SURVEY OF CURRENT PROJECTS AND NOVEL TECHNOLOGIES IN THE STEEL INDUSTRY

2020

IETS SECRETARIAT
Rikard Edland
Per-Åke Franck

Technology Collaboration Programme
by iea

CONTENTS

INTRODUCTION

Steel is omnipresent in the developed world. For developed countries, the in-use stock of steel, i.e. the total amount of steel in buildings, machinery, and vehicles, tends to be saturated at about 13 tonnes (t) per capita [1]. Once a country has reached this level, it should in theory be possible to rely on steel recycling only. However, for many countries (including China and India) the in-use stock of steel is lower than 5 t/capita and can be expected to rise until it reaches saturation at about 13 t/capita. Thus, the demand for primary steelmaking (i.e. from iron ore) is expected to be high for many years to come.

There are currently two dominating routes for primary steelmaking: (1) The "Blast Furnace – Basic Oxygen Furnace" (BF-BOF) route and (2) the "Direct Reduced Iron – Electric Arc Furnace" (DRI-EAF) route. An illustration of the two steelmaking routes is provided below (Figure 1). When a blast furnace (BF) is used, the iron oxide is melted and reduced in the BF. The product is called pig iron and has a high carbon content which makes it brittle. To reduce the carbon content, the pig iron is injected in a basic oxygen furnace (BOF) where pure oxygen is used to burn off the carbon. Afterwards, additives are added to the molten metal and liquid steel is obtained. Direct reduced iron (DRI), or so-called sponge iron, is produced when the reduction of iron ore occurs in the solid state (i.e. not molten). The reduction process is often performed in shaft furnaces where the iron oxide is reduced by using e.g. natural gas. Sponge iron contains gangue (commercially worthless material) and is also porous and thus easily re-oxidize due to its high specific surface area. These two problems are solved by melting the sponge iron, typically in an electric arc furnace (EAF).

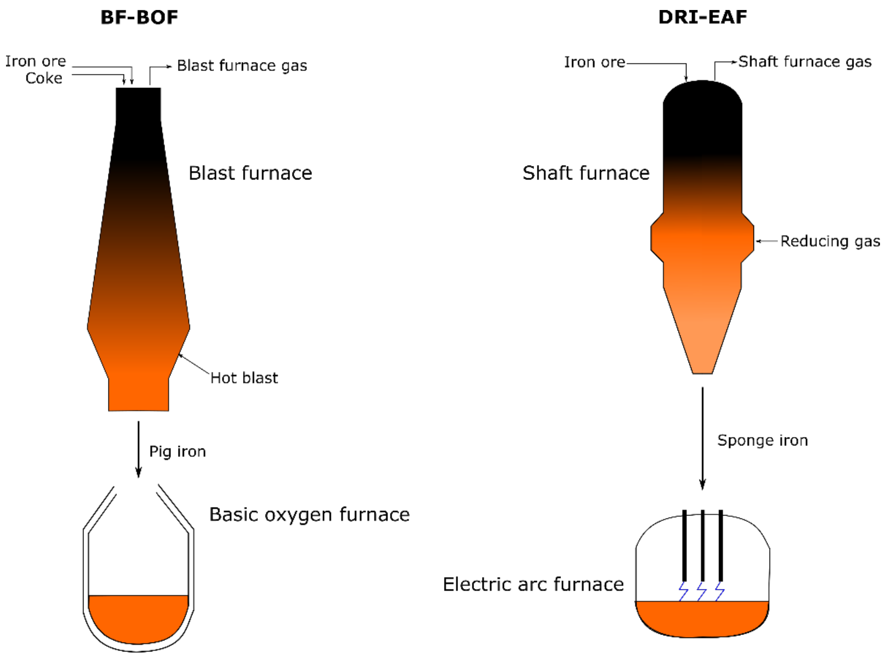

Figure 1. An illustration showing the 'blast furnace – basic oxygen furnace' (BF-BOF) route and the 'direct reduced iron – electric arc furnace' (DRI-EAF) route

The CO_2 intensity for primary steelmaking is high since it currently relies heavily on fossil resources, both as a heat source and as a reducing agent for the reduction of iron oxide to iron. In 2014, the iron & steel industry stood for 28% of the global industrial CO_2 emissions [2]. The CO_2 intensity for crude steel is about 1630-1960 kg CO_2/t and 550-1300 kg CO_2/t for the BF-BOF and DRI-EAF, respectively

[3]. The reason for the large span in CO_2 emissions for DRI-EAF is due to variations in the CO_2 emissions from the electricity grid as well as amount of steel scrap added in the EAF.

There are currently many on-going projects worldwide with the objective to reduce the emissions of fossil CO_2 from the iron & steel industry. This document is a survey of current projects and upcoming technologies regarding primary steelmaking.

TECHNOLOGIES

This section is divided into three sections on how to reduce CO_2 emissions: Carbon capture, carbon direct avoidance, and alternative methods. Important projects in each section are described.

Carbon capture

Carbon capture and storage (CCS) and carbon capture and utilization (CCU) rely on separating the CO_2 from the gas streams in process and either storing it permanently in geologic formations (CCS) or finding some use for it (CCU), often implying a release of CO_2 back to the atmosphere. Carbon capture is especially interesting in steelmaking since the CO_2 concentration in the off-gases is higher (up to 30% CO_2) than in conventional combustion process, making the absorption more efficient. There is also excess heat produced on site which can power the CO_2 capture process to a large extent. Below follows a list of projects concerning carbon capture.

DMX Demonstration in Dunkirk. The DMX Demonstration in Dunkirk [4] (referred to as "3D") is part of the EU's research program Horizon 2020. It was launched in May 2019 and will end in May 2023. It relies on using the DMX™ CO_2 capture process, which is reported to require significantly less energy than the reference absorption process due to the solvent used. The cost of CO_2 capture is reported to be as low as 40 €/tCO_2 (combining the capital cost and operating cost). The DMX™ process will be applied to an industrial pilot plant (0.5 tCO_2/h) located by a steel mill in Dunkirk, France. The project will also prepare for a first large CCS implementation on a full-scale unit (1.5 Mt CO_2/year) and provide a platform for further investigations into a future CCS cluster in the North Sea.

Abu Dhabi CCS project. Since 2016, CO_2 has been captured from the Emirate Steel Factory (Abu Dhabi, UAE) with the purpose of enhanced oil recovery (EOR) [5]. The plant is capturing 0.8 Mt CO_2/year from a DRI process. At the time of writing, it is the only commercial carbon capture operation connected to a steel mill.

Course 50. Course 50 is a Japanese national program which combines CCS and hydrogen usage [6]. The goal is to reduce the CO_2 emissions by 30% by using the BF-BOF route with a higher H_2 content in the Coke Oven Gas (COG), and to capture the CO_2 from the BF gases. Demonstration scheduled for 2030 and commercial implementation 2050.

CARBON4PUR. Carbon4pur aims at converting gases from steel mills into intermediates for polyurethane (PUR) plastics for rigid foams/building insulation and coatings [7]. The project focus on developing a process that can use the gases directly, instead of first separating the CO/ CO_2 from the gases, thus removing an energy-intensive step.

Carbon2Chem. Carbon2Chem aims at converting steel mill gases (CO/CO_2) from the steel industry into fuel, fertilizers or plastics [8][9]. The conversion requires hydrogen gas which will be obtained from renewable energy sources.

BAO-CCU. This project [10][11] was carried out by Baosteel and Lanzatech with the objective to produce ethanol from the steel mill off-gases. A pilot plant was operated successfully, and a commercial plant was planned for 2013. However, very little information has been published since then.

FReSMe. The FReSMe project [12] is a continuation of two previous EU projects that focused on CO_2 capture (STEPWISE) and methanol production from CO_2 (MefCO_2). The goal is to capture CO_2 and H_2 from the BF gases and produce methanol. The capture process is also called sorption-enhanced water-gas-shift reactor, which shifts CO and H_2O to H_2 and CO_2 whilst retaining CO_2 via adsorption. Additional H_2 from electrolysis will also be used. A pilot plant will be built with a production capacity of 50 kg/h using a blast furnace gas input of 800 m^3/h.

CO2stCAP. The CO2stCAP project [13] investigated the concept of partial capture in four different industries in Sweden and Norway, of which one was the iron & steel industry. Partial capture means that the capture technology is only applied where it is most cost-efficient. Full capture usually means capturing around 90% of the produced CO_2, and partial capture thus means a significantly lower capture rate. The project lasted 2015-2019 and evaluated partial capture by means of cost optimization. The results relating to the iron & steel industry was that the cost for CO_2 partial capture is in the range of 28-45 €/tCO_2. This cost is lower than using full capture due to the use of excess heat which allows steam prices to drop sufficiently to overcome the economy of scale effect which typically would favour full capture.

Carbon direct avoidance

Avoiding the carbon dependency altogether is another possible path for reducing CO_2 emissions. Most efforts are directed towards using the DRI-EAF route with hydrogen replacing carbon as reducing agent.

HYBRIT. HYBRIT [14] is a Swedish project with the goal to achieve 100 % fossil-free steelmaking. The steel industry will implement DRI-EAF with 100% H_2 and the iron ore industry is investigating alternative fuels, such as bio-oil or pulverized biomass. A pilot-scale unit for the steel process is currently being built in Luleå, Sweden, and experiments will be carried out in 2021-2024. Apart from the Swedish steel manufacturer SSAB, the iron ore producer LKAB and the electricity company Vattenfall are also part of the project.

H2 Hamburg. An experimental installation with 100% H_2 at an existing DRI plant in Hamburg is planned by ArcelorMittal [15]. The production capacity will be 100000 t/year and the objective is to investigate and overcome practical problems relating to the industrial scale usage of hydrogen in the DRI process. Initially, the hydrogen will be produced by gas-separation, i.e. not electrolysis of water.

Thyssenkrupp project. The steel company thyssenkrupp Steel have started to replace pulverized coal (in the hot blast) with hydrogen gas in their industrial 'blast furnace 9' in Duisburg [16]. The plan is to start replacing pulverized coal in all three blast furnaces from 2022. In the mid-2020s, construction of DRI plants with hydrogen-containing gases are planned.

SUSTEEL and H2future. In the SuSteel project [17], a breakthrough technology is developed where hydrogen plasma is used to reduce the iron ore directly in a type of EAF. The H_2 is produced in the H2future project [18], which aims at generating green hydrogen that is specifically intended for the steel and iron manufacturing industry. A 6 MW electrolysis plant has been built and pilot tests have been carried out during 2019.

SALCOS and GrInHy 2.0. The SALCOS project [19] aims at using DRI with methane and a gradually increasing share hydrogen. The hydrogen is produced by electrolysis of water in a sister-project called GrInHy 2.0 [20].

HBIS & Tenova project. The Chinese iron and steel company HBIS and Italian company Tenova declared in 2019 [21] that they will, together with CERI (Capital Engineering & Research Incorporation Ltd), build a hydrogen metallurgy demonstration plant with a capacity of 1.2 Mtons/year. At the time of writing, no more information is publicly available.

SIDERWIN. The goal with the SIDERWIN project [22] is to develop a breakthrough technology based on electrolysis of iron ore, i.e. directly separating iron and oxygen from the iron ore. This technology is often referred to as 'electrowinning' and has been developed in a previous project called ULCOWIN where it was taken from Technology Ready Level (TRL) 0 to TRL 4. SIDERWIN will take the technology to TRL 6 (9 is highest, i.e. commercially ready).

Molten oxidation electrolysis (MOE). This technique was developed by Massachusetts Institute of Technology (MIT), with support from NASA and AISI (American Iron and Steel Institute) [23]. MOE is an electrowinning technique where the iron ore is in a molten state.

Alternative paths for CO_2 reduction

Apart from using CCS/CCU and eliminating fossil carbon, there are other ways to reduce CO_2 emissions. One way is to replace the fossil carbon with biogenic carbon, and another is to simply increase the efficiency of the process. The projects described in this section cover both paths. The implementation of CCS/CCU is possible on these processes but not necessary for CO_2 reduction.

Torero and Steelanol. The Torero [24] and Steelanol [25] projects aim at producing a bioethanol stream by fermenting the BF gases using microbes. The focus of the Torero project is to replace the fossil coal with bio-coal created from torrefaction of wood waste, while the focus of the Steelanol project is the production of bioethanol. A torrefaction plant with a bio-coal production capacity of about 37000 t/year and a plant for bio-ethanol production with a capacity of 64000 t/year are currently being built.

HIsarna process. The HIsarna process [26] is a process that utilizes a new type of furnace where iron ore is melted in a high-temperature cyclone where it reacts with pulverized coal, followed by an iron bath. A large advantage with this process is that it does not require iron ore to be pre-processed into sinter or pellets, and it does not require coke production. The process requires about 20% less energy than using a BF and the specific CO_2 intensity is thus 20% lower as well. CCS is often suggested to be suitable and would result in a CO_2 reduction of 80%. A pilot plant with a production capacity of 60000 tonnes hot metal (thm) per year has been built and operated [27]. As comparison, a full-scale commercial plant can produce about 10000 thm/day, i.e. about 3.6 Mthm/year.

Top Gas Recycling Blast Furnace (TGRBF). The TGRBF technology [28] was proposed by the ULCOS (Ultra Low CO_2 Steelmaking) consortium. The concept reduces the coal consumption by recycling gases from the top of the blast furnace and replacing air with pure oxygen. The gases from the top contain mainly CO, H_2, H_2O and CO_2, of which CO and H_2 are desirable to circle back. The water is condensed, and the CO_2 is separated prior to re-injection of the gases. Since pure oxygen is used instead of air in the blast furnace, N_2 is absent and the CO_2 concentration becomes high which makes it suitable for carbon capture. The concept has been proved in an experimental blast furnace with a production rate of 1.5 thm/h.

IGAR. The IGAR project [29] applies the TGRBF concept and reforms separated CO_2 into CO and H_2 by using a high-temperature plasma torch. The reported CO_2 savings are 0,1-0,3 tCO_2/t crude steel.

Flash ironmaking technology. The university of Utah developed a concept for steel production that, like the HIsarna process, removes the requirement of pre-processing iron ore into pellets or sinter as well as the requirement of coke production. Furthermore, the time for reduction is in the order of seconds rather than minutes/hours since the iron ore fines are very small with a high specific surface area. The concept was proven in a project called ‘A Novel Flash Ironmaking Process’ [30] that used a large scale bench reactor with a production capacity of 43 t/year, and plans are to build a larger unit designed for 3000 t/year.

Step up. The Step-Up program [31] is launched by the World Steel Association and aims at supporting steel mills in reaching the same level of performance as the industry’s top performers. Four areas are focused upon: raw material quality, energy efficiency, process yield and process reliability. The program was tested on 5 steel mills during 2019 and is planned to be rolled out in larger scale during the years 2020-2025.

REFERENCES

[1] S. Pauliuk, T. Wang, and D. B. Müller, “Steel all over the world: Estimating in-use stocks of iron for 200 countries,” *Resour. Conserv. Recycl.*, vol. 71, pp. 22–30, 2013, doi: https://doi.org/10.1016/j.resconrec.2012.11.008.

[2] International Energy Agency (IEA), “Energy Technology Perspectives 2014,” Paris, 2017. [Online]. Available: https://www.iea.org/reports/energy-technology-perspectives-2014.

[3] M. Kirschen, K. Badr, and H. Pfeifer, “Influence of direct reduced iron on the energy balance of the electric arc furnace in steel industry,” *Energy*, vol. 36, no. 10, pp. 6146–6155, 2011, doi: https://doi.org/10.1016/j.energy.2011.07.050.

[4] “DMX Demonstration in Dunkirk,” 2019. https://cordis.europa.eu/project/id/838031 (accessed Dec. 20, 2019).

[5] “Taweelah Project Fact Sheet: Carbon Dioxide Capture and Storage Project,” 2016. http://sequestration.mit.edu/tools/projects/uae_project.html (accessed Jun. 05, 2020).

[6] The Japan Iron and Steel Federation, “Outline of COURSE 50.” https://www.jisf.or.jp/course50/outline/index_en.html (accessed Jun. 05, 2020).

[7] “Turning industrial waste gases (mixed CO/CO2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings,” 2017. https://cordis.europa.eu/project/id/768919 (accessed Jun. 05, 2020).

[8] Thyssenkrupp, “The Carbon2Chem project.” http://www.circulary.eu/project/carbon2chem/ (accessed Jun. 05, 2020).

[9] FONA, “Carbon2Chem.” https://www.fona.de/en/measures/funding-measures/carbon2chem-project.php (accessed Jun. 05, 2020).

[10] LanzaTech, “LanzaTech and Baosteel’s 100,000 gallon/year waste-gas-to-ethanol pre-commercial facility exceeds productivity expectations and hits major milestones in advance of commercialization,” 2012. .

[11] BAOSTEEL, “Opening of Demo Project of Ethanol Production from Steel Mill Off-Gases in the World,” 2011. .

[12] “From residual steel gasses to methanol.” https://cordis.europa.eu/project/id/727504 (accessed Jun. 05, 2020).

[13] SINTEF, “CO2stCap - Cutting Cost of CO2 Capture in Process Industry.” https://www.sintef.no/en/projects/co2stcap-cutting-cost-of-co2-capture-in-process-industry/ (accessed Jun. 05, 2020).

[14] Hybrit Development, “HYBRIT - towards fossil-free steel.” http://www.hybritdevelopment.com/ (accessed Apr. 29, 2020).

[15] ArcelorMittal, “Hydrogen-based steelmaking to begin in Hamburg.” https://corporate.arcelormittal.com/media/case-studies/hydrogen-based-steelmaking-to-begin-in-hamburg (accessed Jun. 05, 2020).

[16] thyssenkrupp Steel, “World first in Duisburg as NRW economics minister Pinkwart launches tests at thyssenkrupp into blast furnace use of hydrogen,” 2019. https://www.thyssenkrupp.com/en/newsroom/press-releases/world-first-in-duisburg-as-nrw-economics-minister-pinkwart-launches-tests-at-thyssenkrupp-into-blast-furnace-use-of-hydrogen-17280.html (accessed Jan. 10, 2020).

[17] “Project SuSteel - Sustainable steel production utilising hydrogen.” https://www.k1-met.com/en/research_programme/susteel/ (accessed Jun. 05, 2020).

[18] "HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS." https://cordis.europa.eu/project/id/735503 (accessed Jun. 05, 2020).

[19] "Salzgitter Low CO2 Steelmaking." https://salcos.salzgitter-ag.com/en/ (accessed Jun. 05, 2020).

[20] "Green Industrial Hydrogen via Reversible High-Temperature Electrolysis." https://cordis.europa.eu/project/id/700300 (accessed Jun. 05, 2020).

[21] HBIS group, "HBIS & Tenova Upgrading Tradtional Steel Making Technology With Hydrogen," 2019. http://www.hbisco.com/site/en/groupnewssub/info/2019/15260.html (accessed Jul. 01, 2020).

[22] "Development of new methodologieS for InDustrial CO2-freE steel pRoduction by electroWINning." https://www.siderwin-spire.eu/ (accessed Jun. 05, 2020).

[23] Boston Metal, "Metal Oxide Electrolysis." https://www.bostonmetal.com/moe-technology/.

[24] "TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration." https://cordis.europa.eu/project/id/745810 (accessed May 06, 2020).

[25] "Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry." https://cordis.europa.eu/project/id/656437 (accessed Jun. 05, 2020).

[26] Tata Steel, "HISARNA: GAME CHANGER IN THE STEEL INDUSTRY." https://www.tatasteeleurope.com/static_files/Downloads/Corporate/About us/hisarna factsheet.pdf (accessed Jun. 05, 2020).

[27] Tata Steel, "Hisarna Facts and Figures." https://www.tatasteeleurope.com/en/innovation/hisarna/facts-and-figures (accessed May 06, 2020).

[28] European Comission, "ULCOS - top gas recycling blast furnace process," 2014. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/0371a7f6-3e10-40aa-a8ec-16c1bfabdc38.

[29] ArcelorMittal, "Climate Action Report 1," 2019. [Online]. Available: https://corporate-media.arcelormittal.com/media/hs4nmyya/am_climateactionreport_1.pdf.

[30] American Iron and Steel Institute (AISI), "A Novel Flash Ironmaking Process," 2018. [Online]. Available: https://www.osti.gov/servlets/purl/1485414.

[31] WorldSteel Association, "Step up programme." https://www.worldsteel.org/steel-by-topic/technology/Step-up-programme.html (accessed Jun. 05, 2020).

PROJECT PARTNERS

The following table presents the partners in each project/technology mentioned in this document.

Project	Partners	Countries involved
DMX Demonstration in Dunkirk	– IFP ENERGIES NOUVELLES – ARCELORMITTAL ATLANTIQUE ET LORRAINE SAS – TOTAL RAFFINAGE CHIMIE – AXENS SA – RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN – DANMARKS TEKNISKE UNIVERSITET – ACP POLSKA – COCKERILL MAINTENANCE & INGENIERIE – GASSCO AS – BREVIK ENGINEERING AS – CU CHEMIE UETIKON GMBH	France Germany Denmark Poland Belgium Norway
Abu Dhabi CCS project	– MASDAR CLEAN ENERGY – ABU DHABI NATIONAL OIL COMPANY	UAE
Course 50	– NEW ENERGY AND INDUSTRIAL TECHNOLOGY DEVELOPMENT ORGANIZATION – KOBE STEEL, LTD – JFE STEEL CORPORATION – NIPPON STEEL & SUMIKIN ENGINEERING CO., LTD – NISSHIN STEEL CO., LTD	Japan
CARBON4PUR	– COVESTRO DEUTSCHLAND AG – RECTICEL SA – VIOMICHANIA RITINON MEGARON ANASTASIOS FANIS ANONYMOS ETAIRIA – UNIVERSITEIT GENT – DECHEMA GESELLSCHAFT FUER CHEMISCHE TECHNIK UND BIOTECHNOLOGIE E.V. – UNIVERSITEIT LEIDEN – TECHNISCHE UNIVERSITAT BERLIN – COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES – ARCELORMITTAL MAIZIERES RESEARCH SA	Belgium Greece Netherlands Germany France Switzerland United Kingdom

	– SOUTH POLE CARBON ASSET MANAGEMENT AG – GRAND PORT MARITIME DE MARSEILLE – RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN – PNO CONSULTANTS BV – IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE	
Carbon2Chem	– THYSSENKRUPP STEEL – MAX PLANCK INSTITUTE – FRAUNHOFER INSTITUTE – SIEMENS – ZBT GMBH – AKZONOBEL INDUSTRIAL CHEMICALS – CLARIANT – RUHR UNIVERSITÄT BOCHUM	Germany
BAO-CCU	– BAOWU STEEL GROUP – LANZATECH	China USA
FReSMe	– I-DEALS INNOVATION & TECHNOLOGY VENTURING SERVICES SL – STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND – SWERIM AB – CRI EHF – KEMIJSKI INSTITUT – UNIVERSITATEA BABES BOLYAI – SSAB – STENA REDERI AB – KISUMA CHEMICALS BV – TATA STEEL NEDERLAND TECHNOLOGY BV – ARRAY INDUSTRIES BV – POLITECNICO DI MILANO – NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	Spain Netherlands Sweden Iceland Slovenia Romania Italy
CO2stCAP	– SSAB – GLOBAL CCS INSTITUTE – IEAGHG – ELKEM AS – NORCEM BREVIK AS, – UNIVERSITY OF SOUT-EASTERN NORWAY – CHALMERS	Norway Sweden

	– SINTEF – SWERIM AB, – RISE – AGA GAS AB.	
HYBRIT	– SSAB – LKAB – VATTENFALL – HYBRIT DEVELOPMENT	Sweden
H2Hamburg	– ARCELORMIOTTAL – MIDREX TECHNOLOGIES	Germany
Thyssenkrupp project	– THYSSENKRUPP STEEL	Germany
SUSTEEL	– VOESTALPINE STAHL GMBH – UNIVERSITY OF LEOBEN	Austria
H2future	– VERBUND SOLUTIONS GMBH – VOESTALPINE STAHL GMBH – K1-MET GMBH – SIEMENS AKTIENGESELLSCHAFT – AUSTRIAN POWER GRID AG – STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND – NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	Austria Germany Netherlands
SALCOS	– SALZGITTER AG – FRAUNHOFER INSTITUTE	Germany
GrInHy 2.0	– SALZGITTER AG – SUNFIRE GMBH – PAUL WURTH GEPROLUX S.A – TENOVA – COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES	Germany Luxembourg France Italy
HBIS & Tenova project	– HBIS – TENOVA TECHINT – CERI	China Italy
SIDERWIN	– ARCELORMITTAL – **JOHN COCKERILL** – ÉLECTRICITÉ DE FRANCE – CFD-NUMERICS – QUANTIS – TECNALIA – THE UNIVERSITY OF AVEIRO – MYTILINEOS S.A. – THE NATIONAL TECHNICAL UNIVERSITY OF ATHENS – N-SIDE	Luxembourg Belgium France Spain Portugal Greece Norway

	– DYNERGIE – NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY	
Molten ore electrolysis	– MASSACHUSETTS INSTITUTE OF TECHNOLOGY – NASA – BOSTON METAL	USA
Torero	– ARCELORMITTAL BELGIUM NV – CHALMERS TEKNISKA HÖGSKOLA AB – RENEWI – JOANNEUM RESEARCH FORSCHUNGSGESELLSCHAFT MBH – TORR-COAL INTERNATIONAL BV – UNIVERSITAET GRAZ	Belgium Sweden Austria Netherlands
Steelanol	– ARCELORMITTAL BELGIUM NV – ARCELORMITTAL MAIZIERES RESEARCH SA – PRIMETALS TECHNOLOGIES AUSTRIA GMBH – LANZATECH UK LTD – E4TECH (UK) LTD	Belgium France Austria United Kingdom
HIsarna	– ULCOS members: The ULCOS consortium consist of 48 companies and institutions	ULCOS countries: Germany France Belgium Netherlands United Kingdom Italy Sweden Luxembourg Austria Finland Norway Denmark Spain Portugal
TGRBF	– ULCOS members: The ULCOS consortium consist of 48 companies and institutions	ULCOS countries: Germany France

		Belgium Netherlands United Kingdom Italy Sweden Luxembourg Austria Finland Norway Denmark Spain Portugal
IGAR	– ARCELORMITTAL	France
Flash ironmaking technology	– UNIVERSITY OF UTAH	USA
Step up	– World Steel Association	