EPFL

IPESE
Industrial Process and Energy Systems Engineering

ROSMOSE: A Web-based Tool for Pinch Analysis and Utility Integration

Process development – CHE-459
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École polytechnique fédérale de Lausanne

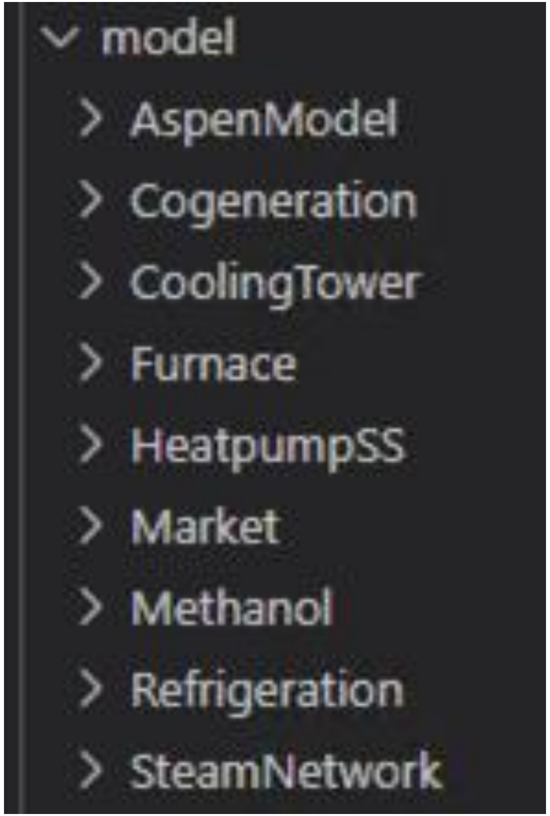
OUTLINE

The utilities

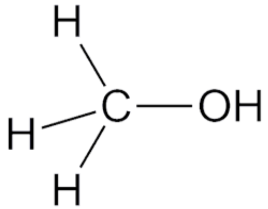
Using Rosmose – definition of the model

- In the model folder, you define the model for your Energy Technologies (ET). In the example case, we have:
  - A sample Aspen Model demonstrating how to import flowsheet data from Aspen into ROSMOSE
  - The utilities ETs *Cogeneration*, *Cooling Tower*, *Furnace, Heatpump, HeatpumpSS, Methanol, Refrigeration, and Steam Network*
  - The *market*, to close the mass and energy balance with the resources consumed/produced.

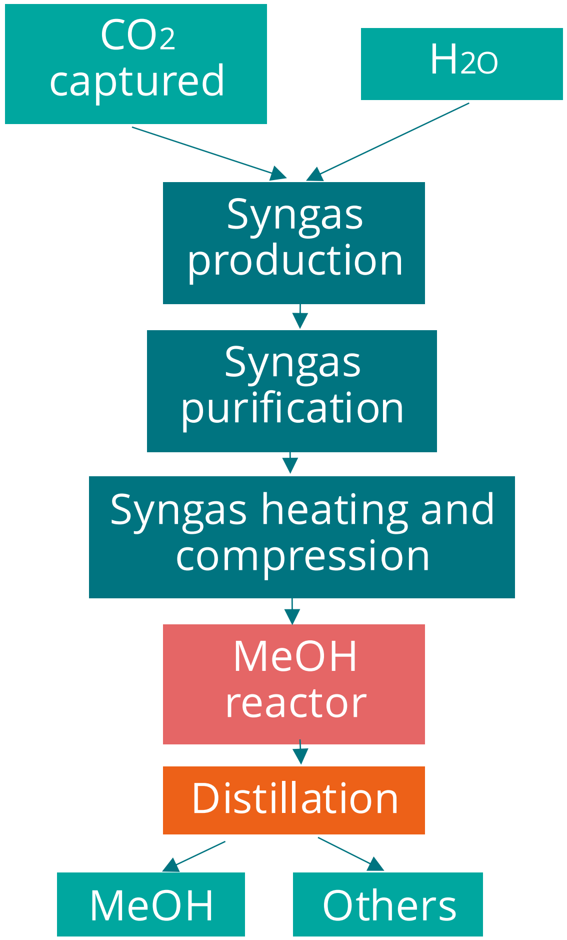
- In this class, we will see what is inside the ETs



Methanol



- This ET models methanol (CH_3OH) processing from syngas ($CO+H_2$) using electricity.
- Using compressors, heat exchangers, MeOH reactor, distillation, cooler, reboilers, condenser, multi-stage compressors



Methanol – Rosmose ET

Electricity → Methanol

- Layers and units

````
# Biomass ET {-}

```{rosmose Methanol}
! OSMOSE ET Methanol
```
This ET will use the following Layers

```{rosmose Methanol_layers}
: OSMOSE LAYERS Methanol

|Layer      |Display name    |shortname  |Unit       |Color  |
|:----------|:---------------|:----------|:----------|:------|
|ELEC       |Electricity     |elec       |kW         |yellow |

```

The methanol ET contains the following units

```{rosmose Methanol_units}
: OSMOSE UNIT Methanol

|unit name  |type    |
|:----------|:-------|
|Methanol   |Process|
```

## Methanol Unit {-}

```{rosmose Methanol_params}
: OSMOSE UNIT_PARAM Methanol

|cost1|cost2|cinv1|cinv2|imp1|imp2|fmin|fmax|
|:----|:----|:----|:----|:---|:---|:---|:---|
|0    |0    |0    |0    |0   |0   |1   |1   |
```
````

Methanol – Rosmose ET

Electricity → Methanol

- Streams

````
**Methanol Unit Streams**

After importing the powers of your compressors and pumps in your Aspen model.
you can use this ET to sum up everything and report your net electricity consumption.

```{rosmose}
Power_consump = %MSC_power_tot%-%Electrolyzer_size%
```

```{rosmose Methanol_rs}
: OSMOSE RESOURCE_STREAMS Methanol

|layer      |direction|value                |
|:----------|:--------|:--------------------|
|ELEC       |in       |%Power_consump%      |
```
      Dareen, last week • Rosmose updates
**Heat Streams**

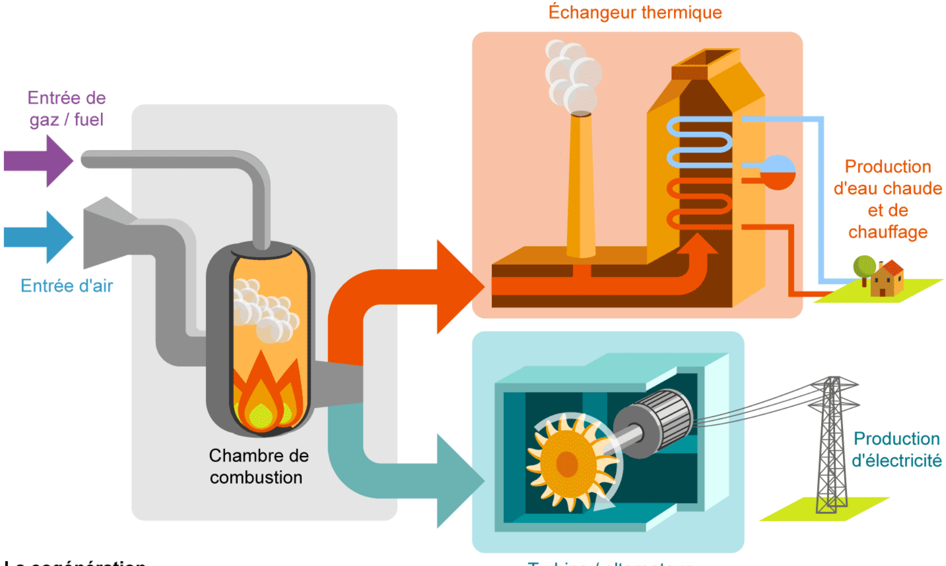
```{rosmose Methanol_hs}
: OSMOSE HEAT_STREAMS Methanol

|name     |Tin         |Tout         |Hin  |Hout        |DT min/2|alpha|
|:--------|:-----------|:------------|:----|:-----------|:-------|:----|
|heater_1 |%T_AIR_1%   |%T_AIR_2%    |0    |%heater_1%  |2.5     |1    |
|heater_3 |%T_FUEL_1%  |%T_FUEL_2%   |0    |%heater_3%  |2.5     |1    |
|heater_4 |%T_FUEL_2%  |%T_FUEL_3%   |0    |%heater_4%  |2.5     |1    |
|heater_5 |%T_FUEL_3%  |%T_FUEL_4%   |0    |%heater_5%  |2.5     |1    |
|cooler_1 |%T_AIR_OUT% |%T_AIR_4%    |0    |%cooler_1%  |2.5     |1    |
|cooler_2 |%T_FUEL_OUT%|%T_LTFUEL%   |0    |%cooler_2%  |2.5     |1    |
|MSC_cooler_1 |%MSC_cooler_1_Tin% |%MSC_cooler_1_Tout% |0    |%MSC_cooler_1_Duty%  |2.5     |1    |
|MSC_cooler_2 |%MSC_cooler_2_Tin% |%MSC_cooler_2_Tout% |0    |%MSC_cooler_2_Duty%  |2.5     |1    |
|HX_1    |%T_S1%      |%T_S2%       |0    |%HX1_Duty%  |2.5     |1    |
|HX_2    |%T_S4%      |%T_S5%       |0    |%HX2_Duty%  |2.5     |1    |
|HX_3    |%T_S7%      |%T_S8%       |0    |%HX3_Duty%  |2.5     |1    |
|R_1     |%T_S3%      |%T_S4%       |0    |%R1%        |2.5     |1    |
|reb     |%reb_ti%    |%reb_to%     |0    |%reb_Q%     |2.5     |1    |
|cond    |%cond_ti%   |%cond_to%    |0    |%cond_Q%    |2.5     |1    |

```
````

Cogeneration

- Cogeneration consists in producing at the same time electricity and heat (thermic energy)
- Gas and air enters the combustion chamber
- There is a thermic exchanger that allows to produce hot water and heat
- A turbine produces electricity



La cogénération

Cogeneration – Rosmose ET

- Inputs

```
```{rosmose}
! OSMOSE ET cogen
```

```{rosmose}
eta_el = 0.4 #electrical efficiency
eta_th_fg = 0.22  #thermal efficiency - high grade heat if form of flue gases (typically available @ 450 can be cooled down to 150°C)
eta_th_cw = 0.25  #thermal efficiency - low grade waste heat in form of cooling water (@ 90 - 50°C)
Cogen_natGas_LOAD = 6000 [kW] # Reference cogeneration unit load
fg_Tin = 450 [C] #high-grade waste heat (Flue_gas) available temperature
fg_Tout = 150 [C] #high-grade waste heat (Flue_gas) exit temperature
cw_Tin = 90 [C] #low-grade waste heat (cooling_water) available temperature
cw_Tout = 40 [C] #low-grade waste heat (cooling_water) exit temperature
n = 40.0 [yr] #lifetime
i = 0.06 [-] #interest rate
CEPCI_2020 = 596.2 [-] # actual CEPCI
CEPCI_2008 = 575.4 [-] # CEPCI 2008
```

```{rosmose}
Cogen_elec = %eta_el%*%Cogen_natGas_LOAD% #Power generation assuming ~40% efficiency
Q_cogen_fg = %eta_th_fg% * %Cogen_natGas_LOAD%  #high grade heat generated from flue gases assuming 22%
Q_cogen_cw = %eta_th_cw% * %Cogen_natGas_LOAD%  #high grade heat generated from flue gases assuming 25%
Annuity = (%i%*(1+%i%)**%n%)/((1+%i%)**%n%-1) [-] #annualization factor
Cinv2_cogen = 1200*%Cogen_elec%*(%CEPCI_2020%/%CEPCI_2008%)*%Annuity% [Euro/y] #1200 Euro/kW natural gas load of the cogeneration unit
```
```

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Cogeneration – Rosmose ET

- Layers and parameters

```
**Layers of the Cogeneration ET**

```{rosmose}
: OSMOSE LAYERS cogen

|Layer      |Display name   |shortname  |Unit       |Color  |
|:----------|:--------------|:----------|:----------|:------|
|NATGAS     |Gas            |ng         |kW         |green  |
|ELEC       |Electricity    |elec       |kW         |yellow |

```

Cogeneration unit of the Cogeneration ET

```{rosmose}
: OSMOSE UNIT cogen

|unit name  |type     |
|:----------|:--------|
|cogen      |Utility  |
```

Parameters of the Cogeneration unit

```{rosmose}
: OSMOSE UNIT_PARAM cogen

|cost1  |cost2  |cinv1  |cinv2         |imp1   |imp2   |fmin   |fmax   |
|:------|:------|:------|:-------------|:------|:------|:------|:------|
|0      |0      |0      |%Cinv2_cogen% |0      |0      |0      |5      |
```
```

Cogeneration – Rosmose ET

- Streams

```
**Cogeneration Streams**

*Resource Streams*
Defining the resource streams, in this case natural gas to, and electricity from, the cogeneration unit

```{rosmose}
: OSMOSE RESOURCE_STREAMS cogen

|layer      |direction|value                |
|:----------|:--------|:--------------------|
|ELEC       | out     |%Cogen_elec%         |
|NATGAS     | in      |%Cogen_natGas_LOAD%  |
```

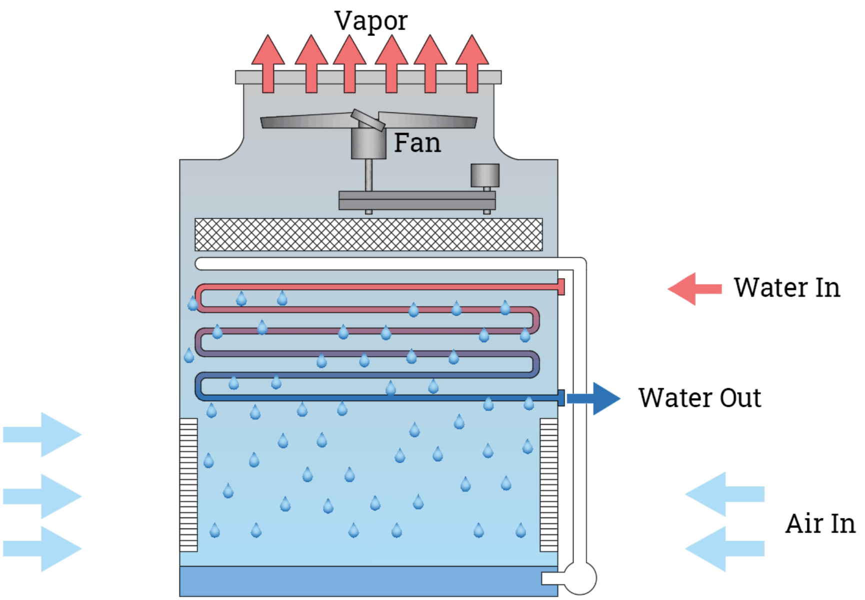

Heat Streams

```{rosmose}
: OSMOSE HEAT_STREAMS cogen

|name          |Tin        |Tout       |Hin           |Hout       |DT min/2   |alpha|
|:-------------|:----------|:----------|:-------------|:----------|:----------|:----|
|fg            |%fg_Tin%   |%fg_Tout%  |%Q_cogen_fg%  |0          |2.5        |1    |
|cw            |%cw_Tin%   |%cw_Tout%  |%Q_cogen_cw%  |0          |2.5        |1    |
```
```

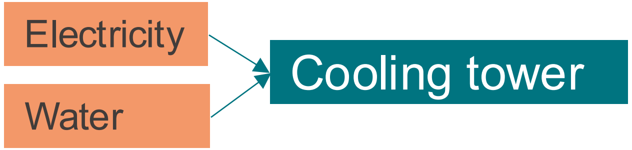
Cooling tower

- Cooling towers are basically heat exchangers, generating cooling by bringing water and air into contact.
- They remove heat from water by latent heat loss from evaporation while coming into contact with an air stream.
- Water is also cooled by sensible heat transfer due to the temperature difference between air and water.



Cooling Towers: Types, Principles, Parts and Applications. Available at: https://www.iqsdirectory.com/articles/cooling-tower.html

Cooling tower – Rosmose ET



- Inputs

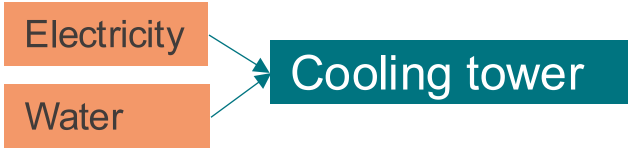
```
# Cooling Tower {-}

```{rosmose coolingtower}
! OSMOSE ET coolingtower
```

```{rosmose}
Cool_Tin = 15 [C] #Cooling tower inlet temperature
Cool_Tout = 30 [C] #Cooling tower outlet temperature
Cool_Qmax = 1000 [kW] #Cooling tower reference heat load
Cool_Elec = 0.021 [kW/kW] #Cooling Tower electricity input kWel/kWth
dtmin_liq = 5 [C] #delta Tmin of the cooling water (w/ liquid streams)
deltaH = 62.8 [kJ/kg] #Enthalpy change for cooling water @1 bar between 15 to 30°C
Twetbulb = 12.17 [C]
n = 40.0 [yr] #lifetime of a cooling tower
i = 0.06 [-] #interest rate
CEPCI_2020 = 596.2 [-] # actual CEPCI
CEPCI_2008 = 575.4 [-] # CEPCI 2008
```

```{rosmose}
E_ref_CT = %Cool_Elec%*%Cool_Qmax% [kW] # Electricity consumption
deltaT_CT = %Cool_Tout%-%Cool_Tin% [C]
approach = %Cool_Tin%-%Twetbulb% [C]
water_flow = %Cool_Qmax%/%deltaH%*3600 [kg/h] #water flow rate
watermu_CT = 0.000851*%water_flow%*(%Cool_Tout%-%Cool_Tin%) [kg/h] #makeup water in the CT system
Annuity = (%i%*(1+%i%)**%n%)/((1+%i%)**%n%-1) [-] #annualization factor
CTCost = 746.49/0.066*((%water_flow%/1000)**0.79)*(%deltaT_CT%**0.57)*(%approach%**-0.9924)*(0.022*%Twetbulb%+0.39)**2.447 [Euro]
Cinv2_CT = %CTCost%*(%CEPCI_2020%/%CEPCI_2008%)*%Annuity% [Euro/y]
```
```

Cooling tower – Rosmose ET



- Layers and parameters

```
**Layers of the Cooling Tower ET**

```{rosmose}
: OSMOSE LAYERS coolingtower

| Layer      | Display name | shortname | Unit | Color ||        Soline Florenc
|:----------|:-------------|:----------|:-----|:------|
|ELEC       |Electricity   |elec       |kW    |yellow |
|WATER      |Water         |water      |kg/h  |blue   |
```

Cooling tower unit of the Cooling Tower ET

```{rosmose}
: OSMOSE UNIT coolingtower

| unit name |type   |
|:----------|:------|
| CoolTower |Utility|
```

Parameters of the Cooling Tower unit

```{rosmose CoolTower_params}
: OSMOSE UNIT_PARAM CoolTower

|cost1  |cost2  |cinv1  |cinv2       |imp1   |imp2   |fmin   |fmax   |
|:------|:------|:------|:-----------|:------|:------|:------|:------|
|0      |0      |0      |%Cinv2_CT%  |0      |0      |0      |100000  |
```
```

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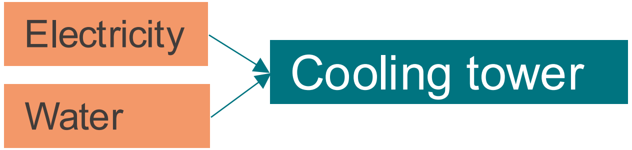
Cooling tower – Rosmose ET



- Streams

```
**Cooling Tower Streams**

Defining the resource streams, in this case electricity to the Cooling Tower

*Resource Streams*


```{rosmose CoolTower_rs}
: OSMOSE RESOURCE_STREAMS CoolTower

|layer      |direction|value                |
|:----------|:--------|:--------------------|
|ELEC       |in       |%E_ref_CT%           |
|WATER      |in       |%watermu_CT%         |
```

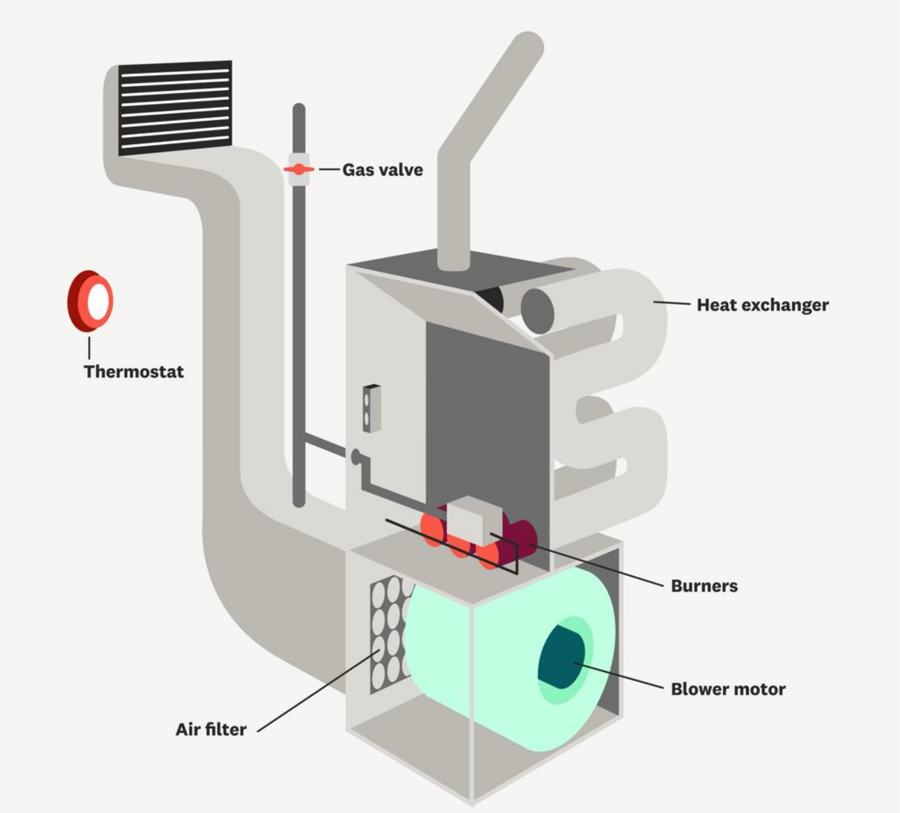
Heat Streams

```{rosmose CoolTower_hs}
: OSMOSE HEAT_STREAMS CoolTower

|name          |Tin        |Tout       |Hin |Hout          |DT min/2       |alpha  |
|:-------------|:----------|:----------|:---|:-------------|:--------------|:------|
|cooltowerheat |%Cool_Tin% |%Cool_Tout%| 0  | %Cool_Qmax%  | %dtmin_liq%   |1      |
```
```

Furnace

- Used to generate heat via a fluid movement (air, steam, hot water).
- **Thermostat activates** the furnace when room temperature drops below the set level.
- **Gas burners ignite** using fuels like **natural gas**, **propane**, or **oil**, heating the **heat exchanger**.
- The **blower motor** pushes air through the **air filter** and over the hot exchanger, warming the air.
- **Warm air is circulated** through ducts, while combustion gases are safely vented outside.



How Does a Furnace Work? Breaking Down the Process of Gas, Oil, Electric, and Propane Heating. Available at: https://www.angi.com/articles/how-does-it-work-understanding-your-gas-furnace.htm

Furnace – Rosmose ET

Natural Gas → Furnace → Heat

- Inputs

````
```{rosmose}
Tad = 2025 [C] # Adiabatic flame temperature of the fuel
dtmin_radiation = 2 [C] # radiation delta t mininum
dtmin_convection = 8 [C] # convection delta t mininum
To = 25 [C] # Tamb = To = Tchemicalreference
Trad= 1050 [C] # Radiation temperature threshold, actual temperature is 1050°C but 400 can be used for plot visualization
Tstack = 100 [C] # Stack temperature threshold for no dew point
MWair = 29 [kg/kmol] # Molecular weight of dry air = 79% N2 + 21% O2
MWfuel = 16 [kg/kmol] # Molecular weight of methane
losses = 0.03 [-] # 3% Furnace losses
LHV = 50000 [kJ/kg] # natural gas LHV @ 25°C,1 bar
molratst = 9.52 [kmol/kmol] # Stoich molar air to fuel ratio
a = 1.02 [-] # excess air as in: CH4 + a*2(O2+3.76N2) --> CO2 + 2H2O + 2*3.76N2 + 2(a-1)(O2 + 3.76N2)
cpair = 1.075 [kJ/kg/K] # Air heat capacity @427°C, 1bar (Engineering toolbox)
Tprin = 26 [C] # Preheating temperature
Furnace_natGas_LOAD = 1000 [kW] # Reference furnace load
Spec_heaterCost = 200 [Euro/kW]
n = 40.0 [yr] #lifetime of a furnace
i = 0.06 [-] #interest rate
CEPCI_2020 = 596.2 [-] # actual CEPCI
CEPCI_2008 = 575.4 [-] # CEPCI 2008
```
```{rosmose}
v = %molratst% * %MWair% / %MWfuel% [kg/kg] # stoich air to fuel mass ratio
cpg = %Furnace_natGas_LOAD% / (%Tad% - %To%) [kW/K] # Flue gases heat capacity @1bar
Tad_corr = %To% + (%Furnace_natGas_LOAD% / (%cpg% + (%cpair% * (%a% -1) * %v% * %Furnace_natGas_LOAD% / %LHV%))) [C] # Corrected adiabatic flame temperature
cpg_corr = %Furnace_natGas_LOAD% / (%Tad_corr% - %To%) [kW/K] # Corrected flue gases heat capacity @1bar
Q_rad_gross = (%Furnace_natGas_LOAD% * (%Tad_corr% - %Trad%) / (%Tad_corr% - %To%)) [kW] # Heat flow rate at the radiation threshold temperature
Q_conv_gross = %Furnace_natGas_LOAD% * (%Trad% - %Tstack%) / (%Tad_corr% - %To%) [kW] # Heat flow rate at the convection threshold temperature
Q_preh = %cpair% * %v% * %Furnace_natGas_LOAD% / %LHV% * (%Tprin% - %To%) [kW] # Air preheating load
Q_stack = %cpg_corr% * (%Tstack% - %To%) [kW] # Stack losses
Q_radpreh = %Q_preh% + %Q_rad_gross% [kW] # Preheating load added to the highest temperature
Q_demand = %Furnace_natGas_LOAD% / (1-%losses%) [kW] # Total energy consumption by the furnace
Annuity = (%i%*(1+%i%)**%n%)/((1+%i%)**%n%-1) [-] #annualization factor
Cinv2_NGFur = %Spec_heaterCost%*%Furnace_natGas_LOAD%*(%CEPCI_2020%/%CEPCI_2008%)*%Annuity% [Euro/y]      Soline Florence Marie Corre, 6 days ago • ROSMOSE tes
```
````

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Furnace – Rosmose ET

- Layers and parameters

```
**Layers of the Furnace ET**

```{rosmose}
: OSMOSE LAYERS furnace

| Layer          | Display name | shortname | Unit | Color |
|:-------------|:------------|:----------|:-----|:------|
|NATGAS          |Gas           |ng          |kW     |green   |

```

Furnace unit of the Furnace ET

```{rosmose}
: OSMOSE UNIT furnace

|unit name  |type   |
|:---------|:------|
|Furnace     |Utility|
```

Parameters of the Furnace unit

```{rosmose Furnace_params}
: OSMOSE UNIT_PARAM Furnace

|cost1  |cost2  |cinv1  |cinv2          |imp1   |imp2   |fmin   |fmax   |
|:------|:------|:------|:-------------|:------|:------|:------|:------|
|0       |0       |0       |%Cinv2_NGFur% |0       |0       |0       |100     |
```
```

Furnace – Rosmose ET

- Streams

````
**Furnace Streams**

*Resource Streams*
Defining the resource streams, in this case natural gas to the furnace

```{rosmose Furnace_rs}
: OSMOSE RESOURCE_STREAMS Furnace

|layer      |direction|value               |
|:----------|:--------|:-------------------|
|NATGAS     | in      |%Q_demand%          |
```


*Heat Streams*

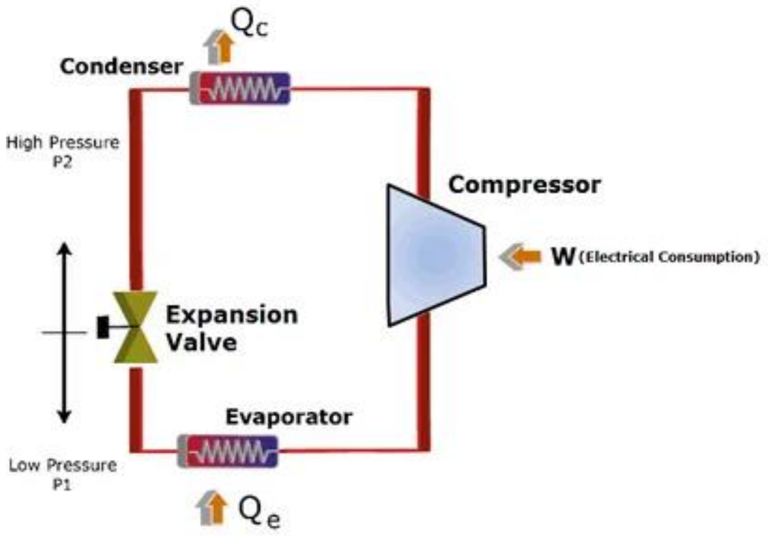
```{rosmose Furnace_hs}
: OSMOSE HEAT_STREAMS Furnace

|name       |Tin   |Tout    |Hin            |Hout             |DT min/2          |alpha|
|:----------|:-----|:-------|:--------------|:----------------|:-----------------|:----|
|radiation  |%Trad%|%Trad%  |%Q_radpreh%    |0                |%dtmin_radiation% |1    |
|convection |%Trad%|%Tstack%|%Q_conv_gross% |0                |%dtmin_convection% |1    |
|preheating |%To%  |%Tprin% |0              |%Q_preh%         |%dtmin_convection% |1    |
```
````

Refrigerator

- This unit removes unwanted heat

1. A **compressor** pressurizes the refrigerant.
2. A **condenser**, where the refrigerant condenses from vapor to its liquid form giving off heat.
3. A **metering device** regulates the flow and consequently lowers the pressure, of the refrigerant.
4. An **evaporator** also referred to as a cooling coil, where the refrigerant expands removing heat from the area as the refrigerant "evaporates" changing into its vapor state once again.



Industrial Process Refrigeration: An In-Depth Look at Each Component. Available at: https://www.araner.com/blog/industrial-refrigeration-cycle-components

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Refrigerator – Rosmose ET

Electricity → Refrigerator → Cold

- Inputs

```
# Refrigerator {-}

```{rosmose refrigerator}
: OSMOSE ET refrigerator
```

```{rosmose}
Evap_Tin = 5 [C] # Evaporator temperature inlet
Evap_Tout = 5 [C] # Evaporator temperature outlet
Cond_Tin = 35 [C] # Condenser temperature inlet
Cond_Tout = 35 [C] # Condenser temperature outlet
Evap_Qmax = 5000 [kW] # evaporator reference heat flow rate (Q_L)
exeff = 0.5 [-] # Second law efficiency
dtmin_2ph = 2 [C] # phase-change delta t minimum
n = 40.0 [yr] #lifetime
i = 0.06 [-] #interest rate
CEPCI_2020 = 596.2 [-] # actual CEPCI
CEPCI_2008 = 575.4 [-] # CEPCI 2008
```


```{rosmose}
COPcarnot = (%Evap_Tin% + 273) / (%Cond_Tin% - %Evap_Tin%) [-] # Carnot COP
COP = %exeff% * %COPcarnot% [-] # Actual COP
W_refrig = %Evap_Qmax% / %COP% [kW] # Heat pump power consumption
Cond_Qmax = %Evap_Qmax% * (%COP% + 1) / %COP% [kW] # Condenser heat flow rate (Q_H)
Annuity = (%i%*(1+%i%)**%n%)/((1+%i%)**%n%-1) [-] #annualization factor
Cinv2_RF = 300*%Cond_Qmax%*(%CEPCI_2020%/%CEPCI_2008%)*%Annuity% [Euro/y] #300 Euro/kWth at the condenser
```
```

Refrigerator – Rosmose ET

- Layers, units, parameters

```
**Layers of the Refrigerator ET**

```{rosmose}
: OSMOSE LAYERS refrigerator

|Layer      |Display name|shortname|Unit    |Color  |
|:----------|:-----------|:--------|:-------|:------|
|ELEC       |Electricity |elec     |kW      |yellow |
```

Refrigerator unit of the Refrigerator ET

```{rosmose}
: OSMOSE UNIT refrigerator

|unit name      |type   |
|:--------------|:------|
|Refrigerator   |Utility|
```

Parameters of the Refrigerator unit

```{rosmose Refrigerator_params}
: OSMOSE UNIT_PARAM Refrigerator

|cost1  |cost2  |cinv1  |cinv2       |imp1   |imp2   |fmin   |fmax   |
|:------|:------|:------|:-----------|:------|:------|:------|:------|
|0      |0      |0      |%Cinv2_RF%  |0      |0      |0      |10     |
```
```

Refrigerator – Rosmose ET

- Streams

````
**Refrigerator Streams**

*Resource Streams*
Defining the resource streams, in this case electricity to the refrigerator

```{rosmose Refrigerator_rs}
: OSMOSE RESOURCE_STREAMS Refrigerator

|layer     |direction|value              |
|:---------|:--------|:------------------|
|ELEC      | in      |%W_refrig%         |
```

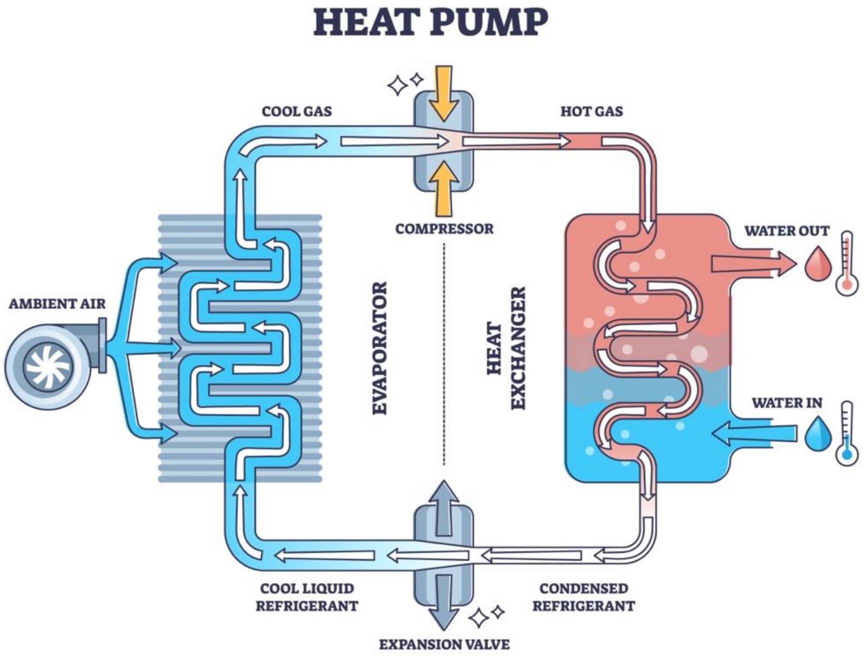

*Heat Streams*

```{rosmose Refrigerator_hs}
: OSMOSE HEAT_STREAMS Refrigerator

|name           |Tin        |Tout       |Hin        |Hout       |DT min/2    |alpha|
|:--------------|:----------|:----------|:----------|:----------|:-----------|:----|
|evaporation    |%Evap_Tin% |%Evap_Tout%|0          |%Evap_Qmax%|%dtmin_2ph% |1    |
|condensation   |%Cond_Tin% |%Cond_Tout%|%Cond_Qmax%|0          |%dtmin_2ph% |1    |
```
````

Heat pump

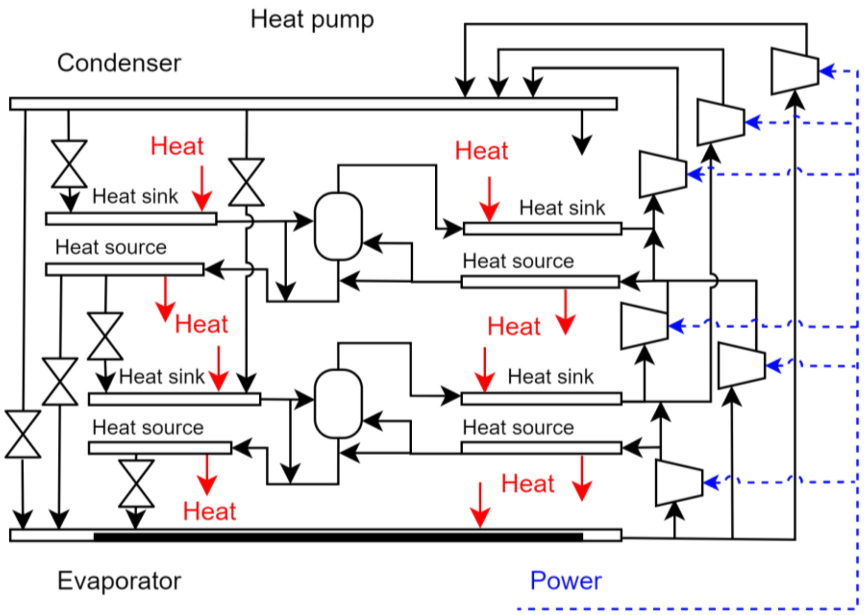
- Heat pumps use electricity to transfer heat from a cool space to a warm space.
- **Ambient air** transfers heat to the **refrigerant** in the **evaporator**, turning it into a **cool gas**.
- The **compressor** increases the pressure and temperature of the gas, turning it into **hot gas**.
- This hot gas flows through the **heat exchanger**, heating water as it passes through (e.g. for heating systems).
- The **refrigerant cools and condenses**, then passes through an **expansion valve** to lower its pressure and temperature before repeating the cycle.



ROS

Arpagaus, C. et al (2018). "High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials." Energy 152: 985-1010.

HP superstructure approach



Some fluids:
IsoButane
Methane
Ethylene
R141b
Water
Ammonia
R123
R12
R134a
n-Propane
R1234yf
Propylene
R32
Ethane
CarbonDioxide
R13
+
Vendors data

The heat pump superstructure considers a combination of evaporators, condensers, mixers, economizers, saturators, superheaters, subcoolers, and throttling valves, as well as optimal working fluids and operating conditions (e.g. temperatures, # stages, discharge T, compressor type, etc.)

HP superstructure template

- List of candidate fluids
- Candidate temperature levels of condensers or evaporators
- Superheating and subcooling temperatures
- Minimum temperature difference contribution
- Fixed and variable investment of compressor, evaporator, and condenser
- Bounds for compressor capacity, evaporators and condensers duty
- Number of compressors per fluid
- Compressor isentropic efficiency
- Bounds of compressor pressure and pressure ratio
- Heat transfer coefficients
- Bounds of valves differential pressure
- Bounds of flash drums, mixers, and super heater (if any)
- Compressor power supply (connection layer)

Define here the main parameters : change temperature

Parameter	T1	T2	T3	T4	T5	Unit	Comment
Temperatures	117.15	50	30	20	-10	C	Evaporation and condensation temperatures
SuperheatDT	20	0	0	0	0	C	Superheating temperature difference
SubcoolingDT	64	0	0	0	0	C	Minimum temperature difference contrib
CompressorDT	0	2	19.5	20	2	C	Superheating temperature difference
DT	2	2	2	2	2	C	Minimum temperature difference (dTmin/2)
MixForceUse	0	0	0	0	0	-	Sensible heat contained

Param	Min	Max	Unit	Comment
size	7	500	kW	Compressor size
pressure	0.5	20	bar	Range cost linear
ratio	1.2	7	-	Pressure ratio

Efficiency	Per_fluid	Per_model	Per_cluster
0.8	4	4	4

Choose the fluid

Fluid
IsoButane
Methane
Ethylene
water
Ammonia
n-Propane
R1234yf
Propylene
R32
Ethane
CarbonDioxide
R245fa
R1233zd(E)
R1234ze(Z)
R1234ze(E)
R365MFC
n-Pentane
Isopentane
n-Butane
R134a
R152a

Heat pumps – Rosmose ET

- Inputs

Fluids

```
**Fluid list**

Define the fluids list from wh

```{rosmose}
: OSMOSE FLUIDS heatpump_ss

|Fluid       |
|:-----------|
|Ethylene    |
|Methane     |
|water       |
```
```

temperature

```
```{rosmose}
: OSMOSE TEMPERATURES heatpump_ss

|Parameter    |T1   |T2   |Unit |Comment                                  |
|:------------|:----|:----|:----|:----------------------------------------|
|Temperatures |70   |30   | C   |Evaporation and condensation temperatures|
|SuperheatDT  |2    |2    | C   |Superheating temperature difference      |
|SubcoolingDT |2    |2    | C   |Minimum temperature difference contrib   |
|CompressorDT |2    |2    | C   |Superheating temperature difference      |
|DT           |2    |2    | C   |Minimum temperature difference (dTmin/2) |
|MixForceUse  |1    |0    | -   |Sensible heat contained                  |
```
```

elec

```
```{rosmose}
: OSMOSE LAYER heatpump_ss

|Balance_type     |LayerOfElec  |Supercritical|
|:----------------|:------------|:------------|
|ResourceBalance  |ELEC         | no          |
```
```

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Heat pumps – Rosmose ET

Electricity → Heat pump → Heat

- Parameters

```
```{rosmose}
: OSMOSE HEX_PARAMS1 heatpump_ss

|Component  |Fmin  |Fmax  |Inv1  |Inv2  |
|:----------|:-----|:-----|:-----|:-----|
|Evaporator |0     |100   |     0|     0|
|Condenser  |0     |100   |     0|     0|
```

The following parameters can be set by default or changed by experts to help convergence (OPTI

The area of the evaporator and condenser can be estimated as: cost = a * Area ^ b (used only t

```{rosmose}
: OSMOSE HEX_PARAMS2 heatpump_ss

|Param    |Value  |Unit   | Comment                                              |
|:--------|:------|:------|:-----------------------------------------------------|
|U        | 1     | W/m2K | Heat transfer coefficient                            |
|dT       | 10    | K     | Minimum temperature difference                       |
|a        | 500   | Euro  | Cost multiplication coefficient                      |
|b        | 0.8   | -     | Cost power coefficient                               |
|Min      | 100   | kW    | Minimum size of heat exchangers                      |
|Max      | 1000  | kW    | Maximum size of heat exchangers                      |
|force    | 0     | -     | Binary {0,1} to force the sizing of HEX              |
|DSH      | 0.2   | -     | Percent use of desuperheating % of a condensation level  |
```
```

Heat pumps – Rosmose ET

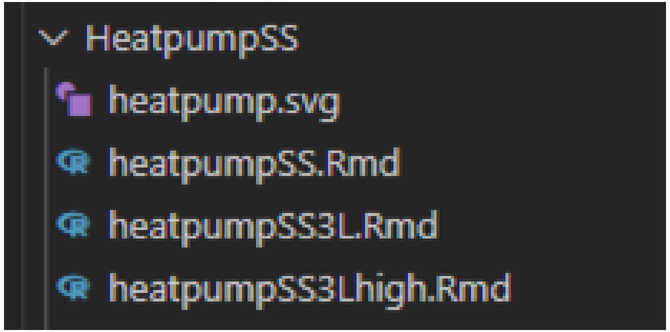
- Streams

```
```{rosmose}
: OSMOSE LAYER heatpump_ss

|Balance_type      |LayerOfElec   |Supercritical|
|:-----------------|:-------------|:------------|
|ResourceBalance   |ELEC          | no          |
```
```

3 Heat pumps available

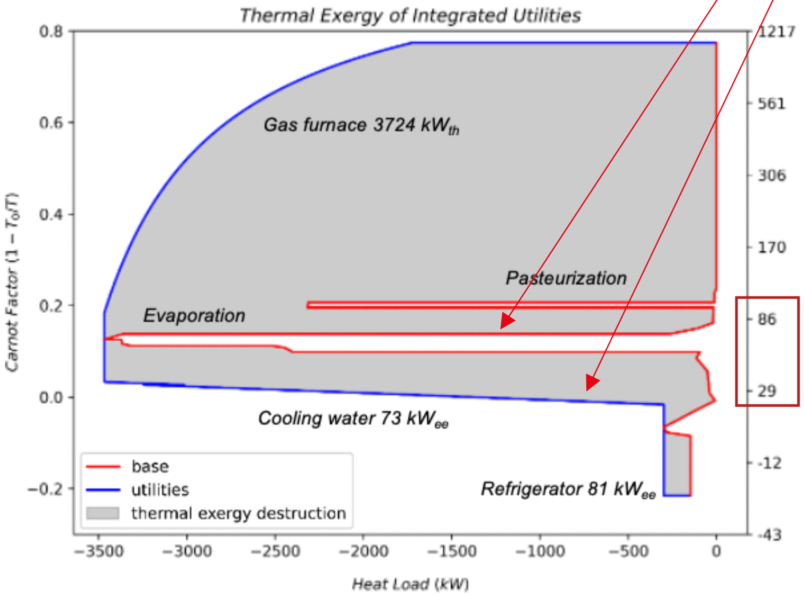
- Define a set of temperature levels and refrigerants that are potentially favorable.
- ROSMOSE will select the best parameters to reduce energy consumption and maximize waste heat recovery.
- Combine of multi-stage and cascaded HPs

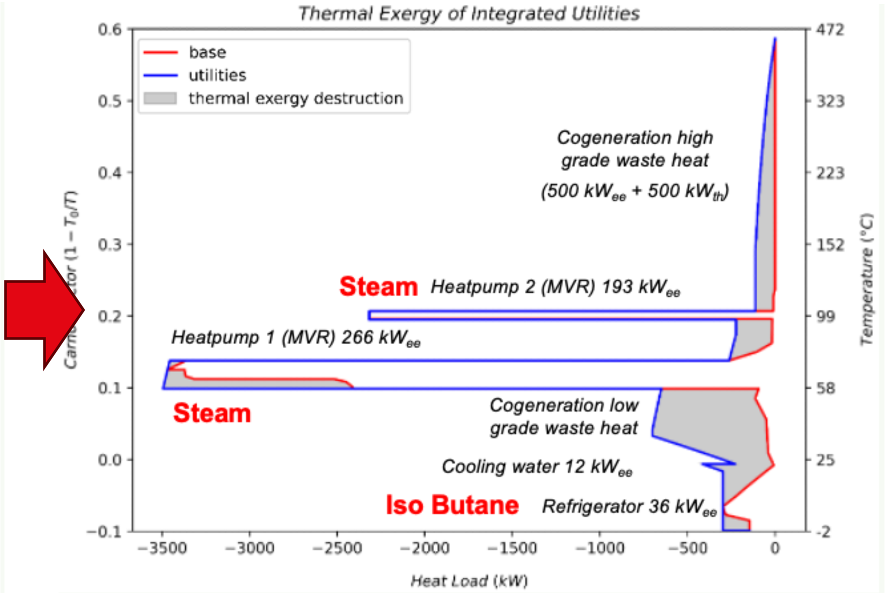


Heat pump superstructure 2 levels:
heatpumpSS
Heat pump superstructure 3 levels:
heatpumpSS3L
Heat pump superstructure 3 levels at high pressure:
heatpumpSS3Lhigh

When do you need to use heat pump superstructure?

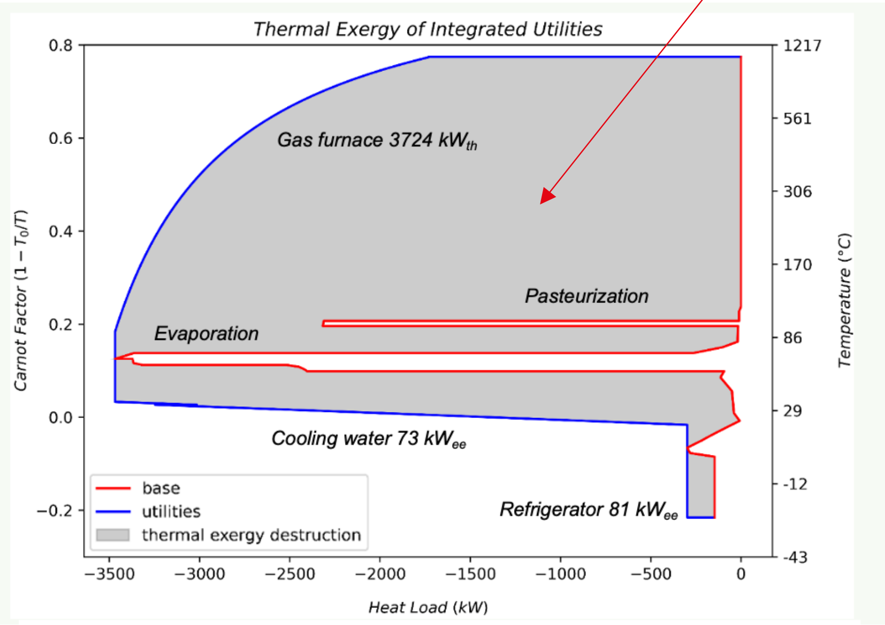
Availability of low grade waste heat could be used to feed HTTP

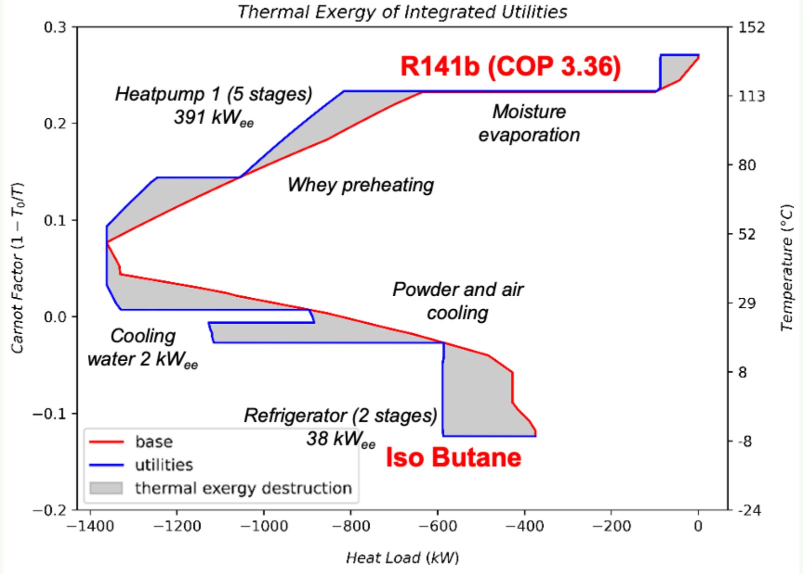




When do you need to use heat pump superstructure?

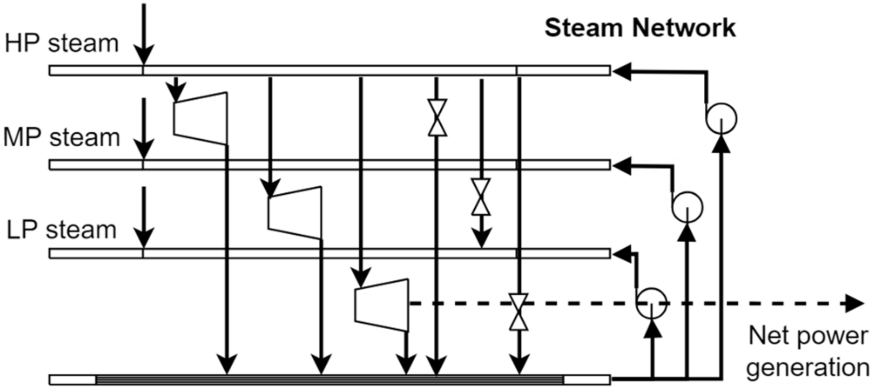
Availability of waste heat could be used to feed HTTP





Steam network

- This unit transforms waste heat in elec
- Several levels of pressure, to activate or not



Can go > 100 bar

```
: OSMOSE LEVELS steamnetwork_ss

|Parameter     |L1     |L2     |L3     |L4     |Unit |Comment
|:-------------|:------|:------|:------|:------|:----|:---------------------
|Pressure      |30     |3      |1      |0.04   | bar |Pressure levels define
|layerofpressure|p1    |p2     |p3     |p4       | -   |Layer of pressure
|Temperature   |1      |1      |1      |1       | C   |Temperature level, on
|isturbine     |1      |0      |0      |0       | -   |Activate turbine at t
|issteam       |1      |0      |0      |0      | -   |Activate steam generat
|superheatdT   |200    |2      |2      |2     | K   |Superheating temperatur
|layerofdrawoff |droffp1|droffp2|droffp3|droffp4| -   |Layer of draw off for
```

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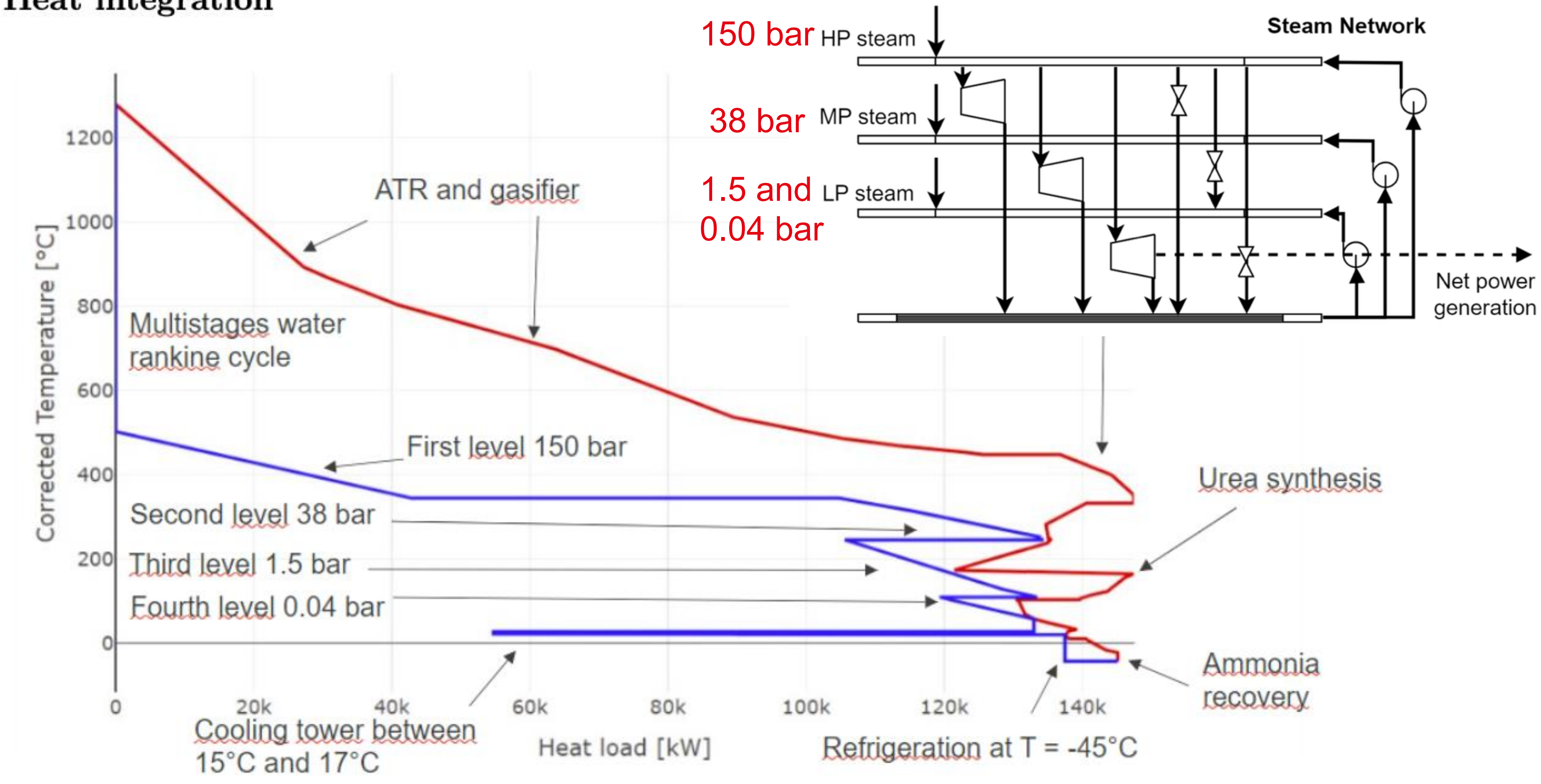
Steam network – example of heat integration

Heat integration



Market

The Market is modelling the transfers with the exterior, such as:

- the natural gas
- the electricity
- the water

that are needed for the different units.

The costs associated are also defined in the Market.

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.powerpal.net%2Fblog%2Fheat-pumps%2F&psig=AOvVaw1BnurqG-mcRivsICSRquDC&ust=1706888770968000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCMin4aq-ioQDFQAAAAAdAAAAABAI

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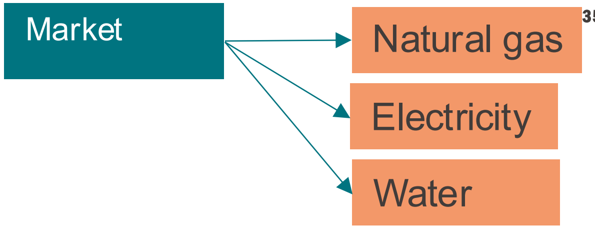
Market – Rosmose ET



- Inputs

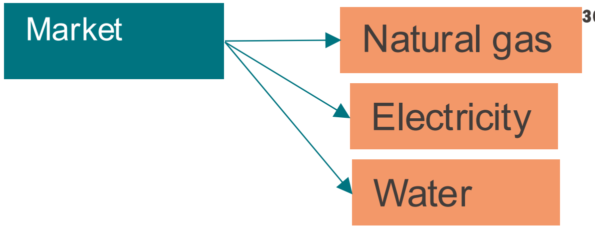
```
```{rosmose market}
! OSMOSE ET market
```


```{rosmose}
water_cost = 0.0025 [Euro/kg] # Water price in Switzerland is 2-2.5 CHF/m3 (wfw.ch and Swiss gas and water industry association)
CW_ref_LOAD = 1000 [kg/h] # Reference capacity of water supply
elec_cost = 0.25 [Euro/kWh] # price of electricity for businesses in Switzerland 2023 (Oiken)
ELEC_ref_POWER = 1000 [kW] # Reference capacity of electricity supply
natgas_cost = 0.119 [Euro/kWh] # price of natural gas for businesses in Switzerland (globalpetrolprices.com)
NATGAS_ref_LOAD = 1000 [kW] #Reference capacity of natural gas supply

```


```{rosmose}
CW_COST = %water_cost% * %CW_ref_LOAD% [Euro/h] # Reference cost of water supply
ELEC_SELL_COST = %elec_cost% * %ELEC_ref_POWER% [Euro/h] # Reference cost of electricity supply
NATGAS_COST = %natgas_cost% * %NATGAS_ref_LOAD% [Euro/h] # Reference cost of natural gas supply
```
```

Market – Rosmose ET



- Layers and units

~~~~
**Layers of the Market ET**

```{rosmose}
: OSMOSE LAYERS market

|Layer      |Display name   |shortname  |Unit       |Color  |
|:----------|:--------------|:----------|:----------|:------|
|NATGAS     |Gas            |ng         |kW         |green  |
|ELEC       |Electricity    |elec       |kW         |yellow |
|WATER      |Water          |water      |kg/h       |blue   |

```

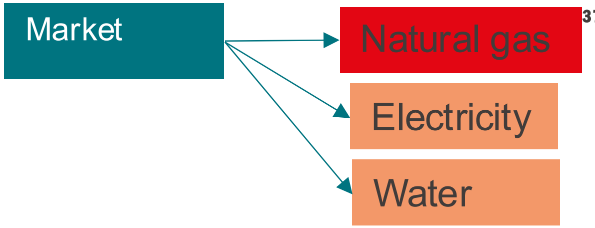
**Units of the Market ET**

```{rosmose}
: OSMOSE UNIT market

|unit name    |type   |
|:------------|:------|
|ElecSell     |Utility|
|NatgasSell   |Utility|
|WaterSell    |Utility|

```
~~~~

Market – Rosmose ET



- Natural gas unit

```
## Natural Gas Selling Unit {-}

**Parameters of the Natural Gas Selling unit**

```{rosmose NatgasSell_params}
: OSMOSE UNIT_PARAM NatgasSell

|cost1  |cost2          |cinv1  |cinv2  |imp1   |imp2   |fmin   |fmax   |
|:------|:--------------|:------|:------|:------|:------|:------|:------|
|0      |%NATGAS_COST%  |0      |0      |0      |0      |0      |1000   |
```

Natural Gas Selling Streams

Resource Streams

Natural gas sold from the market to the process. In addition to total CO~2~ emissions (direct and indirect) from the use of natural gas

```{rosmose NatgasSell_rs}
: OSMOSE RESOURCE_STREAMS NatgasSell

|layer      |direction|value                |
|:----------|:--------|:--------------------|
|NATGAS     |out      |%NATGAS_ref_LOAD%    |
```
```

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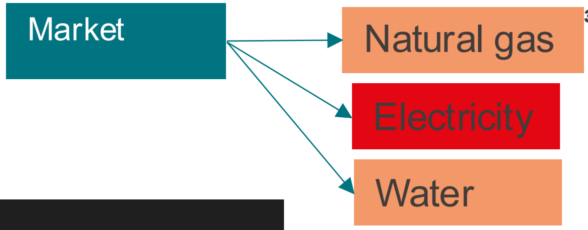
Market – Rosmose ET



- Electricity unit

```
## Electricity Selling Unit {-}

Electricity sold by the grid to the process

**Parameters of the Electricity Selling unit**

```{rosmose ElecSell_params}
: OSMOSE UNIT_PARAM ElecSell

|cost1  |cost2              |cinv1  |cinv2  |imp1   |imp2   |fmin   |fmax   |
|:------|:------------------|:------|:------|:------|:------|:------|:------|
|0      |%ELEC_SELL_COST%   |0      |0      |0      |0      |0      |100000 |
```

Electricity Selling Streams

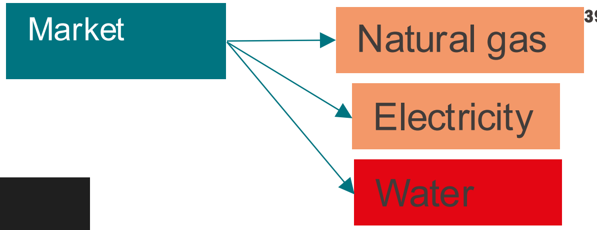
Resource Streams

Electricity sold from the market to the process and the indirect CO~2~ emissions from the electricity generated by the grid.

```{rosmose ElecSell_rs}
: OSMOSE RESOURCE_STREAMS ElecSell

|layer     |direction|value               |
|:---------|:--------|:-------------------|
|ELEC      | out     |%ELEC_ref_POWER%    |
```
```

Market – Rosmose ET



- Water unit

```
## Water Selling Unit {-}
Water from the market to the process

**Parameters of the Water Selling unit**

```{rosmose WaterSell_params}
: OSMOSE UNIT_PARAM WaterSell

|cost1  |cost2      |cinv1  |cinv2  |imp1   |imp2   |fmin   |fmax   |
|:------|:----------|:------|:------|:------|:------|:------|:------|
|0      |%CW_COST%  |0      |0      |0      |0      |0      |10000  |
```

Water Selling Streams

Resource Streams

Water sold from the market to the process

```{rosmose WaterSell_rs}
: OSMOSE RESOURCE_STREAMS WaterSell

|layer|direction|value          |
|:----|:--------|:--------------|
|WATER|out      |%CW_ref_LOAD%  |
```
```

Questions

1. Run the frontend Total Cost considering the colling tower, furnace and market to close the energy balance.
   - What is the NG consumption by the furnace?
   - What is the electricity consumption by the cooling tower?
   - What is the OPEX in Eur/y?

2. Now, run the frontend Total cost including the steam network superstructure.
   - What is the NG consumption by the furnace?
   - What is the electricity consumption by the cooling tower?
   - What is the OPEX in Eur/y?

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IPESE
Industrial Process and Energy Systems Engineering

Thank you!

École polytechnique fédérale de Lausanne