

Vinyl 2010 Essay Competition Submission

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Summary:

*The concept of the Energy Cascade is motivated by the requirement to enhance the life and efficiency of existing energy technology. The link between the Food and Energy Crises is considered. The limitations of present nuclear power motivate the need for a hybrid system, a concept that has been recently proposed elsewhere. This hybrid system can form the base of a cascaded set of power plants, which benefit from mutual synergy, so that efficiency is maximised. Circumvention of the Energy Crisis requires a multi-pronged attack, in which this concept can play a crucial role and maximise societal well-being.*¹

Essay:

The Food and Energy Crises are critical drivers for technological innovation today. An overall systems approach to tackle them has been delineated.

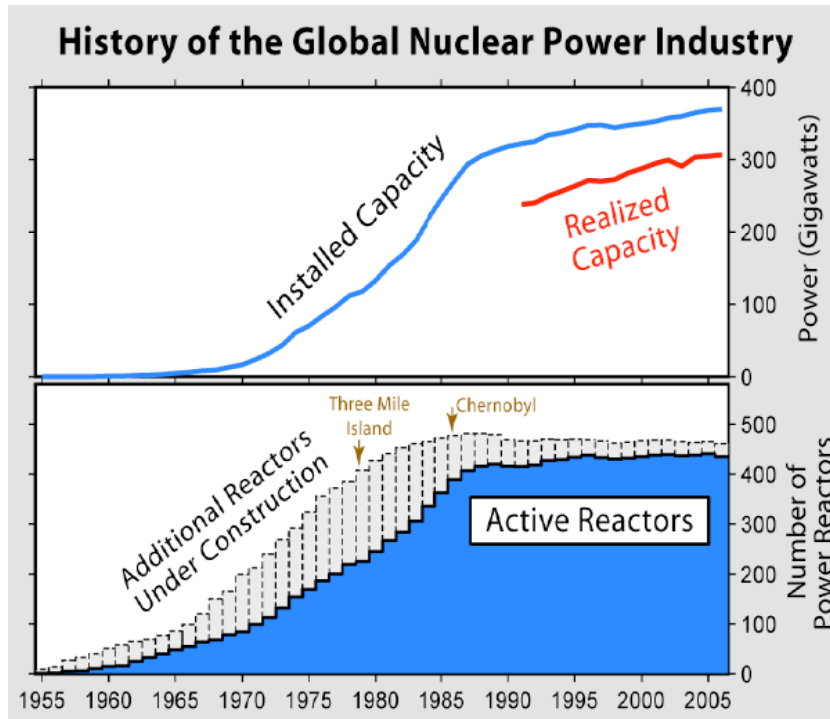
Based on the average solar insolation and efficiency of biological nitrogen fixation, food crops cannot autonomously give enough yield to satisfy global food requirements. Without the 'fixed' nitrogen that is anthropogenically obtained, through fertilisers, the food crisis would have occurred much sooner. However, fertilisers require energy to produce, derived for the moment from fossil fuels. In layman terms, this tells us that we are literally 'eating' our way through our fossil fuel reserves. A long-term solution to our energy needs plays a major role in alleviating the food crisis.

Although fossil-fuel fired and nuclear-based solutions are considered as unclean, inefficient and unsustainable, the fact remains that for the present and the near future, they will continue to be the main sources of energy on a global scale. Here, the proposition is made that they can indeed be developed to be a part of a sustainable society.

In brief, the Energy Cascade is a centralised, interdependent system of power plants, arranged in a cascaded manner, such that the exergy output of one is the exergy input of the next power plant. It is similar to the concept of a binary-cycle thermal power plant. Each stage of the Cascade is considered below.

Nuclear fusion, as an inexhaustible energy resource has been subject to intense research from around 1975. The most recent experiments with nuclear fusion have been JET (EU) and TFTR (US). There is currently an internationally-initiated test facility under construction at Cadarache, France, the International Thermonuclear Experimental Reactor. It is however, to be noted that none of these ventures were intended for the commercial production of power. The obstacles in achieving commercial fusion power remain high-temperature materials, inability to confine neutrons magnetically and the inability to transfer exergy from the extreme high-temperature plasma.

Nuclear fission, in contrast, has had a much greater commercial success, with nearly 300 GW of installed power (16% of total world energy production). As can also be appreciated from the graph, the rate of installation of nuclear fission power has declined to almost zero at the end of 2005. Again, from the graph, this decline has occurred after the nuclear disasters of Chernobyl and Three Mile Island. This leads to the conclusion that nuclear fission power, in spite of existing commercial potential, is not being exploited due to inherent safety concerns, including both operational and disposal issues. Another cause for concern impeding the development of nuclear fission power is the possibility of proliferation.



At the heart of the Cascade lies the concept of the hybrid fusion-fission reactor, as developed in the 'LIFE' project of the Lawrence Livermore National Laboratories, USA. This concept involves the cascading of fusion and fission reactors in such a way that the drawbacks of each system appear to be negated. The fusion core (Deuterium/Tritium) is surrounded by a blanket of subcritical fissionable or fertile material. The fusion core needs to be excited by laser pulses, as in the current state-of-the-art fusion reactors. The advantages of such a system are:

1. The neutrons and thermal output of the fusion reaction can be directly used by the blanket material to undergo fission.
2. The sub-criticality of the blanket layer ensures that in the absence of laser pulsing, there can be no sustained/accelerated chain reactions, or in common words, 'nuclear meltdown'.
3. As the blanket can be any fertile/fissile material, this includes present nuclear waste, which can be actively degraded. This means that the potential feedstock

- for a hybrid reactor is many times larger. Further, the fusion-enhanced fission theoretically produces no radioactive waste to be disposed off.
4. As there is no intermediate that can be conveniently used to manufacture nuclear weapons, this technology is less prone to proliferation.

According to LLNL postulations, the input energy to initiate fusion is reduced to half. Also, energy obtained is considered to be around 100-300 times that of input. In previous fusion reactions, output energy has always been less than input energy. There still exist a number of fundamental and engineering challenges to be overcome in this concept.

This can be augmented to enhance the efficiency of other power generating systems. Both fusion and fission systems require heat removal once steady operating conditions have been reached. This high quality heat can be used in the following steps in the Cascade:

1. A partial oxidiser or a reformer can be heated by the waste heat from the hybrid reactor, to convert fossil fuels or other organic matter, bio-waste to a more suitable gaseous fuel, also achieving waste disposal in the process.
2. High/intermediate temperature solid oxide fuel cells can be supplied with this fuel. This is the most efficient option, as it bypasses the Carnot limit. *The turn of the century culminated in the current successful commercial prototype 150 cm cells, and a 100 kW cogeneration system that operated in the Netherlands, Italy, and Germany for more than 36,000 hours.* It can be hoped that cost-effective and reliable fuel cell technology will develop simultaneously.
3. Also, fluidised-bed combustion chambers can be developed for organic matter that is less susceptible to gasification. Heat from higher stages of the Cascade can be used to preheat the high-velocity air entering the fluidised bed reactor.
4. Gas turbines can also be alternatives in the lower stage of the Cascade, utilising exergy from higher stages as preheat.

Any further low-quality heat can be used to drive a bottoming Rankine cycle or simply as process heat, which forms the last stage of the Cascade. As can be seen, the Cascade achieves large efficiency benefits over existing power production technologies.

There has been recent public focus on decentralisation and the development of renewable energy technologies; this proposition urges simultaneous attention towards increasing sustainability of existing commercial energy technologies by exploiting their inherent synergy.

ⁱReferences:

1. US Department of Energy facts and figures
2. TU Delft SET3011 Lecture Series
3. National Ignition Facility facts and figures