EFFICIENT ENERGY CONVERSION IN THE PULP AND PAPER INDUSTRY:

APPLICATION TO A SULFITE WOOD PULPING PROCESS

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Responsable OFEN du projet	Martin Stettler
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Summary :

This report measures the actions performed in 2006 and the actions planned for 2007 within the framework of the project *Efficient Energy Conversion in the Pulp and Paper Industry*. In addition to the data reconciliation models of the steam and condensate networks and of the process of *Borregaard Schweiz a.g*, process models have been developed with the goal of defining the heat requirements of the process. The combination of utility system data reconciliation with the process models allows to considerably reduce the need for detailed process modelling and for on-site data collection and measurement. A systematic definition of the hot and cold streams in the process has been developed in order to compute the minimum energy requirement of the process. The process requirements have been defined using the dual representation concept where the energy requirement of the process unit operations are systematically analysed from their thermodynamic requirement and the way they are satisfied by the technology that implements the operation. Corresponding to the same energy requirement but realised with different temperature allows on one hand to define the exergy efficiency of the heat transfer system in each of the process unit operations and to identify possible energy savings by heat exchange in the system. The analysis has been completed by the definition of the possible energy recovery from waste streams. The minimum energy requirement of the process using the different requirement representation has been realised and the analysis of the energy savings opportunities is now under preparation. This new step will first concern the definition of the utility system integration and the systematic analysis of the energy savings opportunities followed by the techno-economic evaluation of the most profitable energy savings options in the process.

The national and international collaborations constitute also an important part of this project. The project is done in close collaboration with the engineers of *Borregaard Schweiz a.g* and with the support of the *Bonnard & Gardel* engineering company. In addition to the systematic analysis of the process plant, the energy efficiency analysis allows the engineers of *Borregaard* to define road maps and procedures for energy savings measures on their plant. By developing a collaborative project with a Canadian consortium (*E^3PAP*), the *EPFL* researchers profits from the expertise of the specialists of the *Centre de Recherche en Ingénierie du Papier* of the *Ecole Polytechnique de Montréal*.

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1 Introduction

Reduce energy consumption in the pulp and paper industry can lead to considerable cost savings. When implementing an energy efficiency program in a mill, the three main points to take into consideration are the reduction of the energy requirement, the energy recovery and the efficient integration of the energy conversion system. This analysis results in the definition of an energy efficiency road map with the evaluation of the energy savings and their related costs. Due to the high level of integration of a pulp and paper process, simple methods can not be applied alone; computer-aided process engineering tools have to be used. In this project, we present the application of a process integration methodology for energy savings options in the pulp and paper industry. Energy efficiency enhancement options are developped for the Borregaard Schweiz AG calcium bisulfite pulp manufacturing mill. This mill has the particularity that it does not only produce pulp but, it produces also bioethanol and precipitated lignin. It is highly integrated and individual processes (pulp making, lignin extraction, bioethanol production, chemical recovery and recovery boilers, etc.) interact with each other. In this context, mill-wide process simulation combined with the application of process integration tools, such as pinch analysis, is the key of the methodology to reach the energy savings target. A comprehensive computer-aided methodology for analysing the integration of utility systems and energy conversion technologies in the mill has been developed. The goal of the methodology is the identification of energy savings options considering process integration and thermo-economic optimisation techniques. The study focuses on process integration with combined heat and power generation and environmental impact abatement, i.e. the reduction of sulphur emissions in the sulphur recovery loop from the lignin combustion process.

2 Summary of the work performed in the second period

The process requirement analysis is made based on the system analysis approach of Figure 1.

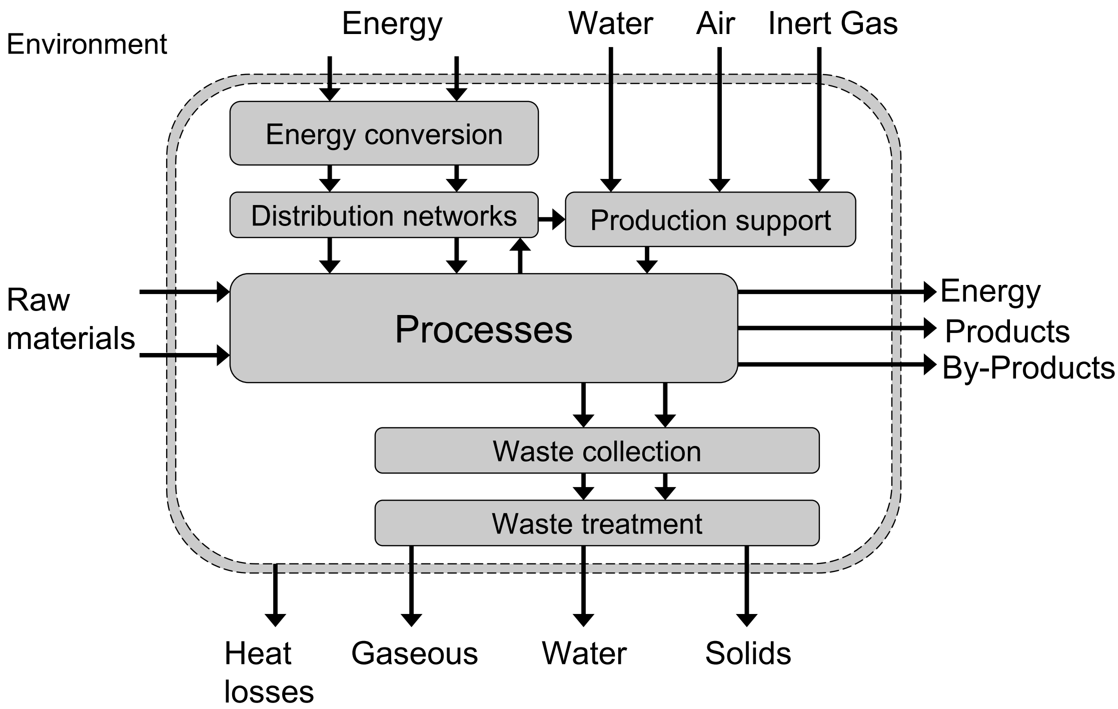

Figure 1: System analysis of a process

The analysis aim at identifying ways of maximising the horizontal flows and minimising the vertical flows, i.e. minimise the energy consumption or maximise the energy efficiency. From this representation, it has to be mentioned that the minimisation of the vertical streams means also minimising the waste production of the plant, therefore reducing in the same way the environmental impact.

The method is applied to a bisulfite pulp mill located in Switzerland that produces 127 000 t/a of cellulose as a main product. This cellulose is used for pulp making and as chemical intermediate and plastic moulding. The mill also enters in a biorefinary concept since it produces from the main lignin stream by-products such as yeast, ethanol and lignin and furnished fuel for the main boiler of the mill. A simplified process flow diagram is given in Figure 2.

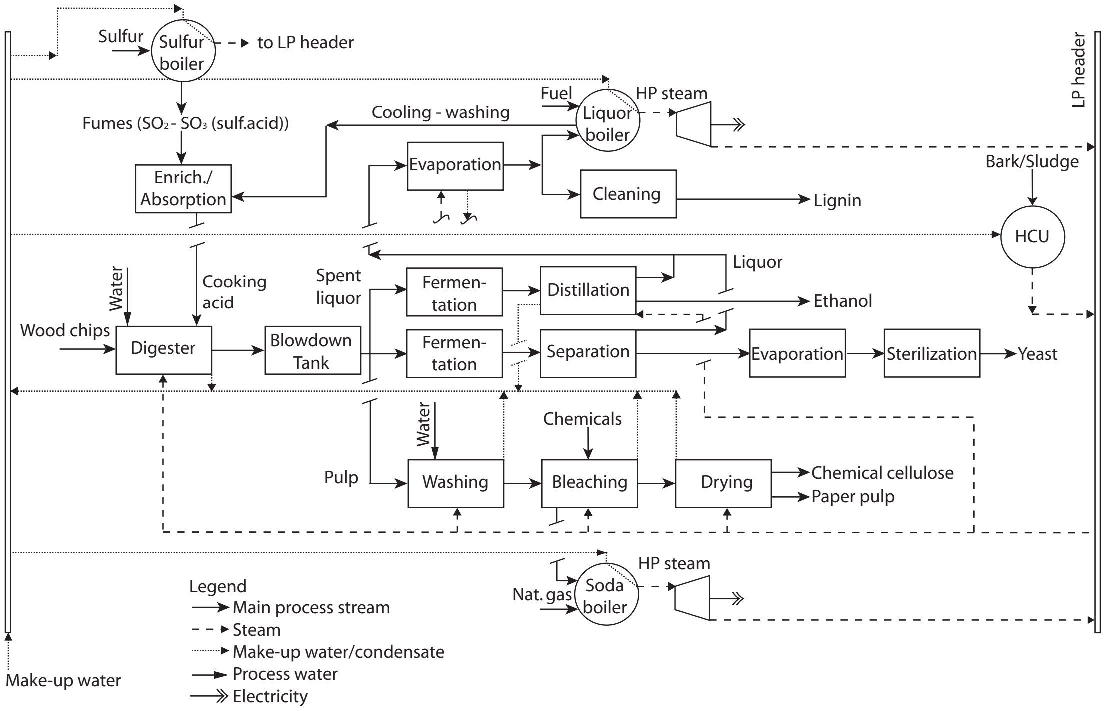

Figure 2: Simplified process diagram, *Abbreviations*: HCU: heat conversion unit, LP & HP: low and high pressure steam

2.1 Characterisation of the process energy requirement

The first year of the research has targeted the definition of the key performance indicators of the process applying a top-down approach aiming at analysing the process from the utility system perspective. The key performance indicators have been analysed (Tables 1 and 2). The indicators have been set for the plant performances (i.e. energy intensity of the process) but also for the energy conversion systems : recovery boilers, bark boilers and the distributed energy and their respective usage in the process. The streams characterisation is based on the systematic analysis of the process unit operation as described on Figure 3 for the drying section of the pulp and paper process of Borregaard.

Table 1: Operating nominal conditions of the mill (2003)

Stream	**Value**
Production	**t/a**
Cellulose	127 206
Ethanol	9311 (117 871 hl/a)
Yeast	5850
Lignin	100 000
External energy	**t/a except NG**
Wood	810 000
Heavy oil	9589
Natural gas	8 185 717 Nm3/a
Sulphur	7800
Calcium carbonate	14 000
Internal energy	**t/a**
Liquor	122 819
Utilities	**t/a**
Steam production	619 488
Steam bought	264 384
Steam consumption	883 872
Fresh water	31 884 804
Electricity	**kWh**
Site production	25 044 710
Bought	185 221 137
Total consumed	210 265 847

Table 2: Load and efficiencies of boilers (2003)

Boiler	**Load**	**Spec.load**[a]	**Efficiency**
	kW	kW/t	%
Liquor boiler	38 733	2651	81.9
Soda boiler	14 817	1014	87.8
Biomass boiler	5661	387	65.0
Sulphur boiler	1253	86	ND

[a]Specific load: kW per ton of cellulose produced

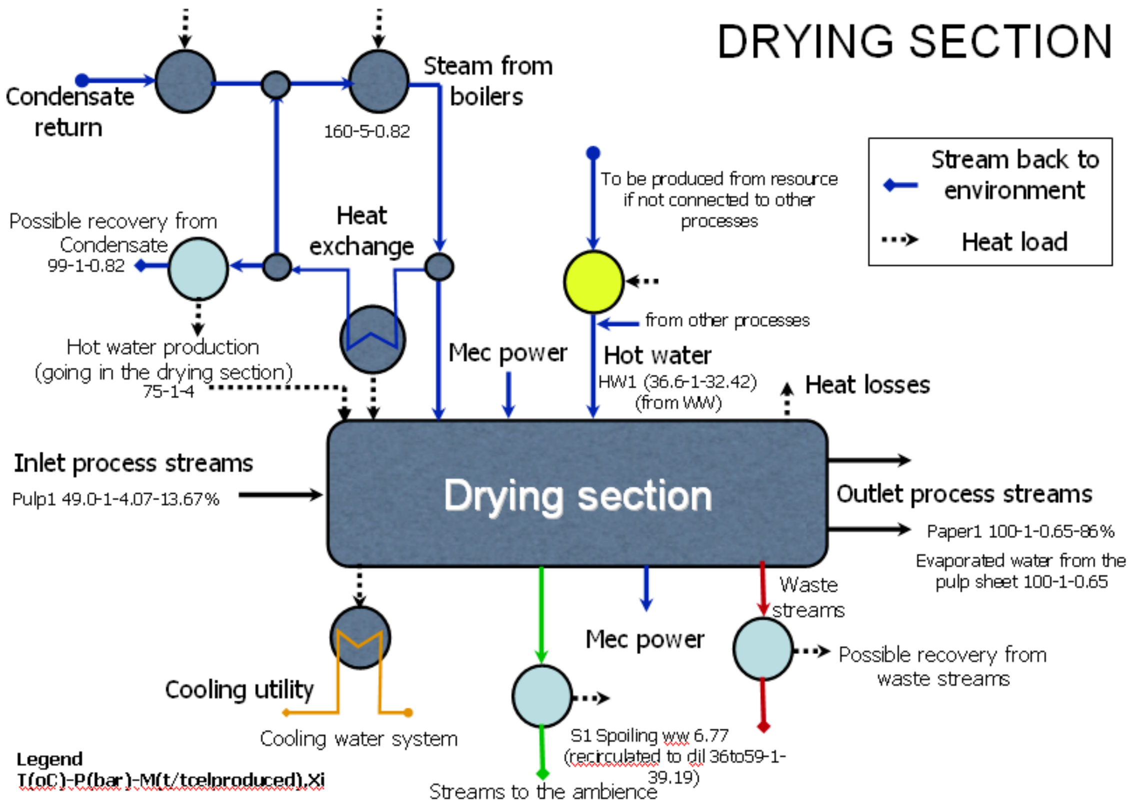

Figure 3: Representation of the drying section using the systematic definition of the energy requirement

2.2 Definition of the process energy requirement

The concept of the dual representation has been used in order to define the process requirements. The dual representation aim at analysing each unit operation from the perspective of the energy requirement. In our approach, only the heat and power requirements have been considered. For the heat requirement perspective, the process requirement is defined as a list of hot and cold streams characterised by their enthalpy temperature diagram. This allows also to perform an exergy analysis simultaneously to the process integration approach. In the dual representation approach, each unit operation is represented in different ways considering the level of technology modification that will be required by the unit.

1. the thermodynamic representation is the definition of the enthalpy-temperature heat profile that is required to thermodynamically realise the unit operation. The thermodynamic requirement is assuming that the physical and chemical operations will not be modified but that there is the possibility of changing the heat transfer operations that are required by the operation.

2. the technological representation defines the heat transfer required by the technology that is realising the operation : e.g. a hot air dryer. The comparison between the technology and the thermodynamic requirement allows to identify the heat transfer performance of the technology used to realise the operation. The difference between the exergy balances of the thermodynamic requirement of a unit operation and its technology implementation allows to quantify the exergy losses that are due to the technology implementation.

3. the utility representation defines the heat transfer as required by the unit from the utility system perspective. It represents the way the unit operation is consuming heat from the energy distributions systems. The sum of the utility representation of the unit operations defines the heat-temperature profile of the process as it is seen by the energy conversion system.

The concept of the dual representation has been presented in [1] and presented at PRES 2006 conference [2] and ATIP conference [3].

3 Definition of the energy recovery streams

When adopting the system analysis as described on Figure 1, it is important to consider that the waste streams should be near their equilibrium state when they leave the system. This allows one to identify possible energy recovery by valorising waste streams heat. When defining the process requirements, the focus is also put on the identification of the energy recovery potential that results from the waste streams. The major benefit of this definition is to segregate the waste streams allowing to capture the exergy content (i.e. the temperature level) of the effluent in order to quantify the heat that could be recovered by avoiding effluent mixing and avoiding emissions in a state that is not in equilibrium with the environment (this is for example the case for streams with high level of humidity content). For the heat recovery streams, the same approach with the three representations has been used since the quality of the heat recovery streams will depend on the technology implementation and the energy distribution or collection systems. Figure 3 shows for example the representation of the drying section. From this analysis, the energy requirement and the recovery streams are plotted as hot and cold composite curves for the different requirement representations (see Figure 4).

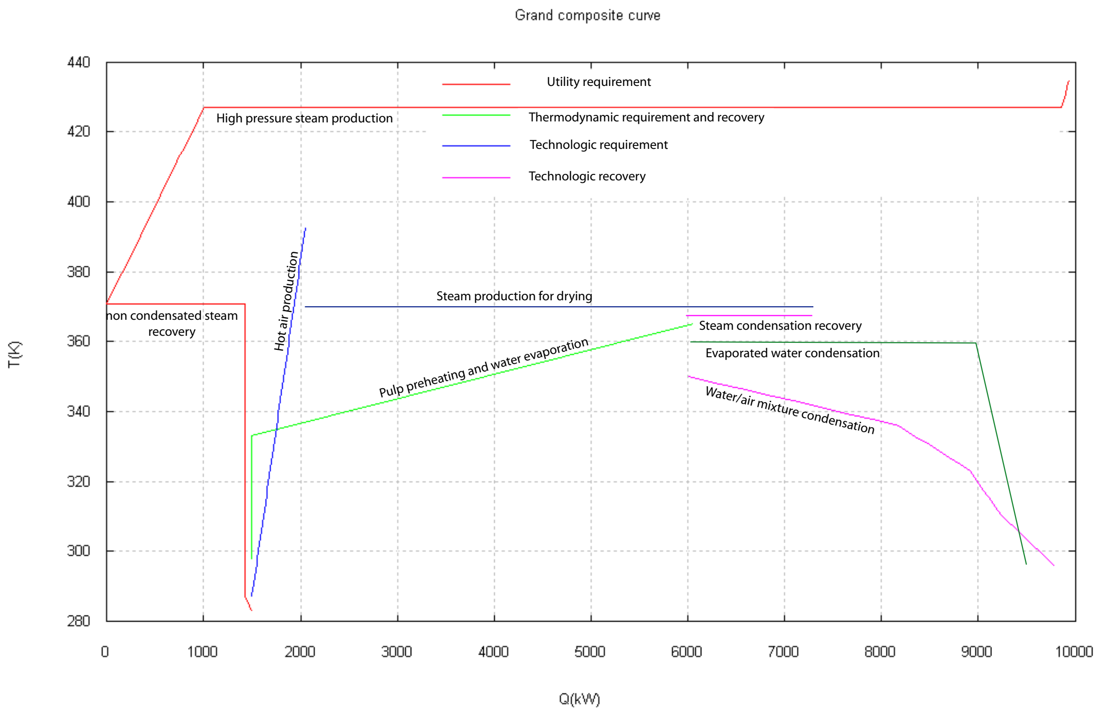

Figure 4: Composite curves of the requirements for different representations of the drying section requirements

It is important to note that when considering the heat recovery streams, the heat balance of the different representations will have the same heat balance.

3.1 Definition of the minimum energy requirement

The dual representation defines the list of hot and cold streams that will be handled to define the minimum energy requirement of the system using pinch analysis techniques. The pinch analysis allows identifying the possible heat recovery between the hot and the cold streams of the system. The fact that the temperature of the heat requirement as well as the stream definition will change from one representation to another will allow to compute different heat recovery and combined heat and power production solutions

even if the heat balance is identical. The minimum energy requirement calculation adds therefore another dimension to the calculations by allowing not only to consider the exergy efficiency of the process unit operations but also by adding the dimension of the process integration.
The minimum energy requirement of the plant of Borregaard has been defined and the different representation of the requirements have been compared. The comparison of the grand composite curve of the utility and technological requirememts are compared on Figure 5. These curves concern only the section of the steam consumption with the recovery boilers section. It can be seen that a considerable energy saving could be obtained by changing the definition of the requirement, meaning that a careful analysis has to be done concerning the integration of the utility system and the technologies. Investigations are under way to quantify the savings both in terms of energy and in terms of process modifications.

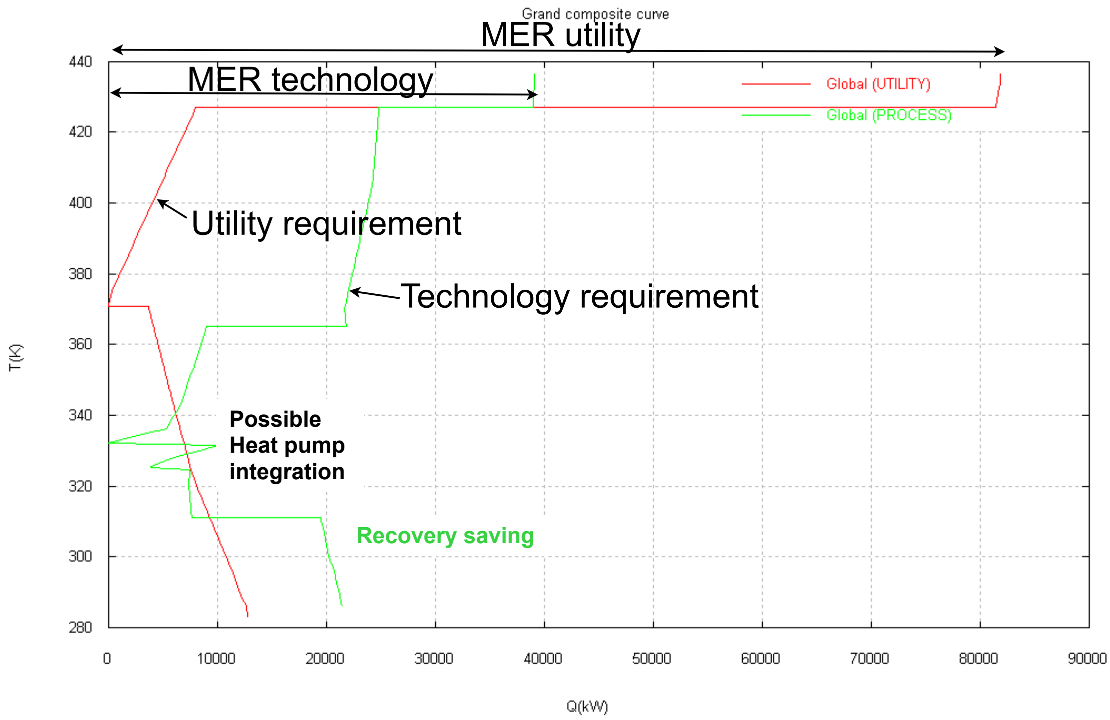

Figure 5: Comparison of the grand composite curves of the utility and technological requirements integration

The analysis of the energy savings results from the possible heat recovery of the process streams. For example, the Figure 6 shows the possible energy saving that would results from the heat recovery of the exhaust of the air dryer. The heat recovery results mainly from the condensation of the evaporated water, it is useful for the preheating of the water in the process.

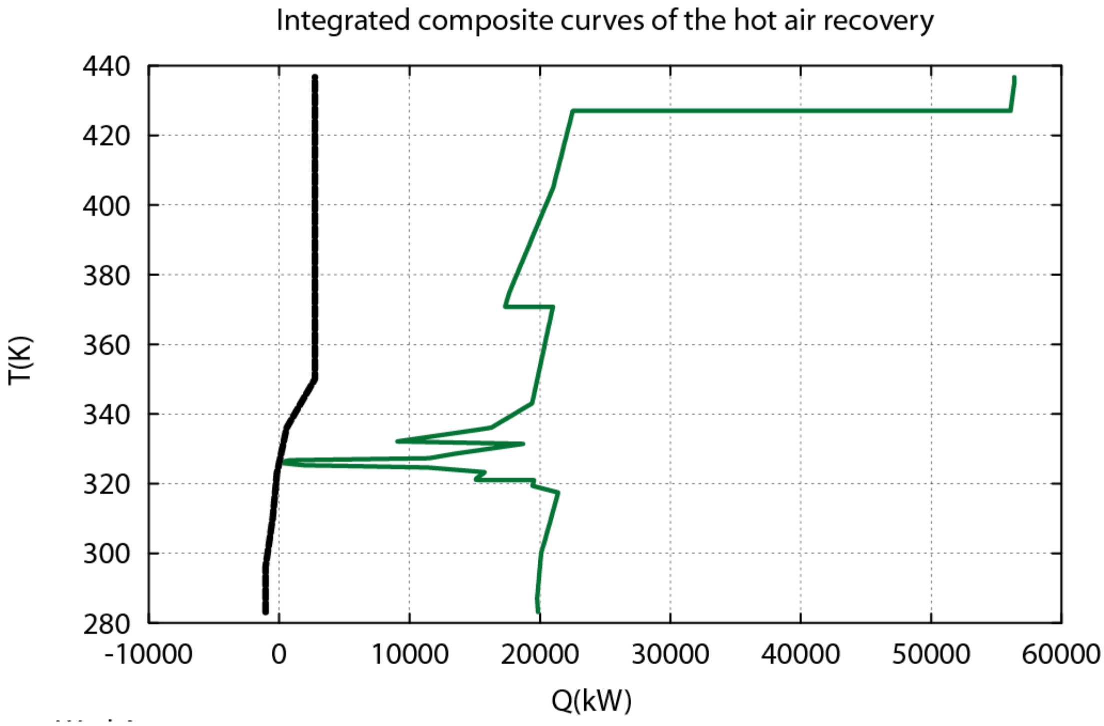

Figure 6: Integrated composite curve of the hot air recovery

Furthermore, the use of the integrated composite curves concept combined with the decomposition of the process integration problem into sub-systems following the sections as described in Figure 2 allows to identify the necessary exchanges between sections that allow to realise the heat recovery potential. As an example, Figure 7 shows that a heat recovery of 6000 kW is possible by heat recovery from the processes to preheat the streams of the bleaching section.

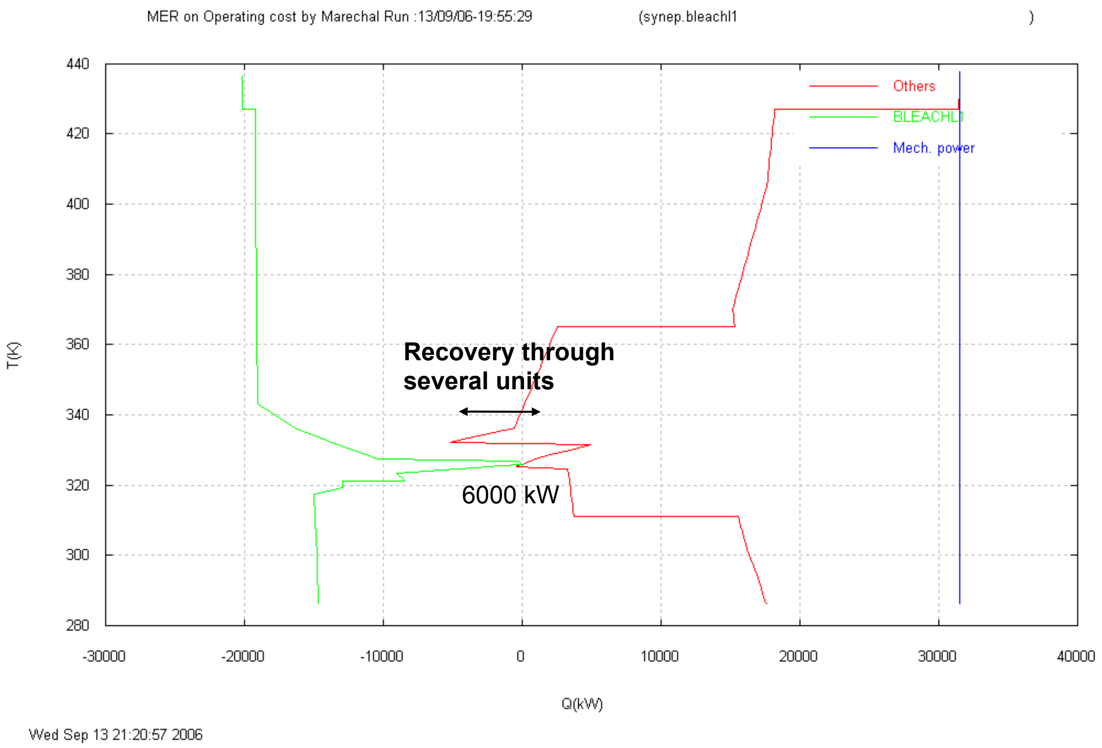

Figure 7: Integrated composite curves of the bleaching section

4 Next steps in the analysis

4.1 Complete data collection

- Integrate the sulphur loop, fuel consumption (liquor, sulphur, etc) in the energy integration process
- Modeling of the ethanol plant
- Validation of the evaporation section (measurements and representation)
- Report

4.2 Validation of the data on the Borregaard process

Most of the process sections have been characterised, the energy conversion units remains to be defined with the perspective of the process integration. In particular, we will represent the liquor, soda and sulphur boilers that have to be considered as recycling streams unit operations rather than utility boilers.
The data of the process requirements for each of the representation will be validated together with the engineers of Borregaard. A detailed report of each process section representation will be issued.

4.3 Integration of the energy conversion units

Analysing the grand composite curve will allow to define the characteristics of the energy conversion system, namely validate the steam network pressure characteristics as well as the possibility of integrating heat pumps or cogeneration devices.
Applying the process integration techniques using optimisation tools will then allow to quantify the energy savings in terms of fuel savings rather then in terms of energy.

4.4 Identification of the energy saving opportunities

A systematic analysis of the energy recovery opportunity is now under examination. A method that systematically analyses the different representations will be developed. This will be done by considering that switching from the technology representation to the thermodynamic representation corresponds to an important investment since it corresponds to modify the technology in use for the given unit operation while changing from utility to technology representation is not really difficult to realise. By realising a systematic analysis, it will be possible to identify the most important process improvement actions with a holistic analysis.
Discussion with the engineers from Borregaard and Bonnard & Gardel will allow to validate the preliminary feasibility of the selected options.

4.5 Definition of the most important energy savings options

For the analysis of the targeting results, the most important energy savings options will be characterised. This will be realised by a critical techno-economic review of the energy savings options identified. This work will be done in collaboration with the engineers of Borregaard and Bonnard & Gardel.

5 International collaboration

The EECPPI project is realised in the frame of collaboration with a Canadian consortium (E3PAP) that will study in more details the aspects of eco-industrial clusters and the integration of energy conversion technologies like heat pumps. A general description of the associated Canadian project can be found below.

5.1 Objective of the E3PAP project

The objective of the E3PAP project is to establish that it can be technically feasible and cost effective to integrate Canadian pulp and paper mills in eco-industrial clusters by the retrofit of advanced thermal cycles for enhanced energy efficiency. E3PAP focuses on two components of such a cluster, the mill supplying energy and the surrounding community using it. The economics will be assessed in terms of infrastructures required versus energy savings and environmental benefits achievable for both mill and community. The technology to be implemented in the mill will be trigeneration combined with new types of absorption heat pumps.

5.2 Progress of the contribution of the Swiss team to the project in Canada

The approach developed for the bisulphite process of Borregaard has been applied to the kraft pulp and paper process in Canada. The Canadian Team has developed a simulation model of the pulp and paper process and has collected the information concerning the process requirement. Together with the Canadian team, the Swiss team has contributed to the analysis and the validation of the utility system characterisation. The application of the dual representation concept to analyse the energy requirement of the process has been realised in a collaborative project between the PhD student in Canada and the one in Lausanne. A close relationship between the two research team allows to validate the developed approaches and to profit from the complementary experience of the two teams.
The collaboration is bilateral : Dr F. Marechal is co-director of a Ph D. thesis in Montreal while Prof Jean Paris (Ecole Polytechnique) is the co-director of the thesis of Mrs Zoe Perin Levasseur in Lausanne.

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[3] David Brown, Zoé Périn-Levasseur, François Maréchal, and Jean Paris. Une nouvelle méthode d'analyse thermique et son application aux procédés papetiers. ATIP (Association technique de l'industrie papetière), Annecy, 27 au 29 avril 2005, 2005.

6 Annexes

6.1 Presentation at the PRES 2006 conference

PRES 2006 - 9th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction

Methodology for Process Energy Analysis: application to a sulfite wood pulping case

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École Polytechnique Fédérale de Lausanne, CH
[2] Borregaard Schweiz AG., CH
[3] CRIP- Research Center for Paper Engineering
École Polytechnique de Montréal, CA

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ÉCOLE POLYTECHNIQUE MONTRÉAL

Introduction

- P&P processes are energy intensive

Cost percentage related to energy	12%
GJ/ton of pulp produced	4
Energy consumption	2/3 heat (steam and water) 1/3 electricity

For EU (2006)

- Retrofit efficient energy program
- Mill goal: reduce its energy cost

Our objective

Define an approach for the optimal management of energy use and conversion in the pulp and paper industry

Outline

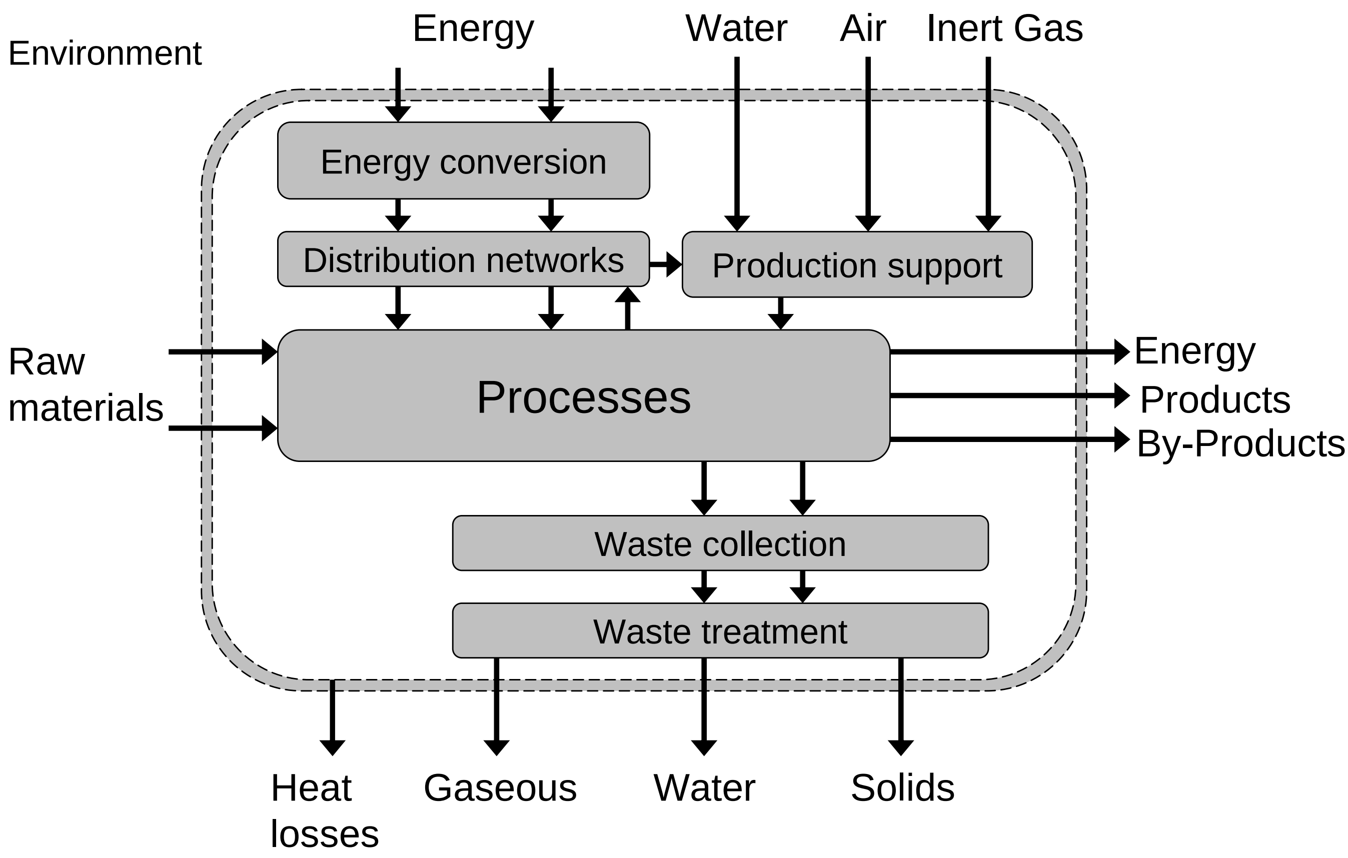
- Definition of the nominal conditions for a process integration study
  - Set of coherent data
  - Data reconciliation
  - Nominal operating conditions and key performance indicators

- Method for identification of preliminary potential of energy recovery
  - Dual representation

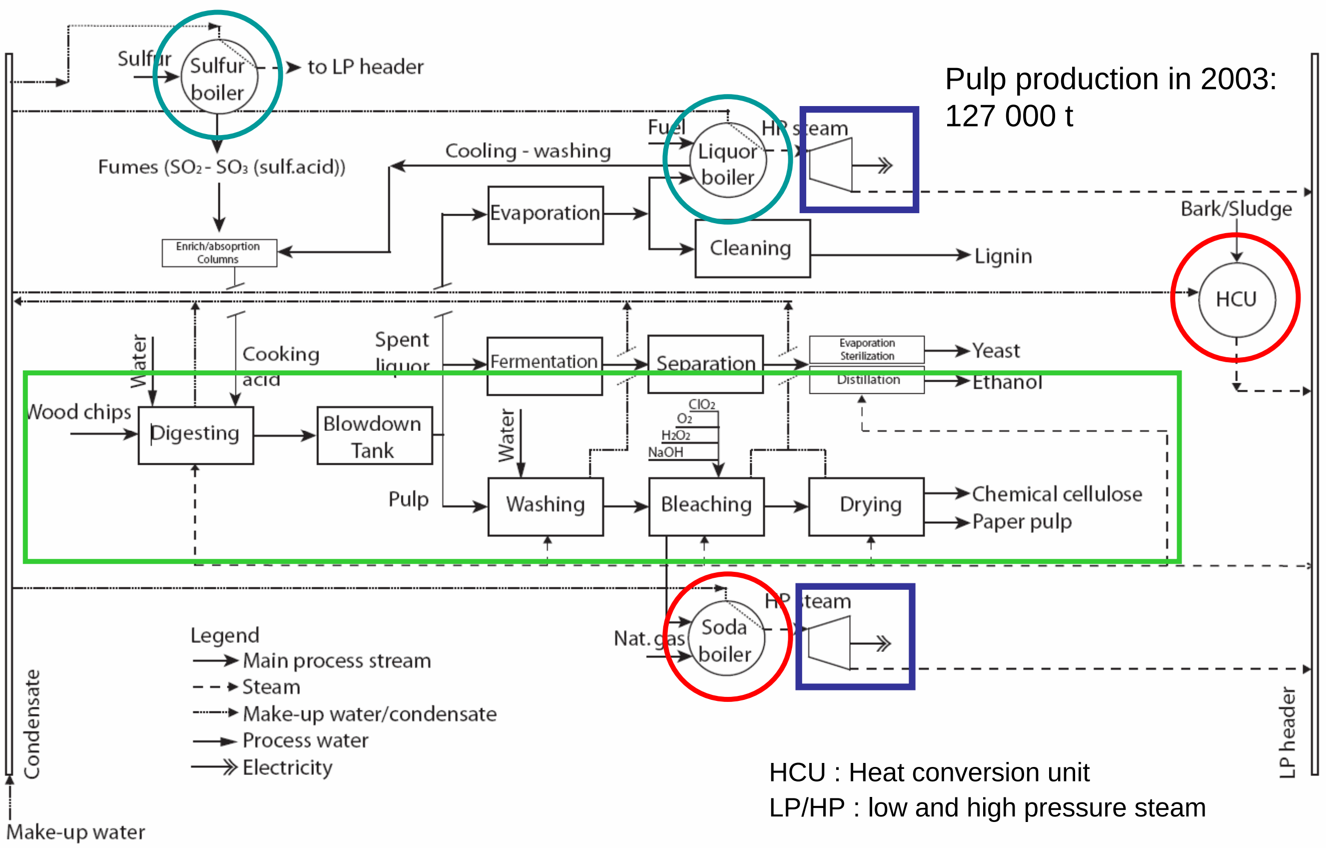
Illustration: Sulfite wood pulping mill

- Concluding remarks

Integrated process system



Process layout



Defining the nominal conditions (1/6)

- From a standard simulation to a data reconciliation model

Available data

Online/offline measurements, design data, specification sheets, etc

Belsim s.a 2005

Vali 4.0

Coherent data

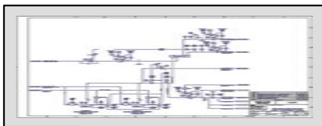


Table 4: Reconciliation example on key steam production indicator

	Value t/h	Acc[a] %	RVal t/h	RAcc %	Corr %
Liquor boiler	46.6	5	43.5	4.2	7.1
Soda boiler	19.4	5	17.4	4.0	11.5
Biomass boiler	8.5	5	8.2	4.8	3.7
Sulphur boiler	2.6	5	2.6	5	0
Total site production	**77.1**		**71.7**		**7.5**
Incinerator (steam import.)	33.3	5	30.6	4.3	8.8
Total	**110.4**		**102.3**		**7.9**

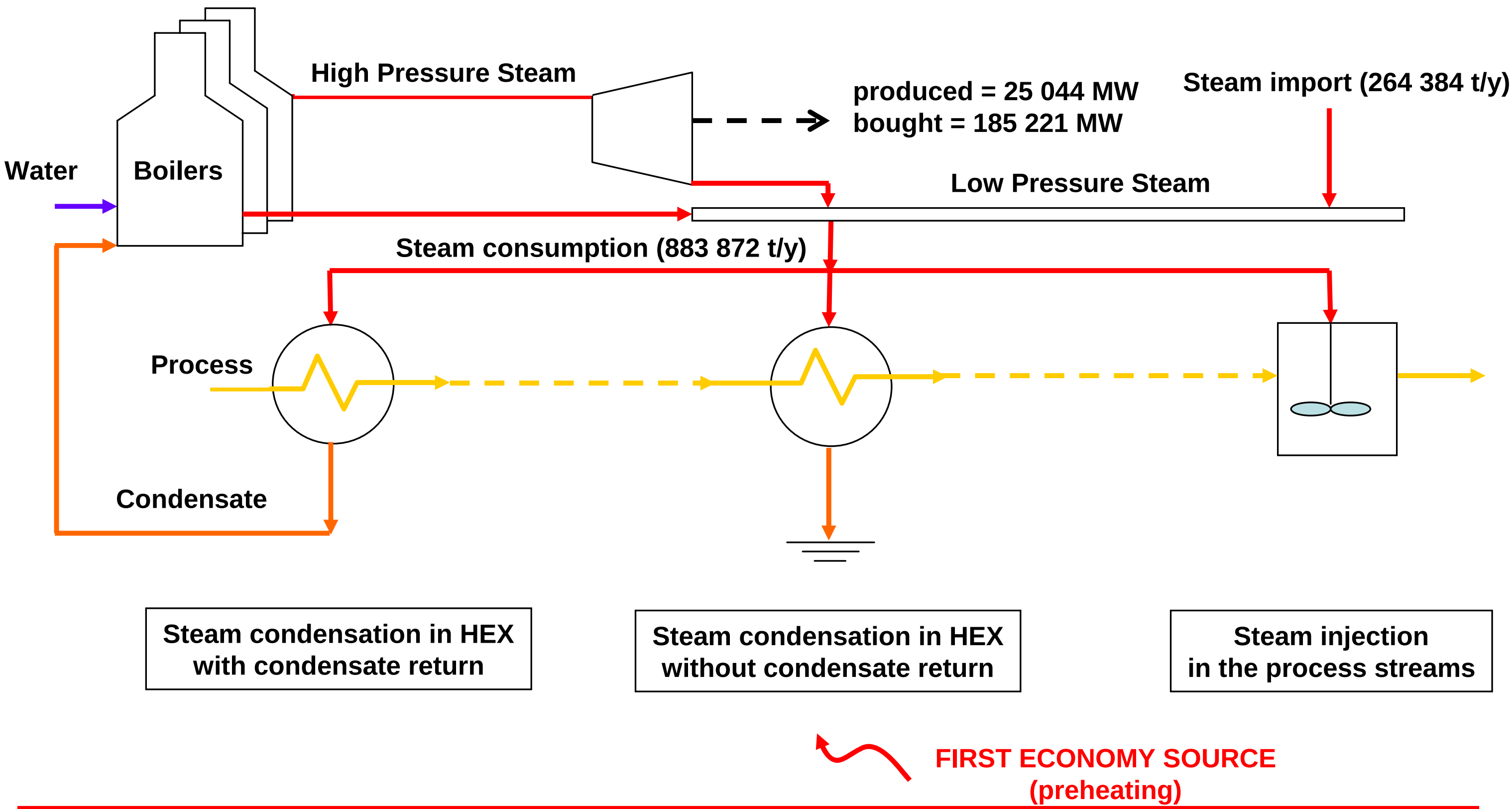
[a]Abbreviations: Acc: accuracy, RVal: reconciled value, RAcc: reconciled accuracy, Corr: correction

Aiming a process integration energy study (2/6)

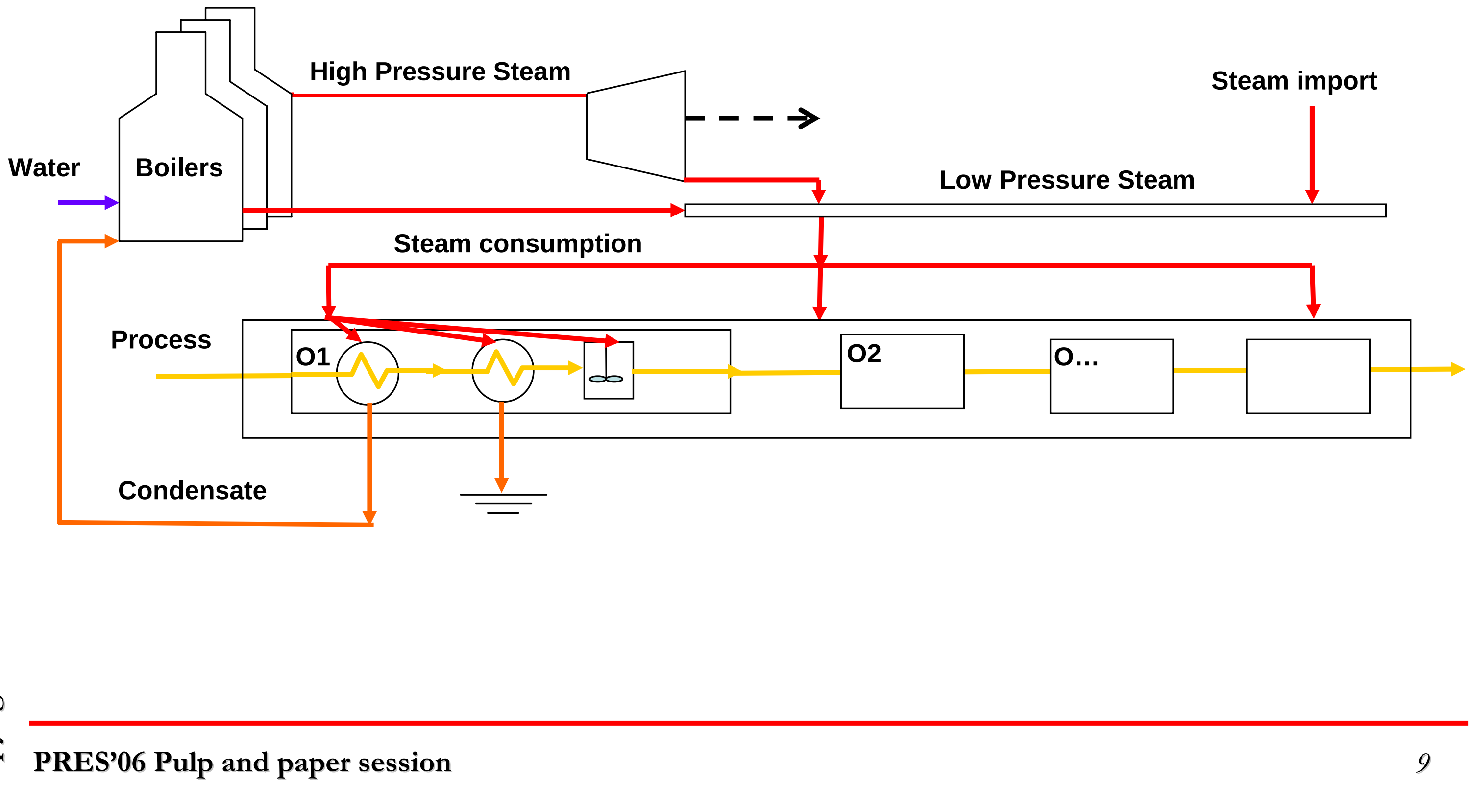
- Obtain a set of coherent data defining the nominal conditions
- Characterise the thermodynamic states of the hot and cold streams of the process
  - For each stream: heat content and temperature levels
- Center our approach on process <u>and</u> utility network simulations
  - General flowsheeting tool usually doesn't contained utility network
  - Utility system is generally well measured/followed

Defining the nominal conditions (3/6)

- Modeling in 3 parts – systematic approach



Top-down approach (4/6)



Defining the nominal conditions (5/6)

- From the data reconciliation model:
  - Key performance indicators (KPI) derived

Table 6: Operating nominal conditions of the mill (2003)

Stream	Value
Production	**t/a**
Cellulose	127 206
Ethanol	9311 (117 871 hl/a)
Yeast	5850
Lignin	100 000
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Heavy oil	9589
Natural gas	8 185 717 Nm3/a
Sulphur	7800
Calcium carbonate	14 000
Internal energy	**t/a**
Liquor	122 819
Utilities	**t/a**
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Steam bought	264 384
Steam consumption	883 872
Fresh water	31 884 804
Electricity	**kWh**
Site production	25 044 710
Bought	185 221 137
Total consumed	210 265 847

Table 7: Load and efficiencies of boilers (2003)

Boiler	**Load** kW	**Spec.load**[a] kW/t	**Efficiency** %
Liquor boiler	38 733	2651	81.9
Soda boiler	14 817	1014	87.8
Biomass boiler	5661	387	65.0
Sulphur boiler	1253	86	ND

[a]Specific load: kW per ton of cellulose produced

Boiler efficiencies

Steam production and distribution
Electricity production, consumption and bought

Defining the nominal conditions (6/6)

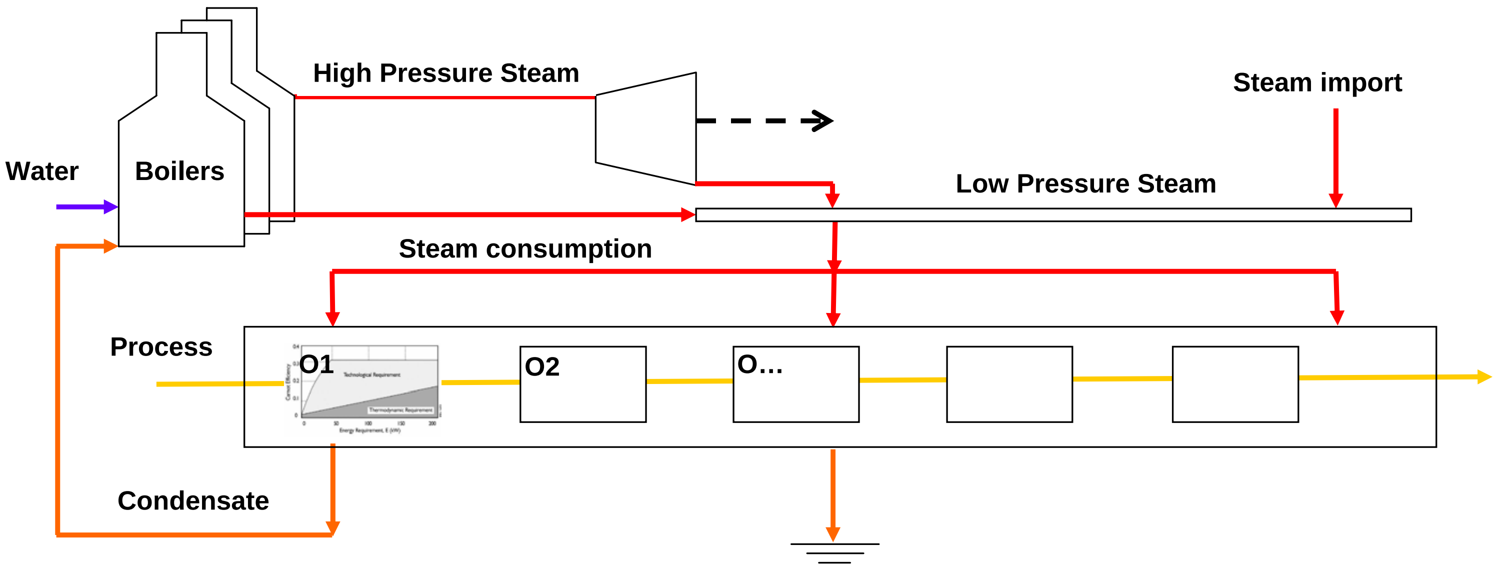
- From the data reconciliation model:
  - Sensitivity analysis:

Table 5: Example of a sensitivity analysis on specific or generic assumptions

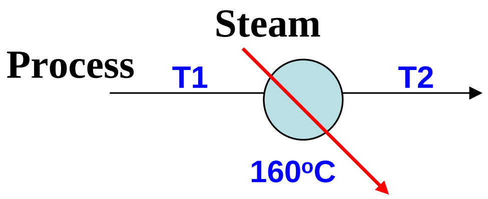
Parameter	**Meas[a] (Prec[%])/RVal**	**Main contributors**	**%**
Bark humidity (%)	50 (10)/49.2	Bark humidity	58.2
		Fumes temperature	30.6
		Steam flowrate	8.5
Warm water T (°C)	50 (10)/50.15	Warm water T	99.9

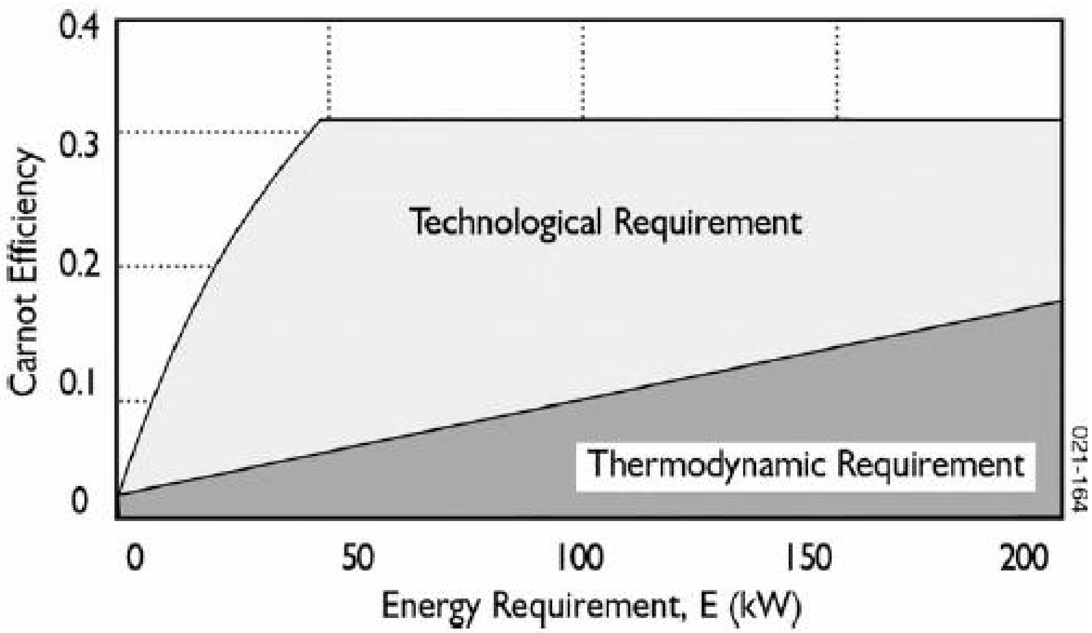
[a] Abbreviations: Meas: measurement, Prec: precision, RVal: reconciled value

Bottom-up approach

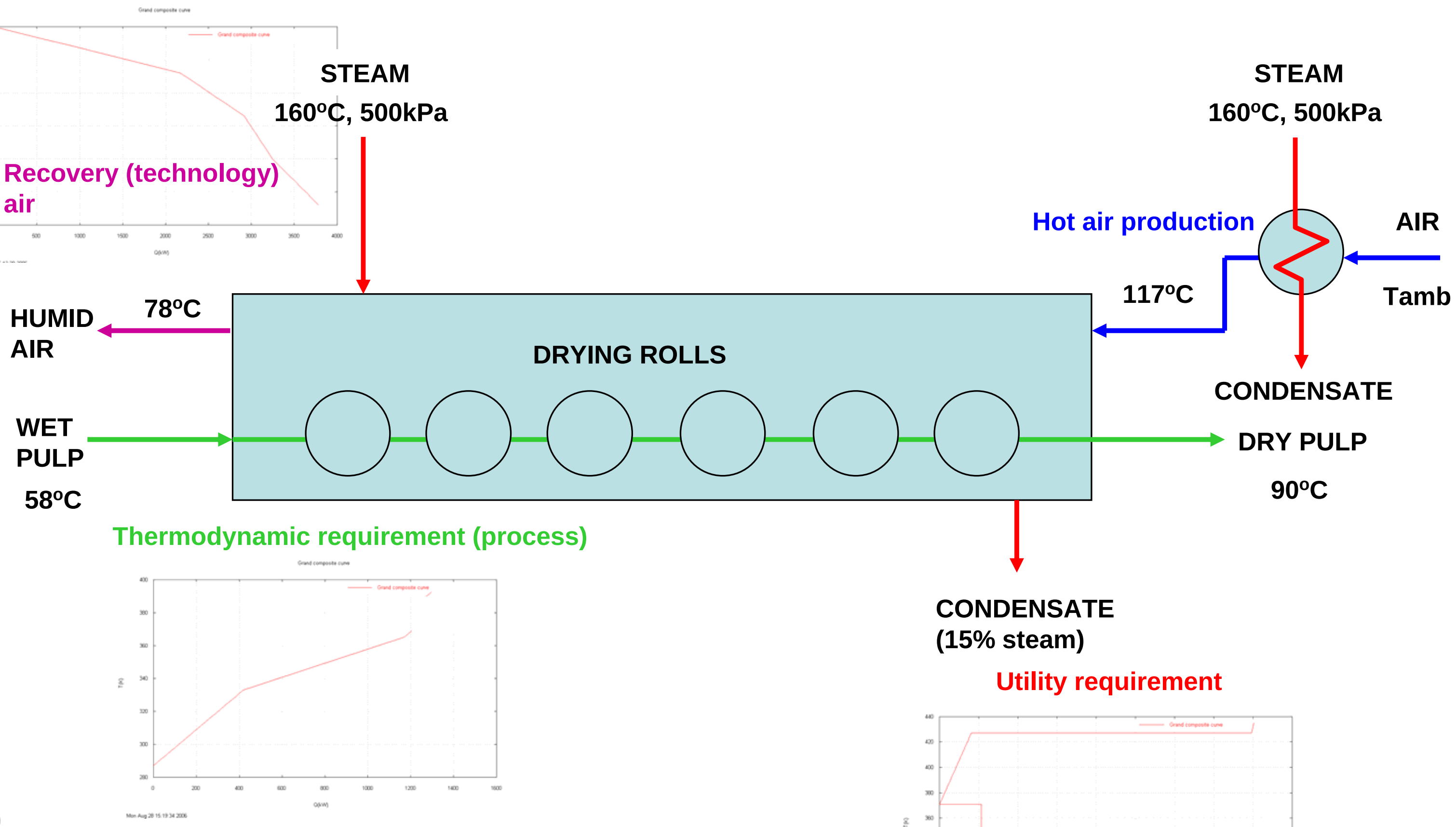


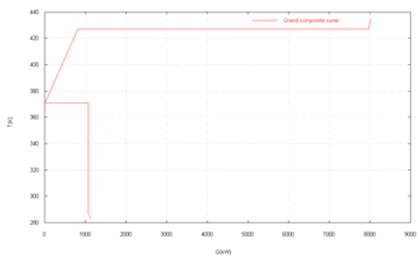
Dual representation principle (1/5)



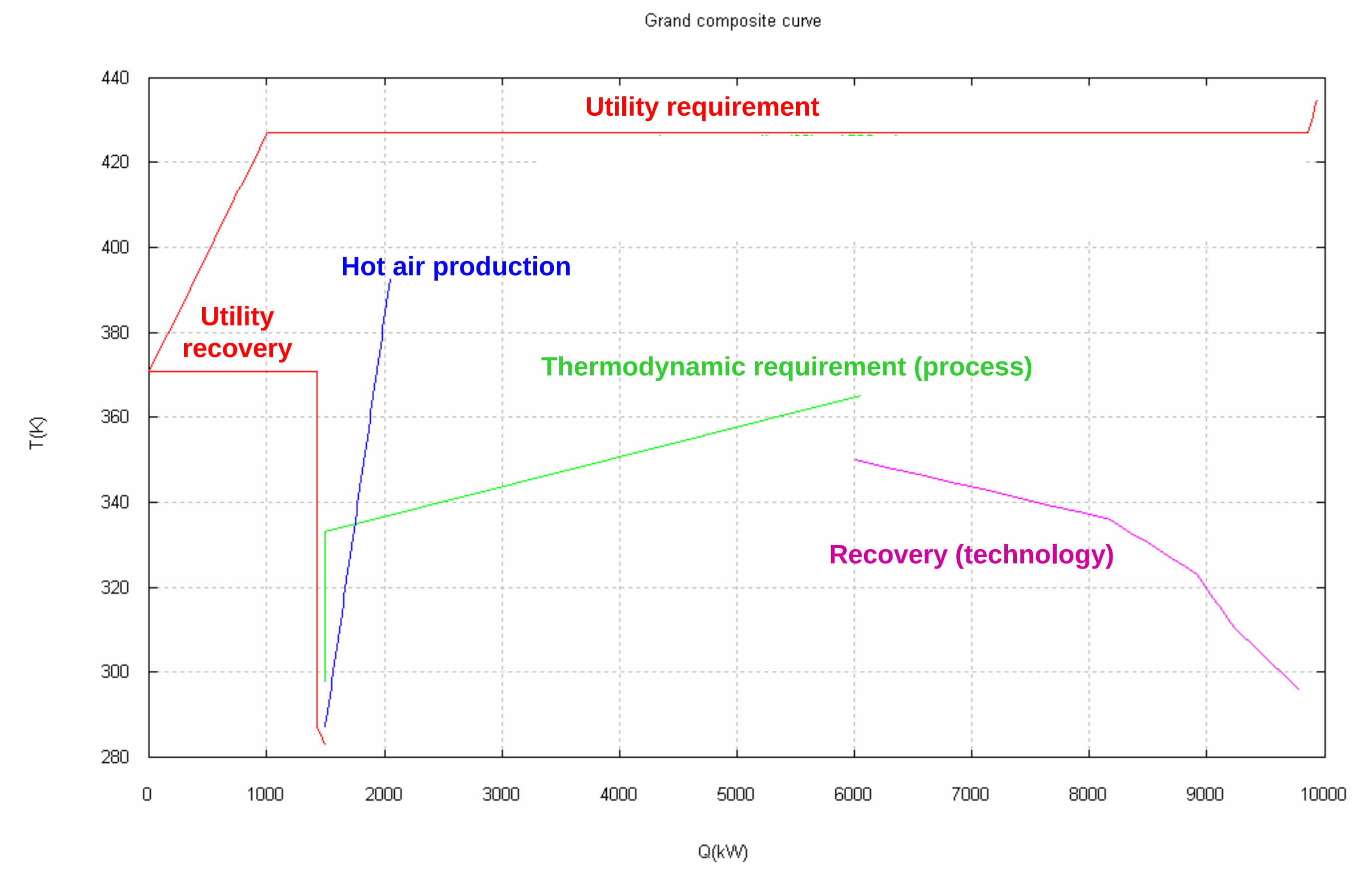


Energy requirement – drying section (2/5)

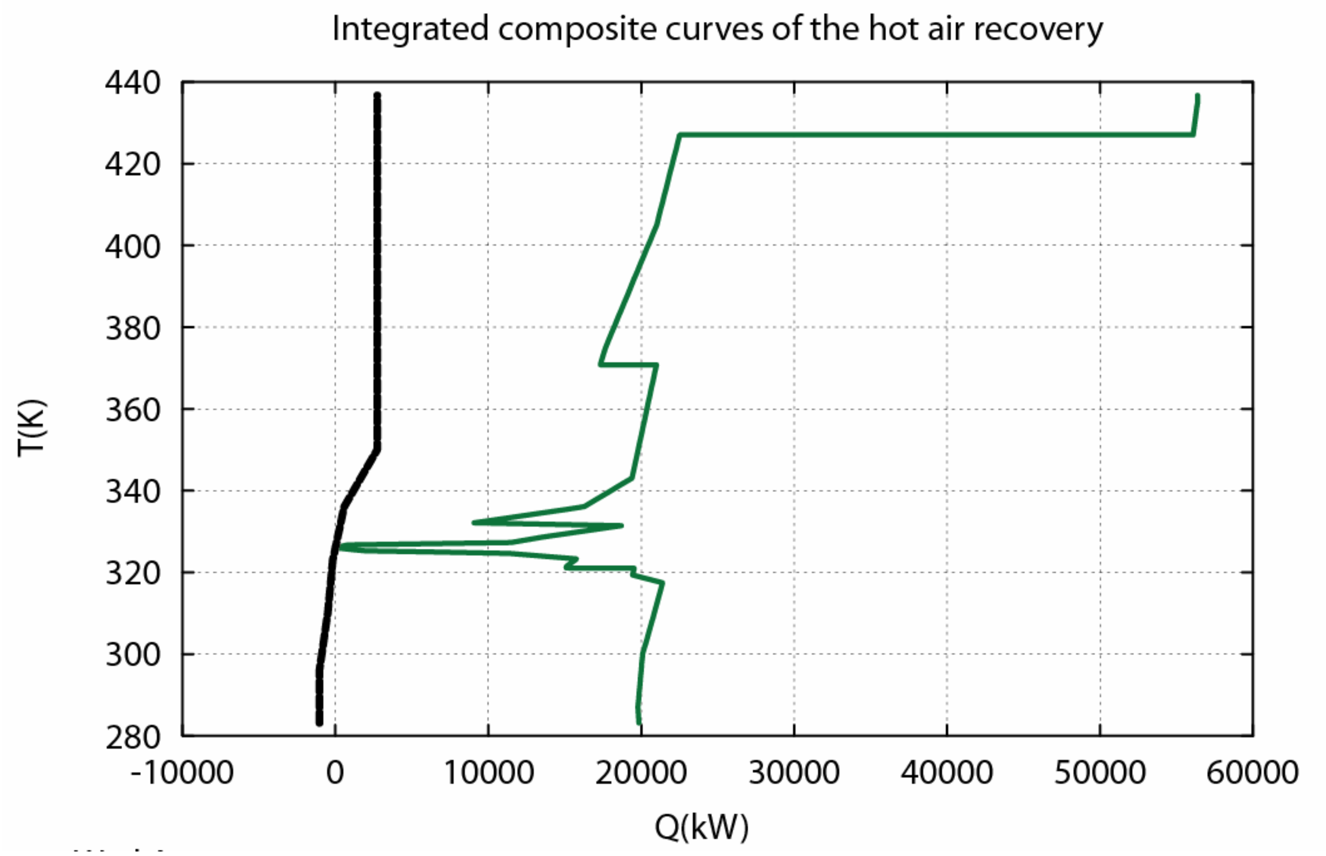




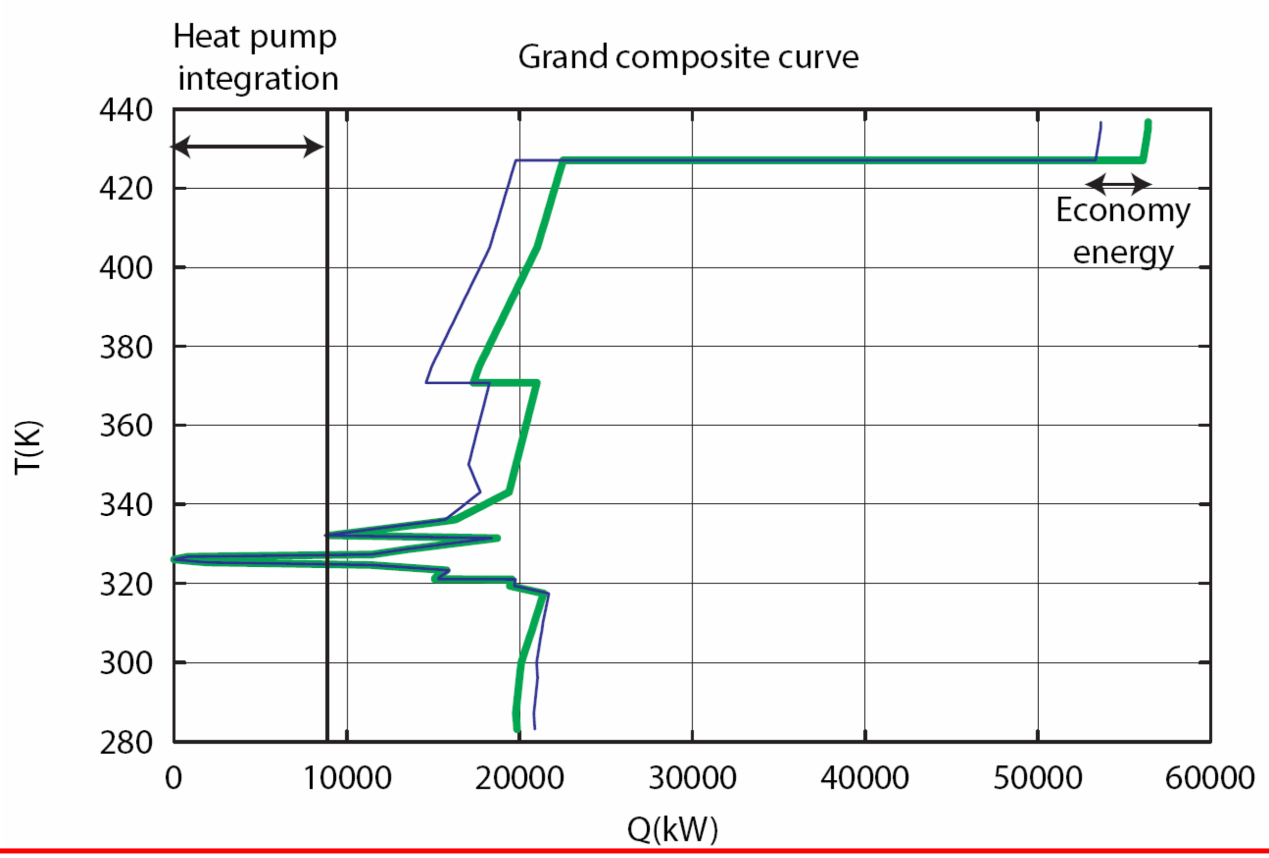
Energy requirement – drying section (3/5)



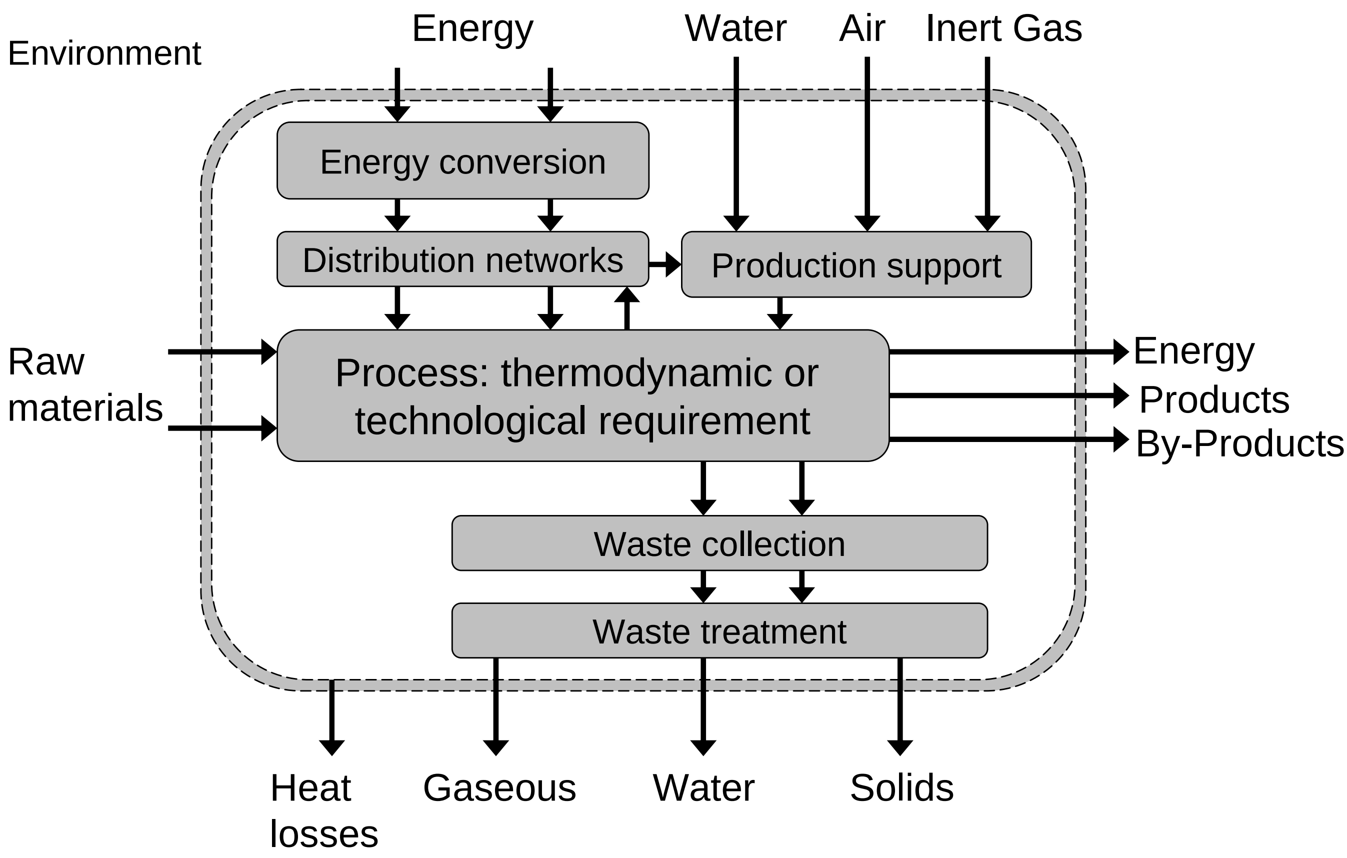
Hot air recovery (4/5)



Energy requirement – global (5/5)



Integrated process-energy system



An overview of process energy enhancement

NOMINAL CONDITIONS
- Data extraction
- Data reconciliation
- State of the system
- Top-down requirement definition

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PROCESS INTEGRATION TARGETING
- Process requirement analysis
  - Dual representation
- Energy savings target
  - Heat recovery by heat exchange
  - Heat recovery streams
- System closure – water management
- Energy conversion (CHP, HP)
- Site scale integration (eco-industrial clusters)

↓

PROCESS ENGINEERING AND OPTIMISATION

↓

THERMO-ECONOMIC EVALUATION OF SOLUTIONS

Thank you for your attention

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6.2 Presentation at the Borregaard meeting 27-09-2006

This document is confidential.

6.3 Report of the Canadian team, Prof Jean Paris

This document is confidential.