Innovative tools, methods and indicators for optimizing the resource efficiency in process industry

What is the value of Exergy in Process Industry

Antonio Valero
CIRCE – Research Centre for Energy Resources and Consumptions

SPIRE Workshop on Resource Efficiency Monitoring, Assessment and Optimization
Brussels 27th January 2016

"This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 604140"

Exergy

Exergy is the maximum amount of useful energy that a stream can produce when becomes exhausted in a given environment (T_0,P_0, H_0, S_0)

$$B = (H - H_0) - T_0(S - S_0)$$

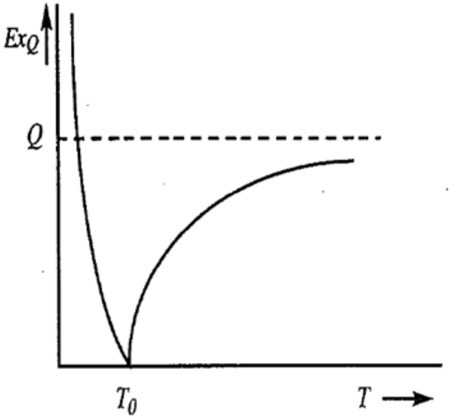
Exergy accounts for energy quality and becomes degraded to a greater or lesser extent in any real process.

An exergy analysis locates and quantifies irreversibilities or degradations in a process.

Exergy assessment

- Kinetic, potential, electrical, and magnetic exergy coincide with energy.
- But the exergy of a heat flow do not coincide with Q.

$$B_Q = Q\left(1 - \frac{T_0}{T}\right)$$



- The same happens with chemical exergy where the entropy term is low for a solid, higher for a liquid and very high for a gas:

$$B = (H - H_0) - T_0(S - S_0)$$

Energy vs Exergy Balances

- **Energy balances indicate Losses crossing the limits of the system. But they do not locate causes.**

Energy in –Energy out = Losses crossing limits

- **Exergy Balances indicate Degradations and their Location**

Exergy in –Exergy out = Degradations within the system

- **Differential Exergy balances indicate Causes of Degradation and Avoidable Losses**

Irreversibilities or degradations

- Mechanical Irreversibilities. Due to friction.
- Thermal Irreversibilities. Due to heat transfer in finite temperature gradients.
- Chemical Irreversibilities. Due to chemical disequilibriums in mixing, solutions and chemical reactions.

- Wastes, effluents and residues are the stream carriers of internal degradations that cross the limits of the system. They further thermally, mecanically and chemically degrade to reach equilibrium with environment.

THE OBJECTIVE OF RESOURCES EFFICIENCY MUST BE TO MINIMIZE DEGRADATIONS (IRREVERSIBILITIES) RATHER THAN TO MINIMIZE WASTES!

Pinpointing Degradations

- The analysis of Exergy Losses allows to identify, locate and quantify inefficiencies in real processes. It helps to locate causes of consumed resources.
- If exergy is destroyed in real processes, some natural resources are consumed and lost forever, which creates cost. Cost is in fact a sacrifice of resources.
- As well as minimizing degradations is equivalent to improve resources efficiency.

Applications.

1. Sama-Szargut Second Law rules for Process improvement and design.
2. Operation thermoeconomic diagnosis of a Power plant
3. Selection among alternatives using exergy.

Sama-Szargut Second Law rules

- 1. Do not use excessively large or excessively small thermodynamic driving forces in process operations.
- 2. Minimize the mixing of streams.
- 6. Introduce polygeneration
- 9.Use energy cascades
- 10. In heat exchangers, try to match streams where the final temperature of one is close to the initial temperature of the other.
- 14. Minimize the throttling.
- 15. Eliminate leaks.
- 16. 17. 18. Avoid large chain processes. The exergy costs increase "downstream". Recirculate streams. Integrate processes., make systems multifunctional…
- 19. … Concentrate in exergy destructions with higher costs. The more advanced the production process is, the greater the cost of the irreversibility malfunction, and the greater its fuel impact.
- 21. …..

Sama-Szargut Second Law rules

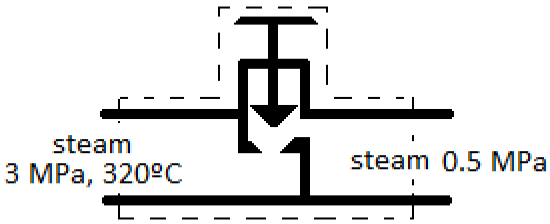
- *One would expect that most, if not all, of the rules be routinely implemented in new designs and in retrofit projects. It turns out, that the contrary is rather true:* **even a superficial survey of some of the current most common energy conversion installations shows that most of the rules are actually disregarded in practice.**

J. Szargut, D.A. Sama, 1995: Practical Rules of the Reduction of Energy Losses Caused by the Thermodynamic Imperfections of Thermal Processes, Proc. of The II Int. Thermal Energy Congress, Agadir, Morocco, June, v. 2, 782-785

E. Sciubba. Why are some of the Sama-Szargut Second Law rules routinely violated in practical applications? Conference Proceedings Paper - Energies „Whither Energy Conversion? Present Trends, Current Problems and Realistic Future Solutions" 1st International e-Conference on Energies, March 2014, http://sciforum.net/conference/ece-1

The Principles of Resource Efficiency . Ch 16. in A Valero and Al. Valero D. "Thanatia: The Destiny of Mineral Resources" World Sci. ,The Imperial College Press, 2014. ISBN 9789814273930

- Expansion valve →



Energy Eff = 3043/3043 → 100%

Exergy Eff = 836/1074 → 77,8%

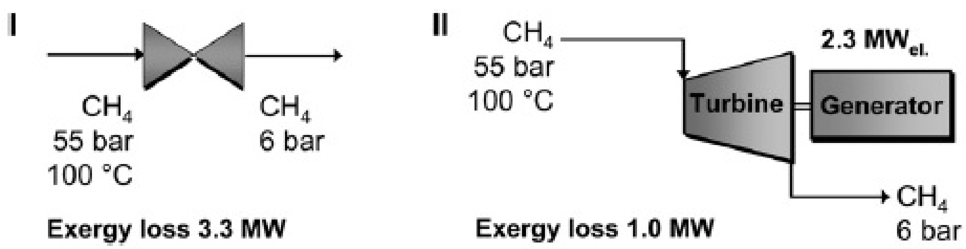
	Pressure [bar]	Temperature [°C]	Enthalpy [kJ/g]	Entropy [kJ/kg·K]	Exergy [kJ/kg]
Inlet, 1	30	320	3043.4	6.6245	1073.89
Exit, 2	5	290	3043.4	7.4223	836.15
Reference, 0	1	25	104.89	0.3674	0

The use of an exergy indicator reflects the loss in terms of quality.

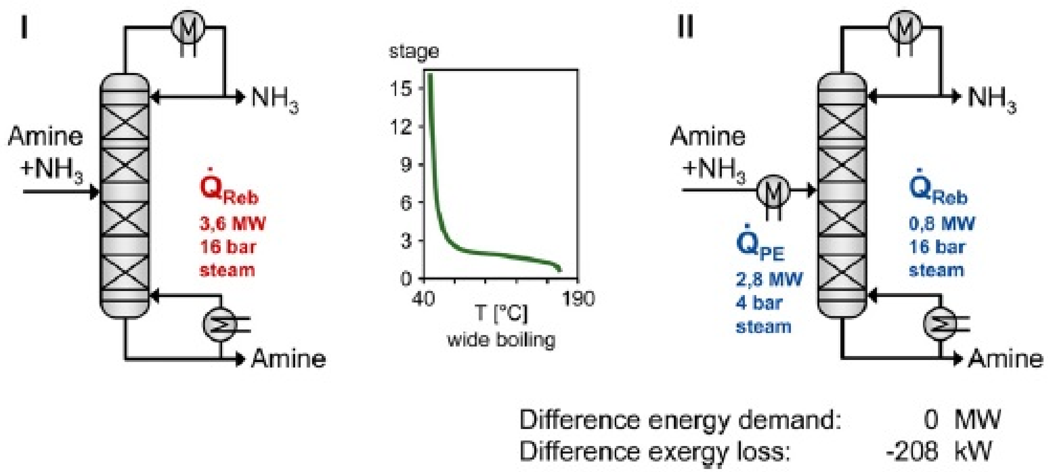
BASF exergy studies (7M€/y)

Exergy analysis is a powerful method to identify exergy losses and to compare different concepts

BASF: *N. Asprion et al. / Applied Thermal Engineering 31 (2011) 2067–2072*



Comparison of concepts for pressure reduction of natural gas: I) let-down valve, II) use of a turbine.



Exergy losses in the columns of two different concepts for the separation of an amine and ammonia: I. conventional distillation, II. distillation with pre-evaporator.

Thermoeconomic diagnosis

Diagnosis is the art of discovering and understanding signs of malfunction and quantifying their effects.

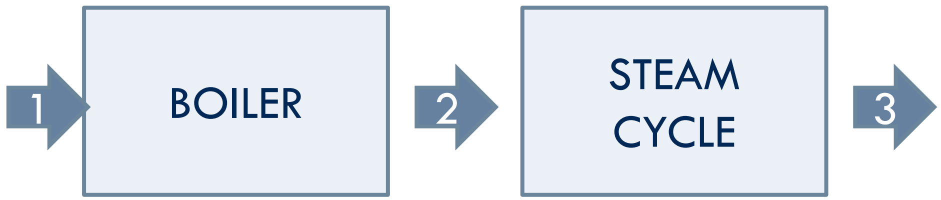
All systems degrade and all of their components too! And each degradation influences each other.

How to identify the amount of degradation of each and every subsystem between two states of a plant?

SYSTEM´S DIAGNOSIS

Thermoeconomic analysis: example

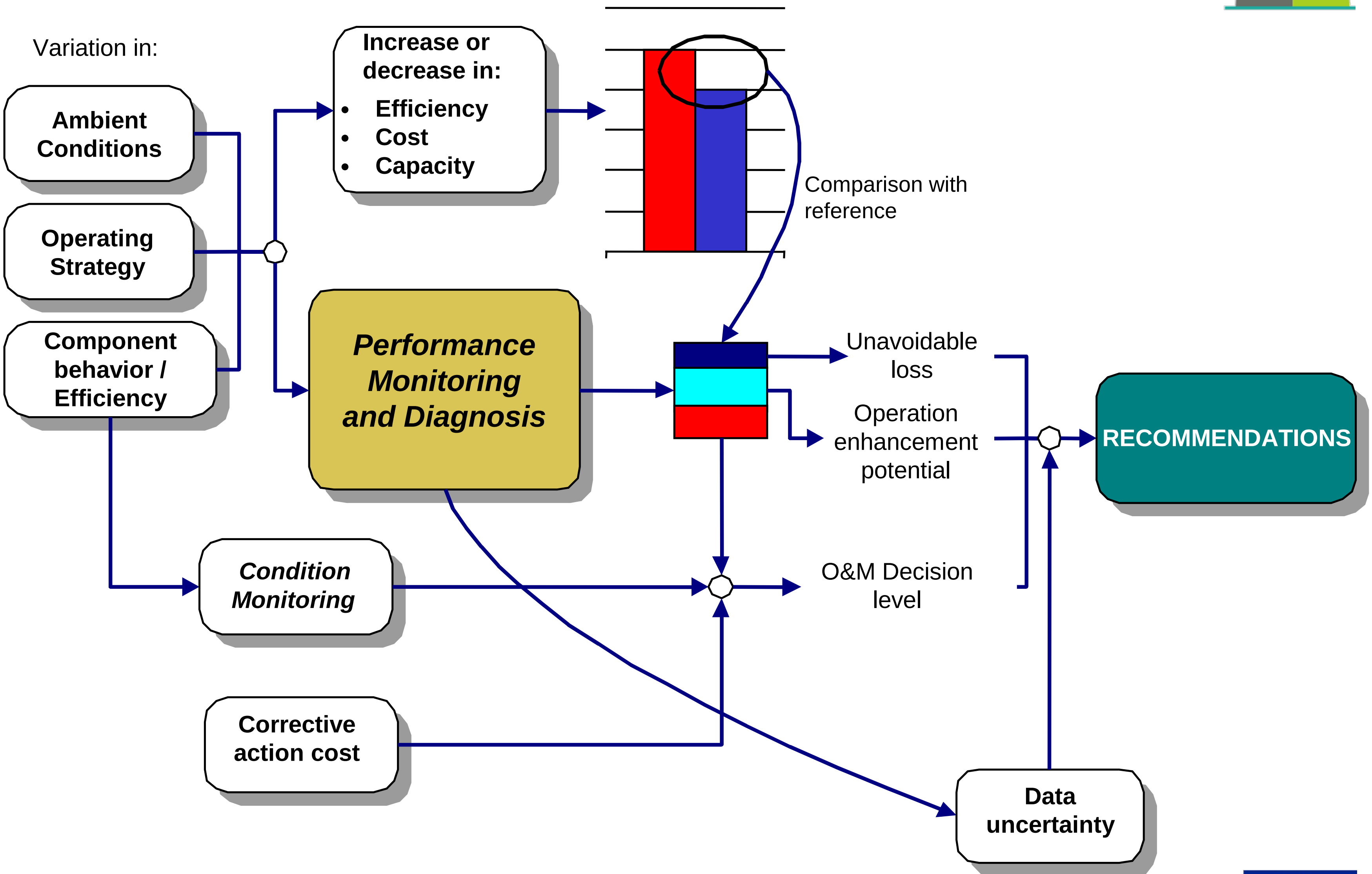
A very simplified power plant



FLOW	B (kW)	B* (kW)	k*
1	1000	1000	1
2	500	1000	2
3	350	1000	2.86

- Unit exergy cost increases due to irreversibility: Thermoeconomics allocates those costs.
- It is possible to transform exergy cost into **economic costs (cost of the resources used in the system)**.

Thermoeconomic Diagnosis Scope



Diagnosis conclusions

- Compares two plant states
- Distributes the operation deviation into the diagnosis variables.
- Allows to find the last reasons that causes such deviation.
- Early recognition of component fault and degradation.
- Eases to take decisions concerning O&M STRATEGIES.
- Evaluates the modifications made during a Shut Down.

Diagnosis conclusions

Thermoeconomic diagnosis is a methodology that combines thermodynamics (concept of 'exergy') and economics (concept of cost)

It is an **exportable methodology** that can be applied at macro and micro level to any kind of industry, sector or facility

Some of the main advantages of this methodology are:

- Provide quality information to support a **better decision-making process** for investments & implementation of more efficient systems & equipment
- Identification of the **quality of the by-product** resources
- Support to the **industrial symbiosis** initiatives
- It is possible to transform exergy cost into **economic costs (cost of the resources used in the system**

Selection among alternatives using exergy.

- **PROBLEM:** A raise of condenser pressure due to problems in the SEALING of the VACUUM valves.
- **OBJETIVE:** Evaluation of an 30% INCREMENT in the Condenser Backpressure from design value.
- **POSSIBLE SOLUTIONS:**
  - The problem must be solved INMEDIATELY .
  - The problem will be solved in the NEXT SHUT-DOWN.

Practical cases.Results and Conclusions

Variable	Study	**Desing**	Difference	Units
Condenser Pressure	0.061	**0.047**	0.014	bar
Production Cost	0.916	**0.913**	0.003	c€/kWh
Power	294,822	**295,859**	-1,037	kW

- **Conclusions:**

The losses are equivalent to TWO DAYS of shut-down.

Must be included in the MAINTENANCE Schedule.

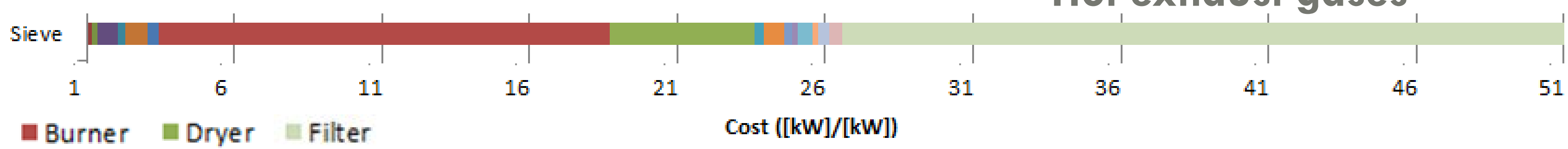
Energy Saving decisions at industry

LEVEL	ACTIVITY	DESCRIPTION	TERM	INVESTMENT	IMPACT
I	Operation	Courses, Attitudes	Short	Low	Low
II	Instrumentation & Control	Measurements, Hard & Soft Changes	Short to Mid	Low to Mid	Mid
III	Maintenance	Preventive, Predictive & Corrective Management. Repairing.	Short to Mid	Low to Mid	Mid
IV	Processes	Changing Machinery & Equipment. Refurbishing and Renovating.	Mid to Long	Mid to Large	Large
V	Plant Layout	Improving the System´s Structure. Retrofitting.	Mid to Long	Mid to Large	Large
VI	Systems Integration	Industrial Symbiosis (off premises)	Mid to Long	Large	Very Large
VII	Procedures	Choosing new Sci/Tech production bases	Long	Very Large	Very Large

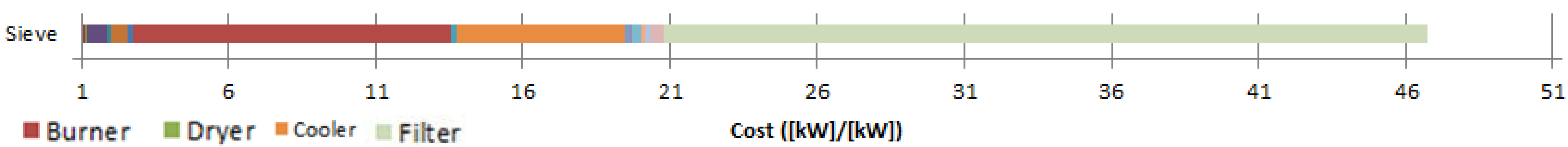
Application of exergy+TA in Top-Ref

- **FERTINAGRO**: MKP Fertilizer
  - Accounting the beneficial **impact** of using **recycled raw** materials
  - **Disaggregating**, in term of costs, the impact of raw materials, water and fuels in the final **cost** of the market **product (7%** raw material, **81%** Natural Gas, **12%** Electricity**)**
  - **Disaggregating** in term of costs the effect of the irreversibility of each device

Hot exhaust gases

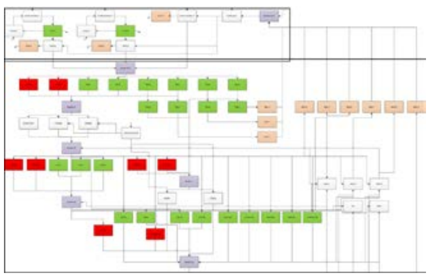


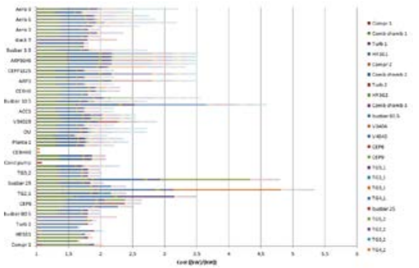
Proposed solution: air preheating → **Reduction cost:** 10%



Application of exergy+TA in Top-Ref

- **DCI and PETROGAL:** Analysis of the steam grid
  - **Disaggregating** in term of costs the irreversibility of each device



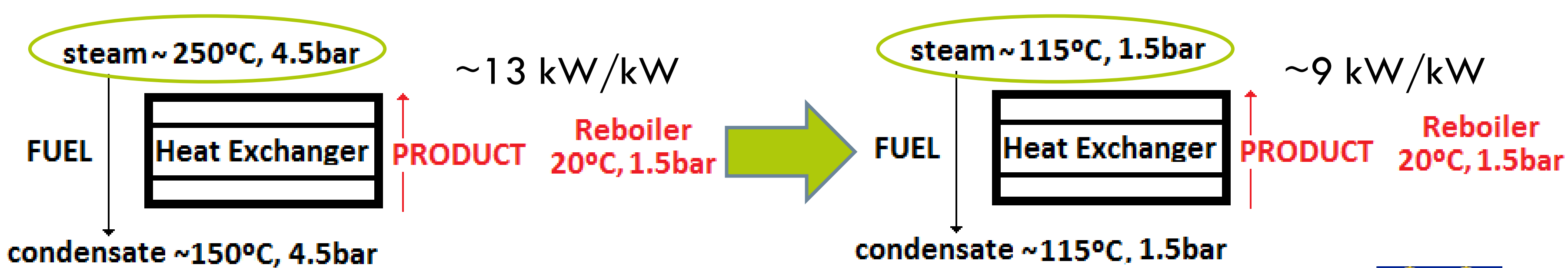


  - Obtaining the exergy (and economic) **cost** of the **steam** at **each pressure level** according the production schedule
  - **Identifying** optimal **steam flows** to be used in the Heat Exchangers (**minimizing** high ΔT)
  - Accounting the **use** of **let-down valves** in term of exergy **cost**

Application of exergy+TA in Top-Ref

	Exergy cost [kW_{fuel}/kW_{steam}]	Economic cost [€/kg_{steam}]
STEAM PRODUCTION SYSTEM	~1.8	Depending on the T, P and Fuel Price and HVV (from 3.2 to 4.6 c€/kg)
HIGH PRESSURE AND TEMPERATURE STEAM	~2.0	
MEDIUM PRESSURE AND TEMPERATURE STEAM	~2.4	
LOW PRESSURE AND TEMPERATURE STEAM	~3.0	

- Exergy and economic cost of each steam level (it is possible to know the cost of the steam injected in other facilities)
- It is possible to evaluate alternative uses of the steam



Improving Efficiencies

Exergy Analysis can be used in many ways to improve efficiencies

1. Process design and improvement.
2. Process optimization.
3. On-line Thermoeconomic Diagnosis: Detection of inefficiencies and calculation of their economic effects in operating plants.
4. Rational cost assessment of plant products based on physical criteria.
5. Evaluation of alternatives among various designs or operation decisions and profitability maximization. Energy (Exergy) audits.
6. Industrial Simbiosis and price setting of interchanged commodities.
7. Setting rational legislation about comercially efficient solutions.

Final remarks

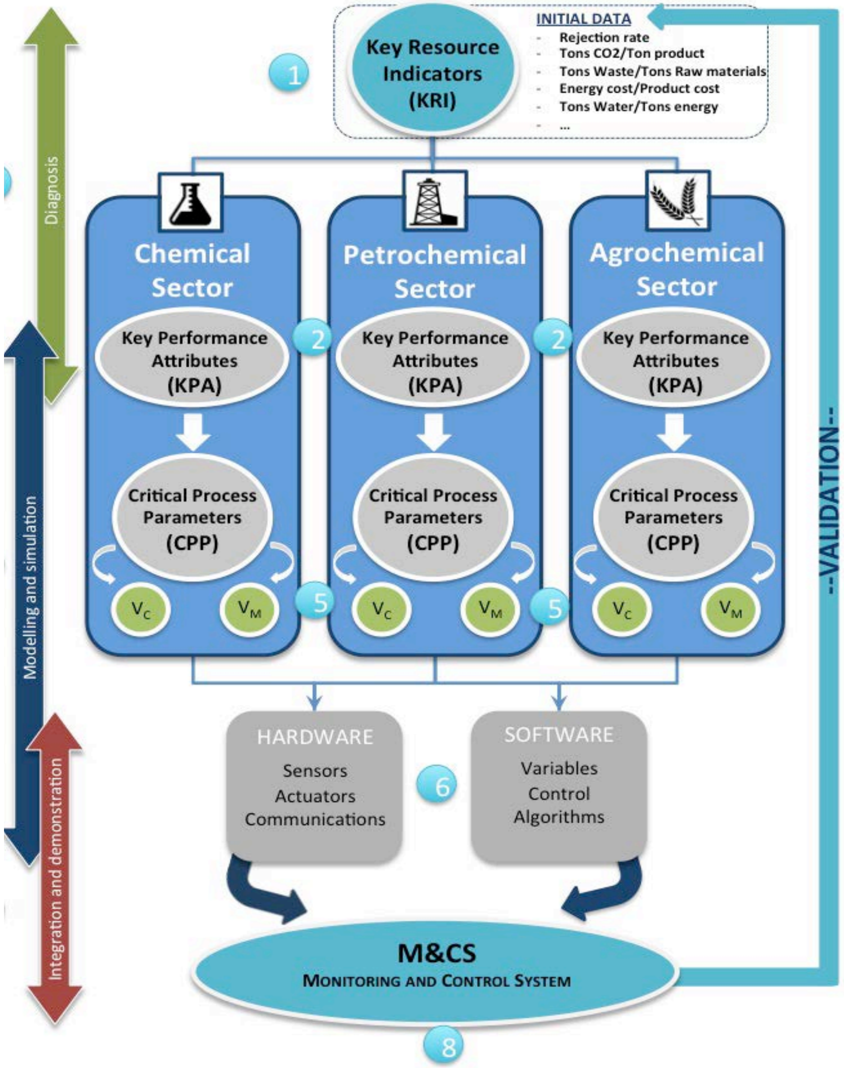
- Second law analysis does provide new information and enhances the ability of the analyst to identify innovative solutions to thermal science problems. When compared to traditional analysis, second law analysis accurately identifies the true sources of thermodynamic losses.

- Exergy is the only rational basis for evaluating: fuels and resources; process, device, and system efficiencies; dissipations and their costs; and the value and cost of system outputs.

Gaggioli, In Thermodynamics: Second Law Analysis; Gaggioli, Richard A.; ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

Assessment, Diagnosis and Optimization of the resource efficiency potential of the global process by performing Thermoeconomic audits and diagnosis over the sub-processes and equipment.

Beyond Simulation



EU COMMISSION

R&D funding, SPIRE, H2020, …

Tools that allow identification of:

- Inefficiencies
- Byproduct costs
- Residues costs
- Industrial Symbiosis
- Fuel, raw material and water savings

ACADEMY

Looking for causes

Exergy, Thermoeconomics, Diagnosis

INDUSTRY

Know-how & demos

Technical issues, production processes, effective costs

Innovative tools, methods and indicators for optimizing the resource efficiency in process industry

Thanks for your attention

Antonio Valero
CIRCE – Research Centre for Energy Resources and Consumptions

SPIRE Workshop on Resource Efficiency Monitoring, Assessment and Optimization
Brussels 27th January 2016

"This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 604140"

The Krakow Declaration for Energy Efficiency in the Process Industries

- ***Processes and systems analyses:*** those activities identified as priorities for increasing energy efficiency.
  Products: these should relate to advanced techniques with the clear aim of improving the energy efficiency per unit of production.
  Procedures: standardised systems are required for precise energy and CO_2 accounting, as well as developing industries for auditing, and instrumentation for monitoring and control.
  Promotion: there is an urgent need to disseminate information on energy efficiency techniques and achieved savings, as well as strategies for knowledge transfer.