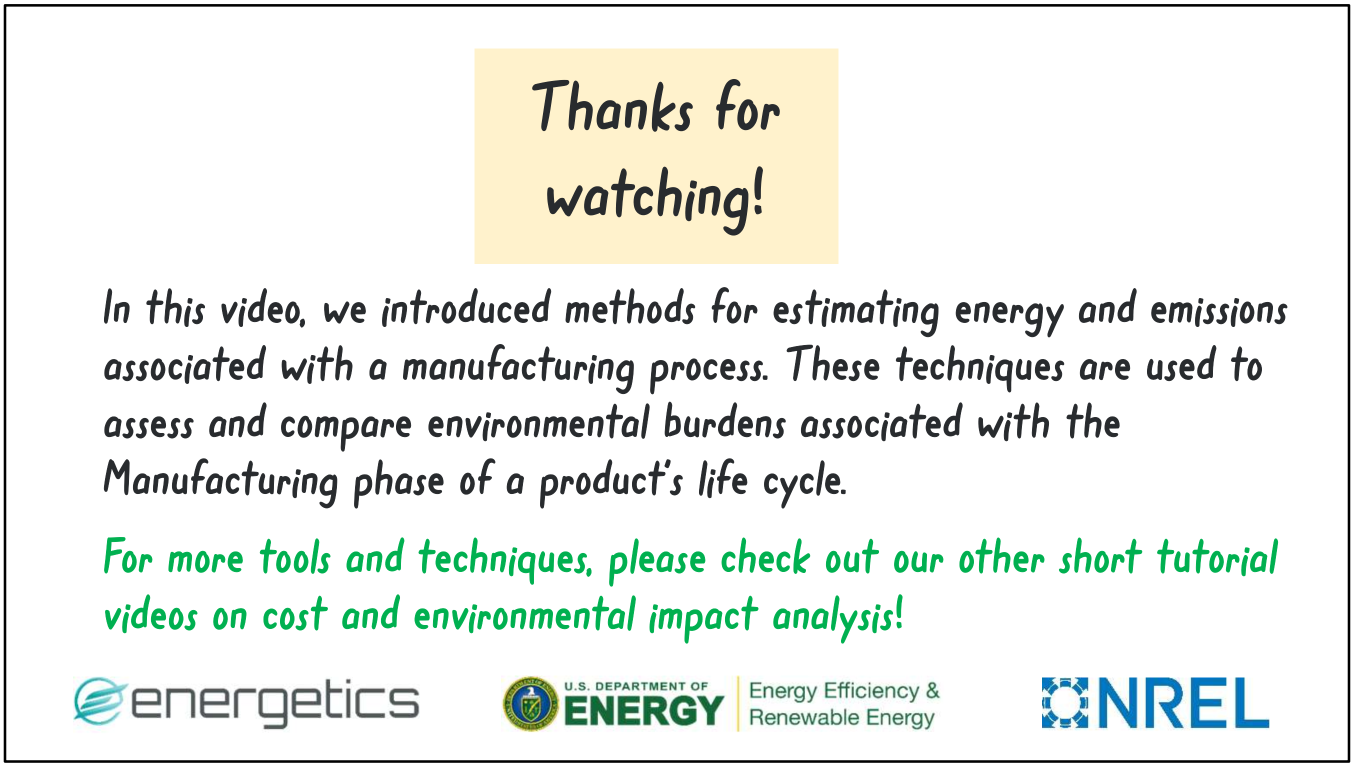


Earlier, we calculated energy consumption for this example manufacturing process. Now let's take a look at its associated emissions.

First, let's look at emissions associated with fuel consumption. This manufacturing process consumes 1.9 million Btus of natural gas and 0.7 million Btus of electricity. We can look up emissions factors for stationary fuel consumption in the IPCC Guidelines for National Greenhouse Gas Inventories. For natural gas, values are provided directly. For electricity, we'll need to consider the grid mix to determine the source fuels and apply a weighted average. Once we have an estimate of the volumetric quantities of greenhouse gases emitted during combustion, we can then convert these emissions to a CO2-Equivalent value by multiplying by the GWP.

Next, let's look at non-energy emissions. In this manufacturing process, let's say that there is a process-related volatile organic compound emission, or VOC, of 40 lbs in the furnace exhaust. Consulting IPCC tables, the 100-year GWP for this VOC is 5.6 – so we can convert this emission of VOC to a CO2-equivalent value by multiplying by 5.6.

Finally, we can estimate the total GWP for the manufacturing phase by summing the contributions from combustion-related and process-related emissions.



In this video, we introduced methods for estimating energy and emissions associated with a manufacturing process. These techniques are used to assess and compare environmental burdens associated with the Manufacturing phase of a product’s life cycle.

For more tools and techniques, please check out our other short tutorial videos on cost and environmental impact analysis! Thanks for watching.