Steel & CCS

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• Steel & CO$_2$
• the expected role of CCS
• what can we seriously say about costs??
• any other operational solutions?
• Conclusions?
Steel and CO$_2$
Steel & iron have been a core material of the economy for 3000 years and this is not about to change soon! Steel is based on cumulative technologies, which are constantly renewed (and thus are utterly modern) and constitute a KET.

Production from 1913 until today rose from 100 to 1500 Mt/yr. Projections for 2050 vary between 2.5 and 3.5 billion tons.

Iron (Fe) is the most common element on Earth, but in the Geosphere (the Crust) Fe has combined with oxygen to form iron ore (mostly Fe$_2$O$_3$ & Fe$_3$O$_4$).

The Steel Industry uses iron ore as a resource (70%, of its iron input, worldwide) to revert it back to metallic status - like it is in mature stars, the earth core or in meteorites. This is carried out by high temperature chemistry (pyrometallurgy), using reducing agents like carbon and hydrogen – thus like coal and natural gas. It is called ironmaking and it makes use of a Blast Furnace (integrated steel mill).
CO₂ is the by-product of Fe reduction. It is not the result of combustion, like when coal is burned in a power plant. This puts the issues of CO₂ emissions in a particular perspective:

- ironmaking produces iron, not heat like a power plant, and thus cannot be "easily" replaced by renewable energy
- ironmaking releases oxygen which was trapped in the geosphere for 100 millions of years
- CO₂ is produced by very efficient processes, from an energy utilization standpoint (roughly twice more efficient) and ends up being highly concentrated in the off-gas

Greener routes than the Blast Furnace exists and they are used as much as possible, from different points of view:

- reduction based on natural gas (direct reduction) has peaked at 50-60 Mt/yr, because cheap (enough) NG is only available in oil producing countries. This seems to be changing in the US with the boom in shale gas.
- reduction based on biomass has been concentrating on charcoal, about 10 Mt/yr production in Brazil (eucalyptus plantations).
- direct use of REN not seriously considered, except as an input for producing electricity or hydrogen. The most efficient of the two is direct use of electricity in electrolysis (cf. ULCOWIN & ULCOLYSIS processes)
- scrap use (EAF) greatly decreases GHG emissions and energy consumption, but presently all available scrap is used! The economy of Fe is as closed as can be for the time being.
• the steel industry produces roughly 2.0 tons of CO$_2$ per ton of steel in the integrated route (scope I and II) and 0.8 t in the EAF route.

• this represents between 3 and 8% of anthropogenic emissions, depending on calculation assumptions

• is it a lot? or not very much? a very political question and an important one, from a practical policy making point of view!!! (see further)
The "expected" role of CCS
the steel sector started thinking of CO$_2$ mitigation in the late 1980s, before Rio and the Kyoto protocol.

indeed, the challenge was high, as energy efficiency runs high in the sector and further savings range between 5 to 15% depending on the the level of technology sophistication of the steel mill.

thus, significant cuts in emissions (50% in 2050 as of 2004 or 85-98% as of today) meant decoupling energy efficiency and CO$_2$ mitigation and using breakthrough technologies, still to be developed.

better to start early! An inventory of options was developed early, in an international context – as cooperation seems mandatory before public funding could be gathered to support such an ambitious and high-risk endeavor:

- CCS was an important option, as it would continue relying on the BF
- ... but also on other smelting reduction technologies, with CCS
- and direct reduction based on NG, with CCS
- direct steelmaking using either electricity or hydrogen were also considered
- the use of biomass, plus a whole range of "SF" technologies.
the ULCOS program was launched in the EU in 2004 (at TRL 1) and has been running since, with a kind of PPP approach (EU (RFCS + FP6), national programs, private financing, roughly 100 M€ and 40% EU finding). It involved the steel sector as a group (more or the ESTEP community) and not competitors developing competing technologies.

80 routes were examined from the start and eventually 4 families of ULCOS solutions were selected rationally and scale up to various TRL – e.g. ULCOS-BF is presently frozen between TRL-7 & 8 or 9.

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<th>Coal &amp; sustainable biomass</th>
<th>Natural gas</th>
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<td>Revamping BF</td>
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<td>Revamping DR</td>
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| **ULCOS-BF** | **Hlsarna** | **ULCORED** | **ULCOWIN**
| Pilot tests (1.5 t/h) | Pilot plant (8 t/h) | Pilot plant (1 t/h) | Laboratory pilots |
| Demo phase under way | start-up 2010 | to be erected in 2013 | pilots |

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**Revamping DR**

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**ULCOWIN**

**ULCOLYSIS**
Diff CV: differentiated carbon value according to the sector. Projected steel production does not change, nor do the \(\text{CO}_2\) emissions compared to the results for a unique \(\text{CO}_2\) value (F2 world)
CCS is present in 3 out of 4 ULCOS solutions: a "mandatory" solution because of energy/emission decoupling and because of the high constraint set on the steel sector.

In view of the slow introduction of CCS in the power sector, it has been said that CCS was maybe more "useful" or "necessary" for industry applications (process industries): this sounds like a pro domo argument for CCS.

Actually, if the pressure to cut CO2 emissions remains on steel, then CCS in the steel sector may be more than a bridging technology as it is often presented.

But what is exactly CCS?

- It is not a technology, neither the capture part nor the storage part.
- It is rather a concept and a question for which technologies adapted to various sectors have to be developed.
- Note that capture categories have been named according to power plant solutions, with one broad category devoted to industry as a whole.
- For steel, ULCOS-BF and ULCORED, the true name of the technology principle ought to be "in-process capture".
- The kind of gas to be captured depends also on the process and the geochemical issues this raises in the storage site depend very much on it.
What can we seriously say about costs??

Air, iron & water, by Robert Delaunay
ULCOS-BF, the most mature steel solution, needs to be tested on a demonstrator, not simply to test CCS, but the new total process concept! Until this is done, calculating and publishing OPEX is a kind of *jeu de dupe*! Risk is high and OPEX may be small or extremely high, depending on level of success, learning speed (rather than curve), etc.

ULCOS-BF is not simply costs but also gains (energy gains = 25% less coke consumption) and trade offs (BF gas "disappears" - has to be replaced by NG) not at the boundaries of BF alone but of the whole steel mill. Results ripe with uncertainties and indexed on coke price, NG & electricity price, CO₂ ETS value, etc.

This kind of thing is extremely difficult to communicate, as was experienced in the discussion about NER-300 evaluations in Summer 2012.
Any other operational solutions?
Other operational solutions?

- internalize the value of CO$_2$ by using a sectoral value rather than a unique multisectoral value

- go beyond the "polluter pays" principle: charge at the source – or as a mixture of both. This would point to solutions which are not considered today.

- "Forget" the CO$_2$ emissions of the steel (etc.) sector (stop "huge" constraint), but give them a credit if they cut. Objective should be 80% (of emissions) compliance, nor necessarily 100%.

- Cf. Seminar on the economics of CO$_2$, Industry & Climate Change policy, ESTEP, Brussels, 17/09/2013
Thank you!

Air, iron & water, by Robert Delaunay