ANCRE
Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

December 2015 – www.allianceenergie.fr

LOW-CARBON STEELMAKING

The steel industry emits significant amounts of CO_2 —it accounts for 5% of global anthropogenic emissions— and consumes large quantities of coal. Steelmaking requires the use of coal to reduce ore (at high temperature the most common ore is hematite, Fe_2O_3, so the reduction is: $Fe_2O_3 + C \rightarrow Fe + CO_2$) and to a lesser extent for heating —better to achieve optimized thermodynamic and kinetic efficiency.

Steel producers have optimized their coal consumption because of high energy prices for several decades. Reducing CO_2 emissions therefore implies developing radical technologies, which comes with high costs.

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

Technology 1: EAF[1] steelmaking (circular economy)
This technology involves smelting steel scrap in an electric arc furnace. EAFs currently account for one third of global steel production.

EAF technology will likely replace BF technology by the 2100s, when the demand for steel stops growing and steel recovered as scrap after a life-in-use of roughly 40 years. Thus, although the recycling rate of steel is one of the highest among other materials (85%), switching to secondary raw materials will only have an impact almost half a century in the future. The issue of scrap quality should however be taken proactively.

Technology 2: ULCOS[2]-BF[3] (also called TGR-BF), ArcelorMittal (France)
This technology involves recycling top gas for iron production by recovering partially oxidized gases (CO) which still have iron-reducing properties. ULCOS-BF technology should be considered a radical innovation and is being studied and validated on industrial pilots, prior to a larger scale test on a demonstrator (TRL7-9).

Technology 3: HIsarna, Tata Steel (the Netherlands)
HIsarna is a smelting-reduction process, which involves coupling a bath smelter (HIsmelt[4]) and a cyclone reactor to melt ore[5]. It has been designed and implemented as a pilot operated during several ongoing experimental campaigns. This technology is also a radical innovation.

Technology 4: ULCORED, LKAB (Sweden)
This technology involves using coal instead of natural gas for heating and iron reduction —after methane reforming in CO/H_2, CO reduces ore.

Technology 5: ULCOWIN, ArcelorMittal (France)
This technology is much more innovative than the other ULCOS-BF technologies mentioned previously as it involves using only electricity through low temperature electrolysis (110°C).

Technology 6: ULCOLYSIS, ArcelorMittal (France)
This technology is the most innovative of all low-carbon steelmaking technologies as it involves reducing iron into liquid iron.

The first four technologies mentioned above can be boosted by use of CCS[6] technology. This is actually the only way to achieve the large CO_2 reductions targeted by climate policies.

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[1] EAF: Electric Air Furnace
[2] ULCOS: Ultra-Low Carbon Dioxide
[3] BF: Blast Furnace
[4] For the past 30 years, HIsmelt technology has been benefitting from intensive fundamental work and R&D programs to achieve HIsarna from HIsmelt steps (Australia operated a large demonstrator).
[5] This technology has also been studied in the Netherlands twenty years ago.
[6] CCS: Carbon Capture and Storage

2. Maturity level and technological perspectives

Maturity of Low-Carbon Steelmaking

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
EAF	5	5	5	5	5
ULCOS-BF	3	3	4	5	5
HIsarna	3	3	4	4	5
ULCORED	3	3	4	4	5
ULCOWIN	3	3	3	4	5
ULCOLYSIS	2	2	3	3	4

Although these technologies are not mature yet, they will reach maturity by 2050. This will considerably reduce CO_2 emissions.

Potential development of Low-Carbon Steelmaking

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
Potential develop-ment	0	1	2	4

Technology 2: ULCOS-BF and TGR-BF, ArcelorMittal
This technology pertains to radical innovations and its effects would likely be visible by 2030-2035. There are still bottlenecks to overcome for ULCOS-BF technologies. Provided Western countries engage in a pro-active approach, the contribution of ULCOS-BF technology in this part of the world could reach 30 to 40%.

Technology 3: HIsarna, Tata Steel
There are several ongoing experimental campaigns. If the technology develops as planned, this would lead to a demonstrator with a 0.5Mt/year capacity. Such a decision could occur in 2016. An industrial line could be implemented by 2020 or —more probably— later.

Technology 5: ULCOWIN
This technology has reached a large laboratory pilot level on the maturity scale: current pilots can produce steel in batches of 4 kg. Further development could lead to a demonstrator (that is an industrial-sized furnaces), which could be designed, built and validated within 5 years. Because of risks and uncertainties concerning electricity costs, the first furnace could only be implemented by the 2030s. Industrial development would then follow in the mid-2030s.

Technology 6: ULCOLYSIS
This technology has reached very small-sized lab experiments on the maturity scale: current furnaces can a few grams of steel with each batch. Research and pilot basis is still needed and further development to industrial scale will not be possible before 2040.

With a pro-active approach these technologies could bring the 5% of emitted anthropogenic CO_2 of the steelmaking industry (including CCS) to zero by 2050.

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.

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**
EAF	Rank				6		
	Keywords				Recylced steel		
ULCOS-BF	Rank	3	6	5			4
	Keywords		No business model	Carbon tax			Low acceptability with CCS
HIsarna	Rank	4	6	5			3
	Keywords	Technology needs to be validated	No business model	Carbon tax			Low acceptability with CCS
ULCORED	Rank	4	5	6			3
	Keywords	Pilots need to be built and validated	No business model	Lack of support from countries			Low acceptability with CCS
ULCOWIN	Rank	6	5	4			
	Keywords	Technical difficulties	No business model	Carbon tax			
ULCOLYSIS	Rank	6	5	4			
	Keywords	Technical difficulties	No business model	Carbon tax			

Some of the mentioned fields do not represent bottlenecks; this is why there are no number associated with bottlenecks.

There is no current business model for most of these technologies. Manufacturers bear all the investment risks, which is not encouraging at all in a globalized market context —indeed a carbon tax might lead to an industry drain for steel production (carbon leakage). By 2050 a significant reduction of global emissions from the steel industry might be considered, provided that a business model is secured until then.

Technology 1: EAF steelmaking
There are few challenges involved with EAF steelmaking and low-risk investments have been made with this technology. On the other hand there are no doubts concerning the development of EAF steelmaking and there is a growing contribution to the solution with a long-term characteristic time. The only bottleneck is the available steel for recycling, which is entirely related to past steel production.

Technology 2: ULCOS-BF and TGR-BF, ArcelorMittal
The main bottleneck pertains to economics —i.e. the fact that there is no business model. Regulation could be a solution as it could add value to carbon but could also lead to carbon leakage. CCS raises issues of public acceptance, especially in Germany. Some technological issues remain to be solved.

Technology 3: HIsarna, Tata Steel
This technology shares the same bottlenecks as ULCOS-BF technology —i.e. no business model, adding value to carbon, public acceptance and technological issues— except that HIsarna technology also needs to be validated and until it is done, validation remains the main deadlock.

Technology 4: ULCORED
ULCORED is more adapted to countries using natural gas —however those countries are not interested in reducing CO_2 emissions at the present time.

Technology 5: ULCOWIN, ArcelorMittal
ULCOWIN technology needs to reach the next maturity level. ULCOWIN also shares the same issues as other ULCOS-BF technologies.

Technology 6: ULCOLYSIS
For ULCOLYSIS, same as ULCOWIN, except that technological issues are more difficult.

4. Potential radical and incremental innovations

<u>*Methodological information:*</u>

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**
EAF	I or R	I					
	Key-words						
ULCOS-BF	I or R	R	R	R			R
	Key-words		Expensive low-carbon technologies. No business model	Buyback tariffs			No readiness for low-carbon technologies. Acceptability CCS
HIsarna	I or R	R	R	R			R
	Key-words	Idem					
ULCORED	I or R	R	R	R			R
	Key-words	Idem					
ULCOWIN	I or R	R	R	R			I
	Key-words	Idem					
ULCOLYSIS	I or R	R	R	R			I
	Key-words	Idem					

Technology 1: EAF steelmaking
EAF involves no particular challenge.

Technology 2: ULCOS-BF and TGR-BF, ArcelorMittal
ULCOS-BF is already a developed technology. The current project in Florange, France, might resume eventually —however this is highly improbable if no initiatives are taken concerning the financial environment and regulation framework.

Technology 3: HIsarna, Tata Steel

HIsarna is a more radical technology than ULCOS-BF as it requires re-building blast furnaces or new steel mills, which will not happen in Europe: indeed investments are too expensive —100 billion euros should be invested in Europe, and ten times as much in the world.

Technology 4: ULCORED

ULCORED technology is at a standstill: few market outlets in Europe (relative high price of natural gas) and outside Europe (low incentives to reduce climate impacts).

Technology 5: ULCOWIN, ArcelorMittal

ULCOWIN is a strong asset, especially as renewable energies are taking up a larger share of the grid electricity. Indeed this technology would counterweight the intermittence of renewables —with no need for quick-start thermal plants and without making assumptions about whether or not electricity mass storage will be possible.

Technology 6: ULCOLYSIS

ULCOLYSIS technology is unlikey to be implemented before long.