MATH MODEL FOR REMANUFACTURING
See Gutowski et al Remanufacturing and Energy Savings ES&T 2011

\[ E_{\text{ Tot}}^N = E_{\text{ M}}^N + E_{\text{ T}}^N + E_{\text{ U}}^N + E_{\text{ D}}^N \]
\[ E_{\text{ Tot}}^R = E_{\text{ M}}^R + E_{\text{ T}}^R + E_{\text{ U}}^R + E_{\text{ D}}^R \]

\[ E^N - E^R = (E_{\text{ M}}^N - E_{\text{ M}}^R) + (E_{\text{ T}}^N - E_{\text{ T}}^R) + (E_{\text{ U}}^N - E_{\text{ U}}^R) + (E_{\text{ D}}^N - E_{\text{ D}}^R) \]

The terms \( E^i_j \) are defined below.

\( E \), refers to energy requirement

\( i = N \), refers to new version
\( i = R \), refers to remanufactured version

\( j = \text{ Tot} \), total or cumulative sum across the lifecycle
\( j = \text{ M} \), refers to new materials processing and manufacturing (when \( i = N \)) or remanufacturing (when \( i = R \))
\( j = \text{ T} \), refers to transportation
\( j = \text{ U} \), refers to use
\( j = \text{ D} \), refers to disposal or end-of-life (EOL)

\( L = \) length of service life of product (in units of time)
\( e_U = \) energy consumed for providing service for a unit time, related to energy efficiency of the product.

Note that:

- in almost all cases \( E_{\text{ M}}^N > E_{\text{ M}}^R \)
- generally \( E_{\text{ T}}^N > E_{\text{ T}}^R \) but in many cases this component is small (see text)
- \( E_{\text{ U}}^N - E_{\text{ U}}^R \) can be written as \( (e_{\text{ U}}^N L_N^N - e_{\text{ U}}^R L_R^R) \rightarrow \) this term plays a large role (see text). In many cases, remanufacturing brings product back to like-new making \( L_N \equiv L_R \). However, if this is not true it can be easily included into the model.
- if EOL treatment is the same then \( E_{\text{ D}}^N - E_{\text{ D}}^R \equiv 0 \).