ESTIMATING RAW MATERIAL EMBODIED ENERGY & EMISSIONS

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

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

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Estimating Raw Material Embodied Energy and Emissions

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Welcome to DOE's video tutorial series on cost and environmental impact analysis for manufacturing technologies!

Heather

In this module, we will:

- Define "embodied energy" and "embodied emissions"
- Describe techniques for estimating these parameters for raw material inputs to a manufacturing process

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I'm Heather.

In this module, we will:

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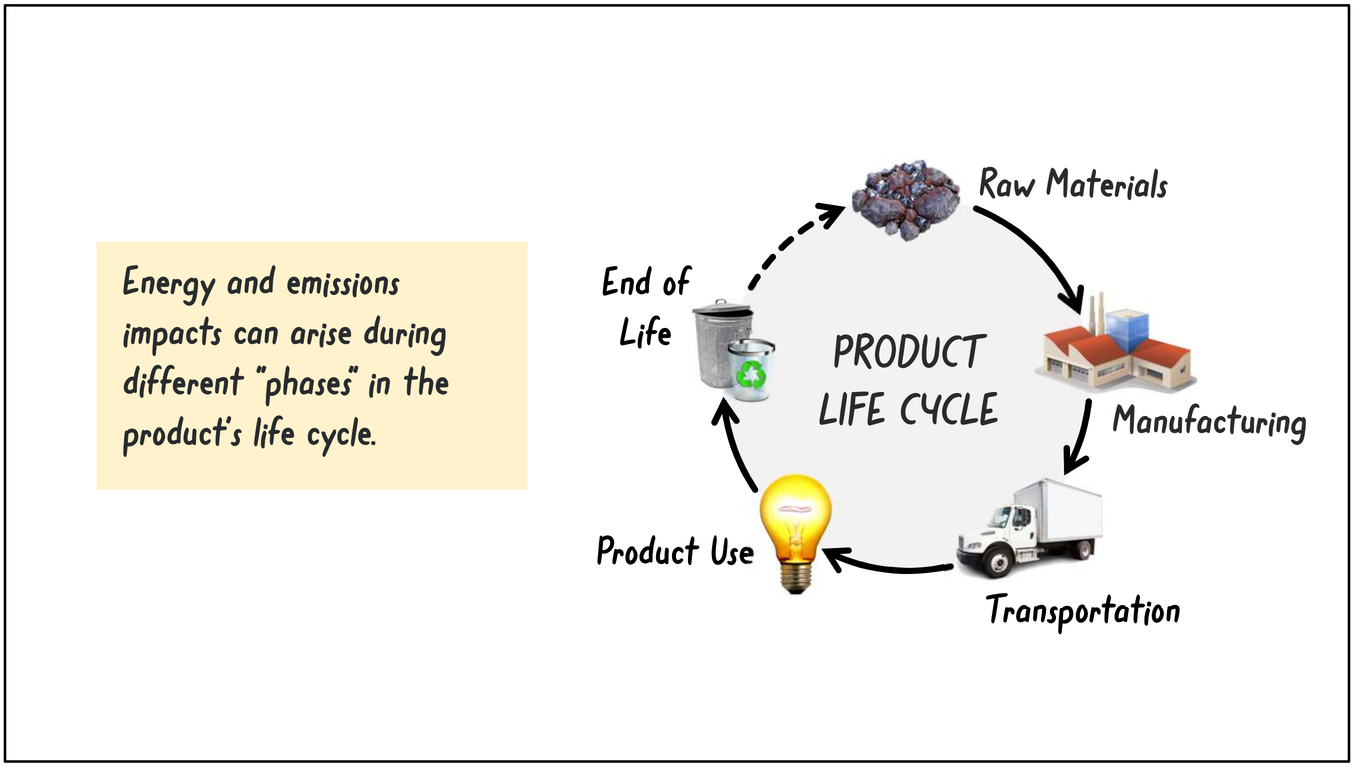
- Describe techniques for estimating these parameters for raw material inputs to a manufacturing process.

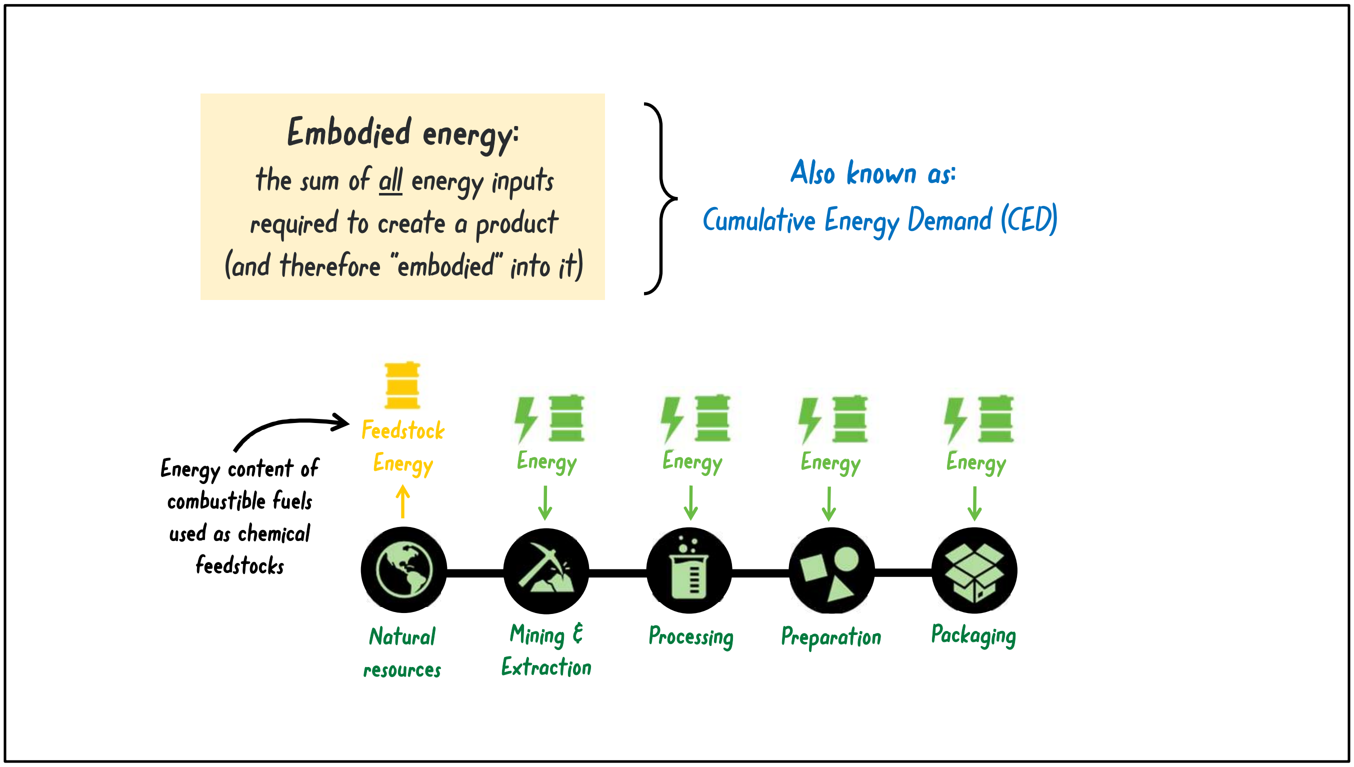


Every manufactured product has a life cycle. Energy and emissions impacts can arise during different "phases" in the product's life cycle.

This includes:

- Raw materials extraction and processing;
- Product manufacturing;
- Transportation of the product to its point of use;
- Use phase; and
- End of life.

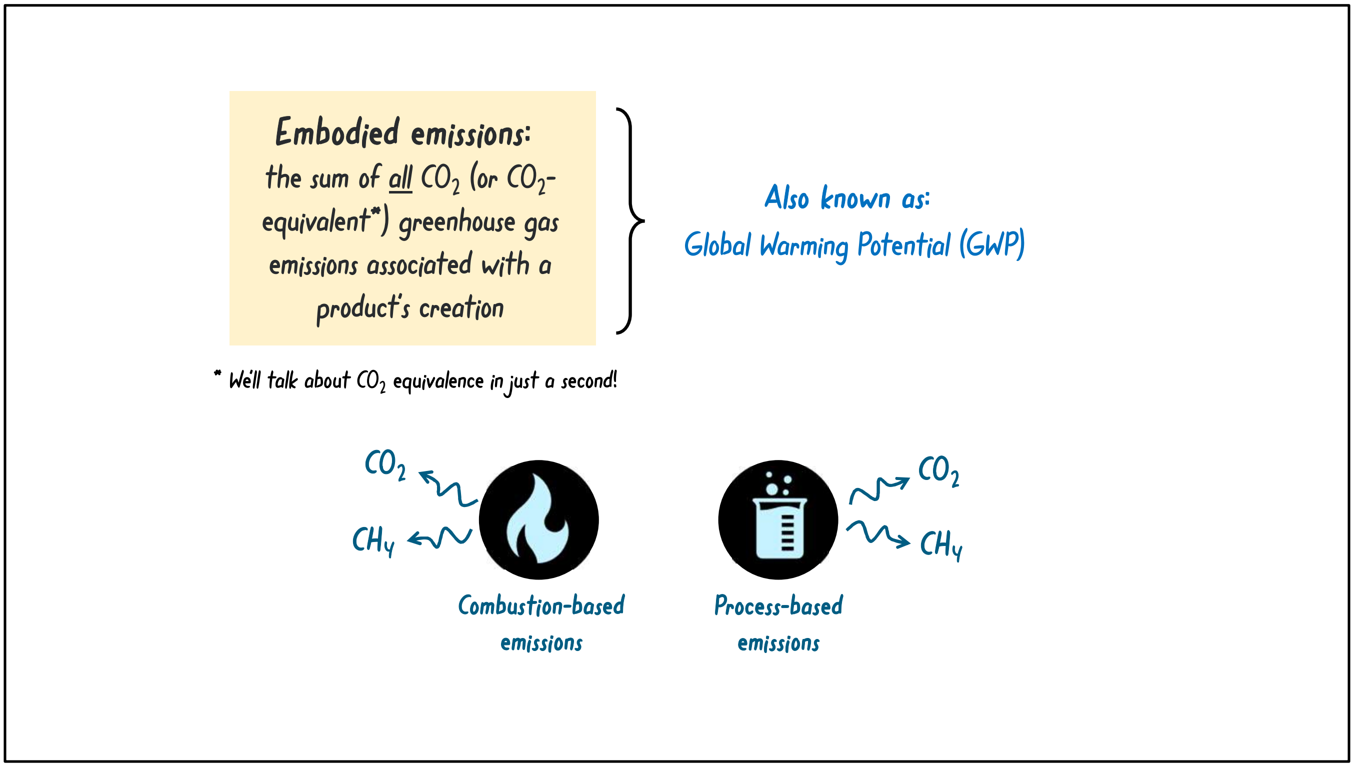
In this video, we'll focus on the first phase in the product life cycle: energy and emissions embodied in the raw materials.



“Embodied energy” is the sum of all energy inputs required to create a product, and therefore “embodied” into it. In life cycle assessment literature, embodied energy is also called the “cumulative energy demand,” which emphasizes that this value reflects a cumulative accounting of energy consumption.

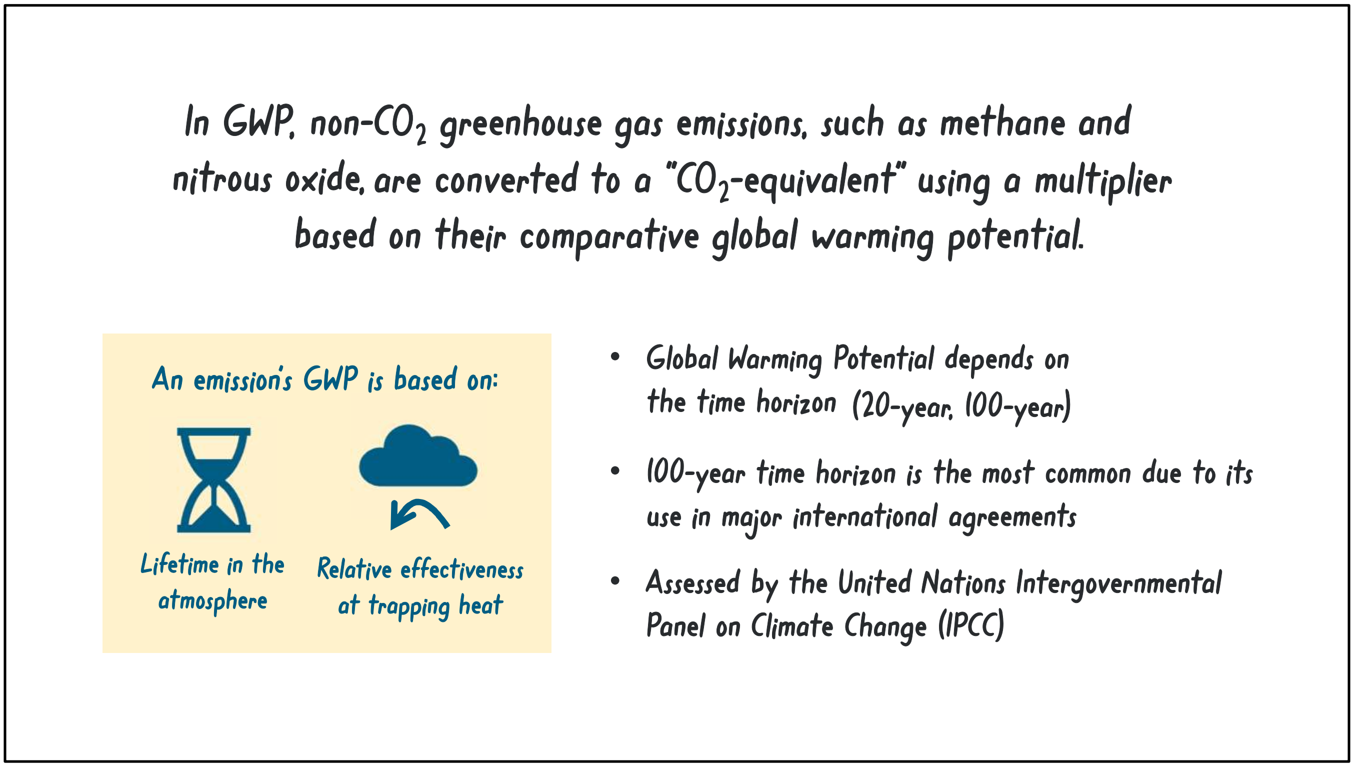
Starting from a material’s very beginnings as natural resources, embodied energy will include all energy involved in mining and extracting the raw materials from the Earth, plus the energy required for processing, preparation, and packaging.

If applicable, embodied energy will also include feedstock energy. Feedstock energy is the energy content of combustible fuels used as a chemical feedstock, such as the petroleum used to produce plastics.



Embodied emissions is the emissions analog to embodied energy. A material's "embodied emissions" is the sum of all CO2 (or CO2-equivalent) greenhouse gas emissions associated with a product's creation. These emissions are typically dominated by emissions associated with combustion of fuels, whether onsite to support manufacturing or offsite at power plants. But they can also include process-based emissions related to mining and manufacturing.

Embodied emissions as defined here can also be referred to as "global warming potential," or GWP. That's because CO2 and other greenhouse gases trap heat on Earth and contribute to global warming.



In GWP, non-CO2 greenhouse gas emissions, such as methane and nitrous oxide, are converted to a "CO2-equivalent" using a multiplier based on their comparative global warming potential. An emission's GWP is based on its lifetime in the atmosphere and its relative effectiveness at trapping heat on Earth in comparison with CO2.

Given that different pollutants have different lifetimes in the atmosphere, global warming potential depends on the time horizon considered in an analysis. 20-year and 100-year time horizons are commonly used. The 100-year time horizon is the most common due to its use in major international agreements, such as the Kyoto Protocol and the Paris Agreement. Standard GWP factors for each timescale are assessed by the United Nations Intergovernmental Panel on Climate Change, or IPCC.

Example Process

100 tons CO_2

1 ton CH_4

Excerpt from IPCC (AR6) GWP Tables

Emission Gas	100-year GWP	20-year GWP
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	30	83
Nitrous oxide (N_2O)	273	273

GWP Calculation (100-year GWP)

100 tons CO_2 = 100 tons CO_2-eq

1 ton CH_4 = 30 tons CO_2-eq

Total: 130 tons CO_2-eq

GWP Calculation (20-year GWP)

100 tons CO_2 = 100 tons CO_2-eq

1 ton CH_4 = 83 tons CO_2-eq

Total: 183 tons CO_2-eq

As an example, imagine a process that emits 100 tons of carbon dioxide (or CO2) plus 1 ton of methane gas (or CH4). We can consult IPCC tables to find the relevant GWP multipliers to convert the 1 ton of methane to its CO2-equivalent.

For a 100-year time horizon, the GWP for methane is 30, meaning that 1 pound of methane is 30 times more effective at trapping heat in Earth's atmosphere than 1 pound of carbon dioxide over a 100-year timeframe. But for a 20-year time horizon, the GWP for methane is 83. That's a lot higher than the 100-year GWP value because methane is a very potent greenhouse gas, though shorter-lived in the atmosphere than CO2.

Our example process emits a total of 100 tons of CO2 plus 1 ton of methane. For the 100-year timeframe, we can convert the 1 ton of methane to its CO2-equivalent by multiplying by 30 to express the total emissions as 130 tons of CO2-equivalent. That's the 100-year GWP of this process. However, if we assume a 20-year time horizon in our calculation of GWP for our example process, we find that the total CO2-equivalent emissions is 183 tons of CO2-equivalent. In this case, the one ton of methane has almost as much effect as the 100 tons of CO2!

Given the significant differences between GWP estimated for different timescales, it's important to clearly note the time horizon being used in calculations. The most common time horizon is 100 years, but this can disguise the effects of potent gases like methane over shorter time horizons, so it's important to keep that in mind.

Embodied energy:
the sum of <u>all</u> energy inputs required to create a product (and therefore "embodied" into it)

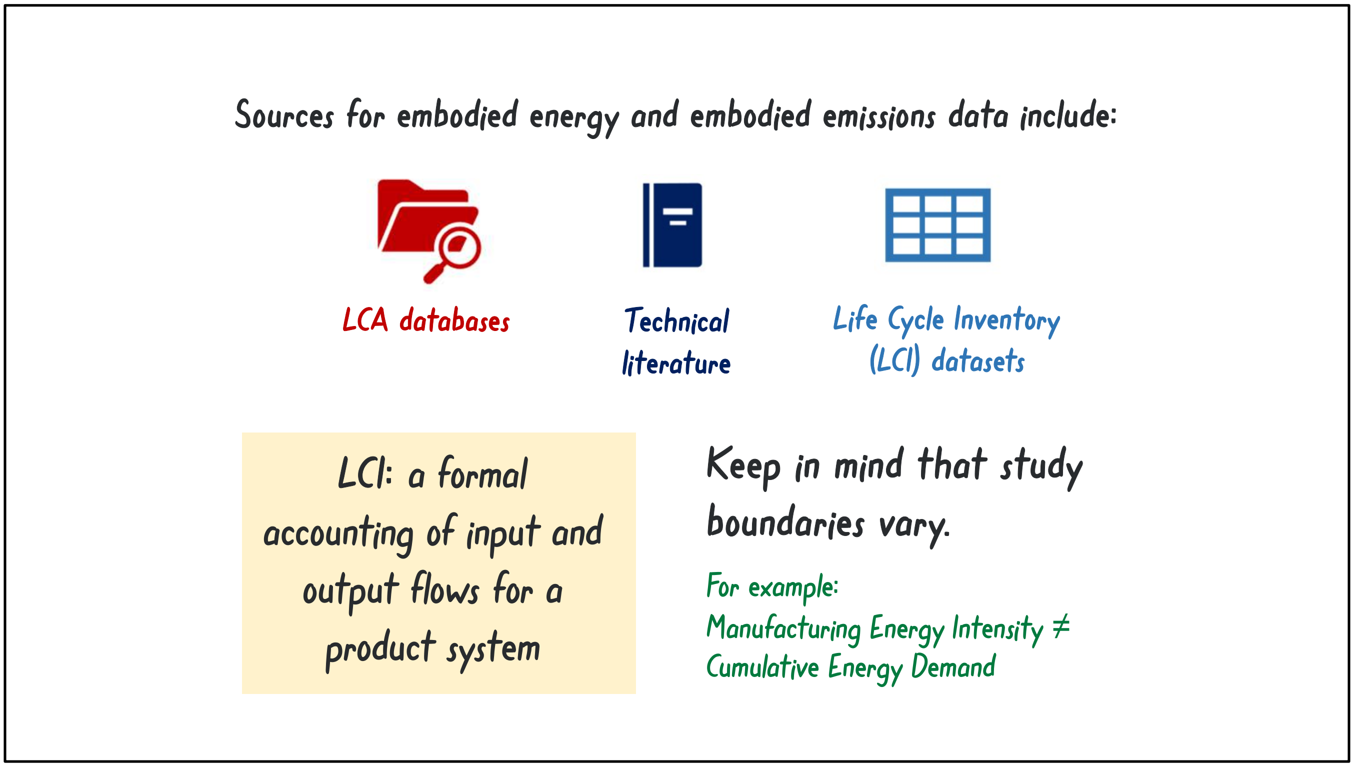
Embodied emissions:
the sum of <u>all</u> CO_2 (or CO_2-equivalent) greenhouse gas emissions associated with the creation of a product

Let's explore how we might estimate these quantities for a life cycle assessment.

We saw that embodied energy is the sum of all energy inputs required to create a product – and therefore "embodied" into it.

And embodied emissions is the sum of all CO2, or CO2-equivalent emissions, associated with the creation of that product.

Now that we've pinned down these definitions, let's explore how we might estimate these quantities for a life cycle assessment.



For many materials, good sources for embodied energy and embodied emissions data include:

- LCA databases (including both free and paid resources);
- Technical literature; and
- Life cycle inventory, or LCI, datasets.

An LCI is a formal accounting of input and output flows for a product system prepared as part of an LCA.

When searching for the data you need in technical literature, keep in mind that study boundaries vary. Pay careful attention to calculation methods to ensure that definitions match what you are expecting.

For example, a study reporting a "manufacturing energy intensity" is likely using different boundaries than a study reporting "cumulative energy demand."

DATA AVAILABILITY AND ACCESSIBILITY CHALLENGES

Some data in technical literature and databases may be difficult to access because the data are:

- Located behind paywalls
- Provided in file types accessible only through LCA software

One example of a free resource for industry-average embodied energy and emissions information is the "Materials Flows through Industry" tool, or MFI.

Aside from inconsistencies in study boundaries, you might also encounter challenges in access to certain data.

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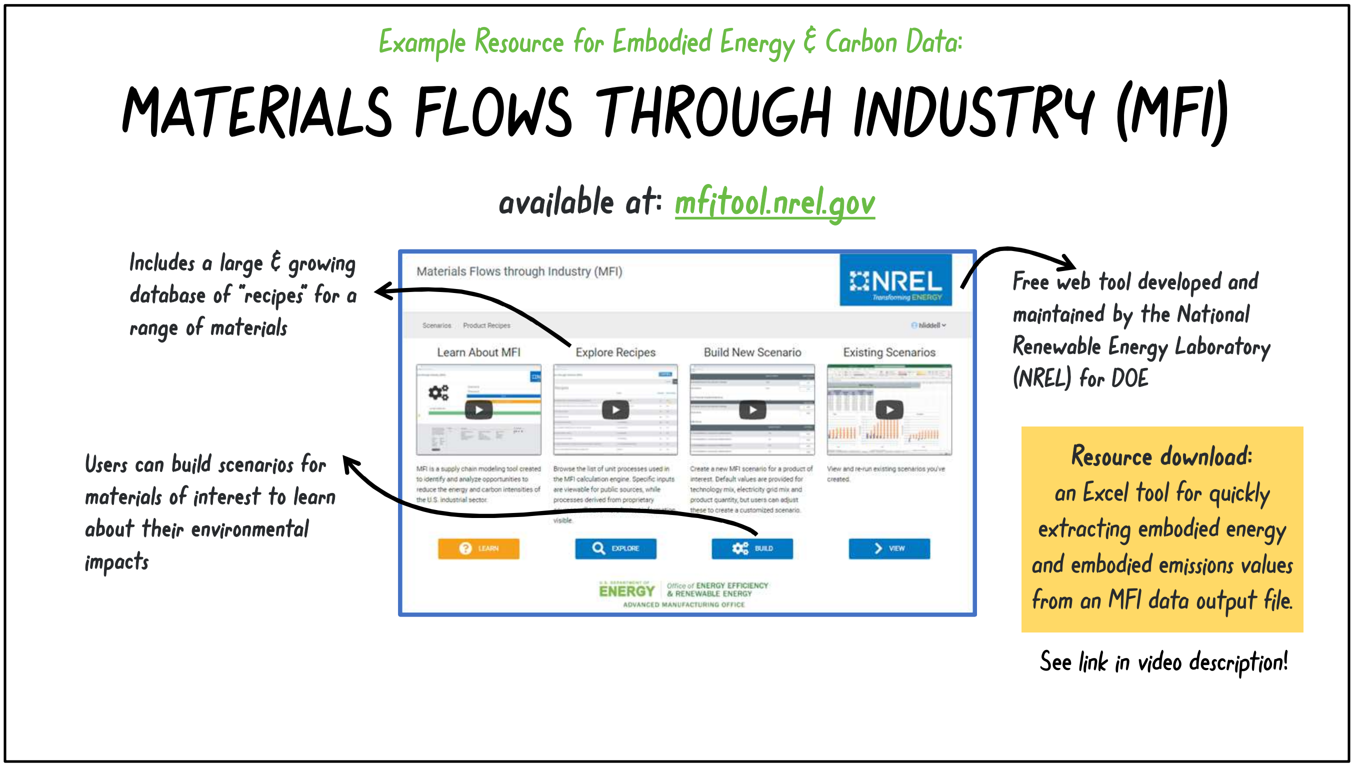


MFI is a free web tool developed and maintained by the National Renewable Energy Laboratory for DOE.

MFI includes a large and growing database of "recipes" for a range of materials.

Users can build scenarios for materials of interest to learn about their environmental impacts.

To help you get started with MFI, our team has created a simple Excel tool for quickly extracting embodied energy and embodied emissions values from an MFI data output file. To download that resource, see the link in the video description.

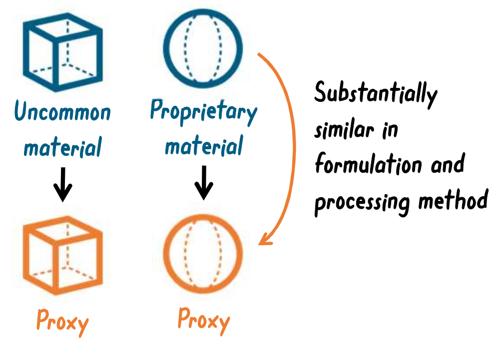
Tool is available at https://mfitool.nrel.gov/

PROXY MATERIALS

While embodied energy and emissions data are available for a wide range of materials, you may encounter a material for which data are not available.

In cases such as these, you can consider selecting and using a "proxy" material

Assumptions regarding proxy selection and use should be clearly documented.



While embodied energy and emissions data are available for a wide range of materials, you may encounter a material for which data are not available.

For example, you might need data for an uncommon material for which values cannot be located. Or, you may have a proprietary material in your process for which you may not know the composition or be able to disclose it.

In cases such as these, you can consider selecting and using a “proxy” material. The proxy material selected should be substantially similar to the actual material in its formulation and processing method, such that it can be reasonably assumed to have a similar embodied energy and emissions footprint.

If using a proxy material, assumptions regarding proxy selection and use should be clearly documented in your analysis.

Thanks for watching!

In this video, we defined embodied energy and embodied emissions, and introduced methods for estimating these values for raw input materials in a product's supply chain. These techniques allow us to estimate impacts for the Raw Materials phase of the product life cycle.

For more tools and techniques, please check out our other videos on cost and environmental impact analysis!

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