AMPERE Newsletter

Trends in RF and Microwave Heating

http://www.ampere-newsletter.org

Issue 120 **October 11, 2024**

In this Issue:

ISSN 1361-8598

Assessment of the electromagnetic field around electrical installations

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In response to Ricky's Afterthought in the latest issue of the AMPERE Newsletter [1], I am happy to confirm that Laborelec has over 25 years of experience in the assessment of the electromagnetic field (at all non-ionizing frequencies) around electrical installations.

The assessment with a view of the safety of persons or from the perspective of interaction with telecommunication is made by measuring or calculating the electromagnetic field (EMF) and comparing the results with the relevant limits as specified in the prevailing legislation.

Measurements and numerical studies with recommendations are carried out in a broad frequency domain ranging from static fields (0 Hz) to several tens of GHz.

The first thing to do on the site under investigation is identifying all possible sources of an EMF. This will include obvious sources such as high-voltage stations (50 Hz) and dielectric heating installations (MHz range), but also sources of a static magnetic field such as excitation of alternators, electrolysis installations or permanent magnets on conveyer belts.

Care must be taken to measure the EMF in all relevant operating conditions. In particular for dielectric heating installations, the leakage field is not only dependent on the applied power, but also on the dielectric characteristics and geometry of the charge.

Different legislation for workers and general public

In all countries to my knowledge, the legislation is different for workers and the general public. In particular the legislation for the general public stipulates in several countries more strict limits than those proposed by the ICNIRP (International Commission for Non-Ionizing Radiation Protection).

Therefore, in industrial practice, reference should be made to the legislation rather than to the ICNIRP limits. The latter are interesting to get some understanding of the underlying reasoning that constitutes the basis for the legislation. The assessment of EMF in locations accessible to the general public is triggered by a-posteriori complaints or by the a-priori procedure to get an installation permit for electrical equipment.

By now, all EU member states have transposed the European Directive on "*the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (EMFs)*" [2] into national legislation. This creates a legal obligation for employers to assess the possible risk of exposure of employees to EMFs. The level of exposure found in all relevant areas of the site must be properly documented and filed.

Measurement equipment

The measuring equipment to be used is dependent on the frequency spectrum in which the EMF is measured. **Figure 1** gives the equipment used for measurement of the electric and magnetic field at power frequency (50 Hz). For dielectric heating installations, the leakage field is measured by equipment that allows a measurement of the fundamental frequency as well as of some neighboring harmonic frequencies (**Figure 2**).

Fig. 1: Measurement equipment at power frequency (50 Hz).

Fig. 2: Measurement of EMF at dielectric heating frequencies.

Numerical modelling for assessment in design stage

In addition to the measurement service, Laborelec offers EMF related assistance in the design stage of new equipment and installations.

Using state-of-the-art numerical software, a model of the equipment is built and the EMF in every point of the three-dimensional surrounding area is calculated (**Figure 3**).

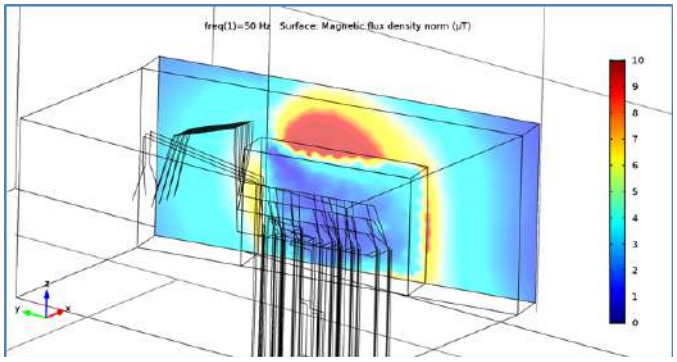

Fig. 3: Numerical model of the magnetic field around an electrical installation.

Based on this, recommendations to optimize the design can be formulated. A sensitivity analysis on the input parameters of the numerical model gives indications for material, geometrical dimensions, and position of the shielding to put in place.

Compliance with telecommunication limits

Industry needs also to check the compliance with the limits established by telecommunication authorities.

These limits are much more strict, and appropriate measurements antennas are needed. **Figure 4** and **Figure 5** give an example for the measurement at the outside of a factory where a dielectric dryer is used.

Fig. 4: Loop-antenna for the measurement at 27.12 MHz.

Fig. 5: Biconic antenna for measurement of harmonics between 50 MHz and 300 MHz.

Conclusion and outlook

An assessment of the EMF around electrical installations from the perspective of the safety of workers and the general public is in most countries a legal obligation.

Because the limits vary according to the frequency of the EMF, a broad range of measurement equipment is needed. In particular the assessment of possible interaction with telecommunication necessitates appropriate measurement antennas.

If the AMPERE Scientific Committee deems it useful, at the next AMPERE conference more ample information can be given concerning the underlying scientific reasoning used by ICNIRP that explains the difference in limits for workers and the general public. At the same occasion the variety in scientific models that are at the base of the huge spread in limits, as applied by different countries, can be discussed.

For further reading

1. AMPERE Newsletter, Issue 119, 8 July 2024, pp.7-8.
2. Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC.

About the author

Koen Van Reusel received the degree of Master of Electrical Engineering from the KU Leuven (Belgium) in 1985, and the degree of Doctor of Engineering from the KU Leuven in 2010. Since 1992 he is at LABORELEC (Belgium), a technical competence center in energy processes and energy use. As senior expert he is member of the Power Networks Department. His current focus is on electrification of industrial thermal processes, lightning protection in wind turbines, and measuring the effects of electromagnetic fields from a human health perspective. He is visiting professor at the KU Leuven, where he teaches "Electromagnetic Processing of Materials" and "Power Quality". Koen Van Reusel is Member of the Management Committee of AMPERE; General Secretary to UIE, the International Union for Electricity applications; Member of the Board of Directors of FISUEL, the International Federation for the Safety of the Electricity Users; and Member of the International Electrotechnical Committee n° 27 "Industrial Electroheating and Electromagnetic Processing of Materials".

Next generation of Püschner industrial microwave applications

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At the beginning of 2023 the Püschner Microwave business has been transferred to the 3rd generation.

Founded in 1970 by former Phillipps microwave engineer Herbert-Alexander Püschner, the business was handed over to his son Peter-Alexander in 1996 and has constantly developed into various fields of industrial microwave applications ever since. With installations around the world Püschner has innovated multiple industrial heating and drying processes for its customers. Its engineering DNA has led Püschner to multiple application product lines with the latest development being microwave assisted vacuum freeze dryers in an industrial scale specifically for biotec and active pharmaceutical ingredients.

Peter´s oldest daughter Pia and her husband Jörn (**Figure 1**), the new owners of Püschner, are deeply thankful for this opportunity to benefit from

such a vast stock of application experience and fully equipped microwave application lab. Especially as with microwaves, any new application still starts in the lab and needs to be consequently developed into production scale.

We can feel that the technology is in motion with solid state generators creating new industrial opportunities in the 2450 as well as in the 915 MHz field. Also, we are experiencing that carbon foot-print reduction is an important aim for our customers and that microwaves have now the opportunity to move into even larger scale operations which were traditionally dominated by gas and fuel powered systems in the past.

We are very much looking forward to the next few years in this exciting area of electrical heating and drying and especially to the exchange of ideas and opportunities with the entire AMPERE community.

Fig. 1: From left to right, Pia Püschner, Jörn Lidde and Peter Püschner.

Report on 5 GCMEA

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A rumble of drums opened the 5th Edition of the Global Congress on Microwave Energy Applications, 5-GCMEA at the Shiiki Hall of Kyushu University, in Fukuoka, Japan (https://www.5gcmea2024.jp/). In fact, the conference had already started in the morning with workshops on specific topics, consisting of 30-minute oral presentations by a good number of the international experts. However, the participation of the attendees in the new type of "vibrating" message of the drums fully engaged them and highlighted how the tradition of Japanese culture began to accompany the entire conference (**Figure 1**).

Fig. 1: Conference participants performing with drummers at the opening ceremony (more photos at https://www.5gcmea2024.jp/gallery.html).

The 5 keynote lectures, 7 invited lectures, 2 JEMEA Award presentations interspersed the 4 parallel sessions organised during the 3 days of the technical programme for the 292 participants.

Twenty-nine posters (**Figure 2**) and 106 oral presentations reported the most advanced developments in the fields of MW and RF applications, devices, measurements & modelling, and scale-up for microwave industrial applications (more details on the programme can be found at: https://www.5gcmea2024.jp/program.html).

The conference attracted 10 Gold sponsors (Panasonic Corporation Living Appliances and Solutions Company, Mini-Circuits /M-RF CO., LTD, Mitsubishi Electric Corporation, JSPS R024 Electromagnetic Wave Excited Rection Field Committee, ANRITSU METER CO. LTD., Tokyo Instruments, Inc., S-TEAM Lab, Shenzhen Megmeet Electrical Co., Ltd, Dotwil, Kyushu University), 8 Silver sponsors (MUEGGE GmbH, Motoyama Co. Ltd., Keisoku Engineering System Co. Ltd., Shikoku Instrumentation, CO. LTD., AnHui MingBian Electronic Science &Technology Co. Ltd, Euler Microwave Devices Co. Ltd,, Chengdu Wattsine Electronic Technology Co. Ltd., TOKYO KEIKI INC.), 8 media partners (Orient Microwave Corp, Nissi-inc., Plasma Applications Co. Ltd., SHARP CORPORATION, YAMAMOTO VINITA CO. LTD, Ryowa Electronics Co. Ltd., Milestone General k.k., Fusion Fission Powers Co. Ltd.), and 3 scientific international journals (Frontiers in Chemistry, Catalysis Today, JMPEE) (**Figure 3**).

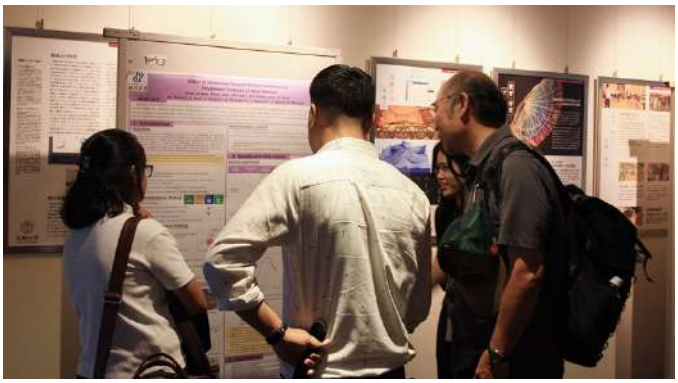

Fig. 2: Discussion in front of a poster.

The Round Table on industrial scale-up risks and threats, where international experts (**Figure 4**) who have successfully applied MW and RF technology at industrial level, stimulated the discussion among the participants and efficiently concluded the technical program.

Fig. 3: Coffee breaks in the exhibition area.

The Best Oral (J. A. Cuenca, S. Mandal, O. A. Williams, Cardiff University, UK, OD103 - Microwave Plasma Modelling for Heterogeneous Diamond Growth on III-Nitrides; A. Ono, A. I. Fujiwara, J. Liu, T. Kon, K. Ohno, Kyushu University and Munakata High School, Japan OC108-Hydrogen Reduction of Tungsten Oxide with Microwave Rapid Heating; K. Liu, H. Li, Z. Zhao, X. Gao, Tianjin University and Haihe Laboratory of Sustainable Chemical Transformations, China, OB105-Revealing the Quantitative Regulation Rules of Microwave Hotspots in Liquid-Solid Systems via Microscale Heat Transfer Model and In-situ Fluorescence Spectroscopy; Y. Kwak, Q. Kim, C. Wang, K. Yu, Weiqing Zheng, D. G. Vlachos, University of Delaware, USA, OA107-Mechanistic Insights into Microwave-Assisted Thermal Catalysis for Shale Gas Upgrade) and Best Poster (T. Nakamura, S. Uemura, AIST, Japan-P08-Effects of Magnetic and Electric Fields on Heating Characteristics in Microwave Soldering) presentation awards in the Closing Ceremony were the farewell message for the participants (**Figure 5**).

Fig. 4: Speakers at the Round Table: from left to right: Eiji Yamasue, Ritsumeikan University, Japan; Junming Tang, Washington State University, USA; Georgios Dimitrakis, Nottingham University, UK; Satoshi Hrikoshi, Sophia

University, Japan; Yoshio Nikawa, Kokushikan University, Japan.

Fig. 5: Conference attendees. At the rear, with dark T-shirts, some of the 25 Kyushu University students who supported the local organizers with their enthusiasm and participation.

In addition to the successful technical program, the social events, from the welcome buffet to the banquet dinner, were simply fascinating. Together with the accompanying program of visits to the surrounding area of Fukuoka, the 5 GCMEA organizers managed to showcase the various cultural aspects of the rich Kyushu Island territory, the rice fields surrounding the ITO campus where the conference was held, the climb to the mountain observatory, visits to temples, a noodle factory and a sake brewery.

A special attraction was the banquet dinner with the opening of the sake barrel by some of the presidents or delegates of the 5 associations of the MAJIC confederation (**Figure 6**) and the award giving ceremony.

The two traditional GCMEA awards: the Rustum Roy Innovator Award went to José Manuel Catala-Civera, Universidad Politecnica de Valencia, Spain, and the Ricky Metaxas Pioneer Award went to Cristina Leonelli, University of Modena and Reggio Emilia, Italy (**Figure 7**).

Probably the most significant event of this edition of the GCMEA conference is the announcement of the creation of the Association of Industrial Microwave Heating and High Frequency Applications (AIMHHA) and its affiliation to the MA^{2}JIC, which has consequently had to change its acronym: MAJIC. The confederation agreed to hold the next GCMEA edition in India in 4 years; the exact date and venue will be finalized in the future.

Fig. 6: The Presidents of the 5 MA^{2}JIC associations opening the sake barrel at the beginning of the Banquet dinner. From left to right: Youshio Nikawa (Conference Chair); Parag Prakash Sutar (representing AMIHHA); Satoshi Horikoshi (President of JEMEA); Li Wu (representing CAMPA); Georgios Dimitrakis (President of AMPERE); John Gerling Jr. (representing IMPI).

Fig. 7: The winners of the two traditional GCMEA awards: José Manuel Catala-Civera, Universidad Politecnica de Valencia, Spain, (left) and Cristina Leonelli, University of Modena and Reggio Emilia, Italy (right).

Report on IMPACIE Conference 2024

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The 4th Conference on Microwave Power for Chemical Engineering Applications was successfully held in Qingdao during August 9 to 11, 2024. The conference was organized by the Institute of Microwave Power Applications for Chemical Industry and Engineering (IMPACIE, one of the CAMPA members) and hosted by Shandong University and Yantai North Microwave Technology Ltd. This conference attracted a total of 234 participants (**Figure 1**) and received 137 papers, showing the latest research results and progresses in the field of microwave power in chemical engineering applications.

Fig. 1: Group photo.

A number of well-known scholars were invited (**Figure 2**) to share their cutting-edge research results, including Prof. Tien-Chien Jen from University of Johannesburg, South Africa; Prof. Roger Ruan from University of Minnesota, USA; Prof. Tohru Yamada from Keio University, Japan; Prof. Chenggong Sun from University of Birmingham, U.K.; Prof. Kama Huang from Sichuan University, China; Prof. Tao Wu from University of Nottingham, Ningbo, China; Prof. Yong Nie from Zhejiang University of Technology, China; and Prof. Wenxiang Hu from Beijing Excalibur Tianjun Institute of Medical Science, China.

This conference also organized a roundtable forum (**Figure 3**) with the theme of "Microwave Science and Technology Innovation Enabling Industrial Development", which provided in-depth discussions and exchanges on topics such as the current status, challenges, opportunities and the future direction of microwave power applications in industries.

Fig. 2: Plenary speakers.

Fig. 3: Roundtable forum.

16 sessions (**Figure 4**) were set up for in-depth discussions and exchanges on 11 topics of microwave power applications in chemical engineering. In addition, poster presentations and a young scientists' forum were organized.

Fig. 4: Session report.

10 exhibitors also took this opportunity to demonstrate their latest products and technologies, and had exchanges and cooperations with experts and scholars (**Figure 5**).

This conference not only demonstrated the latest progress and applications of microwave technologies in the field of chemical engineering, but

also provided a platform for participants to exchange ideas, addressing wisdom and seek cooperations.

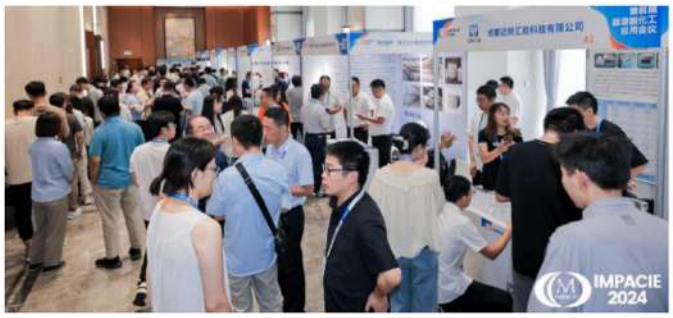

Fig. 5: Exhibitor communicating with participants.

Report on the Royal Society discussion meeting: Microwave science in sustainability

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A recent two-day scientific discussion meeting held at the Royal Society in London on the 13th and 14th of May 2024, brought together over 150 participants both in person and online to explore the role of Microwave Science in Sustainability (**Figure 1**).

Fig. 1: Social media card of the event.

The event, organised by Professor Daniel Slocombe and Professor Adrian Porch from Cardiff University, drew a diverse audience of researchers, industry professionals, and policymakers from across the world, all focused on the potential of microwave technologies to contribute to sustainable development.

The meeting was structured to encourage in-depth discussions and meaningful exchanges on the latest advancements in microwave science. Unlike traditional conferences, this event fostered a dynamic and interactive environment, with lively debates that addressed some of the most pressing challenges in the field.

The opening session set the tone for the event, focusing on how microwave technologies can enhance recycling processes and support a circular economy. The presentation highlighted the potential of microwaves to improve energy efficiency and effectiveness in material recovery, sparking a robust discussion on the practical implementation and scalability of these technologies.

Another key presentation explored the use of microwaves in green chemical processes. The discussion emphasised how microwaves can drive more sustainable chemical reactions by reducing energy consumption and minimising the use of harmful solvents. This approach offers promising avenues for advancing green chemistry, making it more environmentally friendly and efficient.

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.

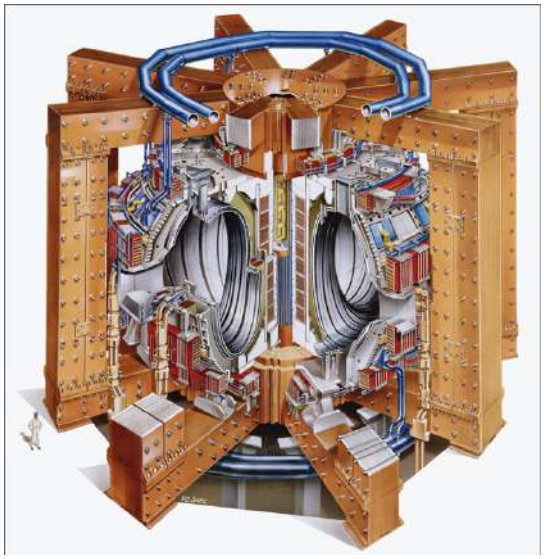

Fig. 1: Schematic representation of a fusion reactor using the Tokamak principle.

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.

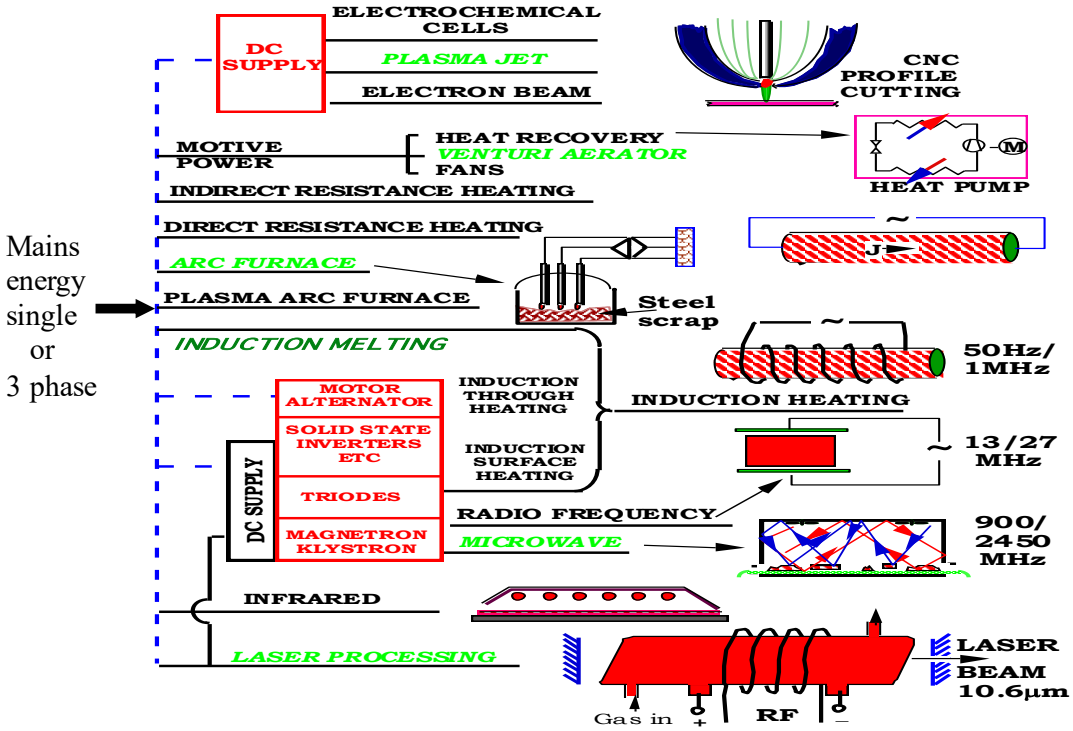

Fig. 2: Electricity utilisation from DC to very high frequencies.

The European Journal of Microwave Energy (EJME) is on line

This Journal showcases major scientific developments from fundamental and applied work using energy in the microwave spectrum. EJME celebrates breakthroughs at microwave frequencies in all areas of scientific discovery. The Journal focuses upon fundamental questions and advances in science and engineering using microwave energy and is highly interdisciplinary, bringing together the fields of chemistry, material science, physics, engineering and the physical and biological sciences.

This inaugural issue includes the very best papers (top 5%) selected from the 19th International Conference on Microwave and High-Frequency Applications, held in Cardiff in 2024, as selected by the scientific committee of the Association for Microwave Power in Europe (AMPERE). The papers published in this issue reflect the range of topics covered by the AMPERE community and they set the standard for quality for this new European journal.

It is easy to navigate and can be readily accessed at https://ejme.cardiffuniversitypress.org/.

The Newsletter congratulates Editors in Chief, Daniel Slocombe, Adrian Porch and Georgios, Dimitrakis for a very impressive Volume 1.

About AMPERE Newsletter

AMPERE Newsletter is published by AMPERE, a European non-profit association devoted to the promotion of microwave and RF heating techniques for research and industrial applications (http://www.ampereeurope.org).

New structure of the AMPERE Newsletter

At a management meeting during AMPERE23 it was decided that in view of the introduction of the new scientific Journal entitled "European Journal of Microwave Energy" supported by CUP, no technical papers will be published in future Issues of the Newsletter. Instead, AMPERE welcomes submissions for short bios on individuals, articles, research proposals, projects, briefs as well as news.

AMPERE Disclaimer

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AMPERE Newsletter

ISSN 1361-8598

https://www.ampereeurope.org/newsletter/