Magnetic Confinement Fusion Enhancement Solutions (MCFES project)

1. The aim of this proposal is to provide additional solutions to any current Magnetic Confinement Fusion reactors, in order to enhance their efficiency, and become potentially commercial with a possible ROI potential. There are several geometries and systems for fusion, design will improve efficiency but might not meet the desired results of a continuous long term fusion reaction … These are the current fusion reactors research carried on: [Nuclear Fusion : WNA - World Nuclear Association (world-nuclear.org)](world-nuclear.org)

2. What we are trying to solve:
   - Improve fusion ignition efficiency
   - Improve a continuous fusion reaction for a longer term

3. Main changes to any existing reactors:
   - New gas fuel type supply via neutral beam injectors
   - Pellet injector

4. Introduction of the solutions value :
   - Carbon-Nitrogen-Oxigen CNO cycle
     i. Carbon may act as an energy catalyst since it is in no way actually changed by this process of converting hydrogen into helium. Under certain high temperatures the hydrogen can potentially penetrate the carbon nuclei. Since the carbon cannot hold more than four such hydrogen protons, when this saturation state is attained, it begins to emit protons as fast as new ones arrive. In this reaction the ingoing hydrogen particles come forth as a helium atom.
     ii. The first proposed catalytic cycle for the conversion of hydrogen into helium was initially called the carbon–nitrogen cycle (CN-cycle), also referred to as the Bethe–Weizsäcker cycle in honor of the independent work of Carl Friedrich von Weizsäcker in 1937-38 and Hans Bethe. Bethe's 1939 papers on the CN-cycle drew on three earlier papers written in collaboration with Robert Bacher and Milton Stanley Livingston and which came to be known informally as "Bethe's Bible". It was considered the standard work on nuclear physics for many years and was a significant factor in his being awarded the 1967 Nobel Prize in Physics. Bethe's original calculations suggested the CN-cycle was the Sun's primary source of energy. This conclusion arose from a belief that is now known to be mistaken, that the abundance of nitrogen in the sun is approximately 10%; it is actually less than half a percent. The CN-cycle, named as it contains no stable isotope of oxygen, involves the following cycle of transformations:

$$^{12}_{6}C \rightarrow ^{13}_{7}N \rightarrow ^{13}_{6}C \rightarrow ^{14}_{7}N \rightarrow ^{15}_{8}O \rightarrow ^{15}_{7}N \rightarrow ^{12}_{6}C$$

This cycle is now understood as being the first part of a larger process, the CNO-cycle, and the main reactions in this part of the cycle (CNO-I) are:

$$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma \quad + 1.95\ \text{MeV}$$

$$^{13}_{7}N \rightarrow ^{13}_{6}C + e^{+} + \nu_{e} + 1.20\ \text{MeV (half-life of 9.965 minutes}$$

$$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma \quad + 7.54\ \text{MeV}$$

$$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma \quad + 7.35\ \text{MeV}$$

$$^{15}_{8}O \rightarrow ^{15}_{7}N + e^{+} + \nu_{e} + 1.73\ \text{MeV (half-life of 2.034 minutes}$$

$$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He \quad + 4.96\ \text{MeV}$$

   - Production of muonic deuterium
     i. To create this effect, a stream of negative muons, most often created by decaying pions, is sent to a block that may be made up of all three hydrogen isotopes (protium, deuterium, and/or tritium), where the block is usually frozen, and the block may be at temperatures of about 3 kelvin (−270 degrees Celsius) or so. The muon may bump the electron from one of the hydrogen isotopes. The muon, 207 times more massive than the electron, effectively shields and reduces the electromagnetic repulsion between two nuclei and draws them much closer into a covalent bond than an electron can. Because the nuclei are so close, the strong nuclear force is able to kick in and bind both nuclei together. They fuse, release the catalytic muon (most of the time), and part of the original mass of both nuclei is released as energetic particles, as with any other type of nuclear fusion. The release of the catalytic muon is critical to continue the reactions. The majority of the muons continue to bond with other hydrogen isotopes and continue fusing nuclei together. However, not all of the muons are recycled: some bond with other debris emitted following the fusion of the nuclei (such as alpha particles and helions), removing the muons from the catalytic process. This gradually chokes off the reactions, as there are fewer and fewer muons with which the nuclei may bond. The number of reactions achieved in the lab can be as high as 150 d-t fusions per muon (average).
     ii. To create a muon beam a combination of a PW laser and the MICE setup (Muon Ionization Cooling Experiment) can be achievable .

- Muon-catalysed Fusion
    i. In the muon-catalyzed fusion of most interest, a positively charged deuteron (d), a positively charged triton (t), and a muon essentially form a positively charged muonic molecular heavy hydrogen ion (d-μ-t)+. The muon, with a rest mass about 207 times greater than the rest mass of an electron, is able to drag the more massive triton and deuteron about 207 times closer together to each other in the muonic (d-μ-t)+ molecular ion than can an electron in the corresponding electronic (d-e-t)+ molecular ion. The average separation between the triton and the deuteron in the electronic molecular ion is about one angstrom (100 pm), so the average separation between the triton and the deuteron in the muonic molecular ion is about 207 times smaller than that. Due to the strong nuclear force, whenever the triton and the deuteron in the muonic molecular ion happen to get even closer to each other during their periodic vibrational motions, the probability is very greatly enhanced that the positively charged triton and the positively charged deuteron would undergo quantum tunnelling through the repulsive Coulomb barrier that acts to keep them apart. Indeed, the quantum mechanical tunnelling probability depends roughly exponentially on the average separation between the triton and the deuteron, allowing a single muon to catalyze the d-t nuclear fusion in less than about half a picosecond, once the muonic molecular ion is formed. The formation time of the muonic molecular ion is one of the "rate-limiting steps" in muon-catalyzed fusion that can easily take up to ten thousand or more picoseconds in a liquid molecular deuterium and tritium mixture (D2, DT, T2), for example. Each catalyzing muon thus spends most of its ephemeral existence of about 2.2 microseconds, as measured in its rest frame wandering around looking for suitable deuterons and tritons with which to bind.
    Another way of looking at muon-catalyzed fusion is to try to visualize the ground state orbit of a muon around either a deuteron or a triton. Suppose the muon happens to have fallen into an orbit around a deuteron initially, which it has about a 50% chance of doing if there are approximately equal numbers of deuterons and tritons present, forming an electrically neutral muonic deuterium atom (d-μ)0 that acts somewhat like a "fat, heavy neutron" due both to its relatively small size (again, about 207 times smaller than an electrically neutral electronic deuterium atom (d-e)0) and to the very effective "shielding" by the muon of the positive charge of the proton in the deuteron. Even so, the muon still has a much greater chance of being transferred to any triton that comes near enough to the muonic deuterium than it does of forming a muonic molecular ion. The electrically neutral muonic tritium atom (t-μ)0 thus formed will act somewhat like an even "fatter, heavier neutron," but it will most likely hang on to its muon, eventually forming a muonic molecular ion, most likely due to the resonant formation of a hyperfine molecular state within an entire deuterium molecule D2 (d=e2=d), with the muonic molecular ion acting as a "fatter, heavier nucleus" of the "fatter, heavier" neutral "muonic/electronic" deuterium molecule ([d-μ-t]=e2=d), as predicted by Vesman, an Estonian graduate student, in 1967.
    Once the muonic molecular ion state is formed, the shielding by the muon of the positive charges of the proton of the triton and the proton of the deuteron from each other allows the triton and the deuteron to tunnel through the coulomb barrier in time span of order of a nanosecond[13] The muon survives the d-t muon-catalyzed nuclear fusion reaction and remains available (usually) to catalyze further d-t muon-catalyzed nuclear fusions. Each exothermic d-t nuclear fusion releases about 17.6 MeV of energy in the form of a "very fast" neutron having a kinetic energy of about 14.1 MeV and an alpha particle α (a helium-4 nucleus) with a kinetic energy of about 3.5 MeV. An additional 4.8 MeV can be gleaned by having the fast neutrons moderated in a suitable "blanket" surrounding the reaction chamber, with the blanket containing lithium-6, whose nuclei, known by some as "lithions," readily and exothermically absorb thermal neutrons, the lithium-6 being transmuted thereby into an alpha particle and a triton.
    ii. More recent measurements seem to point to more encouraging values for the α-sticking probability, finding the α-sticking probability to be around 0.3% to 0.5%, which could mean as many as about 200 (even up to 350) muon-catalyzed d-t fusions per muon. Indeed, the team led by Steven E. Jones achieved 150 d-t fusions per muon (average) at the Los Alamos Meson Physics Facility. The results were promising and almost enough to reach theoretical break-even.
    iii. (*Unfortunately, these measurements for the number of muon-catalyzed d-t fusions per muon are still not enough to reach industrial break-even. Even with break-even, the conversion efficiency from thermal energy to electrical energy is only about 40% or so, further limiting viability. The best recent estimates of the electrical "energy cost" per muon is about 6 GeV with accelerators that are (coincidentally) about 40% efficient at transforming electrical energy from the power grid into acceleration of the deuterons.)* - Today we use PW lasers and Turbines have 61% efficiency.

- Nuclear fusion–fission hybrid concepts
    i. Fusion–fission designs essentially replace the lithium blanket with a blanket of fission fuel, either natural uranium ore or even nuclear waste. The fusion neutrons have more than enough energy to cause fission in the U-238, as well as many of the other elements in the fuel, including some of the transuranic waste elements. The reaction can continue even when all of the U-235 is burned off; the rate is controlled not by the neutrons from the fission events, but the neutrons being supplied by the fusion reactor.
    ii. Fission occurs naturally because each event gives off more than one neutron capable of producing additional fission events. Fusion, at least in D-T fuel, gives off only a single neutron, and that neutron is not capable of producing more fusion events. When that neutron strikes fissile material in the blanket, one of two reactions may occur. In many cases, the kinetic energy of the neutron will cause one or two neutrons to be struck out of the nucleus without causing fission. These neutrons still have enough energy to cause other fission events. In other cases the neutron will be captured and cause fission, which will release two or three neutrons. This means that every fusion neutron in the fusion–fission design can result in anywhere between two and four neutrons in the fission fuel.
    iii. This is a key concept in the hybrid concept, known as fission multiplication. For every fusion event, several fission events may occur, each of which gives off much more energy than the original fusion, about 11 times. This greatly increases the total power output of the reactor. This has been suggested as a way to produce practical fusion reactors in spite of the fact that no fusion reactor has yet reached

break-even, by multiplying the power output using cheap fuel or waste. However, a number of studies have repeatedly demonstrated that this only becomes practical when the overall reactor is very large, 2 to 3 GWt, which makes it expensive to build.

iv. These processes also have the side-effect of breeding Pu-239 or U-233, which can be removed and used as fuel in conventional fission reactors. This leads to an alternate design where the primary purpose of the fusion–fission reactor is to reprocess waste into new fuel. Although far less economical than chemical reprocessing, this process also burns off some of the nastier elements instead of simply physically separating them out. This also has advantages for non-proliferation, as enrichment and reprocessing technologies are also associated with nuclear weapons production. However, the cost of the nuclear fuel produced is very high, and is unlikely to be able to compete with conventional sources.

5. Possible Products, budgets and timeframe:

Product	Budget	Timeframe
Muonic Deuterium - Produced by PW laser bombardment in metal targets and passing the muons by EM and cryogenic fields, bombarding frozen Deuterium gas	5.000k Euros	3 years
Uranium 238 micro pellets and carbon pellets injector	2.500k Euros	3 years

6. Proposed added solutions

A. In deuterium - tritium reactors : DT reaction (for Magnetic-Confinement Fusion and Stellarators) :
   a. Manufacture and supply deuterium with a small percentage of muonic deuterium to be injected via the Neutral beam injectors
   b. Uranium 238 micro pellet injector (Pellets with or without beryllium coating)

B. In deuterium - hydrogen reactors : DD reaction + possible HC reaction (for Magnetic-Confinement Fusion and Stellarators) :
   a. Manufacture and supply deuterium with a small percentage of muonic deuterium to be injected via the Neutral beam injectors
   b. Uranium 238 micro pellets injector (Pellets with or without beryllium coating)
   c. Carbon Pellets injector

7. For Space propulsion the pellet system with Fusion fuel gas injector activated by a laser might create sufficient impulse in a specifically designed nozzle for a spacecraft to generate space speeds of 75% the speed of light.

8. References

- CNO cycle - Wikipedia https://en.wikipedia.org/wiki/CNO_cycle
- Muon-catalyzed fusion - Wikipedia https://en.wikipedia.org/wiki/Muon-catalyzed_fusion
- Nuclear fission - Wikipedia https://en.wikipedia.org/wiki/Nuclear_fission
- Nuclear fusion - Wikipedia https://en.wikipedia.org/wiki/Nuclear_fusion
- International Muon Ionization Cooling Experiment - Wikipedia https://en.wikipedia.org/wiki/International_Muon_Ionization_Cooling_Experiment
- SGT5-8000H | H-class Gas Turbine | Gas Turbines | Manufacturer | Siemens Energy Global (siemens-energy.com)
- ITER Pellet Injector produces deuterium ice
- Nuclear fusion–fission hybrid - Wikipedia