Response to UK Government Clean Steel Request for Evidence.

On behalf of the Institution of Chemical Engineers' Clean Energy Special Interest Group. Drafted by Professor Paul Fennell, with comments received from a number of committee members.

1. The UK steel sector has a number of strengths identified above, are there any others that we have not identified?

No comment

2. Are there any further opportunities, not already identified, from a UK clean steel sector?

Deep integration with other industries as both a potential user and supplier of hydrogen.

3. What other wider benefits could the Fund deliver?

Boosting UK RD&D, developing UK IP (to be clear, options exist *today* for decarbonization without further R&D, further R&D will make them more efficient / cheaper, but there is no reason to delay).
Acting as a source of hydrogen for decarbonization of other industries.

4. How could the UK government facilitate creation of a market for low carbon steel?

Most likely through setting a procurement threshold for steel carbon intensity, and ensuring that UK business was in a position to meet it.

5. Have we identified the most significant barriers to investment in decarbonisation of steel production? Are there others we should consider?

A study in 2014 by the Grantham Institute, which surveyed different stakeholders in industry with the specific aim of investigating barriers to the deployment of ICC[1] found the following key barriers at that time:

1. **The economic barriers of deployment;**
2. **The absence of long-term policies and frameworks** guiding future development of industrial CCS;
3. Infrastructural constraints such as the **lack of nearby storage sites** and **connectivity to transport and storage infrastructure**.

It is clear that the government is aiming to address (1) and certainly (2). If the aim is to decarbonize industrial clusters in the UK, then (3) should also be addressed. In the wider arena, it will be necessary to enact border tariffs to prevent steel from countries which do not

[1] https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/institute-reports-and-analytical-notes/Attitudes-and-Barriers-to-CCS---GR6.pdf

currently have decarbonization requirements from sending in cheaper high carbon steel. For this to be allowable under WTO rules[2] (which we are all now experts in):

In order for a trade-related environmental measure to be eligible for an exception under Article XX, paragraphs (b) and (g), a member has to establish a connection between its stated environmental policy goal and the measure at issue. The measure needs to be either:

- *necessary for the protection of human, animal or plant life or health (paragraph (b)) or*
- *relating to the conservation of exhaustible natural resources (paragraph (g)).*

It has been argued that the capacity of the atmosphere to take up CO_2 without causing climate change is an exhaustible natural resource and therefore exempt.

Multiple discussions with industry representatives indicated that they understand the requirement for decarbonization, and that should costs be incurred their customers would be more than capable of meeting them, but that as a commodity product they cannot unilaterally raise prices.

6. How are investment decisions on decarbonisation projects made in your organisation? What evidence is required to support decisions?

No comment

7. What would help your Boards to agree to decarbonisation projects?

Members of the Clean Energy SIG are involved in current industrial decarbonization projects in the UK Iron and Steel arena. They have identified that they need a financial framework that makes decarbonization possible without affecting the commercial position of the company, and for policies to provide *long term security to investors and operators.*

8. Have we correctly identified the objectives for this Fund?
9. How can we maximise broader societal benefits, alongside value for money, in the design of the Fund?

There should be some dedicated work on the integration of electric arc furnaces with intermittent renewable energy for demand management.

10. What estimates do you have on the costs and availability of these three technology options for reducing emissions?

There are multiple pathways to low/no carbon emissions steelmaking, set out in Figure 1 below from a recent report by Arcelor Mittal

[2] https://www.wto.org/english/tratop_e/envir_e/envt_rules_exceptions_e.htm

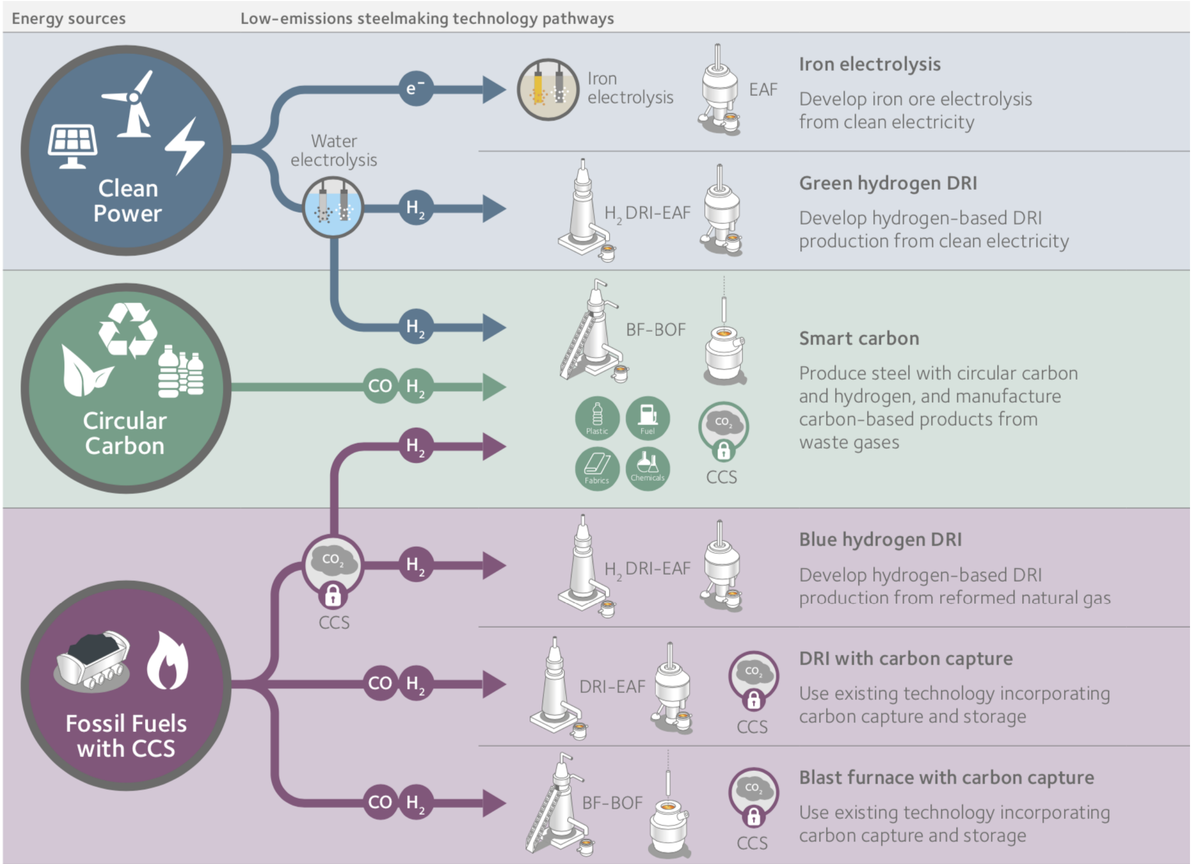


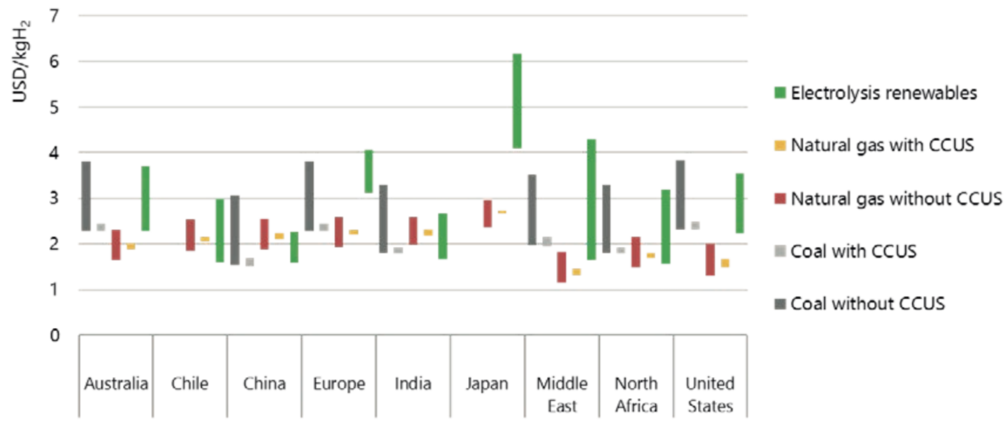
Figure 1: Pathways to low emissions steelmaking. Source: ArcelorMittal, Climate Action Report 1 (May 2019)

Here we will focus on (1) the development of zero-carbon hydrogen for use in DRI and (2) back-end CCS.

Two technology pathways are available for near-elimination of emissions reduction for virgin steel production using CCS: (1) reforming and shift of natural gas into hydrogen and carbon dioxide, followed by separation, and reduction of the iron ore using hydrogen, and (2) capture of CO_2 from the exhaust of a blast furnace (and other locations within the steelworks which produce CO_2).

(As Figure 1 notes, there are also two major routes to produce low- or no-carbon hydrogen for steelmaking: "green" hydrogen production from sources such as wind, solar and nuclear energy, and "blue" hydrogen production from such sources as natural gas with steam methane reforming and CCS (It should be noted that there are other methods for producing hydrogen from methane than SMR, which is used here as a catch-all for brevity). Both are viable, although, as Figure 2 below suggests, natural gas with CCS today holds a significant cost advantage in the developed world.)

Figure 19. Hydrogen production costs in different parts of the world



Notes: Bars indicate range between near- and long-term hydrogen production costs, which include a CO_2 price of USD 25/t CO_2 in the near term and USD 100/tCO_2 in the long term. For options from coal and natural gas, the higher value indicates the long-term costs (due to the increasing CO_2 price), whereas for hydrogen from renewable electricity the lower value indicates the long-term costs.

Source: IEA 2019.

Figure 2: Global hydrogen production pathway costs. Source: International Energy Agency, "The Future of Hydrogen" (June 2019)

Hydrogen-based production of iron using natural gas and CCS is a near-commercial technology/ A commercial demonstration using natural gas, steam methane reforming and CCS is currently under way in Abu Dhabi: the Al Reyadah project[3]. The project is run by the Abu Dhabi National Oil Company (ADNOC), and MASDAR and has plans to inject 800,000 tonnes of CO_2 per year.[4] Abu Dhabi considers this project to be strategic in terms of enabling future CCS projects and also to the production of clean energy [Abu Zahra 2017].

ArcelorMittal notes that it is presently planning a hydrogen-DRI pilot project in Hamburg,[5] although the hydrogen source is unspecified.

Several other demonstration projects using CCS in steelmaking are underway globally, summarized in Table 1 below:

[3] Abu Zahra, M. (2017). CCUS Status and Potential in the United Arab Emirates. UKCCSRC Biannual Meeting, London, UK. Available from: https://ukccsrc.ac.uk/sites/default/files/documents/event/CCUS%20Activities%20in%20UAE_UK%20CCSRC%20Biannual%20Meeting_Abu%20Zahra.pdf

[4] In this project the captured CO_2 is used to enhance oil production from the Rumaitha and Bab oil fields in the near term. While this provides value and revenue to offset the initial costs of this demonstration project, over the long run, a zero emissions state will require that captured CO2 be sequestered permanently

[5] ArcelorMittal, Climate Action Report 1 (May 2019), p. 28.

Table 1: Steel CCS demonstrations around the world

Project	Location	Start Date	Scale	Approach
ULCOS[6]	EU	2009	Pilot demonstration and paper-based work	Blast Furnace Top Gas Recycling – large pilot Novel Reactors (HIsarna) – large pilot Pilot demonstration of aspects (ULCORED)
Course 50[7]	Japan	2011	30 tpd	Chemical absorption from blast furnace
POSCO[8]	South Korea	2012	10 tpd	Chilled Ammonia-based capture from blast furnace
Shougang Jingtang Iron and Steel	China	2014	Feasibility Study	300 tpd chemical absorption from a variety of sources
Al Reyadah[9]	UAE	2016	2400 tpd	Solvent based capture from Direct Reduced Iron unit
Stepwise[10]	Sweden	2017	14 tpd	Sorption-Enhanced Water-Gas Shift (SEWGS) for blast furnace gas

The major programme of works in the EU is the ULCOS project. This programme has demonstrated Top-gas recycling (removal of CO_2 from the CO-rich gases leaving the blast furnace and recycling it to the blast furnace. (The demonstration was at Luleå in Sweden and included demonstration of a vacuum pressure swing adsorption system.) This approach has dual benefits of both reducing coke use (by up to 25 %) in the blast furnace and when the captured CO_2 is sent for sequestration, up to a total of 75 % reduction in overall CO_2 emissions.

For the demonstration of ULCORED (a methane-based direct reduction system), there was a partial oxidation burner demonstrated by Linde, although not much progress has been made since 2012. The Hisarna process, led by TATA at its Ijmuiden plant started in 2011. A

[6] https://www.sustainableinsteel.eu/p/532/ulcos_=_ultra_low_co2_steel_making.html

[7] http://www.jisf.or.jp/course50/outline/index_en.html

[8] https://ieaghg.org/docs/General_Docs/Iron%20and%20Steel%20Presentations/07%20Ahn%2020111108_IndCCSWS_CHI%20KYU%20AHN.pdf

[9] https://ukccsrc.ac.uk/sites/default/files/documents/event/CCUS%20Activities%20in%20UAE_UK%20CCSRC%20Biannual%20Meeting_Abu%20Zahra.pdf

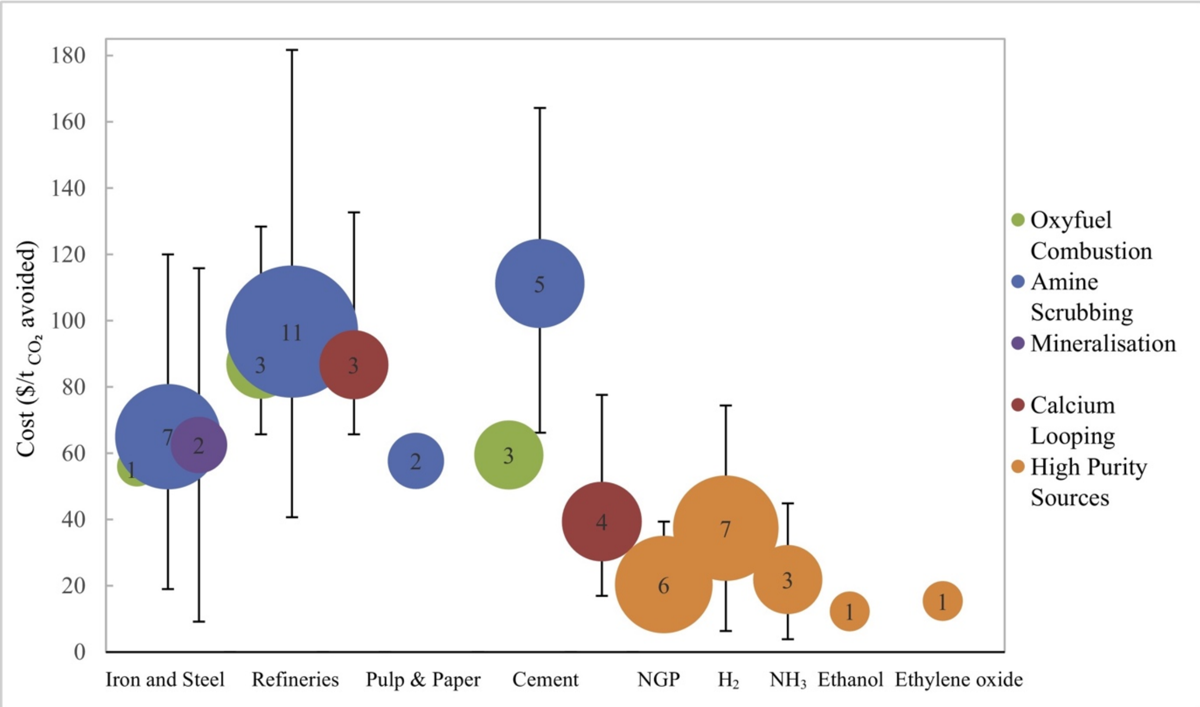
[10] https://www.stepwise.eu/wp-content/uploads/2018/09/Stepwise_GHGT-13_abstract.pdf

number of demonstration tests have been successfully completed. A six month sustained program started in October 2017. The key advantage over blast furnace top gas recycling is that off-gases only need a little cleaning to produce high quality CO_2 for sequestration.

A UK demonstration could be associated with research and development activities to reduce the energy efficiency penalty of the carbon capture technology, producing valuable intellectual property in an area where other countries are starting to pull ahead.

It is important to undertake efforts to bring the cost of CCS on steel down. While the cost of "blue" hydrogen from natural gas is at present far lower than cost of hydrogen production via renewables and electrolysis, producing heat for steel from blue hydrogen would still likely add a significant price increment to steel production costs.

With Regards to CCS on Iron and Steel, a recent formal literature review at Imperial College[11] found the following costs of CO_2 avoided via ICCS, in $\$_{2010}$.



11. How does the availability of these technologies align with your refurbishment/replace- ment cycles?

No comment

12. Are there any other technology options that we should consider? What evidence do you have to support this, including on costs and availability?

[11] D Leeson, N Mac Dowell, N Shah, C Petit, PS Fennell. International Journal of Greenhouse Gas Control 61, 71-84. 2017.

Eventually, a hydrogen-based reduction process is going to be necessary; it is highly doubtful that post combustion CO_2 capture will be able to fully decarbonize iron and steel production. Continued and dedicated support for low TRL technologies will be necessary to realise this aim for deployment by 2050.

13. Are there any additional policies that government should consider to support the steel sector in the shift to decarbonisation pathway?

Border tariffs, as discussed above.

14. Do you have suggestions on how best we might engage with Industry as we develop the work programme to inform the design of the Clean Steel Fund?

Utilising both the carrot (low carbon steel procurement, but bearing in mind that you don't just want EAFs to rebrand so there may be a requirement for EAF steel and one for other steel.