The second day continued with a focus on the application of microwaves in sustainable material processing. Research was presented on the potential of microwaves to create new materials with reduced environmental impacts, offering significant benefits to the manufacturing sector. The discussions highlighted the ability of microwave technologies to lower carbon footprints and improve material properties, indicating a strong potential for future developments in sustainable manufacturing.

Throughout the meeting, discussions were notably vibrant and collaborative, reflecting the critical importance of shared perspectives in addressing the opportunities and challenges presented by microwave science.

An associated special issue of the Philosophical Transactions of the Royal Society, the world's oldest scientific journal, will be published later in the year to mark the event. For further details and to watch the recorded presentations visit: https://royalsociety.org/science-events-and-lectures/2024/05/microwave-science/.

Ricky's Afterthought:

Fusion, electricity use and electricity utilisation

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Latest reports suggest that large fusion reactors using the Tokamak principle (**Figure 1**) will not be operational for decades.

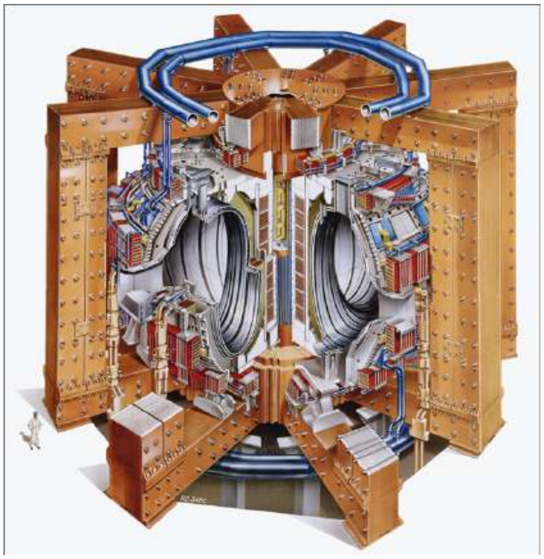

Fig. 1: Schematic representation of a fusion reactor using the Tokamak principle.

The joke has it that fusion reactors are always 20 to 30 years ahead and this has been suggested ever since the first experiments carried out in the UK in the late 1950's (see Afterthought July 2022, Issue 111).

As a reminder, Europe including Switzerland and the UK, in collaboration with five other countries, has decided to invest heavily in the tokamak fusion reactor which culminated in the so called ITER (International Experimental Thermonuclear Reactor) Fusion reactor currently being constructed at Saint Paul les Durance in Southern France. Although the prospect for fusion reactors to come on stream within the next decade is very remote there are, however, spin offs from current R&D on such large Fusion reactors that will assist certain areas. Possible examples are the following:

Propulsion

To confine the plasma away from the walls for several seconds in a Tokamak fusion reactor in order to fuse the particles requires very powerful magnets. Magnetohydrodynamics (MHD) drives used in propulsion could make use of the developments in very powerful superconducting magnets used in the Tokamak to confine the plasma. Over 30 years ago, Mitsubishi did produce an MHD ship but the top speed was only 15 km/h so the project was abandoned. The new superconducting magnets used in the Tokamak may revive schemes based on MHD for propulsion.

Nuclear waste

Neutrons can be used as x-rays for imaging but are more penetrating, that is they can examine substances much deeper than current systems. This means that the contents of spent fuel stored in barrels from fission reactors could be examined using fast neutron beams used in fusion reactors.

Destroying cancer cells

Using boron with protons for fusion pointed to an old technique for fighting cancer. Boron bombarded with fast neutron beams produce lithium and helium which releases large amounts of energy over the range of 5-9 micrometres which is the size of a typical cancer cell. TAE Technologies' fusion programme produced focused neutron beams using small particle accelerators. These beams are used to fuel the fusion reactors.

What is becoming more and more certain is that, as time progresses, there will be less use of oil and gas as these are becoming scarcer and we will be relying more and more on the use of electricity. So there are two main paths for achieving fusion, either through the giant Tokamak reactors or other large schemes or a much smaller and less elaborate design.

Alternative fusion design

Worldwide there is a host of smaller enterprises that are experimenting with small fusion reactors with outputs of the order of 100MW and are turning away from the vast national and international schemes such as ITER.

Research on such smaller fusion reactors goes apace with huge amounts of funding having been secured on a number of projects worldwide. One such project is a spin off from Oxford University, First Light Fusion (See Afterthought July 2022, Issue 111), which recently confirmed that they have achieved fusion which the UK's Atomic Energy Authority (UKAEA) has independently validated. This entails bombarding suitably designed targets with projectiles travelling at 6.5 km/s, imploding the target fuel at 70 km/s thus compressing it to 10 Terapascals (incidentally this is 100 times greater than atmospheric pressure!). The fuel, when it fuses, it is compressed to 100µm. In a power plant the process should be repeated every 30s and each target would power an average house for 2 years.

Will they succeed? First Light Fusion claims that their results are supported by computer modelling. They claim that: *"such capability sheds light, in exquisite detail into the processes that generate these neutrons. Such tools are in daily use by their scientists, helping design unique targets, launchers and amplifiers, navigating the challenging path towards gain and a first-of-a-kind reactor."* There is still a considerable amount of R&D to be done to achieve a small fusion plant capable of delivering power in a sustainable way.

Electricity use

Whether it is large Tokamak's, or smaller inertial designs or indeed, in the meantime, fission reactors or renewables, one thing for certain is that electro-production will once again come to the fore for a number of industrial processes or even for heating our homes using electrically driven heat pumps.

I once again show here the number of processes that could be powered by electricity from DC to higher frequencies (**Figure 2**). Lasers are also part of this family as some are powered by a combination of DC and RF energy. Classic processes entail ohmic heating for the treatment of foodstuffs, induction heating for heating billets and melting metals in a coreless furnace to RF drying of textile packages and microwave curing of rubber products. The biggest consumer of electricity is of course the electric arc furnace for melting scarp metals. Infrared energies are used extensively in car production for curing/drying of the epoxy resins on body surfaces. Such schemes overcome bottlenecks caused by less efficient systems. Most of these processes will be discussed at the forthcoming UIE conference to be held in Nice early in October including electroheating technologies and sustainability, computational electromagnetics, benchmarks for model validation, process design and optimization, machine-learning, AI & EPM, digital twins, predictive maintenance, power quality, security issues, and electromagnetic wave exposition and health issues.

Re-evaluation of the costs

Processes that in the past were technically feasible using electricity but were deemed too expensive compared with the use of fossil fuels should now be revisited and re-examined to see whether the energy balance shifts towards using electricity.

I always argued that careful design of a large process for drying textiles or paper which uses both conventional energy and electricity will produce optimum results and this may still be the case but the mix shifts to using more and more electricity. Processes that use gas priced at several p/kWhr were deemed not suitable candidates for electricity but in a decade or two when the price of gas, assuming it is still available for industrial use, may shoot up by an order of magnitude, then the energy balance changes dramatically.

Younger colleagues who enter our field at the present stage and face some 40-50 years of active working career, I ask them over the span of a few years to reflect on a number of scenarios when electricity will offer a viable, and in some cases, the only alternative to conventional energy.

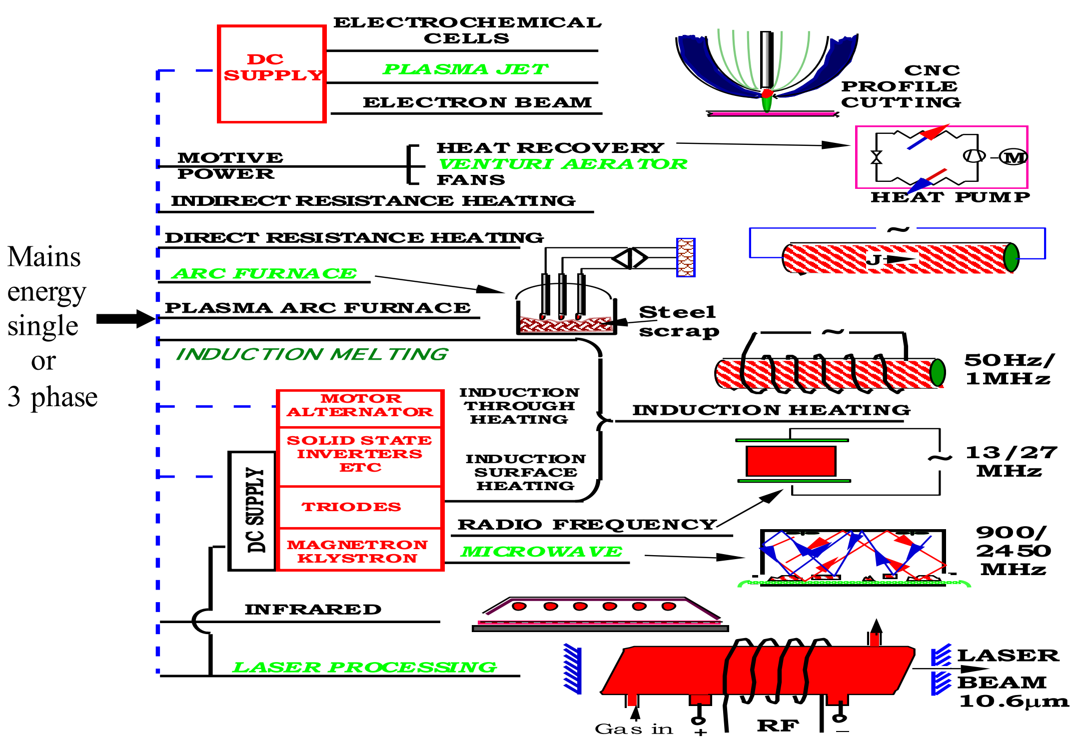

Fig. 2: Electricity utilisation from DC to very high frequencies.