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Achieving Net-Zero Emissions Through Nuclear: The "New Clear" Energy of the Future | *Alvin Chew*

The world is abuzz with ambitions of reaching the goal of net-zero carbon emissions by 2050. UN Secretary-General Antonio Guterres has called on countries to align their climate action with the UN Sustainable Development Goals (SDGs) 2030, which can serve as a guiding framework to ensure a just and inclusive energy transition. SDG 7, a goal for sustainable energy, is aimed at providing access to affordable, reliable, sustainable and modern energy. There is only one source of energy that satisfies these four characteristics – nuclear. Nuclear energy forms an integral part of the net-zero equation. Among advanced reactor technologies is a class of high temperature gas-cooled reactors (HTGRs) that could enhance the civilian applications of nuclear energy to help countries meet their net-zero ambitions.

Safety and Security of HTGRs

The International Atomic Energy Agency (IAEA) projected that the global adoption of nuclear energy will more than double to 890GW by 2050, mostly driven by the advent of small modular reactors (SMRs). While these new reactors incorporate advanced passive safety features, the main attractiveness of an SMR is its smaller output (less than 300MW) compared to conventional large reactors.

From an economic standpoint, the lower upfront costs associated with an SMR makes it more affordable for states that are newcomers in the nuclear market. Its modular feature allows countries to scale up by adding on more reactors in accordance with their increasing grid capacities. Most importantly, SMRs can be sited closer to city centres, which is why Singapore remains open to the nuclear option.

While the size of reactors has come down, t advances have been made in terms of technology. More than 96% of operating reactors use water-cooled technology. Over the course of 70 years, only two major accidents have occurred thus far involving such reactors: (i) Chernobyl (1986) and (ii) Fukushima (2011).

As no accident is considered too small, the nuclear industry can certainly strive to improve the design by making reactors inherently safe. The HTGR is one such design that will have zero possibility of a core meltdown. Firstly, instead of water, the HTGR uses helium as a coolant. Helium is an inert gas and it has no reactivity effects. Secondly, the graphite that serves as a moderator has a high heat capacity and thus is able to withstand very high temperatures. During operation, the graphite core of the reactor is capable of sustaining the low pressure but high temperature, thus making the structure stable. Finally, the fuels used in HTGRs – known as TRISO fuel particles, each particle being made up of a uranium, carbon and oxygen kernel – will not degrade as they are coated with several layers of protection to hold all fissionable products in the event of an accident.

In a HTGR, forced cooling is not required as waste heat removal will be through natural convection. Hence, to facilitate the cooling process, the HTGR plant theoretically does not need a containment building. However, it is still essential for the HTGR to be housed within a fortified building to protect the reactor against any external security threats, such as drone or missile attacks.

Regulatory Standards for Safeguards

Currently, there are two types of reactor cores for HTGRs. The experimental HTGR in Japan uses the prismatic block design, which resembles the conventional fuel assemblies used in most reactors. The test reactor, which has an output of 30MW, was commissioned in 1999, but development was stopped owing to regulatory reviews after the Fukushima accident. In 2021, this test reactor restarted its operations as a testbed for future HTGRs that could be deployed for hydrogen production.

In China, scientists adopted the “pebble-bed” module based on the German design of the 1960s for their HTGRs. China had commissioned the first of such HTGRs in 2021 and started commercial operation in 2023. However, the design has a shortcoming – it is difficult to trace the pathway of the fuels in the pebble-bed module – and thus uncertainty arose as to when the fuel will be expended. This difficulty poses a safeguard challenge as there is currently no developed mechanism to account for the fissionable products during operation. It is not an issue for China, being one of the five permanent members of the UN Security Council that have committed to perform safeguards on a voluntary basis. Nevertheless, safeguarding spent fuels by the IAEA will be necessary if such a reactor is to be exported to and operated in other countries.

Cogeneration Capability

Nuclear power plants primarily produce heat, which can then be used directly for district heating during wintry seasons. A nuclear power plant can also directly convert seawater to potable water, a process known as desalination. In most cases, the heat from the nuclear power reactor is transformed to electricity, which is an energy carrier that has wider applications.

As the nuclear process does not emit any carbon dioxide, the electricity that it produces is environmentally friendly. In addition, the energy content derived from nuclear power is millions of times greater than burning coal, oil or gas. In this regard, nuclear power is able to constantly provide stable electricity for industrial and residential uses, a trait that many intermittent renewables, such as solar or wind, do not have.

However, not all industrial sectors run on electricity. There are hard-to-abate sectors like transportation or steel reforming that resort to the burning of pollutive hydrocarbons. Therefore, hydrogen has been identified as the future alternative energy carrier to help decarbonise such sectors.

HTGRs, owing to their high temperature heat output, can be used to produce hydrogen via the thermochemical process, which requires very high heat (more than 800 degrees Celsius) that cannot be achieved with conventional water-cooled reactors. This process is more efficient than electrolysis – the splitting of water into hydrogen and oxygen elements – and HTGRs can serve as cogeneration facility for clean and sustainable hydrogen as well as electricity for deep-carbonisation efforts (i.e., total abstinence from hydrocarbons).

Artificial Intelligence

However, hydrogen is not easily stored and transported. Hence, the supply of hydrogen has to be intricately managed. Artificial intelligence (AI) can be incorporated into HTGRs to optimise the channelling of heat for hydrogen production in a cogeneration plant.

Generative AI can also be used to analyse and process large data accumulated from modelling the fuel paths in a pebble-bed module. It can then serve as a predictive tool to help IAEA officers conducting safeguards to better account for the TRISO fuels used throughout the entire operation.

Conclusion

Finland faced an energy crisis when it banned energy imports from Russia. In 2023, its long-awaited nuclear power plant was commissioned, and it immediately enjoyed access to clean energy so much that the prices of energy plunged below zero Euros, that is, its population is paid to use electricity! Furthermore, the reliable supply of energy from the nuclear power plant means that the country need not worry about energy imports or whether there is sufficient sunshine or strong winds. Nuclear energy is environmentally sustainable because it is carbon-free.

The relentless pursuit of technological advancement in the field of nuclear science has indeed made nuclear power the only affordable, reliable, sustainable and modern option to achieve our global goal of net-zero emissions.

About the Author

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