Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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ENERGY AND ENVIRONMENTAL EFFICIENCY IN INDUSTRY

1. State of the art and current development in different world regions

Technology 1: Potential radical and incremental innovations for components of industrial processes
Equipment such as ovens, dryers and heat exchangers have a very significant impact on consumption and energy efficiency of industrial processes. Although the performances of these equipments have increased steadily, the design and the development of more efficient industrial compounds would benefit from a better understanding of the phenomena involved, including their dynamics, and, from then, their modeling and their simulation. Due to the renewal rate of industrial processes (i.e. 6 to 7%/year), the most innovative technologies are disseminated quite rapidly. The cost (investment and use) is an essential variable, and time of return on investment should be as short as possible and not exceed 2 to 3 years.

Technology 2: Potential radical and incremental innovations in industrial processes
The development of energy integration methodologies (e.g. Pinch, Exergy) is an effective way to improve the design of processes. In addition, breakthroughs in the most energy-consuming processes (e.g. steel, cement) are expected and the conditions to favor them have to be put in place. Like for the components, the cost is an essential variable, and the decision to invest is directly linked to the energy price and to the environmental regulations that vary from a country to another.

Technology 3: Metrology and control
The advanced and predictive control systems, based on simple, reliable and non-intrusive sensors, must be developed, and if possible, the extension to "communicating" components and processes must be promoted. Thanks to a better understanding and modeling of the phenomena involved in industrial components and processes, improvements might be made in industrial processes control, taking into account energy consumption and CO_2 emissions but also maintenance, if coupled to the development of low-cost and reliable sensors and of optimization methods.

Technology 4: Recovery and valorization of industrial fatal heat
The recovery and valorization of fatal energy (in general, heat) has a direct impact on greenhouse gas emissions. Even though fatal heat recovery systems do exist and are marketed (heat pump, Rankine cycle, etc.), their potential and their capabilities are far from covering the entire field of applications (e.g. high temperatures, resistance to fouling, corrosion, erosion). The recovery without transformation of fatal heat between industry players imposes interdependencies to which these actors are not favorable. One solution involves the pooling via industrial heating networks managed by a third party at any time, thus ensuring supply. This is a first step towards industrial eco-parks.

Technology 5: Industrial eco-parks
Eco-industrial parks, designed on the principle of symbiosis between actors (optimized exchange of flows of energy and materials), enable very significant gains in terms of energy consumption and emissions. However, there are three main obstacles to achieve these industrial synergies (between industrials and between industry and territory): the knowledge of opportunities, the adequacy between supply and demand, and the interdependencies between the different actors that are imposed by these synergies. This requires actions in technical areas (e.g. technology in flow transfer and/or valorization), on legal and marketing aspects, as well as on societal aspects.

Technology 6: Direct integration of renewable energy in the industrial processes
Integrating renewable energies into industrial processes is a mean to reduce significantly their environmental impacts. This could be done through the design and the development of new processes using these energies directly, (e.g. biomass to combustion or to chemicals; solar thermal to heat; wind or hydraulic to mechanical) or indirectly (e.g. renewable or nuclear power; renewable hydrogen; biomethane or bio-syngas). The intermittency of some of these energies may require the use of electric, chemical, mechanical or thermal local energy storage..

Main comment: these technologies do not develop independently from each other and their effects are not cumulative. For instance, the sensors and the efficient control systems will certainly be included in new components and processes.

2. Maturity level and technological perspectives

Maturity of elementary technologies associated with industry efficiency

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Components improvement	2	2	3-4	4-5	5
Processes improvement	2	2	2-3	3-4	4-5
Metrology and control	2-3	2-3	4	4-5	5
Fatal heat recovery	2	2-3	3-4	4-5	5
Industrial eco-parks	2-3	3	3-4	4	4-5
Renewable energy integration	1-2	1-2	3	3-4	4-5

For the time being these technologies are not very mature. Tangible results are expected by 2030-2040. The CO_2 emissions reduction will reach its full potential by 2050 (see following table).

Potential development of technologies related to industry efficiency

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
Components improvement	0	0	1	2
Processes improvement	0	0	1-2	3-4
Metrology and control	0	1	2	3
Fatal heat recovery	0	1	2	4
Industrial eco-parks	0	1	2	3
Renewable energy integration	0	0	1	2
All technologies	0-1	1	2-3	4

The improved processes —which are mostly used in newly built plants— will have a significant impact on decarbonization. Even though metrology is less efficient, this technology will be very used and will contribute significantly to reducing GHG emissions. On the contrary, industrial eco-parks will develop slowly —but their strong impact on GHG emissions will compensate this.

As mentioned before, the effects of these technologies on GHG emissions are not cumulative (the last row of the table on potential development illustrates this). Indeed if a plant integrates renewable energy as part of its energy production, it will no longer emit CO_2: this will cancel all effects of any other technology. Furthermore the lifetime of industrial equipment is often long, which means that the speed of implementation of new technologies is relatively low — this is especially true in countries with mature industries. The last table thus attempts to assess the cumulated impacts of the technologies according their effects (which are sometimes not cumulative) as well as their deployment pace.

3. Technological, economic and social bottlenecks

<u>Methodological information:</u>

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

It must be stressed that the ranking of such different factors must be considered with caution; as an expert's judgement, not a quantitative assessment.

Technology		**Research & technological bottlenecks**	**Economy and financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Components improvement	Rank	5	6	1	2	3	4
	Key-words	Heat exchangers, ovens, cold production systems, dryers	Time of return on investment too long	Technical standards	Strategic and critical materials	Security and safety must be higher than current systems	The dissemination rate of the new technologies is directly linked to the renewal speed of facilities
Processes improvement	Rank	6	5	1	2	3	4
	Key-words	Energy integration, new breakthrough in processes	Time of return on investment too long, Access to capital for investment	CO_2 quotas	Strategic and critical materials	Security and safety must be higher than current systems	The dissemination rate of the new technologies is directly linked to the renewal speed of facilities
Metrology and control	Rank	4	6	1	2	5	3
	Key-words	multicriteria optimization methodologies Non-intrusive sensors	Time of return on investment too long	Technical standards	Strategic and critical materials	Reliable and safe sensors	Reduction of the number of employees, specific qualifications needed
Fatal heat recovery	Rank	6	5	4	1	2	3
	Key-words	High temperatures, fouling, corrosion, heat transport over long distances	Time of return on investment too long, Access to capital for investment	No status of industrial heat Management of heat networks No value of heat-generated electricity	Strategic and critical materials, working fluids	Safety of high temperature and very high temperature heat networks	Interdependencies, , heat networks managed by local authorities Collective heating systems
Industrial eco-parks	Rank	2	5	3	4	1	6
	Key-words	Flux recovery and transformation Legal and business models	Third-party investor, new economic stakeholders	Status of "wastes", distribution networks	Need for available land	Integration of classified facilities close to non-classified ones.	Interdependencies, legal aspects
Renewable energy integration	Rank	5	6	2	4	1	3
	Key-words	Storage, intermittency of renewable energies (solar / wind), direct integration	Higher production costs than for conventional energies	CO_2 quotas	Need for available land	Variability of the biomass resource	Competition with food crops, Intermittent industrial processes?

The first bottleneck to be mentioned is investment, both in terms of capital to be invested and in terms of time of return on investment. Other bottlenecks are also to tackle by research and development programs, not only in terms of technical R&D but the economical, legal and societal aspects need also to be studied.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		Research & technological innovations	Economy and financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
Components improvement	I or R	R	I	I			I
	Key-words	Heat exchangers, ovens, cold production systems, drying	Investment aid mecanisms	Technical standards to evaluate performance			Investment aid
Processes improvement	I or R	R	I/R	R			I
	Key-words	Modeling, energy integration	Investment aid mecanisms and third-party investor	Global disincentives on CO_2 emissions Competitiveness			Investment aid
Metrology and control	I or R	R/I	I	R			
	Key-words	multicriteria optimization methodologies, non-intrusive or connected sensors	Investment aid mecanisms	Communication standards, connected sensors			
Fatal heat recovery	I or R	R	I/R	R/I			I
	Key-words	Heat recovery from high temperature solids, heat transport over long distances, heat transformation systems, heat transfer fluids	Investment aid mecanism and third-party investor	What status (renewable energy or pollutant) and what CO_2 emissions for fatal heat. Status / value of heat-generated electricity			legal models
Industrial eco-parks	I or R	R	R	I	I		R
	Key-words	New business and legal models Flux recovery and transformation systems	Administrators and developers of industrial eco-parks	(New) definition of the status of some "wastes", implication of local authorities	Need to privilege already industrialized areas, especially industrial wasteland		Legal and business models
Renewable energy integration	I or R	R	I	R	I		I
	Key-words	Electricity and heat storage at the production site scale. Processes using directly renewable sources	Financial aid mecanism	Global constraint on CO_2 emissions / competitiveness	Integration of renewables into processes to be adapted to the local resource availability		Importance of life-cycle assessments

Industrial actors invest in reducing their energy and their environmental footprints only when they have a strong economic interest or when the regulatory framework compels them to do so. However when regulations leave industrial actors no other choice, one must check not to increase inequalities in terms of competitiveness between industries in countries having a strong regulatory framework concerning environmental protection and others, especially when transport costs do not hinder outsourcing.