



Deployment of Nuclear Energy Systems for Beyond Electricity Application

in Pakistan

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Nuclear Energy Applications

Introduction

Nuclear power plays a significant role in electricity production. It produces around 10% of global electricity and is the leading low-carbon source in advanced economies.

In the same period, global electricity demand has more than doubled and global energy demand has increased by more than 50%.

However, energy is more than just electricity. Heat is the largest energy end-use.

Nuclear Energy Applications

Introduction

From heating our homes to Industrial processes this energy is used in many ways.

From low-grade heat to district heating and industrial process heating, nuclear energy can supply, and in some cases already supplying, the heat necessary to decrease emissions in many sectors.

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Pakistan Nuclear Energy Dynamics

The deployment of nuclear energy systems in Pakistan has primarily been centered on electricity generation to address country's increasing energy demands and reduce dependence on non-renewable energy resources.

2

Applications Beyond Electricity in Pakistan

Pakistan has always had a clear take on deployment of nuclear energy systems for applications beyond electricity generations in critical sectors

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Challenges

Markets for nuclear beyond electricity applications could be described as chronically undervalued shadowed by many limiting factors like Governmental policies etc.

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Conclusion

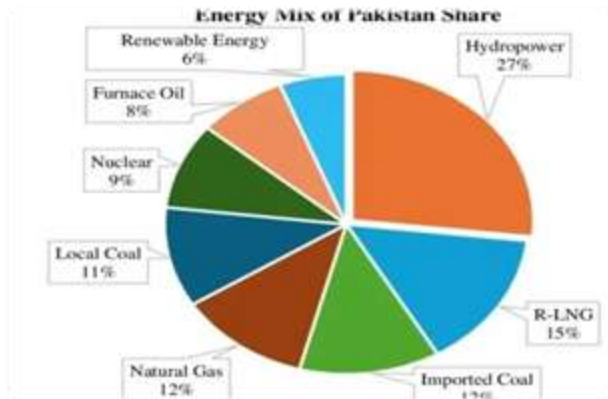
With the appropriate incentives and measures, nuclear could play an important part on the global decarbonisation journey.

01

Pakistan Nuclear Energy Dynamics

Pakistan Nuclear Energy Dynamics

Pakistan's nuclear energy program largely focuses on electricity production with recent take on non-electric applications as well.



Nuclear Energy Contribution

Nuclear power has become an important component of Pakistan's energy mix, contributing to energy security, economic stability and reduction of carbon emissions.

As nuclear technology is considered a clean and green energy source, it is imperative for Pakistan to fully harness this technology, which will eventually assist in climate change mitigation. Presently, Pakistan operates six Nuclear Power Plants (NPPs). These NPPs are playing a vital role in fulfilling energy requirements, which contribute around 3530 megawatt to the national grid. The utilization of nuclear technology for energy helps in reducing Pakistan's dependence on fossil fuels.

Pakistan Nuclear Energy Dynamics

Pakistan's nuclear energy program largely focuses on electricity production with recent take on non-electric applications as well.

Reactors operating in Pakistan

Reactor Name	Alternative Name	Model	Reactor Type	Net Capacity (MWe)	Construction Start	First Grid Connection
CHASNUPP-1	<u>Chashma Nuclear Power Plant 1</u>	CNP-300	PWR	300	1993-08	2000-06
CHASNUPP-2	<u>Chashma Nuclear Power Plant 2</u>	CNP-300	PWR	300	2005-12	2011-03
Chashma Nuclear Power Plant Unit 3	<u>Chashma Nuclear Power Plant 3</u>	CNP-300	PWR	315	2011-05	2016-10
Chashma Nuclear Power Plant Unit 4	<u>Chashma Nuclear Power Plant 4</u>	CNP-300	PWR	313	2011-12	2017-06
K-2	<u>Karachi 2</u>	HPR1000	PWR	1,017	2015-08	2021-03
K-3	<u>Karachi 3</u>	HPR1000	PWR	1,017	2016-05	2022-03

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Nuclear Energy Non-Electric Application in Pakistan

In a world grappling with climate change, food security, and resource scarcity, few technologies hold as much transformative potential as nuclear science. Too often, however, the word “nuclear” is narrowly associated with weapons and deterrence, overshadowing its broader contributions to sustainable development.

Nuclear Energy Non-Electric Application in Pakistan

Nuclear technology has quickly emerged as a vital enabler of the United Nations Sustainability Goals (SDGs). And for Pakistan, this story is even more striking. Beyond the headlines of strategic security, the country's nuclear program is silently powering hospitals, enabling water desalination, transforming agriculture, and mitigating climate risks. Pakistan is currently working on 13 SDGs out of 17, aligning its nuclear policies with global development priorities.



Sea Water Desalination

Desalination of seawater is a very energy intensive process. Today, that energy is supplied primarily from fossil fuels but with fossil fuel prices volatility, uncertain availability, carbon taxes, and increasing environmental and geopolitical concerns, developers of desalination plants are looking to other energy sources such as renewable energy or nuclear energy

- There are three main desalination processes :
Evaporative desalination through Multiple Effect Distillation (MED) or Multi-Stage Flash (MSF) distillation and membrane distillation through Reverse Osmosis (RO)
- MED and MSF uses Thermal Energy, RO uses Electrical Energy



Sea Water Desalination

Pakistan operates a Nuclear Desalination Demonstration Plant (NDDP) coupled with the Karachi Nuclear Power Plant (KANUPP).

- The facility utilizes extraction steam to produce thousands of cubic meters of potable water daily through Multi-Effect Distillation (MED) process coupled directly to the reactor via an Intermediate Coupling Loop to prevent any radioactive contamination of the water.
- The MED plant produces 1,600 cubic meters (m³) of potable water per day.



- Alongside the MED plant, an indigenous Reverse Osmosis (RO) facility operates at the site, contributing an additional 454 m³ per day, primarily utilized for reactor operations and clean water needs.
- This model is designed to provide safe drinking water to local coastal communities

Future Projects

District Heating

Using steam or hot water produced at the NPP and distributing it through a network of underground pipes

Small Modular Reactor (SMR) Roadmap

Small Modular Reactors (SMRs) are advanced nuclear reactors with a power capacity of up to 300 MW(e) per unit, which is about one-third of the generating capacity of a traditional nuclear power plant



Hydrogen Production

Nuclear energy is in a good position to support the envisioned hydrogen economy. It can produce large quantities and high-quality hydrogen

Other Services

Nuclear Energy Systems can be used for other non-electric applications.

District Heating

District heating relies on a centralized energy plant for the distribution of heat to residential and commercial buildings. In nuclear district heating, steam produced by a nuclear power plant serves to heat regional heating networks. This practice has been implemented in several countries – Bulgaria, China, Czech Republic, Hungary etc.

Technical features:

- Steam or hot water: 80-150 °C
- Typical distribution: 10-15km



Small Modular Reactors (SMRs)

The intersection of Small Modular Reactors (SMRs) and nuclear cogeneration represents a major shift in clean energy, moving nuclear power directly into industrial manufacturing and urban heating SMRs and Hydrogen Production

Modular Design

Factory-assembled units can be shipped via truck or train and installed incrementally to meet growing energy demands Benefits of SMRs



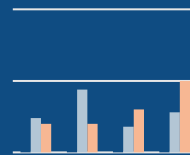
Flexible Siting

Their small footprint allows them to be built in remote locations or directly adjacent to heavy industrial sites that require massive amounts of heat



Inherent Safety

Many SMR designs use passive safety systems that rely on natural forces like gravity and convection to shut down safely without human intervention or electrical power.



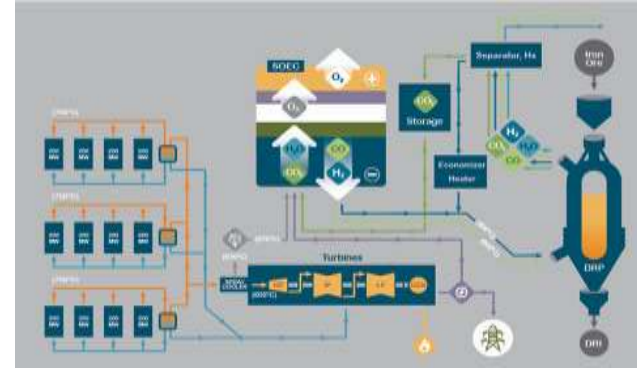
Scalable Output

Industrial heat and water markets are highly fragmented; multiple SMR modules can be added incrementally to match specific local demands

Small Modular Reactors (SMRs)

Introduction

Since Pakistan's national grid suffers from high line losses and infrastructure constraints, the state is officially evaluating SMRs as localized energy and industrial solutions.



Small Modular Reactor (SMR) Roadmap

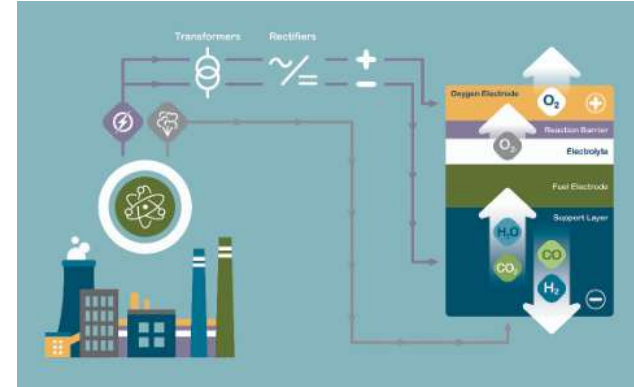
Strategic Positioning: PAEC's technical criteria specify a preference for Generation III+ innovative Pressurized Water Reactors (PWR) with a modular unit capacity between 35 MW electricity (MWe) and 100 MWe per module.

Target Deployments: Plans focus on deploying marine or land-based SMR clusters along the Makran Coast to run large-scale desalination, providing district heating in the freezing northern territories, and powering isolated industrial/mining clusters without drawing from the fragile main grid.

Hydrogen Production

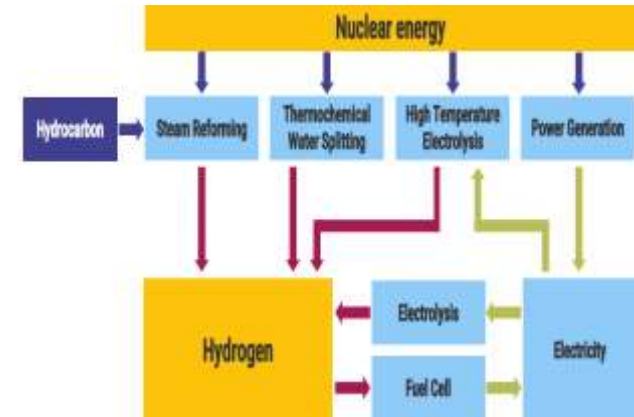
Introduction

Hydrogen is an environmentally friendly energy carrier that, unlike electricity, can be stored in large quantities. It can be converted into electricity in fuel cells, with only heat and water as by-products. It is also compatible with combustion turbines and reciprocating engines to produce power with near zero emission of pollutants.



Process of Hydrogen Production

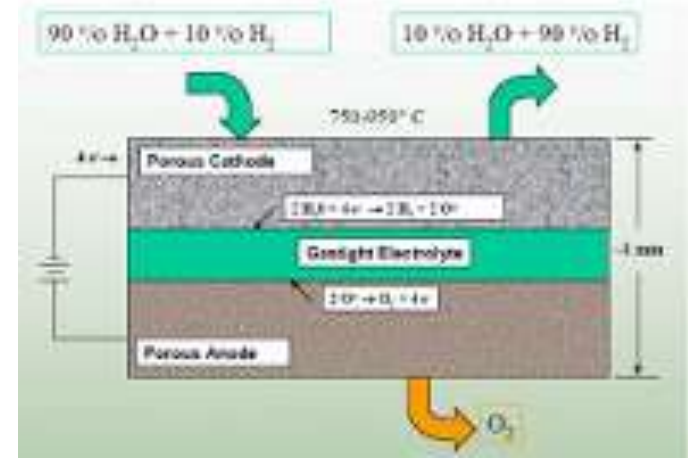
As a greenhouse-gas-free alternative, methods of using nuclear energy to produce hydrogen from water by electrolysis, thermochemical, and hybrid processes are being explored.



Hydrogen Production

By Electrolysis (Low Temperature)

Alkaline water electrolysis combined with nuclear energy produces highly scalable, zero-emission hydrogen.

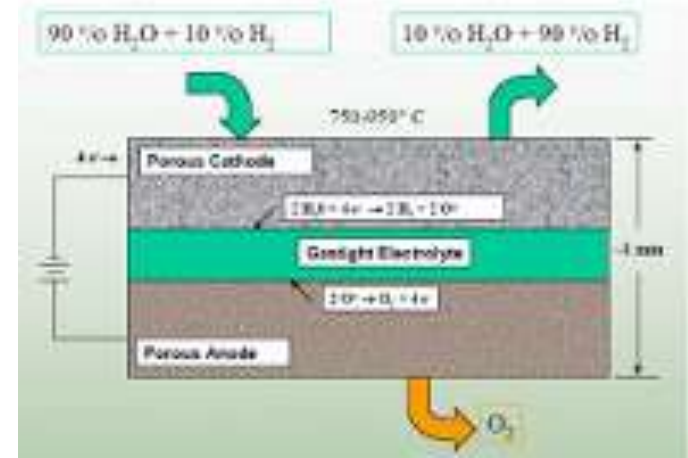


Nuclear reactors supply constant, large-scale electricity to the electrolyzer stacks. Some advanced systems also utilize low-temperature steam or waste heat (up to 200°C) from the nuclear plant's secondary circuit to reduce the electrical energy required for the splitting process, boosting overall thermal efficiency

Hydrogen Production

By Electrolysis

HTSE operates at 700-800 °C, but input steam is typically only needed at 150-200 °C, so the current fleet of LWRs and all types of advanced reactors, including SMRs, can effectively produce the heat needed for this process.

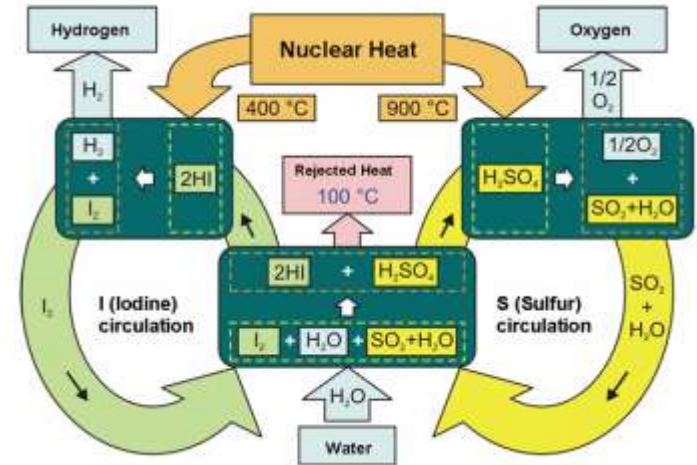


Efficiency can reach 40–50%, higher than conventional low-temperature electrolysis (~30–35%) because part of the energy input is supplied as heat rather than electricity

Hydrogen Production

By Thermochemical Cycles

It consists of a series of thermally driven chemical reactions where water is decomposed into hydrogen and oxygen at moderate temperatures. The only input to the cycle is water and high temperature heat.



It consists of three core reactions:

- the decomposition of sulfuric acid into sulfur dioxide, water vapor, and oxygen
- the hydrolysis of sulfur dioxide in the presence of iodine to regenerate sulfuric acid
- produce hydrogen iodide; and the catalytic splitting of hydrogen iodide into hydrogen gas and iodine

Ancillary Services

Hybrid energy systems

Applications of nuclear energy systems in hybrid configurations integrate nuclear reactors with renewables and industrial processes to produce electricity, hydrogen, and thermal energy



Thermal storage

At times when electricity sales are not profitable for nuclear plants, energy storage could be a viable application



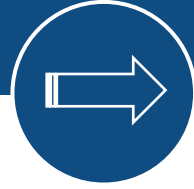
Data centres (power and cooling)

Nuclear energy systems offer a dual-benefit framework for data centers by simultaneously delivering zero-carbon electricity and high-temperature thermal energy to drive cooling



Marine propulsion

Nuclear marine propulsion utilizes small-scale nuclear reactors to generate heat, which produces high-pressure steam to drive propulsion turbines



04

Challenges

Using nuclear energy for non-electric uses—like hydrogen production, water desalination, and industrial heating—faces major hurdles. Key challenges include economic viability and business models, complex safety licensing for coupled systems, and strict site selection constraints

Challenges

Proximity to population centers

District heating and water desalination require locating the nuclear heat source near cities or industrial plants

Management

- Nuclear Waste
- Public perception

Continuous demand mismatch

Industrial processes and district heating require steady or seasonal load variations

Contamination prevention

Systems must be engineered with intermediate secondary loops to guarantee that radioactive material from the reactor.

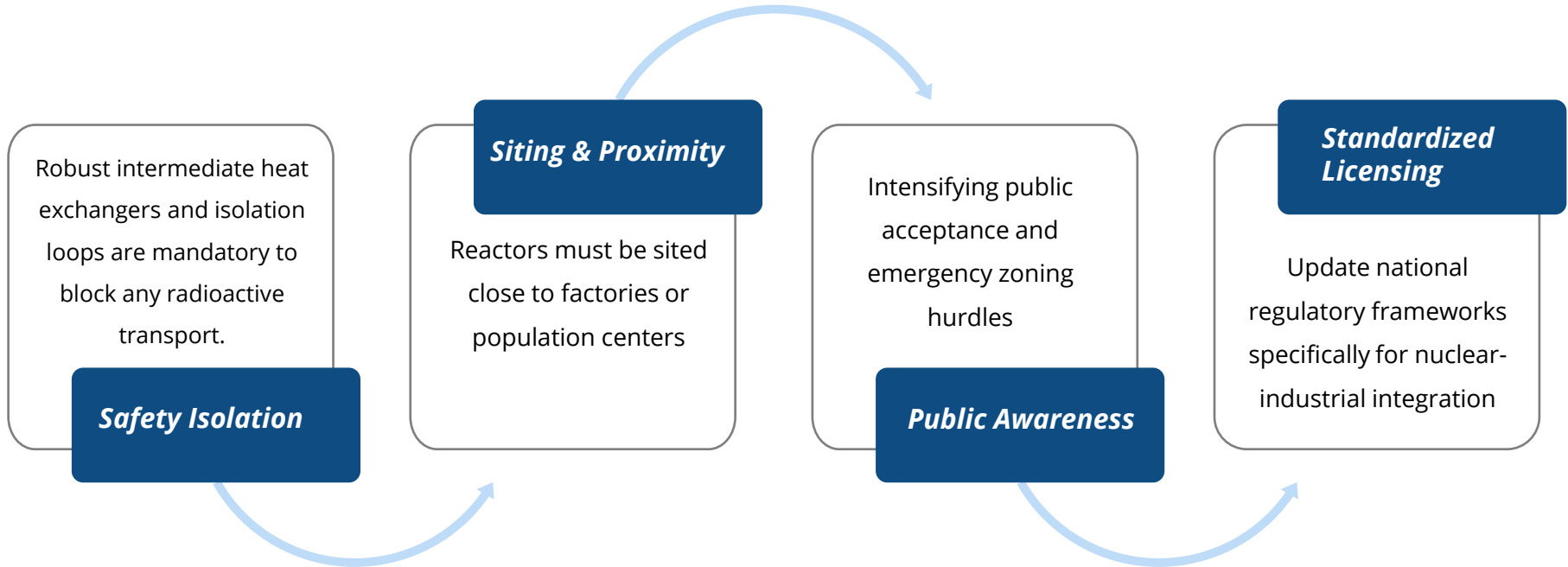
High initial investment

Building dedicated nuclear cogeneration plants requires massive upfront capital compared to burning fossil fuels for process heat.



Solutions & Recommendations

Overcoming these hurdles requires targeted strategies in reactor design and infrastructure integration aswell as strong policy making



CONCLUSION

*THE FUTURE OF NUCLEAR
ENERGY LIES NOT ONLY IN
POWERING HOMES, BUT ALSO
IN IMPROVING LIVES*

Summary

- Ø Nuclear energy already plays an important role in global electricity production.
- Ø It can also aid in the decarbonisation of otherwise hard to abate sectors
- Ø Diversifying nuclear applications can support sustainable development and energy security, market growth and other benefits to the user

Recommendations

- Ø Nuclear energy can provide clean energy (through electricity and heat) to sectors currently using fossil fuels such as Water desalination, District Heating, Hydrogen production etc.
- Ø However, Safe and responsible deployment is essential.



THANK YOU
