18th IAEE EUROPEAN CONFERENCE
Milan, 23-27 July

Nuclear Energy -Based Hydrogen Production : A Cost Analysis of Diverse Geographical Regions

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Motivation

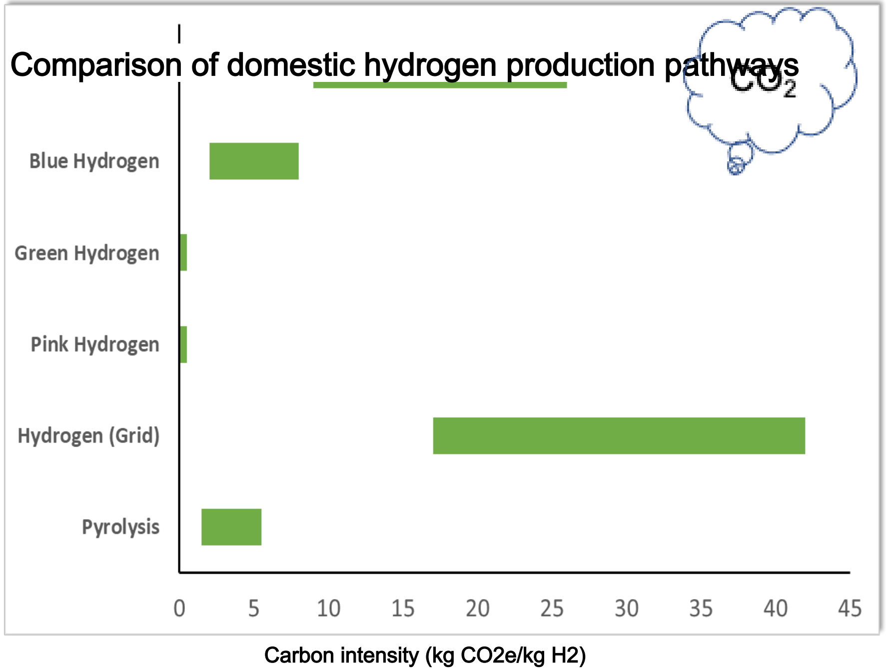
Why Nuclear - based Hydrogen ?

✓

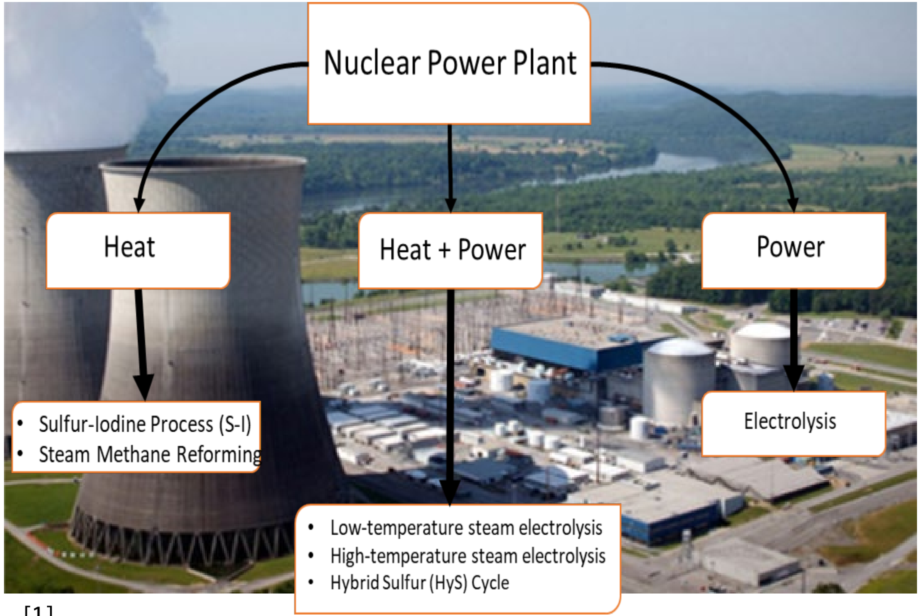
- ➢Low Carbon Footprint
- ➢Reliable and Continuous Power
- ➢Scalability

✗

- ➢Safety Concerns
- ➢Decommissioning and Long-Term Liability



Introduction



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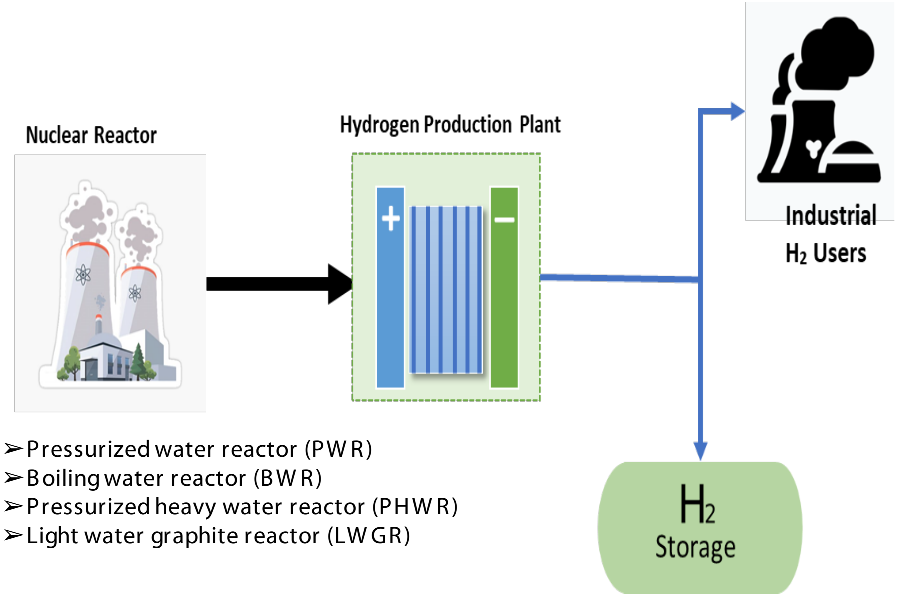

- Pressurized water reactor (PWR)
- Boiling water reactor (BWR)
- Pressurized heavy water reactor (PHWR)
- Light water graphite reactor (LWGR)

Power Plant Comparison: USA, South Korea, and India

Software : Hydrogen Economic Evaluation Program (HEEP) IAEA International Atomic Energy Agency

USA - COOK NPP

Power Plant Type : PWR
Power Plant Name : WH-4LP
Operating : American Electric Power Company, Inc.
Power Capacity : 2362MW
Number of Units : 2

SOUTH KOREA- SAEUL NPP

Power Plant Type : PWR
Power Plant Name : APR-1400
Operating : Korea Hydro & Nuclear Power CO.
Power Capacity : 5779MW
Number of Units : 4

INDIA- KUDANKULAM NPP

Power Plant Type : PWR
Power Plant Name : VVER V-412
Operating : Nuclear Power Corporation of India,LTD.
Power Capacity : 6000MW
Number of Units : 6

Specification of Nuclear Power Plants

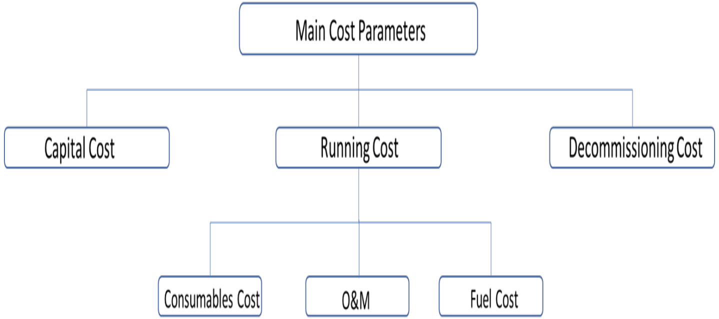

Fig 3 : Major cost components in HEEP

In examining the costs associated with nuclear power reactor construction, it's crucial to consider the findings of a notable study conducted by ***The Breakthrough Institute*** *in 2016.*
This study shed light on the historical construction costs of nuclear power reactors across seven countries, revealing intriguing insights that challenge conventional narratives .

70% Equity Financing

40 Years Analysis Period

	SAEUL NPP	KUDANKULAM NPP	COOK NPP
Thermal Capacity	3983 MWt/unit	3000 MWt/unit	3304 MWt/unit
Electric Rating	1339 MWe/unit	917 MWe/unit	1030 MWe/unit
Number of Units	2	2	2
Overnight Capital Cost ($/kWe)	2157	3058	4000
Capital cost fraction for electricity generating infrastructure	10%	10%	10%
O&M Cost	5% (of capital cost)	5% (of capital cost)	5% (of capital cost)
Decommissioning Cost	2.8% (of capital cost)	2.8% (of capital cost)	2.8% (of capital cost)

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Economics of Nuclear Energy (2022), World Nuclear Association
Jessica R. Lovering, Arthur Yip, Ted Nordhaus, (2016) Historical construction costs of global nuclear power reactors,

LCOH CALCULATION

$$C_{H2} = \frac{E_{NPP}(t_0) + EH_{2GP}(t_0) + EH_{2T}(t_0)}{G_{H2}(t_0)}$$

$E_{NPP}(t_0)$ = Present value of expenditures of nuclear power plant at time t_0
$E_{H2GP}(t_0)$ = Present value of expenditures of hydrogen generation and storage plant plant at time t_0
$E_{H2T}(t_0)$ = Present value of expenditures of hydrogen transportation facility at time t_0
$G_{H2}(t_0)$ = Present value of gross hydrogen generation at time t_0

$$E(t_0) = \sum_{t_{start}}^{t_{end}} \frac{CI_t}{(1+r)^{t-t0}} + \sum_{t_{start}}^{t_{end}} \frac{R_t}{(1+r)^{t-t0}} + \sum_{t_{start}}^{t_{end}} \frac{DC_t}{(1+r)^{t-t0}}$$

CI_t = Capital Investment expenditures at year t
R_t = Expenditures towards running the facility in the year t
DC_t = Decommissioning expenditures at year t

$$G_{H_2}(t_0) = \sum_{t_{start}}^{t_{end}} \frac{G_{H_2}(t)}{(1+r)^{t-to}}$$

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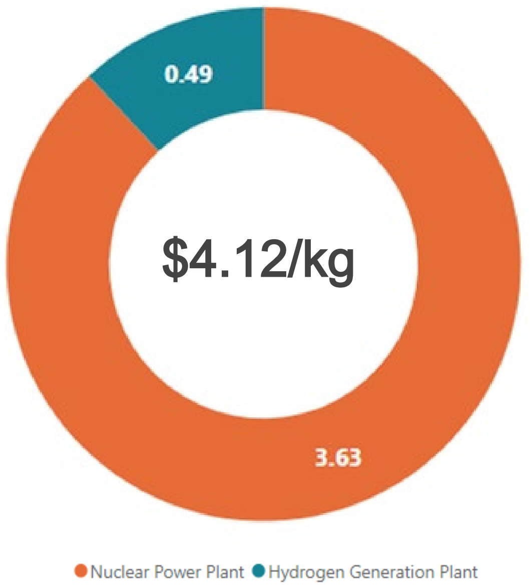
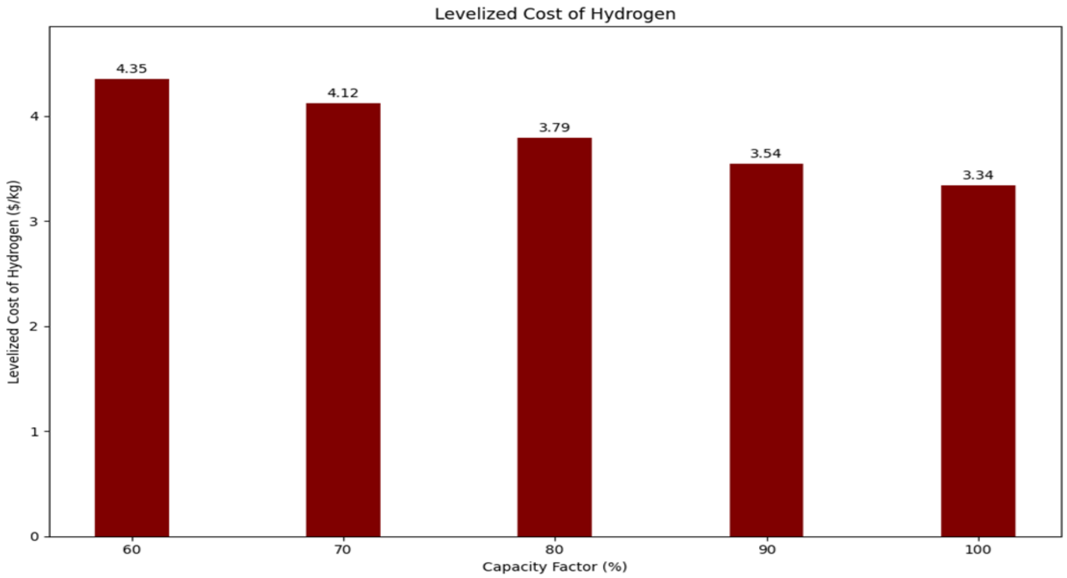
Results - Cost Breakdown
Case Study : USA





Notes . Based on a discount rate of 5%

- ❑ At a capacity factor of 70%, United States has achieved a levelized cost of $4.12 per kilogram

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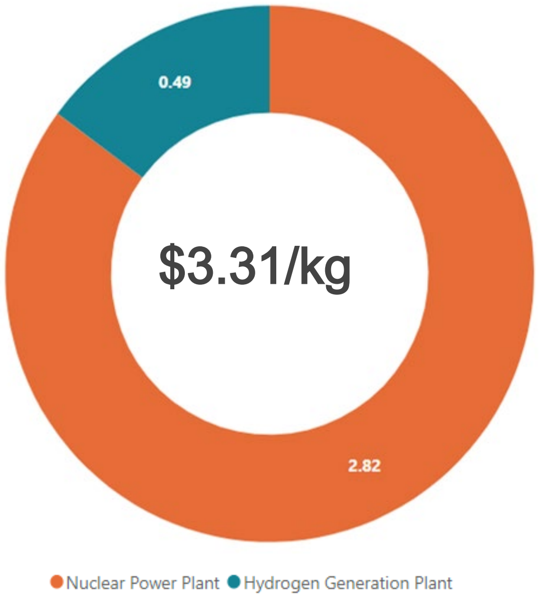
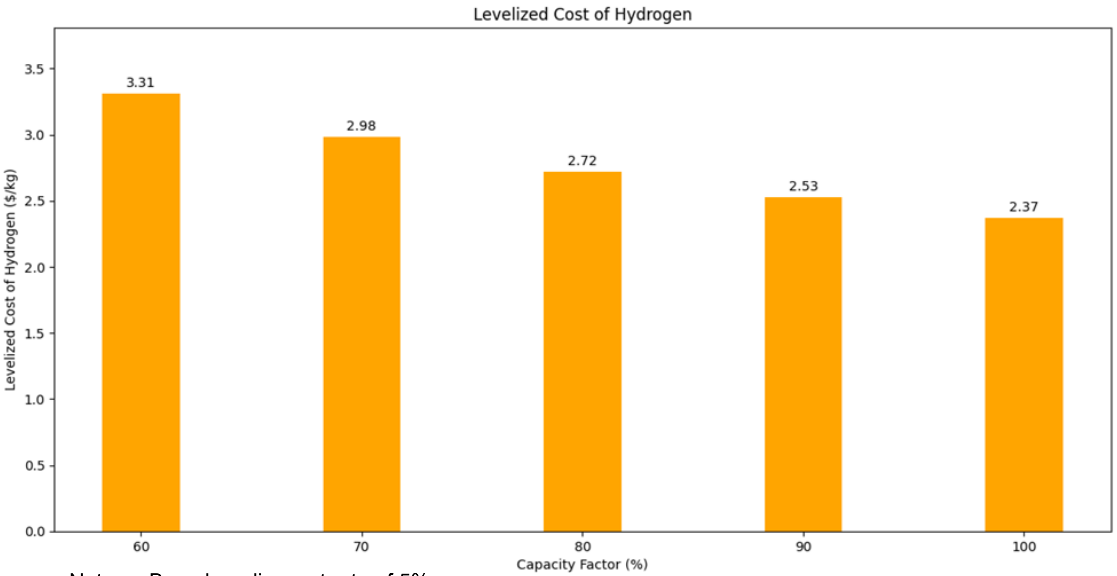
Results - Cost Breakdown
Case Study : India

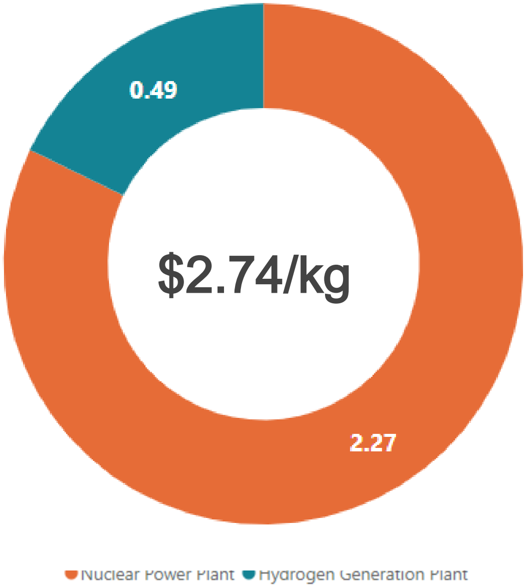


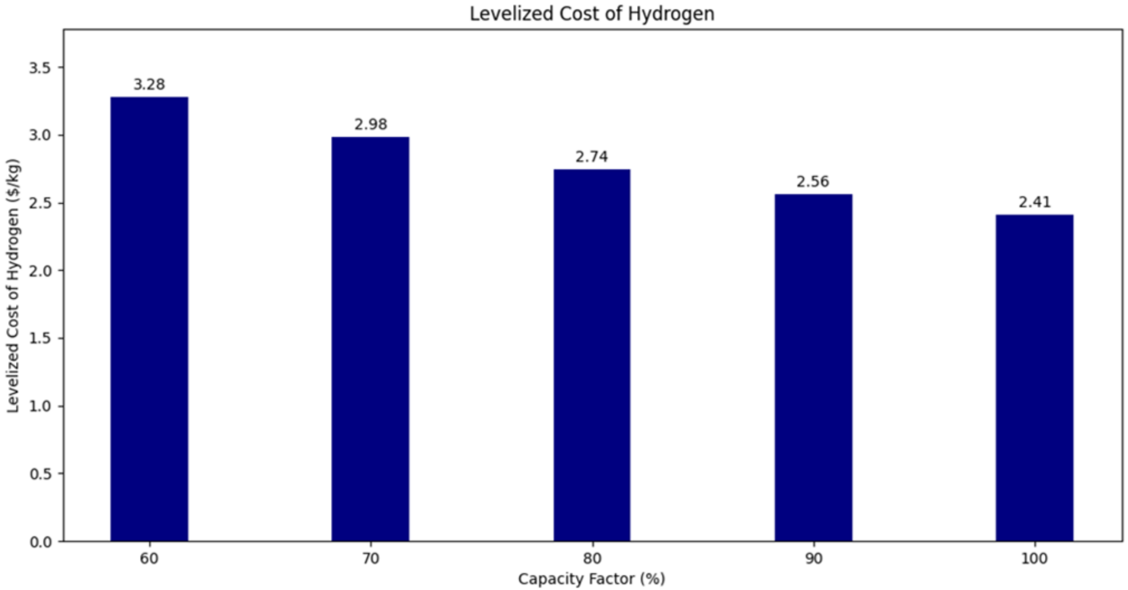


Notes : Based on discount rate of 5%

- ❑ Capacity factor of 60%, India has achieved a levelized cost of hydrogen of $3.31 per kilogram
- ❑ India has one of the **highest** unplanned capability loss factor .

Results - Cost Breakdown
Case Study : South Korea





Notes : Based on a discount rate of 5%

- Capacity factor of 80%, South Korea has achieved a levelized cost of hydrogen of $2.74 per kilogram
- South Korea boasts one of the **lowest** unplanned capability loss factors.

Conclusion

- ➢ Nuclear energy for hydrogen production is economically viable in select regions, with South Korea offering the most affordable hydrogen at **$2.74/kg**.

- ➢ Hydrogen prices vary significantly, with the United States and India showing higher costs (**$4.12/kg** and **$3.31/kg**, respectively

- ➢ As countries prioritize sustainable energy alternatives, exploring nuclear-based hydrogen production in Asian markets can play a crucial role in achieving affordable and eco-friendly energy transitions.

- ➢ Variations in **overnight capital costs** highlight differences between developing industrial economies and established markets, affecting the feasibility of nuclear energy for hydrogen production

- ➢ Nuclear energy holds immense potential as a viable and low-carbon solution for various sectors, including hydrogen production

Recommendations

Policy

- Establish clarity to the incorporation of nuclear-produced hydrogen, ensure **standardised definitions for renewable energy sources** and low-carbon energy in policies.

- Make **long-term policy commitments** to boost investor confidence in nuclear energy initiatives and promote sustainable sector growth.

Technology

- Allocate resources towards R&D to propel advancements in nuclear and electrolysis technologies
  1- Small Modular Reactors (SMR)
  2 -Solid Oxide Electrolysis Cells

THANKS!

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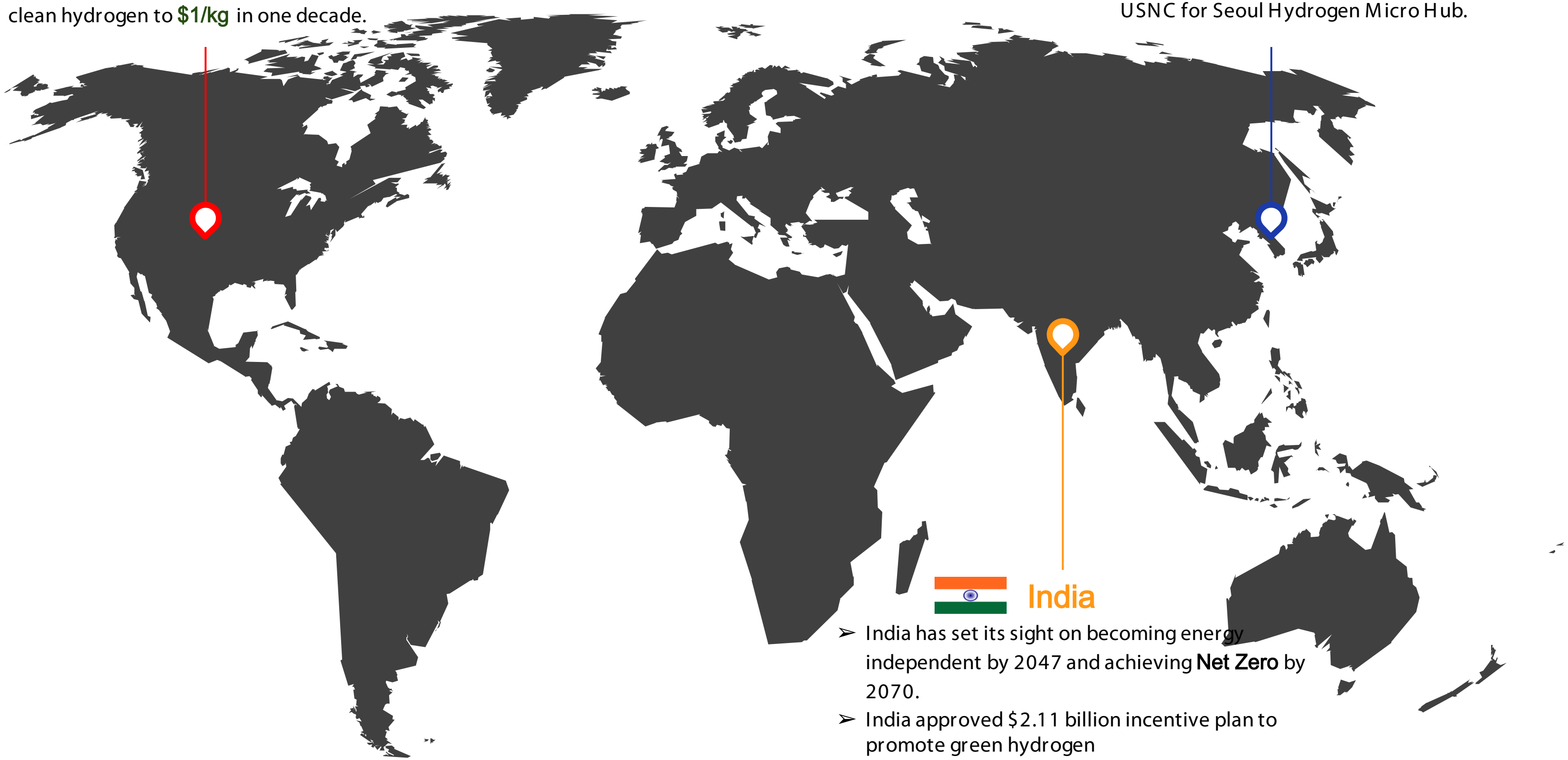
Hydrogen Plan

United State of America

- U.S. government has allocated **$7 billion** for establishment of clean hydrogen hubs
- **Three** nuclear power plants are preparing to produce clean hydrogen
- DOE's 'Hydrogen Shot' goal of reducing the cost of clean hydrogen to **$1/kg** in one decade.

South Korea

- South Korea aims to boost hydrogen production to 28Mt by 2050
- Hyundai Motor Group and SK Group Partner with USNC for Seoul Hydrogen Micro Hub.



India

- India has set its sight on becoming energy independent by 2047 and achieving **Net Zero** by 2070.
- India approved $2.11 billion incentive plan to promote green hydrogen
- Green hydrogen production capacity of at least **5 MMT per annum** 2030

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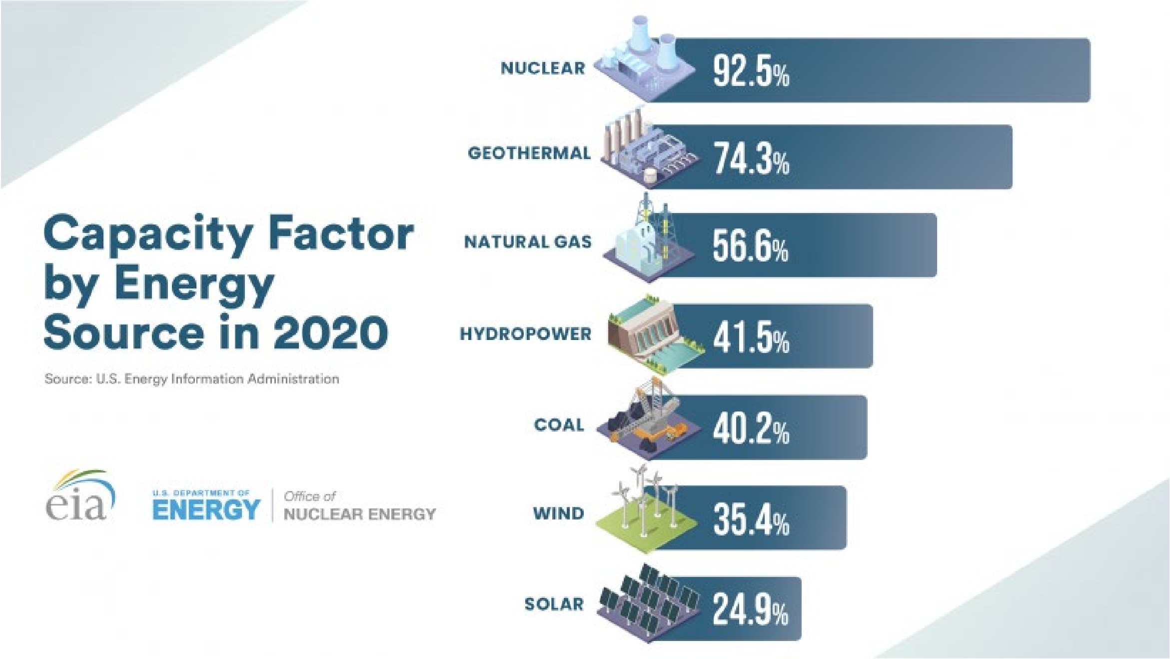
Extra Resources



A nuclear reactor's electricity production typically amounts to 1 gigawatt (GW). However, it is not directly interchangeable with a 1 GW coal or renewable plant.

Due to differences in capacity factors, **nearly two coal plants or three to four renewable plants of the same size would be required to match the electricity output of a single nuclear reactor** when supplying power to the grid.

Source : Office of Nuclear Energy (2023)

Extra Resources

Front end fuel cycle costs of 1 kg of uranium as UO_2 fuel

Process	Cost	Proportion of Total
Uranium	$842	51%
Conversion	$120	7%
Enrichment	$401	24%
Fuel Fabrication	$300	18%
Total	$1663	

Source : Economics of Nuclear Power, World Nuclear Association

Extra Resources

Electricity generating cost projections

Country	Cost (¢/kWh)
India	83.9
South Korea	67.2
United State of America	98.6

Based on a 10% discount rate

Source : Economics of Nuclear Power, World Nuclear Association