EPFL

AIChE Annual Meeting 2023
November 5 – 10, 2023, Orlando, Florida, USA

Renewable Energy Integration and Waste Heat Recovery for the Production of Sustainable Jet Fuel and Decarbonization of Industrial Heating Applications

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Introduction

- Large heating/cooling demands → Waste heat is an important byproduct.
- More stringent regulations (> 100 EUR/t_{CO2}) → Need for decarbonization.
- Power-to-gas for grid-scale energy storage.
- Sustainable aviation fuels: solution for a hard-to-abate economic sector.

- Aluminium remelting

Remelting 0.5 t_{CO2}/t_{Al}

Reduction 18 t_{CO2}/t_{Al}

- Sustainable aviation fuels

SAF may help attaining 70% of the CO_2 emissions reduction needed by aviation sector.

- Urban agglomerations

Seasonal requirements:

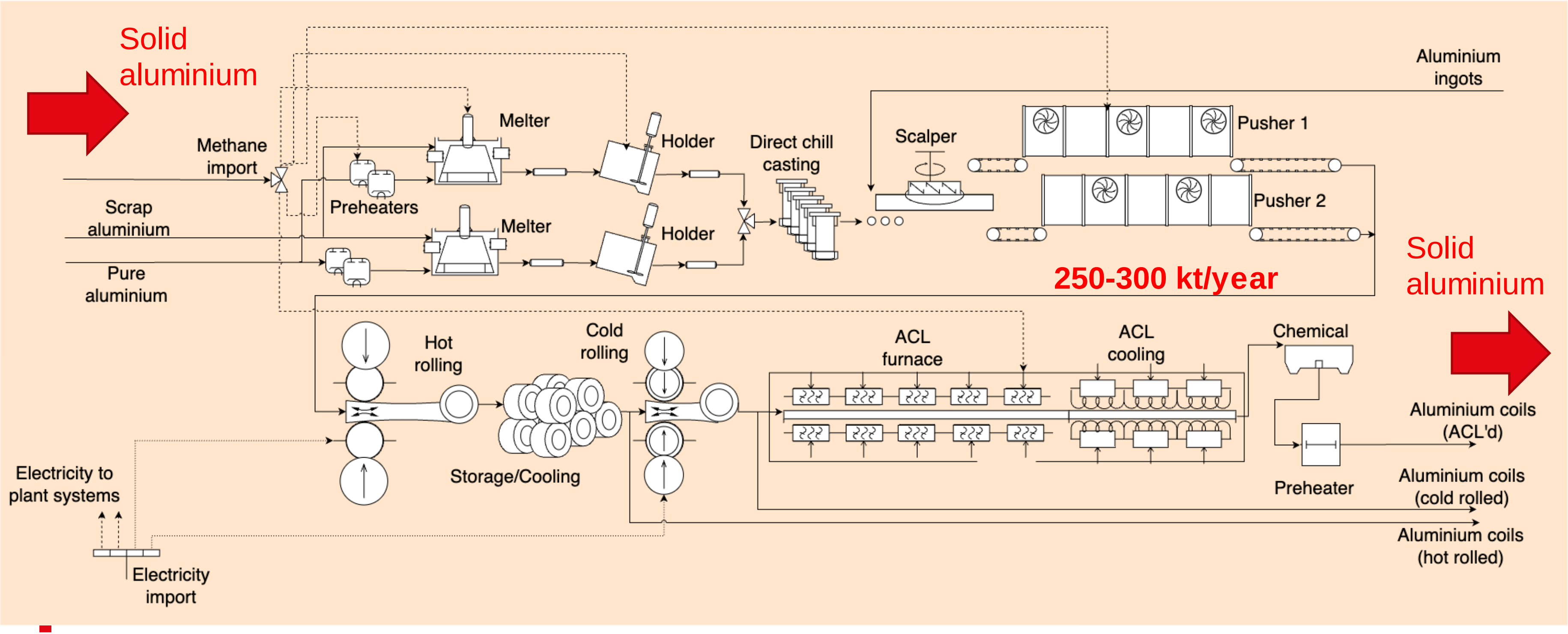
➢ space heating
➢ air conditioning
➢ refrigeration
➢ domestic hot water

Aluminium France Federation, Climate and carbon footprint, 2023 [Link]
International Air Transport Association, NetZero2050: Sustainable aviation fuels, 2023 [Link]

Aluminium remelting units

Power consumption:
~ 50-80 GWh/y

Natural gas consumption:
~ 190-210 GWh/y

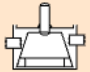
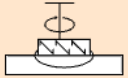
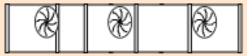
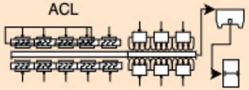


Aluminium remelting units

Aluminium processing units

Base case operation:

Heating and cooling loads and temperature levels per equipment.

Unit	Energy consumption (kWh/tAl BSO)	Temperature level (°C)
Preheater 	33.3	230°C
Melter 	355.1	730 - 750 °C
Holder 	27.0	750 °C
Casting 	178.4	750 - 60° C
Scalper 	--	--
Pushers 1 & 2 	186.8	570 °C
Hot rolling	48.6	400 °C
Storage /Cooling 	85.9	400 - 80 °C
Cold rolling	49.2	130 °C
ACL 	129.0	570, 130 °C

Biomass gasification and syngas treatment

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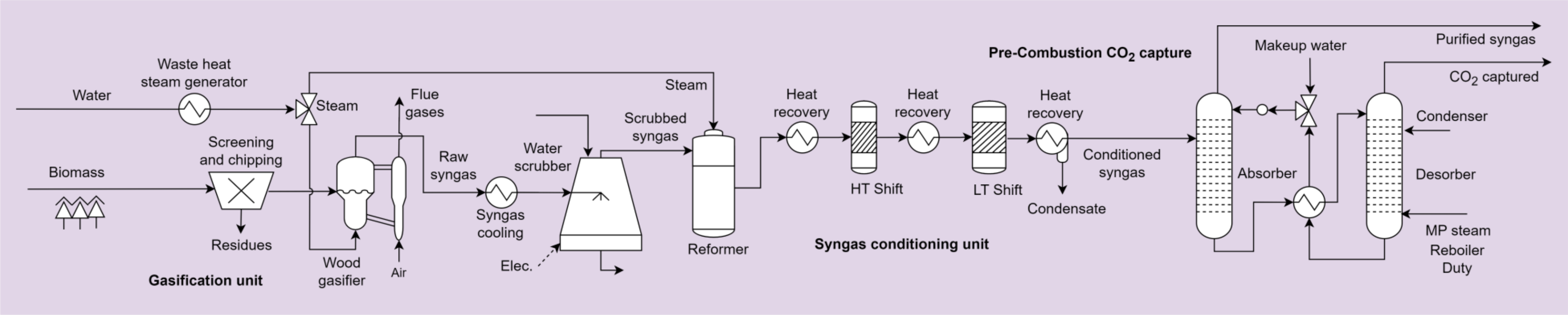
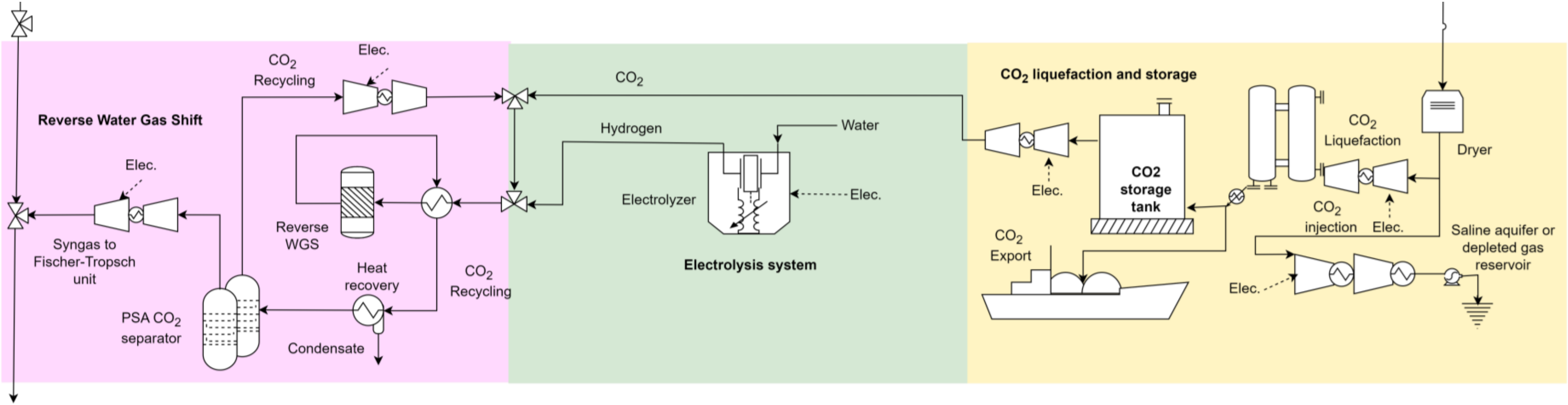
- Dual bed biomass gasification unit produces syngas that can be either be used as fuel directly or as feedstock in a Fischer Tropsch process (H_2:CO → 2:1) .



Power to Gas, Reverse WGS, Storage and CO_2 injection

- Liquefied gas storage (CO_2 management).
- CO_2 import, injection, utilization or venting (subject to taxation).
- Reverse water gas shift unit to boost syngas feed to FT section.



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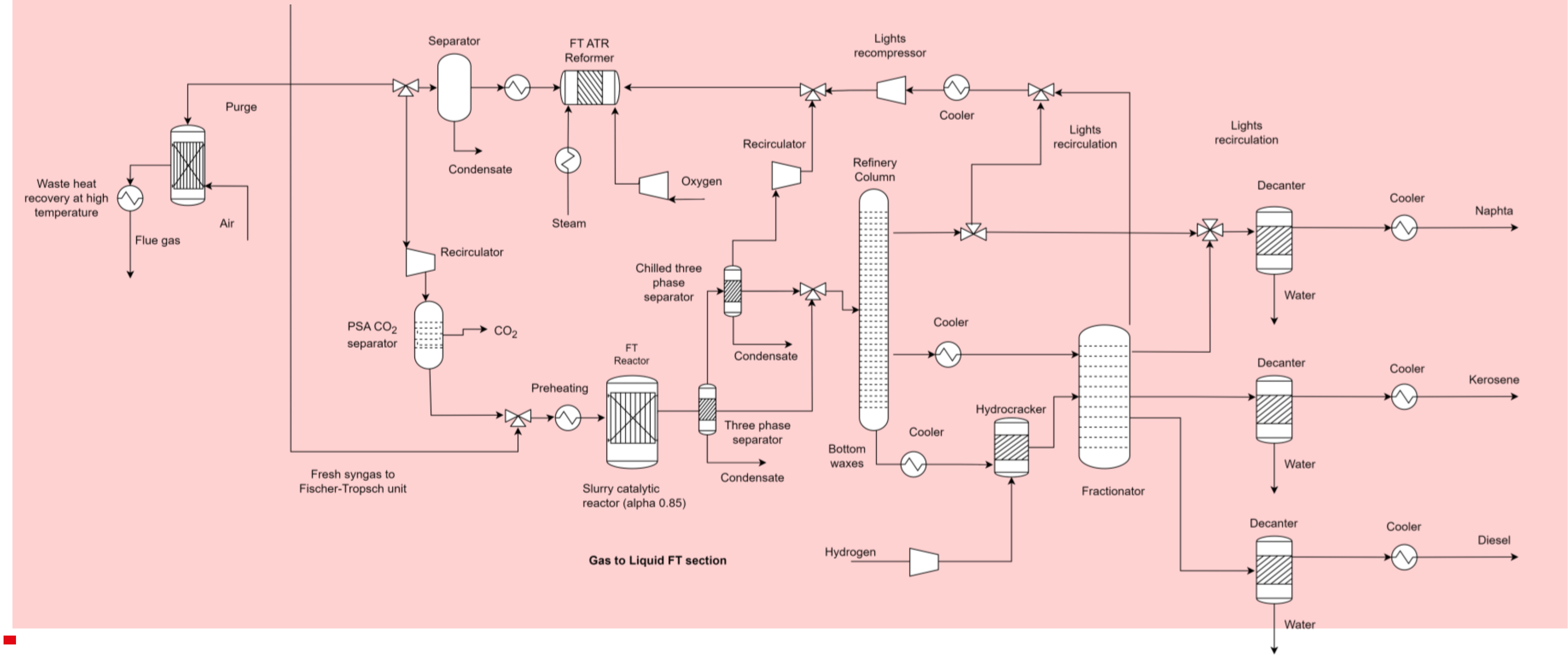
Fischer-Tropsch liquids production

- A Fischer-Tropsch unit is designed produce mostly kerosene, also diesel and naphtha from syngas.



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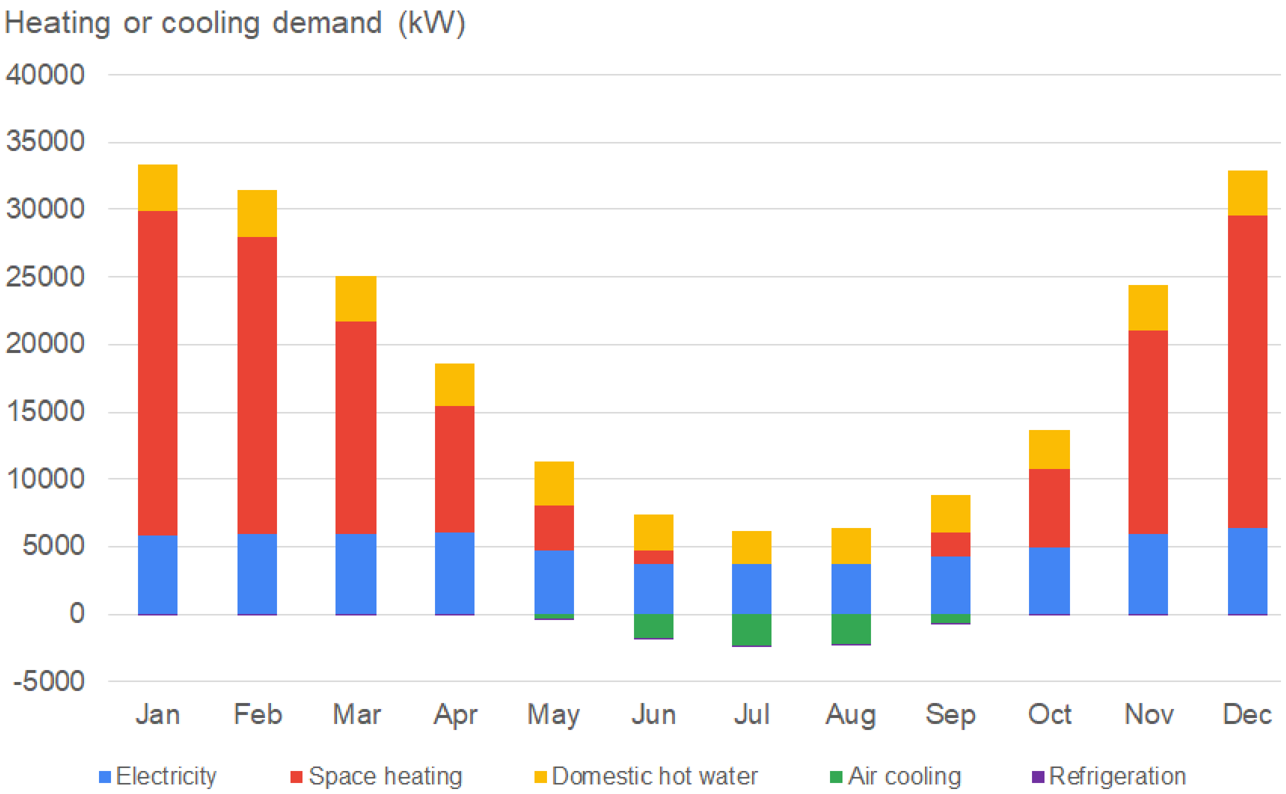
City 20,000 inhabitants

- Space heating, domestic hot water, air conditioning, refrigeration.



20000 cap.

0.682 kW/capita

~2.0 kW_{th}/dwelling

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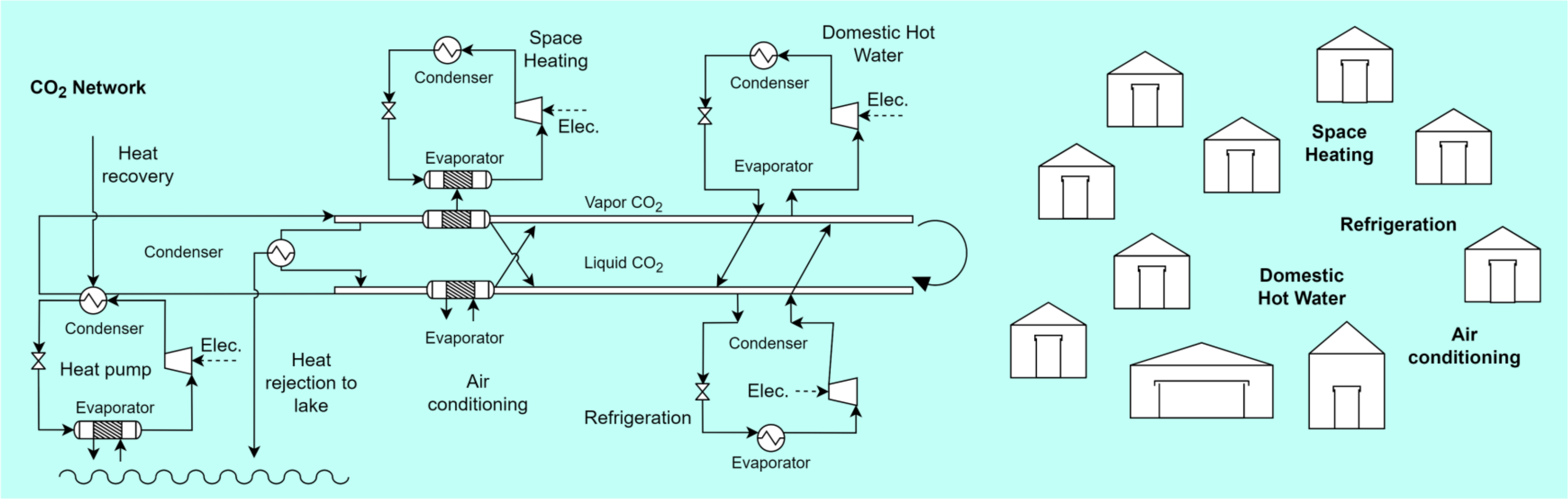
City 20,000 inhabitants

- Space heating, domestic hot water, air conditioning, refrigeration.
- CO_2 district heating network.



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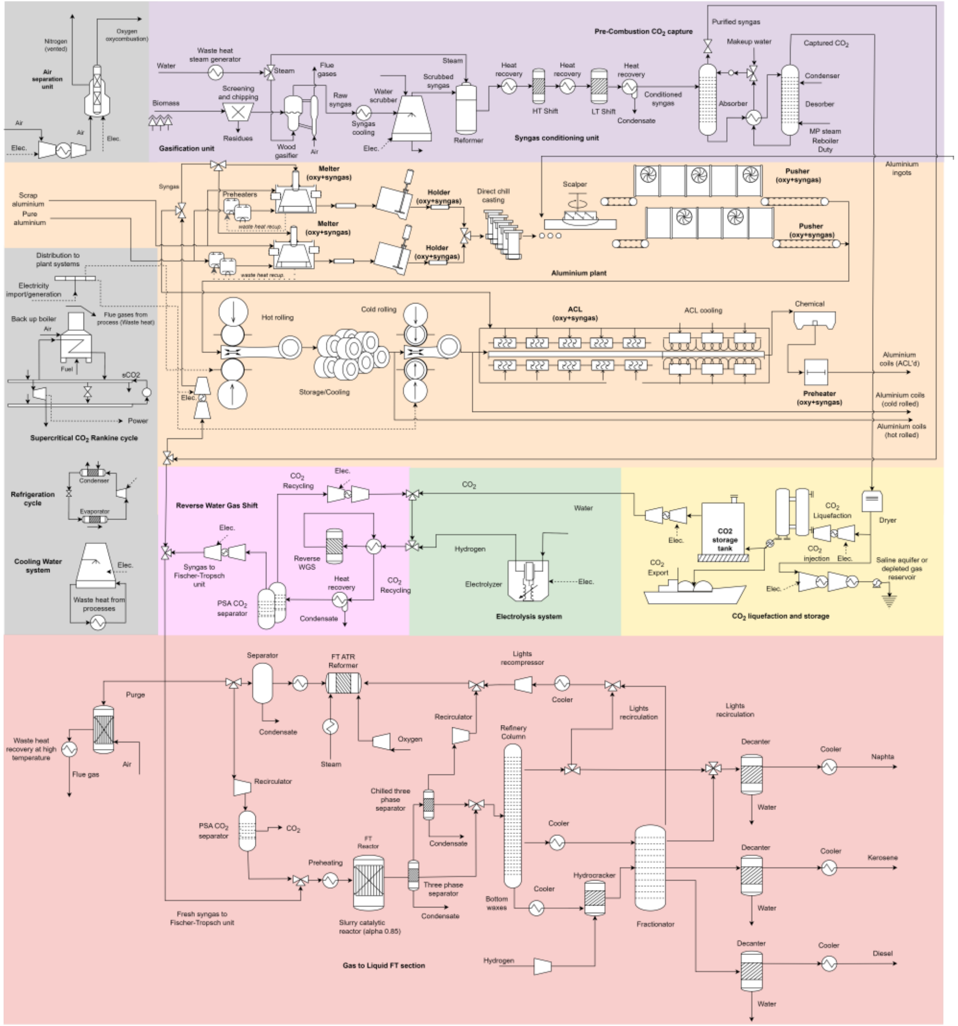
EPFL Energy Technologies

- Aluminium remelting plant
- Space heating (city, plant)
- Domestic hot water (city)
- Air conditioning (city)
- Refrigeration (city)
- Furnaces (syngas + oxycomb)
- Gasification system
- Cooling/chilling systems
- Carbon abatement units
- Power-to-gas systems (electrolysis)
- Reverse water gas shift
- Storage units (liquid CO_2)
- Waste heat recovery network
- Transcritical sCO_2 power cycle
- Air separation units

Others: Biodigestion, Cogeneration, Heat Pump, etc.



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Methods

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***w* = {*utility units, resources*},** y_w existence (binary) and f_w load factor variables

Optimization problem: minimum operating cost or maximum revenue:

$$\min_{f_\omega,\, y_\omega,\, R_r,\, W} \left[\begin{array}{l} f_{Biomass}(m\cdot c)_{Biomass} + f_{NatGas}(B\cdot c)_{NatGas} \pm f_{Elec}(W\cdot c)_{Elec} + f_{EnvEm}(m\cdot tax)_{EnvEm} + f_{Water}(m\cdot c)_{Water} \\ + f_{\substack{CO_2\\ \text{Imported}}}(m\cdot c)_{\substack{CO_2\\ \text{Imported}}} + \dfrac{Z_{equip}\times Ann\_factor}{N_{hours\ per\ year}} - f_{\text{Aluminium}}(B\cdot c)_{\text{Aluminium}} - f_{\substack{heat,biofuel,CO_2\\ \text{Exported}}}(m\cdot c)_{\substack{heat,biofuel,CO_2\\ \text{Exported}}} \end{array} \right]$$

Subject to:

$$\sum_{\omega=1}^{N_\omega} f_\omega q_{\omega,r} + \sum_{i=1}^{N} Q_{i,r} + R_{r+1} - R_r = 0 \quad \forall r = 1..N$$

$$\sum_{\omega=1}^{N_\omega} f_\omega W_\omega + \sum_{\substack{chemical\\ units}} W_{net} + W_{imp} - W_{\exp} = 0$$

$$f_{\min,\omega} y_\omega \le f_\omega \le f_{\max,\omega} y_\omega \quad \forall \omega = 1..N_\omega$$

$$W_{imp} \ge 0,\ W_{\exp} \ge 0$$

$$R_1 = 0,\ R_{N+1} = 0,\ R_r \ge 0$$

c_{NG}= 0.45 EUR/kWh; cBiom = 0.014 EUR/kWh; c_{EE}=0.15 (Nov-Feb) or 0.001 (Mar-Oct) EUR/kWh; $c_{CO2import}$=0.0084 EUR/kg; $c_{CO2,tax}$=100 EUR/t

Methods

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Process Modeling and Simulation:

CoolProp aspentech

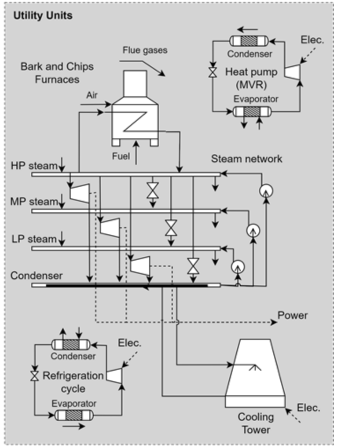
Sequential
Modular
Simulation

IPESE
Industrial Process and Energy Systems Engineering

Lua — the programming language — 25 years

Energy integration framework: OSMOSE Lua / Refprop

Equation
Oriented
Modeling and
Simulation



$$\min_{R_r} R_{N_r+1}$$

Subject to

Heat balance of temperature intervals

Minimum
Energy
Requirement

$$\sum_{i=1}^{N} Q_{i,r} + R_{r+1} - R_r = 0 \qquad \forall r = 1..N$$

Feasibility of the solution $R_r \geq 0$

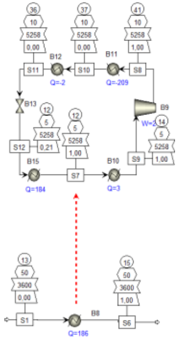
Methods

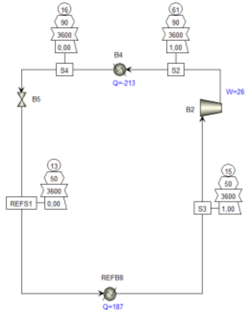
- **Tank cycling**: $Storage\,Level_t = f_{\mathrm{tank},t}$

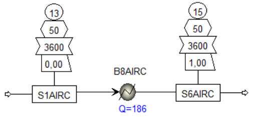
$$Storage\,Level_{t+1} - Storage\,Level_t = Mass \text{ or } Energy\,Inlet_t - Mass \text{ or } Energy\,Outlet_t$$

CO_2 stored at -50°C and 7bar (1155 kg/m^3)

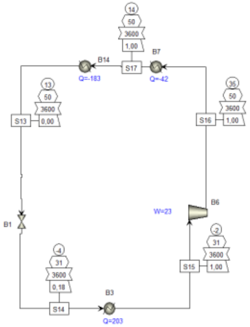
- **CO_2 network (Aspen Plus and Coolprop):**

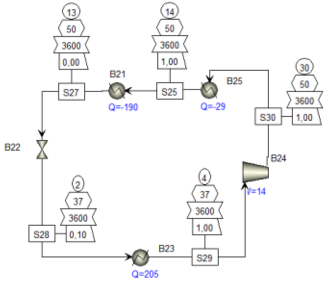

Space heating


Hot water production



Air conditioning


Refrigeration


Central plant

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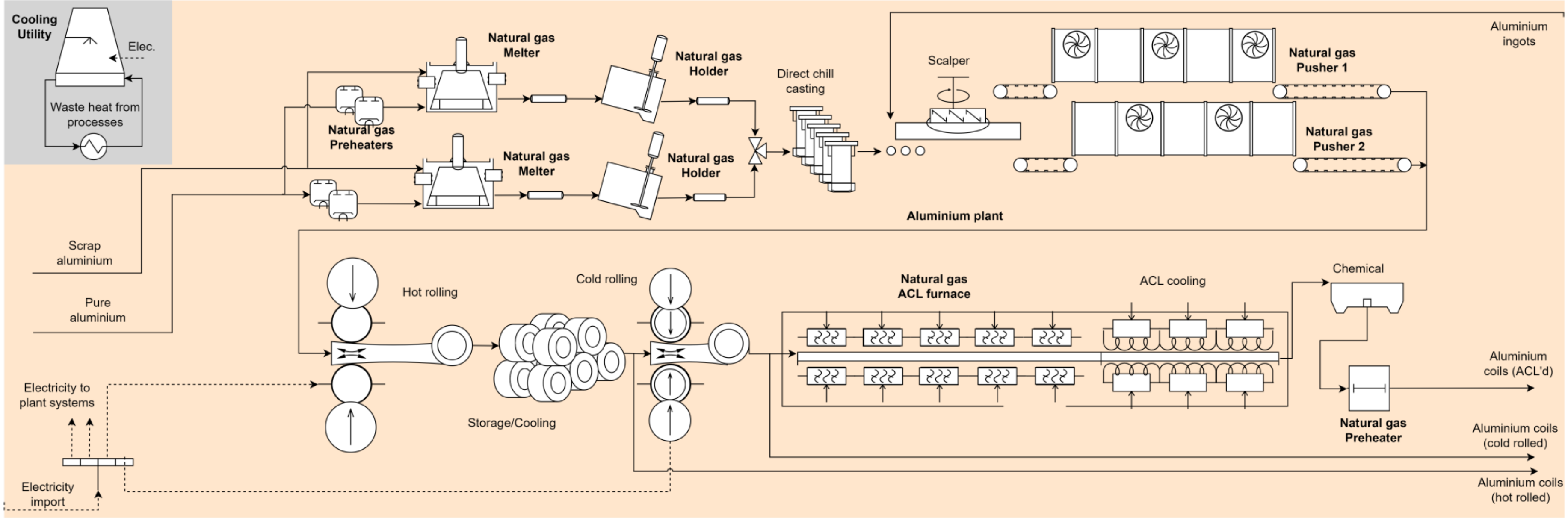
Results and discussion

Base case solution

The heating needs are provided by natural gas and electricity is imported from the grid to be used in different appliances of the plant (rolling, fans, doors etc.).



Results and discussion

Base case solution

- Natural gas consumption **252.61 GWh/y** (includes aux boiler NG cons. 59.67 GWh/y, 11.81 kt/y CO_2)
- Biomass consumption: **0 GWh/y**
- Electricity consumption: **68.86 GWh/y**
- Electricity air conditioning: 0.95 GWh/y
- Electricity self-generation: **0 GWh/y**
- Diesel consumption 0.23 kt/y
- Total emissions: **58.79 kt/y (only fossil)**
- Indirect emissions: NG cons. 4.46 kt/y, **EE cons. 4.31 kt/y**

CAPEX: 1,492,560 EUR/y
OPEX: -1,077,183,970 EUR/y

Results and discussion

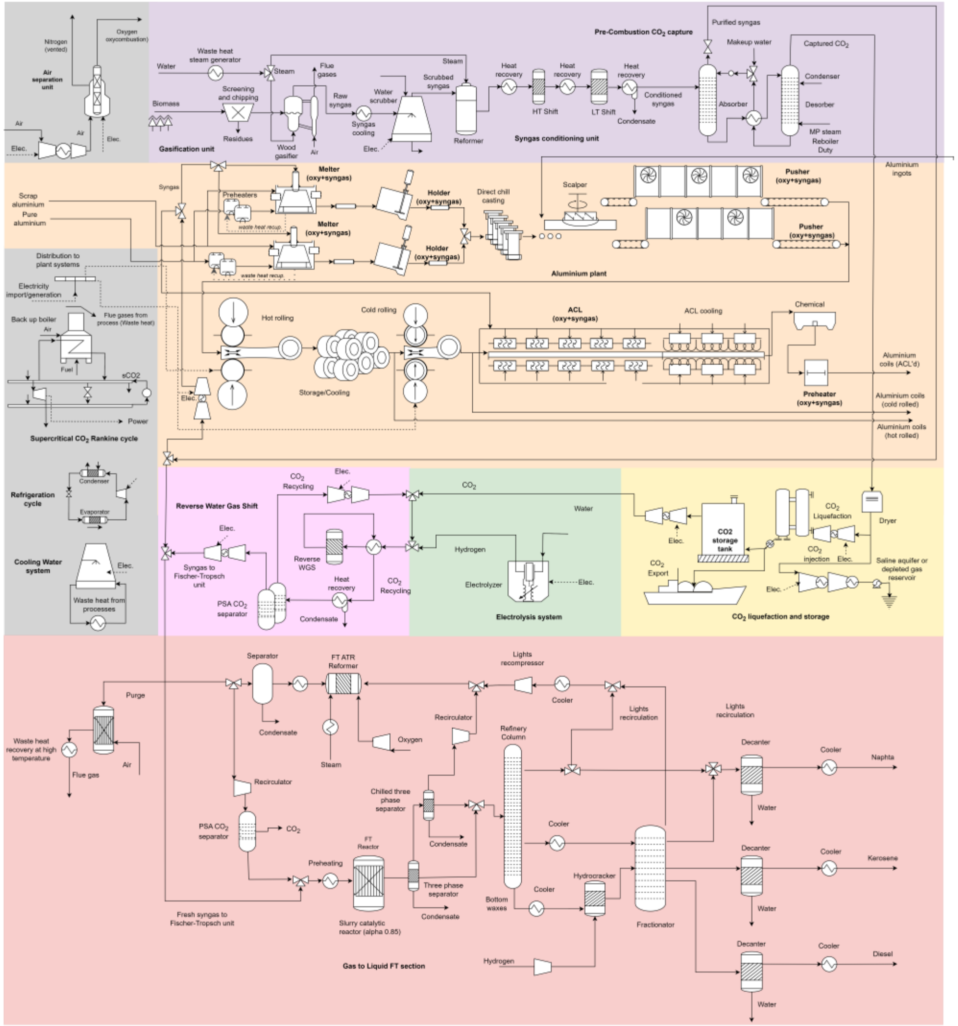
Power-to-gas and biomass gasification solution with CO_2 seasonal storage: SAF and Aluminium production integration

Electricity is partially generated in a super-critical CO_2 cycle.

Large amount of waste heat available from biomass conversion units, FT synthesis and stack gases.

Energy intensive furnaces and rWGS.

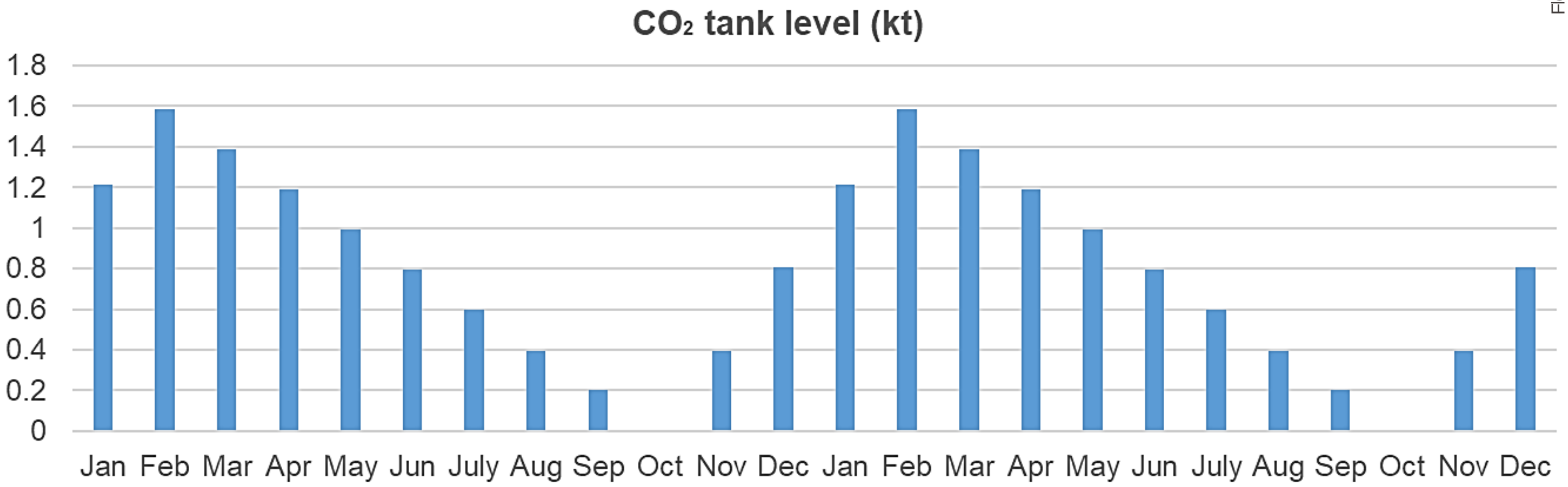
The district heating network is supplied with the waste heat recovery from industrial processes using heat pumps.



Results and discussion

Monthly variation of CO_2 storage

Frozen-earth or double-wall storage systems



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Results and discussion

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- Natural gas consumption: 0 GWh/y
- Biomass consumption: 526.88 GWh/y
- Electricity import: 792.23 GWh/y
- Electricity self-generation: 118.59 GWh/y
- Diesel consumption: 0.23 kt/y
- Power consumption in FT unit: 4 GWh/y
- Power cons. gasification (fuel and feed): 13.45 GWh/y
- Power consumption in rWGS unit: 18.41 GWh/y
- Aluminum plant power consumption: 67.88 GWh/y

- O_2 production in electrolyzer: 111.93 kt/y
- H_2 production in electrolyzer: 13.99 kt/y
- Oxygen production by ASU: 0 kt/y
- Nitrogen production by ASU: 0 kt/y
- Oxygen import: 0 kt/y
- Electrolyzer max. size: 88 MW (769.49 GWh/y)

- Kerosene production: 17.57 kt/y
- Naphtha production: 9.40 kt/y
- Diesel production: 4.08 kt/y

CAPEX: 17,959,107 EUR/y
OPEX: -1,185,532,282 EUR/y

- Syngas from gasification: 20.58 kt/y
- Syngas from rWGS: 62.32 kt/y
- Syngas fed to FT section: 82.89 kt/y

- Total emissions (all not captured): 141.28 kt/y
- Indirect emissions: EE 49.62 kt/y, Biom 7.39 kt/y
- Direct emissions (biogenic): Balance
- Import CO_2 (compensate losses): 0 kt/y
- CO_2 injected: 0 kt/y
- CO_2 in flue stack from gasifier: 58.03 kt/y
- CO_2 processed in rWGS: 89.30 kt/y

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Conclusions

- Hard to decarbonize heavy industries (**transportation and metallurgical**) require breakthrough approaches for a proper management of waste heat recovery, cogeneration and carbon abatement technologies (oxyfuel).
- Renewable energy together with an enhanced waste heat recovery and enlarged products portfolio can be more attractive and environmentally friendly ways to produce SAF and aluminium.
- Electricity import is used in the plant to drive the auxiliary aluminium remelting processes. A fraction of electricity is used in a seasonal way (power-to-gas-to-heat approach) to increase the production of SAF, when integrated with the biomass route (CO_2 available). This process is currently more expensive capex-wise though.
- Thus, a carbon tax is an important factor that may boost the deployment of carbon abatement technologies and more efficient energy conversion systems, although may not be enough for reducing the risk perception.
- Installing a novel CO_2-based district heating network may increase efficiency, as the amount of power consumed is much lower than the heat supply using fired heaters (harvest energy from environment).

Acknowledgments

The authors would like to thank the Swiss Federal Office of Energy for funding this research work in the frame of the Net Zero Lab, through the project grants “Sustainable natural gas (SNG) and aluminium production via biomass gasification and enhanced waste heat recovery in Novelis plant in Sierre City” and “Enhanced waste heat recovery approach for the reduction of fuel consumption in the aluminium industry”.

Thanks for your attention