Scientific Concept
of the CleanHME project

University of Szczecin, Szczecin, Poland
Institute for Solid-State Nuclear Physics, Berlin, Germany
Institut Josef Stefan, Ljubljana, Slovenia
Maritime University of Szczecin, Szczecin, Poland
FutureOn, Roma, Italy
Uppsala Univeristy, Uppsala, Sweden
BroadBit Energy Technologies, Komarno, Slovakia
Instituto Nazionale di Fisica Nucleare, Frascati, Italy
Politecnico di Torino, Torino, Italy
Universita Degli Studi di Siena, Siena, Italy
Vegatec, Rousset, France
Centre National de la Recherche Scientifique, Paris, France
SART von Rohr SAS, Bitschwiller les Thann, France
LIFCO Industrie, Saint-Etienne, France
Lakoco, Woluwe Saint Pierre, Belgium
Massachusetts Institute of Technology, Cambridge, USA
Lakehead University, Thunder Bay, Canada

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SECTION 1- INTRODUCTION

History of the cold fusion research

On March 23, 1989 the Professors Stanley Pons from the University of Utah and Martin Fleischmann of the University of Southampton, during a press conference announced that they had produced anomalous heat in a “test tube”. While their equipment was very simple, they performed electrolysis of heavy water (D_2O) with a cathode made and a platinum anode. The amount of anomalous heat measured was not understandable by any known chemical reaction. Their conclusion was that they had fused two deuterium nuclei and produced a helium-4 nucleus.

The most probable outcomes in nuclear reaction of fusion of two deuterium nuclei produce either helium-3 and a neutron, or tritium and a proton, with equal probabilities. In very rare cases, there is formation of helium-4 and a gamma ray. Though Pons and Fleischmann tried to detect gamma rays, their data were not conclusive.

Following this astonishing announcement, many laboratories worldwide tried to replicate the experiment. However, at that time, very little was known about how to be successful. Many failed, but a few succeeded[1,2,3]. In spite of the positive results, the whole field was considered as pathological science. Positive experimental results were supposed to be due to systematic errors, and theoreticians showed using their known two body models that the rate of reaction between two deuterium nuclei was orders of magnitude too low to be possible in the temperature range of the original experiments.

The field was excluded from official scientific research everywhere in the World. However, in spite of this rejection a sparce but qualified group of scientists continued either in their institutions or in private groups.

In the early years of research, most of the work was done in electrolysis, but soon people started working with plasma devices and in gas phase. The important evolution came from the change from palladium to nickel and deuterium to hydrogen. In spite of many attempts, extremely low levels of neutrons and gamma rays have been detected. These particles cannot explain the amount of heat produced. What has been measured by several experimentalists is a correlation between helium-4 production and anomalous heat[4,5]. Therefore, new theories must be developed taking into account the very important fact that the reactions occur in a condensed matter where many atoms are present. A two-body model cannot explain what is observed.

Laboratories around the World continue working in the field of Low Energy Nuclear Reactions. International conferences are organized on a regular basis. The last one ICCF22 occurred in Italy in

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[1] Appleby, A.J., et al., *Evidence for Excess Heat Generation Rates During Electrolysis of D2O in LiOD Using a Palladium Cathode-A Microcalorimetric Study*, in Workshop on Cold Fusion Phenomena, 1989, Santa Fe, NM.

[2] Arata, Y. and Y.C. Zhang, *Achievement of intense 'cold fusion' reaction*, Kaku Yugo Kenkyu, 1989, 62, p. 398.

[3] Edited by Iyerngar, P.K. and Srinivasan, M., *BARC studies in cold fusion,* Government of India, Atomic Energy Commission, Bhabha Atomic Research Centre, Trombay, Bombay, 1989.

[4] De Ninno, A., et al., *4He Detection In A Cold Fusion Experiment*, in 10th International Conference on Cold Fusion., 2003

[5] Miles, M.H. et al., *The Science of Cold Fusion*, Italian Physical Society, 1991, pp. 336.

2019, and the next one ICCF23 will take place in China. Japan and Russia organize yearly conferences on LENR.

The electronic Journal of Condensed Matter Nuclear Science publishes hundreds of papers on the subject. In January of this year Elsevier published a book "Cold Fusion, Advances in Condensed Matter Nuclear Science". There was the situation in 2020.

What is already known

The early experiments indicated a good correlation between the amount of heat produced and the formation of helium in experimental setups supplied with deuterium. The logical reaction responsible for the energy was thought to be the fusion of deuterium nuclei into helium. At that time the term of Cold Fusion seemed appropriate because this reaction was mimicking the thermonuclear process occurring in the stars and in plasma reactors. The absence of neutrons and of gamma rays showed however that this Cold Fusion process does not obey the rules of the conventional thermonuclear fusion.

Later, other experiments showed that light hydrogen was also producing heat in particular conditions. This proved that other reactions than deuterium fusion exist and that the term Cold Fusion was too restrictive. Hence, the specialists coined the name Low Energy Nuclear Reactions or LENR.

It is now agreed that the energy can be produced when 3 conditions are satisfied:

- Presence of light elements: hydrogen isotopes, light hydrogen or deuterium or also maybe lithium;
- Condensed mater materials, like metallic structures able to react with the light elements;
- Presence of an excitation process, could be electric, magnetic, pressure etc., but also thermal.

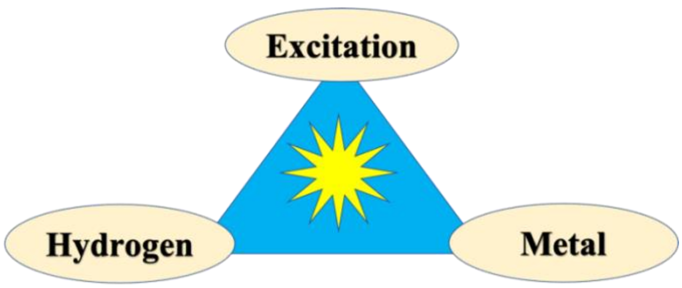

Fig. 1. The H-M-E triangle

The hydrogen can be introduced in the reactor in gaseous form. It can also be generated directly on the metal, for instance by electrolysis. Deuterium seems to be the most active species, but the light isotope of hydrogen was found to generate heat when associated with some metallic structures.

The metal must enter in contact with the hydrogen. For this reason, the metal must be in a divided form, like thin films, wires or powders. In order to offer a large interface area between the solid and the gas nano-powders are favored.

The experience showed that the metallic structures are active if they contain atoms of different metals, for example: nickel-copper, palladium-nickel, etc.

The excitation can be a process that drives a movement of the hydrogen atoms in the metallic structure. Positive results are obtained when "out of equilibrium conditions" exist. For example, hydrogen diffusion into or out of the metal by a gas pressure unbalance, electromigration created by an electrical current, flow of electrons hitting the surface, illumination by a laser light, flux of radiofrequency waves, etc.

The generic name of this new form of energy in this document and for the project is HME (Hydrogen-Metal-Energy).

This name does not describe the physical process that causes the reactions, simply because this process is not understood at the present time.

It is one essential aim of the project to develop a complete understanding of the physics at play. If this comprehension is obtained it will then be appropriate to invent a new denomination that reflects the physical source of the energy.

Meanwhile, HME is the name used in this document, in accordance with the name of the CleanHME project.

The ambition of the project

The ambition of the project is to develop the following advances:

- Perform accelerator experiments in order to validate the theoretical basis of HME.
- Develop a predictive theory to be able to specify materials that can be used in reactors with an increased efficiency.
- Synthetize active materials that work reliably and can be delivered to any users at an affordable cost.
- Develop a sufficient knowledge of HME to be able to design devices that will deliver heat and electricity at will and that can be easily controlled.
- Design efficient portable and compact stationary energy sources.
- Gather data in terms of material quantities, processing and lifetime for a given use.
- Gather data to evaluate the potential costs for a given power and a given energy production.
- Develop the procedures and safety rules for the future dissemination of the technology.
- Gather data for further studies of the recycling of the materials after exhaustion.

  CleanHME project results are expected to have strong impacts at four main levels and will definitely address any of the expected impacts mentioned in the work program:

- A disrupting impact, in the medium term, on the energy and transport industry. The new HME technology has the full potential to be a game changer in the clean energy production arena, allowing for distributed, on demand, autonomous and affordable clean energy production, theoretically for any human need.

- Breakthrough advances in nuclear physics and power engineering which will allow many research institutions to re-utilize the public released interdisciplinary scientific know-how, thus allowing new advances and discoveries. Scientific and technological results of CleanHME will deeply contribute to the foundation and consolidation of a radically new energy technology.
- CleanHME project results are of direct economic interest to many kinds of industrial companies. Not only the energy industry but also the manufacturers and end users of heat as well as electricity generators manufacturers of many other different machines, for which HME based generators could make energetically autonomous, thus creating a big potential for future returns in terms of economic innovation and market creation.
- Huge ecological impacts are expected in the medium-long term, as the new energy source has the potential to gradually replace fossil fuels as the main energy source on the planet.

Moreover, the large number of both scientific institutions and commercial/research companies collaborating to the project, based all over Europe and also abroad (US and Canada), will allow to build-up a goal oriented interdisciplinary community having the potential to lead the development of this strategic energy technology both in Europe and at global level.

Scientific activities

Objective work packages have the following structure:

- WP2 is focused on accelerator experiments which should build a basis for gas loading experiments of WP3, the theoretical description of WP5 and development of new effective materials in WP4.
- WP3 involves gas-loading and relative experiments, beginning with already existent facilities and ending with new devices working with optimized construction and new active materials.
- WP4 is responsible for development and diagnostics of new active materials that will show strongly enhanced reaction rates and high loading density of hydrogen.
- WP5 aims on theoretical understanding and description of the energy generation, comparing different theoretical backgrounds and allowing for an interdisciplinary approach.
- WP6 is devoted to a conceptual design of a compact HME source producing both heat and electricity. Some recommendation for follow-up study will be given.

SECTION 2 – DESCRIPTION OF SCIENTIFIC WORK PACKAGES

WP2 – Accelerator experiments

In the WP2 accelerator experiments are carried out at three different laboratories specialized in different experimental techniques which are complementary for project topics.

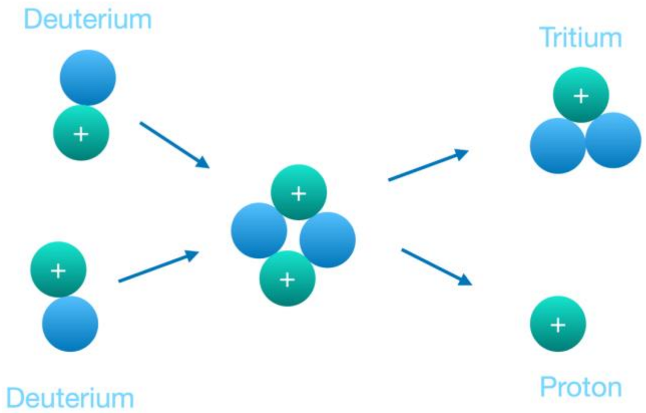

Fig. 2. One branch of deuteron fusion reaction. A simple nuclear reaction that is studied in laboratory experiments for cold fusion.

Measurements of the screening effect in proton and deuteron induced reactions on chosen metallic alloys and nanocomposite are performed at the University of Szczecin applying an electrostatic accelerator with ultra-high vacuum placed in eLBRUS laboratories[6]. The system will be completed by an additional decelerating module to deliver proton and deuteron beam currents of a few mA at the cooled down or heated metallic targets at the lowest possible energies. This will allow for measurements of nuclear reaction cross sections at energies down to 1 keV for which reaction enhancement factor due to the screening effect reaches values larger than 1000. Influence of crystal lattice defects and nanostructures on the reaction rates will be investigated additionally.

[6] Kaczmarski, M., *New accelerator facility for measurements of nuclear reactions at energies below 1 keV*, Acta Physica Polonica B, 2014, 45.

Fig. 3. Accelerator set-up for low-energy nuclear reactions at eLBRUS laboratories, University of Szczecin, Poland

The group at the Jožef Stefan Institute is focused on study of electron screening in nuclear reactions induced by hydrogen isotopes in inverse kinematics employing a 2 MV Tandem accelerator equipped with three ion sources, capable of accelerating almost every negative ion beam from the periodic table[7]. This technique allows to be insensitive to target surface contamination and other surface physics effects. The accelerator experiments are accomplished by application of important diagnostic techniques as Elastic Recoil Detection Analysis and Nuclear Reaction Analysis with a 3He beam for determination of the hydrogen depth profile. During the experiments, the electron conversion channel is also examined. The experiments are performed in cooperation with the Szczecin group, studying similar target materials.

Another series of accelerator experiments will be carried out using single crystal Li targets and ultra-high vacuum technique to measure the proton reaction cross sections that can be enhanced by correlated quantum states. Penetrability through the Coulomb barrier and influence of crystal impurities on reaction rates will be precisely determined.

Accelerator experiments devoted to study of ultra-dense hydrogen states in materials used in high temperature experiments are examined in the laboratory of FutureOn. Simultaneously with continues or pulsed irradiation of different frequencies, a special shock wave technique will be applied to achieve high density layers of H/D. Different charged and neutral particle detection techniques and hydrogen spectroscopy methods (as ERDA, X-ray diffraction, Raman Spectroscopy and Electron Microscopy) in collaboration with other groups will be utilized.

[7] Lipoglavsek, M., et al., Electron screening in the $^{1}H(^{7}Li,\alpha)^{4}He$ reaction, Eur.Phys. J. A 44, 71-75, 2010.

WP3 – Gas-loading experiments

The main goal for WP3 is to prove the candidate LENR active materials is suitable for applications.
Experiments producing excess power with metals heated in hydrogen or deuterium atmosphere have been mainly performed with nickel-based metal alloys. It has been experimentally shown that the reactions responsible for the effect are located either at surfaces and sub-surfaces or at interfaces. Therefore, two main directions have been taken: solid materials with specific surface treatments or powders. It will be one of the main aims to find out suitable active materials for future applications.

The work encompasses reactor experiments operating at temperatures not higher than about 500 °C and 1500 °C for deuterium and hydrogen loading experiments, respectively. The work aims testing reactors of different types in order to find optimal running conditions and reduce the operating temperature by choice of appropriate materials and reactor constructions. Strong focus will be put on maximizing the production of heat power /fuel mass and reliable start up and running processes in order to obtain long-term stability of heat production. Special attention will also be paid to occurrence of any radiation around the reactors when running, both for safety reasons but also as a mean to identify the reaction channels responsible for heat production. Only a low- level radiation, far below safety levels, is expected and can be used as a signature of studied reaction mechanisms.

Based on experimental and theoretical results, new test reactors will be constructed of a general purpose to perform long-term experiments with new active materials and additionally optimize energetic efficiency of reactors. The experiments will be open for all project participants in order to improve their own reactor constructions.

The works on verification of excess heat production will cover replication of some experiments performed in the past using a unified research protocol and active materials to compare obtained results. The test will be performed on the following reactors: Uppsala reactor, BroadBit reactor, Futureon reactor, INFN reactor, VEGATEC calorimeter. Use of metallic bulk and powder materials is planned.

The energetical efficiency of bulk material reactors and metallic powder reactors will be improved according to the results by modification of construction, choice of optimal operating parameters and stable excess power production. The new materials proposed after accelerator experiments will be tested in long-term experiments using both hydrogen isotopes. The obtained results will be a basis for construction of new reactor type in WP3.6. The experimental data obtained in experiments on a new reactor will feed back further development of old constructions. Some additional innovative methods reducing operating temperature and reactor efficiency, as use of ionized gases or electric discharge for initial activation, will be investigated.

TeraHertz phonons produced in condensed matter by mechanical instabilities at the nano-scale (i.e., fracture in solids and turbulence in fluids) present a frequency that is close to the resonance frequency of the atomic lattice and thus they are able to influence energy production of HME systems. Especially, appearance of micro- defects in the crystal lattice and hydrogen embrittlement of used materials will be studied in series of experiments to improve the choice of appropriate

materials for reactor experiments. In the case of use of water vapor in gas-loading experiments, the implosion of micro- and nano-bubbles produced by cavitation can increase the reactor power, additionally. These effects will be studied using facility at the Politecnico di Torino.
For a better knowledge of HME phenomena, implementation of old and new techniques, special diagnostic systems are necessary. They will be used for reliable control parameters and detection systems necessary for HME activation, pollution monitoring and material aging evaluation as well as low-level radiation emission in reactors. It will be of large importance for work out of a unified research protocol applied in gas-loading experiments. Diagnostic methods of different reaction products and physical parameters, design of experimental set-ups integrated or external to the reactors, extraction, transport and measurement procedures for metal samples and gases used in reactors will be subject of the first project meetings. The group of the University of Sienna will be responsible for calibration of instruments and sensors in the laboratory (in the case of continuous monitoring) and analysis of materials used in the reactors before activation (background). Furthermore, characterization of the composition of metals and gases, structural characterization of the materials to be activated will be also performed. Monitoring of processes in different laboratories and a comparison between the groups that measure the same parameters and products will be done.
For the new reactors long-term tests VEGATEC will install and operate new reactors to test the materials selected as the most appropriate ones. The reactors will incorporate the features considered useful after the work of other WPs and their construction will enable to use both hydrogen isotopes at variable temperatures and pressures as well as suitable diagnostic systems. The experiments will be performed in cooperation with other project participants on large number of materials under different experimental conditions. The most important experiments will be long duration tests to find out how long a given charge of materials is able to maintain its activity. Any prolonged experiment after month 48 will be supported by VEGATEC.
INFN has been engaged in LENR studies since 1989. In the last decade the work transitioned from the initial study of Palladium based systems, to Nickel and its alloys. In fact, hot Constantan ($Cu_{55}Ni_{44}Mn_1$) wires became the focus of a long series of experiments that leveraged on the unique set of properties of this alloy, notably a moderate cost, a remarkable capability to absorb hydrogen and the durability in various experimental conditions. Heated Constantan show indeed the occurrence of anomalous heat if a series of conditions are met, remarkably a sufficiently high temperature and the occurrence of a flux of atomic deuterium or hydrogen. Both the magnitude and reproducibility of these anomalous heat effects are dependent on the surface properties of the wires and the presence of non-equilibrium conditions such as thermal gradients, electric fields and/or the emission of electrons. INFN participates in CleanHME project aiming at increasing anomalous heat effects thanks to the use of an innovative voltage-current pulses technique. Pulses are applied longitudinally along the wires and, in a second phase, among the constantan and a counter-electrode (fig. 1) to induce: 1) the impulsive heating of the wires, 2) a sudden emission of electrons, 3) the ionization of the gas via a dielectric barrier discharge (DBD). These conditions are deemed effective at inducing a flux of active species through the surface of the wires. Also, a

significant part of the work is dedicated at replacing the current glass reactor with a stainless-steel vessel and to implement a Residual Gas Analyzer to monitor the species present during the experiments.

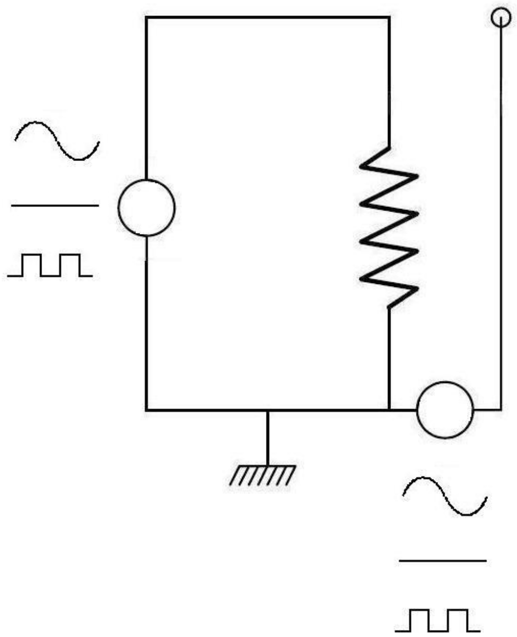

Fig 4. Wire arrangement.

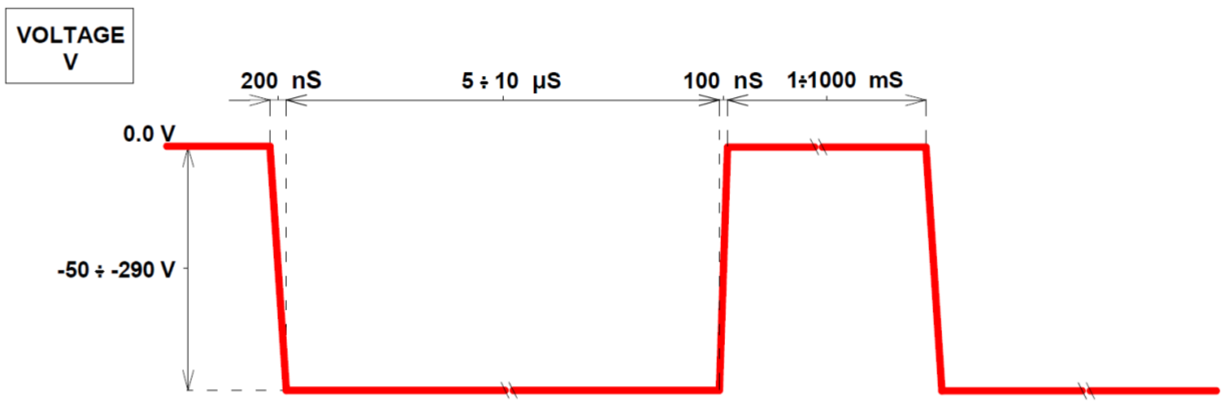

Fig 5. Typical Voltage Curve of the pulses that is used in experiments.

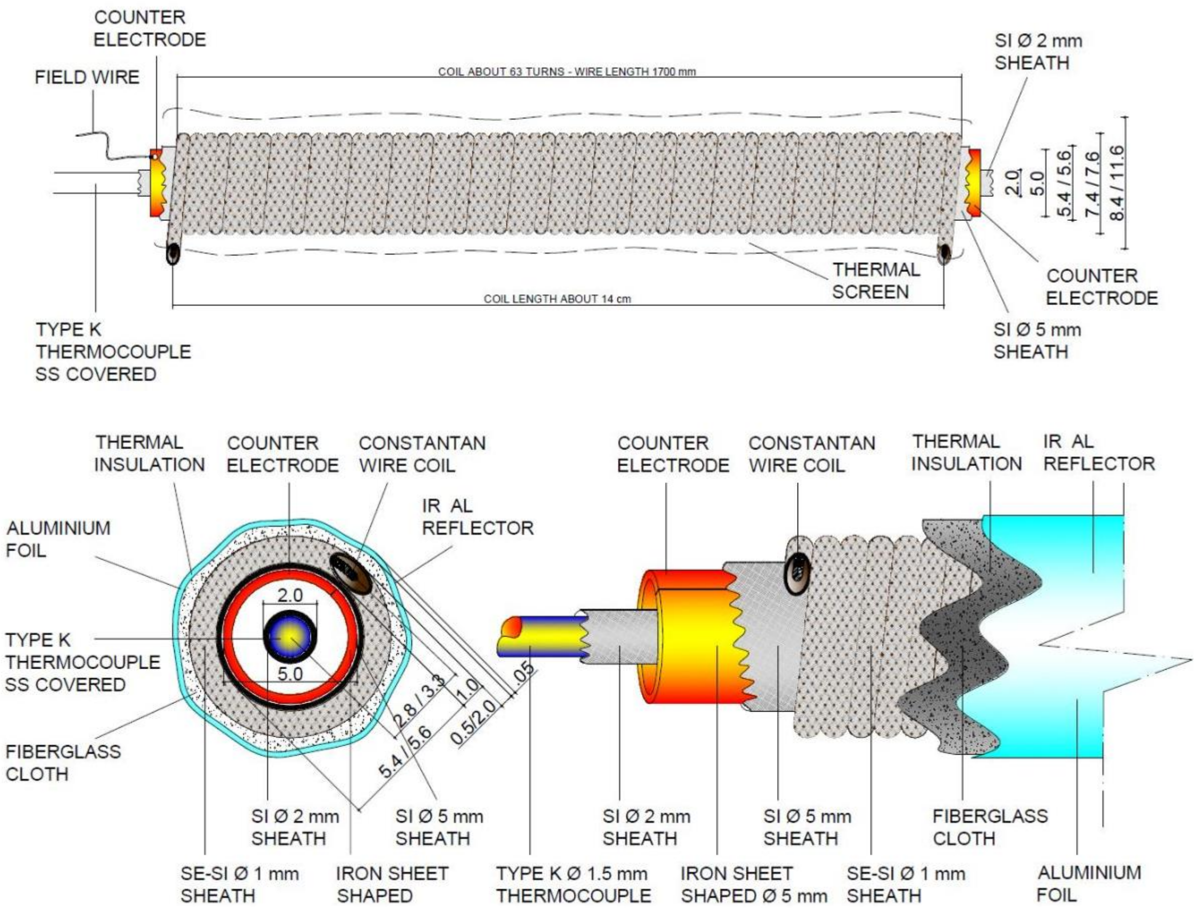

Figure 6. A coil of Constantan wire in its glass fiber sheath, wound on iron tube counter-electrode.

WP4 – Preparation of active materials

The work within WP4 will gather knowledge and know-how preparation techniques of active reactor materials that have been proven to be effective in accelerator and gas-loading experiments. Thus, the objectives of WP4 require the expertise and equipment of each participant. The specific tasks involve preparation and design of different materials such as nanostructured materials, bulk materials and high-density hydrogen and deuterium.

After 30 years of underfunded research experimentation, the community of cold fusion understood the necessary a-minima experimental parameters required to show repetitively anomalous heat effect (AHE) production. For example, the palladium-deuterium system requires a physical loading in the range of stochiometric amount of D/Pd>0.86 as a necessary parameter, among other specifics to generate substantially observable energies produced by nuclear reactions. In comparison, for nickel-hydrogen systems, levels of loading system are much smaller, which is in agreement with mainstream literature.

These examples show how Material Science takes a crucial role into the making of this novel and disruptive energy source, which is the subject of this central part within the project. With the development of novel approaches to the material science and inclusion of techniques issued from the catalysis science processing, some research groups are using powders or wires to generate AHE. These techniques are generating a broad range of defects that amplifies the loading of hydrogen or deuterium at interfaces, and developed heat analysis techniques that tends to show AHE. This working hypothesis emphases on interface between a given material with two phases, or an interface between two different materials.

With these hypotheses, we can understand that, in the case of palladium cathodes, interfaces between alpha and beta phases of D-Pd are playing an important role. In other experiments with Ni/Pd and Ni/Cu compounds, there are also interfaces between two metals with different hydrogen or deuterium loading. Following this new understanding, we are planning to prepare and already test materials with large quantities of interfaces. The best ways to achieve that goal is to use nano powders, structured multilayered materials, solid diffused alloys and any interface-rich materials.

WP5 – Theoretical analysis

The main aim of WP5 is to propose a unified theoretical description of experimental results obtained both in accelerator and gas-loading experiments. It is important to recognize all effects that can contribute to enhancement of the nuclear reaction rates at room temperature. In particular, study of the mechanism of the electron screening effect[8] enhanced by crystal lattice defects and specially prepared nanostructures will allow a rational optimization and design of reactors for breakthrough clean power production. Nevertheless, some other effects as resonance states, correlated quantum states, electron orbital effects and high-density hydrogen states may also play a crucial role. Furthermore, the excitation mechanisms for activation of hydrogen-loaded materials by an increased temperature, charged particle irradiation or electromagnetic fields will be also investigated to support the experimental approaches.

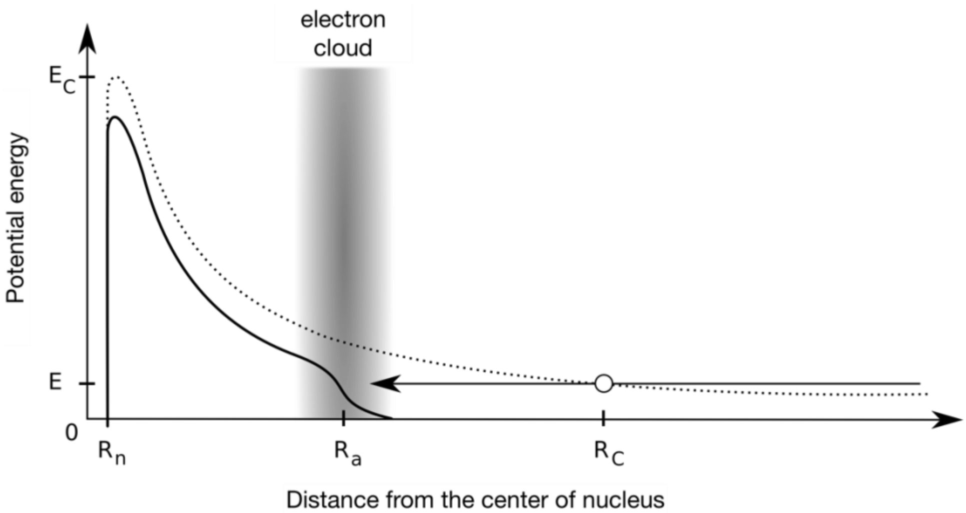

Fig. 7. Electron screening effect in nuclear reactions. Incoming particle has to overcome the Coulomb potential of a nucleus if the reaction is to occur. The Coulomb potential (dotted line) between the two particles is reduced (solid line) due to the electron cloud of metallic medium increasing the probability of the tunnel effect and enhancing the reaction cross section.

One of the aims is to build a theoretical framework, which allows the development of predictive tools for describing the occurring reaction dynamics, allowing a quantitative experimental validation. The theoretical models applied have to predict experimental results obtained in gas-loading experiments. The main challenge lies in the fact that many physical effects and reaction mechanisms can contribute to the experimental observations. Therefore, a comparison between different theories and their predictive power is necessary. As a result, some important signatures (e.g. energy spectra of emitted particles, reaction cross sections) identifying corresponding physical effects should be given to plan experiments properly. Forward predictions of all theories will be validated in the course of the project. The involved theories will be also used for the detailed physical modeling.

[8] Czerski, K., *Deuteron-deuteron nuclear reactions at extremely low energies*, Phys. Rev. C 106, L011601, 2022.

Another task is to introduce the detailed description of the experimental results obtained in accelerator and gas-loading experiments delivering theoretical values of important parameters, such as screening energies, enhancement factors due to correlated quantum states, electron orbital effects and high- density hydrogen states. For gas-loading experiments, effects of mechanical coupling and creation of very dense hydrogen states in metallic lattices will be studied, additionally.

WP6 – Application and Design of HME sources

The WP6 of the project will study the potential applications of HME.
In order to identify the potential applications a review of the present uses of energy will be made.
Concepts of practical solutions for heating purposes and generation of power will be described. A focus will be made on solutions for transport. The work of WP6 is split into 4 tasks. The lead partner will be SART VON ROHR. FutureOn will study the direct conversion into electricity. The work will take into account the characteristics of the heat sources defined by the other WPs: Type of materials, suitable reactor configurations, operation parameters, lifetime of a given load. VEGATEC will input the knowledge learnt during the long duration tests for the design of the HME sources.

<u>HME as a direct source of electricity</u>

Some experiments suggest that electricity can be generated directly, for example by the collection of particles or ions produced by the reactions. Up to now only very low electrical powers were obtained. Any future breakthrough in the direct generation of electricity during the timeframe of the project will be taken into account. Direct electricity generation is a subject included in the WP6 activities.

Analysis of the present uses of heat for domestic and industrial purposes

Heat is a very general term that can indicate very different energetic processes ranging from the energy collected by solar panels to the energy released by the burners inside a gas turbine.
Heat can be used as such for heating purposes at a low temperature level. Sometimes heating needs are provided by the waste heat of other processes, like combined heat & power cycles.
Heat is the intermediate form of energy in many industrial uses, including steam boilers, chemical reactors, internal combustion engines, steam turbines and so on.
With the notable exceptions of photovoltaic solar panels, fuel cells and possibly future direct HME converters, all the electricity consumed in the World is produced via thermodynamic processes that convert heat into motive power to drive electrical generators. Even wind turbines harvest some solar heat converted into air movement by the atmosphere acting as a natural thermodynamic machine.
Therefore, a major part of the global energy consumption can be analyzed in terms of heat generation and processing.
The different sources of heat correspond to a large multiplicity of usages. In order to elaborate a classification of all the types of heat sources one can refer to the following sets of parameters:

<u>Heat generation:</u>

- Intended use
- Type of fuel for the heat generation (Oil, gas, coal, HME in this project)
- Temperature level of delivered heat (°C)
- Source power level (Watts)
- Power density (kW/kg)
- Energy density for sources working with embarked energy (kWh/kg)

Engineering parameters:

- Geometrical sizing and masses of the whole system and the subparts
- Ancillary equipment (cooling, supply of fluids, electrical equipment, control system, etc.)
- Power Control: Starting and stopping modes – power adjustments
- Safety aspects

Economical parameters:

- Investment costs of the heat source (€/kW)
- Running costs of the energy produced (€/kWh)
- Maintenance costs (€/kWh)
- Lifetime of the equipment

Environment and lifecycle:

- Emissions during operation (e.g. masses of greenhouse gases per kWh)
- Emissions of minor pollutants (e.g. particles, radiations if any, dust, etc.)
- Environmental impact for the manufacture of the sources and preparation of the fuels
- Energy return on energy invested (EROI)
- Recycling of the disposed sources at end of life
- Wastes control of spent materials

Suitability of HME sources for potential applications

The above-described analysis will make it possible to decide if a given type of HME system is suitable or not for some applications.

HME reactor temperature

The temperature level of the heat source will be the prime parameter for this analysis.

Some uses definitely require a minimum temperature to operate, like chemical reactors.

In other cases, the temperature only influences the thermodynamic efficiency of the system according to Carnot's theorem. In such cases a lower temperature and a lower thermodynamic yield might be acceptable provided the overall economics is favorable. As an existing example of such a compromise let us remember that the steam turbines of a PWR nuclear power plant work at 315°C while the turbines of a supercritical boiler are fed by steam at 620°C. The lower Carnot efficiency is largely compensated by the relatively low cost of the nuclear heat.

It is already known that the temperature influences the heat power of a HME system. In general, more heat is released when the temperature rises. This is a particular feature of HME reactors that must be carefully taken into account to design a stable operation, to avoid runaway conditions or inversely self-extinction.

HME excitation consumption

HME reactors require some form of excitation (See HME triangle). Any kind of excitation translates into the consumption of some energy. The energy balance of the complete system must consider the energy consumed by the reactor itself for its excitation, also accounting the losses introduced during the conversion of the heat into excitation energy.

The ratio between the HME energy output to the excitation energy is called Coefficient of Performance (COP). Referring to the concept of COP obliges to clearly define the types, qualities and quantities of energies considered for the input and the output.
In some experiments the reactions seem to be excited by the sole effect of the temperature itself. In this extreme case there is no apparent excitation energy input, apart from the initial reheating during the start-up phase. Further work will confirm the feasibility of such HME reactors.
<u>HME power density</u>
The overall dimensions of a HME system might not be a limitation for stationary sources. In contrary, this is a very important factor for all moving equipment.
<u>HME energy density</u>
It is thought that the HME reactors will be delivered with a load of fresh active materials. This reactor will be able to produce a given quantity of energy before the active materials are exhausted. Following the use foreseen this amount of energy may be different.

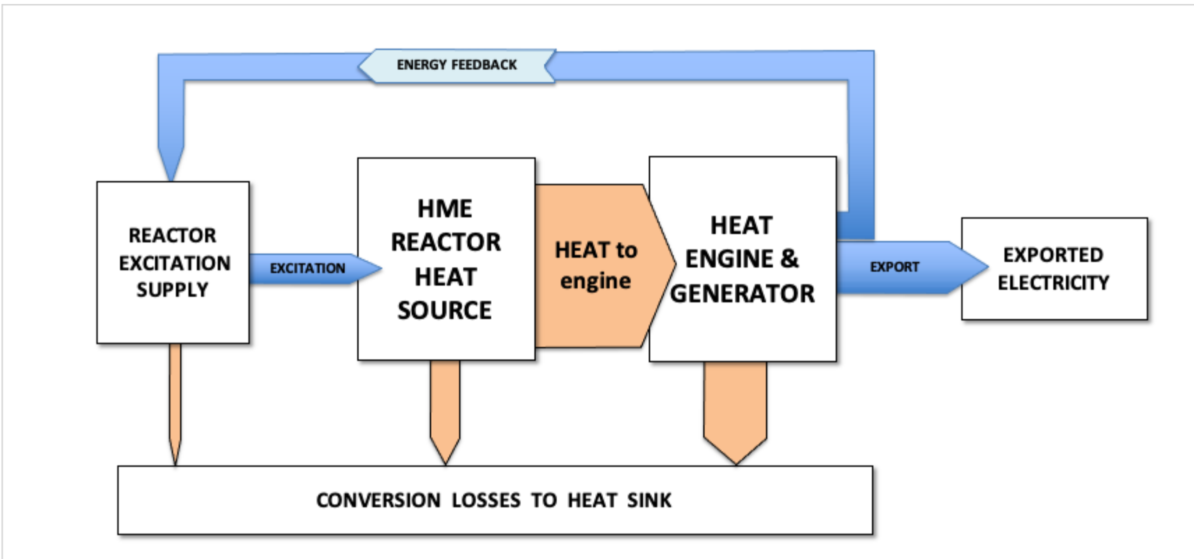

Fig. 8. Schematic energy flow of an HME energy source.

<u>Other HME parameters</u>
It must be understood that HME is still in its infancy and that many follow-up studies will be required after the completion of the CleanHME project.
In particular, the economics of the new sources of energy will only be estimated by a broad approach. Many economic factors will still be missing.
The initial cost will largely depend on the type of materials required and the amount of sophistication for the fabrication of the sources. Hopefully, a minimal quantity of expensive metals will be necessary.
Another example is the HME pace of deployment. Prime market segments will be identified, and the cost of the reactors will sharply fall as the cumulated HME power increases. It is generally accepted that the price of such commodities is divided by 2 each time the cumulated quantity of

units is multiplied by 10. It can reasonably be considered that HME technology will follow a similar learning curve.

The learning curve will depend on the legal frame adopted to develop the technology. Like most advanced technologies economic incentives will be needed to launch the new industry.

A positive aspect of the technology is that no large infrastructure will be needed. The reactors consume minor intrants. Only maintenance facilities will have to be organized. Systematic and preventive maintenance requirements could be assessed by remote service operators.

Recycling and waste control of spent reactors should be organized since the onset of the technology. The reactors contain valuable materials and a large share of them can be reused to manufacture new reactors.

In terms of safety, it is already known that no harmful radiations are produced. This fact will be checked again during the project with sufficiently large experimental reactors.

This list cannot be exhaustive. Other items will be identified as the study proceeds.

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Contact information

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