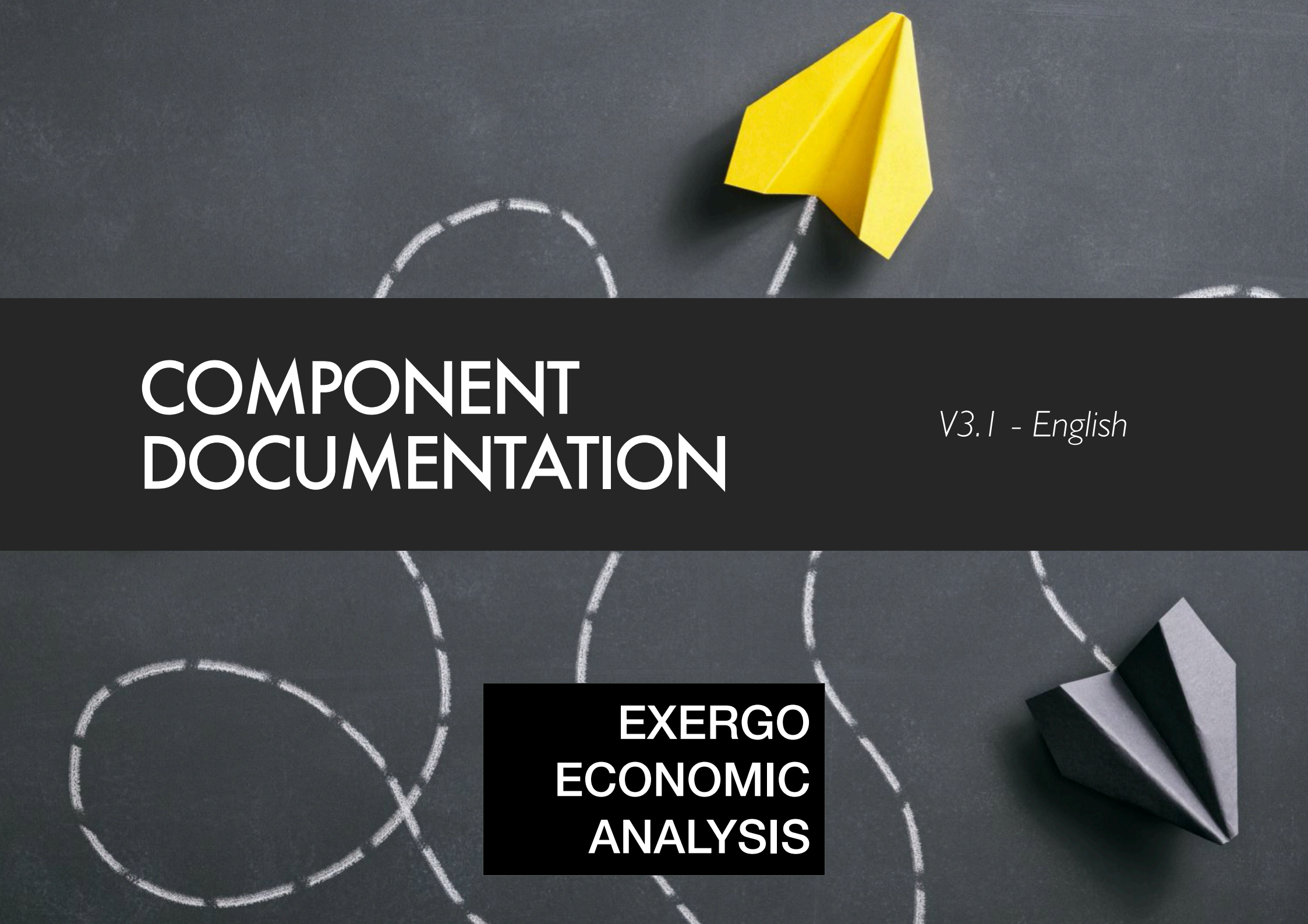


COMPONENT DOCUMENTATION

V3.1 - English

EXERGO ECONOMIC ANALYSIS

INTRODUCTION

An exergo-economic analysis is the combination of economic and thermal analysis. It study the mechanism of **cost build-up** inside a thermal process relying on the main assumption that "*users should pay only for the useful part of energy [i.e. the exergy]*" [1].

Following this approach, we define a **generic *component*** of a thermal system as an element that **produce some useful effects** (called *products*) starting from some **exergy streams** (*fuels*). Hence an *exergy cost balance* for each component could be defined as well as follows:

$$\sum_{product} \dot{c}_p \dot{E}_p = \sum_{fuel} \dot{c}_f \dot{E}_f + \dot{Z} \qquad (1)$$

Where [1]:

Variable	Description	Unit
$\dot{c}$	*specific cost* of an exergy stream	[€/kW]

Variable	Description	Unit
$\dot{E}$	*exergy flux* of the stream	[kW/s]
$\dot{c}\dot{E}$	*total cost* of an exergy stream	[€/s]
$\dot{Z}$	*amortisation cost* for the component	[€/s]

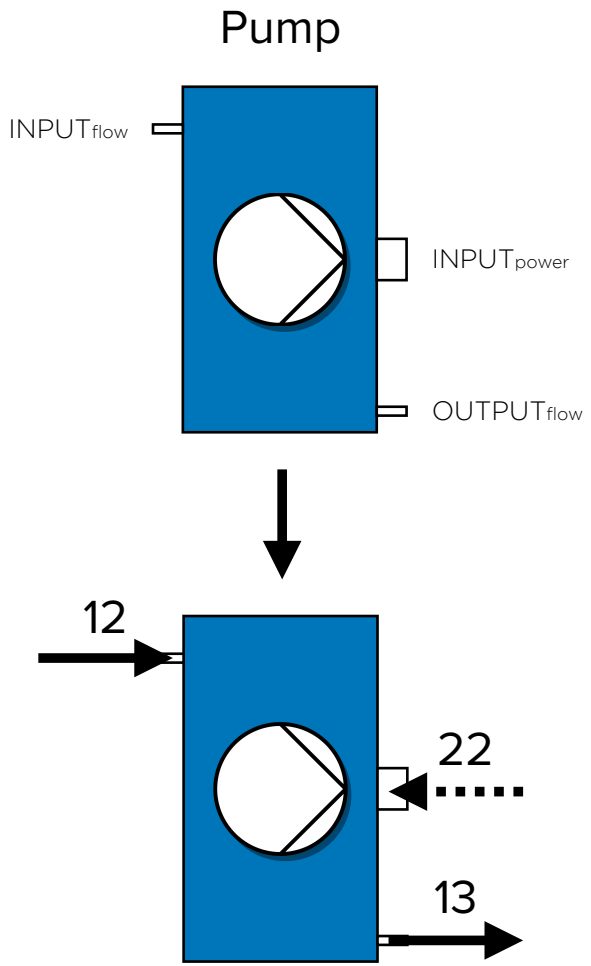
Equation (1) means that the *total cost* of the produced exergy should be equal to the cost of the exergy needed for its production plus the actual cost of the component.

The unknowns of the exergo-economic problem **are the specific costs** $\dot{c}$ for each exergy stream, while the value $\dot{E}$ is obtained from **a pre-existing thermodynamic analysis.** The specific costs are calculated, following the approach of Lazzaretto and Tsatsaronis [2], defining a **system of equation** that is composed of the ***exergy cost balances*** for each component and some **auxiliary equation** needed to close the problem. The auxiliary equations used are reported in the component's sheets in the following chapters.

If you are not familiar with exergo-economics and you desire a deeper knowledge in this field, you can refer to the texts in the bibliography.

INDEX

GENERAL INFORMATIONS



As explained in the *user guide*, the topology of the system has to be provided as a combination of **components** connected by some **streams**. Streams have to be connected to components *ports* as shown in the figure.

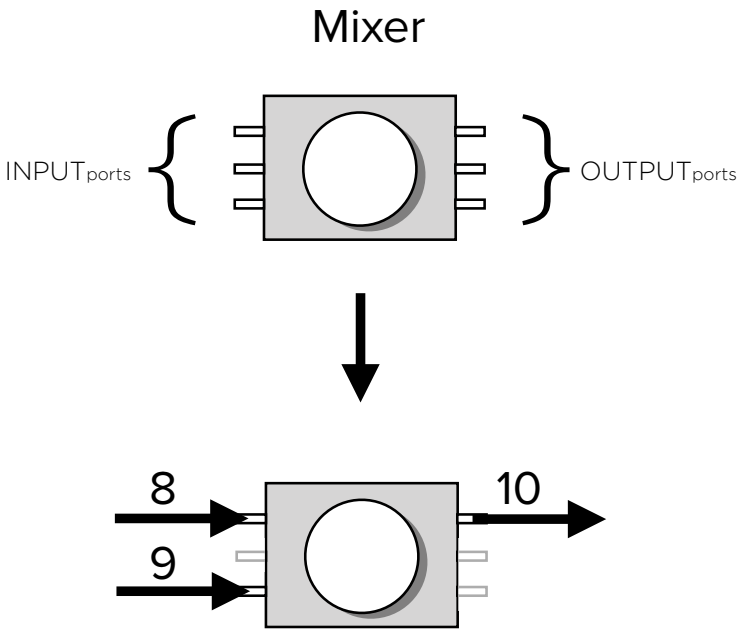
In the excel sheet, the hint displayed represent a specific component port and had to be replaced with the correct stream number. For example, the pump shown in the figure would correspond in the excel sheet to:

HINTS				**STREAM NUMBERS**	
Power Input	*Flow Input*	*Flow Output*	→	22	12	13

Depending on the number of ports they have, components can be divided into two **main categories**:

A. Components with **defined** number of ports: **Standard components** (like the pump shown in the previous page)

B. Components with **undefined** number of ports: in this case, the output streams number have to be inserted in the sheet as a **negative number** and "**-1000**" has to be added at the end of the row as **a termination character**. For example, the mixer shown in the figure would correspond in the excel sheet to:



HINTS

Inputs (positive)	*Output (negative)*	...	*-1000*

STREAM NUMBERS

8	9	-10	-1000

SUPPORT COMPONENTS

As explained in the *user guide, there are two types of support components:*

- **Input Fuel Component:** each **exergy stream** entering in the system (*e.g. the methane entering into the gas turbine's combustion chamber*) has to be connected to an input fuel component **otherwise Its relative cost will be set to zero**.

- **Useful Effect Component:** Every **output stream** (*e.g. the energy produced in a power plant)* has to be connected with this block otherwise the app will consider it an **exergy loss**.

An undefined number of streams can be connected to both of them, hence the row containing the stream's number had to finish with "-1000"

For example, if both streams 14 and 23 are useful effects (e.g. *the electrical and thermal power outgoing from a cogeneration plant*) they could be connected to the useful effect block as follows:

Stream Numbers

14	*23*	*-1000*

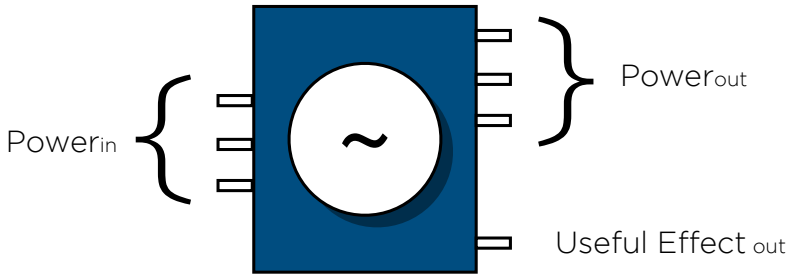
LOSS TREATMENT

As already said we consider as an exergy loss every stream coming out from the system that is not connected whit the useful effect component. Example of exergy loss are *the thermal power discharged by a condenser* or the *residual heat in an engine exhaust*

Following the assumption that "*users should pay only for the useful part of energy [i.e. the exergy]*" [1] the relative cost of an exergy loss **is automatically set to zero.**

1. *ALTERNATOR*

Connections:



The alternator has an undefined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Alternator Efficiency (e.g. 0,99)	*Power Inputs (positive)*	*Power Outputs (negative)*	*...*	*-1000*

in wich:

Port	*Note*
Alternator Efficiency	The efficiency of the alternator (had to be **between 0 and 1**)
Power Inputs	Inputs **from expanders** (could be multiple)
Power Outputs	**Electrical output** towards pumps (could be multiple, negative sign)
Useful Effect Output	**Automatically Generated**, further details in the following pages

Notes:

- Is possible to add an undefined number of power inputs an output.
- The program automatically add a new stream, called *Useful Effect Output,* representing the **net produced electrical energy**, connect it to the **useful effects** and set its value to the **net exergy outgoing** from the component tacking into account the imposed efficiency:

$$\dot{E}_{usefull} = \epsilon \sum \dot{E}_{in} - \sum \dot{E}_{out} \qquad (2)$$

Where: $\dot{E}_{usefull}$, $\dot{E}_{in}$ and $\dot{E}_{out}$ are the net outgoing exergy, the input exergy and the output exergy. ϵ is the efficiency of the alternator.

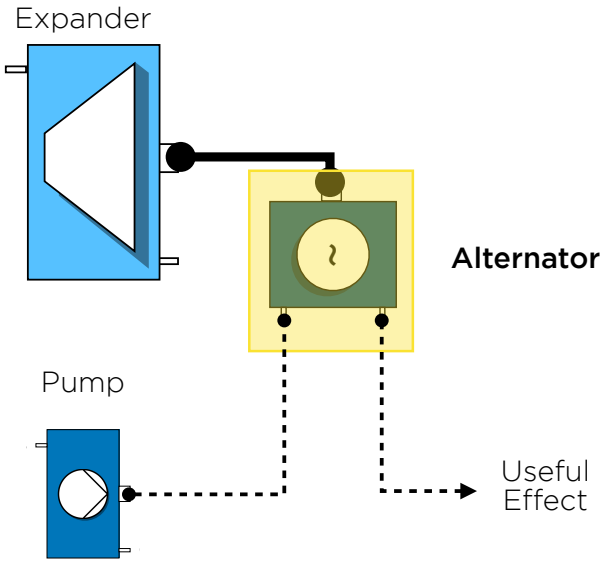
Notes (cont.):

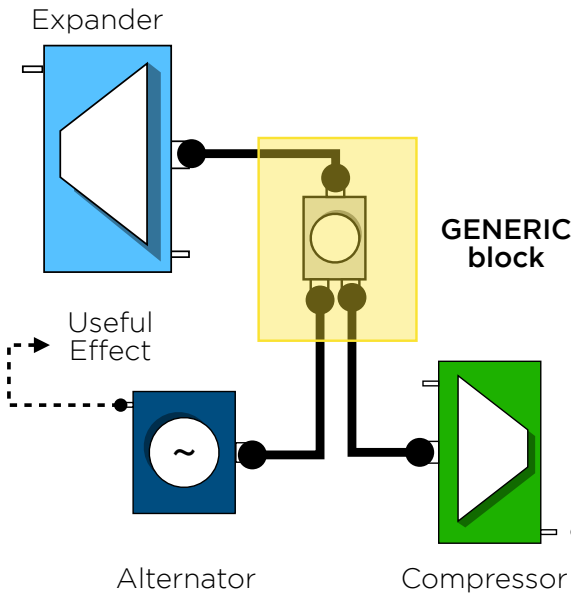
- Equation (2) can be re-written as:

$$\epsilon \sum \dot{E}_{in} = \dot{E}_{usefull} + \sum \dot{E}_{out}$$

In this form it is evident that $\dot{E}_{out}$ represents an **electrical power output** (as it is not multiplied by ϵ). In fact, such ports are meant to be used for the **connection of the power input of pumps** (as shown in the upper figure) as pumps are usually driven by the electrical energy generated by the alternator.

On the other hand, if a **compressor** has to be powered is better to use a **generic block** to split the exergy output of the expander, as usually compressors are powered directly by the mechanical output of the expander through a common axis. This case is represented in the lower figure.



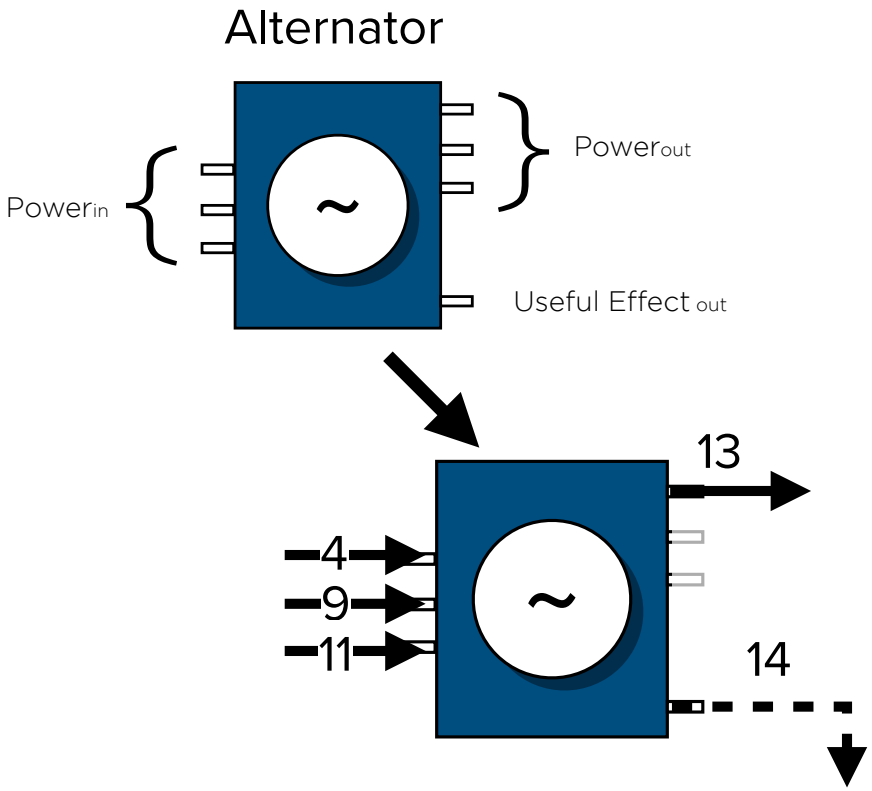


Support Equations:

- The specific exergetic cost **is equal for each output** (*Useful Effect output* Included)

Connection Example:

By reference to the figure and considering an efficiency of 0.9, the excel sheet should be compiled as follow (notice that stream 14 will be automatically generated):



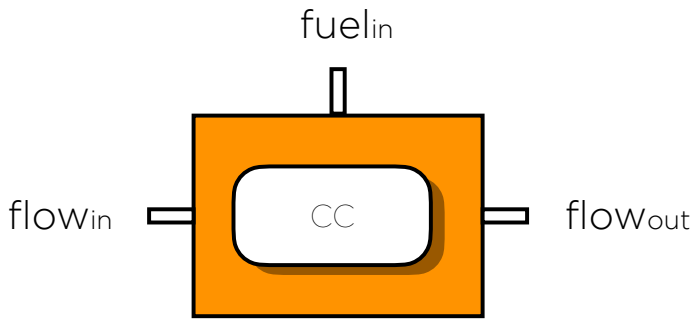
STREAM NUMBERS

0,9	*4*	*9*	*11*	*-13*	*-1000*

HINTS

Alternator Efficiency (e.g. 0,99)	*Power Inputs (positive)*	*Power Outputs (negative)*	*...*	*-1000*

2. COMBUSTION CHAMBER



Connections:

Combustion Chamber has a defined number of connections, The hint line provided by the excel sheet is the following:

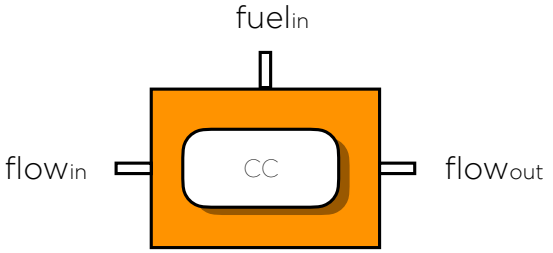
Fuel Input	*Flow Input*	*Flow Output*

Where:

Port	*Note*
Fuel Input	Stream index of fuel input
Flow Input	Stream index of flow input
Flow Output	Stream index of flow output

Support Equations:

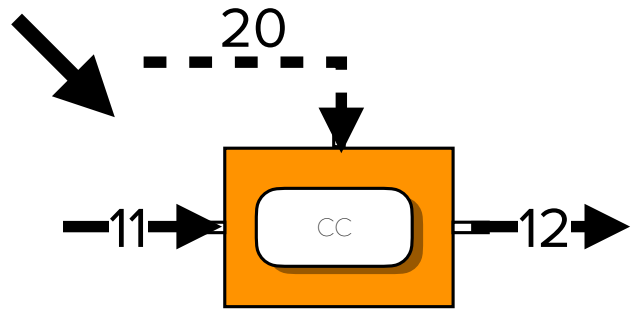
- **not needed** (only 1 output)



Combustion Chamber

Connection Example:

By reference to the figure the excel sheet should be compiled as follow:



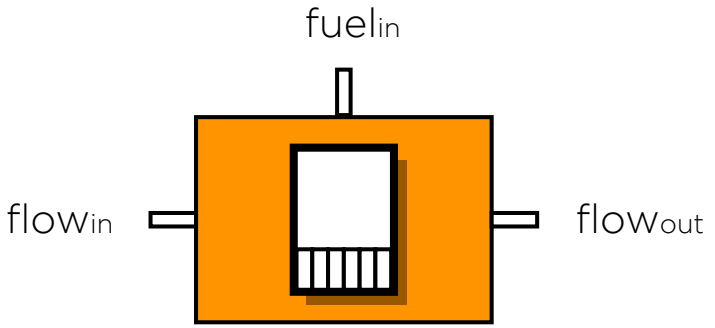
HINTS

Fuel Input	*Flow Input*	*Flow Output*

STREAM NUMBERS

20	*11*	*12*

3. *BOILER*

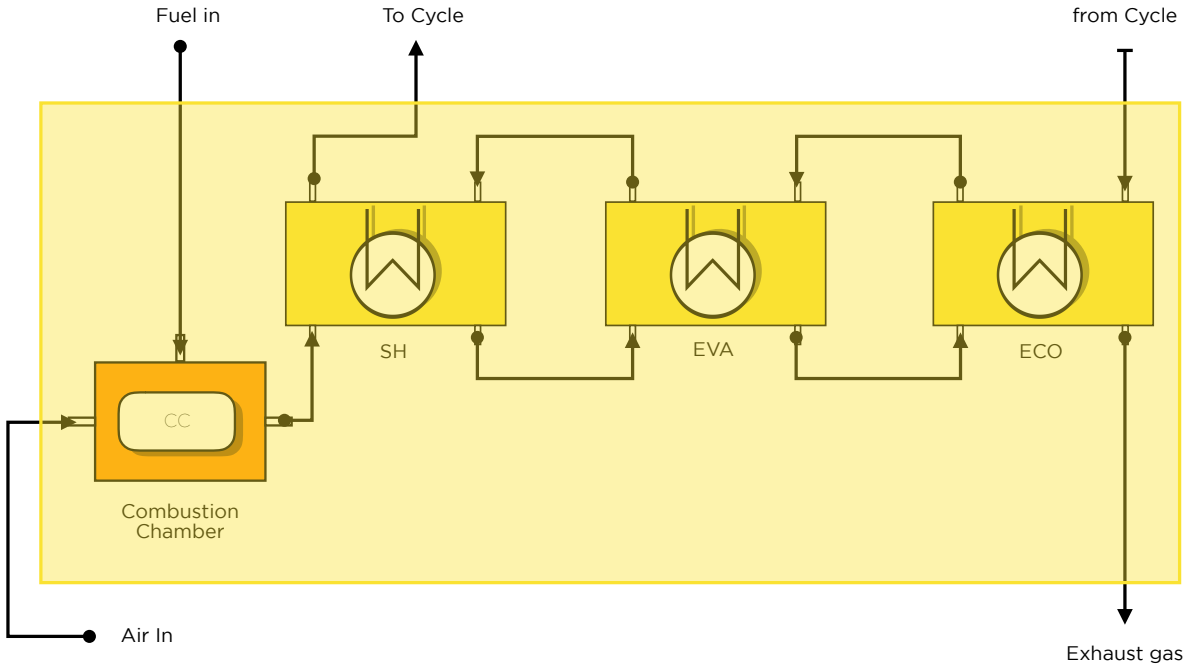


Connections and support equation:

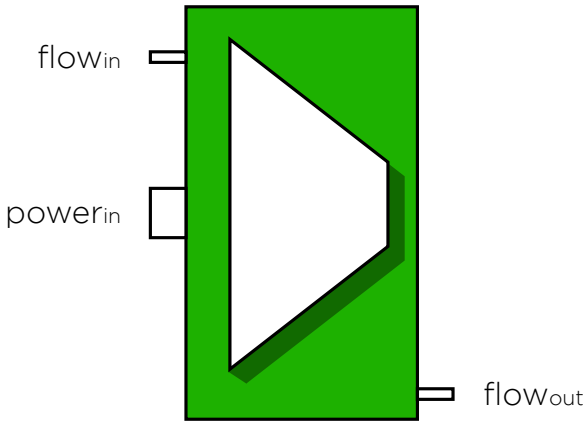
Same as combustion chamber

Suggestion:

For a much detailed analysis is better to use a scheme with multiple heat-exchangers like the one represented in the figure



4. COMPRESSOR



Connections:

Combustion Chamber has a defined number of connections, The hint line provided by the excel sheet is the following:

Power Input	*Flow Input*	*Flow Output*

Where:

Port	*Note*
Power Input	Stream index of power input
Flow Input	Stream index of flow input
Flow Output	Stream index of flow output

Support Equations:

- **not needed** (only 1 output)

Connection Example:

By reference to the figure the excel sheet should be compiled as follow:

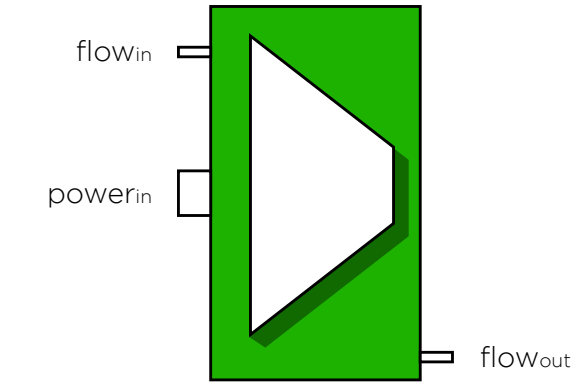
HINTS

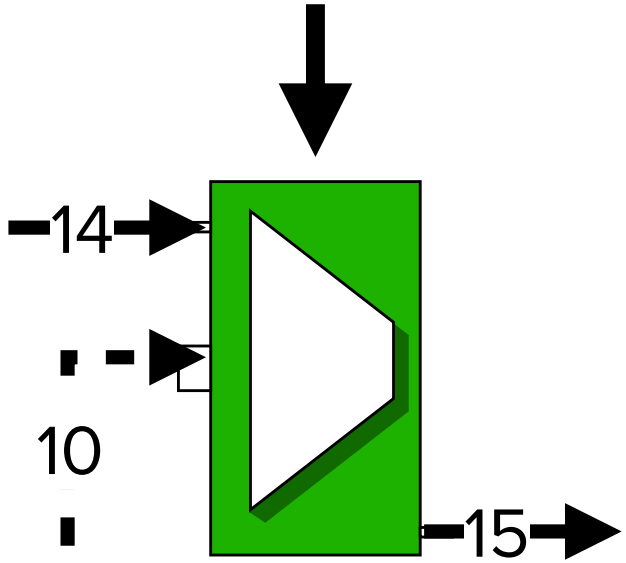
Power Input	*Flow Input*	*Flow Output*

STREAM NUMBERS

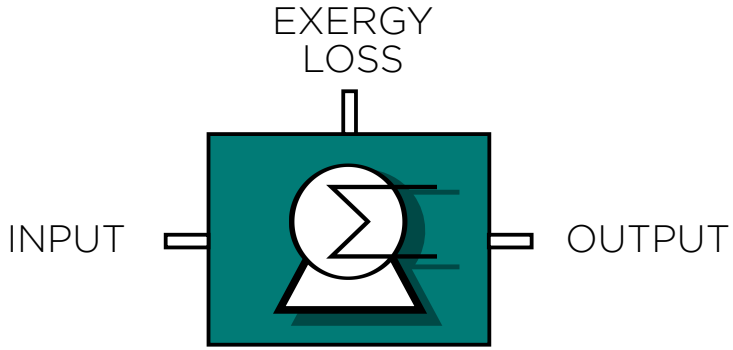
10	*14*	*15*

Compressor





5. CONDENSER



Connections:

Condenser has a defined number of connections, The hint line provided by the excel sheet is the following:

Input	*Output*

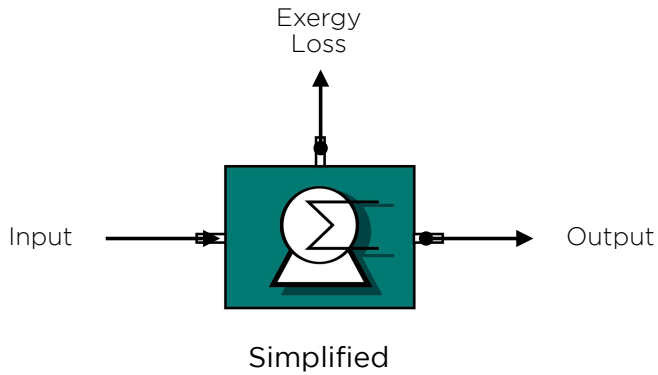
Where:

Port	*Note*
Input	Stream index of flow input
Output	Stream index of flow output
Exergy Losses	**Automatically Generated**, further details in the following pages

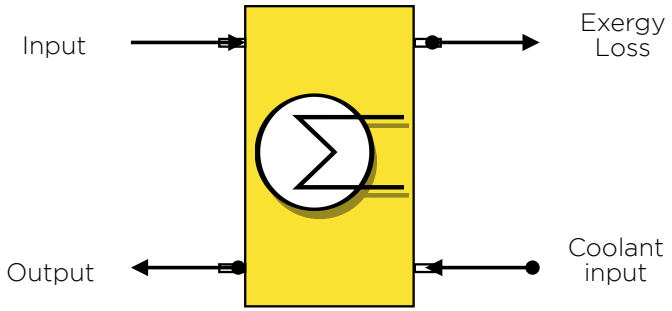
Notes:

The program automatically generate a new stream representing the exergy discharged from the condenser and connect it to the exergy losses. The exergy value of this stream will be defined as **the difference between input and output.**

Using this component is impossible to **make a distinction** between **exergy loss and destruction**.
If such distinction is important, a much detailed scheme containing an **heat exchanger** could be used as shown in the figure.



Simplified



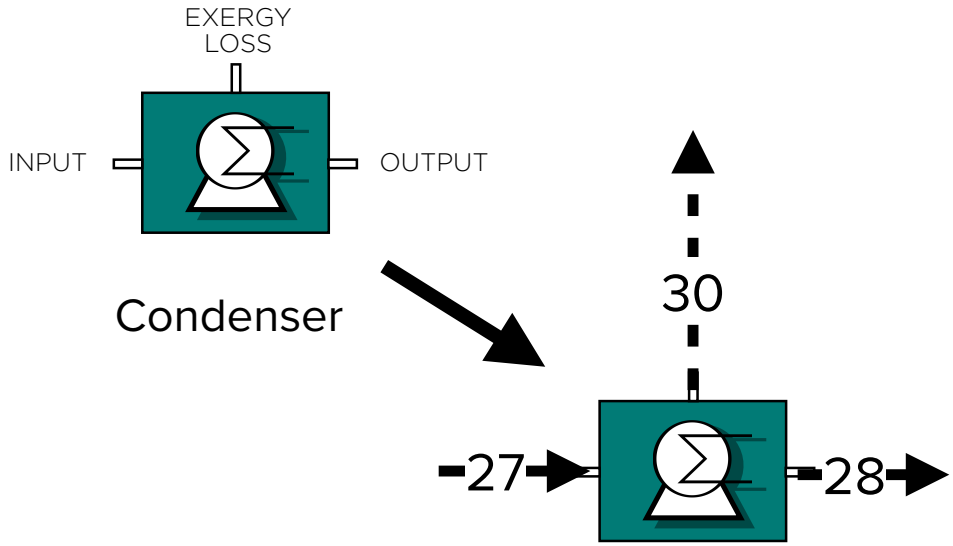
More Complete

Support Equations:

- **Not needed** (only 1 output)

Connection Example:

By reference to the figure, the excel sheet should be compiled as follow (notice that stream 30 will be automatically generated):



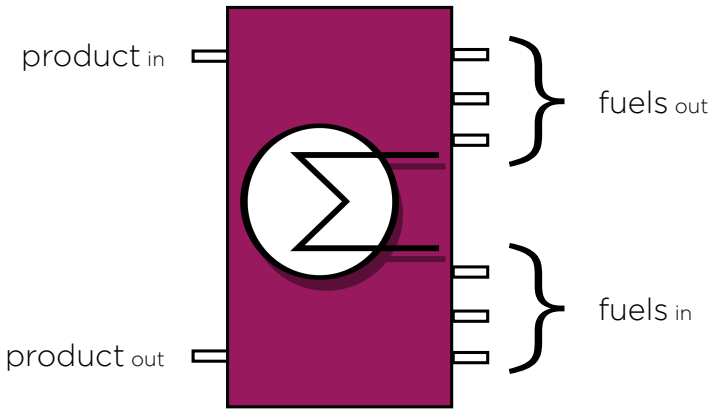
HINTS

Input	*Output*

STREAM NUMBERS

27	*28*

6. *EVAPORATOR*



Connections:

The evaporator has an undefined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Product Input	*Product Output*	*Fuel Inputs (positive)*	*Fuel Outputs (negative)*	*...*	*-1000*

where:

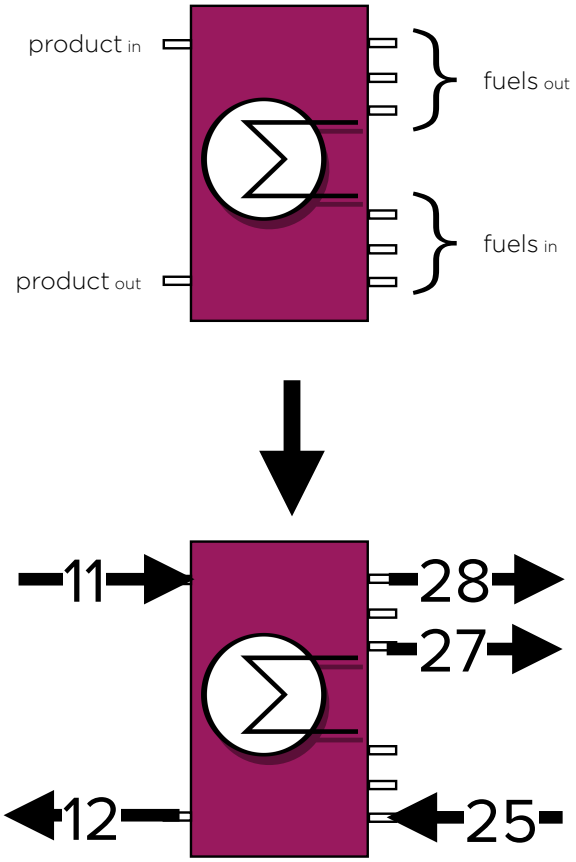
Port	*Note*
Product Inputs	Stream index of the phase changing fluid input
Product Outputs	Stream index of the phase changing fluid output
Fuel Inputs	Stream index of flows used as energy input for the evaporation (input)
Fuel Outputs	Stream index of flows used as energy input for the evaporation (output)

Support Equations:

- the **specific exegetic cost for each fuel output** is calculated as the **weighted average of the fuel inputs costs:**

$$\dot{c}_{out} = \frac{\sum_{in} \dot{c}_{in} \dot{E}_{in}}{\sum_{in} \dot{E}_{in}}$$

Evaporator



Connection Example:

By reference to the figure the excel sheet should be compiled as follow:

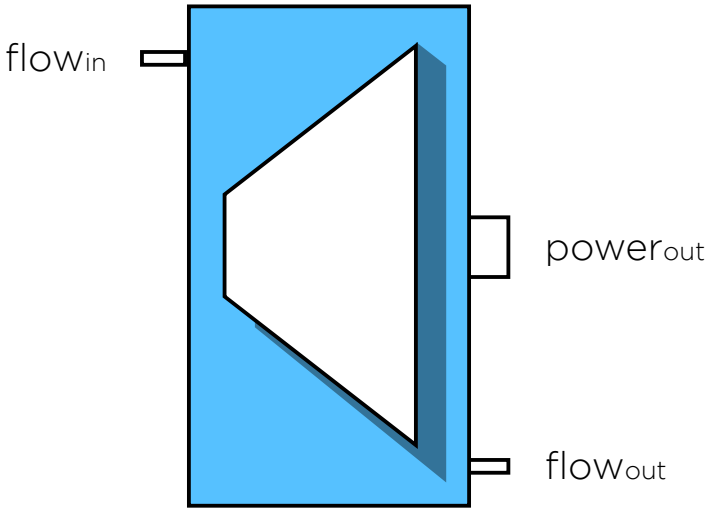
STREAM NUMBERS

11	*12*	*25*	*-27*	*-28*	*-1000*

HINTS

Product Input	*Product Output*	*Fuel Inputs (positive)*	*Fuel Outputs (negative)*	*...*	*-1000*

7. EXPANDER



Connections:

The expander has a defined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Power Output	*Flow Input*	*Flow Output*

Where:

Port	*Note*
Power Output	Stream index of power output
Flow Input	Stream index of flow input
Flow Output	Stream index of flow output

Support Equations:

- the specific exegetic cost of the **flow output is equals** to the specific exergetic cost of the **flow input:**

$$\dot{c}_{out} = \dot{c}_{in}$$

Connection Example:

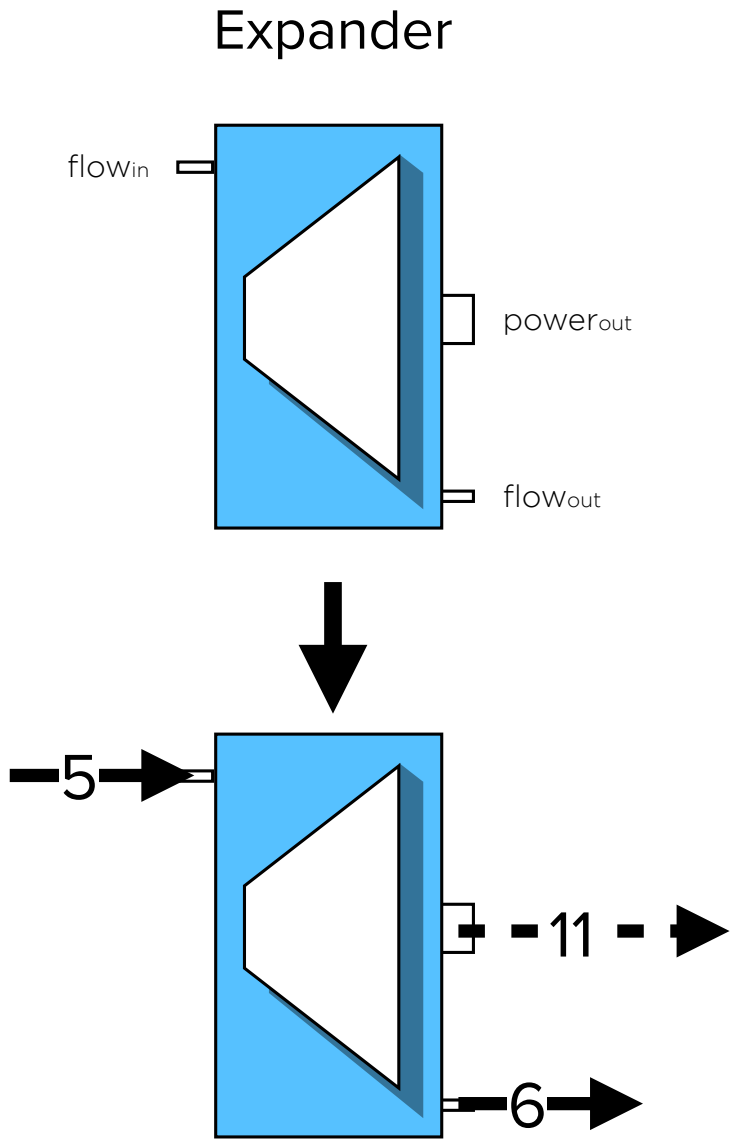
By reference to the figure the excel sheet should be compiled as follow:

HINTS

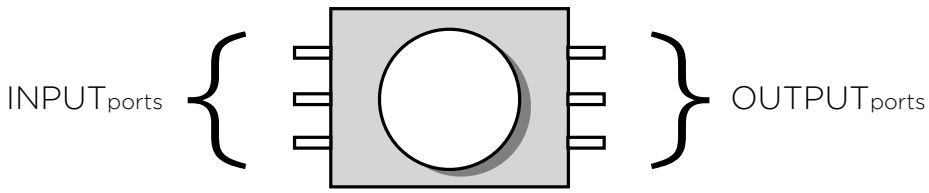
Power Output	*Flow Input*	*Flow Output*

STREAM NUMBERS

11	*5*	*6*



8. GENERIC BLOCK



Connections:

The Generic Block has an undefined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Inputs (positive)	*Outputs (negative)*	*...*	*-1000*

Where:

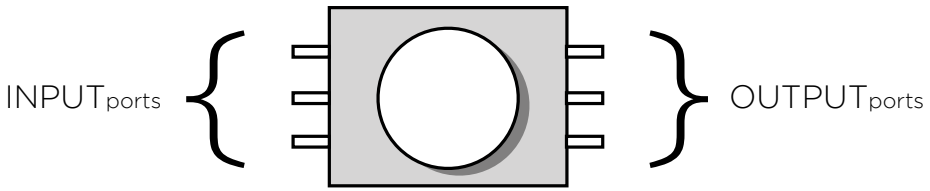
Port	*Note*
Inputs	Stream index of input flows
Outputs	Stream index of output flows

Support Equations:

- the specific exegetic cost of each **flow output is the same:**

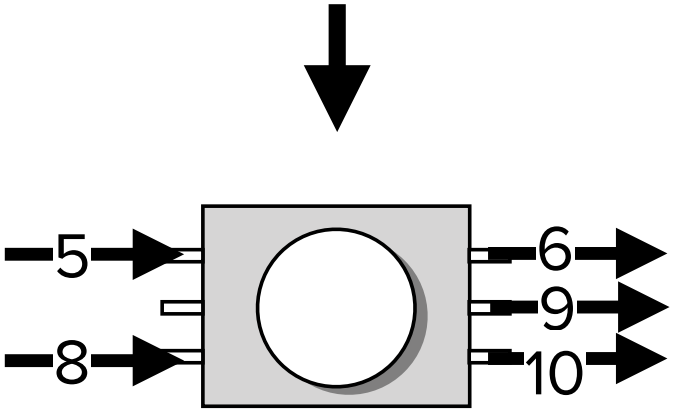
$$\dot{c}_{out_i} = \dot{c}_{out_j}$$

Generic Block



Connection Example:

By reference to the figure the excel sheet should be compiled as follow:



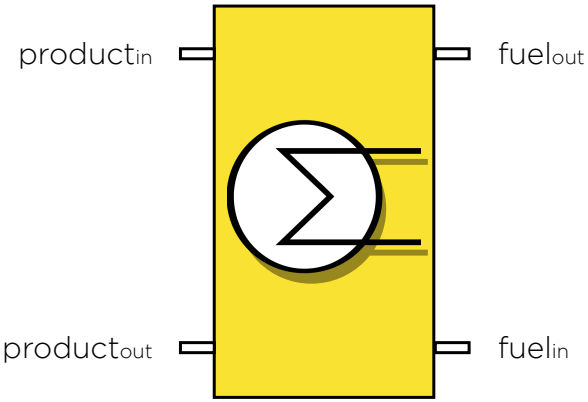
HINTS

Inputs (positive)	*Outputs (negative)*	*...*	*-1000*

STREAM NUMBERS

5	*8*	*-6*	*-9*	*-10*	*-1000*

9. *HEAT EXCHANGER*



Connections:

The heat exchanger has a defined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Product Input	*Product Output*	*Fuel Input*	*Fuel Output*

Where:

Port	*Note*
Product Input	Stream index of product input
Product Output	Stream index of product output
Fuel Input	Stream index of fuel input
Fuel Output	Stream index of fuel output

Note:

To decide which stream has to be considered as the product, it is important to understand **what is the task that the heat exchanger is designed for**. Some examples:

- The **condenser of a power plant** has to chill the vapour stream. Hence in this case, the stream that is cooled has to be considered as the product while the cooling water is the fuel.
- The **regenerator of an ORC cycle** is designed to pre-heat the fluid before it reach the boiler. Hence the stream that is heated is the product while the other one is the fuel.
- The **heat-exchanger in a fan coil** heat or chill the air that passes trough it so as to control the temperature of the environment in which it is installed. Hence the air is the product while the refrigerant gas inside the fan coil is the fuel.

Support Equations:

- the specific exegetic cost of the **fuel output is equals** to the cost of the **fuel input:**

$$\dot{c}_{fuel_{out}} = \dot{c}_{fuel_{in}}$$

Connection Example:

By reference to the figure the excel sheet should be compiled as follow:

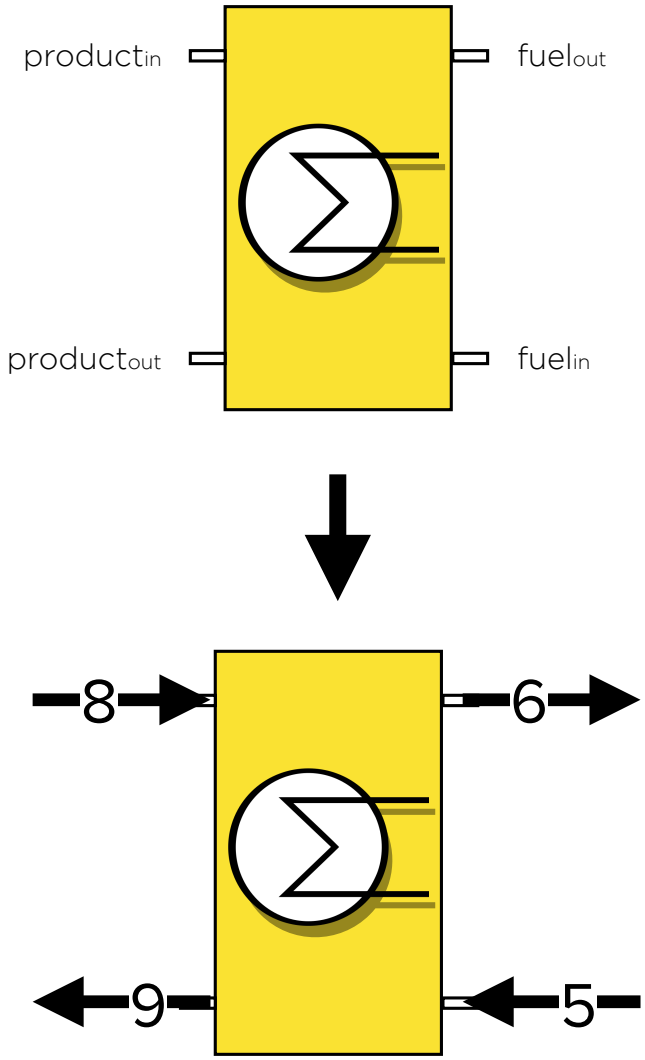
HINTS

Product Input	*Product Output*	*Fuel Input*	*Fuel Output*

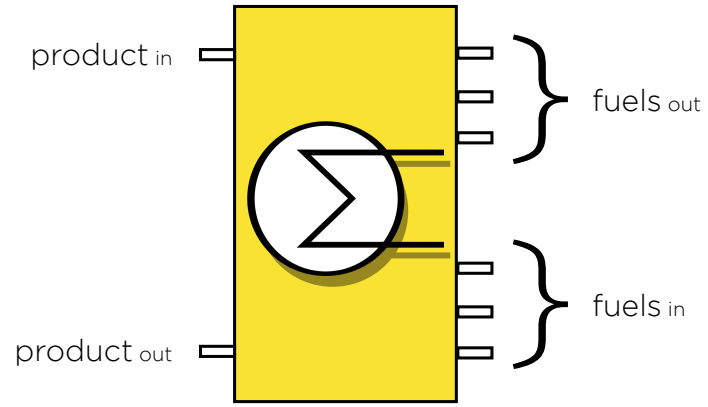
STREAM NUMBERS

8	*9*	*5*	*6*

Heat-Exchanger



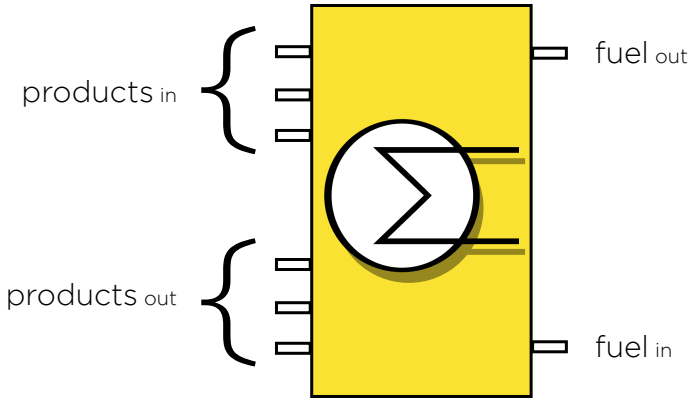
10. *HEAT EXCHANGER MULTI FUEL*



Connections and support equation:

From an exergo-economic point of view the mixer is indistinguishable from the Evaporator. Please refers to that component's data sheet

11. *HEAT EXCHANGER MULTI PRODUCT*



Connections:

The heat exchanger - multi product has an undefined number of ports as represented in the figure. The hint line provided by the excel sheet is the following:

Fuel Input	*Fuel Output*	*Product Inputs (positive)*	*Product Outputs (negative)*	*...*	*-1000*

Where:

Port	*Note*
Fuel Input	Stream index of fuel input
Fuel Output	Stream index of fuel output
Product Inputs	Stream indices of product input
Product Outputs	Stream indices of product output

Support Equations:

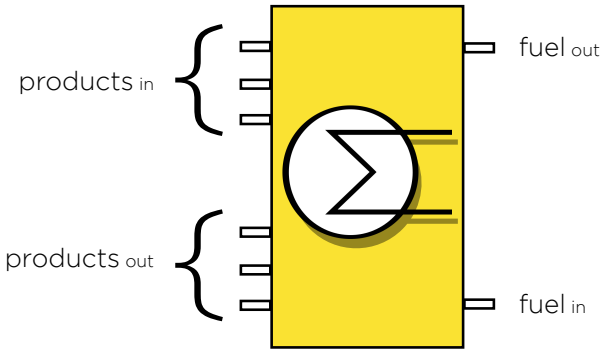
- the **specific exegetic cost for the fuel output** is equal to the fuel input cost:

$$\dot{c}_{fuel_{out}} = \dot{c}_{fuel_{in}}$$

- the specific exegetic cost of each **product output is the same:**

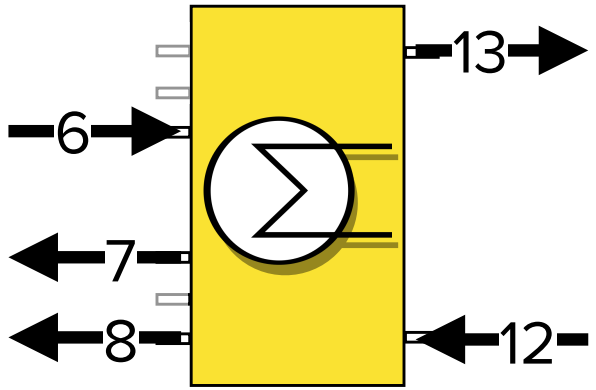
$$\dot{c}_{prod_{out_i}} = \dot{c}_{prod_{out_j}}$$

Heat Exchanger - Multi Product



Connection Example:

By reference to the figure the excel sheet should be compiled as follow:



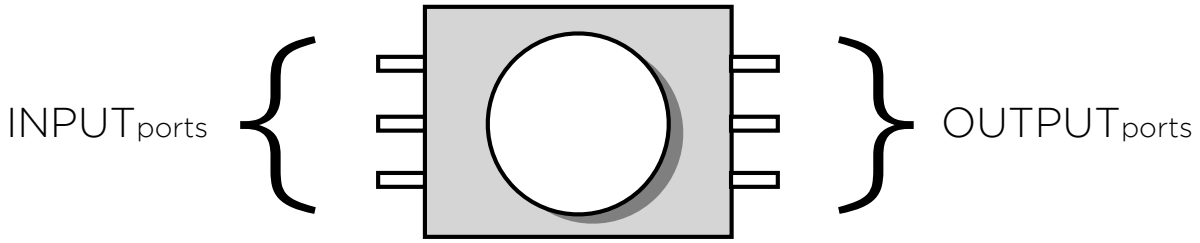
STREAM NUMBERS

12	*13*	*6*	*-7*	*-8*	*-1000*

HINTS

Fuel Input	*Fuel Output*	*Product Inputs (positive)*	*Product Outputs (negative)*	*...*	*-1000*

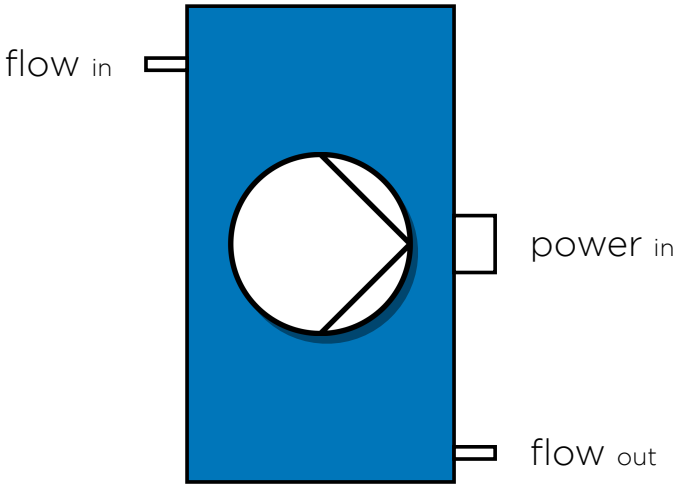
12.*MIXER*



Connections and support equation:

From an exergo-economic point of view the mixer is indistinguishable from the Generic Block. Please refers to that component's data sheet

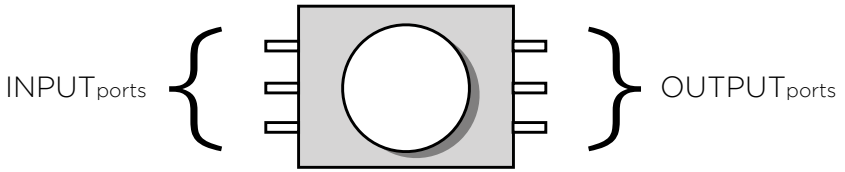
13.*PUMP*



Connections and support equation:

From an exergo-economic point of view the mixer is indistinguishable from the Compressor. Please refers to that component's data sheet

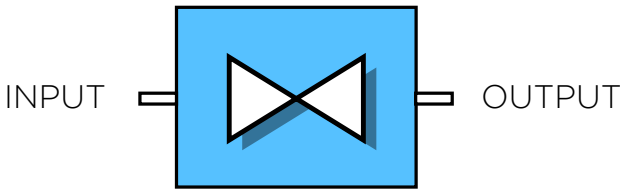
14.*SEPARATOR*



Connections and support equation:

From an exergo-economic point of view the mixer is indistinguishable from the Generic Block. Please refers to that component's data sheet

15. *VALVE*



Connections:

Valve has a defined number of connections, The hint line provided by the excel sheet is the following:

Input	*Output*

Where:

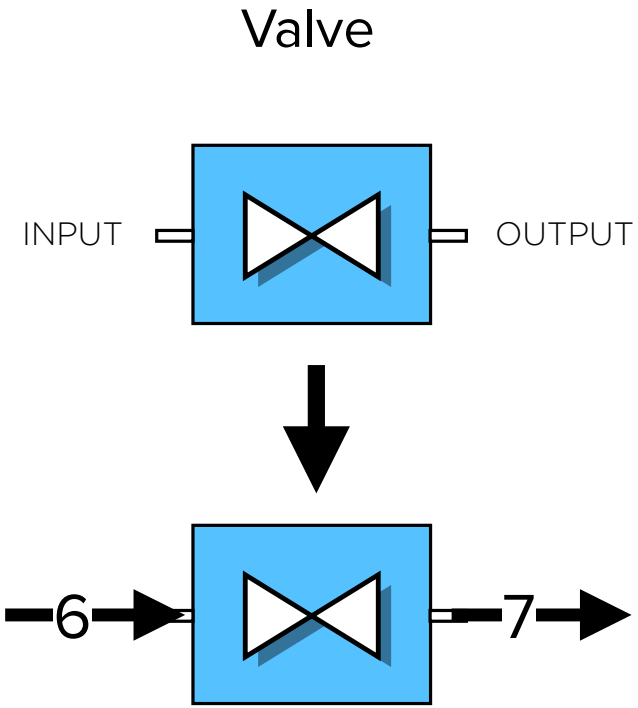
Port	*Note*
Input	Stream index of flow input
Output	Stream index of flow output

Support Equations:

- **Not needed** (only 1 output)

Connection Example:

By reference to the figure, the excel sheet should be compiled as follow:



HINTS

Input	*Output*

STREAM NUMBERS

6	*7*

BIBLIOGRAPY

[1] A. Valero Capilla and C. Torres Cuadra, Thermoeconomics. 2005.

[2] A. Lazzaretto and G. Tsatsaronis, “SPECO: A systematic and general methodology for calculating efficiencies and costs in thermal systems,” Energy, vol. 31, no. 8–9, pp. 1257–1289, Jul. 2006.

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