RCEA
(SUSSEX)

An Association for Retired Professional Engineers

NEWSLETTER December 2023

President's message

Hello everyone, it's that time of year again when Christmas will soon be upon us and that means the December Newsletter.
We have had a successful session of talks starting in September with the AGM and a talk on Artificial Intelligence.
Attendance has settled down at around 30 / 33 each month, so always room for more!!!
Like a lot of organisations, the result of the pandemic has left folk perhaps a little wary of returning to things they used to do without thinking. This is only natural as we all get into habits and sometimes, they are hard to break. Hopefully as the months and years pass, attendance at our meetings will once again return to pre-pandemic numbers.
Getting speakers to commit to some dates has been a headache for Mike who continues to work tirelessly along with all the committee on your behalf to bring you successful meetings.
Moving forward, we are all fixed up for the rest of the season (January 'till April) so hope to see as many of you as possible on the 2nd Tuesday of each month.

The annual Christmas lunch has once again got a new venue. In a week or so 33 members and guests will be off to the Findon Manor Hotel, who I am sure will do us proud and I look forward to reporting in the next newsletter.
I would like at this point to thank all the existing committee members for the help and support they have given me in this my 3rd term as your President.
Finally, may I wish you and your families a very Merry Christmas and a Happy and Healthy New Year, and the support of you all which keeps our association up and running.

George Woollard
President
December 2023

PROGRAMME OF EVENTS December 2023 – April 2024

7th Dec	**Thursday**	**Christmas Lunch at Findon Manor hotel, Findon**
12th Dec	**Tuesday**	**Talk – A cluttered and noisy sky**
21st Dec	**Thursday**	**Coffee – at Spotted Cow, Angmering**
28th Dec	**Thursday**	**Coffee – with Partners at Swallow's Return**
9th Jan	**Tuesday**	**Talk – Flight Simulation**
18th Jan	**Thursday**	**Coffee – at Spotted Cow, Angmering**
25th Jan	**Thursday**	**Coffee – with Partners at Swallow's Return**
13th Feb	**Tuesday**	**Talk – The decline of British automotive manufacturing and the quality revolution that helped restore it.**
15th Feb	**Thursday**	**Coffee – at Spotted Cow, Angmering**
29th Feb	**Thursday**	**Coffee – with Partners at Swallow's Return**
12th Mar	**Tuesday**	**Talk - Aspects of Psychopharmacological drug research**
21st Mar	**Thursday**	**Coffee – at Spotted Cow, Angmering**
28th Mar	**Thursday**	**Coffee – with Partners at Swallow's Return**
9thApr	**Tuesday**	**Talk - Worldwide Homologation, the growth of Nissan UK and experiences of UK and other European car testing organisations**
18h Apr	**Thursday**	**Coffee – at Spotted Cow, Angmering**
25th Apr	**Thursday**	**Coffee – with Partners at Swallow's Return**

All talks and meetings will commence at 2.30 pm and are held in the Pavilion, Field Place, Worthing unless another venue or time is indicated. Timings for visits and outings will be as printed in the detailed description of the activity.

Coffee mornings commence at 10.30 am.

We have noticed that the number of members attending our coffee mornings has declined recently. To enable us to continue to offer these coffee mornings, please support them, and in the case of the one at the Swallows Return, please encourage your partner to come along as well, as it is a very good opportunity for partners to meet each other in a relaxed setting.

We apologise for only being able to publish a very short list of our forthcoming events. As you know we sometimes have to cancel/rearrange talks and visits, often at short notice. We do try and inform our members of late changes to our programme by email but suggest that members should increasingly rely upon our website for up-to-date details of events.

Website of the RCEA

Our website, **www.rceasussex.org.uk** carries the very latest information on all of our events.

New Members and Speakers for Talks

The RCEA needs new members to ensure that we can continue as a thriving organisation. Please think of appropriate people you know and encourage them to come along to our talks and hopefully join the RCEA.

We also need more speakers to give talks to us on Tuesday afternoons from September to March/April. We are aware that many members have the knowledge from their working careers to provide interesting talks. If you are willing to give a talk, please let us know. Speakers from outside organisations are increasingly harder to find and often seek payment for their services.

RCEA Insurance

Members need to be aware that the insurance policy that the Association holds is solely for the protection for the assets and liabilities for the Association as an entity. The policy does not provide cover for personal injury or loss to individual members. Members attend the Association's events at their own risk; although under some circumstances there may be some cover from the insurance arrangements of the venue owner.

Newsletter Entries

If you would like to provide an article for inclusion in a future newsletter it would be very welcome as we are always looking for new material in addition to reports on previous talks and visits/outings. From feedback from our members, we know that the newsletter is particularly appreciated by those who are no longer able to get to our meetings and visits, so if you are able to contribute in this way it would be much appreciated. Articles should preferably be Microsoft Word documents, although we can usually convert both text and pictures (even photographs) into a suitable format. Accompanying pictures are best supplied as separate files which will be embedded within the text during editing.

Brief Detail – Talks, Outings and other activities December 2023 – April 2024

Talks

Tuesday, 12th December 2022 – A cluttered and noisy sky

Dr. Robert Massey, Deputy Executive Director Royal Astronomical Society

Some 65 years ago the Soviet Union placed the first satellite in space. There are now around 6,500 satellites in low-Earth orbit, the region up to 2,000 km above the ground, and their deployment is accelerating. In 2019 Starlink came into being, a satellite constellation built and launched by SpaceX, a system that on its own could soon have more than 30,000 spacecraft deployed. With other operators we could see up to 300,000 satellites in low-Earth orbit by the end of this decade.

This is nothing less than a step change in our use of space. And like most paradigm shifts, it will have significant consequences. A key example is how it will affect the science of astronomy and our view of the sky. Some estimates suggest that as many as 1 in 10 ‘stars’ visible could be satellites, and professional and amateur astronomers alike now face significant challenges to their work. As a result, our community has mobilised, working at a national, international, and global level to tackle a complex problem, and to try to find a balance between the positive results of boosting communications and the impact on the space environment.

Robert will set out the problem, what it means for scientists and the wider public, and what we can do about it.

Tuesday, 9th January 2023 – Flight Simulation

Jeremy Hopkins – member

The presentation will briefly describe the use of flight simulation by commercial airlines. It will introduce the main components of the simulator and identify key differences from military aircraft simulators.

The speaker will discuss the pros and cons of simulation versus simulation of cockpit avionics and give a brief history of technology progress in the simulation host computing engine. Jeremy intends to give an overview of the architecture of the Boeing 787 flight simulator and provide an overview of simulator use in pilot training.

Time permitting, Jeremy will present an overview of the small arms training devices which were derived from aspects of flight simulation technology.

Tuesday, 13th February 2024 – The decline of British automotive manufacturing and the quality revolution that helped restore it.

Laurie West

From 1932 to 1955 Britain was the 2nd largest producer of cars in the world next to the USA. By 1950 Britain was the largest exporter of cars in the world with some 38 car manufacturers. Today there are no British owned car producers of any volume in existence. So, what happened and why?

Laurie will outline his experience, progressing from a Ford engineering apprenticeship in the late 60's, through various roles at Ford Motor Company, before moving to the automotive supply industry and ever more senior management positions. Having experienced the often-adversarial relationships that existed within and between automotive companies, he will discuss how, in the late 80's and early 90's he was challenged by a completely different approach to business when bidding to supply the newly established UK plants of Nissan and Toyota. Initially somewhat sceptical, he will tell us how he and his company went through a paradigm shift by embracing and adopting the Japanese approach to manufacturing.
Achievement of the now commonly used term "Lean Manufacturing" is predicated on respect, trust, commitment, relationships, and quality. Successful implementation resulted in his company achieving many accolades in the UK and mainland Europe.

Laurie will provide an overview of Lean Manufacturing and its many benefits, which are applicable to any process; not just manufacturing and not just automotive. He will also highlight how the UK automotive industry may be at risk of falling behind again unless a comprehensive strategic vision and deployment plan for the shift to electric vehicles is executed, noting that this time around it is the Chinese that are currently in pole position and set to dominate.

Tuesday, 12th March 2024 – Aspects of Psychopharmacological drug research.

Prof Ian Stolerman

The Professor of Behavioural Pharmacology at the Institute of Psychiatry, King's College London will give a glimpse into his fascinating career studying the effects of drugs on the brain and behaviour.

Ian gained his pharmacy degree in London in the swinging sixties, a time when both recreational and medical interest in the psychotropic effect of drugs was rapidly expanding. With a keen interest in psychology, he was particularly drawn to understanding how drugs influenced behaviour and left the UK to take up an opportunity to study nicotine with a research team at the prestigious Albert Einstein College of Medicine (New York), which focused on the effects of the drug on learning and memory.

Though highly unfashionable at the time, nicotine and tobacco research is where Ian built much of his global renown. He will share in his presentation how this expertise led to relationships with tobacco companies, and his experience of their underhand dealings in concealing data and corrupting the academic community, as the risks of nicotine and tobacco use became apparent.

Ian will also give insights into a lifetime's research into misused substances, their risks, and potential benefits, and how his findings have gone on to influence drug development in the pharmaceutical industry and further understanding of drug dependence.

Tuesday, 9th April 2024 - Worldwide Homologation, the growth of Nissan UK and experiences of UK and other European car testing organisations

Frank Riddle and Paul Fitchett

Frank tells a remarkable story of how, in 1973 after returning from Canada, he took a job with the embryonic Datsun UK (became Nissan UK). He was allocated to Nissan's Design Administration Department in Japan but based in the UK and worked closely with Octav Botnar.

His presentation will be partly about Botnar's background (twice a political prisoner before coming to the UK), and how he grew Datsun UK from zero, to selling 150,000 cars per year, and partly about his own career and expertise, especially in homologation; certifying cars for compliance with British, European, and International regulations; Federal American, Australian Design Rule etc,
At Nissan he was ably assisted by Paul Fitchett (ex DfT). This work covered Nissan/Datsun cars from 1973 to 1991 and from 1991 to 2008 for many other well-known brands including Rolls Royce, Suzuki, VW/Skoda, Ford, Renault Saab and Aston Martin.

Frank will touch on Botnar's bad press re alleged tax, and Nissan Japan problems, and many other interesting topics.

Botnar was a great philanthropist and gave over £100m to charity as well as supporting numerous charities for less able children.

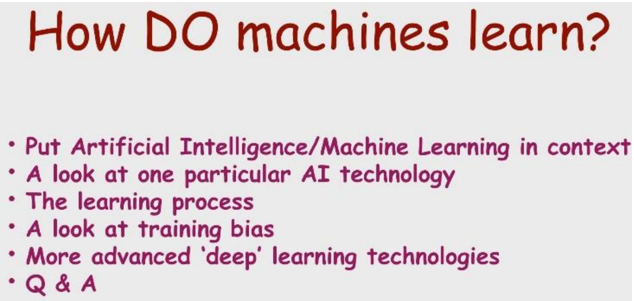
Reports

Tuesday, 19th September 2023 – Artificial Intelligence and simple approaches to machine learning

Dr. David James - member

As Artificial Intelligence (AI) is a very contentious subject, David started his talk by showing the slide on the right which gives two rather differing views on the possible impact of AI in the future. The audience were left to reach their own conclusions as to which was the most likely outcome.

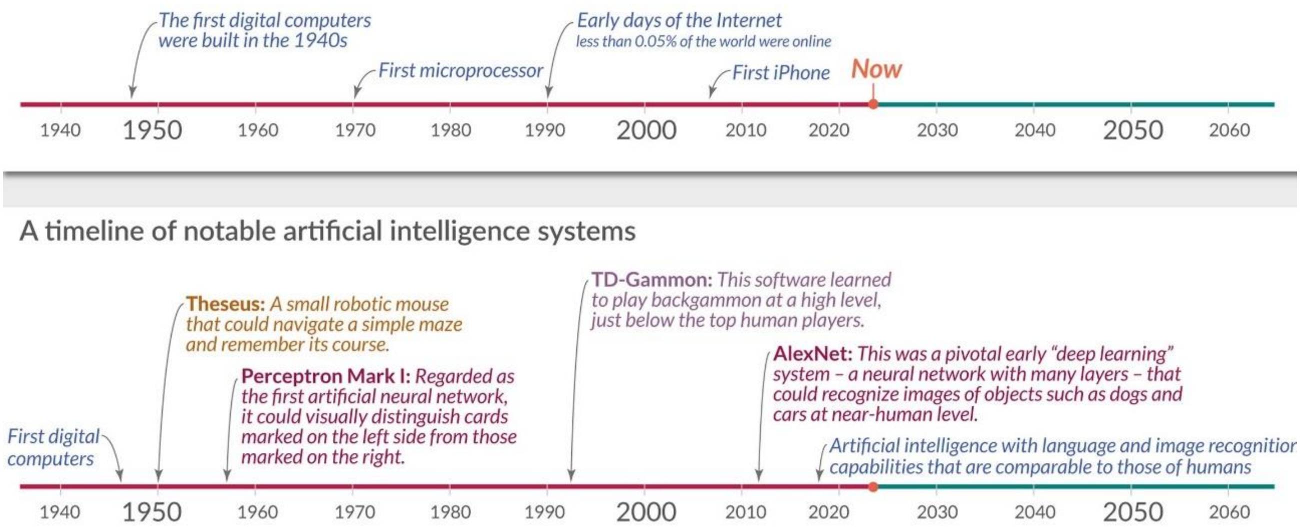
David then went on to define AI as the ability of machines to carry out intelligent tasks typically performed by humans. It involves the use of computers to reproduce or undertake such tasks, sometimes faster and more accurately than humans are capable of.

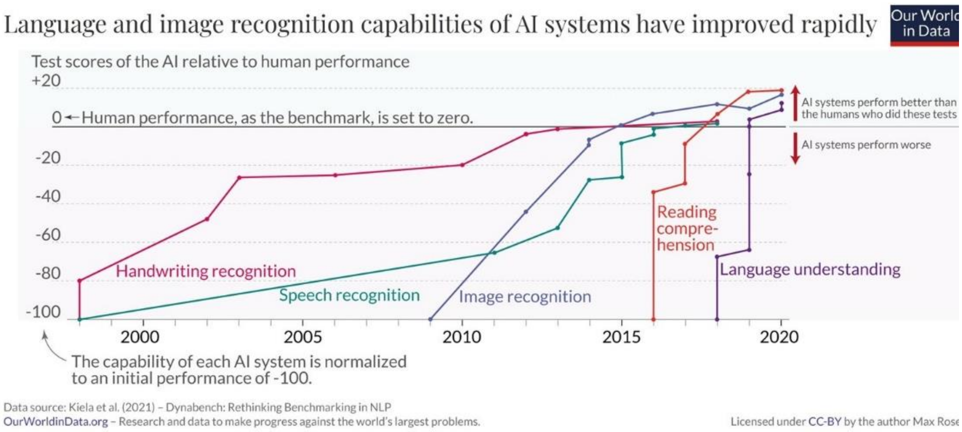


The slide on the left shows the programme that our speaker followed during his talk.

By way of a demonstration, David invited two members of the audience to write down a single digit number on a piece of A4 paper. He had previously written a short AI programme in the programming language Python to which he scanned each sheet of paper, asking the programme to identify each number, which it did correctly. A good example of image recognition.

AI systems are relatively new as they utilize digital computers, which have only a relatively short history as shown in the slide below.



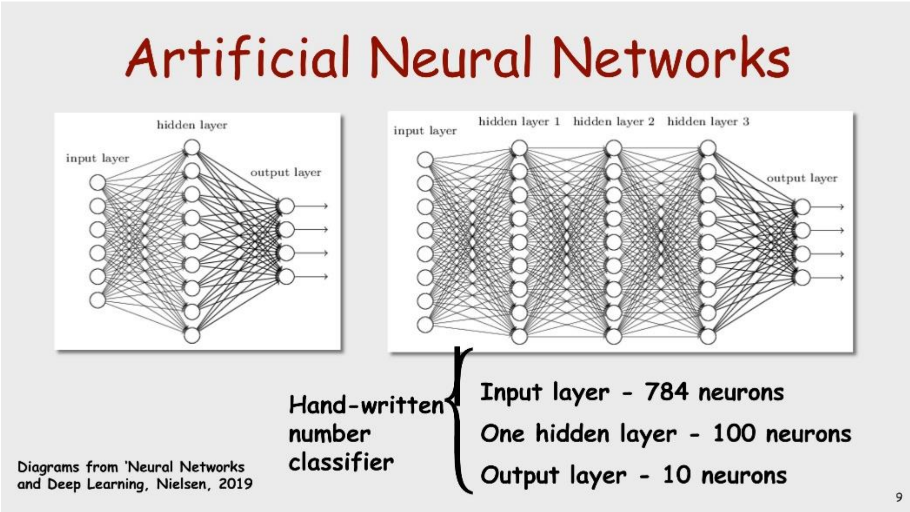


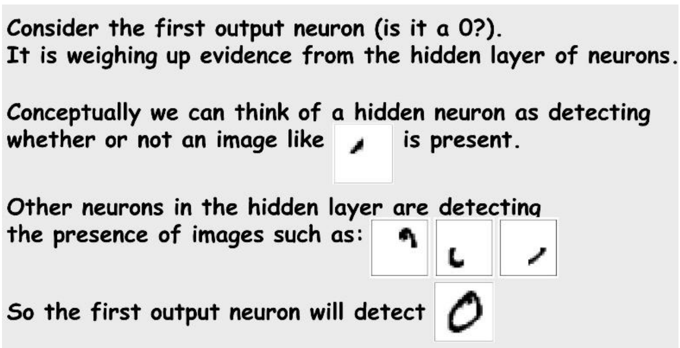
Until the 1990s, AI programmers opted for a top-down approach.

In 2008 Google speech recognition utilized parallel artificial neural networks.

In 2011 IBM's Watson was revealed using lots of AI techniques, including neural networks, but took over 3 years to train.

The techniques used are still evolving. For the purposes of this talk, David went on to describe artificial neural networks (shown in the illustration on the right) as one technique that is frequently used today, and which attempts to mimic how information is processed in the human brain.
The design parameters of David's sample AI programme that he demonstrated at the start of his talk is shown below the main diagrams.



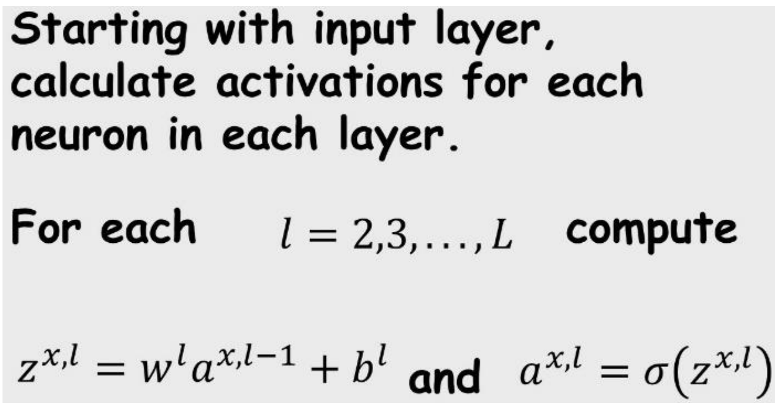


In the previous illustration, readers will have noticed that apart from the input and output layers, there are also multiple hidden layers.

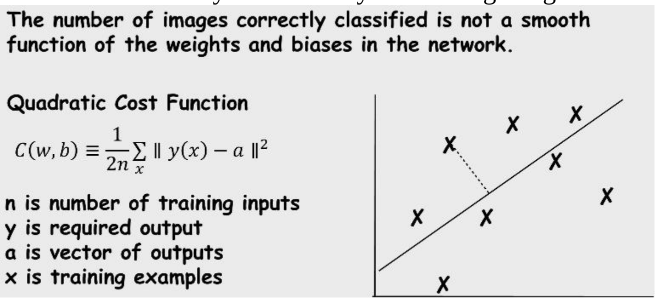
David explained, with the help of the diagram shown on the left, that each neuron in the hidden layer is 'trained' (see later) to detect the presence of one relatively simple image in its inputs.

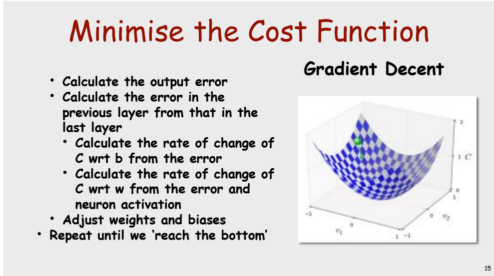
In the example shown on the left, the first output neuron will detect 0 from the outputs of the hidden neurons.

Turning now to the training, or learning function, we need to calculate activations for each neuron as shown in the illustration on the right, where David introduced us to a small amount of mathematics.

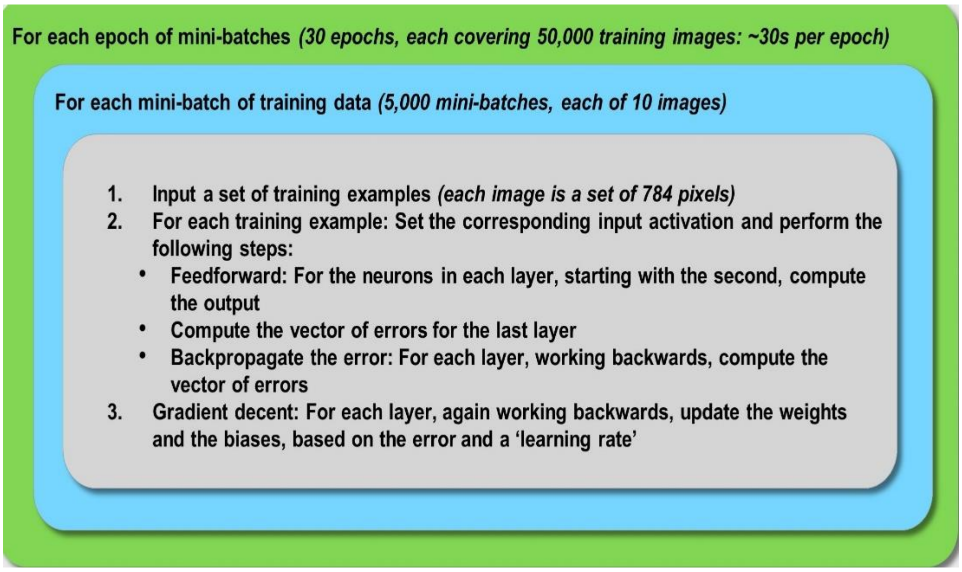


The number of images correctly classified is not however a smooth function of the weights and biases in the network, and we must introduce the cost function shown in the next picture on the left. Readers will recognise this as the least squares method for fitting a straight line between multiple points. The picture to the right below shows the classic minimization of the cost function by continuously descending the gradient.





Each pass through all training inputs moves the weights and biases a little in the correct direction. Instead of using all training inputs, we can use just a few in each pass as described in the picture below on the left.



Randomly select a small number of inputs for a gradient descent pass.

Randomly select another small set of inputs for the next pass.

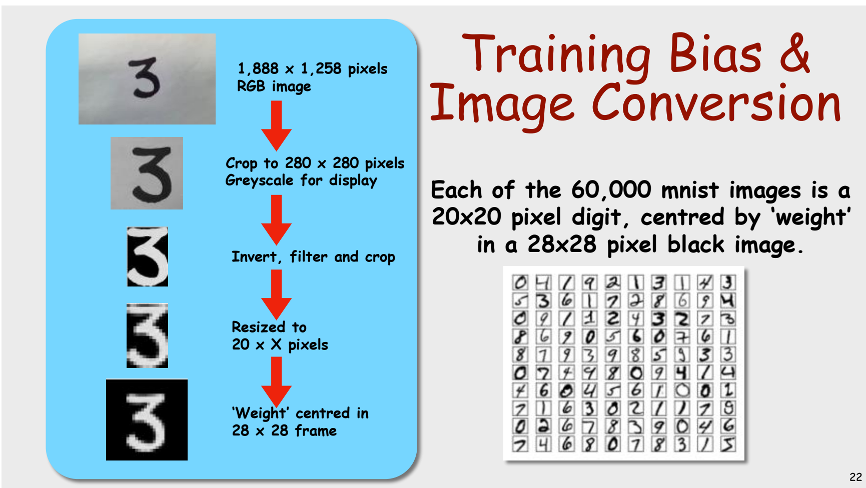
Continue until all training inputs have been used.

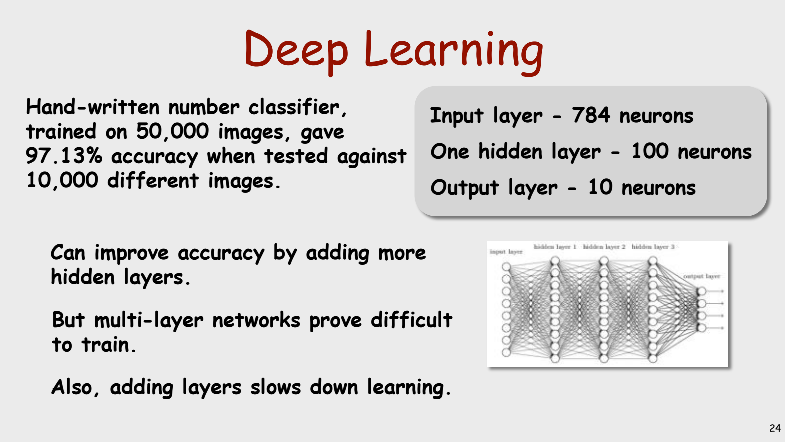
The complete set of passes is known as an epoch. The picture on the left shows the whole training programme.

The network developer has a wide choice of options to decide upon; the number of hidden neurons, the mini-batch size, the learning rate, the number of epochs and the selection of the type of cost function to use.

We have previously mentioned the subject of bias in the training process. Bias is an abnormality or anomaly in the results or output of the machine due to biased assumptions made during either development of the algorithms, or biased training data.

David illustrated how bias occurs in the training process of image recognition AI by showing the picture on the right. Mnist stands for Modified National Institute of Standards and Technology and is a large database of handwritten digits commonly used for training image processing systems.





Our speaker concluded his talk by speaking about deep learning systems as shown in the illustration on the left, using data from his own AI programme.

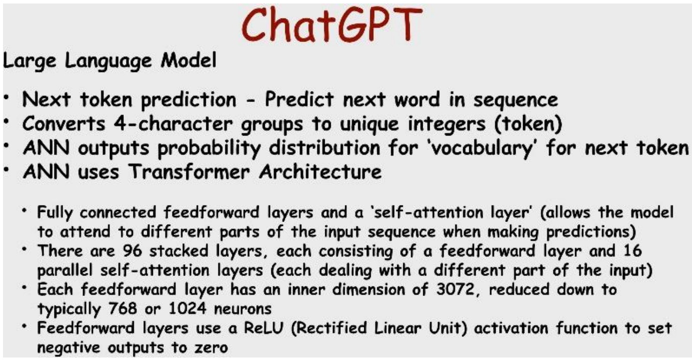
He then discussed other approaches to the construction of AI systems including convolutional networks, recurrent neural networks, dynamic degenerative neural networks and transfer learning.

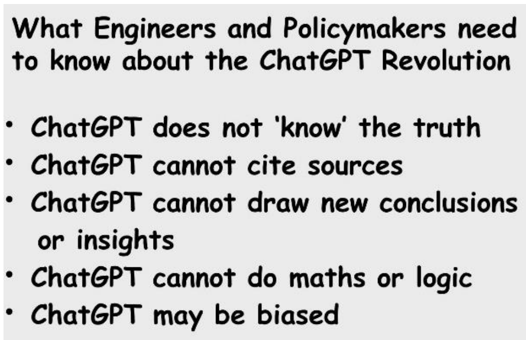
The interested reader is invited to seek further information on these alternatives from published data on the web.

Following a break for refreshments, members were invited to question David on this topic: -

Q1 What can you tell us about ChatGPT?

Our speaker had obviously assumed that this question would come up and had prepared the material shown below. (ANN stands for Artificial Neural Network).





Q2 Can AI play chess? Answer Yes.

Q3 Is AI used in driverless cars? Answer Yes

Q4 Has any work been done using analogue computer techniques in the development of AI? Answer I am unsure, but it would be an interesting topic to investigate.

Footnote. Following this talk the author has discovered that work is indeed ongoing into the use of analogue techniques in the development of AI.

By repeating arrays of programmable resistors in complex layers, researchers have been able to create a network of analogue artificial neurons and synapses that execute computations just like a digital neural network. This network can then be trained to achieve complex AI tasks like image recognition and natural language processing.

If any of our members are familiar with programmable resistors, we would welcome a talk or article on the subject.

We have been able to include only a selection of the detailed material presented in this talk, on what is obviously a somewhat complex subject, and would always encourage members to attend the talks whenever possible to hear the speaker and hopefully participate in the question-and-answer session afterwards.

Our thanks to David for giving us an insight into this fascinating and topical subject.

Malcolm Hind

Tuesday, 10th October 2023 – The History of High-Power Devices and Magnetrons
Prof. Mike Underhill

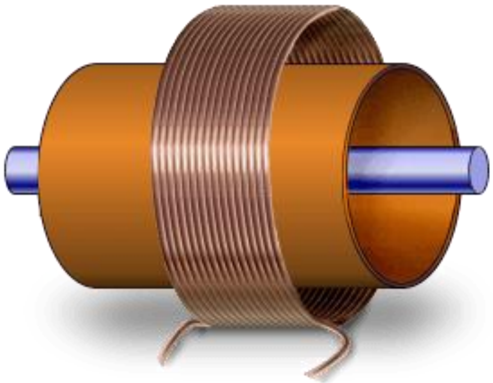
Mike, who is now retired from the University of Surrey, began by explaining that a Magnetron is a diode vacuum tube consisting of a cylindrical (straight wire) cathode and a coaxial anode, between which a dc (direct current) potential creates an electric field. A magnetic field is applied longitudinally by an external magnet. When connected to a resonant line, it can act as an oscillator.

Magnetrons can generate extremely high frequencies and short bursts of very high power and are an important source of power in radar systems (below left) and in microwave ovens (below right).

History of the Magnetron

In 1921 the Swiss physicist Heinrich Greinacher tried to use a diode tube with a cylindrically symmetric arrangement of the anode in an axis-parallel magnetic field to measure the ratio of the electron charge to its mass. The practical attempt failed due to poor vacuum in the tube and consequently insufficient electron emission from the cathode. Greinacher supplied a basic mathematical description of the changes in the electron motion under the influence of the magnetic field.

In the same year, Albert Hull at General Electric Company used the experimental arrangement shown on the right to investigate the motion of electrons under the influence of a homogeneous axial magnetic field. He noticed the possibility of controlling the electron current to the anode by variation of the magnetic field.

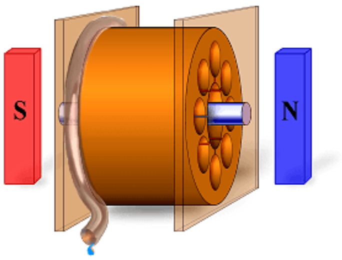


Hull was aiming to develop a magnetically controlled relay or amplifier in competition to the grid-controlled triodes of Western Electric Co., but also noted the possibility of RF generation. He called his novel device a Magnetron.

The magnetron for high frequency oscillations was independently investigated by Erich Habann in Jena (Germany) and Napsal August Zázek in Prague (Czechia) in 1924. Habann correctly predicted the conditions required for the appearance of a negative resistance which would overcome the usual damping caused by the resonant circuit losses.

In contrast to the Hull device, Habann employed a magnetic field which was constant in time as in today's magnetrons. Using his split-anode magnetron, Habann was able to generate oscillations in the 100 MHz range. Zázek developed a magnetron with a solid cylindrical anode and generated frequencies up to 1 GHz.

The breakthrough in the generation of cm-waves by magnetrons came in 1929 when Kinjiro Okabe operated his slotted-anode-magnetron at 5.35 GHz at Tohoku University in Sendai, Japan.



Hans Erich Hollmann filed a patent on the multi-cavity magnetron in Germany on November 27, 1935, and the corresponding US patent was granted on July 12, 1938, well ahead of John Randall's and Henry Boot's work as described below. Nevertheless, the multi-cavity magnetron built by John Randall and Henry Boot in 1940 proved to be a milestone in the sub-marine war against Germany by mid-1940.
They simply built a magnetron using more than the four cavities used by Hollmann to increase the effectiveness of RF-generation as illustrated on the left. Britain had succeeded in improving on the prototype of a water-cooled multi-cavity magnetron (one with 8 concentric resonant cavities), producing a relatively small, light-weight transmitter which could generate RF pulses at 3 GHz, with an output power of 15 KW. The B–17 airplanes were fitted with this radar.

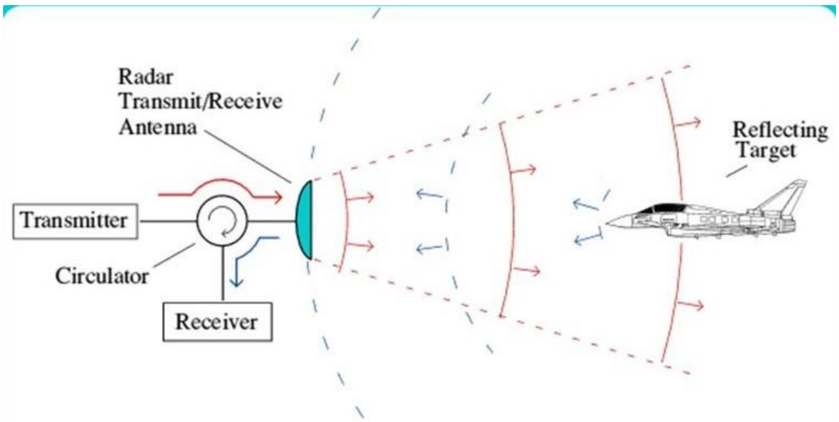
This small but powerful radar using a cavity magnetron gave operational improvements against the German submarines. Using a frequency of 3 GHz the antenna could be small but effective. Since antenna gain is inversely proportional to wavelength squared, an antenna of the same size could now be more powerful. This antenna achieved good accuracy in azimuth, elevation and bearing resolution.

The cavity magnetron which was developed by John Randall and Harry Boot in 1940 at the University of Birmingham is shown on the right. The university workshops could make up to twenty magnetrons a week. Over a thousand were made between 1941 and 1943. (Quoted in "The Birth of Radar" – Sir Robert Watson-Watt).

An attempt to mass-produce in Kettering was not successful – from Alan Parsons the son of the then chief engineer. UK machines were not good enough!

The research results of Henry Gutton on the use of barium oxide cathodes in a multi-cavity magnetron were brought to England by Maurice Ponte of the General Society for wireless telegraphy, shortly before the occupation of France. These results were integrated into the ongoing magnetron development of Randall and Boot. Barium oxide cathodes have a lower temperature compared to tungsten cathode with comparable electron emission and so resulted in a much longer life of the magnetrons.
Henry Tizard led a British delegation in September 1940 (during the Battle of Britain that brought all previously available UK research findings to the United States of America). There, the mass production of magnetron tubes for the war was initiated.

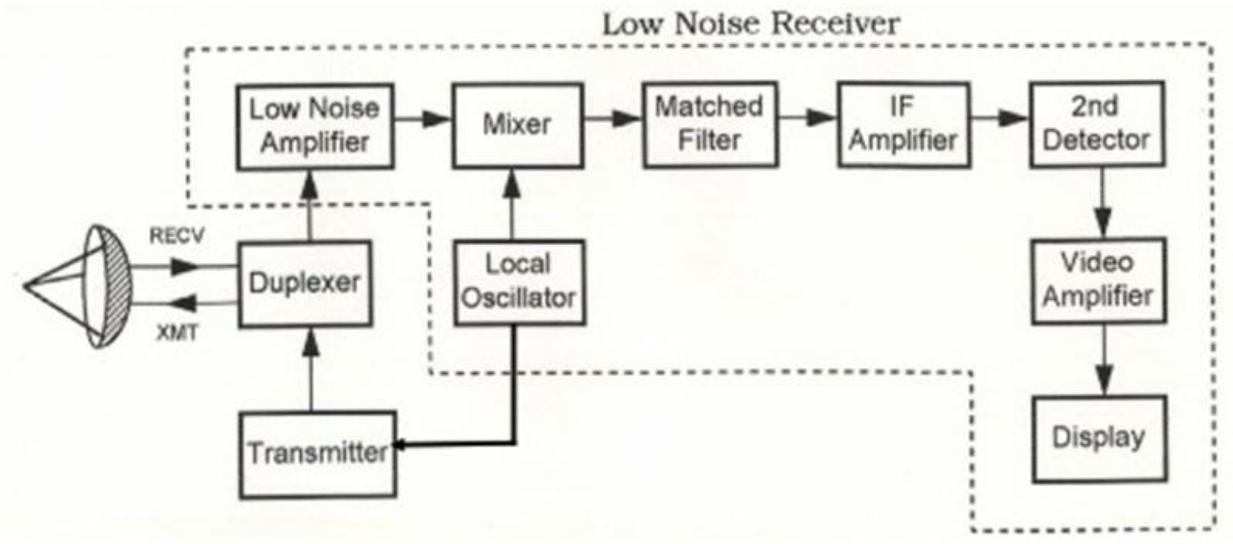
Radar



The first well known application of the Magnetron was in radar during the second world war.

A pulse radar (shown on the left) is a radar device that emits short and powerful pulses and in the silent period receives the echo signals. In contrast to continuous wave radar, the transmitter is turned off before the measurement is finished.

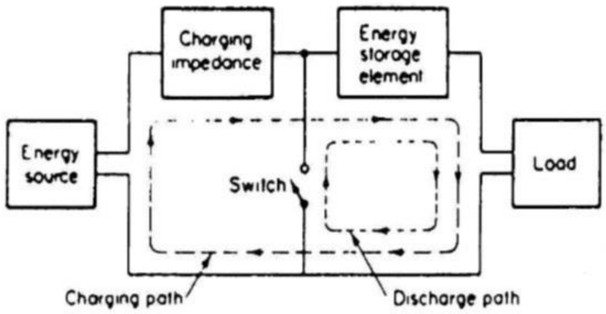
A block diagram of a radar is shown in the diagram below. The receiver is a superheterodyne receiver due to the use of the intermediate frequency (IF) amplifier. A coherent radar uses the same local oscillator reference for both transmit and receive.



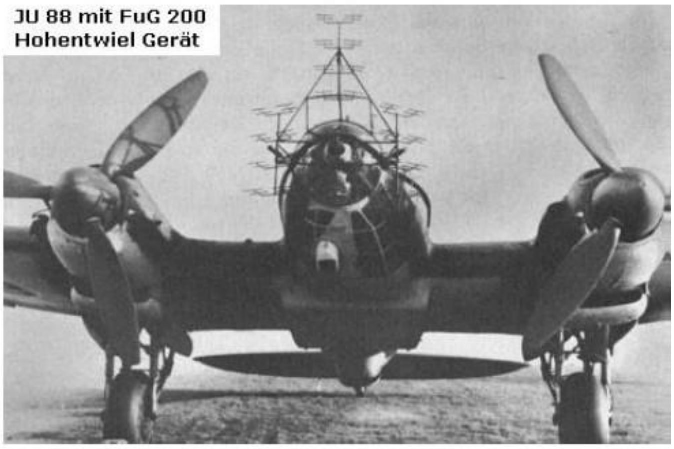
Some radar transmitter power amplifier/oscillators such as the magnetron require the full input power to be pulsed. High power pulse modulators have a pulse forming network as illustrated in the diagram on the right, which is a lumped circuit equivalent of a section of transmission line. The "delay line" is first charged slowly to a high voltage and then shorted across the load, which is the tube being pulsed.

The voltage across the load stays essentially constant until twice the delay time has passed. It then becomes essentially zero. A step-up pulse transmitter can be used to obtain a much higher voltage on the transmitter tube.

Originally gas-filled Thyratron triode tubes were used to switch the pulsed power on and off, but nowadays thyristors and triacs are used.



The Thyratron (and its modern replacements) were a fundamental component in any radar system, and in the picture below we see an image of a German thyratron (see left) as used in the radar system on the Junkers 88 aircraft (see right) equipped with its rather cumbersome radar antenna.

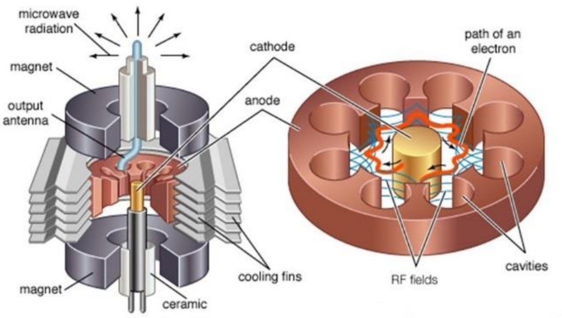


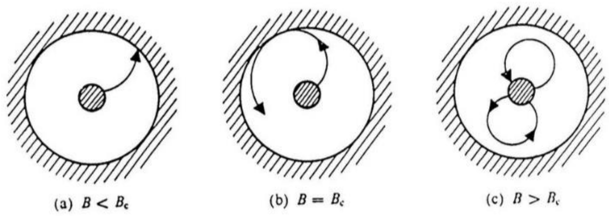
In 1942 German radar devices used relatively low power klystrons because they had a significantly better frequency stability than magnetrons.

Only at the end of the World War II was it realised by analysis of captured devices that high power magnetrons were capable of greater microwave range than the German klystrons. Fortunately, it was already too late for the Germans to learn from these findings.

The Magnetron in detail

The illustration below on the left shows the internals of the Magnetron in greater detail. The strength of the magnetic field has a major impact upon the electron's path and hence the ability of the Magnetron to generate microwaves efficiently as shown in the diagram below right.





(a) is for too little magnetic field, (b) gives the cut-off condition ($B=B_c$), (c) corresponds to $B > B_c$.

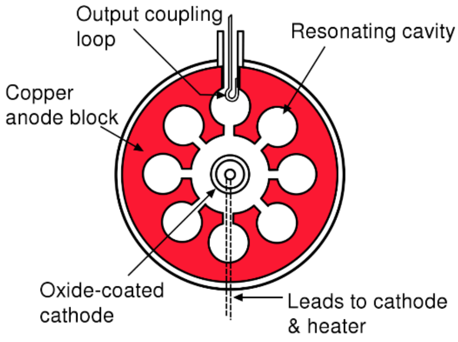
These figures show electron paths for different values of magnetic field strength

The shape and design of the cavity is a critical feature in the Magnetron's performance, as it is here where resonance takes place. During his talk Mike gave us an excellent demonstration of resonance by blowing across the open top of a glass bottle as shown on the left, producing the characteristic sound of wind.

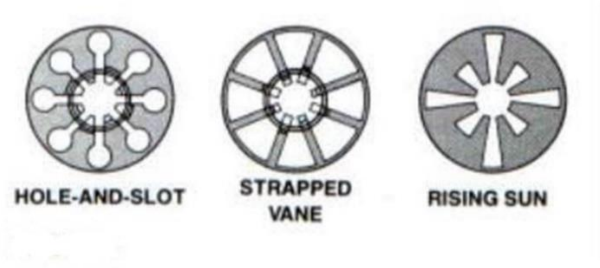
The two diagrams at the top of the next page show a multi-cavity Magnetron on the left and alternative cavity designs on the right.

Frequency stability, as referred to earlier, has always been a particular issue with Magnetrons, and the diagrams at the top of the next page show several designs of cavity.

The use of strapped vanes, where every other cavity is strapped together, in the centre of the right diagram on the next page was thought to be a key method to improve frequency stability, which the Germans apparently never fully understood when they were able to capture a Magnetron during the war.



Resonant cavity magnetron high-power high-frequency oscillator

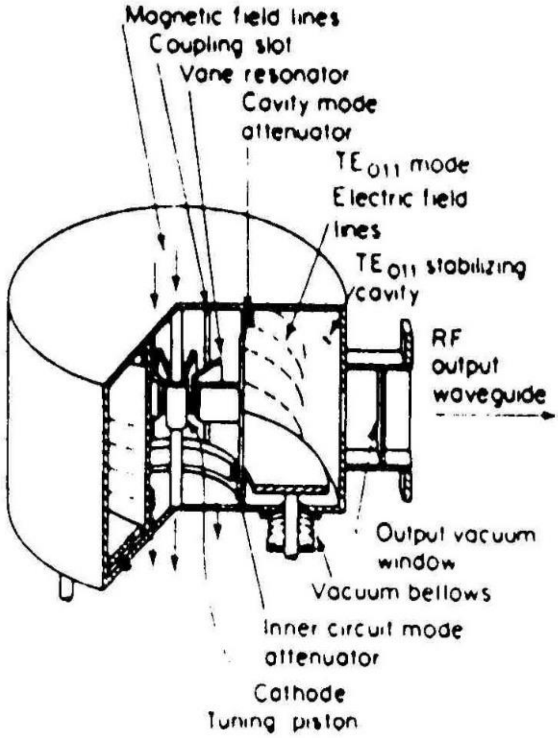


There has been some development into ‘tuneable’ Magnetrons as shown in the schematic view of a coaxial magnetron on the right.

The tuning piston is mechanically actuated by a vacuum bellows.

The electrons take epicycloidal spiral paths around the cathode. The magnetic field and anode voltage must be in the correct relationship for the magnetron to amplify or oscillate and operate at high efficiency.

The power efficiency of a magnetron may be as high as 50 to 60%. Pulse powers range from kilowatts to a megawatt or so.



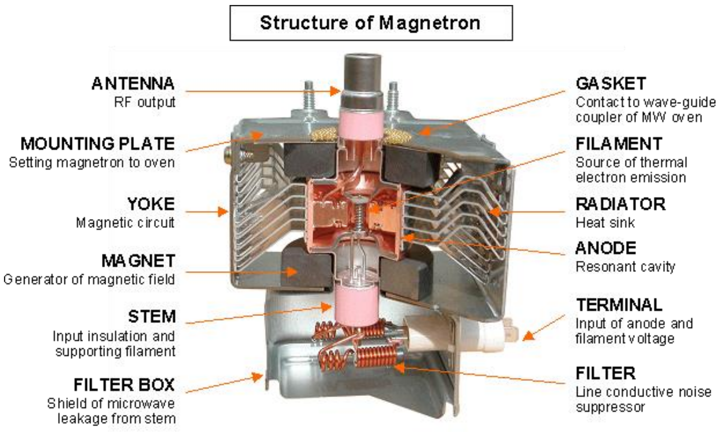
Microwave Ovens

In 1945 the specific heating effect of a high-power microwave beam was accidentally discovered by Percy Spencer, an American self-taught engineer from Howland, Maine. Employed by Raytheon at the time he noticed that microwaves from an active radar set he was working on started to melt a candy bar (chocolate with peanuts) he had in his pocket.

The first food deliberately cooked with Spencer's microwave was popcorn, and the second was an egg, which exploded in the face of one of the experimenters. To verify his finding, Spencer created a high density electromagnetic field by feeding microwave power from a magnetron into a metal box from which it had no way to escape. When food was placed in the box with the microwave energy, the temperature of the food rose rapidly.

On 8 October 1945, Raytheon filed a United States patent application for Spencer's microwave cooking process, and an oven that heated food using microwave energy from a magnetron was soon placed in a Boston restaurant for testing.
The first time the public was able to use a microwave oven was in January 1947, when the Speedy Weeny vending machine was placed in Grand Central Terminal to dispense "sizzling delicious" hot dogs.
Among those on the development team was robotics pioneer George Devol, who had spent the last part of the war developing radar countermeasures.

The pictures below show the internal structure of a modern Magnetron as used in microwave ovens on the left, and the outward appearance of a typical magnetron on the right.



The microwaves generated by the Magnetron are channelled into the food compartment through wave guides which can result in non-uniform heating of the food unless some form of 'stirrer' is used, most commonly as a turntable upon which the food rotates. There are however now coming onto the market microwave ovens not requiring any form of 'stirrer'.

Mike also showed a substantial amount of material relating to Klystrons, Travelling Wave Tubes, Cross-Field amplifiers, LDMOS and Gallium Nitride devices. In this short report, we have limited the article to the Magnetron itself, again emphasising the benefit of attending our talks in person whenever possible.

Our thanks to Mike for both an interesting and wide-ranging talk on this topic.

Malcolm Hind

Tuesday, 14th November 2023 – Hydrogen in the modern steel industry

Dr. Tim Smith, Consulting Editor Steel Times International

Members will recall that Tim spoke to us previously back in February 2020 about Wealden Iron, covering early iron production in Sussex.

Since then, he has been over to Sweden to look into the future potential role of hydrogen in the manufacture of steel, as one of the measures to reduce CO_2 emissions in the steel making process.

He started his talk by setting the scene of global steel production before looking specifically at hydrogen, its production and storage, its potential role within the steel industry, and some of the problems.

Setting the Scene

In 2020 global steel production was responsible for 2.6 billion tonnes of CO_2 equating to 7-9% of global CO_2 emissions for which human activity were responsible. Within the industrial sector, steel's share is 25%. Steel production in the UK has been declining for many years, and now accounts for only 2.7% of UK emissions, compared to domestic heating which accounts for 17%.

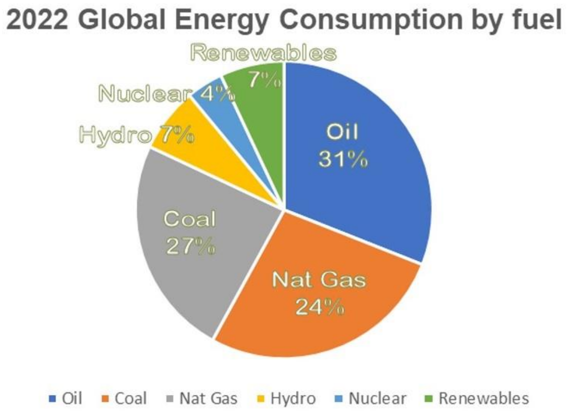
Largely driven by cost considerations, since 1970 the steel industry has reduced energy use by 60%. In 2021 the average CO_2 emissions from an integrated steelmaker per tonne crude steel was 2.32tCO_2/t. This compares very favourably with the production of primary aluminium which emits 10tCO_2/t, 5.3 times more than integrated steelmaking.

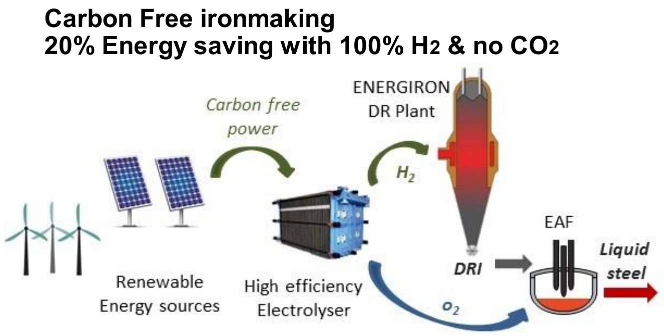
Emissions can be further reduced by using more recycled scrap, and an electric arc furnace (EAF). Using 100% scrap emits only 670 kgCO_2/t, a 70% reduction compared to using iron ore. Furthermore, the use of scrap reduces the consumption of both coal and limestone within the production cycle.

The world is still heavily dependent upon fossil fuels as the chart on the right shows, so that every opportunity to increase energy efficiency and reduce emissions is always worth investigating.

It was for this reason that Tim was particularly interested in the work currently underway in Sweden to research the use of hydrogen in the production of steel.

Overall, the production of steel is a relatively efficient process compared to many other materials, and close to 100% of the by-products can be used – e.g. slag is commonly used in road construction projects.





The diagram on the left shows the ultimate goal of the ENERGIRON project, an innovative Direct Reduction (DR) technology jointly developed by two Italian companies, Tenova and Danieli.

The project is reliant upon the production of large quantities of hydrogen, which Tim then went on to discuss in more detail.

Hydrogen (H_2)

Currently 75Mt of H_2 is produced globally with 48% being manufactured from natural gas, 30% from oil, 18% from coal and only 4% by other means of which only 0.1% by electrolysis.

The 'colour' of H_2
White – Naturally occurring.
Green – Electrolysis using renewable power.
Blue – steam reformation of natural gas with CO_2 capture.
Turquoise – steam reduction of natural gas with carbon produced as a solid.
Grey - steam reformation of fossil fuels without carbon capture.
Red, Pink, Violet – Electrolysis by nuclear power.
Yellow – As a byproduct of other processes

There are currently a number of methods for producing hydrogen as the list below illustrates.

Each method of H_2 production is now given a 'characteristic' colour rating as shown on the left.

- Cracking coke oven gas (Contains 50% H_2 + hydrocarbons) or NG
- Electrolysis of aqueous electrolytes using renewable electricity sources
- High Temperature electrolysis using steam, consuming 3.6kW/Nm3 H_2 (currently small scale)
- Atmospheric Alkaline Electrolysers (AAE) – Currently available producing 4000Nm3/h consuming 4.8 to 3.8kW/Nm3 of H_2 produced
- Proton Exchange Membranes (PEM) – currently available producing 4000Nm3/h of H_2 consuming 4.4kW/Nm3

Producing large quantities of H_2 as would be required for the steel industry presents a significant number of problems:-

To produce 75Mt of H_2 by electrolysis would require 3,600TWh, which equates to 25% of world generation and more than the total generation capacity of the EU.

To produce 1kg of H_2 requires 9 litres of water, putting stress on water supply.

For the same energy content as natural gas, 3 x Vol of H_2 is needed so additional storage capacity is required.

Burning H_2 in the air can produce NOx – a potent greenhouse gas.

The small molecular size of H_2 means that it is difficult to store (tends to leak out) and can embrittle many types of steel. This presents several challenges to the shipping of H_2 which Tim illustrated in the slides below.

Hydrogen is likely to be made where there are ample supplies of oil or natural gas ie Middle East & N Africa

If made without carbon capture & storage this will be 'grey' not 'blue' H_2

To ship, convert to ammonia NH_3 as can be liquefied at -33 deg C at 1atm or 20 deg C at 7.5 bar

To liquify H_2 requires cooling to -253 deg C at 1atm & needs cryogenic steel

Storing as gas is at 350-700 bar

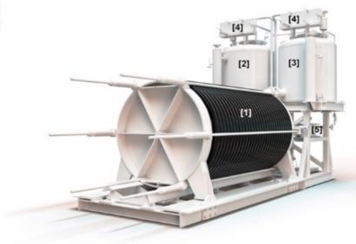
When H_2 is produced by electrolysis, oxygen O_2 is also produced at the same time, which is a valuable byproduct of the process, as illustrated in the two slides below.

Atmospheric Alkaline Electrolyser

Each electrolyser consists of a series of stacks making up the anode, the cathode and a membrane through which water circulates

KEY

1 Electrolyser stack
2 H2 separator tank
3 O2 Separator Tank
4 Gas Cooler
5 Lye Cooler (potassium hydroxide)



Input & Output of electrolyser

Input for 8 electrolysers

- Water – potable grade to which 25% lye (potassium hydroxide) added and recycled
- 9 litres water for each 1kg H_2
- Power – 4.4kWh/Nm3 H_2
- Equates to 17MW/h
- Max power available from grid supply 20MW/h

Output of 8 electrolysers

- H_2 8 tonnes per 24 hour
- H_2 3880Nm3/h
- O_2 1940Nm3/h ie half vol H_2
- O_2 32 tonnes per 24 hours
- Gases are pressurized at 5 bar H_2 & 15 bar O_2

Direct Reduced Iron (DRI)

Iron has traditionally been manufactured from iron ore by charging it with coke and crushed limestone in a blast furnace. The coke and limestone provide both the intense heat and chemical reduction necessary to produce molten iron.

Direct reduction is a less common, alternative process that produces iron from ores without the need for coke using either coal or natural gas for fuel. The product of direct reduction is called sponge iron because the metal is not melted but is produced as a porous solid. It is this process which lends itself to the use of H_2 within the steel making process.

The process of direct reduction is illustrated in the slide on the next page on the left, and the corresponding chemistry on the right.

The key-Direct Reduced Iron

- Produced as solid 'sponge' iron
- 125Mt produced in 2022 = 8.7% of world total iron (pig + DRI)
- Presently produced by H_2 + CO reduction in a vertical tower
- H_2 + CO from reformed natural gas - 25Mt (20%) produced from coal in rotating kilns
- Hot charge to EAF or passivated by CO for transporting cold, or hot briquetted (HBI) to avoid spontaneous combustion
- CO_2 emis. 1.5t/t DRI = 32% < BF
- 100Nm3/h H_2 for each kt/y DRI

Chemistry of Direct Reduction

Reduction with Syngas CO + H_2

- $3Fe_2O_3 + CO + H_2 \rightarrow 2Fe_3O_4 + CO_2 + H_2O$
- $Fe_3O_4 + CO + H_2 \rightarrow 3FeO + CO_2 + H_2O$
- $FeO + CO + H_2 \rightarrow Fe + CO_2 + H_2O$
- Reduction by CO is exothermic

Reduction with Hydrogen

- $3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O$
- $Fe_3O_4 + H_2 \rightarrow 3FeO + H_2O$
- $FeO + H_2 \rightarrow Fe + H_2O$
- Reduction by H_2 is endothermic
- Ammonia (NH_3) can be used as source of H_2 by autocatalytic cracking by ore to H_2 + N_2
- N_2 carries heat and also passivates the DRI

Tim emphasised that using only H_2 requires additional heat input as the process is endothermic.

Sweden

Tim recently visited Sweden to investigate Swedish Steel's green technology.

A partnership has been formed between an ore producer, LKAB, and energy supplier Vattenfall. The process uses the established technology of a shaft furnace to produce solid iron by direct reduction (DRI).

SSAB Swedish Steels Ltd intend to replace their blast furnace at Oxelösund with an electric arc furnace charged with HYBRIT (Hydrogen Breakthrough Ironmaking Technology) DRI by 2025.

To meet the demands of reducing iron ore in this way will require storage of H_2, which reduces the cost of H_2 production by 25-40% by using off peak electricity. SSAB have successfully conducted trials of underground storage of hydrogen in a rock formation.

It is anticipated that HYBRIT will reduce Sweden's CO_2 emissions by 10% and Finland's by 7%. The picture below gives further information about the project.

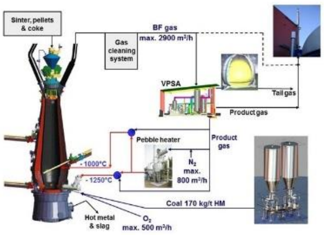
H2 Green Steel - Sweden

- ***H2 Green Steel*** plans to produced steel from steel scrap and DRI charged hot into the EAF with any surplus hotbriquetted (HBI) for storage
- Renewable energy and green hydrogen will be used for all processes
- HBI is produced by agglomerating pellets of Direct Reduced Iron (DRI) to reduce the reactivity of the iron pellets with air.
- The DRI is produced in a shaft furnace as a solid spongy iron with the same shape as the original ore pellets.
- Plant size 5Mt/y by 2030
- Melting scrap and DRI will take place in an electric arc furnace powered by renewable and nuclear produced electricity.
- The plant now under construction is located at Boden in Northern Sweden close to an ore source and renewable energy.
- A reduction in CO_2 emissions up to 95% compared with the blast furnace– basic oxygen steelmaking route
- Steel will be continuously cast as thin slab directly linked to a rolling mill
- Linking the caster with the mill will save 70% of the energy compared with reheating cold cast slab

Tim then discussed alternatives to DRI, including the hybrid process illustrated in the two slides below.

Hybrid Processes

- **Reduce CO_2 from the blast furnace**
- By charging scrap to the BF
- By charging DRI to the BF
- By adding H_2 to the air blast (up to 10%)
- By using bio 'coke'
- By recycling the top gas and capturing the CO_2 (VPSA = Vacuum Pressure Swing Adsorption a molecular 'sieve' to capture CO_2)



Hybrid Processes

- Increase scrap use in the Basic Oxygen Furnace (BOF)
- Normal charge molten blast furnace metal plus 15-25% scrap as coolant
- Can replace molten metal with DRI and scrap to maintain quality of steel and melt with oxy-H_2 burner

Conclusions

Steel is essential for renewable energy eg wind turbines require 320t/MW for direct drive or 110t/MW for gearbox turbines.

Nuclear power stations require 90t/MW. To transition to zero carbon by 2050 will require ~5bnt of steel.

The present annual demand for transition is 170Mt ~10% world production.

Tim presented the following two slides outlining his conclusions from this research work.

My Conclusions

- Blast furnaces will remain the primary source to meet demand. 22 BF presently under construction mainly in Asia
- CO_2 footprint of BF will be reduced eg with 10% H_2 injection, top gas recycling & charging scrap and DRI
- DRI from H_2 will grow but will be unable to meet demand due to lack of H_2 from renewable sources
- Ammonia will increasingly be recognized as an alternative to hydrogen
- Electric arc steelmaking will grow from the present global 28%share but quality of steel maysuffer and renewable electricity will be required
- Penalties for producing steel without CO_2 mitigation will be a driving force towards greener steel
- In October the EU introduced the Carbon Boarder Adjustment Mechanism (CBAM) which levies a tax on 'grey' steel traded across EU boarders or imported to EU
- This has a transition period of two years to 2026 before full implementation

Our thanks to Tim for an interesting talk on this topic.

Malcolm Hind

End of Newsletter