ULCOS - EUROPEAN STEELMAKERS' EFFORTS TO REDUCE GREEN HOUSE GAS EMISSIONS

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Abstract

CO_2 mitigation has been on the agenda of the European Steel Industry since most of the 20th century and in its last 30 years alone the European Steel Industry has reduced its specific emissions by a factor 2 and by 18% between 1990 and 2004, a figure to be compared to the average 8% target of the Kyoto protocol. This has been achieved by the continuing modernization of the European Steel Industry and more particularly by the adaptation of production to the use of the large local scrap generation, which has switch part of production from blast furnace to electric arc furnace.

The result of these important changes is that most of the potential for CO_2 mitigation has already been collected and that production runs very close to the optimum use of available scrap on the one hand and to thermodynamic limits of the processes on the other hand.

Now that post-Kyoto mitigation policies are coming into focus, it seems clear that more drastic reductions will be called for, at the level of factor-4 targets, if Global Warming is to be maintained below 2°C and the CO_2 level in the atmosphere below 450 ppm. Such momentous changes would require deep paradigms shifts in most industrial and human activities, based on the introduction of breakthrough technologies. For the Steel Industry this would mean either pursuing the use of carbon, but complemented by CO_2 capture and storage, or switching over to carbon-lean energy such as natural gas, hydrogen or "green" electricity, or making use of sustainable biomass.

All these routes are presently being explored by a European Consortium called ULCOS (Ultra Low CO_2 Steelmaking), which comprises most of the European Steel Industry, its industrial partners in the steel value chain, research institutes and universities. ULCOS has received support from the European Commission within the RFCS and the 6th Framework programs. It will wield through these many options and propose a limited number of credible ULCOS process options within 5 years.

Introduction

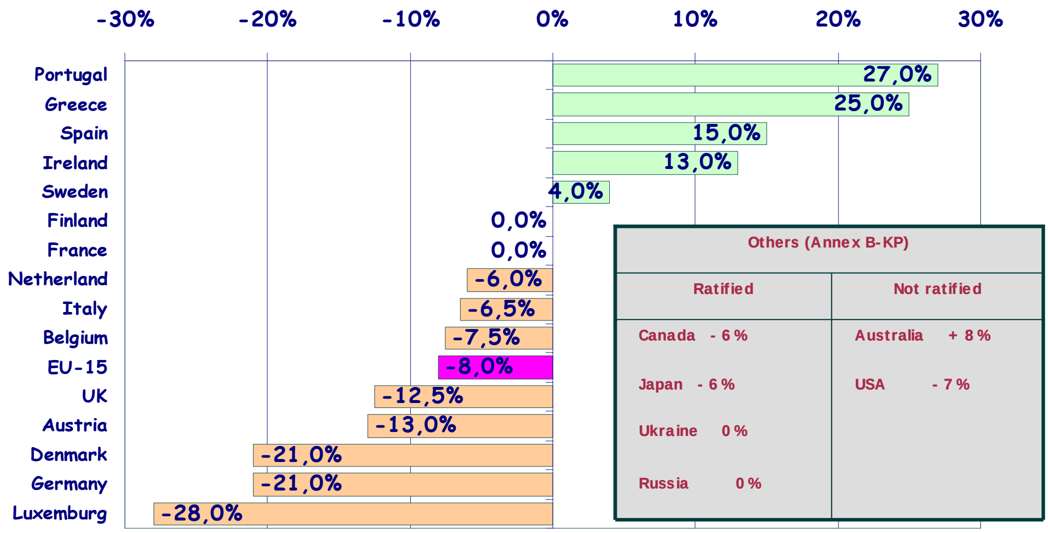

Figure 1 – Kyoto targets for major European and other countries (2012 targets as compared to 1990)

The Kyoto protocol entered into force on 16 February 2005. The atmosphere then was quite different from the one prevailing in 1987, when the Climate Convention was initially signed in Kyoto. Indeed there is today a consensus among scientists, politicians and the general public that the process of Global Warming is under way and that human activities are responsible for tipping the delicate heat budget of the planet towards Climate Change. This means not only a rapid temperature increase, but also as a rise of the ocean level, a general disruption of the weather pattern with more precipitations and more unstable events and a reduction of the biodiversity [1]. The connection is through the population factor on the one hand and the dependency on fossil fuels to provide most of the energy needs of humanity on the other [2]. The Kyoto protocol sets targets for reducing Greenhouse Gas (GHG) emissions to be met by 2012 by developed countries as compared to the baseline of 1990 (cf. Figure 1). While major countries like the US and Australia have not ratified the protocol and therefore have not committed themselves to any mitigation effort, it seems more and more likely that many countries will not meet their target. The European Union, for example, has committed globally to a reduction of 8% and spread the effort among its members, but will be hard put to reach it as several countries had already overrun their own national target by 2004 (Figure 2). This is due to the fact that some carbon-intensive sectors have not yet chosen a GHG mitigation path and are thus steadily widening that gap. On the other hand, it has been recognized that the Kyoto targets will have little effect on the expected Climate Change, both in terms of magnitude and warming kinetics.

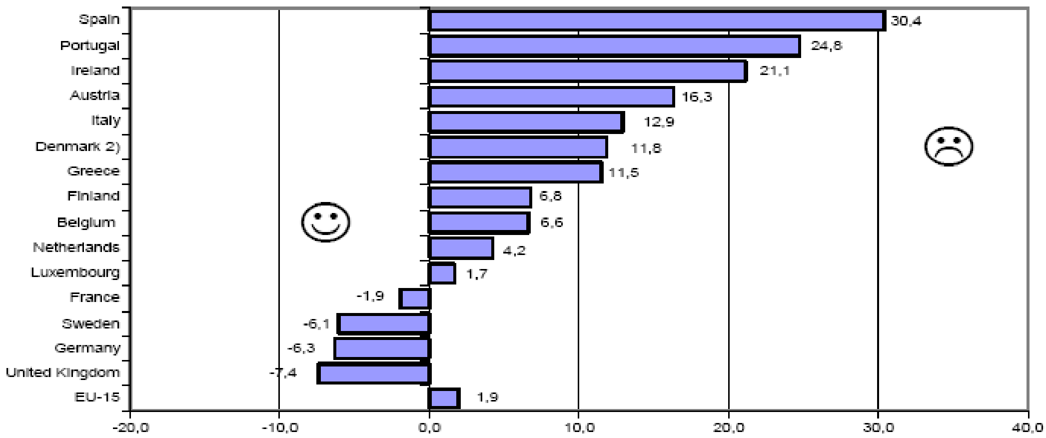

Figure 2 – gap between Kyoto reduction target and actual 2002 performance

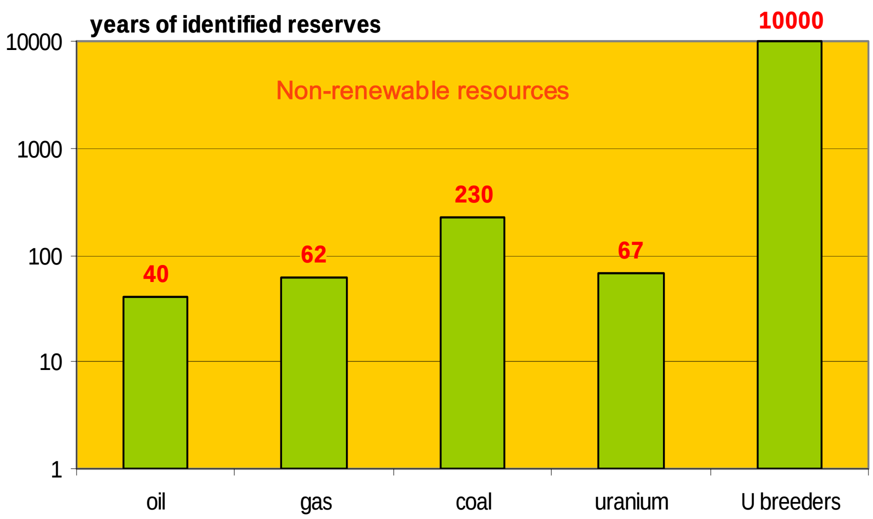

Figure 3 – Identified fuel reserves in years, from the NPE report

The changes necessary to mitigate Climate Change and keep it at a level deemed acceptable, for example by maintaining temperature increase below 2°C, are likely to be much more drastic than the Kyoto targets, which will eventually appear as a warm-up exercise, designed to let all stakeholders become aware of the magnitude of the problems and start looking creatively for society-wide, far-ranging, long-term solutions. This post-Kyoto agenda, which is now under discussion [3,4], is starting on the working assumption that the GHG pick-up in the atmosphere should be maintained at either 450 ppm of CO_2 or 550 ppm of CO_2 equivalent, from 370 ppm of CO_2 today[1]. To reach such an ambitious goal, emission mitigation should be applied at the level of "factor 4" solutions by the middle of this century. Several governments in Europe have already announced that this was indeed the kind of target that they would work to implement inside their own borders [[5],[6]] and the European Summit concurred in its March 2005 meeting [[7]].By 2050, this problem will be compounded by the proximity of the *peak oil* phenomenon (cf. Figure 3) and, soon afterwards, of the *peak gas* [[8]]. This expected reduction of fossil fuel supply will add to the disruptions that GHG mitigation policies will create [[9]], although analysts are starting to recognize that factor-4 mitigation policies would help alleviate the consequences of the peak oil (Figure 4): POLES' simulations [[10]] show that the demand would be stabilized by the middle of the century and the energy mix would shift from a heavy reliance on oil and gas to a larger share of renewables and other carbon-free energies.

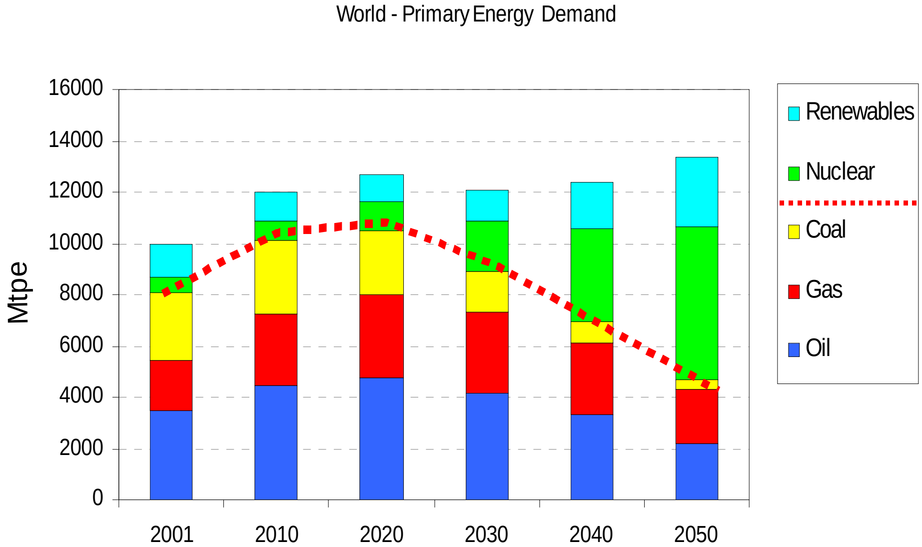

Figure 4 - world energy demand (millions of ton of petroleum equivalent) in the world from POLES' model simulations, assuming factor-4 policies.

Whatever Society decides for the future through its governments, this future is very likely to be deeply different from our experience of today. It should preserve the drive for more wealth and less poverty in the world while addressing the Climate Challenge at the level required by its stakes. Steel has been a major ingredient of the wealth of nations ever since the dawn of History and this will not change any foreseeable future. The Steel Industry should therefore look for solutions that will make it possible to continue delivering the Steel that Society will continue to need within the unfamiliar context of the post-Kyoto period.

This calls for technological breakthroughs and for true paradigm shifts in the way that steel is produced [[11]].

CO_2 mitigation in the Steel Industry

This analysis in terms of technological breakthrough as an answer to factor-4 targets stems from the Steel Industry experience with energy conservation and GHG mitigation over the past 50 years.

Indeed, the Steel Industry has engaged significant efforts to fight CO_2 emissions, without waiting for the Kyoto protocol to come into effect, as shown in Figure 5. By 2000, the European Steel Industry had already decreased its specific emissions by 18% as compared to 1990, which more than twice the 8% European average Kyoto target for the period 1990-2008. Over the last 30 years, this drop in emission levels has reached 50%, i.e. a "factor 2" result.

[1] This "guarantees" a 1/6 chance of meeting the 2°C target.

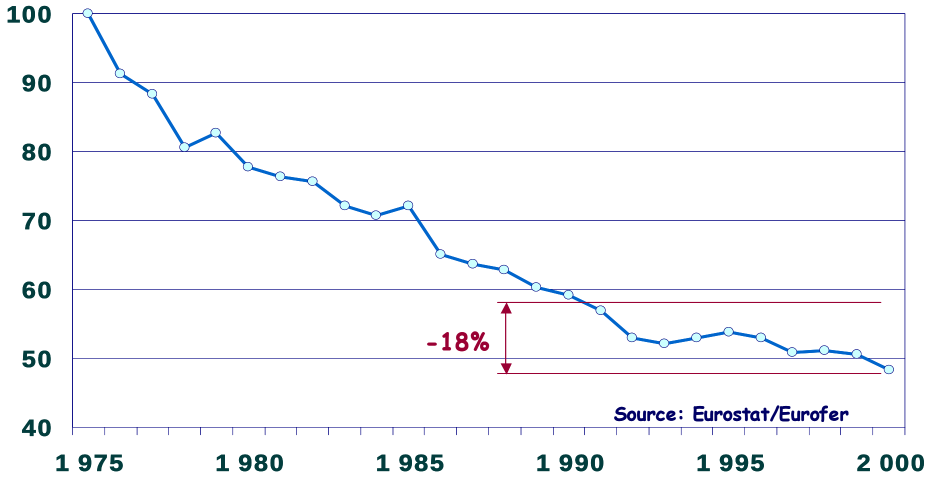

Figure 5 - CO_2 emission per ton of finished product - Index 100 for 1975

This large reduction in emission has been achieved by implementing a number of policies and technologies. Energy savings, improvement of yield and process development have all been instrumental in reaching this result. However, the major explanatory factor is the emphasis on using ever more recycled steel, scrap, either in the Blast Furnace (BF) route, where scrap addition to the level of 250 kg per ton of steel has become the norm, or by replacing BF, iron-based mills, by EAF, scrap-based mills (cf. Figure 6).

Arcelor has for many years pursued its own projects to improve the iron ore-based steelmaking process in order to reduce CO_2 emissions [[12]]. Thanks to these important efforts, the emission reductions largely exceeded the global goals set by the political authorities. For example, Arcelor reduced its CO_2 emissions by 18% in absolute value and by 23% per ton of raw steel between 1990 and 2002, way beyond the European Kyoto commitment (cf. Figure 7).

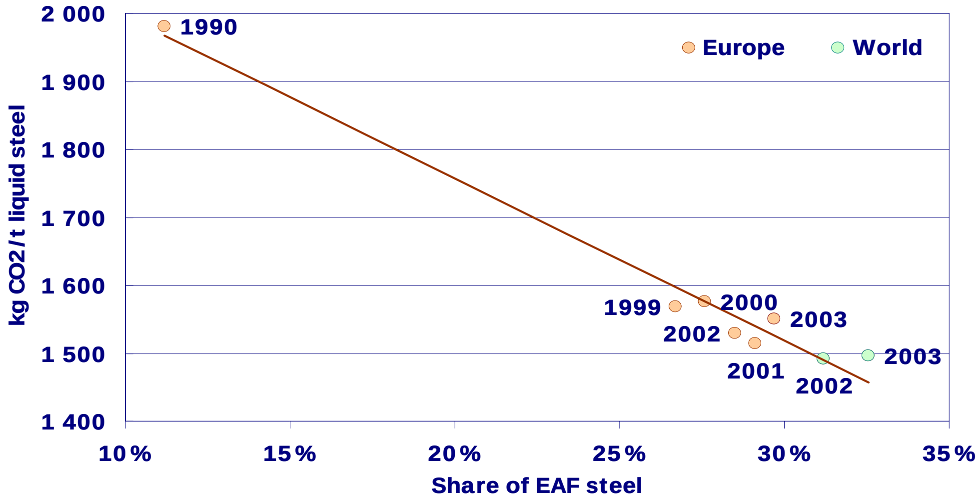

Figure 6 – relation between specific CO_2 emissions and share of EAF production in Arcelor group (year also indicate the shift towards EAF production)

Within Eurofer and with other European steel producers, Arcelor has actively participated in the discussions on the proposed European directive regarding the allocation and trading of Greenhouse Gas emission rights pursuant to the Kyoto Protocol. Despite these improvements, the final version of this directive still poses many problems for the steel industry. It will distort competition not only between materials (certain materials would be exempted by the directive in the short term), but also between European steel producers and, in particular, with regard to companies producing steel in countries that refused to ratify Kyoto (the USA in particular). This is the reason why the Arcelor group decided to lodge an appeal with the European Court of Justice on January 15, 2004.

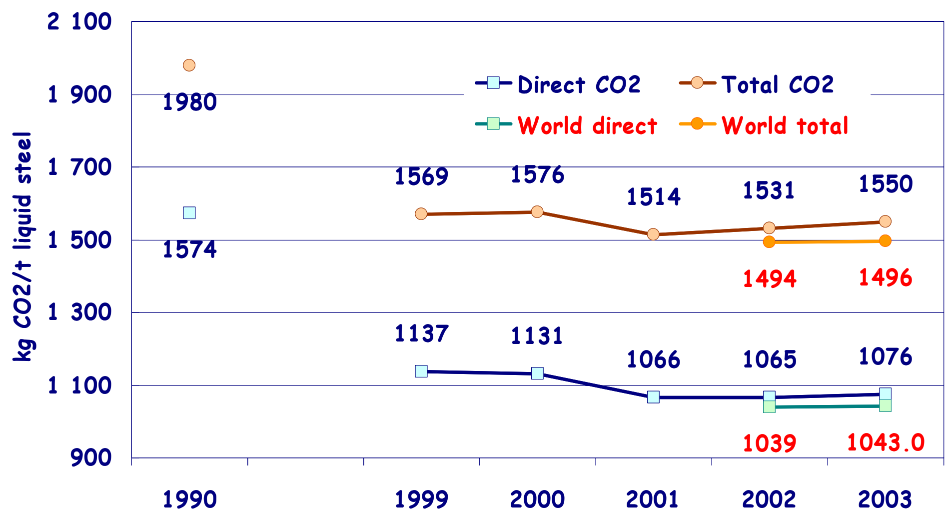

Figure 7 - CO_2 emission per ton of liquid steel –Arcelor scope 1 and scope 2 results, Europe and world perimeters

At the same time, on a country-by-country basis, Arcelor negotiated improved emission rights that permits not only safeguard the production needs at each facility but also contribute, through voluntary commitments, to the national plans to reduce greenhouse gases.

In France, since 1990, Usinor/Arcelor group has undertaken a number of initiatives that have reduced CO_2 emissions. The actual numbers, as well as any future use thereof, form part of the current recommendations issued by AERES (l'Association des Entreprises pour la Réduction de l'Effet de Serre).

Evaluated in accordance with these principles, CO_2 emissions amounted to 46 million tons for the period 1990-2002, while the production of crude steel actually increased by about 13% and specific CO_2 emissions (emissions per ton of steel produced) declined by 22%. In Luxembourg, the changeover from the blast furnace process to the electric furnace process enabled a 92% reduction in CO_2 emissions between 1990 and 2002. In France, Arcelor signed voluntary CO_2 reduction agreements for the periods 2003-2004 and 2005-2007. A similar approach was pursued in other European countries where the Arcelor group has large steel production facilities. In Belgium, Sidmar and ALZ, together with other large industrial energy users, undertook to reach levels of performance that are equal to the best practices in this area by 2012 in terms of energy efficiency. This benchmarking of best practices will be carried out by a special omission that includes the Flemish Government, the industry itself, and an independent oversight entity. Improving energy efficiency will result in a reduction of specific CO_2 emissions.

The kinetics of emission reduction has abated recently, not because efforts have slowed down, but because the return of new changes is diminishing.

In simple words, the utilization rate of available **scrap** matches the generation rate of scrap, which is estimated at 85 or 90%, and the energy efficiency of iron and steelmaking processes has come close to thermodynamical limits: typically, the Blast Furnace has an efficiency of 85%, the gap to 100% accounting for heat losses unavoidable for an operation taking place between 1400 and 1600°C and providing the driving force for ensuring a sufficient kinetics. Pursuing energy savings and continuing process improvement along the same path as in the past does not have the potential of achieving the factor 4 targets that Society will probably be requesting from all industrial activities by the middle of this century.

Large efforts carried out in the past have thus seemingly closed the door to more progress. Can this be true?

CO_2 mitigation in the Steel Industry

The solution to this apparent paradox consists in un-coupling energy conservation and reduction in greenhouse gas emissions. Energy savings remains a top priority to reduce emissions in most countries and for most human activities, but this can no longer be the main lever to reduce emissions for the most advanced industrial sectors, which have already collected most of the achievable reduction in energy consumption during the second half of the 20th century and among which the European Steel Industry stands tall.

Innovation in this area should focus on reducing emissions from the iron-ore route.

Indeed, the use of scrap has already been pushed to the maximum of the scrap supply and there is no major development to be expected around this technology; the main point is that there should be no slack in maintaining tension in this direction.

The main concepts around which breakthrough solutions for reducing iron ore can be designed are summarized in the pseudo-ternary diagram of Figure 8. At the apexes, lie the three fuel/reducing agents that are available for reducing the iron ore into hot metal at the high temperatures of steel-making [13]

On the one hand, one can keep using carbon, in reactors optimized through centuries of historical development and the leap forward of the end of the 20th century, and capture and store CO_2 in a sustainable manner and under careful monitoring. One can also use carbon from biomass, which, if produced in a sustainable steady-state manner in plantations for examples, will be neutral in terms of GHG accumulation in the atmosphere.

On the other hand, one can move away from the carbon apex, and favor hydrogen, either in natural gas or as pure hydrogen, and electrons, in the form of electricity. Both should be produced in a way that does not contribute to the generation of GHG, i.e. from green energies, nuclear power or by carbon-based processes that already include CO_2 capture and storage.

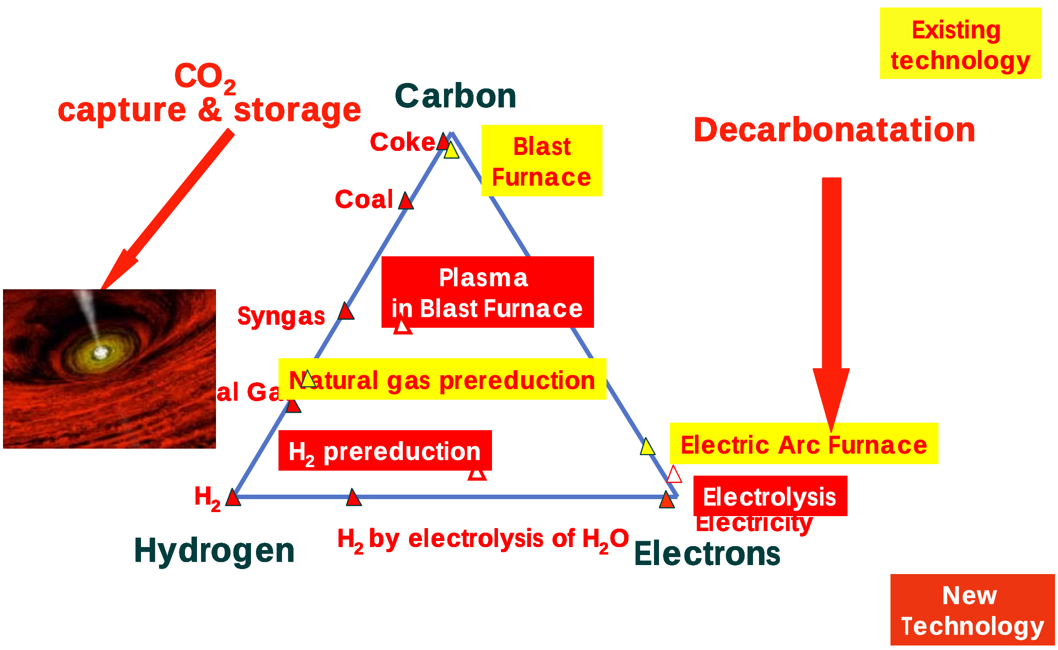

Figure 8 – Solution concepts to bring about breakthroughs in CO_2 emissions of the Steel Industry

It is fairly easy to imagine solutions that meet these requirements, but all of them have to be passed through the tests of technical feasibility, economic realism - at least in the future context of a post-Kyoto economy, and social acceptability. Moreover, most solutions are still at a conceptual stage and need to be demonstrated at a large enough scale to become credible. In simple words, their sustainability has to be established, which is a formidable task, the result of which cannot be taken for granted.

To explore these solutions and choose the most promising ones for further scale-up and industrial validation, a consortium of 48 European industries and research organizations has framed an RTD program, called **ULCOS for Ultra-Low CO_2 Steelmaking** [14], which has been proposed as an answer to a dedicated Call from the European Commission for Priority 3 of the 6th Framework Program in the area of “Very low CO_2 Steelmaking Processes”, in co-ordination with the 2003 and 2004 calls of the

Research Fund for Coal and Steel. Two complementary projects have been accepted under both programs and they constitute the ULCOS Research Program of the Consortium.

The consortium is led by a core-group of steel producers comprising Arcelor, Corus, Thyssen Krupp Stahl, Riva, voestalpine, Saarstahl and Dillingen, and its composition is given in Appendix 1.

Arcelor, which was at the origin of this initiative, is the Consortium's coordinator.

Scope of the ULCOS program

The usage of carbon in the Steel Industry for reducing iron ore is centered on the Blast furnace technology and a family of processes known as Smelting Reduction.

The Steel Industry itself will be asked to reduce its own emissions, even if they amount, today, to only 5% of anthropogenic emissions – because it is unlikely that any activity will be isolated from the total reduction effort and because each integrated mill is by itself a very large and visible source of CO_2. Adapting will be as difficult for Steel as for the other economical sectors. Indeed, Figure 5 shows that progress in the past has been quite brisk and, therefore, that the extrapolation current technologies leaves little leeway for drastic new reductions in emissions.

To overcome this true difficulty, one should examine breakthrough technologies, which have received little attention in the past, because they did not belong to the economic technological episteme of the time. The key to thinking about these changes is to realize that their goal should be to reduce GHG emissions and not simply to save energy: when most energy savings have been collected, as is the case in the most advanced Steel companies, carbon and energy have to be un-coupled!

There are three areas to be explored with this rationale. One consists in capturing and sequestering (C&S) CO_2. Another one consists in using energy and reducing agents not based on carbon, which means hydrogen and electricity, and to a lesser extent, natural gas. A last one consists in using sustainable biomass, as grown in eucalyptus plantations for example. All these issues are being extensively explored by several R&D programs in Europe [[15]] and more generally in the world [[16]].

Capturing and sequestering CO_2 can be carried out as an end-of-pipe technology, and, like all end-of-pipe technologies, will add cost to the present production scheme. With a cost range of C&S between 20 and 80 €/t of CO_2 (target of 40 €/t) and a maximum amount of storable CO_2 of 1.5t per t of steel, this means an extra cost 30 to 120 (60) €/t of steel. On the other hand, if CO_2 C&S is integrated into the ironmaking process, one may expect a better overall efficiency and a potential of more technical progress in the future (cf. the concept **of Blast Furnace with top-gas recycling**, under optimization within the ULCOS program, in Figure 11). The extra cost should in this case be less than calculated in the previous example and might dwindle down to a very small figure if things turn out right with the help of time. This dichotomy is similar to the pre-combustion and post-combustion C&S technologies under study in the power generation sector [[17]].

Some **Smelting Reduction** processes, which are the alternative to the Blast Furnace for using carbon as a reducing agent, also have the potential of reducing CO_2 emissions. The most promising ones consist either:

- in processes that recycle their top gas and therefore use oxygen rather than air to gasify coal. CO_2 can then be removed from the gas before recycling it and later stored (e.g. CCF or O_2-rich Hismelt)
- in processes that produce a more or less reduced iron, which can then be melted by carbon-lean processes, for example and quite simply an EAF fed with "green" electricity (Jupiter, Circofer, RHF, etc.).
- in processes where all the excess CO is burned in the reactor and the heat recovered by the iron charge (e.g. RHF or MHF, Hismelt, etc.)
- or any combination of these (e.g. Circofer and Hismelt, MHF and EAF, etc.)

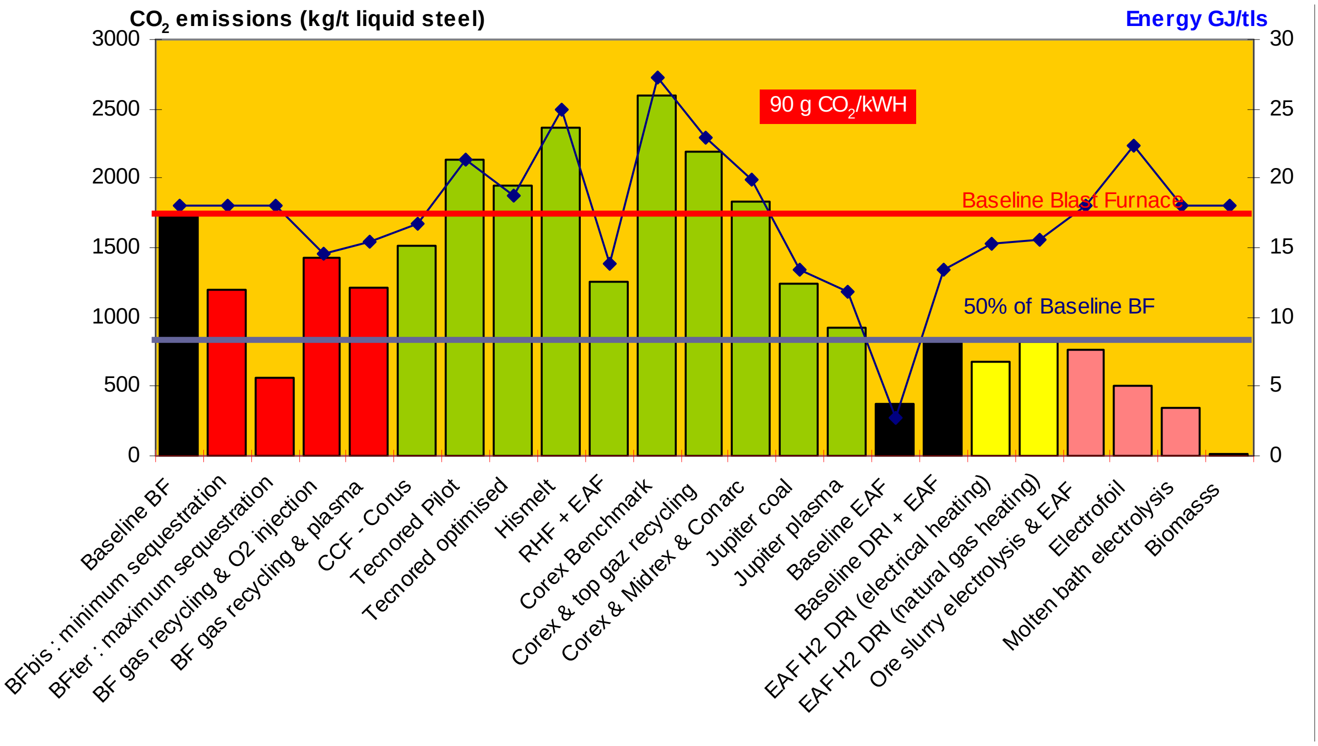

Figure 9 – Comparison of various steelmaking process from the viewpoint of CO_2 emissions (gate-to-gate emission including those linked to electricity generation) and energy consumption

Smelting Reduction never fully developed in the past, beyond the obvious but limited success of COREX and the larger development of pre-reduction associated with electric melting, mainly because the Blast Furnace technology proved capable of improving faster than the SR processes could be developed and scale up. This may change in the future, when the driver for change becomes CO_2 mitigation, as this may give a new boost to these concepts.

Replacing carbon by hydrogen or electricity is a challenge of a higher level, as neither hydrogen nor electricity are fuels, but rather energy carriers that need to be produced from other fuels. Until today, this is the reason why electricity has been more expensive than coal, gas or oil. This is also why mainstream steel R&D has carried out little work on a subject like the production of iron by the electrolysis of iron ore.

The picture may change completely in the future. Indeed, the carbon constraint will change the price structure of fuels. For example, carbon will have an extra price tag due to the need of capturing and sequestering CO_2, which, for a kWh produced by generating 1 000 g/kWh, would add 0.02 to 0.08 € to the cost of one kWh, a figure to be compared to the price of industrial electricity today, which varies between 0.005 and 0.080 €/kWh in the world. Non-carbon-based electricity would not have to carry this extra burden. This would probably change the price structure of energy in a drastic way! Similar orders of magnitude calculation would show that the Steel Industry could use large amounts of hydrogen, if it were available in large quantities at the right price, on a par with what the transportation industry would use if it were to change over to fuel cell cars.

Under such novel economic conditions, **hydrogen prereduction of iron ore** would become a reasonable proposition, especially since the change from natural gas to hydrogen is a rather simple one. Similarly, electrolysis of iron ore is a distinct possibility from the standpoint of physics [[18],[19]]. It has even been argued than it would be an "easier" technology, from a thermodynamical standpoint, than the electrolysis of alumina.

Somewhere in-between hydrogen and carbon, **natural gas** is a natural resource, which can be used also as a fuel and a reducing agent. Today already, with C-lean electricity, the DRI and EAF route reduces GHG emissions by a factor of 2 compared to the Blast furnace route. But they also offer a large potential for improvement. One can imagine capturing and storing CO_2, prereducing iron ore to a lesser degree than in a conventional a direct reduction process and then melting the DRI in more conventional furnaces, either a blast furnace, an EAF, a converter or a cupola. The sensible heat of the off-gas can moreover be recovered, etc. This may also have a large potential in a future where large deposits of gas will start being recovered from Northern fields, like the Snow White field in Norway.

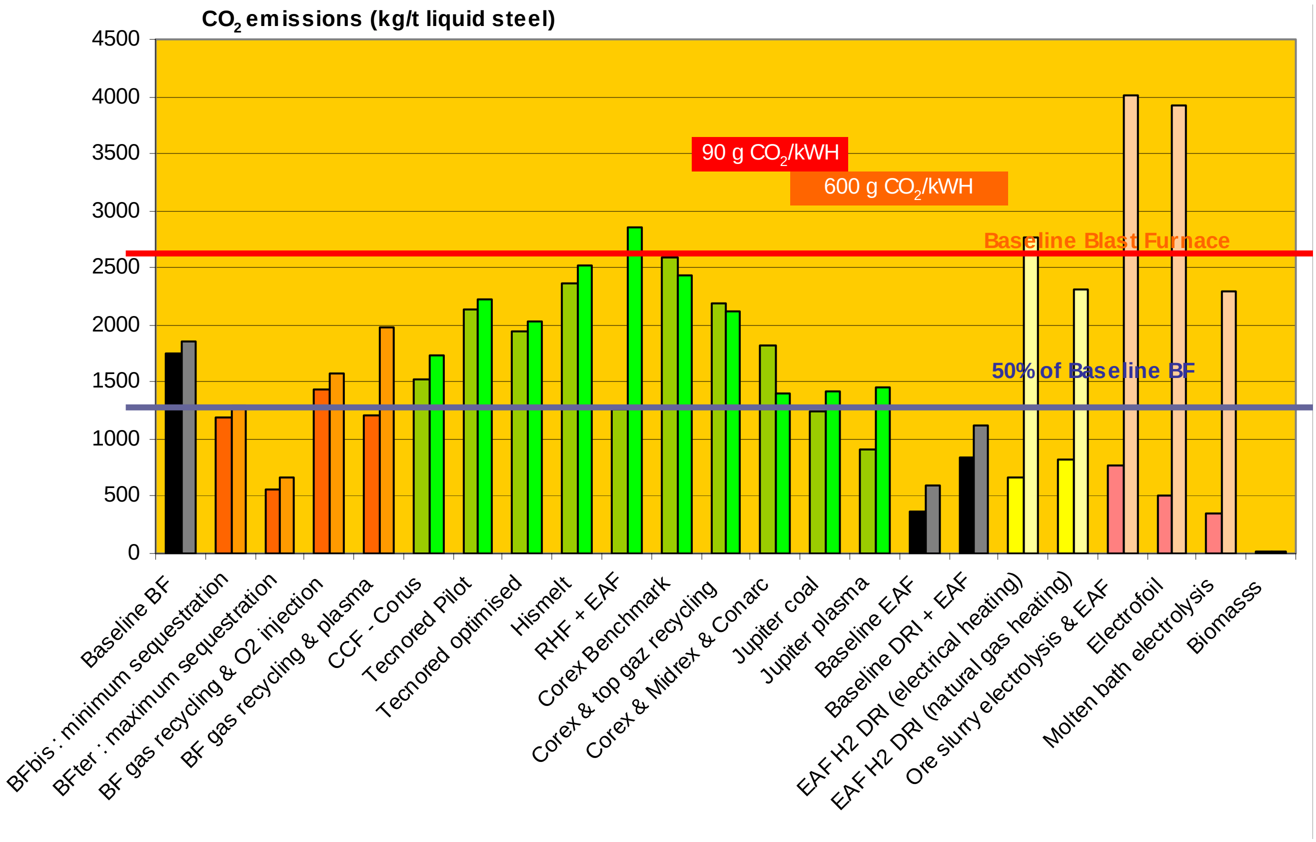

Figure 10 – CO_2 emissions of various steelmaking processes as a function of the CO_2 intensity of electricity

Finally, **sustainable biomass** needs to be seriously considered. This would be an interesting twist, from an historical standpoint, as Steel was produced for millennia from biomass and because industrialization has led to the destruction of forests in Western Europe, as forestry at the time was not sustainable. Sustainable forestry is a reality today, attested by international certification bodies, such as FSC [[20]]. Moreover, forest biologists and ecologists have started to demonstrate that, under sustainable growing conditions, carbon plantations can indeed be neutral to the accumulation of GHG in the atmosphere [[21]]. Last but not least, inventories of land that could be made available for growing energy crops seem to show that there are distinct possibilities of setting up more plantations that could have a clear contribution to the production of the steel in the world. The matter needs very careful attention and is clearly not settled, but the necessary work will be carried out within the ULCOS project.

Separately, or used together, these new avenues for making steel that call for breakthrough technologies have the potential of achieving the targets likely to be set forth for the post-Kyoto period, by the EU in particular.

The magnitude of the changes is enormous and it will take ingenuity, time and money to carry them through. Time means the post-Kyoto period at least for the first industrial implementations and the 2020s and 30s for a generalization in the world. These technologies will have to become mainstream and used all over the world, if the industry is to reduce its emissions globally: it would be meaningless for European Steel alone, for example, to implement these technologies, while the rest of the world would continue to produce CO_2 at the present rate.

On the other hand, this is a challenge worthy of the Steel Industry and a tremendous opportunity to change and adopt into new technologies, which have an untapped potential for progress.

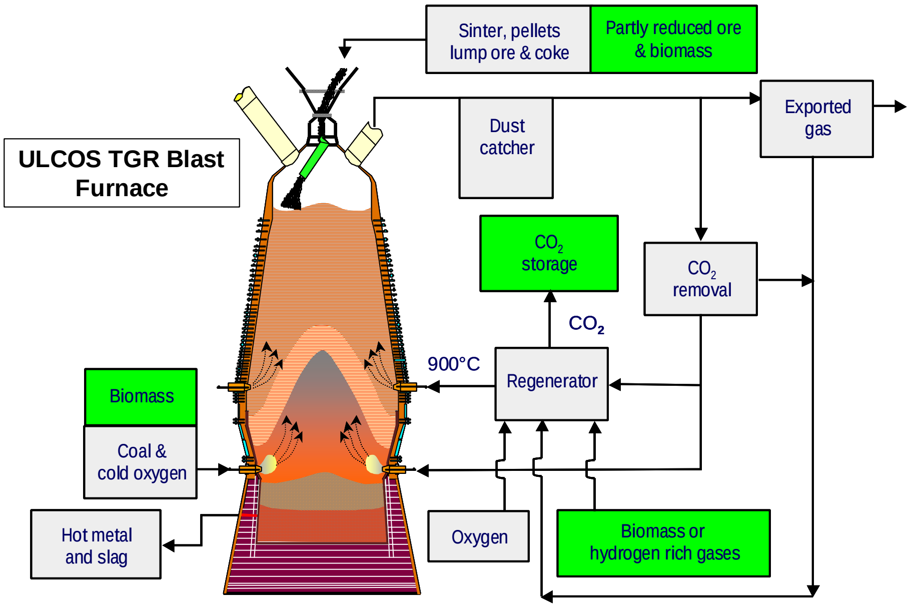

Figure 11 – principle of the Top-Gas Recycling (TGR) Blast Furnace, to minimize GHG emissions. Captured CO_2 would also be sequestered.

Conclusions

The European Steel Industry has been involved in CO_2 mitigation all along the 20th century and this has already resulted into large reductions, a factor 2 in specific emissions in Europe over the last 30 years for example. This more or less exhausts the possibilities offered by energy savings, because the Blast Furnace has reached a very-high level of efficiency as a chemical reactor both in terms of thermodynamics and heat transfer. To reach beyond these results and aim at the post-Kyoto target reductions under discussion now, it is necessary to look at breakthrough technologies that uncouple CO_2 reduction from energy savings. A large program, ULCOS, has been launched to investigate a broad range of potential technologies and check whether the proposed concepts stand up against criteria of technical and economic realism. This five-year program should deliver a small number of candidate technologies ready for further scale-up, which would need a further program, also of 5 years, to demonstrate their viability. Commercial implementation could start afterwards.

Appendix 1 – other ULCOS partners

- other steel producers: SSAB and Ruukki
- industries present in the supply chain of the steel industry, from electricity and energy producers, to plant and equipment manufacturers: L'Air Liquide, Danieli-Corus, EDF, FERROSTAAL, KÜTTNER, LHOIST, Paul Wurth, Statoil, VAI
- Research Institutes: ALPHEA, ARMINES, BFI, BRGM, CIRAD, CRM, CSM, ECN, GEUS, CSIC/INCAR, IPTS, MEFOS, SINTEF, SINTEF-Petroleum, TECNALIA, BTG
- small and medium businesses: EUROPLASMA, GVS, METALYSIS
- and Universities: University of Aveiro, Portugal, LEPII, University of Grenoble, France, University of Kassel, Germany, University of Leoben, Austria, Institut Polytechnique de Nancy, France, University of Luleå, Sweden, NTNU, Trondheim, Norway, SSSA, Pisa, Italy.

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