# How Green Primary Iron production in South Africa could support local development and global decarbonisation

*Concept development work in progress for comment*[1]

**Steel** is **essential** for the functioning of our society and economy. It is the world's largest materials industry, generating an annual turnover of 1 trillion US dollars[2].

Economies need differing amounts of steel at different stages of their development and business cycles. Most primary steel demand will come from the construction of new transport, energy, and urban infrastructure, including buildings. Economies that have already produced generations of infrastructure stock and vehicles can recycle worn-out stock. For example, Europe and North America have in-use steel stocks of 10-14 tonnes (t) per capita and China has 5.5t per capita. By contrast, South Africa has approximately 2t per capita, while the rest of Africa has less than 1t per capita.

Vast amounts of new infrastructure (e.g. sanitation, water supply, buildings, energy production and transmission, transport systems, machinery, etc.) are necessary to meet basic needs and to meet the UN Sustainable Development Goals (SDGs) in developing countries. Africa will need some 3-5t of steel per capita for basic infrastructure and other economic activities. As this demand cannot be satisfied from recycled local steel, huge amounts of primary iron will be required.

*****Technical basics for non-steel experts: iron and steel production, iron ore, primary iron, primary steel, steel products, 'in-use' steel stocks, recycled steel***

*This paper focusses on the potential role that **South African green primary iron (GPI)**, manufactured from feedstocks of indigenous iron ore and hydrogen produced using very low cost solar electricity, can play in global decarbonisation while contributing to the domestic economy. The EU, for which concrete decarbonisation plans have been announced, would be the initial market. Ultimately, South Africa could become a supplier for the growing global net-zero emissions steel market, including the regional African market as this develops.*

*Primary steel is made from iron ore in a two-step chemical process. In the first step, which is the focus of this paper, oxygen is extracted from the iron oxide ($Fe_2O_3$) in iron ore to produce primary iron (Fe). Traditionally, carbon (C), in the form of coking coal has been used in this step, joining with the oxygen (the $O_3$) in a blast furnace producing the desired Fe and carbon dioxide ($CO_2$) waste gas. Heat is supplied by coal combustion which also yields $CO_2$. However, new processes are now being developed with zero $CO_2$ emissions. Hydrogen ($H_2$) produced using electricity is used instead of carbon to join to the oxygen in the $FeO_3$ in a shaft furnace, yielding only Fe and water ($H_2O$) as products. Heat is supplied by electricity.*

*In the second step of primary steelmaking, various types of primary steels (carbon, alloy, stainless, tool steel) are then produced from the iron by removing or adding carbon and other elements. GPI can be made into primary steel with very low embodied emissions in a low-emissions electricity powered electric arc furnace (EAF). These steels are then turned into intermediate steel products such as girders, concrete reinforcing, plate, wire, sheet etc which are then used in final products in buildings, infrastructure, machinery, appliances*

*The manufacture of primary steel by the iron and steel sector produces the most emissions of all heavy industry sectors, at approximately 2.0-3.6 Gt $CO_2$ per annum, amounting to 5.6-10% of global combustion and process $CO_2$ emissions. Decarbonising the manufacture of primary steel is only now becoming potentially commercially viable, but will take decades to achieve at substantial scale to decarbonise this huge industry. In-use steel stocks (steel in existing infrastructure and equipment) is fully recyclable if it is kept uncontaminated. Recycled steel is mostly produced in electric arc furnaces, allowing it to be decarbonised relatively easily and cheaply with low-emissions electricity. By improving material efficiency, recycling, and decarbonising primary steel production, the steel industry can become fully decarbonised in line with climate targets.*

[1] DDP South African Green Iron team: Hilton Trollip, Bryce McCall, Chris Bataille - 18 January 2021

[2] https://www.responsiblesteel.org/

### Opportunity for near zero emissions primary-steel and iron

Commitments to carbon neutrality advanced in recent announcements by governments, industrial steel producers and large consumers, will involve a massive reduction of emissions from the steel sector. While a substantial reduction in steel demand is possible through material efficiency interventions, which could contribute to reductions of up to 40% for main uses like infrastructure, buildings, machinery, equipment and vehicles[3], in many of these uses it cannot be substituted with another material. Primary steel manufacturing will continue to be essential. The long investment cycles in steel-making plants mean that action is required now and over the next 5-10 years, to economically achieve committed decarbonisation goals over the coming decades.

Industrialised economies could in principle meet most of their demand for steel by recycling in-use steel stocks, however, existing complex value chains and huge amounts of sunken assets in industrial and logistics systems are not yet set up to do this. Transforming them will take 2-3 decades. During this time, there will continue to be substantial (even if decreasing) demand for large quantities of primary steel in industrial countries and an increasingly accelerating shift to low/zero-emissions steel. If prudently integrated into global value chains, this demand could not only drive transformation to meet industrial country emissions commitments but also be an important driver of global sector decarbonisation, while supporting economic development goals all-round. A competitively priced, globally traded, certified zero-emissions, primary iron commodity could yield substantial net benefits to both importers and exporters.

Fair and free international trade and the deliberate creation and shaping of national/trade-bloc markets for lower/zero-emissions primary steel in industrialised countries will be a crucial element in the initial phases of the global sector decarbonisation. Recent official publications include these as central and specific implementation measures[4]. A number of Europe's largest steelmakers have conducted successful R&D programmes to develop zero-emissions production processes and already announced plans for investments in commercial-scale, zero-emissions primary iron production plants in the next 5-10 years and committed to net-zero 2050 goals.

It is most likely that near-zero-emissions iron will be in commercial-scale production within ten years. Prices are expected to be 30-50% higher than those of conventional steel, but dedicated market arrangements can drive the transition, similar in concept to those used in renewable energy electricity markets in the 2000s and 2010s.

Taking the above into consideration, this concept outlines opportunities for South African participation in the EU market (initially). Electrolysis-based hydrogen direct-reduction iron-making (eH-DRI) shows particular promise in the South African context. The potentially competitive production costs of GPI in South Africa puts this country in a favourable position to supply GPI as a feedstock for reducing embodied emissions or eliminating them in steel manufacturing in the EU. In addition to immediate financial, economic and environmental benefits, this could prototype the integration of existing steel sectors in developing countries into global economic development and emissions mitigation pathways.

### South Africa's competitive edge for exporting GPI to the EU: sunshine, iron deposits, and existing infrastructure

An optimisation model, the South African TIMES model (SATIM), was used to determine the least-cost configuration of a new 1Mt pa eH-DRI plant in South Africa in 2030 using only solar PV electricity wheeled over the existing transmission grid. See figure 1. A comparison was done between similar GPI plants in South Africa and Europe[5]. The differential in production costs is sufficient to indicate a structural comparative advantage for South Africa–based GPI production sufficient to compete in European markets. The differential in South African local PV electricity production costs and electricity prices expected at a European location over the period 2030-2050 plays a critical role in South Africa's potential competitive advantage over Europe-based production.

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[3] International Energy Agency (IEA). (2019). Material efficiency in clean energy transitions. (2020a). Energy Technology Perspectives.

[4] 2020 Federal Ministry for Economic Affairs and Energy (BMWi). For a strong steel industry in Germany and Europe. The Steel Action Concept. 2020 The European Steel Association (EUROFER). Green Deal on Steel. Making a Success of the EU Green Deal.

[5] See accompanying journal article draft for details.

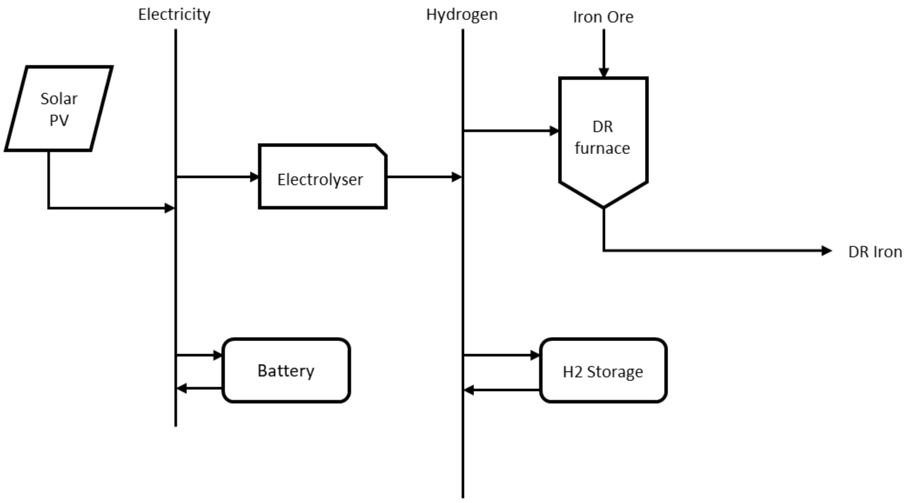


*Figure 1: Basics of hydrogen-based direct reduction of iron plant. The water cycle is a closed loop and omitted here for clarity. The battery was considered by the model but never 'chosen'*

There are many potential configurations of GPI plants and there are high sensitivities to input costs and system configurations, especially in the electricity supply options. To produce a higher degree of robustness, specialised business and engineering research and analysis would be required at an additional level of precision. However, these initial results are sufficient to provide the foundation to illustrate the main concepts.

**Economic benefits: South Africa**

South Africa could bolster crucial export revenues, government revenues, and utilisation of existing infrastructure, while initiating a transition to a sustainable steel industry. These benefits are of special relevance to South Africa, owing to recent interlinked and intensifying financial crises: a persistent, now structural current account deficit since 2004 and increasingly unsustainable national sovereign debt levels.

Compounding the existing current account and debt crises, South Africa also faces an additional imminent decline in coal, one of its largest exports. Substantial expansion of alternative export revenues is crucial to regain and maintain macro-economic stability, a necessity for general economic development. 1 Mt of GPI could yield similar export earnings to 5 Mt of iron-ore or 7 Mt of coal.

**Economic benefits: Europe**

EU steelmakers could use South African GPI to increase scrap pre-loading of blast furnaces and to increase utilisation of electric arc furnaces, which would lower the total system costs of decarbonisation. South African GPI supplied to European steelmakers at competitive prices would also reduce overall input costs to the EU steel sector, hence to the EU economy, contributing to general competitiveness. In addition, EU industrial sector decarbonisation commitments will create substantial pressure on low-emissions electricity supplies in coming decades[6]. South African GPI imports would effectively represent imports of much needed and lower-priced 'embodied' renewable energy electricity. This would lead to lower electricity prices and make more low-emissions electricity available for higher value end-uses including other decarbonisation transformations. The small number of jobs lost in primary iron-making could be more than made up in higher-value downstream links in the steel value chain and elsewhere in the economy[7]. Overall, the total cost of implementing Europe's net-zero commitments could be reduced.

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[6] These required 125TWh in 2010. A complete switch to electricity-based energy and feedstock would require 1,713TWh and a 'substantial change in relative prices for electricity and hydrocarbon fuels'. Lechtenböhmer, S. et al. (2016) 'Decarbonising the energy intensive basic materials industry through electrification – Implications for future EU electricity demand'.

[7] Quantification of systemic electricity system and employment benefits has not yet been done but these are credible dynamics that could yield substantial benefits.

**Incentives-based market creation and shaping of lead markets in a decarbonising world**

Implementing near-zero-emissions iron production involves large, lumpy process step-changes and investments. To achieve the planned rate and scale of transition, there will be an initial phase where the zero-emissions product cannot compete on price with conventional product.

The success of wind and PV electricity generation are instructive when it comes to incentive-based market-pull transitions. They owe their rapid growth and fast declining costs to “created and shaped markets”, informed by renewable energy targets, portfolio standards, and feed-in-tariffs. These “mandated markets” were initially criticized as presenting an unacceptable cost to consumers. However, they have, in fact, spawned large competitively priced renewable energy technology industries with explosive growth within a period of decades.

Similar mandated market concepts have been thoroughly described for net-zero emissions steel (Bataille *et al.*, 2018; Busch, Foxon and Taylor, 2018; Bataille, 2019; Sartor and Bataille, 2019; Wyns *et al.*, 2019; Acworth, Kardish and Kellner, 2020; Nilsson *et al.*, 2020; Vogl, Åhman and Nilsson, 2020)[8]. The scheme would rely on collaboration to establish a regulatory regime to both create and shape lead markets in the EU and, of relevance to this concept, to enable investment in South Africa–based export plant by assuring open and fair access to bankable European markets.

**Next steps and summary**

Key enabling conditions from the perspective of investment in South African plant include: 1) a willing steelmaker with necessary capabilities and intellectual property rights and/or licenses in eH-DRI technology; 2) creation and shaping of lead markets for low embodied emissions steel and associated certified GPI commodity; 3) free and fair access to these lead markets at a bankable level; 4) access to existing domestic logistics, including the existing South African electricity transmission grid for wheeling and existing rail and port facilities; 5) the right to contract or own-build industrial scale PV; and, 6) a reliable policy, legislative, judicial and trade governance regime.

Industry could lead with concrete proposals, at least at this first initial conceptual stage, because of the large potential financial upside, access to human and financial capital to implement a new GPI plant, R&D capacity and intellectual property, industry knowledge, and the fact that the novel GPI process is a small component in complex national, regional and international value chains that have to be co-ordinated. There are already good examples of rapid progress being made by industry[9].

**Next steps**

| TO START WITH | IN PARALLEL |
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| Following on the very concrete documented examples in *Start with Steel*[10], *The Steel Action Concept* and the *Green Steel Deal*, South African industry associations could make specific proposals along the lines of those outlined in this concept document, enriched, and probably substantially modified/extended using their depth of knowledge and expertise. The proposals could be canvassed as necessary with relevant government departments. | The substantially complicated technical and political issues involved in how EU lead markets and the international trade regulatory aspects of ‘creating a level playing field on the global steel market’[11] would need to be further elaborated at a technical level and discussed with the EU. |

[8] See accompanying academic-style paper for details of these references.

[9] https://www.responsiblesteel.org/; https://www.eurofer.eu/publications/position-papers/a-green-deal-on-steel-update/

[10] See accompanying academic-style paper for details of this reference.

[11] This is the first element of the Steel Action Concept (see above) and would be essential for competitively priced South African GPI to prove access to a bankable market to enable investment in the South African located plant.