11 Future energy use and emissions

with one eye open

If we bring together our assessment of all the options we've identified to reduce energy requirements and emissions from the existing production routes for steel and aluminium, and if demand grows as we anticipate, will it be impossible to make a 50 % absolute cut in emissions by 2050?

Isaiah in the Piazza di Spagna in Rome

We ought to start a chapter about forecasting with a word from a prophet:

"What will you do on the day of reckoning, when disaster comes from afar? To whom will you run for help? Where will you leave your riches?" (Isaiah 10:3)

This is a chapter of reckoning: in the last four chapters we've explored every option we can identify 'with one eye open' by which we mean with all possible efficiencies but ensuring that any demand for metal is met. However the target of an absolute 50 % reduction in CO_2 emissions by 2050 is snapping at our heels. The European steel and aluminium industries certainly feel that tighter regulations on emissions being applied in the EU, but not elsewhere, have chewed up their heels so it's increasingly hard for them to stand up. In our survey of energy efficiency options, have we identified enough options for further improvement that there's a chance of it all adding up, or is disaster coming from afar?

Our job in this chapter is to do the adding up carefully. We've been clear from the outset that we face uncertainty in every number we use, so our adding up must reflect our uncertainty. But we've also seen some things which are not uncertain: no one, by any means and whatever the incentive, will ever be able to extract metal from ores with less than the standard chemical exergy; while global demand is growing, we can keep increasing our recycling volumes, but we absolutely cannot achieve a circular or closed-loop economy.

We'll develop our forecasts in two stages. Firstly we'll predict the features of our metals economy in 2050. Then we'll use them to forecast how much CO_2 we'll emit.

What will the metals economy look like in 2050?

We will be able to predict emissions in 2050 if we know how much metal is made, by which processes, how much energy those processes use per unit of output, and how much they emit directly or as a result of energy use. We've examined all of those issues in the earlier chapters of this Part of the book, so in this section we'll draw together our evidence and choose values for the parameters we need to make our forecasts.

We developed forecasts of future demand for both metals in chapter 4, and we'll use these as average values within a range of ±10% for steel and ±20% for aluminium based on the projections of the IEA. We'll use the models of stocks and product life-spans from chapter 4 to calculate future scrap availability, and assuming that post-consumer scrap collection rates improve to 90%, we can then predict the fraction of metal demand that will be met by lower emitting secondary production.

Option	CO_2 abatement potential
Energy efficiency—best available technology	13% for all processes
Direct reduced iron	20% compared to the blast furnace
Smelt reduction	20% compared to the blast furnace
Electrolysis with nuclear power	80% compared to the blast furnace assuming low carbon electricity
Top gas recycling and fuel substitution	10% compared to the blast furnace
Electric motors in fabrication	50% reduction in energy

Table 11.1—**Summary of the emissions abatement from energy efficiency and novel technologies for steel**

In chapter 7 we found that we could make only small savings in the energy required to drive the chemical reactions to extract metal from ore, some savings in furnace management, and further savings in downstream processes, where energy is mainly used in electric motors. However, in predicting the gains available from these process improvements we don't know the distribution of current operating efficiencies across the world: how near are we on average to current best practice? Our exploration of opportunities for heat capture and exchange in chapter 8 leads to a similar uncertainty. We've resolved this by assuming that the IEA's predictions of gains from energy efficiency exclude electric motors but include everything else so we can achieve a 13% emissions saving for steel production and a 12% saving in aluminium by energy efficiency. We won't use a range for these values because they arise from proven technologies, and have a clear economic incentive, so it seems likely that over 40 years they will be adopted universally.

In chapter 9 we found that most current efforts at innovation in steel making are related to carbon capture and storage, principally because the existing routes are so extremely efficient compared with Gibbs' absolute limit. The one exception was to use electrolysis to produce steel, but this is far from commercialisation. We also saw that the candidate process innovations for aluminium production have been known for a long time, and the problems that inhibit their development persist. In tables 11.1 and 11.2 we have summarised what we learnt from chapters 7-9 about the emissions abatement potential of efficiency and process innovations for the two metals.

Option	CO_2 abatement potential
Energy efficiency—best available technology	12% for all current processes
Inert anodes with wetted drained cathodes	30% for smelting but double for anodes
Carbothermic reduction	Smelting increases by 12% and no anodes required
Electric motors in fabrication	50% reduction in energy

Table 11.2—**Summary of the emissions abatement from energy efficiency and novel technologies for aluminium**

Will future steel and aluminium production be powered by 'clean' electricity? It is unlikely that renewable sources will power future materials processing, although an expansion in nuclear power could occur. But the other options for clean electricity, and all the other options for process innovations, require carbon capture and storage (CCS). And for our future rate of implementation of CCS, based on what we found in chapter 10, we can choose any number we like: at the optimistic end of the scale, we can say CCS is tremendous, we're going to apply it to all our industrial processes, and all our electricity generation, and in fact we're going to treble our electricity output because in future we'll have electric cars and heat our homes with electric heat pumps. Joy for all, we're going to bury bury bury the problem. At the pessimistic end, well, CCS has been tried in three sites around the world but not yet attached to an industrial process or power station, it's going to reduce the power output of each process by a quarter[3], it's going to cost a lot, it carries risks and the public may not accept it, even if anyone does generate electricity with CCS every other sector will want it too so there won't be any left for industry, and it seems to us the only rational way to explore future emissions linked to materials processing is to choose zero. If we depend on CCS to solve the problem for us, we need take no other action, and the risk of that approach is too great. So let's support intelligent development and evaluation of CCS, to build up our understanding of what it will cost, how it will operate and how difficult it is to implement. But let's not dream of it taking the problem away. We'll just park it—and have as a caveat to all our predictions "unless CCS is implemented on a massive scale". However, we will assume some decarbonisation of the global electricity system. This is also a risky assumption as demand for electricity is growing significantly with population, economic development and fuel switching. But given strong political commitment at present, and because we could achieve this by more nuclear generation, we'll assume that by 2050 between 10% and 30% of the world's electricity is carbon free.

We started this section by asking how much metal will be made in 2050, by which processes, with how much energy and emissions. Having reviewed our options, the parameters we'll use to make our forecasts are shown in tables 11.3 and 11.4. We're going to assume without uncertainty that all remaining energy efficiency options are fully adopted, and that recycling rates rise to 90% by 2050, but for all other choices, the table shows a range of values. To reflect the uncertainties of forecasting 40 years ahead, we've given an optimistic, medium and pessimistic value for every number: the optimistic values include lowest forecasts of demand, and the most aggressive possible implementation of emissions saving options, so would lead to the lowest future emissions figure we can imagine. The pessimistic

	Low	Medium	High
Demand projection (Mt)	2300	2500	2800
Electricity decarbonisation	30 %	20 %	10 %
Iron reduced by:			
Blast furnace with top gas recycling and fuel substitution	50 %	60 %	75 %
DRI	20 %	20 %	15 %
Smelt reduction	20 %	15 %	10 %
Electrolysis	10 %	5 %	0 %

Table 11.3—**Features of our forecasts for future production of steel goods**

	Low	Medium	High
Demand projection (Mt)	110	130	150
Electricity decarbonisation	30 %	20 %	10 %
Aluminium reduction by:			
Conventional Hall-Héroult implementation	0 %	25 %	50 %
Inert anode implementation	85 %	65 %	45 %
Carbothermic reduction implementation	15 %	10 %	5 %

Table 11.4—**Features of our forecasts for future production of aluminium goods**

values lead to the highest possible emissions forecast, and of course the medium values are in between.

Forecast emissions in the steel and aluminium sectors

Now we can start adding up for our day of reckoning in 2050. Firstly we've scaled our forecast of global demand from chapter 4 according to the values in tables 11.3 and 11.4. Then we've run our model of stocks and recycling to predict the volumes of the two metals made by primary and secondary routes. We've applied our energy and emissions intensities from the tables, and converted electricity to emissions as appropriate. Unlike forecasts made by the steel and aluminium industries, we've included downstream manufacturing and construction processes in our calculations, because these sectors are the key drivers of demand. Finally, we multiplied each process emissions intensity by the relevant metal flow, and summed up the process totals to predict future emissions. We repeated this exercise for optimistic, average and pessimistic settings in the two tables, to arrive at a range of forecast emissions in 2050. For comparison we also predicted a 'business as usual' forecast of emissions, by assuming that demand would increase, but emissions intensities would not change.

Our results are shown in figures 11.1 and 11.2 and are devastating: we have done all we can to reflect every possible move that would lead to improved energy efficiency and emissions abatement in making goods in steel and aluminium, and we simply cannot reach the target 50 % cut, if demand grows as we anticipate.

For steel, if we pursue the energy and process efficiency options identified in table 11.3 with extraordinary worldwide commitment, CO_2 emissions would remain at approximately current levels, despite nearly a doubling in steel demand. However, this would be an astounding achievement as the required changes involve a huge upheaval in the industry. A fifth of iron would be produced by gas-powered DRI and all blast furnaces would be retrofitted with top gas recycling and incorporate further fuel substitution. Significant investment would be needed in the commercial development of smelt reduction and electrolysis and we require the optimisation of all downstream electric motors. Our proposed widespread use of ironmaking technologies other than the blast furnace would dramatically reduce the need for coking and sintering plant while significant investment would be required to build capacity for new ironmaking technologies and recycling.

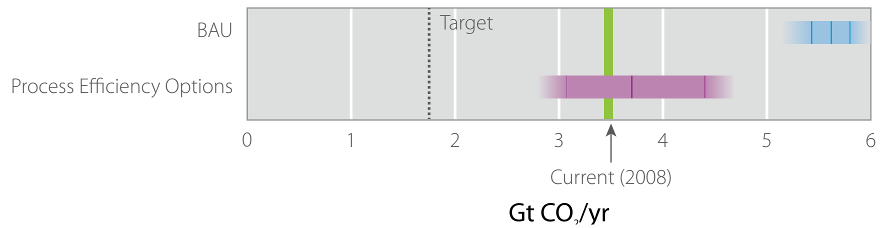

Figure 11.1—**Emissions forecast for steel**

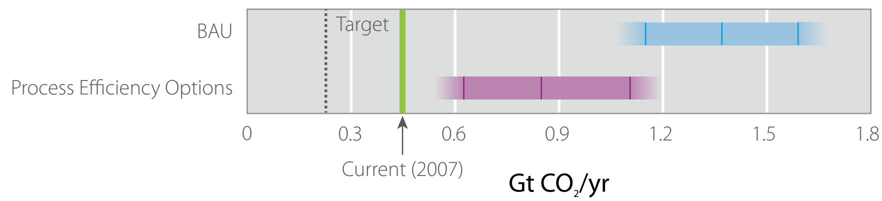

Figure 11.2—**Emissions forecast for aluminium**

The forecast for aluminium suggests that our likely performance will be even further from the targets, with CO_2 emissions nearly doubling as demand for aluminium grows. Even to get to this level of emissions requires a significant change in production technology. The long-anticipated inert anode system is critical to achieving these reductions and would replace the majority of conventional electrolysis. We will need to double our current capacity for primary production, and increase further our capacity for secondary production of aluminium from recycled material. To achieve the emissions levels in our forecast, the aluminium industry while increasing capacity, must develop and deploy a technology that has remained elusive for the last 25 years. This would be an unprecedented achievement.

The most uncertain variable in our forecasts are the rates at which we think different technologies will be adopted by industry. As we discussed in chapter 9, many novel technologies are in the early stages of development and need significant scientific breakthroughs to become commercially viable, so our forecasts may well be optimistic. We're also aware that the emissions abatement potential of these new technologies can only be estimated after full scale implementation, so the numbers we're using for novel process performance may be ambitious.

We can of course re-interpret the results by saying "OK, now we know how much we can gain from efficiency, that tells us how much CCS we need" but we don't think this is reasonable given the current state of the technology. However, if we don't pin our hopes on CCS, these charts show us that we cannot reach our target emissions numbers by efficiency measures. If the climate scientists are correct to be calling for a 50% cut in global emissions to avert serious global warming, the chart has two consequences: either we continue forwards knowing that we are creating irreversible harm to our children's lives; or we accept that as the effects of global warming become more severe, governments will take bolder action to limit emissions, and will eventually ration the output of the steel and aluminium industries. And as we said at the beginning of the book, we're using CO_2 emissions as a proxy for environmental harm more generally: if you're concerned about other problems that inhibit future sustainability, whether emissions to water and land, or resource depletion, or national security—we anticipate that similar analysis will lead to similar results. If you want to reduce harmful side effects while global demand increases, simply aiming to be more efficient within the materials industries is unlikely to make a big enough difference.

Wrought iron railings being collected for the war effort [2]

But the reason we wrote this book is that we don't have to look ahead with only one eye open. If we assume that we must meet any future demand for new metal, we now know that we can't reduce our impacts to sustainable levels solely by pursuing efficiency measures within the industry. We have to do something else, and we raised the 'threat' of rationing above simply because, in a crisis, that's exactly what happens. During the last world war, the UK's population were asked to give up any spare iron or steel in their possession to create materials for the military forces—so iron railings, for example, rapidly disappeared[1]. When forced, we can cope with rationing and our lives do not fall apart.

But we don't want to live between the two precarious extremes of industry efficiency and eventual rationing, and we don't have to if we open our other eye. If we assume production must grow with demand, we can't make enough difference, so why not consider meeting demand with less production? That's what we mean by having both eyes open, and specifically we want to explore the idea of 'material efficiency' to balance the 'energy efficiency' we've looked at so far, with our one eye. We purchase steel and aluminium components as part of goods which we use to deliver a service. Let's call this a 'material service' such as 'transporting us between Cambridge and London' or 'providing a comfortable workspace in town, near to my colleagues'. The objective of making materials is not to have the materials themselves, but to provide material services. So, with both eyes open, can we deliver material services, even allowing for growing demand, while requiring less material production? That's the theme for the rest of the book. In Part III we'll look with both eyes open at the services provided by steel and aluminium. We'll expand on this to look at cement, plastic and paper in Part IV, and then in Part V reflect on how to make enough difference.

Let's turn the page with Isaiah, *"then will the eyes of the blind be opened… and a highway will be there… no lion will be there.. and sorrow and sighing will flee away"*.

The clear conclusion to Part II, is that with one eye open, we can't make enough difference. We need to look instead with both eyes open.

Notes

Forecast emissions in the steel and aluminium sectors

1. John Cole, a child in London during the Second World War describes how in 1943, the wrought iron railings in the front gardens along his street were removed for use in the war effort after Lord Beaverbrook, Minister of Aircraft Production, started a campaign to collect scrap metal. (Cole, n.d).
2. This picture shows the railings from Whitehall Road Recreation Ground being removed in 1942 (Rugby Advertiser, 1942)
3. David MacKay states that cleaning up the gases from a coal-fired power station and storing the CO_2 underground "would reduce delivered electricity by about 25 %" (MacKay, 2009).