香港城市大學
City University of Hong Kong

APEC China Business Council

Efficiency Enhancement in Nuclear Electricity Generation

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Worldwide Nuclear Energy at a Glance

413
Operational Nuclear Reactors in 2023

9%
Share of Global Electricity Generation in 2023

2nd
Largest Source of Low-emissions Electricity

72Gt
CO2 Emissions Reduction by Replacing Fossil Fuels since 1971

>40
Countries Have Introduced Supportive Policies

65
Billion USD Investment Per Year Today

63
Nuclear Reactors under Construction in 2024

50%
Rise in Nuclear Capacity to 650 GW by 2050

Data source: IEA report, *The Path to a New Era for Nuclear Energy*, 2024

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What is Energy Efficiency?

Energy intensity, **the amount of energy used to produce a unit of economic output**, is used as a proxy for energy efficiency.

'Energy efficiency' means **the ratio of output of performance, service, goods or energy, to input of energy**

Energy efficiency means **using less energy to get the same job done** – and cutting energy bills and reducing pollution in the process.

Today, we look at the energy efficiency of nuclear in three ways

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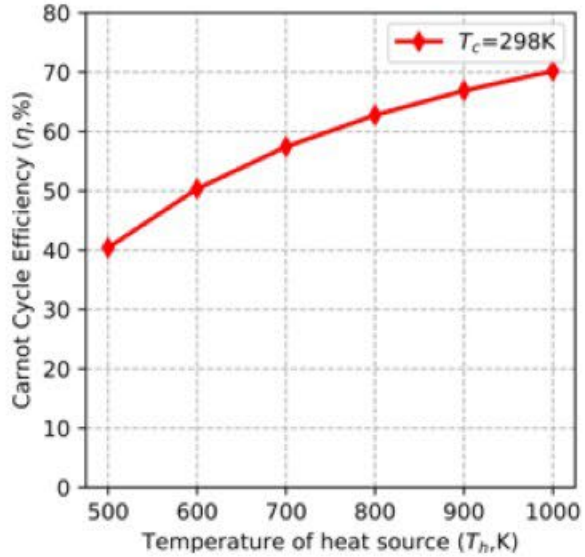
Technical Thermal Efficiency

1. Source temperature determines thermal efficiency, not source type (nuclear, fossil fuel or geothermal)

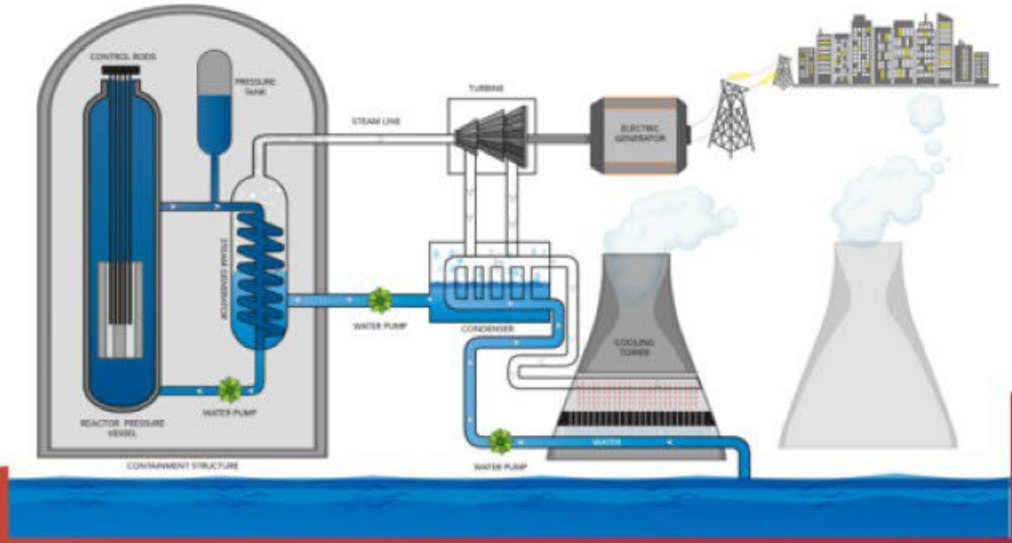
Carnot's theorem $$\text{Thermal efficiency} \le 1 - \frac{\text{Environmental temperature } T_C}{\text{Heat source temperature } T_H}$$



Heat source	Temperature
Geothermal, enhanced	~250°C
Nuclear, PWR	~325°C
Coal, ultra-supercritical	~760°C
Nature gas, combined cycle	~1200°C

The majority of nuclear reactors are subcritical water-cooled, and coolant is used as a heat source for steam generation. The limited temperature of the reactor coolant is the main limitation of the thermal efficiency of nuclear electricity generation.

PRESSURIZED WATER REACTOR (PWR)



Technical Thermal Efficiency

2. Nuclear has long achieved a higher thermal efficiency, but it is not indispensable

Water-cooled VS Gas-cooled

In the last century, gas-cooled reactors have much higher thermal efficiency than water-cooled reactors, but still lost the market competition.
Today, 96% of the nuclear reactors worldwide are water-cooled.

South Texas NPP in US
Pressurized water reactor
Commercial operation in 1990
Thermal efficiency **33%**

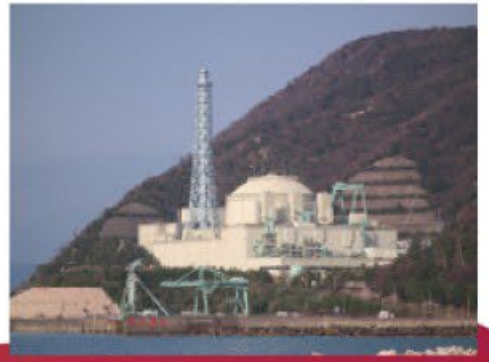
Heysham NPP in UK
Advanced gas-cooled reactor
Commercial operation in 1989
Thermal efficiency **40%**

Fast breeder reactor

Unlike fossil-fuel power plants, the breeder reactor can **produce more fuel than it consumes**. They do not use water for cooling, but other coolants, such as sodium, and thus have higher thermal efficiency. But it also does not guarantee commercial success.

Beloyarsk NPP in Russia
Started design in 1983
Commercial operation in 2016
Thermal efficiency **39%**

Monju NPP in Japan
Confirmed closure without
commercial operation in 2016
Thermal efficiency **39%**



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Technical Thermal Efficiency

3. The 4th generation nuclear reactors under development can achieve higher thermal efficiency

Non-water cooled 4th generation nuclear reactors have a thermal efficiency >40%.

HTR-PM in China
Thermal efficiency **42%**
In operation from 2021

BREST-OD-300 in Russia
Thermal efficiency **43%**
Under construction
Target for starting operation in 2026

Design	Country	Thermal efficiency	Status
GA EM^2	US	53%	Conceptual design
Xe-100	US	50%	Basic design
GTHTR300	Japan	50%	Basic design
AHTR-100	South Africa	50%	Conceptual design
GA FMR	US	50%	Conceptual design
GT-MHR	Russia	48%	Preliminary design
HOLOS-QUAD	US	45%	Detailed design
ThorCon	US	45%	Preliminary design
SC-HTGR	US	44%	Preliminary design
IMSR400	Canada	44%	Detailed design
FUJI	Japan	44%	Preliminary design

Data source: IAEA report, *Advances in Small Modular Reactor Technology Developments*, 2022

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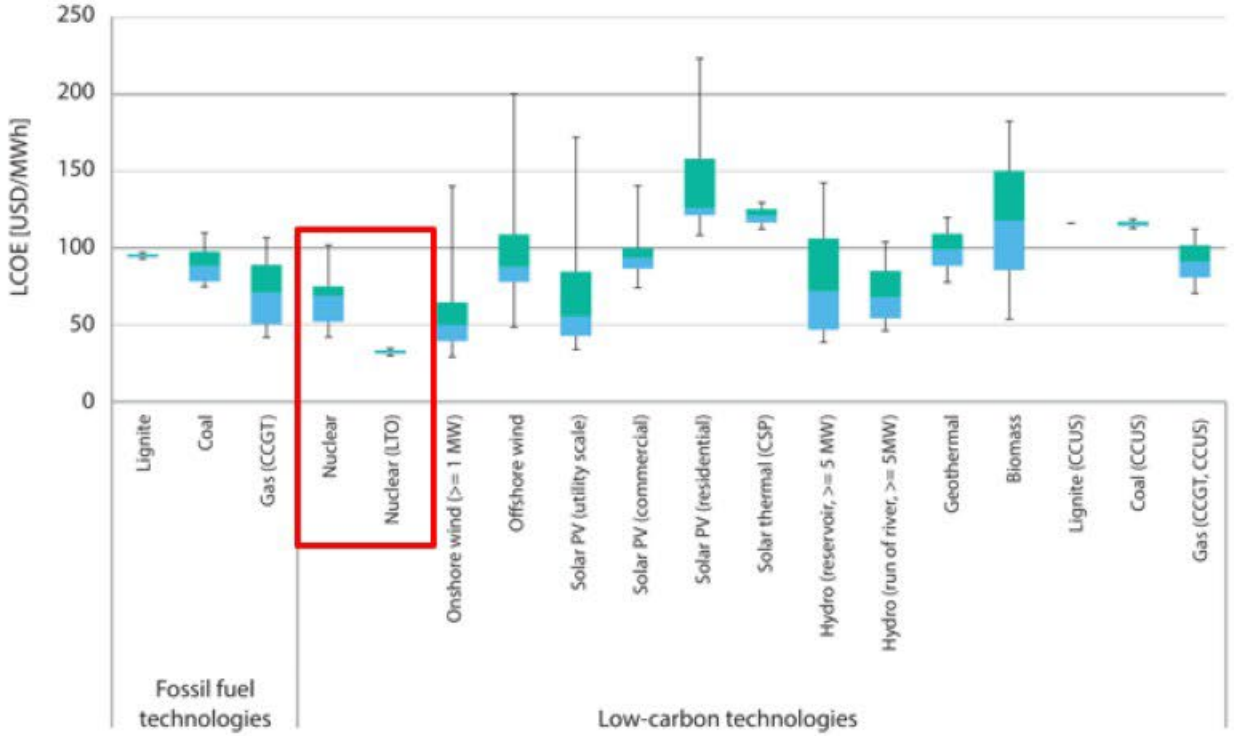
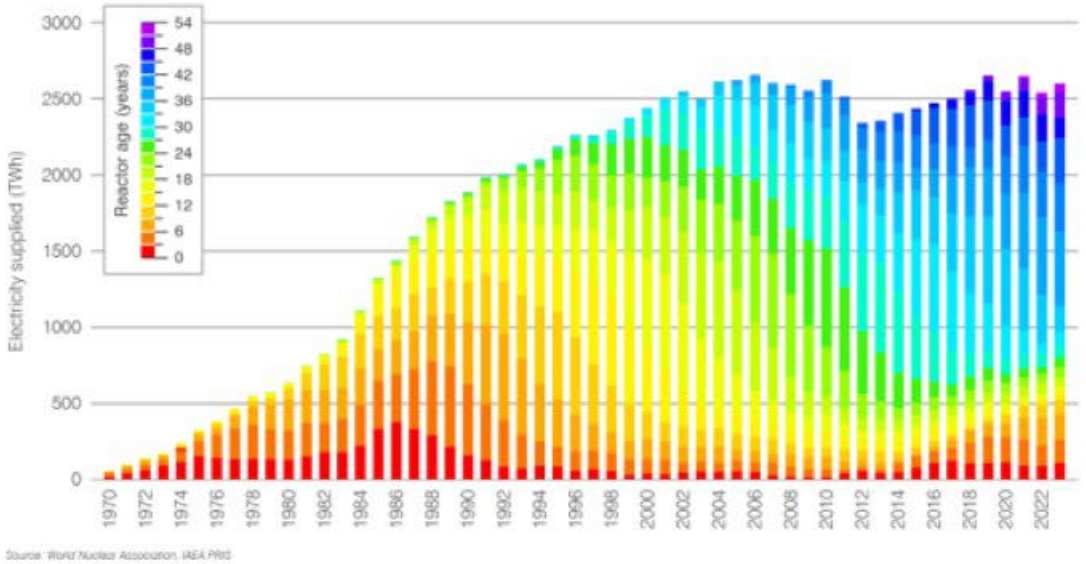
Economical Efficiency

1. Nuclear electricity is cheap, especially for long-term operation (LTO) by lifetime extension

In the latest version of International Energy Agency (IEA) report , *Projected Costs of Generating Electricity*





For the strict requirements of nuclear safety, the lifetime of a nuclear power plant has a very conservative original design. Today, after rigorous reevaluations, many nuclear power plants plan to extend their designed lifetime.

Levelized cost of electricity

$$\text{LCOE} = \frac{\text{Costs over lifetime}}{\text{Electrical energy produced over lifetime}}$$

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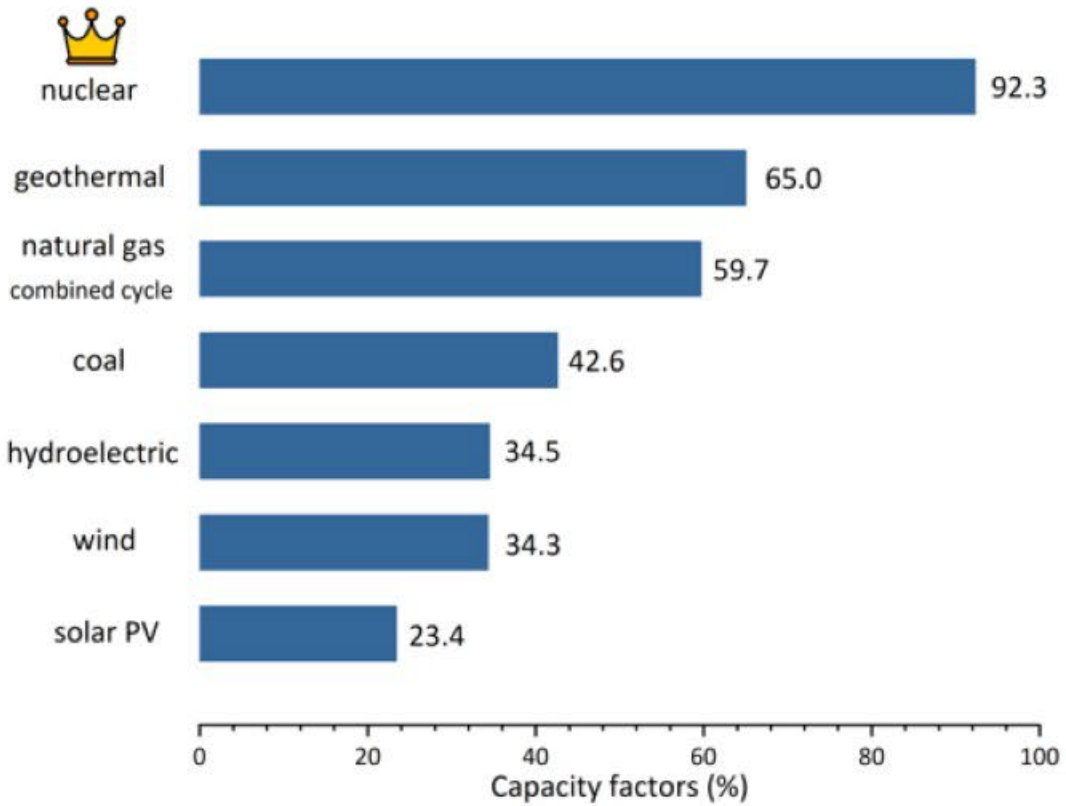
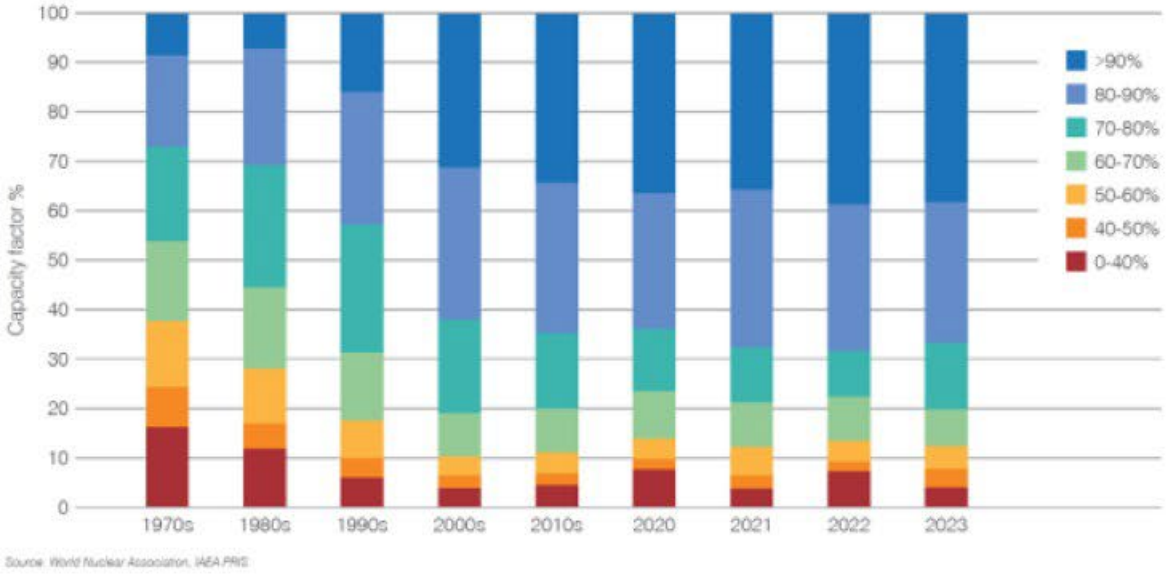
Economical Efficiency

2. Nuclear is a reliable source of electricity generation

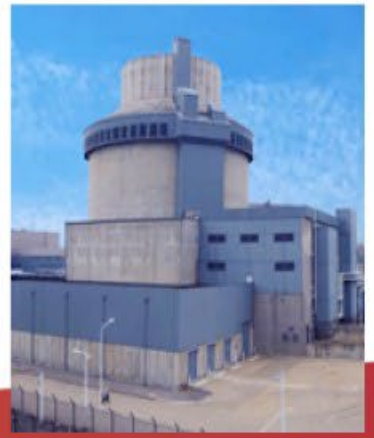
$$\text{Capacity factor} = \frac{\text{Annual electricity generation}}{\text{Nameplate capacity} \times 1 \text{ year}}$$



Data source: U.S. Energy Information Administration, Annual capacity factors by energy source in 2024.



Years of operating experience has enabled nuclear power plants to shorten refueling and maintenance period, optimize design and process, avoid accidents, and finally increase capacity factor.



1st AP1000 NPP in Sanmen, China

Shutdown and refueling period

1st time in 2019 : 46.66 days

3rd time in 2022 : 21.76 days ↓53%

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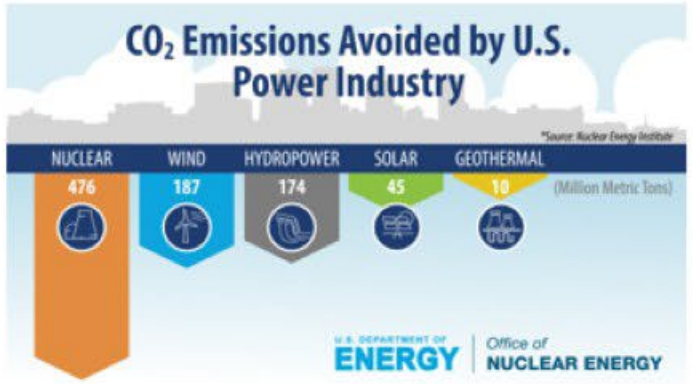
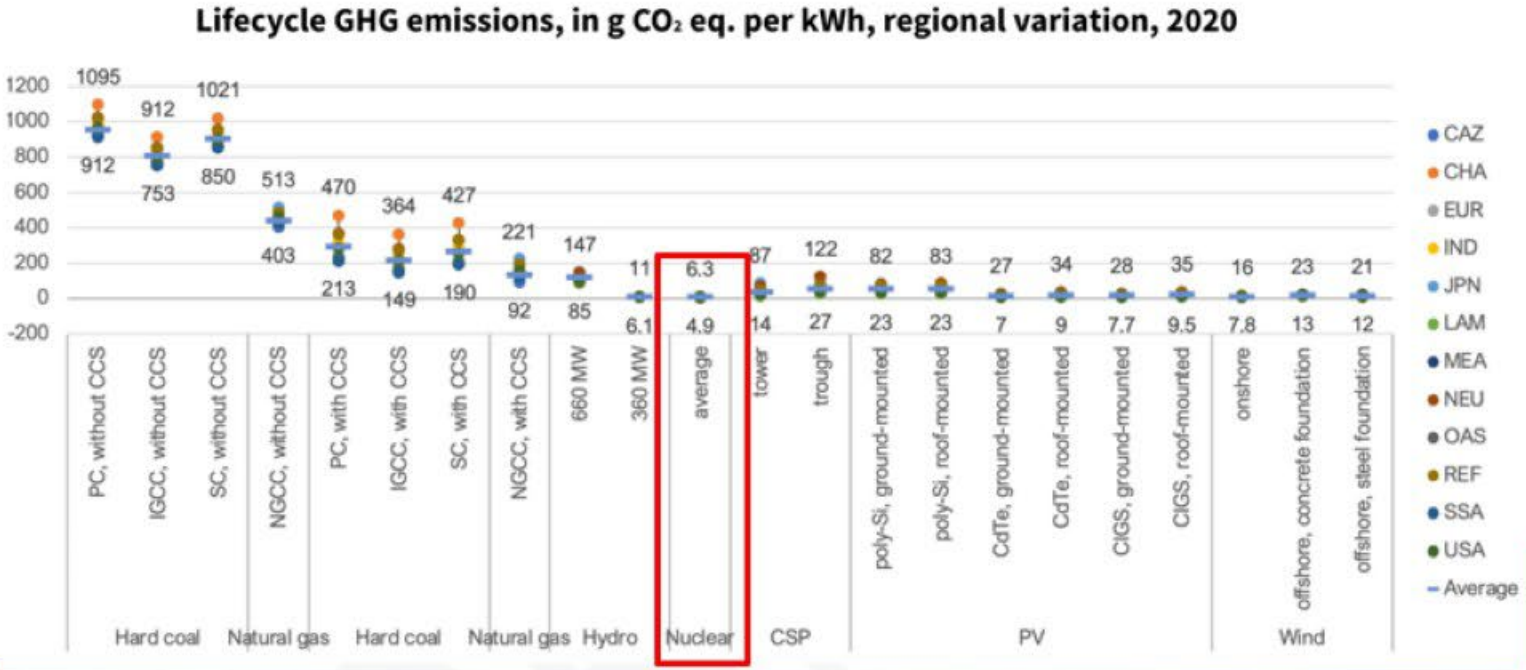
Environmental Efficiency

Nuclear is not only more environmentally friendly than fossil fuels, but even more so than renewables



Even when renewable energy is also considered, Nuclear has the low life-cycle CO_2 emissions which has been proven by history.



UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Carbon Neutrality in the UNECE Region:
Integrated Life-cycle Assessment of Electricity Sources

UNECE

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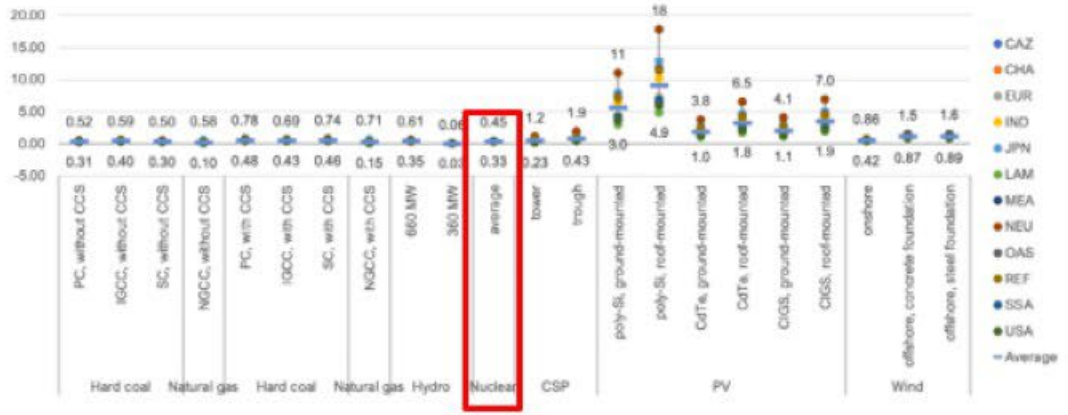
Environmental Efficiency

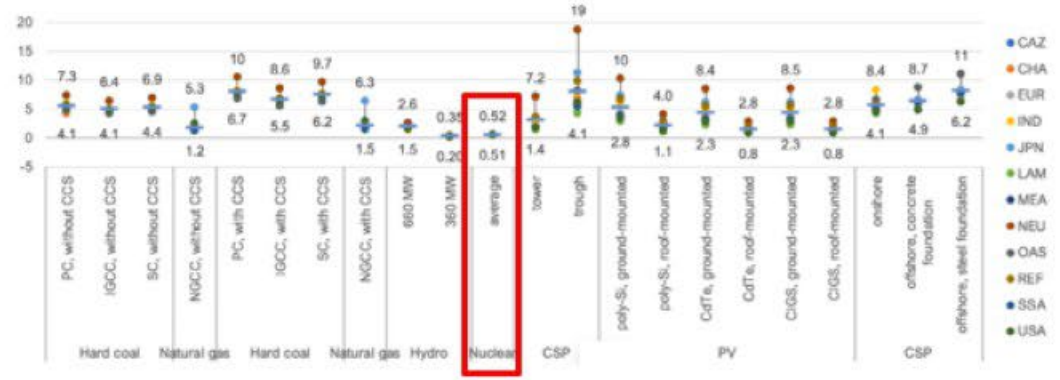
Nuclear is not only more environmentally friendly than fossil fuels, but even more so than renewables

Nuclear also show superior performance in terms of human toxicity potential, mineral and metal requirement and land use.

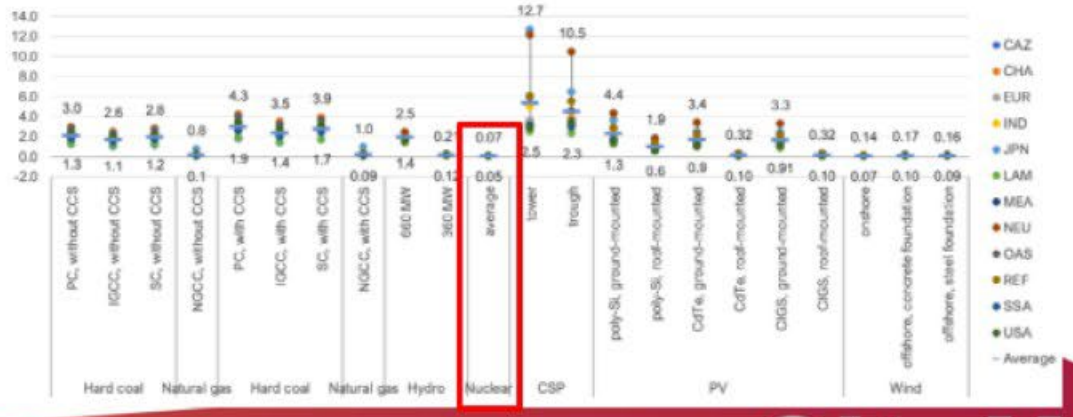
Lifecycle mineral and metal requirement, in g Sb eq. per MWh, regional variation, 2020



Lifecycle human toxicity potential, carcinogenic, in CTUh per TWh, regional variation, 2020



Lifecycle land use, in points per kWh, regional variation, 2020



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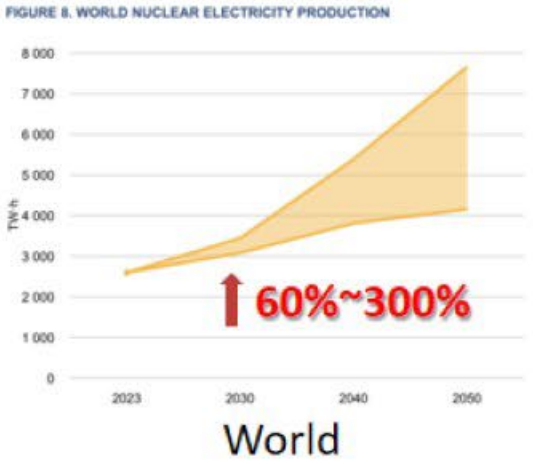
Nuclear Energy Vision

Government: Tripling nuclear energy by 2050

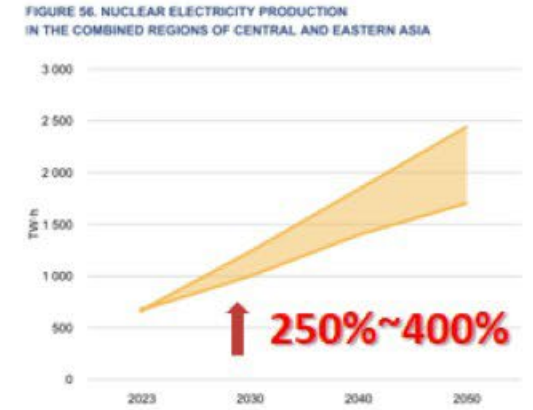
Business: Nuclear Investor Days 2024 in Idaho

International organizations:

IAEA estimation to 2050



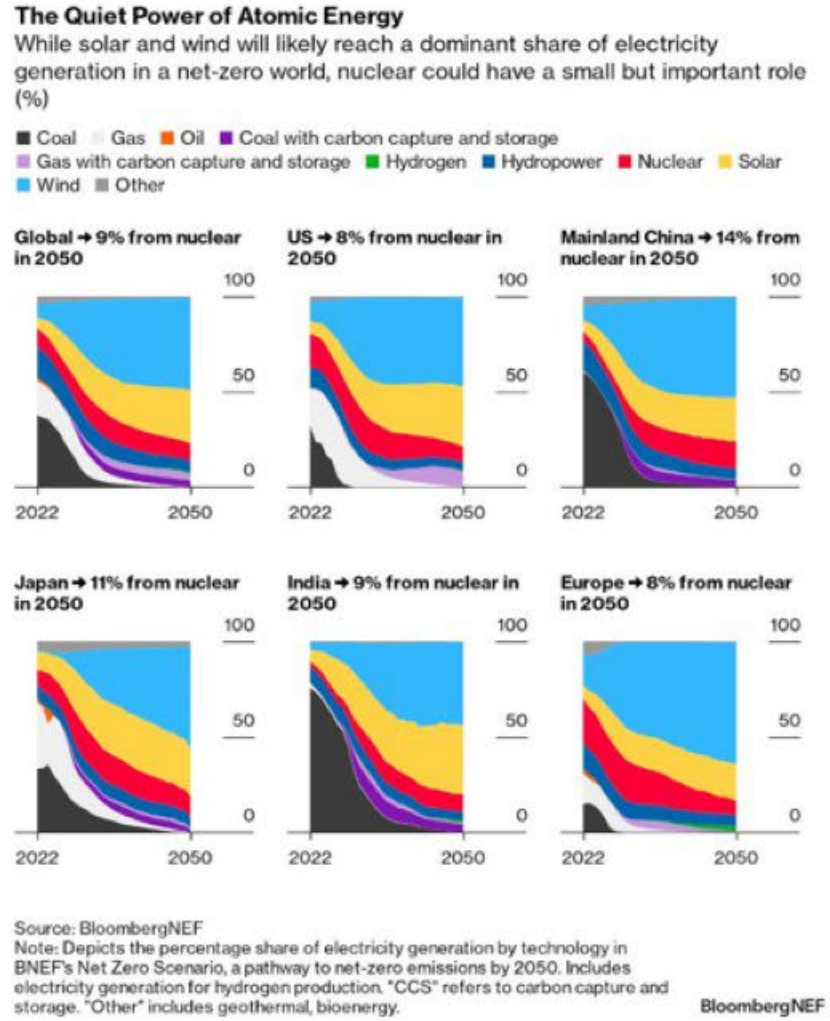
World



Central and eastern Asia

Data source: IAEA report, *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050*, 2024 edition.

Media: BloombergNEF Nuclear vision



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