

## The rise of renewables: can we really afford to stop doing coal research?

Inaugural address delivered on 24 August 2018 in the Senate Hall, North-West University, Potchefstroom, (South Africa)  
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Deputy vice chancellor Professor van Rensburg, members of the university management, colleagues, family and friends, ladies and gentlemen,

Before we start: let me put this on record: Coal is dirty, very dirty. I know it, and I completely agree with this statement. I also believe that global warming is a fact. There is overwhelming scientific evidence for it. It is also clear that it is related to an increase in greenhouse gas concentration in the atmosphere.

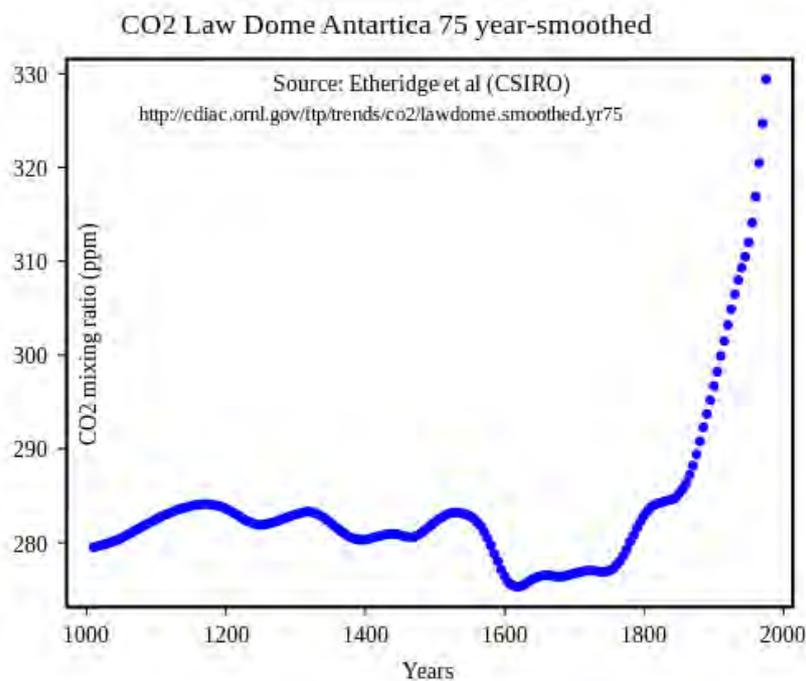


Figure 1: Inferred CO<sub>2</sub> concentration in the atmosphere

On the debate whether the cause is anthropogenic, I am convinced that it is indeed caused primarily by human activity (figure 1). So why am I standing here tonight, promoting the case for research in fossil fuels given that we know the significant impact it has on our future?

### Article 2:

*“...Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change...”*

Figure 2: Excerpt from article 2 of the Paris Declaration, 2015 §

The world is taking cognizance of this impact: at the 2015 Paris Declaration, a number of nations (with one or two notable exceptions) undertook to limit the increase in global temperature to 2° C above pre-industrial levels (figure 2), but a recent disturbing view is that we only have a 5% chance of achieving it. In fact, some research shows that we are already locked into a 1.5° C increase even if we switch off every single carbon emitting source right now. It seems as if we are already beyond the point of no return.

This address will be delivered in three parts: I will start with a bit of a personal background on how I ended up in coal research – and why I am trying to defend the indefensible. And then I will give a brief overview of the science and engineering of coal, especially to the non-coal people in the audience who have a life, and finally, as is appropriate for a typical inaugural address, I will end on a philosophical note, trying to convince you, and ultimately the industry and society as a whole, why it is a good idea to support the research efforts of those who are trying to make the best use of the coal we have left.

When I left university as a fresh graduate metallurgist in 1984, I was not a coal person at all. In fact, during my training period at Gold Fields, I had very limited exposure to coal. I was not too interested either – I was a gold person at heart, working on a gold plant as an expert in the gold process, which I only much later realised was nothing more than a glorified washing machine.

Even during my next appointment at a zinc refinery, I was suddenly challenged by a much more complicated process, involving just about every element on the periodic table. This was the ultimate, I thought. But boy! Was I wrong!

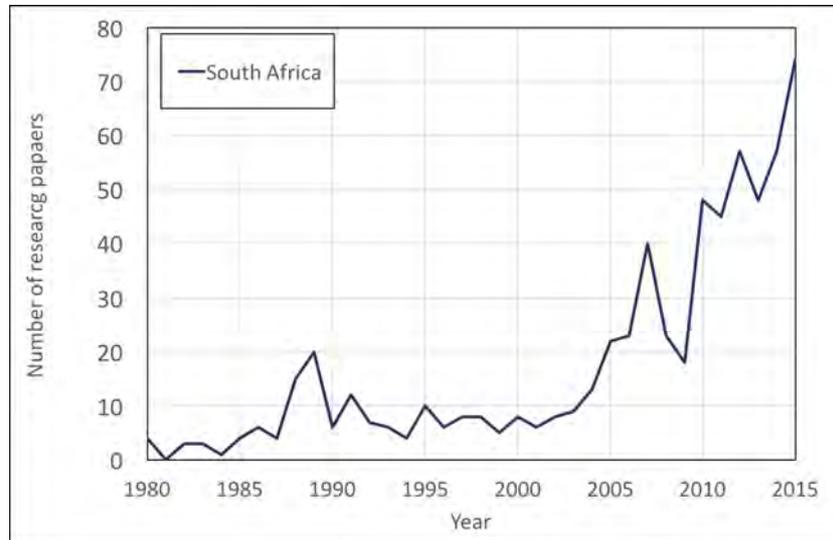
I moved to this University in 1991, thinking that academia was a good introduction into early retirement, and I brought my mineral processing background and skills with me. Coal was nowhere to be seen on my to-do list. As far as I was concerned, it was a combustible black rock, that you dug up and threw into a boiler – end of story. It was only much later that I realised how misinformed I was. At this stage, I should mention that my only real exposure to coal was through my interaction with some very eccentric characters.

I fondly remember the late Professor David Horsfall and his water logged Perspex coal processing demonstration models. I was probably more impressed by his wonderful gift of the gab, than about the topic of coal! Then there was my coal lecturer, Prof Peter van der Walt – a brilliant teacher and a big name in coal. Of course my path inevitably also crossed with Professor Rosemary Falcon, who unfortunately cannot grace us with her presence tonight. I must admit that when I first met her, I thought she was slightly mad, carrying on about this black stuff and it's magic. Of course, these days I share her madness, and I accept that people are now saying the same about me now.

In the late nineties we were required by the University to start focused research. The problem was that I was the only mineral processing person in the department, and I was a bit lost as to what to do, since everybody in the country was specializing in something, like milling, flotation, hydrometallurgy and so forth. I even had a brief foray into expert systems and neural networks, and I planned to pursue a PhD in that field.

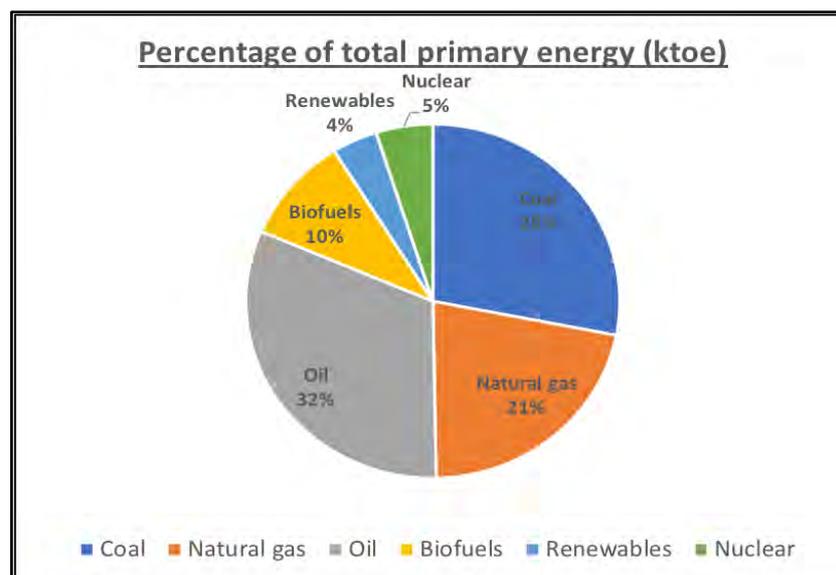
But it all changed one day in 1997 in the office of the then head of Chemical Engineering at UCT, Professor Cyril O'Conner, who, out of the blue, suggested: "Why don't you guys do coal processing research? No-one else is doing it after all." That was just after the passing of David Horsfall, and the departure of J-P Franzidis to Australia – two of the very few South African academics who worked in the field. It soon became clear why "none one else was doing it" – firstly: there was no money for research, since the statutory research levy on all coal sales was withdrawn during that time, and secondly, coal was starting to earn its unfortunate reputation as an evil thing causing more harm than good to mankind. Even to this day, I am suspicious of Cyril's motive when he gave us this advice, but, looking back, it turned out to be the best advice possible.

The problem of funding was partly alleviated by some forward-thinking individuals, some of whom are in the audience tonight, who established the then Coaltech 2020 cooperative research initiative in 1997. It was a structure that enabled the leveraging of funding from both industry and government, allowing universities and other entities research support in coal related topics. This was a welcome injection into our world, and it came at just the right time (figure 3).



**Figure 3: Number of publications annually on coal processing in South Africa. The sudden increase started about 5 years after the establishment of Coaltech in 1997.**

Anyway, I dropped the fancy ideas of fuzzy logic and neural networks, got to know the captains of the coal industry, got some money, did a PhD, delivered a few post graduates, wrote some papers, and the rest is history. Tonight, I stand here as another “slightly mad” but passionate coal person attempting to convince you why it is short-sighted to channel all the resources we have into alternative energy solutions, while there are elegant, cheap (and almost as clean, may I add) options for the clever use of fossil fuels. This action is similar to prohibiting the maintenance on an old building we still live in while the new modern one is being built next door. We must be careful that our old building does not collapse on us while the new one, however elegant it may be, is not quite ready.



**Figure 4: Global primary energy sources \$**

Globally, energy comes from three main sources (figure 4). Fossil fuels, consisting of coal, gas and oil, making up 81 % of the mix, and nuclear and renewables the rest.

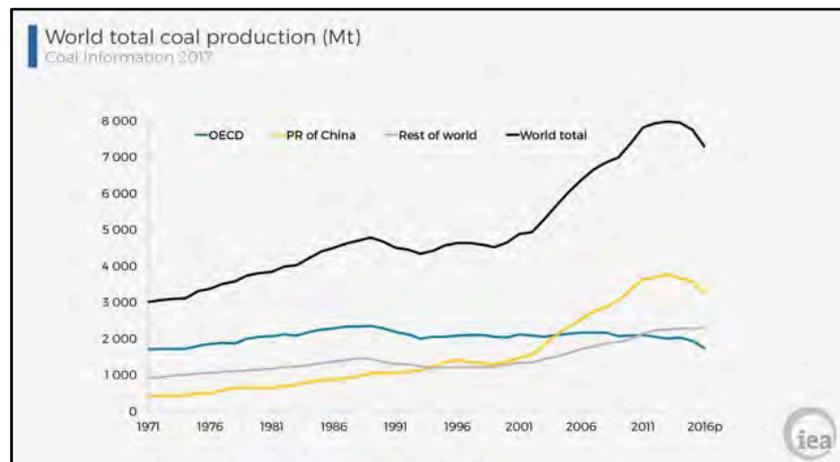


Figure 5: Global coal production

Worldwide, almost 8 billion tonnes of coal are mined annually (figure 5). Its main use is energy generation and as reductants in the iron and ferro-metals industry. It is significant to note the downward turn of the coal growth line in the last few years, mainly caused by China’s reduced production. Whether that is related to a decreasing economic growth or a new-found environmental conscience is an open question. The fact is that the appetite for coal is declining.

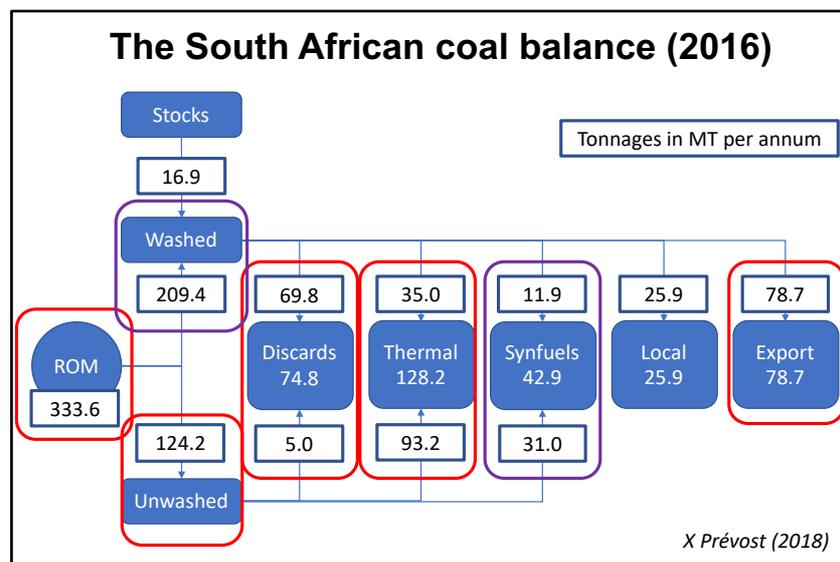
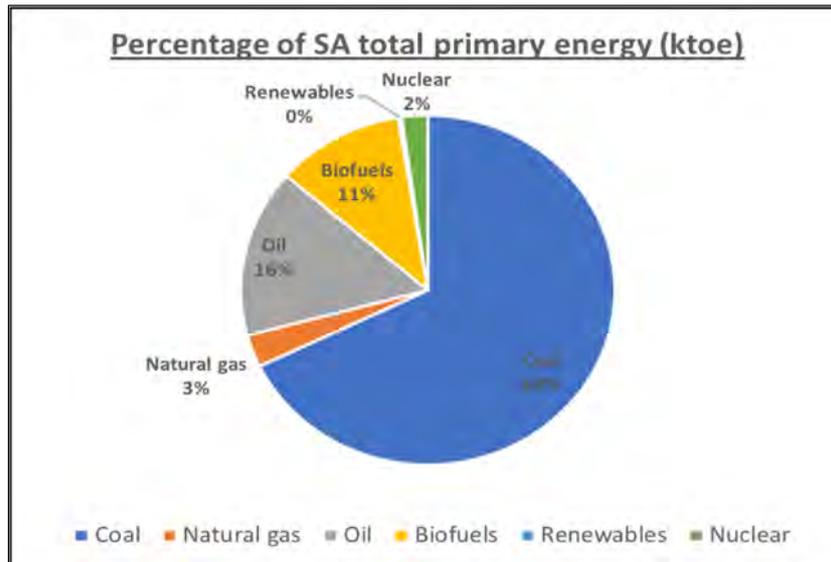


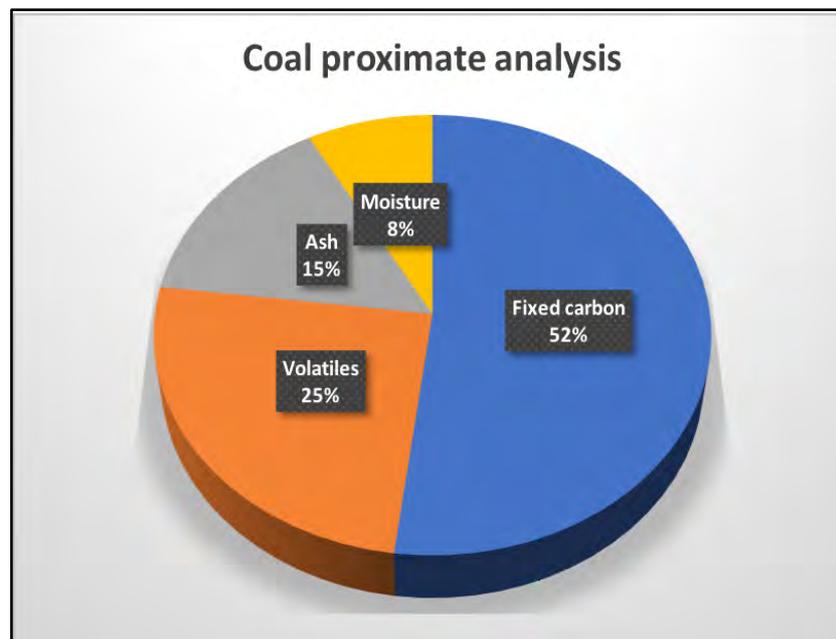
Figure 6: Coal utilization chain for South Africa

The South African coal value chain is described in figure 6: in 2016, we produced 330-odd million tonnes. Of this, 75 million tonnes was lost as discards from coal beneficiation processes and was dumped somewhere becoming an environmental liability. Note that there is still a lot of calorific value in these discards due to poor plant efficiencies, but more about that later. Not all the mined coal is upgraded, and 124 million tonnes of low-quality coal is used as is, mainly by the coal-to-liquids converters like Sasol, and also by some power stations. The washed or clean coal is sold to different end users, and half of it goes to electricity generation. We also export 79 million tonnes superior quality coal per year.



**Figure 7: Sources of primary energy for South Africa**

In South Africa we are inextricably bound to a linear carbon economy (figure 7), as over 90% of our electricity comes from coal. Add to this the coal based liquid fuels from Sasol, and the wide spread domestic coal use by virtue of our unique socio-economic situation. The bottom line is that almost all our coal is either burnt, or turned into something that will eventually burn, to create CO<sub>2</sub>. Other sources of energy like nuclear, hydro and renewables do not really feature in our current South African scenario.



**Figure 8: Proximate analysis of a hypothetical coal sample**

On a simplistic level, coal can be seen to consist of about 50-60% carbon (figure 8). The rest consists of incombustible minerals, and importantly, water. This is because coal is almost always mined from depths below the water table and is also beneficiated using wet processes.

Basic chemistry dictates that when carbon is reacted with oxygen, we get carbon dioxide and energy.



This is a fundamental truth of nature: If you want to get energy from coal, you will make CO<sub>2</sub>. To release more energy, we need to burn more coal and make more CO<sub>2</sub>. Even though the maximum energy released by the reaction of one kilogram of pure carbon in pure oxygen is almost 33 thousand kilojoules, in practice we can never achieve that. Coal is not pure carbon, and air is not pure oxygen, and our power stations are not 100% efficient, hence the useable energy we can harvest is much lower. But the end result is always the release of CO<sub>2</sub>.

This carbon combustion reaction was the very first to be used by humankind for energy purposes, and it is still the easiest and the cheapest. I suspect it is programmed into our human genetic make-up. We can be cynical and state that our climate change problems started with the taming of fire by our ancestors.

There are other reactions too that release energy, like the combustion of hydrogen.



Three times more energy can be generated here, and the nice thing is that the reaction product is water, which is not a greenhouse gas. This makes hydrogen very attractive, but unfortunately all the hydrogen on earth is already in the form of water, and we have to put energy back into the reaction to reverse it to produce hydrogen. The result is that hydrogen is at best an energy store or carrier, and not a primary energy source like carbon. Despite this, there are many reasons why changing over to a hydrogen economy is a good idea.

So, we burn coal for energy. It's cheap, easy and abundant. But by doing that, we release carbon dioxide into the atmosphere. There are also other impacts on our health and the environment, like particulate emissions, water and soil pollution, and – to be honest – a coal mine is not a very nice-looking place.

The use of coal for electricity is a simple enough process that has been used for more than a century. The problem is that our power stations are only about 35% efficient in transforming the coal's energy into electrical energy, even if you do it perfectly. Hence roughly two-thirds of the coal entering a power station is wasted. This is largely a thermodynamic limitation and there is nothing we can do about it.

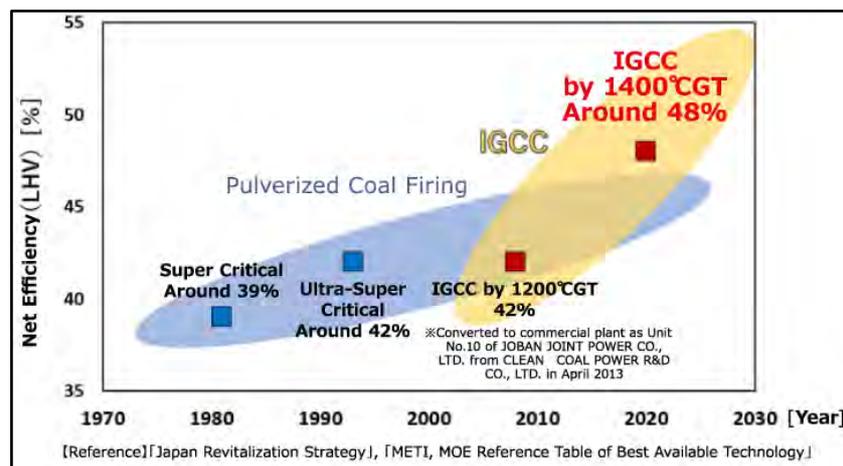


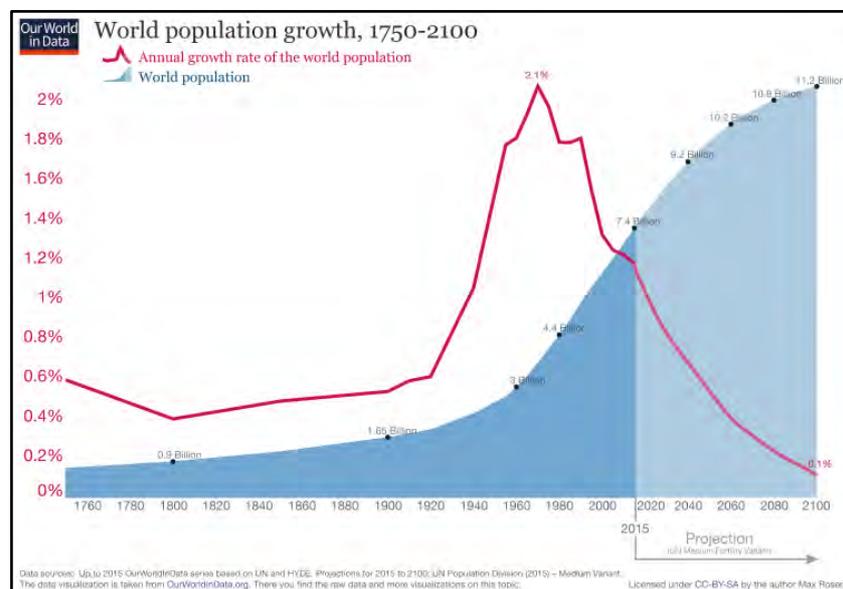
Figure 9: Future coal combustion technologies to increase efficiency

There are newer technologies like gasification (figure 9), integrated gas combined cycles and supercritical combustion that may push up the efficiency to above 50% or even 60%, but it will cost money and huge investment.

While the limitation of conversion efficiency is dictated by thermodynamics, which is beyond our control, there are a number of efficiency factors that is under our control. Firstly, the quality of the coal. Coal, as is occurs in the ground, contains incombustible mineral material, referred to ash. We all know ash – that's what remains

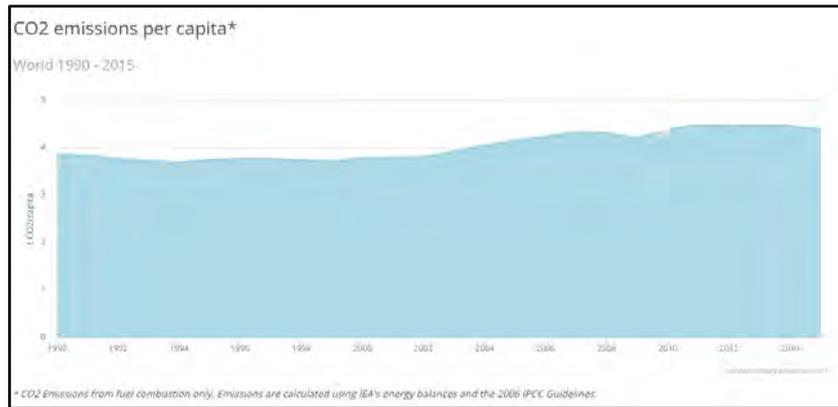
after your braai fire has died. To put it into perspective, export coal contains less than 15% ash, depending on the contract but coal used for electricity generation can contain up to 35 % ash in extreme cases, depending on the power station. This ash, being nothing more than rocks that cannot burn, is useless as an energy source. We are in fact redistributing land through our power stations at great cost, and no compensation. If you consider that these incombustible minerals are being heated up in a boiler to very high temperatures (over a thousand degrees Celsius) only to leave the boiler again to cool down outside, it is clearly an energy drain – the energy that should be used to turn boiler water into steam to drive the turbines. Hence high ash coals are inefficient, causing unnecessary CO<sub>2</sub> release. The argument same applies to the 8 - 10% moisture in the coal. All this water has to be boiled away before the coal can combust, thus wasting more available energy. So, lowering the ash and the moisture of the coal prior to combustion improves efficiency and reduces the impact of coal on the environment. This is under our control.

To solve the problem, we should consider three fundamental causes of the global energy and environmental problems we face: our need to breed, our greed, and our inability to improve things.



**Figure 10: Population number and growth rate**

The first of these, the uncontrolled population growth, as shown by the blue shaded area in figure 10, is the most obvious, but the least likely to be solved – at least not by technology. Any debate about population growth becomes a sociological, psychological and even a political nightmare, but, in my view at least, it does not receive the necessary critical engagement. It is frowned upon to suggest reducing, or at least limiting population growth. Arguments like freedom of choice, human rights and cultural sensitivities are always encountered. I suppose this is human nature – one cannot expect to control the compulsion of a living species to procreate. The pessimistic view is that the problem will solve itself even if we don't – humankind will eventually implode on itself, re-establishing the balance required for sustainability. It is also curious that the same degree of vitriolic criticism levelled against coal by the media, policy makers or pressure groups is never encountered towards the out-of-control population growth phenomenon.



**Figure 11: CO<sub>2</sub> emissions per capita**

It is obvious that this is where the problem lies. Figure 11 shows data from the IEA indicating that the CO<sub>2</sub> emission per capita hardly changed over the last 15 years. This proves that we are simply too many people on earth. Is it fair to blame coal for that?

But let us move on to a more practical solution, and one that we can easily control: Our greed for the good life.

Let us quickly do an experiment. I want everybody to look around and note the other persons sitting around to you. Now I invite you to look at this light: this is a 500 W lamp, and it represents the average energy consumed by every one of you in the audience. It is the energy we consume just to be alive: we are all 500 W lamps. It is not only calculated on your monthly electricity bill, but it includes the electricity required to produce your food, clean your water, manufacture the car you drive, and provide the on-line and social media services you are addicted to. It is even more significant in that it does not include the liquid automotive fuels you use. And no, it does not include the braai fire either. If we include these, called our primary energy demand, each of us would be represented by about seven such lamps. So, this is what you, by simply living, demand from our electricity supply. Note I said, “simply living” and not “living simply”.

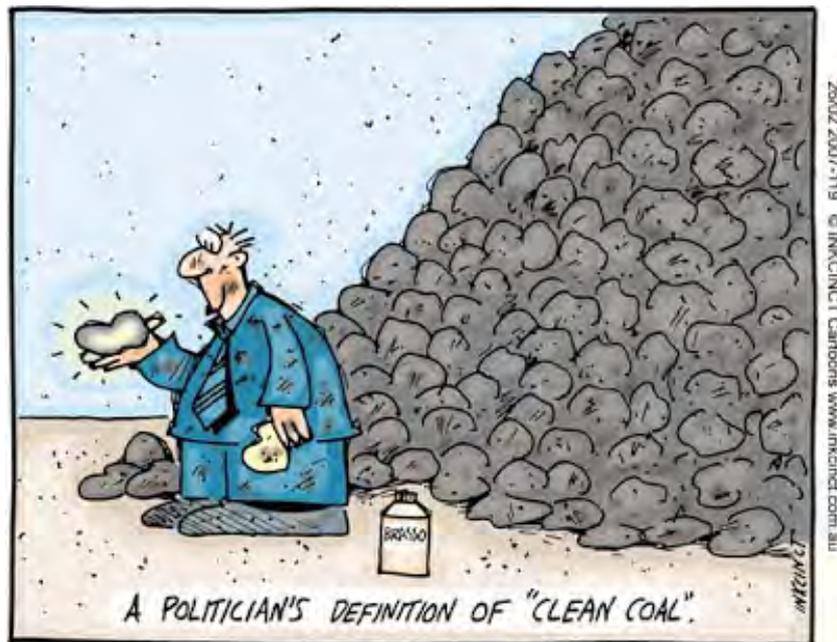
We can calculate the electrical energy that is wasted by the lamp, or by you, in one hour, which is roughly the duration of this ceremony: It equals half a kilowatt hour, or half a unit. During this time 250 grams of coal was burnt and over 500 grams of CO<sub>2</sub> was released to the atmosphere. Assuming that we are 95 people present here, our combined impact becomes more significant. If we multiply this by the number of hours in a year, it means that almost 2.3 tonnes of coal would have been burnt and 4.5 tonnes of CO<sub>2</sub> would have been released – all for nothing. Remember it includes only your electrical energy requirement, but if the total primary energy (that is the fuel in your car, the gas in your cylinders, and yes, the Charka on your braai) is included, each of us we would be responsible for 8 tonnes of CO<sub>2</sub> per year. For just existing and just sitting here. Is it fair to blame coal for that?

An obvious solution is to save energy. Assume one can reduce one’s “existence” energy demand by 10% by simple lifestyle changes like not to run your air conditioner all day, to switch off lights when leaving the room, and to boil 10% less water when making your early morning coffee. This will certainly not have any effect on the quality of your life, but if the entire country can save 10%, we can decommission two medium sized very dirty very nasty power stations! An interesting anecdotal story states that another 5-10% energy can be saved if all equipment requiring standby power (or “vampire power”) like televisions, microwaves, USB cellphone chargers, etcetera, are unplugged from the wall sockets. Those little red 1-watt lights like the one on the television set can consume between 5 and 10% of your electricity bill, and consequently increase your greenhouse gas contribution.

Are our own selfish lifestyle choices then not more responsible for our environmental woes? After all, we determine the demand for by running our air conditioners for that 1 degree below ambient for our own comfort? Is it indeed fair to blame coal for that?

The third element is efficiency. And this is where coal research enters the discourse.

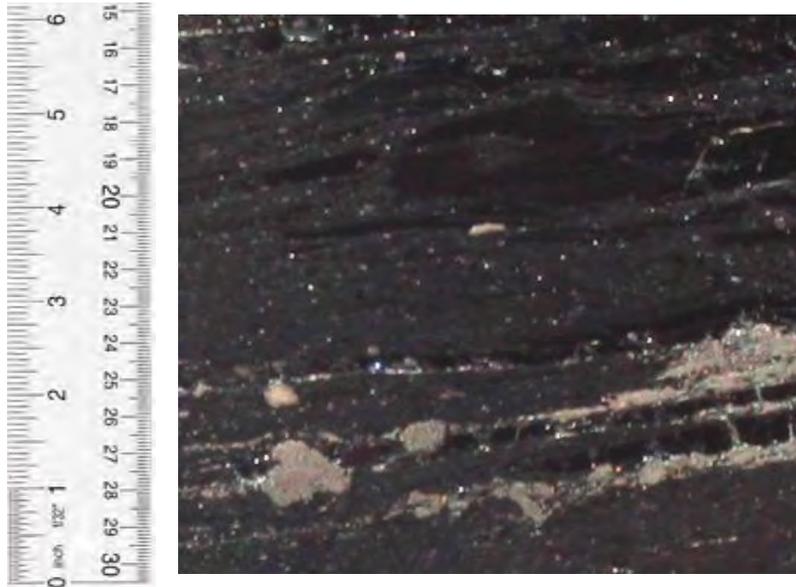
I mentioned earlier that that not everything going into a boiler is burnt. The ash and the moisture scavenge and waste the energy released by the reaction of carbon with oxygen. Improved combustion efficiency (in other words, to get the most energy for the least amount of CO<sub>2</sub>) can be achieved by improving the quality of the feed coal.



**Figure 12: There seems to be some confusion about the term “clean coal”**

This is called coal beneficiation or coal preparation or coal processing, or simply coal washing (figure 12), and it is what I have been doing for the past 20 years.

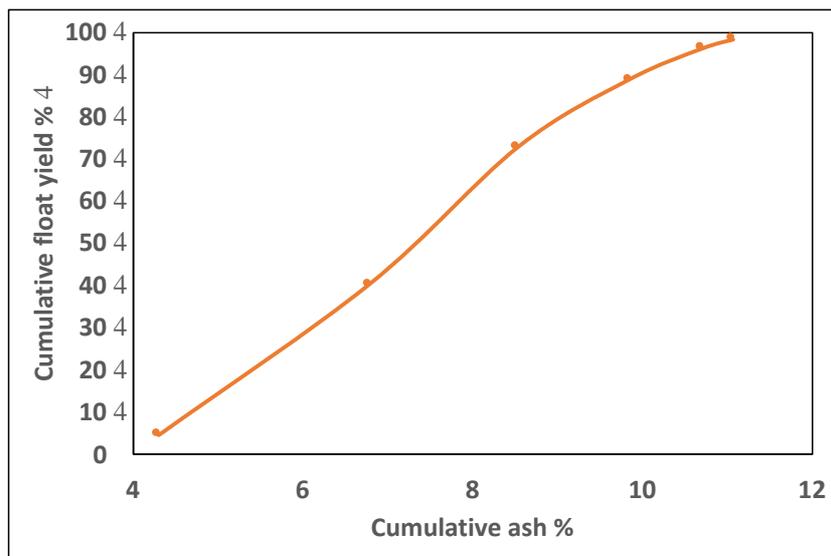
We have seen before that a coal deposit consists of everything ranging from material with high carbon content and no minerals (in theory at least) all the way to material with no carbon at all – essentially pure rocks. Note that the material at the carbon end of the spectrum has a lower density than the material on the other side: pure coal is lighter than pure rock. When it is mined, the material includes a range of qualities and densities, collectively called “coal”.



**Figure 13: Micrograph of a Mozambique coal showing layers of included ash-forming minerals**

The mineral matter is embedded in the coal itself. For example, consider an ancient plant with sand and mud between its roots. When this vegetative matter turns into coal, this mineral debris will be entrained in the coal matrix and will manifest itself as the “ash” when the coal is burnt. There are other types of extraneous ash as well, like layers of sand deposited over the layers of compacted organic material (figure 13).

When the mined coal reaches the processing plant, it occurs as discrete particles or lumps. And depending on how they broke, we get a population of high-quality low ash lumps, and low-quality high ash lumps, all at different densities and contain different carbon/mineral ratios. To wash the coal, we “cut” the population at some density into two fractions: clean coal and discard. Because of the relation between density and quality, we use density as the separation principle. Note that the clean coal particles still contain minerals, and the discard contains combustible material. This is referred to misplaced material, and this is where many research opportunities still exist, even after close to a century of using this principle.



**Figure 14: Typical densimetric curve of a coal resource**

A densimetric curve (figure 14) is used to illustrate a very important and problematic result of the separation ! process. If we want to achieve a quality shown by the blue line, there is a certain yield that can be achieved. The !

problem is that if we want a higher quality coal at lower ash, the yield decreases accordingly. There is a catch-22 here: we can get better coal, but only if we are prepared to lose potentially valuable material. These are the 75 million tonnes per annum of discards that I referred to earlier.

To beneficiate coal, washing plants traditionally use wet density separation processes. To state it simply: the raw coal is immersed in a liquid medium of a certain density and it either floats or sinks depending on its density. It is analogous to throwing a mixture of plastic and steel balls into a swimming pool: some will float, and some will sink. Of course, there are variations of this principle, like the trusty old dense medium cyclone, and water-only methods like spirals and reflux classifiers.

Dense medium cyclones are most widely used to perform coal density separation, being cheap, simple and well understood. Raw coal is fed together with a high-density medium into a cyclone. The medium is usually a suspension of finely ground magnetite in water. The coal is separated by a combination of centrifugal and drag forces into a high-density stream, exiting through the bottom, and a low-density stream exiting from the top, hence the coal and discard streams. This seems simple enough, but unfortunately there is some material that is misplaced, i.e. some high-density stones follow with the product and vice versa. Thus, if one can “sharpen” the separation of the cyclone, one can improve the product quality and reduce the wastage.



**Figure 15: The three-product cyclone**

Much research has been done on these cyclones over many years, but the only real step-change innovation in the last decade has been a development from China, called the three-product cyclone (figure 15). By the way, this is becoming a recurring theme in innovation in the coal business: “the only real game-changers are from China”.

May I then present a game changer from South Africa? A number of years ago, I was involved in the development of a so-called magnetic cyclone with the De Beers mining company – the production of diamonds utilizes the very same dense medium cyclone technology as is used in coal. In any event, we fitted a variable controlled electromagnet around the cyclone, and we could achieve great improvements in the separation efficiency and stability of operation of these cyclones. Since the medium used in these cyclones is magnetic, the solenoid influences the flow and density properties of the medium inside the cyclone, improving its efficiency. This very same technology is currently being researched and developed by us, together with a local cyclone supplier as part of a post graduate study. If this works (and I have no reason to believe it won't) we can improve the quality of the power station feed while reducing the loss of valuable combustibles in the discards. But for this work, we require money and resources, which is becoming more difficult to acquire because of the reputation of coal.

Almost all coal washing processes are wet and consume copious amounts of water – something we do not have much of in this country. Also, the environmental impact of water use (or rather abuse) by mining activities is a serious issue we need to consider.

Again, the Chinese are ahead: they have developed dry beneficiation technologies like the air operated FGX and a dry dense medium fluidized bed separator to eliminate the use of water from a process. Granted, some of these are still immature technologies, but it will not be possible to perfect should all resources go into renewables research.

The good news is that we are also busy developing dry beneficiation processes. For example, we have progressed with dry fluidized beds, and we are also developing a very novel process based on the age-old method of separating wheat from chaff by winnowing. I'm tempted to say: "watch this space", but it depends on whether we get the resources to complete the full path to implementation and commercialization.

If dry processing is not an option, then one must at least reduce the water associated with the coal process. Even here our research group is at the forefront. Many innovative methods to reduce the water content in fine coal slurries have been or are being developed at this institution - this was also the topic of my own PhD.

The previous examples illustrate two of the priority actions highlighted earlier: to reduce the ash value of the coal and to reduce the moisture. As coal processing researchers, we are proud to say that we are also contributing towards the reduction of greenhouse gas emissions into the atmosphere. Our list is long and includes many achievements over the years.

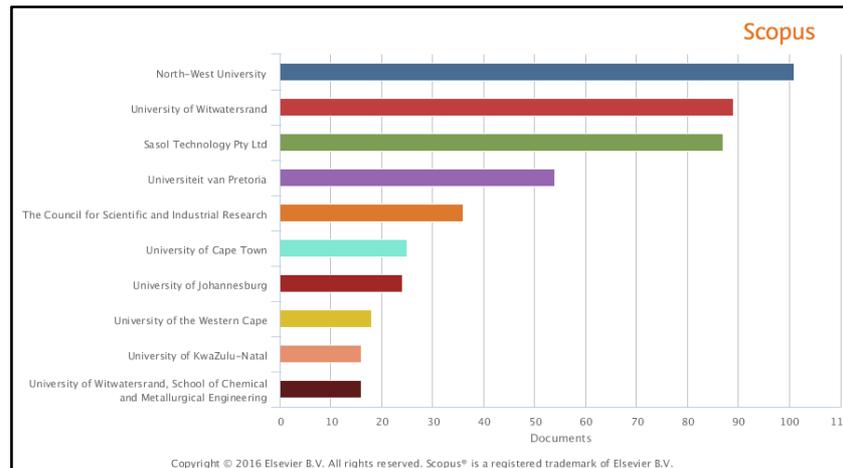
So, we can improve combustion efficiency, and we can reduce the impact of coal mining on, for example water resources. We can recover value from discard dumps and fines slurry ponds, thereby harvesting carbon that has already been mined and processed, thus reducing the necessity to dig new holes. We can, by virtue of our work, both past and present, make an impact on the CO<sub>2</sub> emissions. We can even force these emissions towards close to zero with well-supported research. It is unfortunate, though, that many of our ideas stop just short of commercialization. There is a reluctance to develop technologies to reach maturity. Importing Chinese inventions are somehow OK, because these offer off-the-shelf solutions, but we are not investing in local expertise. We see very few calls, if any, from government funding structures like the NRF for example to fund this type of research.



**Figure 16: Is this good reporting?**

It would seem as if the fake news message about clean coal is busy making an impact. Perceptions are important, and the media plays a major part in it. And without a holistic understanding of the problem, it is easy to propagate emotional messages (figure 16), often with the best intentions, but in fact achieving the opposite effect. This ignorance is the cause of the diversion of resources away from our efforts to clean up fossil fuels. We are struggling to get support even from within the coal industry, and it would seem as they have also given up: "let's just dig and burn, while we still can – there is not real future for coal after that". It is this lack of

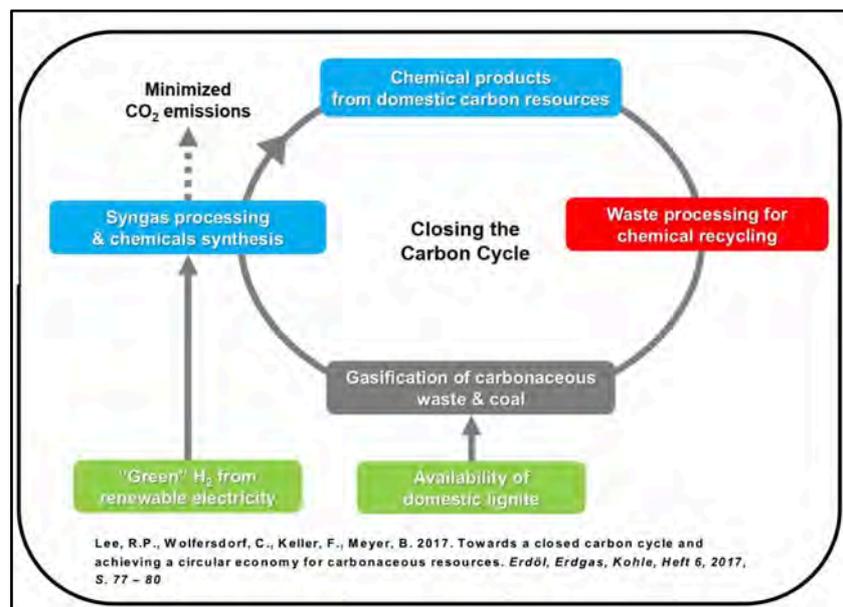
foresight or rather insight into the true state of affairs that I am referring to, and the coal industry is, in a strange way, as complicit as the press and the environmental pressure groups. On the positive side, we still have the supportive examples of Coaltech and the Southern African Coal Processing Society, but that is not nearly sufficient.



**Figure 17: Number of publications on coal processing between 2000-2016**

Our team at North-West University has been doing really well. We have had many academic and research achievements. We can even state without fear of contradiction that we are the best coal processing research group in the country, and one of the most active in the world (figure 17). Our record speaks for itself. And we were fortunate to do this with often-strained support from a few like-minded people and organizations. We did well.

Looking at the future: the only way to continue this momentum would be to redirect our research efforts into solutions that will integrate with and support the inevitable rise in renewables.



**Figure 18: An example of a possible circular carbon economy \$**

An example of such a holistic approach is the concept of a circular carbon economy, as opposed of the linear ! process we have currently (figure 18). This means we can have carbon-based energy and materials processes ! with very low or even zero carbon dioxide emission. These strategies involve the introduction of some green !

energy, and possibly hydrogen, into the cycle. It goes beyond simple carbon capture and storage, but includes the concept of reduce, re-use and recycle. This has great promise, especially in Europe and the developed world, where there is a concerted economic and technical drive towards it at this moment. It is an elegant solution where governments and societies have the time, the will, and the resources to push this. Unfortunately (and I admit this is a rather fatalistic view) the reality is that South Africa is still bound to many decades of burning coal for energy. That is clear from the Integrated Resource Plan of 2010 and its subsequent versions. That said, this is no reason to stop us to research these options and to develop similar technologies as best and fast as we can.

I re-iterate: I do not criticize the popular and well-supported development in renewable energy, nor do I suggest limiting the resources to get it going. On the contrary, I fully support the world's intention to move away from fossil fuels – for the sake of our survival. What I do not support is the rejection of anything that looks and smells like coal, almost like an abandoned orphan, because of misconstrued perceptions that coal is the worst thing that even happened to humanity. I do not support the notion that coal is not the “in-thing” anymore (like vinyl records and disco music). Coal has a role indeed – yes, a very different one. To map out that role, we need a new generation of young and dedicated people who are not tainted by dirty coal dust. We must continue with focused and innovative coal research, and we must be afforded the resources and manpower to do this properly. A new paradigm for use of coal has the potential to take us away from the grime and the dirt into a clean bright future, not in opposition to renewable energy, but as a complimentary and affordable energy source to satiate the world's increasing selfish hunger for energy.

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*I thank you. (*