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RENEWABLE ELECTRICAL POWER AND ENERGY STORAGE FOR EAF STEEL PRODUCTION

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Abstract

The steel industry produced 1864 Mt steel in 2020 with an average 1.9 tCO_2e/t of steel. As the technology for steel production moves towards a lower CO_2 future, an important piece of the solution is the use of Electric Arc Furnaces (EAF). Over 400 Mt steel is produced from EAF each year, using 2.07 GJ/t (liquid steel) of electricity. However, the production of the electricity may still come from non-green sources.

Approximately 7.1% of industrial electricity comes from renewable sources. One difficulty is the ability to use a non-constant supply to support demand whenever required. A method to improve this in the steel industry is the use of wind and solar as an electricity source feeding into a high-capacity storage bank. High-capacity electricity storage with a fast frequency response to discharge and fluctuation in energy demands will be required. Grid-level large electrical energy (GLEES) battery storage is being used around the world for power storage and stabilisation, with battery storage in excess of 1200 MWh. A 2800 MWh battery pack to be constructed in Australia. Flow balance electrical power of 800 MWh is being constructed in China. These can be utilised as a method of powering EAF systems. By supplying the battery storage with power generated from wind and solar, the EAF system can become carbon neutral and decrease the dependency on Scope 2 CO_2 emissions. The use of off-peak electricity can be used as a source of electricity from renewable sources to re-coup charge in the battery storage, increasing the economic value of the steel produced during peak power demands. As we move to 2050, serious attempts have to be made in the steel industry to become carbon neutral. EAF with electrical storage from renewable energy can be part of that solution.

Introduction

Concentrations of CO_2 are averaged at 412 ppm in the atmosphere, which is 48% higher than at the start of the industrial revolution. Global CO_2 emissions were ~37 Gt CO_2 (2019) [1], [2]. It was estimated that there was a 7% drop in CO_2 production through 2020 due to Covid-19 restrictions, however as industry starts to return to normal operations, emissions are returning to pre-pandemic levels. The steel industry produced 2.6 $GtCO_2eq$ in 2020 which accounts for approximately 7-9% of the Global CO_2 emissions [3], [4]. Throughout the steel industry there is a range of technologies and techniques utilised for the production of iron and steel. Each of these carries its own emissions burden. Producing iron in a blast furnace and then onward processing to steel is a basic oxygen furnace produces approximately 1.85 tCO_2/ t hot metal [5], [6].

Methods of steel production

Electric arc furnaces (EAF) are a method of steel production which uses electricity to melt scrap metals and some iron ore from direct reduction iron furnaces (DRI). DRI requires high grade iron ore to produce "sponge iron" as an input into an EAF. Emissions from an EAF are lower than those from a blast furnace, at 0.6 tCO_2/t hot metal [6]. The amount of CO_2 emissions varies for different types of EAF, raw materials and the method used. The use of oxygen lances to inject oxygen direct into the raw material and melt, reduces more costly electrical energy, however can increase the CO_2 production as the O_2 is used to remove carbon content from the steel [7].

Aiming for net zero CO_2 emissions steel

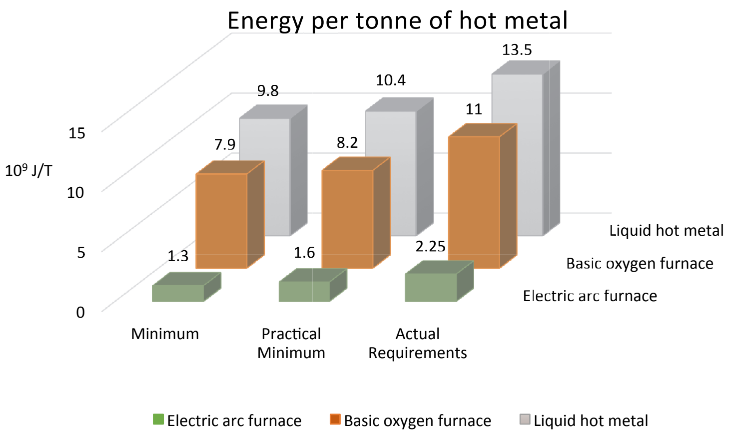
To reduce the carbon footprint and in an attempt to produce net zero steel, the use of renewable energy as a source of electricity is instrumental. The sources of renewable energy is partly dependant on the country and their resources. Globally the main sources of renewable power are hydropower, wind, solar, biopower, geothermal and tidal. Most of these power sources are consistent, however wind and solar are dependent on the local weather conditions [8], [9].

The use of energy storage can provide a solution to these considerations. On site energy storage systems (ESS) can take the form of electrochemical, electro-mechanical, flywheel (FESS), compressed air (CAES), electrical, superconducting magnetic energy storage (SMES), super capacitors energy storage (SCES), thermal and hydro-storage [10]–[12]. As the response time required for an EAF can be as quick as milliseconds, for this work, electro-chemical, i.e., battery energy storage systems (BESS) will be reviewed. The onset of wind and solar energy means they are becoming a greater component in the energy mix; however, these forms of energy have a propensity to have fluctuations due to localised conditions. The use of fossil fuels, bioenergy and hydropower can be used to provide a base load, however the increase in wind and solar use may extend the fluctuations beyond these capabilities. The use of Grid Level electrical Energy Storage (GLEES) can be used as a method to circumvent this problem [12]. This is a system that can be adopted in the steel industry at a local level to alleviate fluctuations affecting production.[10], [11], [13].

Electricity supply for EAF

The primary type of EAF for steel production is 3 phase AC, however there are DC EAF's and vacuum arc remelting. 3 phase EAF are more common in the steel industry. To produce a tonne of steel in an EAF, at the practical minimum, 1.6GJ of electricity (440kWh) is required [14], [15], [16], [17]. Figure 1 compares the energy requirements of steel making.

Figure 1 Energy requirements for steel production. Adapted from [16]

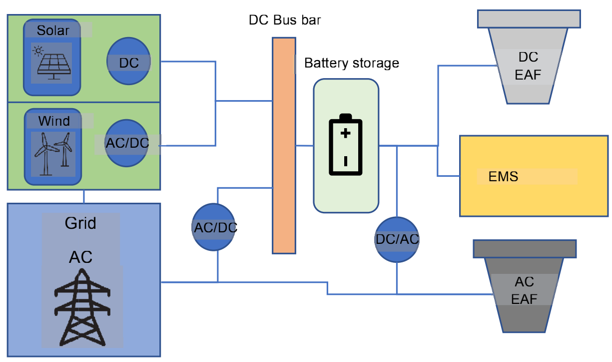


AC EAF's are typically connected to a 33kV electrical supply, which is transformed down to lower voltages with high currents required to achieve the arc for melting the burden. As the melt progresses, the voltage and current are varied to accommodate the optimum melt environment. As the steel raw materials go through phase changes, the electrical demand changes, therefore the energy requirement is not consistent across the melting cycle. To compensate for this change, the power supply is required to be adaptable to fluctuating demand. The refining stage is the final part of the process in an EAF, this is the least energy intensive part [16]. If electrical power were supplied via wind or solar, then there is potential for the full power requirements of a steel works to not be met on an hour-by-hour basis. To compensate for changes to wind strength and the solar intensity, to buffer power fluctuation and to provide a method of monopolising on cheap electricity and operating through more expensive times of the day, energy storage can be used.

Battey storage for steel making

The use of battery storage can therefore be a method of providing electrical power for the production of steel in an EAF. The use of batteries to provide energy tend towards fast response times, and the correct energy storage system can have the advantage of several hours of operating time. To incorporate battery storage into an industrial plant, Figure 2 shows a schematic of the energy power supplies and how a battery could be located in a system operating either an AC or DC EAF.

Figure 2. Simplified schematic diagram for the connection of a battery system into an EAF steel making facility.]

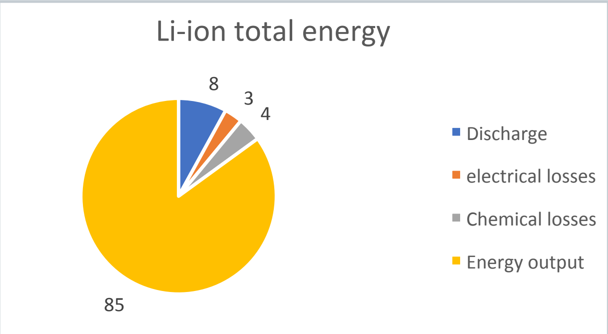


Wind and solar energy, as part of the grid solution, are used to provide electrical energy. As shown in Figure 2, the energy from these sources can be AC from the wind turbines, and DC from solar. The AC is converted to DC, and both power sources are fed to a DC bus bar. From the DC bus bar, the battery system is charged whilst power is constantly supplied to the load. The energy management system (EMS) is used to control the distribution of power to the load, to battery storage and feedback to the grid.

Li-ion

Lithium ion (Li-ion) batteries are commonly found in consumer equipment and as electric vehicle (EV) supplies. Lithium ions move through the electrolyte from the cathode to the anode during discharge, and in the reverse when recharging. They hold a cost of £570-1100 kWh, however recent development in technologies is driving the price lower. Li-ion batteries have a low loss of energy, and hence are able to deliver a high percentage output, Figure 3.

Figure 3. Total energy and losses from a Li-ion battery



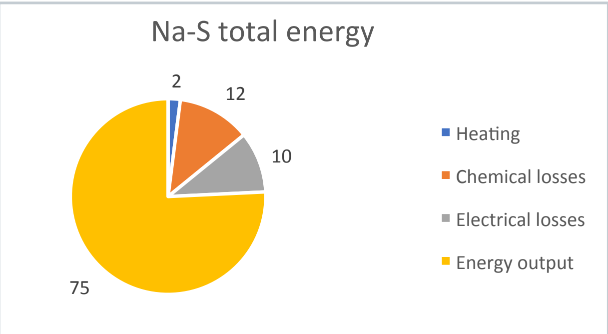
Applications

Lithium ion batteries have been deployed for GLEES for frequency stabilisation and regulation. They have been utilised in renewable energy systems. Japan has installed two Li-ion batteries at two photovoltaic plants with storage energy of 19 MWh and 27.8 MWh. [12]

Na-S

Adopts molten salt technology to store electricity, and operates between 300-350°C. The case acts as the anode, whilst the molten salt is the cathode. Due to the high temperatures of operation, when not in use, the batteries are stored under charge to be ready for use. If allowed to cool, a regenerative heating cycle is required. [21] Na-S hold a cost value of £280-350/ kWh Figure 4 shows the energy totals and losses.

Figure 4. Total energy and losses for a Na-S battery



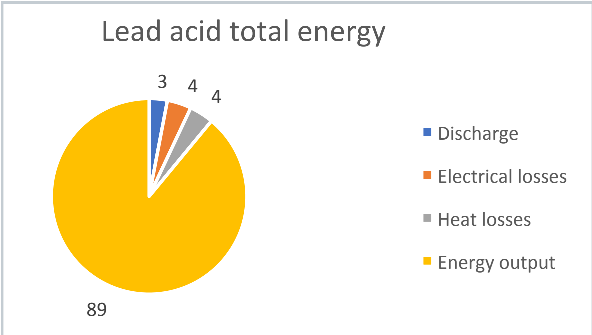
Applications

Extensively used for GLEES, power stabilisation and the integration of renewable energy systems into the main grid.

Lead Acid

Lead acid technology has been established in the motor industry, although there are several technologies, flooded lead acid and sealed lead acid are the most common. [22] They mostly come in 3 voltages, 6v, 12v and 24v. A gel variant utilises silica dust as an immobiliser for the gel. The sealed and gel batteries do not require gas venting or electrolyte replenishment; however the gel batteries have a longer charge cycle. Advanced lead acid batteries are costed at £395-730/ kWh. Figure 5 shows the total energy and losses for a lead acid battery.

Figure 5. Total energy and losses of a lead acid battery



Applications

Predominantly used in the automotive industry, however recent development have seem them utilised in UPS systems and in some larger GLEES applications.

Flow batteries

Flow batteries employ two charged liquids, one positive and one negatively charged. The liquids are stored in two sperate tanks and are pumped passed each other, separated by an ion-membrane, which permits only certain charged ions to pass, dependant on whether under charge or discharge regime. The capacity is restricted only by the size of storage tanks, therefore if larger capacity is required then simply installing larger tanks will facilitate the change. [21] Flow batteries hold a price of £475-525/kWh. Figure 6 shows the total energy and losses of a flow battery.

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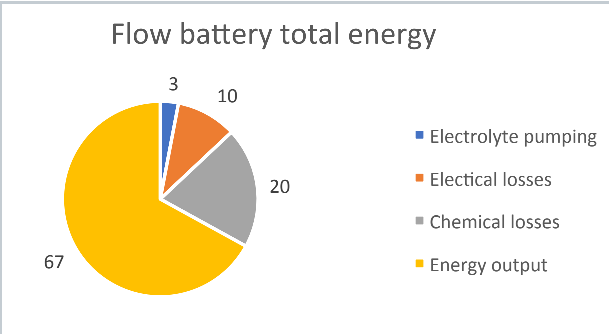
Figure 6. Total energy and energy losses of a flow battery



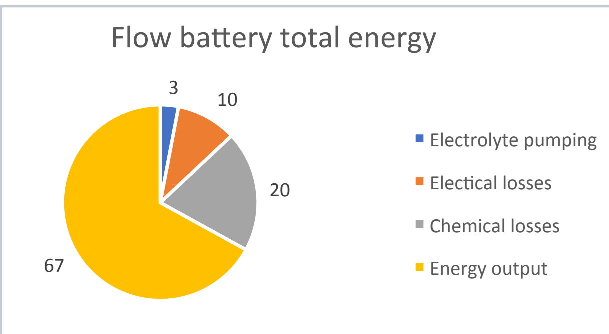
Applications

Can be used for grid balancing, frequency stabilisation, load balancing and integration of renewable energy supplies.

Nickle Chloride (NaNiCl2)

Nickle chloride batteries are a high temperature device operating at 270-350°C. The cathode is nickel chloride, whilst the anode is liquid sodium. The electrodes are separated by an alumina separator. During charge the ions are transported through the alumina to the anode. During discharge, the ions flow in the opposite direction. As the membrane provides no resistance to the flow of ions in either direction or no side reactions, the losses from these batteries is minimal. [18] When not in operation, they are stored under charged condition, due to the temperature of operation. If allowed to cool, then a full reheating process is required before the batteries can be recharged. Nickel chloride technology is costed at £280-350 kWh. The total energy and losses are shown in Figure 7.

Figure 7. energy total and losses in a nickel chloride battery



Applications

Can be used for GLEES applications, load balancing, renewable energy integration and upgrade deferrals. Nickel chloride has been used for UPS systems and have been adapted for automotive use. So far there has been limited GLEES use, and the higher temperatures of operation may limit the deployment of this technology. The battery technologies in this section are constantly being developed and advanced. Table 1 shows the advantages and disadvantages of each battery type.

Table 1 Advantages and disadvantages of battery technology

Battery type	Advantages	Disadvantages
Lithium ion	• Energy density of 400 Wh/l • High levels of efficiencies • Able to maintain large numbers of charge/discharge cycles	• High cost • Can be damaged by overcharging and heavy discharging • Prone to overheat
Sodium sulphur	• High energy density • Fast response (when stored heated) • High efficiency for charge/discharge cycles • High durability under charge/discharge	• May require heating • High heat may cause fire potential
Lead acid	• Well established technology with a robust disposal network. • Good efficiency • Discharge rates of 3%	• Can suffer damage under heavy discharge • Low energy density • Contains hazardous materials
Flow	• Stable under heavy discharge regime • High tolerance to large numbers of charge/discharge cycles • Not susceptible to being downgraded due to single cell degradation • Subject to space availability, potential unlimited capacity. • Several liquid types in development. • Vanadium flow used highly ionised vanadium	• Energy density low • Established technology, but recent chemistry additions make maturity less well known
Nickle chloride	• Energy density is high • No discharge or losses • 20 years life • No cooling required • All materials recyclable	• May require heating before use • Long cycles only • Toxic compounds

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Table 2 highlights the response times and applicability of each battery system. For daily and weekly storage, Na-S, flow and NaNiCl2 give the best response, however from these three battery systems only flow batteries deliver fast responses in the second's range

Table 2. Technology readiness for battery technology.
Adapted from [19], [23]

Storage	Type	Duration	Li-ion	Na-S	Lead acid	Flow	$NaNiCl_2$
Fast response	Power quality	<60 sec					
	Power stability	15 mins					
Power storage		>1 hr					
Energy storage	Day	>6 hr					
	Week	30-45 hr					
	Month	>720 hr					

Technologically ready	
Development required	
Immature technology	

Current technology applications

Battery storage is widely used in small scale applications. In many offices and computer systems, uninterrupted power supplies (UPS) have been incorporated to protect computer systems from interruptions to the grid supply. Recent interventions and loading of the power grid have become more critical, with the increased usage of electrical systems such as electric vehicles (EV). When EV's are connected to the grid they can cause an increase in demand. Whilst most of the EV connections would be overnight, during low demand times, during the winter months this may cause frequency fluctuations. To compensate for energy demand fluctuations, compensation for reduced power supply during low/high wind, periods of solar intensity reduction and frequency balancing GLEES are being deployed. A new port near London, UK, will have a Li-ion battery system of 320 MW/ 640 MWh incorporated, with potential to increase the energy to 1.3 GWh. The largest current system in the UK is in South Yorkshire at 50 MW/75 MWh. [24]. Larger systems globally include 400MW/1600MWh system in California and 250 MW/1.0 GWh in Saudi Arabia. Origin Energy Ltd is to install a 700 MW, four hour (2800 MWh) BESS, in Australia, whilst nationally a further 7 GW is has been proposed [25]. China is to install ten 20 MW GLEES flow battery systems (800 MWh), due to be commissioned in 2022. The flow batteries will be used for grid stability and house power supply [26].

Summary

Steel making using EAF systems provides a method of significantly reducing the amount of CO_2 emissions, however due to quality of product and availability of scrap steel for the process, EAF will not replace the function of an integrated steel plant. EAF operate primarily with electricity from the grid, which may still come from fossil fuels and not renewable primary sources. The use of renewable energy, in particular solar and wind, are subject to local weather conditions, which can make the production of electricity from these systems less reliable as a continuous source. The use of battery storage provides an option for the accumulation of electrical energy, which is already used at grid level for energy balancing, frequency stabilisation and demand fluctuation. Batteries can be applied to the electricity system in a steel works as a method of maintaining a constant supply of power for EAF's. The use of battery systems could be recharged at night or during off peak demand cycles, facilitating a cost advantage for the electricity. The charge can then be used by the EAF during the day when electricity prices are higher.

From the batteries selected, the flow battery may hold the greatest appeal for the steel industry. Whilst it is susceptible to relatively high chemical losses, it does hold the greatest range for response from sub 60 seconds to several hours. To increase the electrical capacity of a flow battery, simply installing larger electrolyte tanks will produce a greater capacity. The technology is well established and flow battery systems are being introduced globally as GLEES systems.

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