# Process Integration in Industrial Clusters and Energy Conversion
# Industrial symbiosis : from energy requirements to large scale integration

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Industrial clusters, practicing industrial symbiosis, are typically composed of several companies or processes geographically concentrated and that are interconnected by material and energy flows. Such large-scale integration is practiced to improve the resource and energy efficiency of generating the products in the cluster and managing the waste generated. Methods developed in process systems engineering and process integration have a large potential to identify symbiosis solutions and define ways of implementing them.

## Energy and resource efficiency of industrial processes

Improving the efficiency of industrial processes begins with the understanding of the processes operations and its requirements for raw materials, energy and production support as well as the products, co-products and wastes resulting from value generation.

When analysing current energy and materials consumption by process integration techniques, it is first important to define the mass and energy exchange interfaces proposed by the units in the systems considering simultaneously the heat exchange, the process and utility flows needed. A structured process integration approach helps targeting the best exchanges that minimize the energy use while minimizing the process retrofits actions and their related investment. In this field, multi-objective optimisation and mixed integer programming techniques is used to generate a set of Pareto optimal solutions for the system. The Pareto front gives a better understanding of the trade-off between efficiency and process modifications or process constraints. An important contribution here is the restricted matches constraints [5] and the related integration of heat transfer fluids like hot water, hot oil or steam system. Combining heat recovery with energy conversion then introduces the optimal integration of combined heat and power technologies, heat pumping and refrigeration options. It defines therefore the process energy requirement as resources consumption and emissions. Industrial examples shows heat recovery potential of typically of 30%, it can reach up to 75 % when heat ungrading using industrial heat pumps having COP of 8 and more are used [6].

## Industrial symbiosis

The industrial symbiosis is achieved by integrating production plants in a similar way that process units are integrated within a production site. Integration studies follow the same methods, transcending scale, and yielding additional potential for novel solutions and unprecedented efficiencies. Reductions in total cost and emissions were demonstrated to reach 25% for conceptual design of an integrated chemical plant [3] and a real application in chemical industry cluster yielded even greater potential reductions of 40% of GHG emissions and up to 30% of the total annualized cost [4]. In such application, the solution emcompasses a cogeneration unit, a steam cycle with combined production of heat and power and a heat pumping system. Applying this method for industrial clusters, within or across sectors, shows a large potential for exchanging material and energy flows to reach new optimal designs and operating conditions. Integrated approaches considering the simultaneous savings of water and energy between different plants is another dimension of the industrial symbiosis. An application in a kraft mill in Canada showed more than 41% reduction in water consumption (including cooling water) with a 19% reduction in low pressure steam consumption [1].

## Large scale integration

Extending the system boundaries to the surrounding urban system is the last contribution of the process integration. In cities with the needs for heating, the idea is to use the building stock as the heat sink of the waste heat of the processes after heat recovery. This comes in competition with waste heat recovery by electricity generation. The difficulty is the integration of the intermittency of the demand and the proper understanding of the system integration to combine waste heat recovery and heat pumping solutions together with district heating applications.

## Integrating renewable energy sources.

### Solar sources

The integration of solar heat or solar photovoltaic electricity in industrial processes, reveals the difficulty of the energy management with the intermittency of the renewable energy sources. PI methods using optimisation methods have then to be used since the question is now not only to realise the heat recovery, but to size also the optimal solar system and the corresponding storage equipment considering the yearly and daily variations. An industrial-scale dairy plant has been studied in [2] by applying PI techniques considering heat pumping and mechanical vapor recompression together with maximum heat recovery together solar system integration. The potential greenhouse gas (GHG) emission reductions reaches 60% while reducing the total annualized cost by 25%.  The combined use of the solar and heat pumping system [2] even more drastically reduces the GHG emissions reaching a total of 90% while minimizing the solar collector area and therewith the investment cost. Similar potentials are expected in much of the food and beverage sector with additional application possible in other low- and medium- temperature processes.

### Biomass sources

The use of biomass as a heat source can be considered to supply the process needs after heat recovery and heat pump integration. If biomass boilers is one solution, the process integration also shows that biomass conversion processes can also be considered. For example, the production of synthetic natural gas from wood is an exothermic process that cogenerates 67% of biofuels and  13% of useful heat with a temperature above 300 °C. This heat is compatible with a lot of industrial processes. The PI then shows that not only the process needs can be supplied by biomass but it is at the same time producing biofuel for the transportation sector. Compared to a natural boiler, the integrated process proposed here leads by substitution to 133% of the $CO_2$ emissions [7].

## Conclusions and perspectives

Combining process integration techniques with optimisation techniques is a critical approach for the good understanding the resource and energy efficiency in complex industrial clusters. System expansion leads to large scale integration that aims at valorising synergies in the system and cascading the heat to lower temperatures usage before releasing the heat to cities or to the environment. Process integration techniques will have therefore to be adapted to consider the energy management together with the energy conversion and the heat recovery. The use of optimisation techniques will be necessary to generate in a systematic way different options and to propose the implementation of resilient solutions.

REFERENCES


[1] Kermani, M., Wallerand, A.S., Kantor I., Maréchal, F. 2017. A Hybrid Methodology for Combined Interplant Heat, Water, and Power Integration, submitted to 27th European Symposium on Computer Aided Process Engineering

[2] Wallerand, A.S., Kermani, M., Kantor I., Voillat, R., Maréchal, F., 2017, Optimal design of solar assisted industrial processes considering heat pumping: case study of a dairy, submitted to Renewable Energy

[3] Kantor, I., Betancourt, A., Elkamel, A., Fowler M., and Almansoori, A. 2015. Generalized mixed-integer nonlinear programming modeling of eco-industrial networks to reduce cost and emissions, Journal of Cleaner Production, vol. 99, pp. 160–176

[4] Pouransari, Nasibeh, 2015, Towards practical solutions for energy efficiency of large-scale industrial sites, Doctoral Thesis, École Polytechnique Fédérale de Lausanne, Switzerland. P.39

[5] Becker, Helen, and François Maréchal. "Energy integration of industrial sites with heat exchange restrictions." *Computers & Chemical Engineering* 37 (2012): 104-118.

[6] Pouransari, N., Mercier, M., Sauvion, G-N., Maréchal, F "A general methodology for energy efficiency of industrial chemical processes." *Proceedings of the 8th International Conference on Foundations of Computer-Aided Process Design*. Vol. 34. Elsevier, 2014.

[7] Celebi A.D., Sharma S, Ensinas A.V., Maréchal F.,Next Generation Boilers using Biomass Resources for the Industry, *Submitted ECOS 2017.*