Future of Nuclear Energy: Small is the New Big

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- As the EU aims for net-zero carbon emissions, a split persists over how to address energy security concerns stemming from the Ukraine-Russia conflict.
- Small modular reactors are expected to be game-changers in this regard as they will have the much-needed load-following capability that will complement renewable generation in the future.

In the last decade, major economies moved away from nuclear energy to produce electricity, including Germany and Japan, which was a direct consequence of the Fukushima nuclear power plant disaster that took place in 2011. Germany announced plans to phase out nuclear power plants in the country completely. The phase-out was initially planned to be completed by the end of 2022, but due to the energy crisis exacerbated by the Russia-Ukraine war, it was delayed for a few months. Finally, on 15 April 2023, Germany shut down its last three nuclear reactors, including Emsland, Isar, and Neckarwestheim.

But at the end of last year, Japan, from where it all started, pledged to re-embrace nuclear power technology in order to meet the increasing energy requirements of the country. Japan is planning to extend the lifespan of existing nuclear power plants, replace the aging nuclear power plants, and build new ones as well. This move, followed by

advancements in nuclear technology, has reignited the debate around the future of nuclear power technology all over the world.

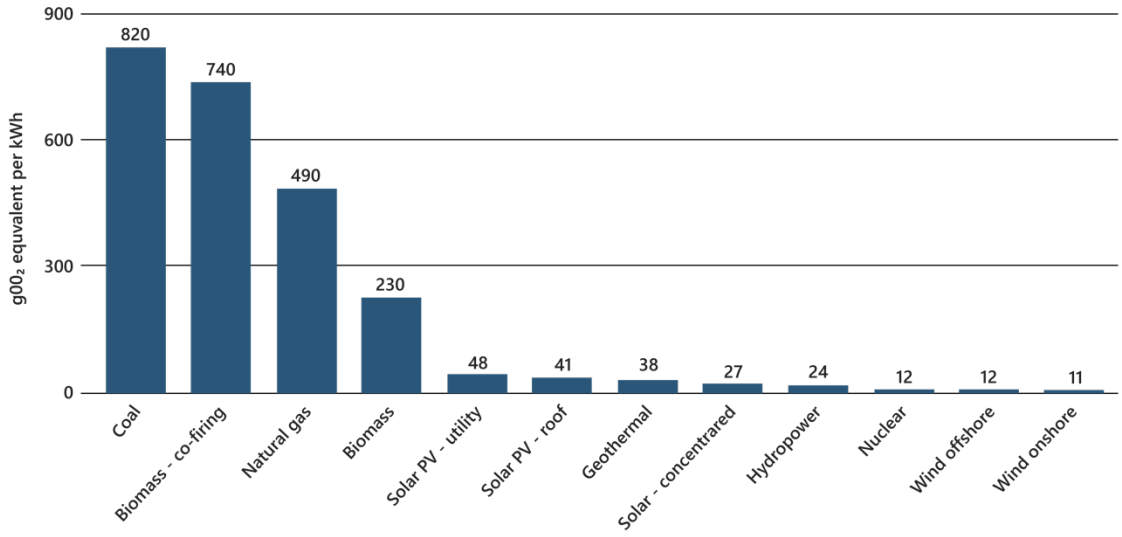

Figure 1: Average Lifecycle Carbon Dioxide Equivalent Emissions for Different Electricity Generation Technologies. Source: IPCC

Challenges that Nuclear Power Faces

Although nuclear power produces less carbon emissions than non-renewable energy resources, there are certain challenges with generating electricity from nuclear energy. These challenges include high upfront costs, long lead time, lack of load-following capability, and public opposition to constructing nuclear power plants. For nuclear power to have a future alongside renewable energy resources, these challenges need to be catered to.

High upfront costs and long lead time

The nuclear power plants have high upfront costs and long lead times. The intricate reactor design requires billions of dollars to reach completion, compounded by a significant time lag in the production process. The planning-to-operation timeline for nuclear power plants ranges from 10 to 19 years, delaying a nation's access to nuclear-generated electricity by more than a decade. The procedure involves locating a suitable site, obtaining permits, procuring land via purchase, negotiating power purchase agreements, constructing the facility, integrating it into the transmission network, and securing the final operational license. These expensive and time-consuming processes discourage potential investors and governments from pursuing nuclear power plant projects.

Lack of load-following capability

Nuclear power plants were mostly designed and operated as base load power plants, which lack load-following capability. This has created operational issues in countries where both nuclear and renewable energy have a significant share in the generation mix. So, during periods of low demand, excess renewable generation must be curtailed as nuclear power plants can't adjust power output at the rate that is required. This, in turn, disincentivized investment in renewable energy projects in a wholesale electricity market regime, as there were instances when electricity prices became negative.

(The nuclear fleet of France is an exception when it comes to load-following capability)

Disposal of spent fuel

Safe disposal of spent fuel has been a challenge for the nuclear power industry all over the world. The challenge of disposal is one of the reasons why we don't see significant growth in nuclear power generation capacity globally. The spent fuel can remain radioactive and deter human health for thousands of years, which is the reason why there are strict regulations that deal with the disposal of nuclear waste.

Public opposition

Catastrophic incidents involving nuclear power plants, such as the Fukushima disaster, have eroded public trust in these facilities. Such events have made countries reluctant to rely on nuclear energy for electricity due to the potential for immense financial losses. The aftermath of Fukushima has left several nations cautious regarding the viability of nuclear power technology.

The European Union (EU) finds itself divided over the use of nuclear energy for electricity generation. The Ukraine-Russia conflict has complicated matters. Faced with the need for energy independence, some EU members, like France and Finland, support nuclear energy. In fact, 70% of the energy needs of France are met by nuclear energy. Conversely, nations like Germany and Sweden oppose nuclear energy. As the EU aims for net-zero carbon emissions, a split persists over how to address energy security concerns stemming from the Ukraine-Russia conflict.

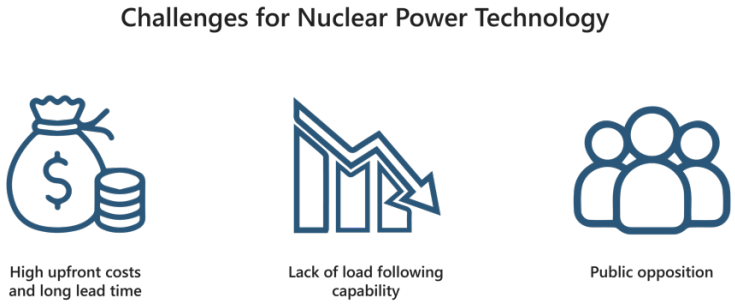

Figure 2: Challenges for Nuclear Power Technology.
Source: PTR Inc

Future Technologies

To meet the energy demands through nuclear energy in a cost-efficient way, small modular reactors are being built. These reactors allow flexible siting and can have a power generation capacity of up to 300 MW per unit. Some parts of the modular reactor can be constructed beforehand and brought together with the modular reactor to extend the facility. Their construction is completed in less time and can be deployed accordingly to match energy needs.

Traditional nuclear power plants are not considered safe for the purpose of load following, which is why they did not go well with renewable energy. During periods of high production and low demand, renewable generation must be curtailed as nuclear power plants lack the capability to adjust power in a short span, as mentioned earlier. But small modular reactors are expected to be game-changers in this regard as they will have the much-needed load-following capability that will complement renewable generation in the future.

Furthermore, there has been a lot of debate and concern regarding the safe disposal of spent nuclear fuel in the nuclear power industry. Finland has addressed this problem by constructing the Onkalo disposal facility, situated 450 meters below ground, designed to accommodate used fuel from nuclear power generation. This fuel will be securely stored in canisters for very long periods. A third of the nation's energy demands are fulfilled by nuclear power plants; the waste from this process will go to the Onkalo repository.

Looking Ahead

The nuclear power industry faces a range of challenges, including high upfront costs, long lead times, public opposition, lack of load-following capability, and disposal of spent fuel. These impediments can be resolved with modern technology, for instance, modular reactors and underground nuclear repositories. It is believed that the future of nuclear power rests with the successful deployment of small modular reactors.

Due to load-following capability, SMRs will complement renewable generation capacity, in turn creating the possibility for deployment of hybrid energy systems (SMRs with renewable generation) in the future. However, in order to deploy SMRs or underground spent fuel repositories (like in Finland), public-private funding worth billions of USD will be required.

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