**0:00 How about this feller then. He’s a pretty spiffy looking dude isn’t he?**

**4:00 This is Gustave Eiffel, and we all know what his main achievement was.**

**7:00 At nearly a thousand feet in height, the Eiffel tower was built for the 1889 World Fair in Paris,**

**12:00 and at the time it was the tallest man-made structure on earth.**

**15:00 With no fewer than eighteen thousand wrought iron components and two point five million rivets,**

**20:00 Eiffel’s masterpiece would quite simply not have been possible using any other material available at the time.**

**26:00 Everyone in Paris hated it of course. They thought it was monstrously vulgar and an insult to the very soul of the ‘fraternité.**

**33:00 But Eiffel saw it as a symbol of the progress he predicted in the twentieth century,**

**37:00 and he wasn’t wrong as he? The wrought iron material that Eiffel used was**

**41:00 vastly improved by other industrialists like Henry Bessemer**

**44:00 who worked out how to regulate the carbon content in iron using oxygen**

**48:00 to mass produce steel and by nineteen thirty the steel framed Chrysler Building**

**52:00 in New York had taken the prize for world’s tallest building,**

**55:00 followed closely by one of the world’s most iconic steel constructions - the Golden Gate bridge in San Francisco**

**1:01 which was completed in nineteen thirty seven.**

**1:04 Nowadays, of course, steel is everywhere in our modern society from the tools and machines we use in our homes through to major infrastructure that construction work**

**1:12 like hospitals, offices and factories, to name just a few.**

**1:16 All of which we take completely for granted. And steel will also play a crucial role in the renewable energy transition, with solar panels, wind turbines, hydroelectric dams and electric vehicles all depending on it to one degree or another.**

**1:31 So, it’s pretty ironic that the iron and steel sector ranks first when it comes to CO2 emissions, and second when it comes to energy consumption.**

**1:38 According to the International Energy Agency the sector directly accounts for two point six billion tonnes of carbon dioxide emissions every year,**

**1:46 which is seven percent of the global total from the energy system and more than the emissions from all road freight.**

**1:53 unsurprisingly then the race is on to establish ways to minimise carbon dioxide emissions from steel production.**

**1:58 Just simply building in greater efficiencies isn’t going to be enough though. Manufacturers urgently need to find ways to completely re-imagine the process.**

**2:07 Luckily for them, recent advances in renewable energy technology look like they could be leading us towards the previously unthinkable goal… of virtually fossil free steel. 2:18**

**2:30 Hello, and welcome to Just Have a Think**

**2:32 Convincing iron ore to split up and release its ferrous bounty for steel making currently requires a lot of energy and a lot of carbon.**

**That comes in the form of coke 2:42 which is produced by super heating coal in the absence of oxygen. 2:46 The reaction gets rid of lots of coal impurities and leaves the coke with a much higher carbon content 2:51, but it also results in nearly 2:53 eight hundred kilograms of carbon dioxide being released for every tonne of coke produced. 2:58**

**That coke is then added to iron ore 3:00 and limestone and tossed into a furnace 3:03 where air is blasted in at temperatures of about 3:05 a thousand degrees Celsius via jets in the base. 3:08 That’s why it’s called a blast furnace. 3:09 Oxygen in the air burns the coke at temperatures around sixteen hundred degrees Celsius 3:14 which reduces the iron ore to iron oxide 3:17 and then to molten iron, known as hot metal. 3:20 The limestone is there to react with other impurities in the ore 3:23 to produce a liquid slag that can be skimmed off. 3:26 The by-products of the process are carbon monoxide 3:29 and yet more carbon dioxide. 3:31 And this one’s even worse than coke production. For every tonne of molten iron produced in a blast furnace, about 3:36 one point two tonnes of CO2 is emitted. 3:39**

**The resultant molten iron has a carbon content of about 3:42 four percent, which is far too high for steel. At that concentration, the material is very brittle, which is not what you want if you’re building an office block, or anything else for that matter. 3:52 That’s where Sir Henry Bessemer comes in. 3:54 The molten iron gets transferred into a modern day version of Bessemer’s original converter, 3:59 nowadays known as a 4:00 basic oxygen furnace, or BOF, where a very precisely controlled amount of air is injected in at extremely high pressure. 4:07 That causes oxygen to react with some of the unwanted carbon in the iron, 4:12 which brings the carbon content down to somewhere between one and one and a half percent, 4:17 at which point you’ve essentially got steel which can then be pulled out of the bottom of the vessel 4:22 and drawn into whatever shape and size is required. 4:26**

**The reaction of oxygen and molten iron is exothermic. In other words it kicks out an awful lot of heat.**

**4:30 So much so that the liquid steel that’s produced would be too hot for casting. So about twenty five percent of the mix is actually scrap steel, which draws this excess heat off as it melts, keeping temperatures down to manageable levels.**

**4:42 And scrap steel can also just be remelted on its own in an electric arc furnace, or EAF - bypassing the blast furnace process altogether**

**4:51 Steel is actually one of the most recycled materials in the world today. About thirty percent of new steel is recycled from scrap and making new steel from scrap only takes about an eighth of the energy compared to making it from iron ore.**

**5:03 But steel production volumes are much higher today than when the products that are currently being recycled were produced, so that still leaves seventy percent of new steel being made from iron ore.**

**5:16 The IEA Sustainable Development Scenario states that the average direct CO2 emission intensity of steel production needs to decline by sixty percent by 2050.**

**5:26 We could just try to bottle the CO2 using the theoretically hopeful concept of Carbon Capture Utilisation and Storage, or CCUS.**

**5:33 And sure enough, the IEA does include this technology in its scenario projection. But in order for CCUS to play a meaningful role the IEA calculate it would need to be preventing four hundred million tonnes of CO2 escaping each year by 2050.**

**5:47 To achieve that a one million tonne per annum CCUS facility would have to come online every two to three weeks from 2030 onwards.**

**5:55 But growing access to low-cost renewable electricity in many countries around the world is providing a competitive advantage to a technology called hydrogen-based direct reduced iron, or H-DR.**

**6:06 A full assessment of the process was carried out by Valentin Vogl, Max Ahman and Lars Nilsson in this 2018 paper published in ScienceDirect.**

**6:16 I’ve metled my brain reading this paper, so you don’t have to, but I HAVE left a link to it in the description box below this video just in case you’re feeling particularly sciency today.**

**6:27 The basic idea is this**

**6:30 Water is split into hydrogen and oxygen in an electrolyser powered by renewables. 6:36 That’s a technology we looked at I a recent video which you can jump back to by clicking up there somewhere. 6:44**

**The hydrogen replaces the coke that would normally be added to the iron oxide to reduce it. 6:47 The hydrogen reacts with iron oxide at the relatively low temperature of about 6:50 eight hundred degrees Celsius to make what the industry calls sponge iron 6:55, and if you’re keen to understand sponge iron then there’s a link in the description to a second Science Direct paper that explains it all in minute detail. 7:04 Make sure you’ve got a strong coffee on hand first though eh?**

**7:08 Anyway the by-product of hydrogen direct reduction is no longer carbon dioxide, but simply water which can be recycled back into the hydrogen electrolyser. 7:17**

**7:18 The sponge iron now doesn’t need to go through a blast furnace. It can 7:22 be charged straight into an electric arc furnace 7:24 along with recycled scrap iron. 7:26 You do still need to add some carbon to make the iron into steel though – there’s no 7:30 getting around that law of physics. And there will still be some impurities to remove too, so 7:35 lime and a carbon source are both added to the electric arc furnace as well.7:39 But because the iron ore reduction work has been done by hydrogen instead of coke, the researchers found that this method emits only 7:46 two point eight percent of the carbon dioxide currently churned out by existing coke and blast furnace systems.**

**7:52 They also calculated that H-DR uses three point four megawatt hours of electricity for every ton of steel produced**

**7:59 and they say that would make it cost competitive against an existing** [**integrated steel plant**](https://www.sciencedirect.com/topics/engineering/integrated-steel-plant) **only if there was an internationally mandated carbon price of between thirty four and sixty eight euros per tonne of CO2,**

**8:12 and assuming electricity costs of forty euros per megawatt hour.**

**8:16 Those are big assumptions, but it’s quite likely that every major carbon dioxide emitter on the planet is going to have to get used to the reality of carbon pricing in near future,**

**8:25 and one of the big bonuses of the Hydrogen reduction system is flexibility in production and electricity demand, which could allow for grid balancing through storage of hydrogen.**

**8:36 The Swedish Energy Agency has calculated that this process could reduce the CO2 emissions of their entire country by up to ten percent.**

**8:43 It’s supporting a major project called Hydrogen Breakthrough Ironmaking Technology or HYBRIT, being developed jointly by steel producer SSAB, iron ore mining company LKAB and power company Vattenfall**

**8:57 The initial production plant in Sweden is costing around a hundred and fifty million euros, with a government subsidy of fifty million euro.**

**9:03 Initially it’ll produce a comparatively modest amount of one metric ton of steel per hour, but in the medium term future it’s expected to expand that to as much as two hundred tons per hour.**

**9:14 SSAB also say that their steel making operations in Iowa will be powered by renewable energy by 2022 and that all their Americas operations will be able to offer fossil-free steel products starting in 2026,**

**9:26 utilizing the sponge iron developed using this new HYBRIT technology. At the same time, they say they’ve started the process of phasing out fossil fuels used in rolling mills and heat treatment plants throughout the company, to reach their corporate goal of becoming fossil-free by 2045.**

**9:43 As steel markets in the big consuming economies like China and India start to mature, the availability of scrap material for recycling will increase of course, and that’s a good thing.**

**9:52 But nevertheless, the IEA still warns that new technologies will need to be deployed at a blistering pace, with new infrastructure to go alongside them.**

**10:00 In the case of hydrogen direct reduction, they reckon it will need to account for at least fifteen percent of all primary steel production by 2050,**

**10:08 and that equates to one new plant every month for at least two decades starting in 2030.**

**A sustainable transition for the iron and steel sector won’t happen on its own though.**

**10:18 As with so many of the new technologies we’ve looked at on this channel, governments will play a key role.**

 **10:24 Although 2050 is often used as a target date, the IEA argues that governments and decision makers should have 2030 firmly in mind as the critical window to accelerate the transition.**

**10:35 Heavy subsidies will most likely be needed to help pay for the capital expenditure to get these industrial scale processes up and running, and of course a global carbon pricing structure will be absolutely essential.**

**10:47 That will no doubt be the topic of great discussion at the pivotal COP26 climate conference in November 2021.**

**10:54 If you’ve got direct experience in the field or you have strong opinions about his technology one way or the other then dive down to the comments section below and leave your thoughts there.**

**11:04 That’s it for this week though.**

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**11:26 and of course, you can hugely support the channel absolutely for free by subscribing and hitting that like button.**

**11:32 And if you want to be notified about new content each week, then make sure you hit the little bell icon too.**

**11:37 Dead easy to subscribe, you just need to click down there or on that icon there.**

**11:42 As always, thanks very much for watching, have a great week, and remember to Just Have a Think.
See you next week 11:51**