FRPC Manufacturing Energy Use Estimator

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27 July 2017

ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE National Laboratory

Fiber Reinforced Polymer Composite (FRPC) Energy Estimator allows to examine any new IACMI composite manufacturing pathways towards achieving its 50%/75% technical *embodied* manufacturing energy reduction goal

Embodied Energy is the energy consumed by all of the processes associated with the production of a product, from the mining and processing of natural resources to manufacturing, transport, and product delivery

Electricity Embodied Energy = 3x Onsite Energy Consumption (kWh)

Manufacturing Energy Savings = **$** Part Cost Savings

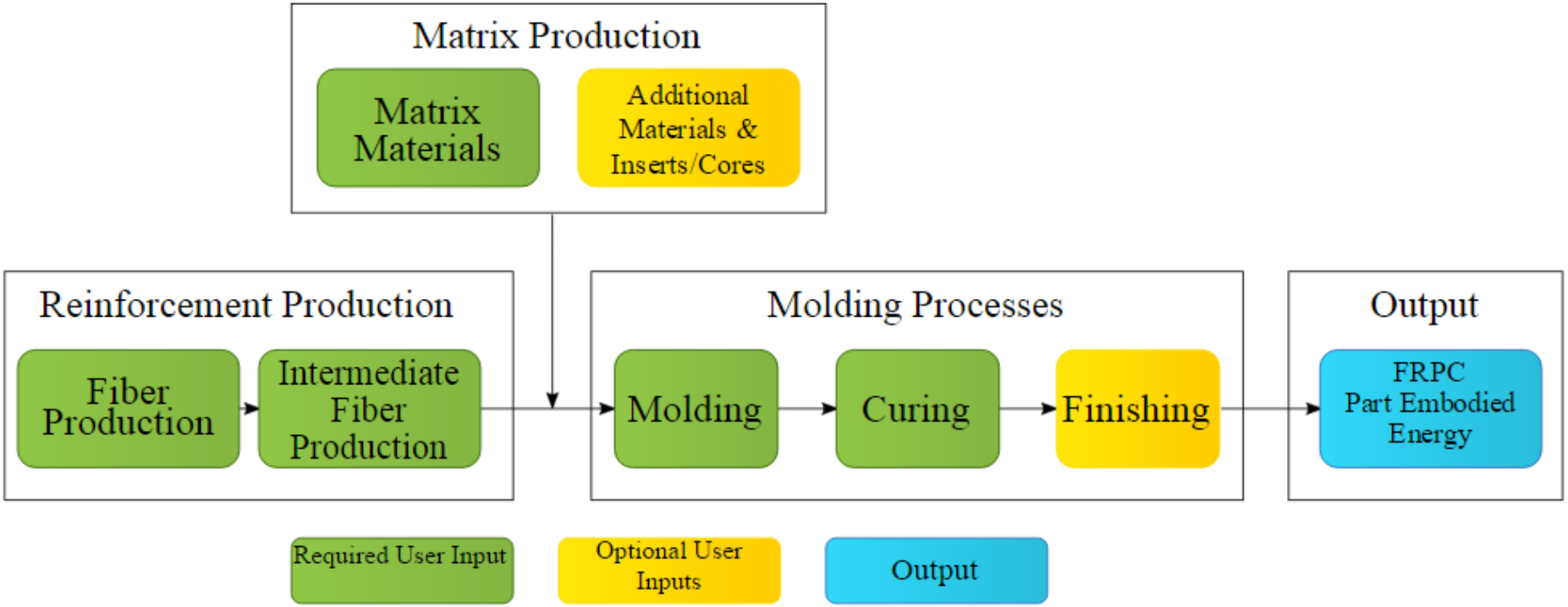
Annual 1500 t Carbon Fiber Manufacturing Facility 10% Energy Savings = $0.7M*

*20 kWh/lb of carbon fiber @ 0.10/kWh

Energy Estimator Tool Goals

- Calculate fiber reinforced polymer composite (FRPC) embodied part manufacturing energy by major process step
  - **Materials**: Fiber, Matrix, Inserts/Cores
  - **Manufacturing**: Intermediate Processing, Molding, Curing, Finishing
- Identify the most energy-intensive FRPC manufacturing process step
  - Compare energy use between different production processes
- Final FRPC part characteristics guidance for the molding technology selection available for analysis
- Energy intensity of alternative FRPC part manufacturing pathways can be estimated with the user-input data
- Open Source Code and User-Friendly Interface

Model Scope



Several available <u>Technology Options</u> for each of the *<u>Seven</u>* <u>Major Process Steps</u>

Allows users to examine <u>Total FRPC Part Embodied Manufacturing Energy</u> using <u>Different Pathways</u>

Materials Options

- Fiber Precursor Materials
  - Commodity Carbon Fiber PAN (24K, 50K)
  - Glass Fiber
  - Natural Fiber
- Intermediate Fiber Configuration
  - Prepreg (Hand/Fiber/Tape)
  - Chopped
  - Sheet Molding Compound
  - Powder P4
  - Dry Knit
  - Dry Weave
  - Dry Braid
- Thermosets
  - Epoxy, PS, PU, etc.
- Thermoplastics
  - PP, Nylon, PEEK, etc.
- Fillers
- Additives
- Inserts (for overmolding)
  - Metal
  - Composites
  - Plastics/Foams

Embodied energy data gathered from LCA literature and machinery specifications

Conventional Molding Processes

- Manual Layup
  - Wet Lay up (open)
  - Spray up (open)
  - Vacuum Bag/Autoclave Molding (closed)

http://www.superchevy.com/how-to/vemp-0906-new-zr1-corvette/

- Shape Specific
  - Pultrusion
  - Filament Winding

http://www.epsilon-composite.com/img/pultrusion.jpg

http://www.compositesworld.com/articles/the-markets-pressure-vessels-2012

Embodied energy data gathered from LCA literature

Newer Molding Processes

- Automated
  - Automatic Tape Placement
  - Automatic Fiber Placement

http://www.mtorres.es/sites/default/files/productos/torresfiberlayup_automatic_fiber%20_placement_MTorres_12.jpg

- Closed Molds
  - Compression Molding
    - SMC molding
    - Thermohydroforming
  - RTM
    - VARTM/SCRIMP
    - HP-RTM
  - Injection Molding
    - Structural Reaction Injection Molding

Embodied energy data gathered from LCA literature, personal conversations, and machinery specifications

http://www.dsm.com/corporate/media/informationcenter-news/2015/03/2015-03-10-dsm-daron-200-rtm-resin-used-by-the-ese-carbon-company-for-making-ultra-light-carbon-fiber-car-wheels.html

Curing & Finishing

- Autoclave Curing
- Out of Autoclave Curing
  - In-mold
  - Oven
  - Microwave
  - Quickstep
  - Infrared
  - Direct Induction
  - Electron Beam

Embodied energy data gathered from LCA literature, personal conversations and machinery specifications

- Finishing
  - None
  - Low – High
    - Rough Estimates Only

http://www.compositesworld.com/news/large-autoclave-on-the-move-for-777x-wing-fabrication

FRPC Energy Estimator Tool -- Software

- Open Source:
  - "denoting software for which the original source code is made freely available and may be redistributed and modified"
  - Tool code is available on Github 
    - Others can download and run themselves or suggest modifications directly to the code
    - Easily track changes to code
  - Program to run/modify code is also freely available at r-project.org and Rstudio.com
- Temporarily housed and hosted on the Shinyapps.io server

FRPC Energy Estimator Tool -- Framework

- Visually appealing/intuitive
  - Less blocky, more fluid
- More fields can be filled automatically and still be adjusted by user
  - Fewer “overrides” needed
  - Example: matrix mass fraction $f_{matrix} = 1 - f_{fiber}$
- Can hide optional fields
  - Additional matrix materials & inserts
- Online tool: no downloads ***required***
  - *Can* also download tool from Github for offline use
  - *Can* download Results, Session Inputs, and Other files from Tool
  - Can upload previous session results

FRPC Energy Estimator Tool – User-Defined

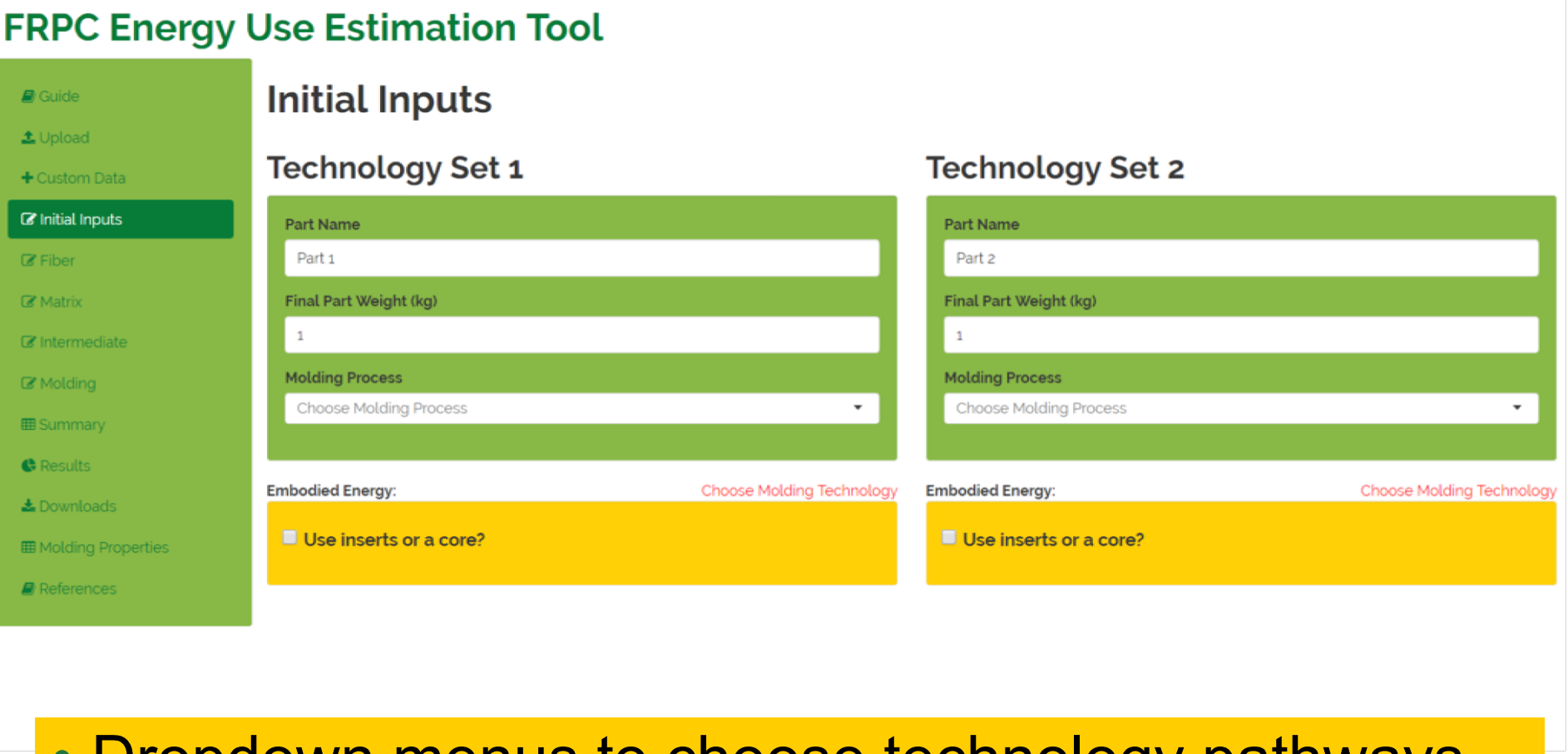
- Allows estimation of energy impacts of user-input alternative manufacturing technology pathways
  - Ability to add technology specific custom energy data (MJ/kg)
    - For all process components (fiber, matrix materials, inserts/cores, fiber intermediate, molding, curing, and finishing)
  - Estimate specific energy for molding and curing from process unit information:
    Rated Power, % Rated Power, Running time, and Weight
    - Vacuum Motor
    - Pump
    - Compressor
    - Process Heating
      - Discrete power vs. time input option to simulate a heating profile curve
    - Other

New Technology Pathways Can be Added to the Technology Database

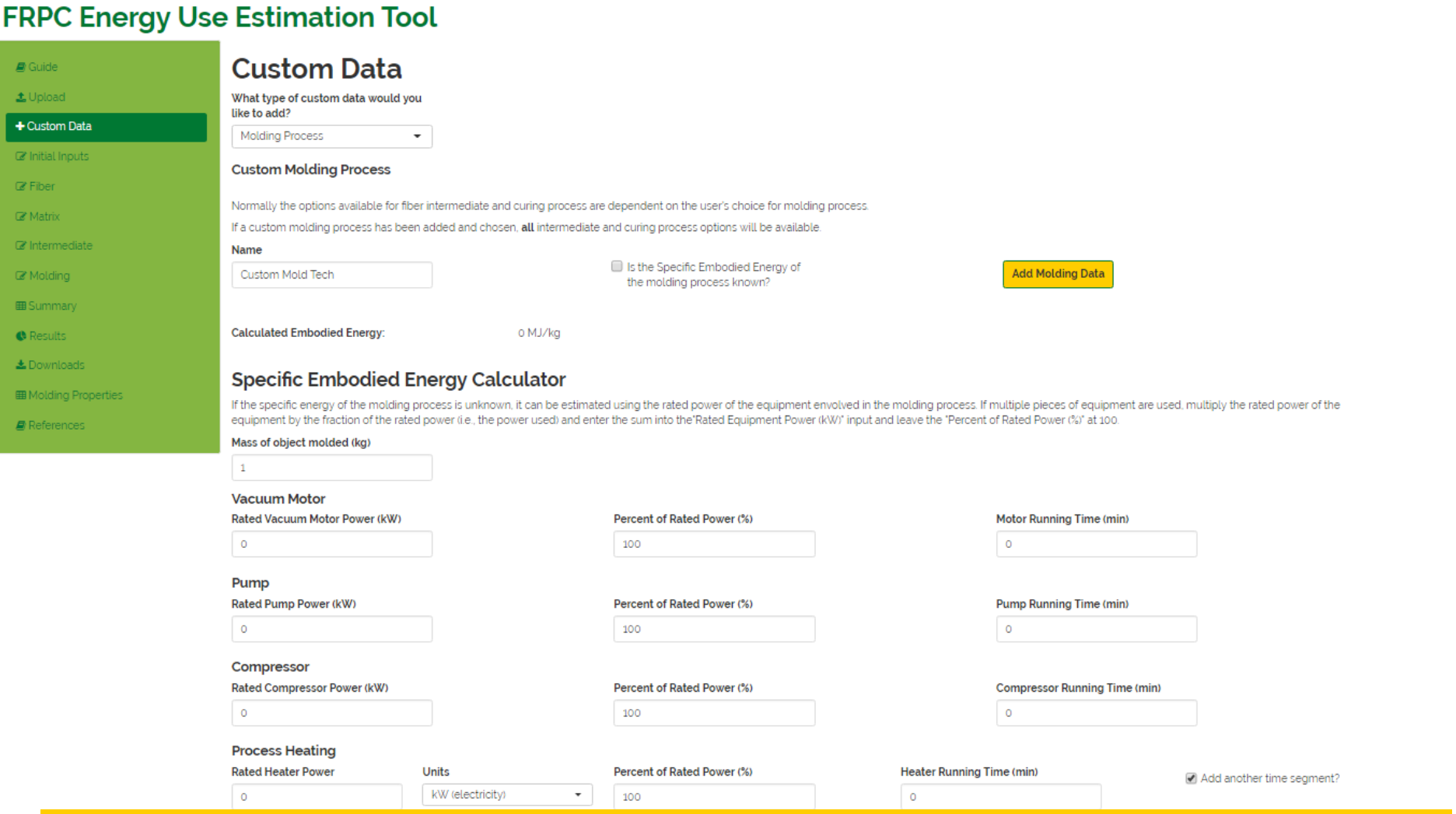
FRPC Energy Estimator Tool -- Design

TOOL SCREEN	CONTENT
Guide	Instructions, Load an Example Scenario, Download Tool Documentation*
Upload	Upload Custom Data, and Technology Set 1 & 2 Data
Custom Data	Input Custom Data by Nine Specific Processing Steps
Initial Inputs	Part Name & Weight, Molding Process and Inserts or Core Use?
Fiber	Fiber Type and Mass Fraction
Matrix	Matrix Type (=1 or > 1) & Mass Fraction
Intermediate	Intermediate Type, Scrap Rate, & Recycle Fraction
Molding	Molding Yield, Recycle Fraction, Curing Process, Finishing Level (Scrap Rate & Recycle Fraction)
Summary	Summary of Selected Technology Data for Technology Set 1 & 2
Results	Results in Bar, Pie, and Table formats by Major Processing Steps
Downloads	Save Files (Results, Custom Data, Input Files, & Calculations), for Future Upload/Use
Molding Properties	Molding Technology Characteristics for its Selection Guidance
References	Citations for Available Technology Embodied Energy Estimates

*Tool Documentation Zip file contains Tool User Manual, Energy Data, References, and FRPC baseline metrics analysis case studies



- Dropdown menus to choose technology pathways
- Options and data based on literature review
- Does not save to tool's server
  - Can download file with data for future uploads



- Can add custom data points for each process step and material type
- Does not save to tool's server
  - Can download file with data for future uploads

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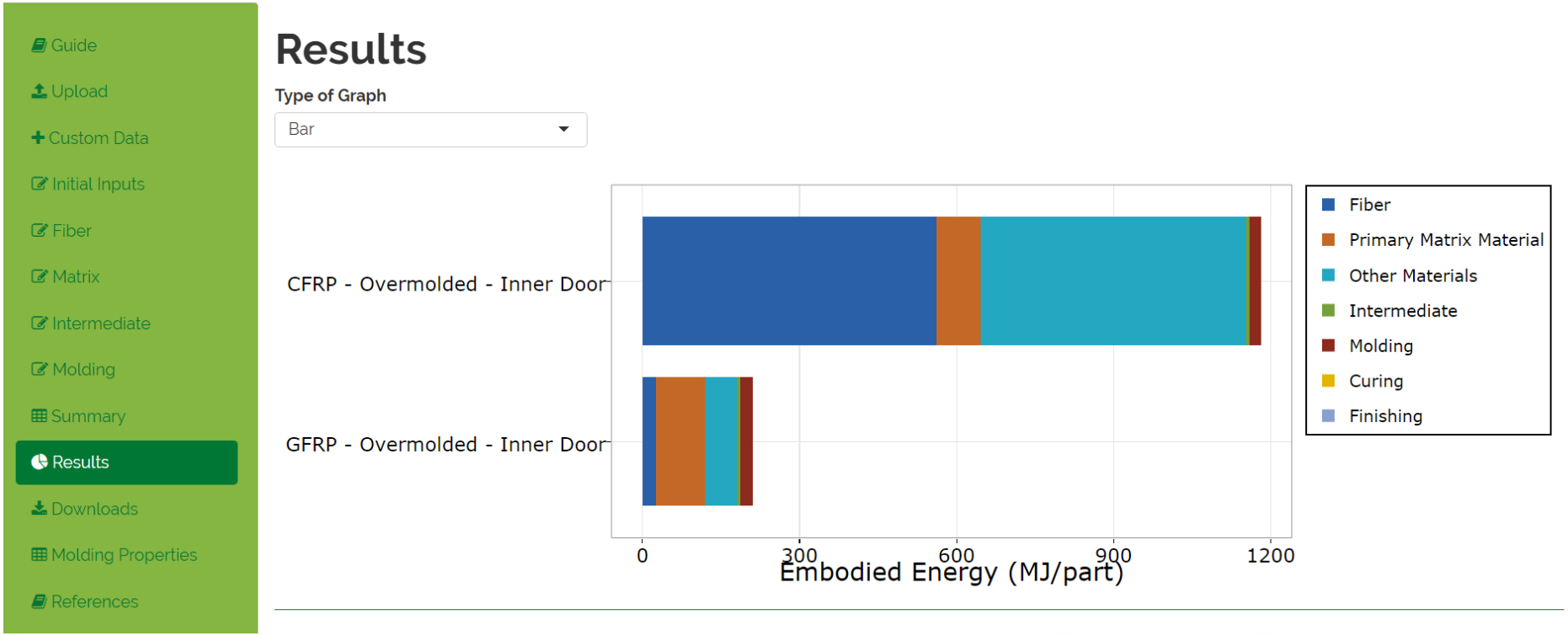
Tool Overview- Results

FRPC Energy Use Estimation Tool



- Results as tables, graph, and downloads
- Calculation tables also available for download

Tool Outline and Walkthrough

- The following slides utilize animations to illustrate how to use the tool.
- Watching in presenter mode is recommended.
- Tool is available at:

https://ornlenergyestimatortools.shinyapps.io/frpc-energy-estimator2/

FRPC Energy Use Estimation Tool

https://ornlenergyestimatortools.shinyapps.io/frpc-energy-estimator2/

Next

- Guide
- Upload
- Custom Data
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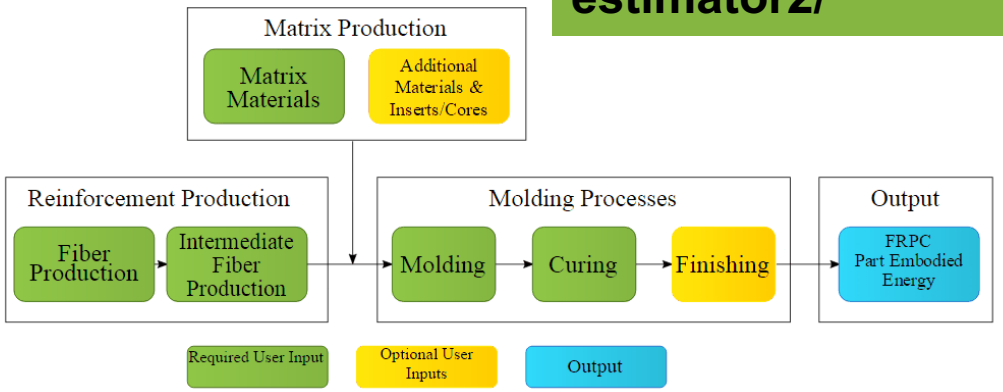
Tool Guide



This tool has been developed by ORNL to provide composite researchers and manufacturers the ability to quickly estimate the embodied energy use of their composite manufacturing process and compare it to other conventional processes.

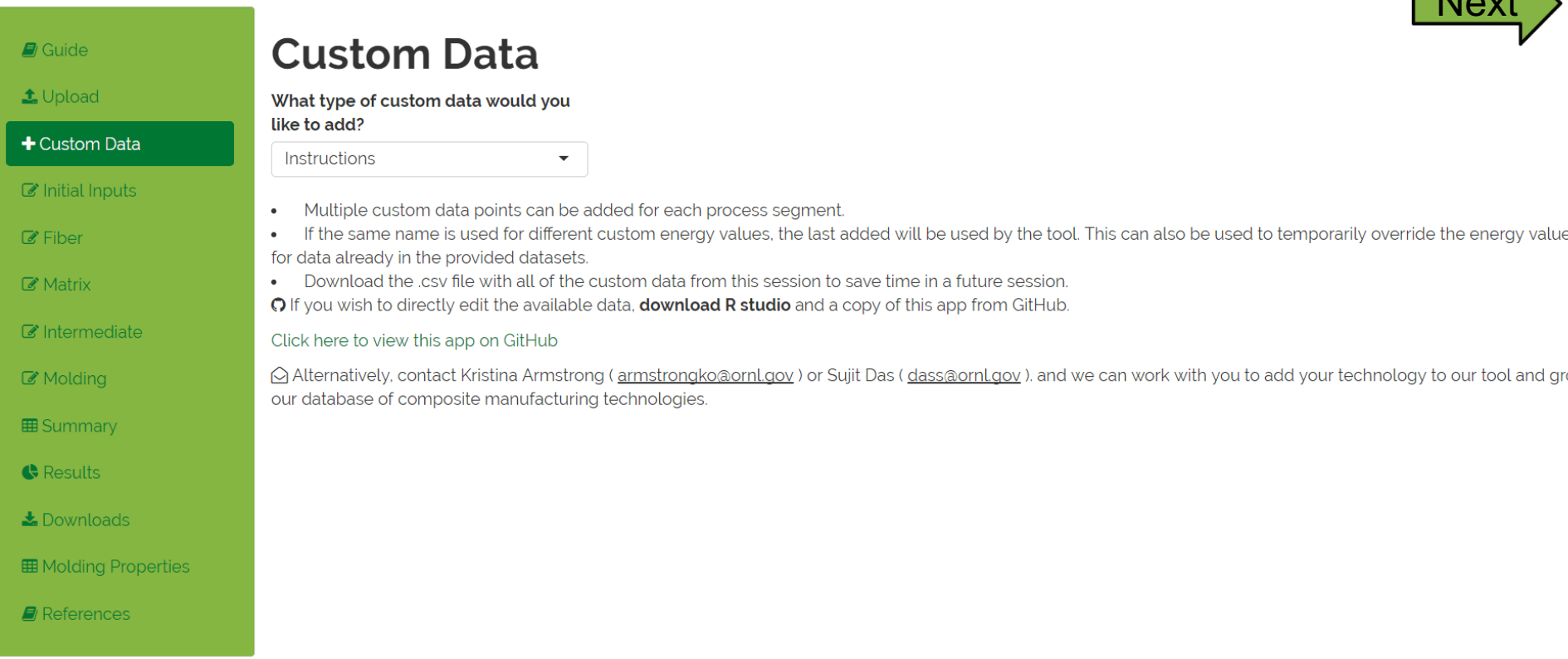
To get started, click "Initial Inputs" in the menu bar on the left, or ...

Click to load an example scenario

For help using or additional information about this tool, **download** the Tool Documentation. This includes includes energy data, molding process properties, references and details of tool computations

- Example Scenario fills in “Technology Set 1” with one of the tool’s case studies
- Tool Documentation includes: user manual, energy data, references, and case studies
- Guide also provides tips for using the tool

FRPC Energy Use Estimation Tool



- Can add multiple custom materials/processes per category
- **Does not save between sessions**
  - Can download session custom data for future upload (Download page)
- Can email to permanently add data (for public use) or suggest changes
- Can download tool or suggest changes at GitHub

FRPC Energy Use Estimation Tool

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Custom Data

What type of custom data would you like to add?

Instructions

- Multiple custom data points can be added for each process segment.
- If the same name is used for different custom energy values, the last added will be used by the tool. This can also be used to temporarily override the energy values for data already in the provided datasets.
- Download the .csv file with all of the custom data from this session to save time in a future session.

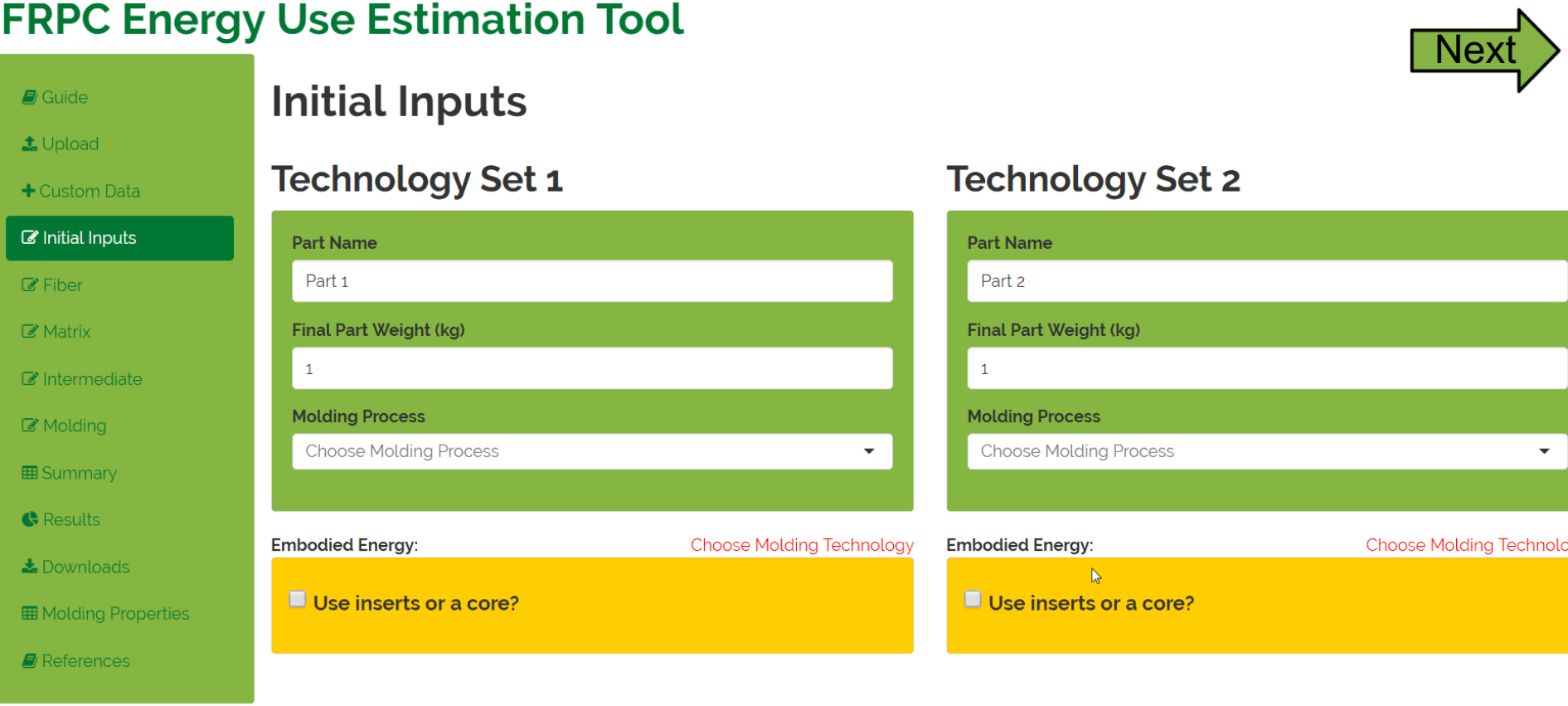
If you wish to directly edit the available data, **download R studio** and a copy of this app from GitHub.

Click here to view this app on GitHub

Alternatively, contact Kristina Armstrong (armstrongko@ornl.gov) or Sujit Das (dass@ornl.gov). and we can work with you to add your technology to our tool and grow our database of composite manufacturing technologies.

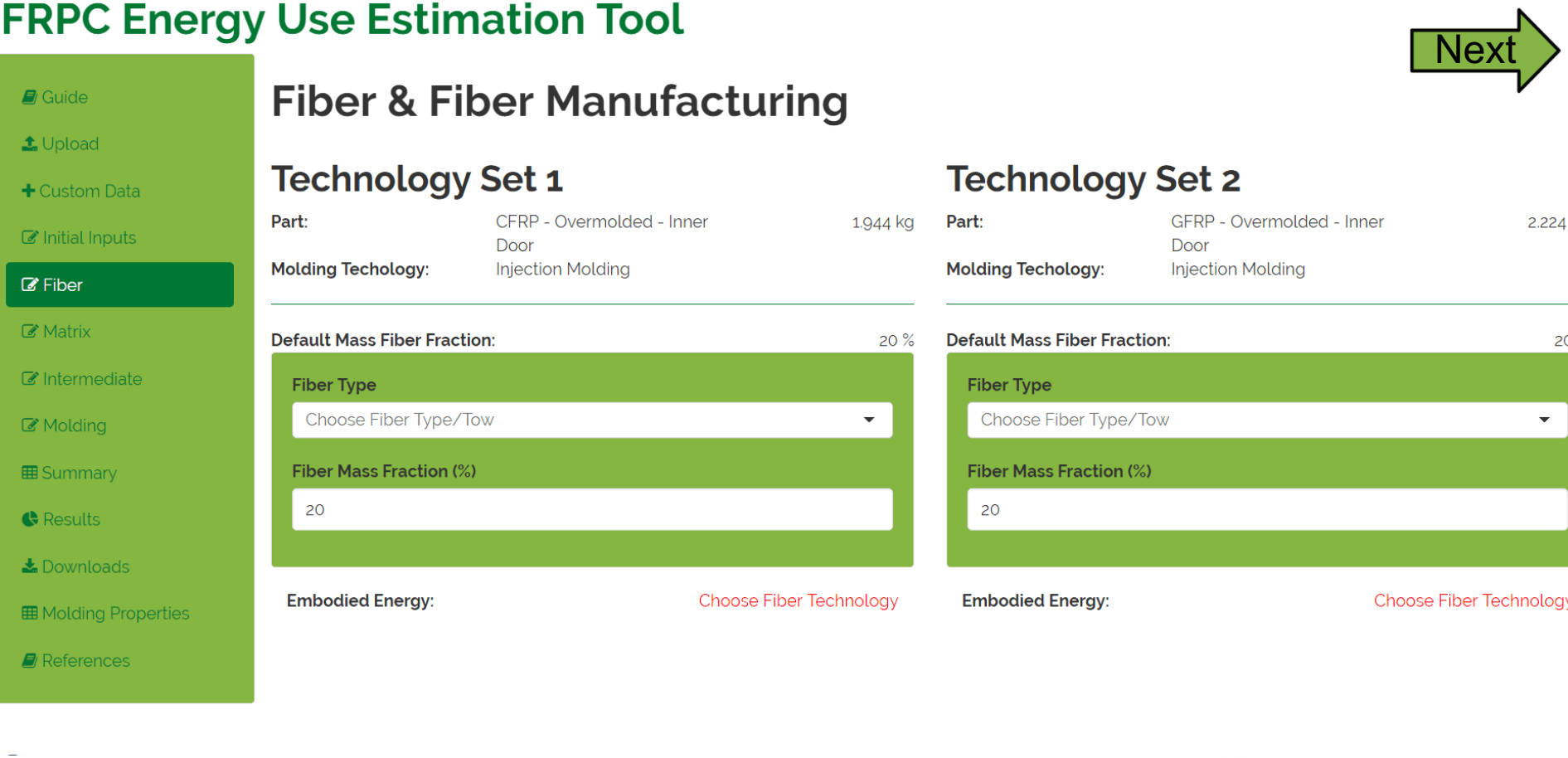
Can calculate specific energy for molding and curing processes, given equipment specifications

FRPC Energy Use Estimation Tool



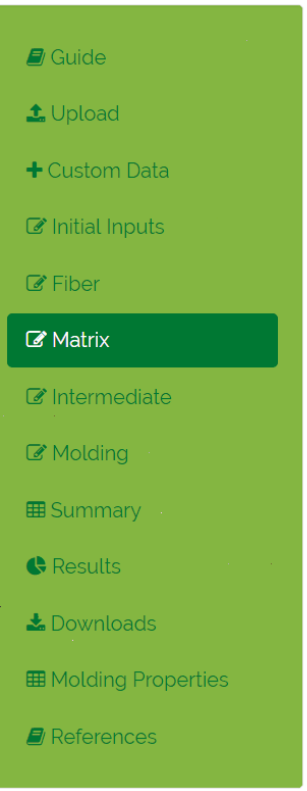
- Choose name, weight, & insert weight
- Choose molding early: intermediate & curing are dependent
- Red error text until molding technology is chosen

FRPC Energy Use Estimation Tool



- Choose Fiber Type & Tow
- Default Fiber Mass Fraction is determined by Molding technology
- Recap section at top reminds user of data entered in previous pages

FRPC Energy Use Estimation Tool



Next

Matrix Materials Manufacturing

Technology Set 1

Part:	CFRP - Overmolded - Inner Door	1.944 kg
Fiber:	Commodity PAN, 24k Tow	30 %
Molding Techology:	Injection Molding	

Primary Matrix Material

Choose Matrix Material

Primary Matrix Mass Fraction (%)

70

Embodied Energy: Choose Primary Matrix

Mass Fraction Check: 100 %

☐ **Use Additional Matrix Materials?**

Technology Set 2

Part:	GFRP - Overmolded - Inner Door	2.224 kg
Fiber:	E-Glass Fiber	30 %
Molding Techology:	Injection Molding	

Primary Matrix Material

Choose Matrix Material

Primary Matrix Mass Fraction (%)

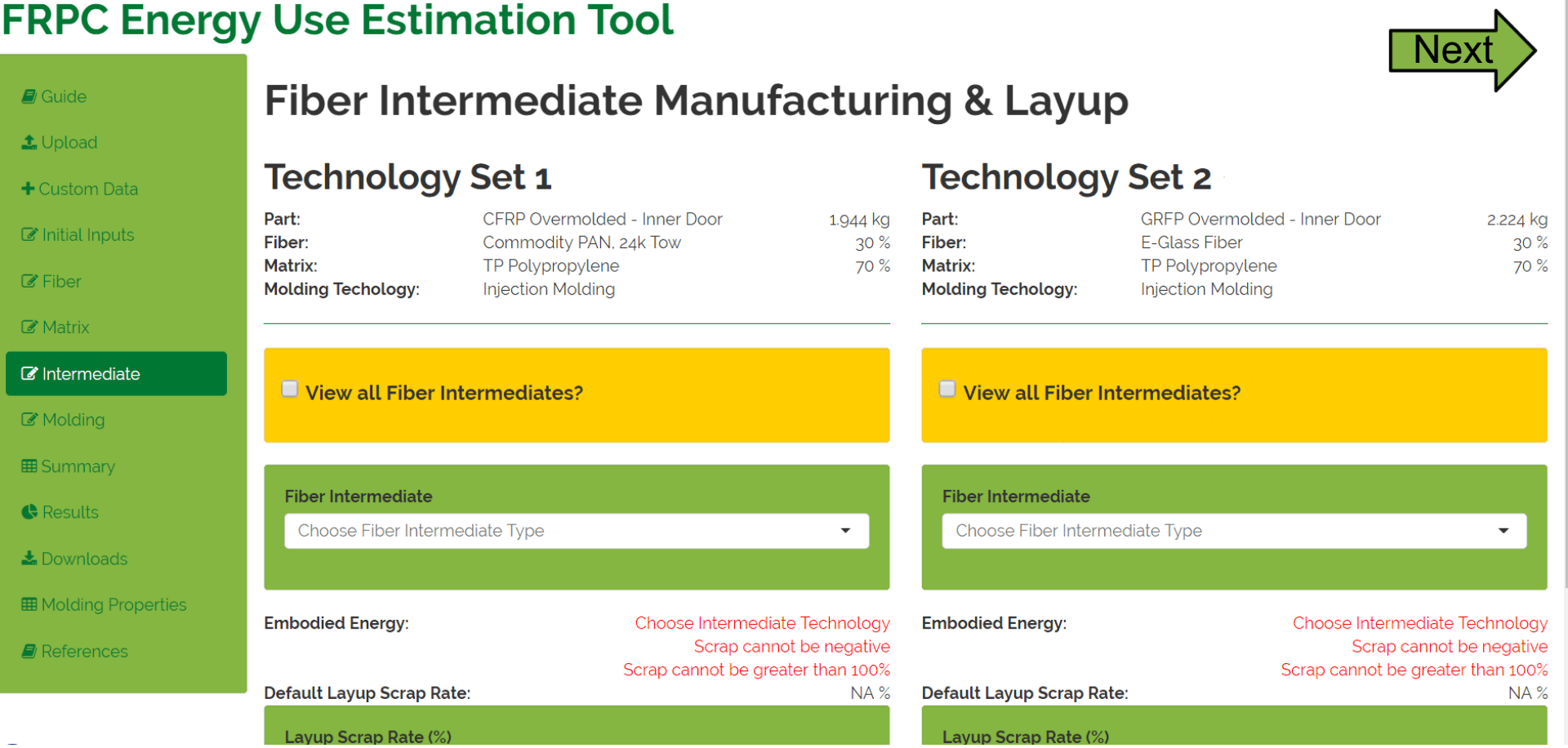
70

Embodied Energy: Choose Primary Matrix

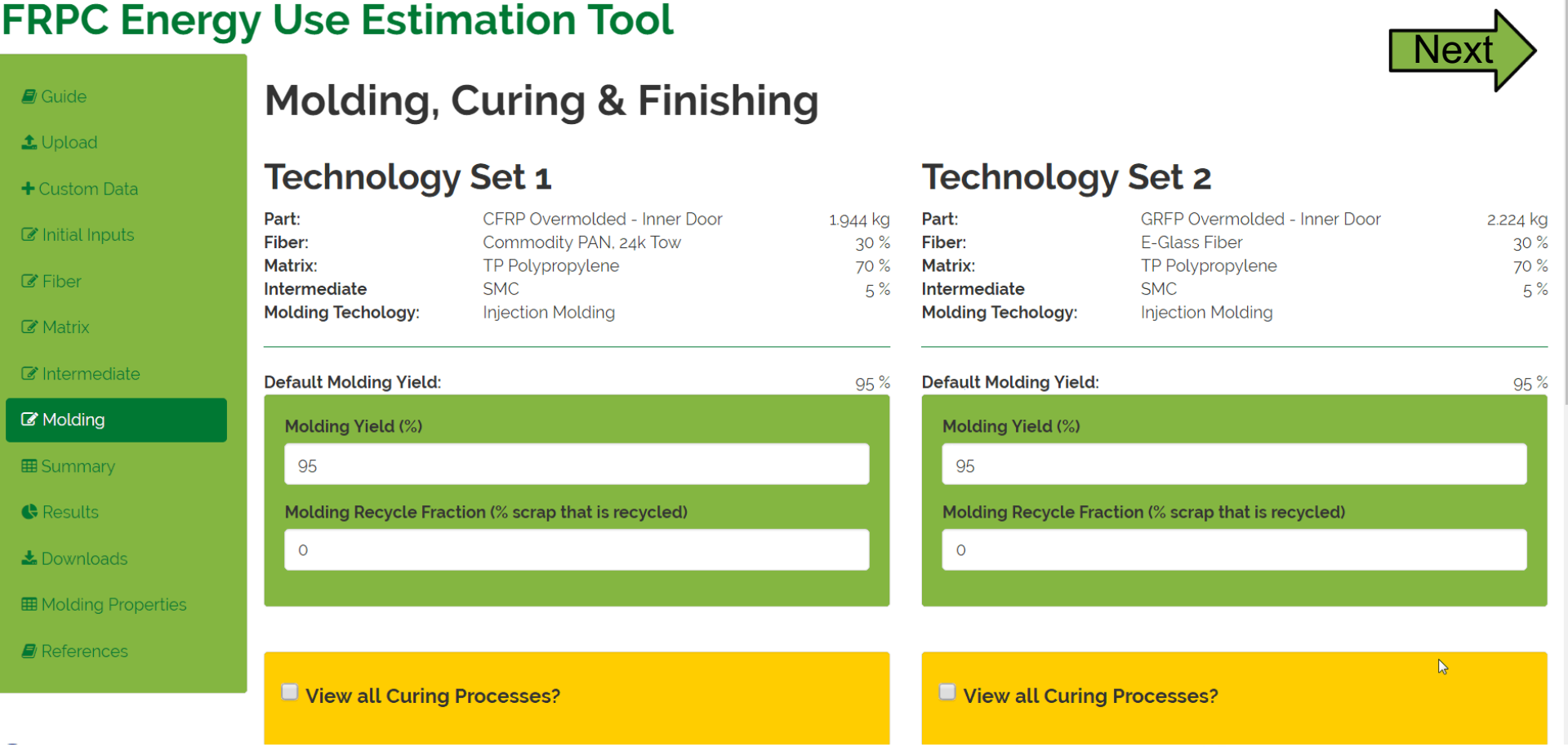
Mass Fraction Check: 100 %

☐ **Use Additional Matrix Materials?**

- Choose matrix materials (resin, filler, additive & inserts) and composition
- Default Primary Matrix Mass Fraction is 1 – Fiber Mass Fraction
- Additional Materials and Inserts entries are hidden until checkboxes are checked



- Choose Intermediate material & layup scrap/recycle rate
- Default Scrap Rate is determined by the type of fiber intermediate
- Recycle Rate is the fraction of scrap that can be recycled



- Choose molding yield, curing technology and finish level & scrap
- Default Molding Yield & Curing Process options determined by Molding technology

FRPC Energy Use Estimation Tool

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Summary

Technology Set 1

Part: CFRP - Overmolded - Inner Door — 1.944 kg

Material	Choice	Effecive Mass Fraction	Embodied Energy (MJ/part)
Fiber	Commodity PAN, 24k Tow	22.81	561.05
Primary Matrix	TP Polypropylene	53.22	85.10
Additional Matrix Material	Not Used	0.00	0.00
Additional Matrix Material	Not Used	0.00	0.00
Additional Matrix Material	Not Used	0.00	0.00
Insert	CFRP - Insert	23.97	507.32
Insert	Not Used	0.00	0.00
Materials Total		**100.00**	**1153.47**

Technology Set 2

Part Name: GFRP - Overmolded - Inner Door — 2.224 kg

Material	Choice	Effective Mass Fraction	Embodied Energy (MJ/part)
Fiber	E-Glass Fiber	21.93	26.47
Primary Matrix	TP Polypropylene	51.18	93.63
Additional Matrix Material	Not Used	0.00	0.00
Additional Matrix Material	Not Used	0.00	0.00
Additional Matrix Material	Not Used	0.00	0.00
Insert	GFRP - Insert	26.89	59.80
Insert	Not Used	0.00	0.00
Materials Total		**100.00**	**179.89**

Review Choices: process step/materials, embodied energy, mass fractions & process scrap/yield

FRPC Energy Use Estimation Tool

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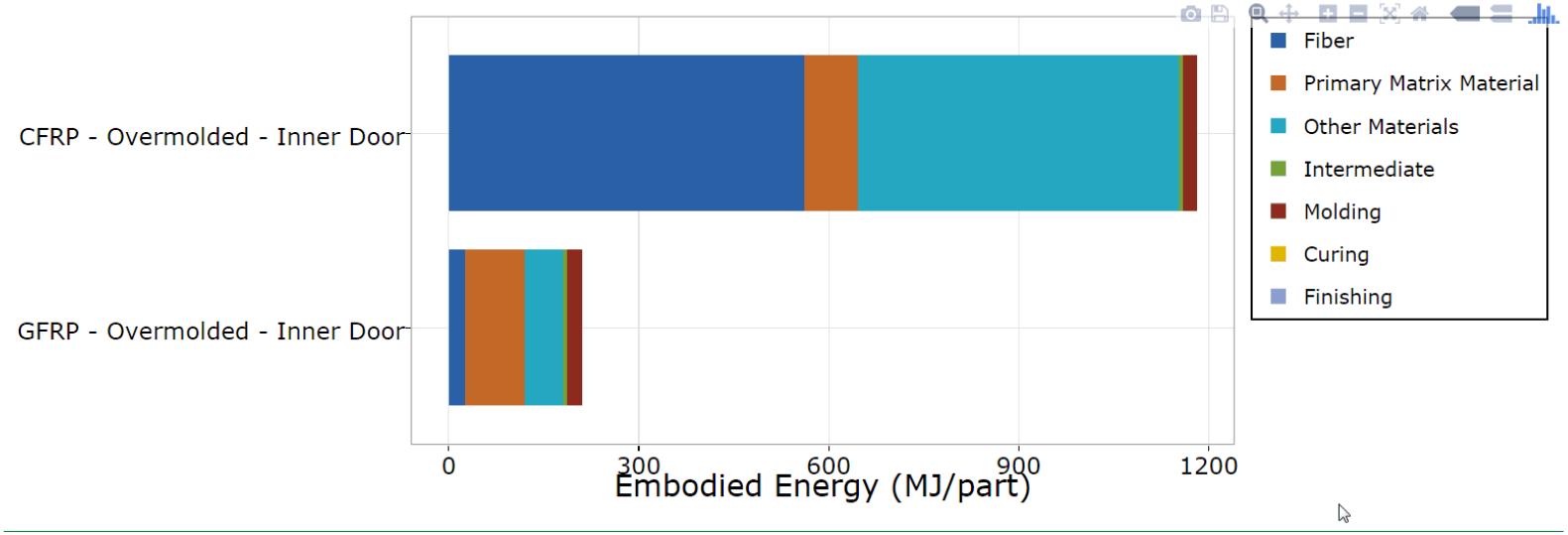
Results

Type of Graph: Bar



Part Weight (kg)	Fiber (MJ)	Primary Matrix Material (MJ)	Other Materials (MJ)	Intermediate (MJ)	Molding (MJ)	Curing (MJ)	Finishing (MJ)	Total (MJ)	Fiber Yield (%)	Matrix Yield (%)	Process Yield (%)

- Compare two technology pathways & save graphs
  - Bar & Pie Charts
  - Energy & percent change grouped by process segment

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Downloads

Technology Set 1

Technology Set 2

Results

- Download the results of the tool, including chosen materials/processes, mass fraction or yield, specific and embodied energy for each stage and mass evaluated at each stage.

Name Results File 1

Results1 2017-06-08

Download Results

Name Results File 2

Results2 2017-06-08

Download Results

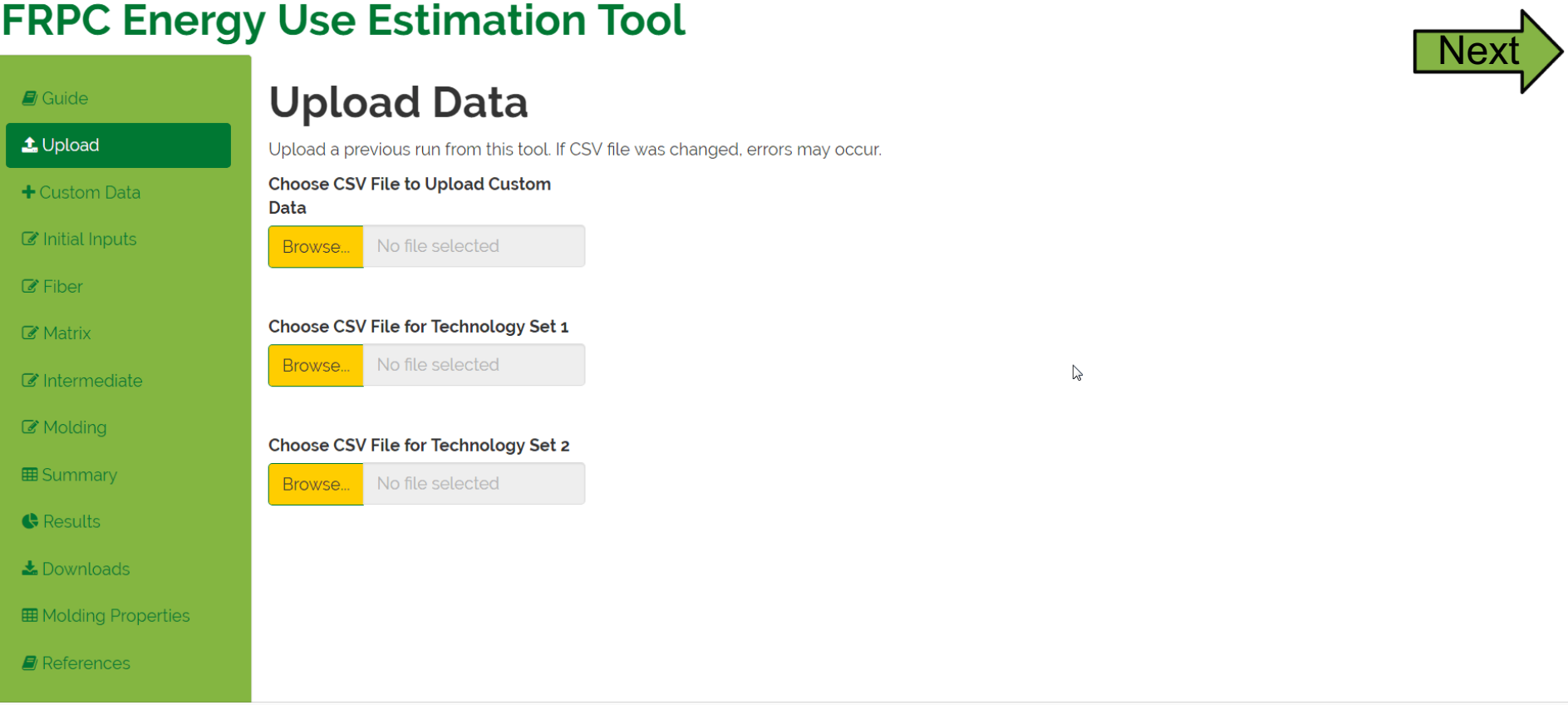
Custom Data

- Download the custom data added in the current session.
- This file can be uploaded in a later session instead of manual data entry.
- **We recommend that users not change the data in these files manually.**

Name Custom Data File

Add_Custom 2017-06-08

- Download the results, inputs, and the tables used for calculations
  - .csv & .zip



- Can upload custom data and inputs from previous runs to save time

FRPC Energy Use Estimation Tool

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Molding Properties

The columns and rows visible can be changed by clicking the "Select all..." boxes or within the "... Visible" boxes and selecting from the list or using the **"Backspace"** or **"Delete"** buttons on your keyboard to remove options

☑ Select all Molding Processes

☐ Select all Columns

Molding Processes Visible:

Automatic Fiber Placement (AFP) Automatic Tape Placement (ATP) Compression Molding Filament Winding High Pressure-RTM (HPRTM) Injection Molding (IM) Pultrusion Resin Transfer Molding (RTM) Seeman Composite Resin Infusion Molding Process (SCRIMP) Sheet Molding Compound (SMC) Spray Up Structural Reaction Injection Molding (SRIM) Thermo-hydroforming (THF) Vacuum Assisted-RTM (VARTM) Vacuum Bag (Autoclave) Wet Lay up (Hand Lay up)

Columns Visible:

Surface Finish Part Size

Show 16 entries

Search:

	Surface Finish	Part Size
Automatic Fiber Placement (AFP)	Fair, One Side	Medium - Large
Automatic Tape Placement (ATP)	Fair, One Side	Medium - Large
Compression Molding	Fair, All Sides	Small - Medium

View all the physical and process characteristics of Molding technologies in one chart

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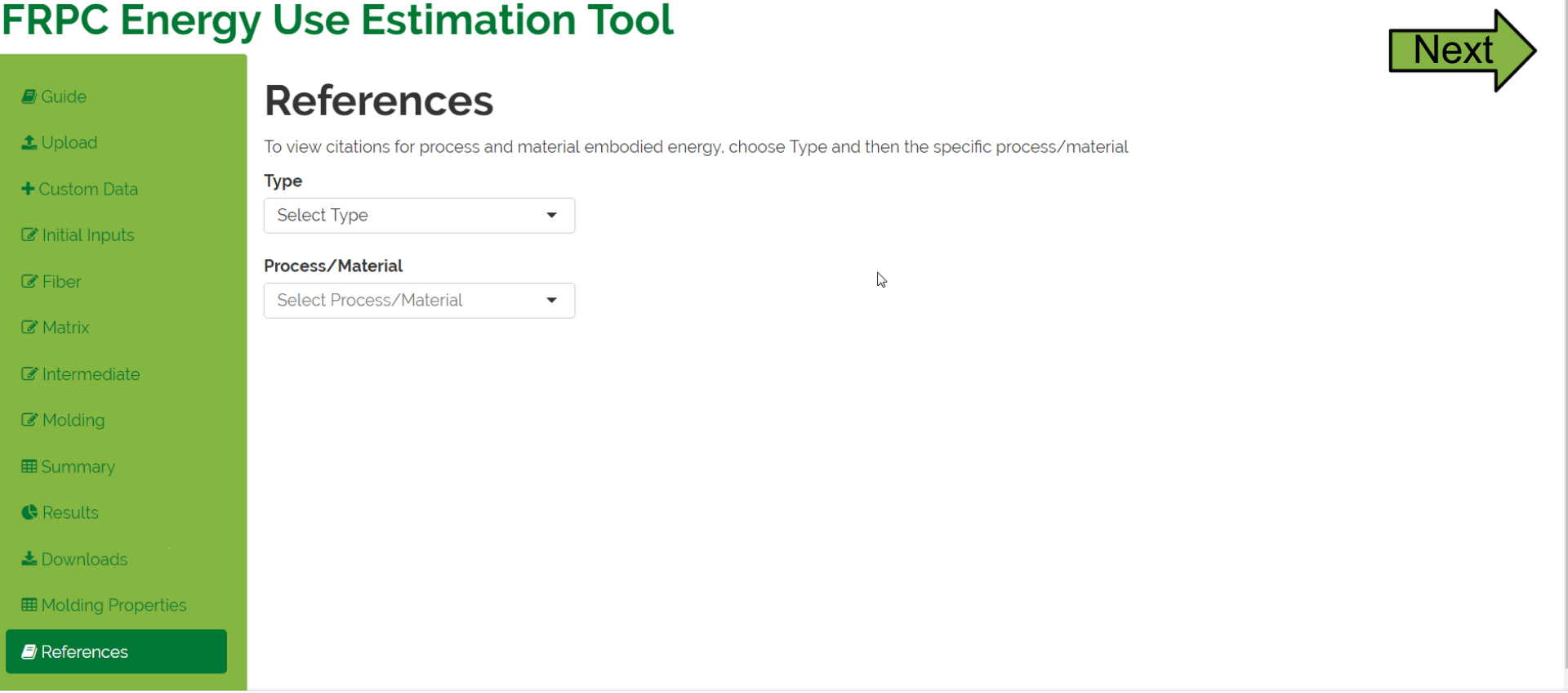

- Quick lookup for data references used in the tool
  - Also available in the background information download

Summary

- Embodied energy intensity of composite part manufacturing can be evaluated for several technology pathways by major manufacturing steps
- Energy use disaggregated up to three levels
  - Individual Material Component
  - Major Production Step
  - Overall Production
- Qualitative final part characteristics for each molding options available as a guidance for manufacturing pathway selection for energy use analysis
- Alternative FRPC part manufacturing pathways can be evaluated with the data availability
- Comparison allows user to estimate impacts of changes to manufacturing processes
- Online, open source, user-friendly tool developed:

https://ornlenergyestimatortools.shinyapps.io/frpc-energy-estimator2/