



POLITECNICO
MILANO 1863

Le prospettive dell'energia nucleare

prof. Marco Ricotti

Politecnico di Milano, Dept. of Energy

Nuclear Engineering division – Nuclear Reactors Group

NUCLEARE SOSTENIBILE: RICERCA,
TECNOLOGIE, SCENARI E PROSPETTIVE

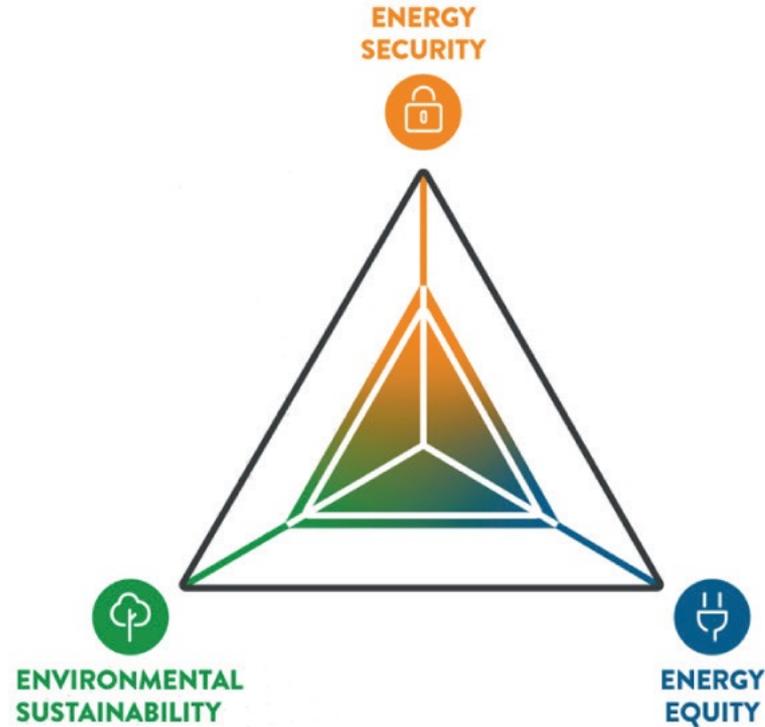
Roma
2024 Maggio 28

ENEA

(I) Global warming

(II) Dipendenze strategiche

(III) Ricadute economiche



Il «Trilemma Energetico» e il ruolo del nucleare

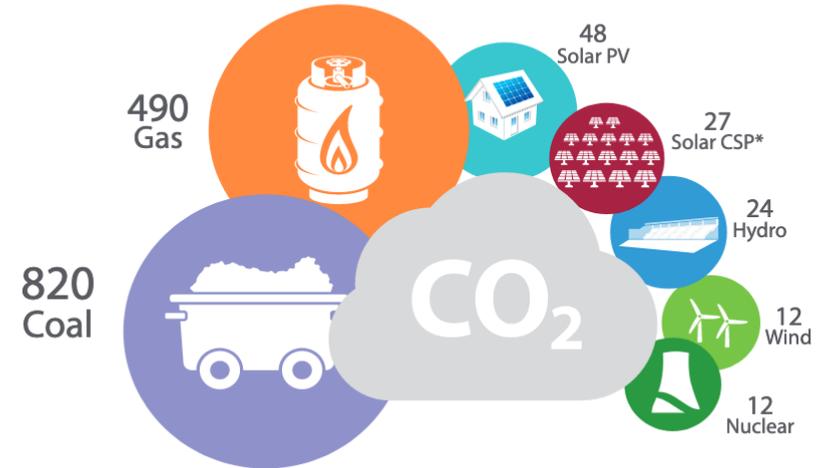
I. Global warming

3

*“ma il Nucleare
danneggia
l’ambiente...”*



Comparison of greenhouse gas emissions
(grammes CO₂ eq/kWh)



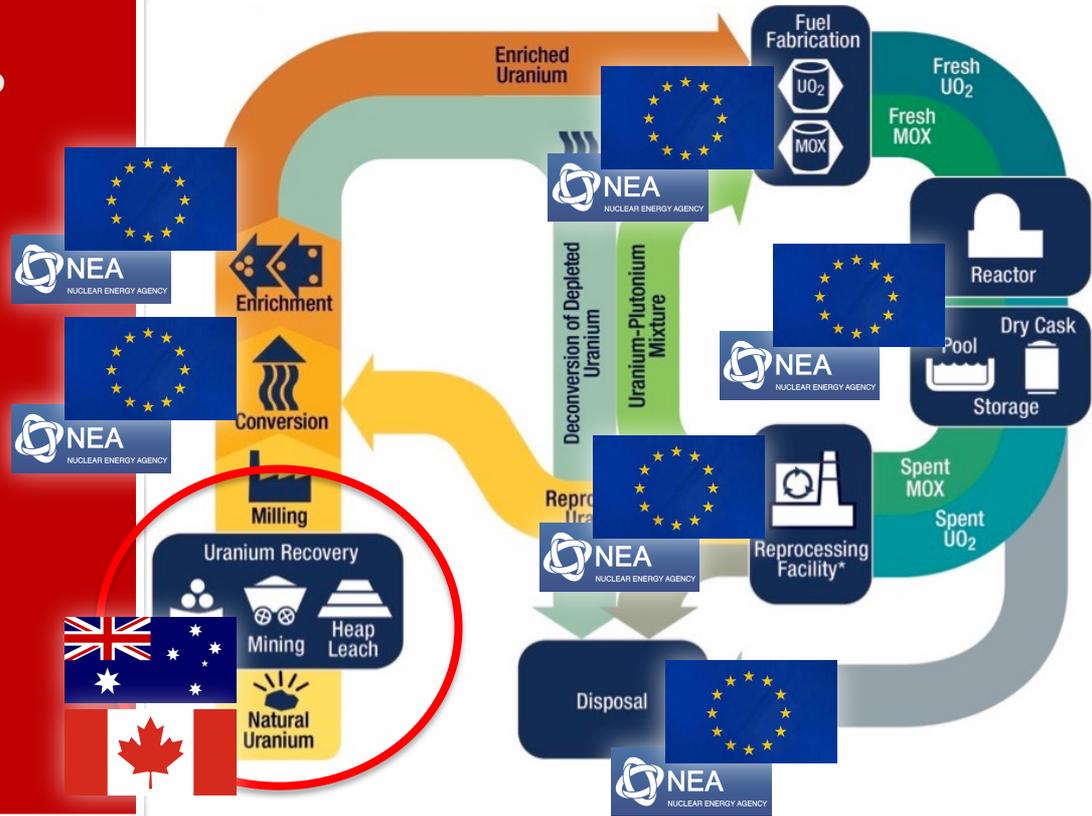
*Concentrated Solar Power

© FORATOM - Source: IPCC 2014

Il «Trilemma Energetico» e il ruolo del nucleare

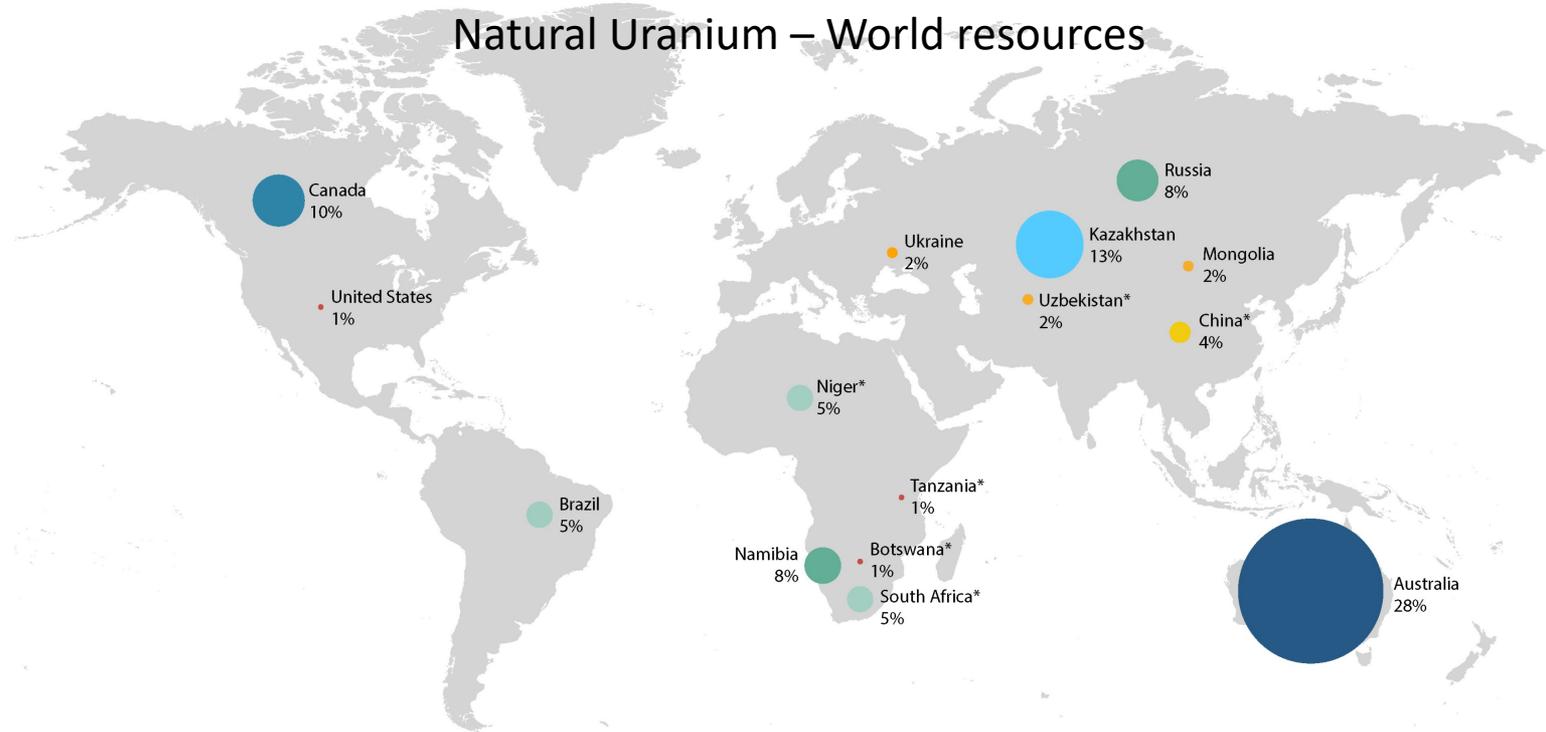
II. Dipendenza strategica

“ma il Nucleare è rischioso...”



II «Trilemma Energetico» e il ruolo del nucleare

II. Dipendenza strategica



IAEA / NEA, *Uranium 2022: Resources, Production and Demand (Red Book)*, 2022

II «Trilemma Energetico» e il ruolo del nucleare

III. Ricadute economiche

“ma il Nucleare non è economico...”



100



€ Billion/year

1



Million Jobs

Supply Chain



€94 bn

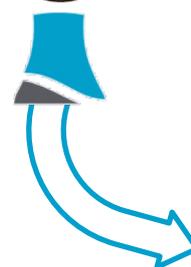
Direct impact

€357.4 bn

Indirect impact

€451.4 bn

GDP generated by the nuclear sector in the EU



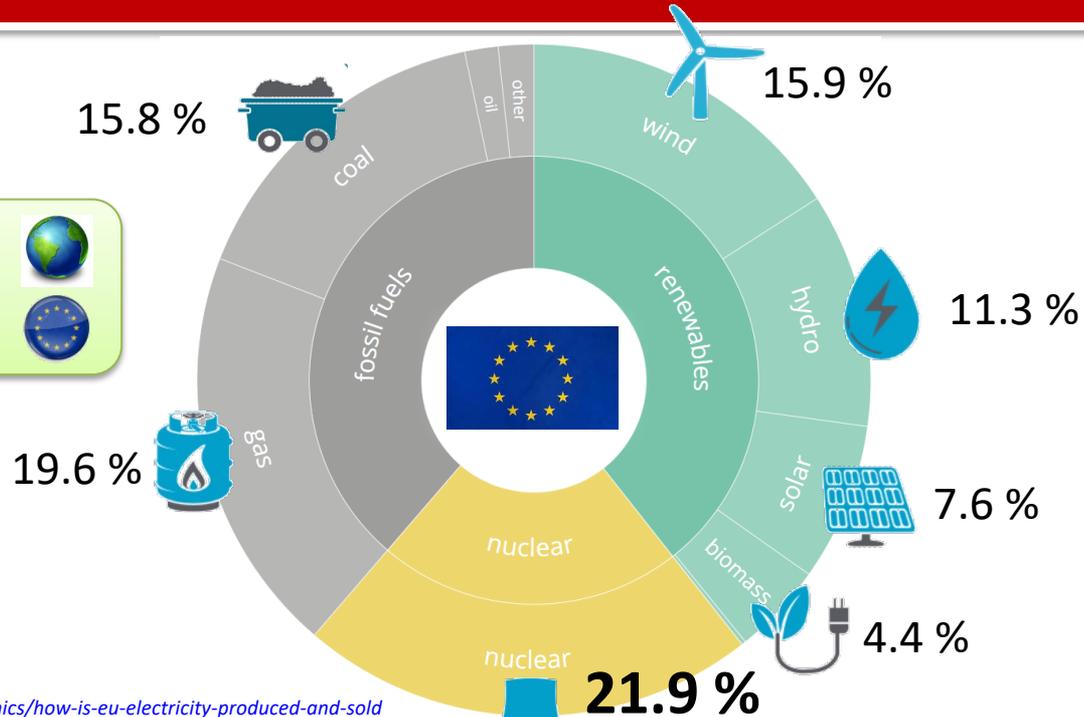
Source: 2023 NuclearEurope

Il «Trilemma Energetico» e il ruolo del nucleare

Elettricità «green» in EU

7

“ma il Nucleare non è poi così importante...”



2023 Eurostat database

<https://www.consilium.europa.eu/en/infographics/how-is-eu-electricity-produced-and-sold>

Il «Trilemma Energetico» e il ruolo del nucleare

Uso del suolo

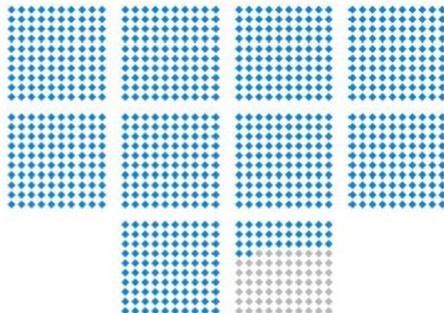
“ma il Nucleare danneggia l’ambiente-2...”

Centrale da
1000 MWe

673-932 square kilometres

117-194 square kilometres

3.3 square kilometres



Source:
IAEA, 2016



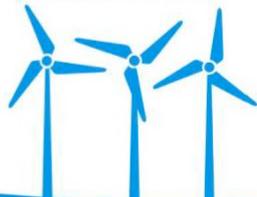
Nuclear

assuming capacity factor 90%



Solar

assuming capacity factor 17-28%



Wind

assuming capacity factor 32-47%

Note:
Surface needed to obtain the same energy production is different within the same technology.
To obtain the same energy production, wind power + energy storage



JRC SCIENCE FOR POLICY REPORT

Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')

Sensitive 2021

energy production

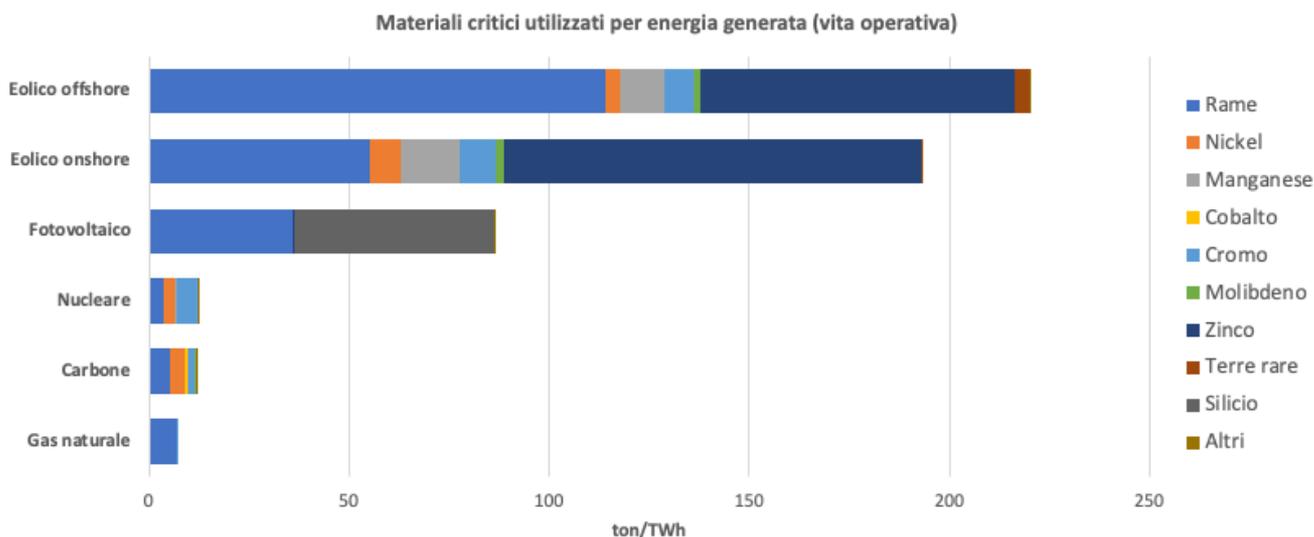
and power + energy storage



Il «Trilemma Energetico» e il ruolo del nucleare

Uso di materiali critici

“ma il nucleare è rischioso-2...”



Dati IEA, rielaborazione POLIMI: materiali critici per elettricità prodotta (intera vita operativa)



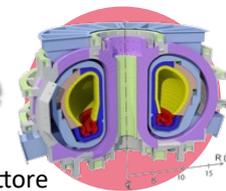
Standard

Quasi tutti i reattori oggi in funzione. Estensione della vita operativa (da 40 a 60-80 anni)



Small Modular Reactors

Piccola taglia (< 300 MWe), progettazione e costruzione modulari.



Fusione

Primo reattore (commerciale) a fusione

DEMO & FOAK

2050 2060

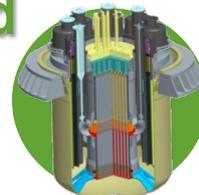


Evolutivi

Alcuni già operativi (Cina, UAE, Corea Sud, Russia, India).
La maggioranza dei 59 reattori in costruzione nel Mondo



Advanced Modular Reactors



Raffreddamento a metallo liquido o a Sali fusi.
Possibilità di riciclare i rifiuti a vita lunga e ad alta radioattività.

“ma il Nucleare costa troppo e ci vuole molto tempo...”

2010



EPR - Olkiluoto Unit 3



Start 2004

Planned COD 2009

Full Op. Apr. 2023

13+ Years Delay



Original Budget 3.2B€

Expected 12 B€

8.8 B€ overrun, +270%

AP1000 - Vogtle Units 3 & 4



Start 2012

Planned COD 2016

Full Op. Jul. 2023

7+ Years Delay



Original Budget 14B\$

Expected 26 B€

12+ B\$ overrun, +85%

VC Summer: stopped

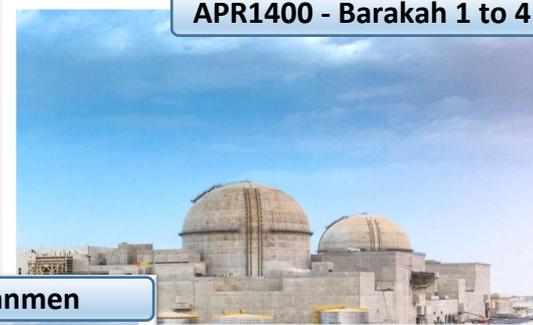


“ma il Nucleare costa troppo e ci vuole molto tempo...”

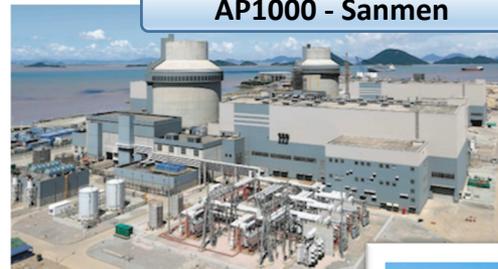
2016



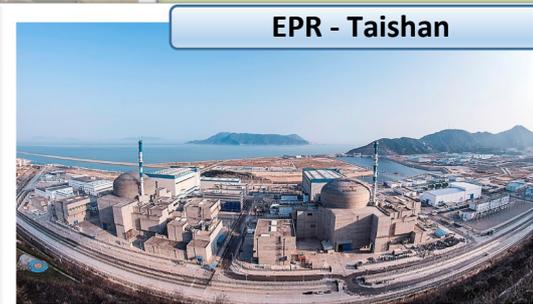
APR1400 - Barakah 1 to 4



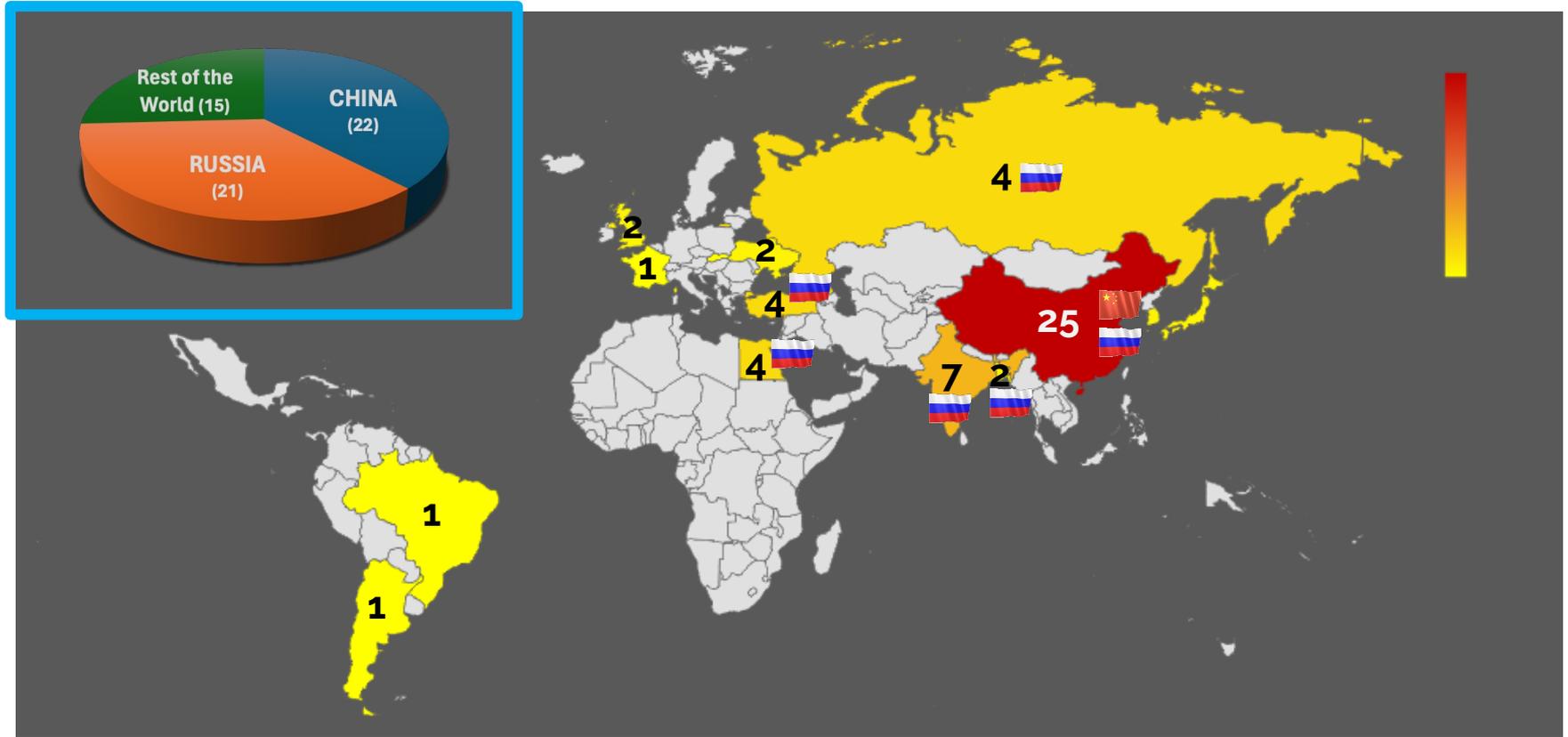
AP1000 - Sanmen



EPR - Taishan



Reattori nucleari in costruzione nel Mondo (Maggio 2024)

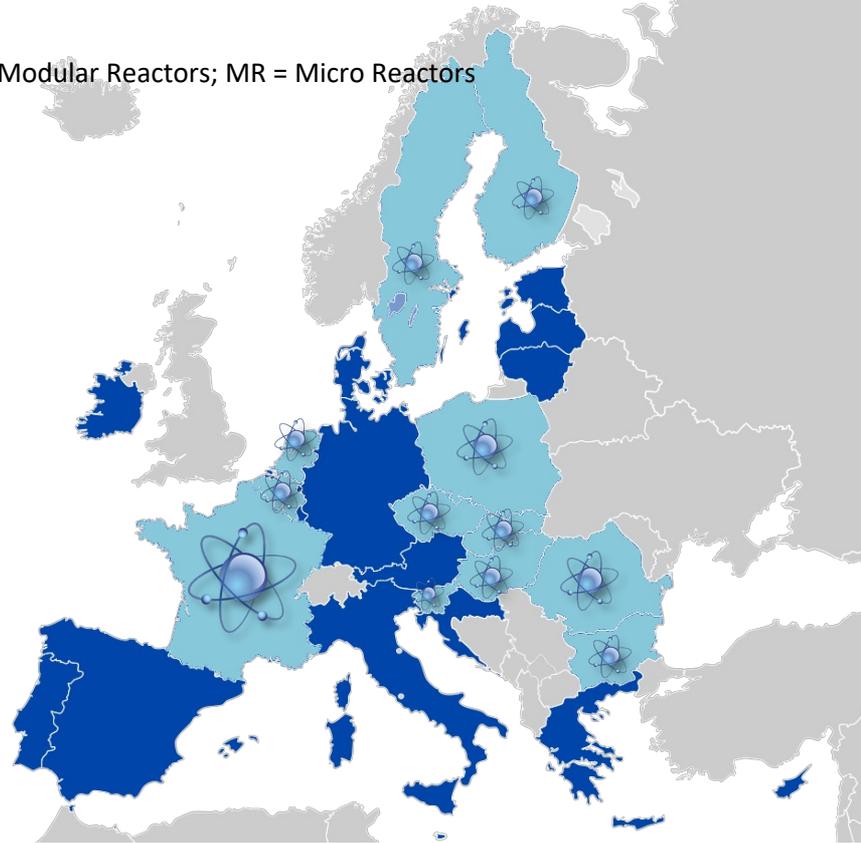


LR = Large Reactors; SMR = Small Modular Reactors; AMR = Advanced Modular Reactors; MR = Micro Reactors

Francia	(LR, SMR, AMR)
Svezia	(LR, SMR)
Belgio	(LR, SMR)
Finlandia	(LR, SMR)
Ungheria	(LR)
Bulgaria	(LR)
Rep. Ceca	(LR)
Romania	(LR, SMR)
Slovacchia	(LR, SMR)
Slovenia	(LR)
Olanda	(LR, SMR)
Polonia	(LR, SMR, MR)

Potenziale mercato SMR in EU:

- 10 unità al 2035
- 10+ unità/anno al 2050



Small Modular Reactors: cambio di paradigma



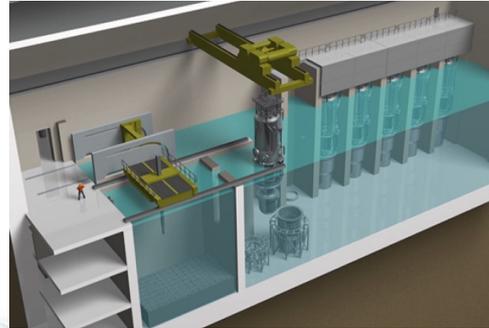
Reattori nucleari di taglia limitata (< 300 MWe)

Vantaggi:

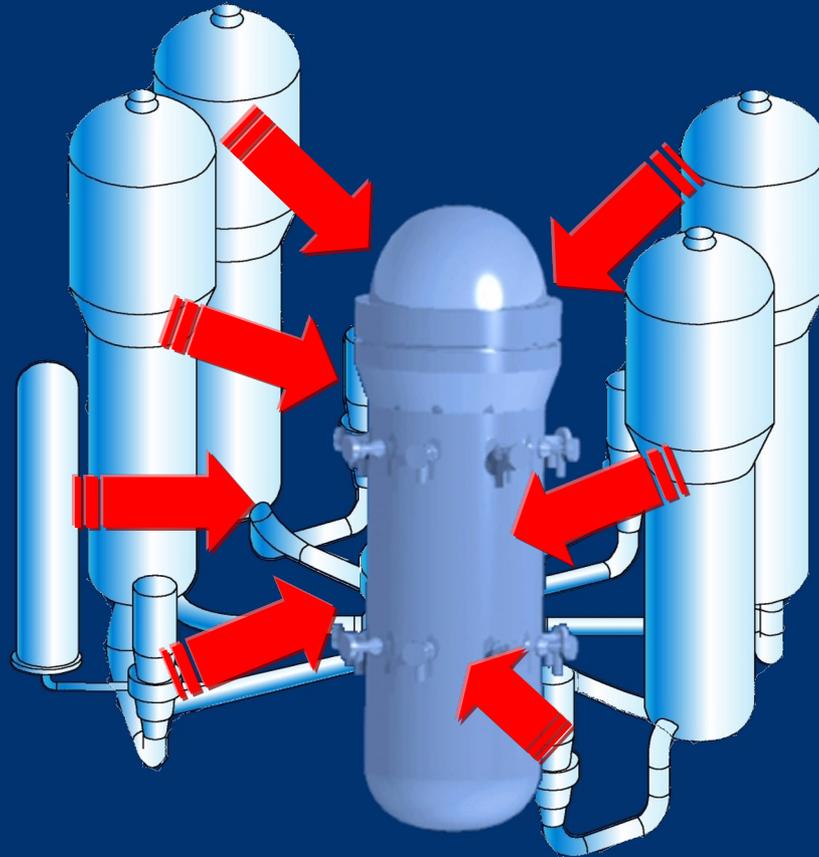
- Design **semplificato**
- Strategia di sicurezza a «**sistemi passivi**» (circolazione naturale: no Fukushima)
- Progettazione e costruzione **modulare**, in officina
- **Cogenerazione** (idrogeno, accumulo termico, teleriscaldamento, desalazione, biofuel)

Sfide:

- Mercato internazionale, costruzione in serie
- Dimostratori: tempi e costi



Small Modular Reactors: integral PWR



La soluzione «Integrale»:

- elimina le penetrazioni dei tubi e i componenti primari esterni

Small Modular Reactors: cambio di paradigma

80+ SMR/AMR/MR designs under development in the World, size: from 1-5 MWe to 300 MWe

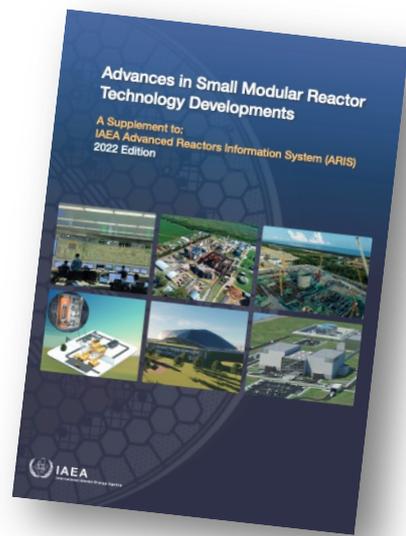
- ▶ Land Based WCRs (25)
- ▶ Marine Based WCRs (6)
- ▶ HTGRs (14)
- ▶ Fast Reactors (11)
- ▶ MSRs (10)
- ▶ Micro (6)

UNDER DEVELOPMENT									
INTEGRAL SMRs		CAREM	NuScale	RITM-200	ACP100	SMART/	NUWARD	BWRX-300	IRIS
Size	MWth	100	(160) 250	165	310	330	540	900	1000
	MWe	27	(50) 77	52	100	100	170	300	335
In operation on:		? (constr.)	2029-2030	2030	2026	>2030	>2030	~2035	(closed)

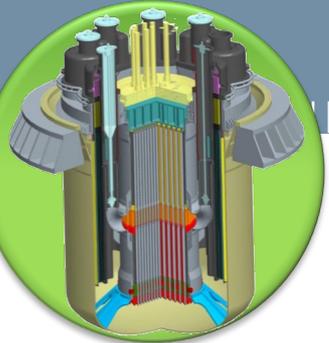
ALREADY IN OPERATION

RUSSIA
KLT-40s: Barge mounted PWR reactor

CHINA
HTR-PM: High Temperature Gas Reactor



Advanced Modular Reactors: opzione riduzione rifiuti



Reattori raffreddati a:
piombo liquido, sodio liquido,
sali fusi

«fisica differente»: eccesso di neutroni

Vantaggi:

- Gli stessi degli SMR (molti GenIV sono SMR)
- Miglior **rendimento**
- Possibilità di **separare e «bruciare» i rifiuti** ad alta radiotossicità

Sfide:

- Economicità
- Integrazione con impianti del ciclo del combustibile (proliferazione)

LA DIMENSIONE DEL PROBLEMA

Rifiuti prodotti per persona, per anno*

1.36 ton rifiuti totali annui



270 kg

rifiuti solidi urbani



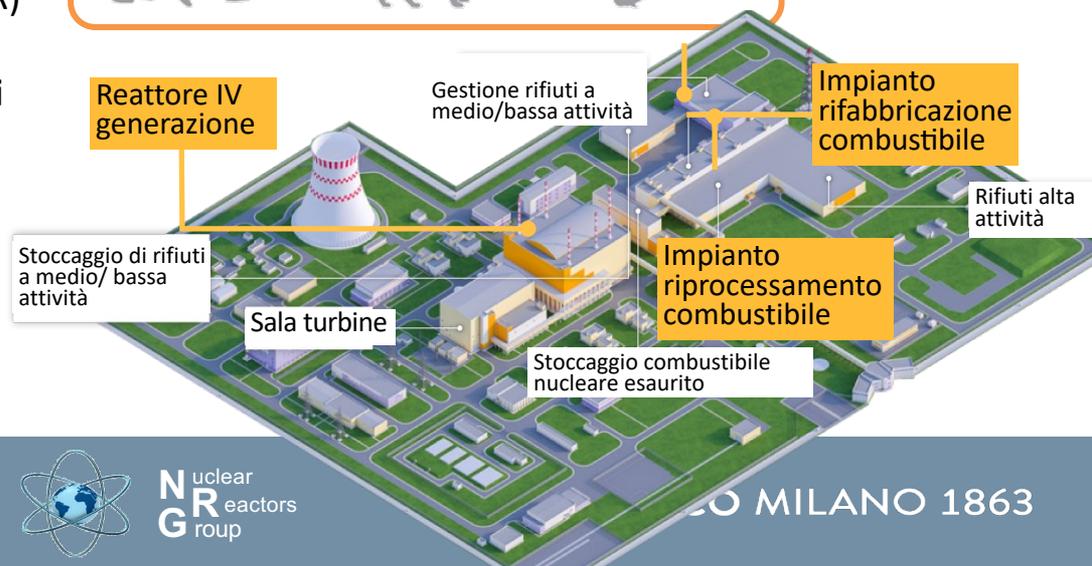
54 kg

rifiuti tossico-nocivi



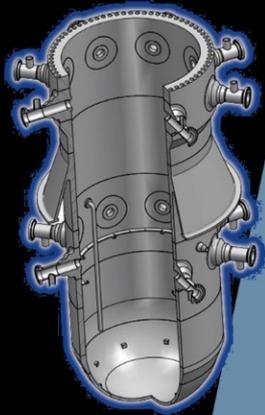
54 g

rifiuti radioattivi



Nucleare e il possibile ruolo dell'Italia: un caso studio

SMR supply chain



How many

Reactor Pressure Vessel for SMRs, the Italian nuclear supply chain is ready to produce every year ?

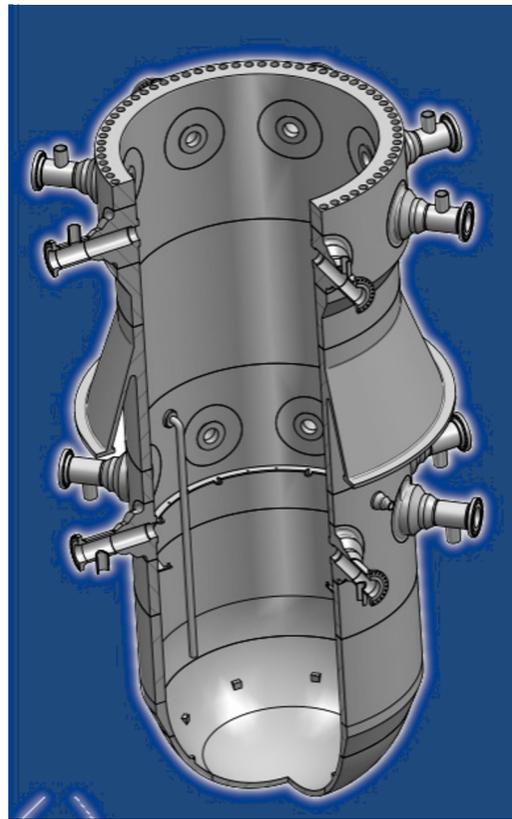
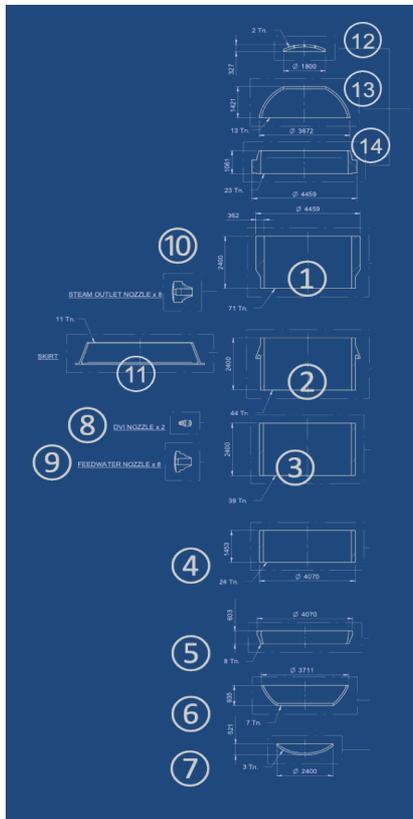
Flip the card and find the answer...



<https://www.nuclearenergy.polimi.it/italian-nuclear-supply-chain-for-small-modular-reactors/>

Nucleare e il possibile ruolo dell'Italia: un caso studio

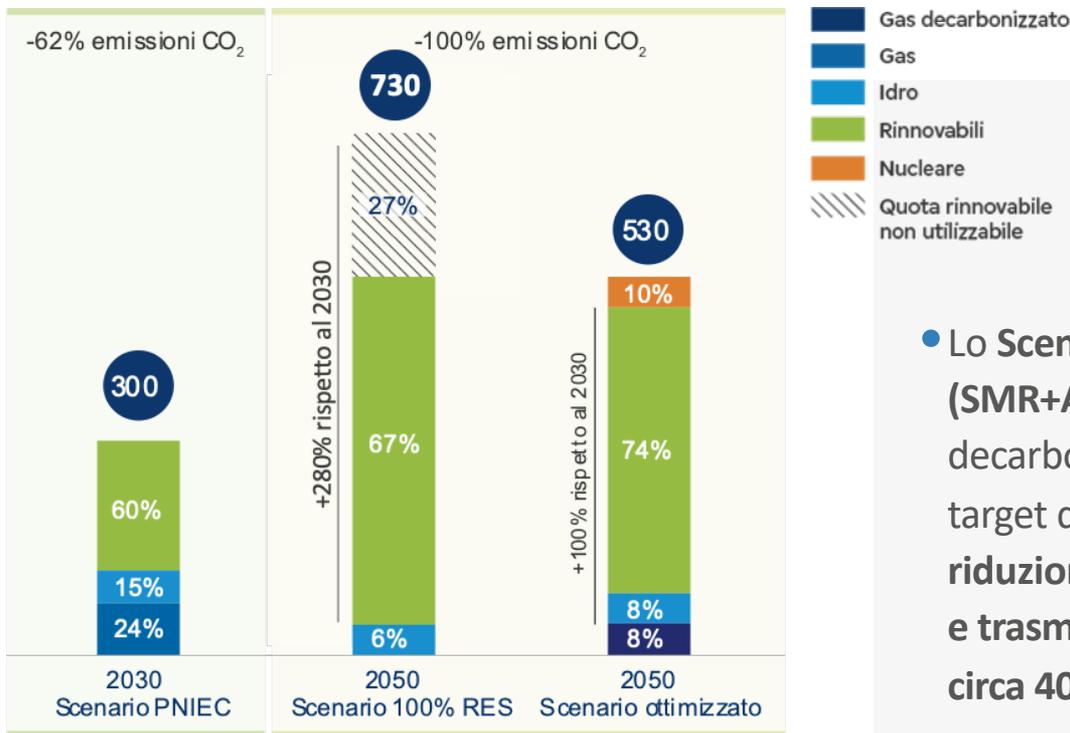
SMR supply chain





Studio EDISON: scenario energetico (elettricità) Italia 2050 senza e con nucleare

Evoluzione Italiana del mix di produzione¹ (TWh)



- Il **nuovo nucleare**, insieme alle rinnovabili, contribuisce al raggiungimento della **neutralità carbonica al 2050**

- Lo **Scenario Ottimizzato** con rinnovabili, **nucleare (SMR+AMR)** e, nel transitorio, produzione a gas decarbonizzata, consente il raggiungimento dei target di decarbonizzazione al 2050 con **una riduzione degli investimenti di sistema (accumuli e trasmissione) e di overcapacity rinnovabile di circa 400 miliardi di euro**

1) Scenario PNIEC giugno 2023 in 2030, Scenario simulato Edison in 2050

Il «Trilemma Energetico» e il ruolo del nucleare

Sicurezza

23

“ma il
pericol



What are the **safest** and **cleanest** sources of energy?

Our World
in Data

Death rate from accidents and air pollution

Measured as deaths per terawatt-hour of electricity production.

1 terawatt-hour is the annual electricity consumption of 150,000 people in the EU.

24.6 deaths

1230-times higher than solar

18.4 deaths

613-times higher than nuclear energy

2.8 deaths

4.6 deaths

171,000 deaths from Banqian Dam failure in 1975, China

1.3 deaths

0.04 deaths

Includes deaths from Chernobyl and Fukushima disasters

0.02 deaths

Coal

36% of global electricity

Oil

3% of global electricity

Natural Gas

22% of global electricity

Biomass

2% of global electricity

Hydropower

12% of global electricity

Wind

7% of global electricity

Nuclear energy

10% of global electricity

Solar

4% of global electricity

Greenhouse gas emissions

Measured in emissions of CO₂-equivalents per gigawatt-hour of electricity over the lifecycle of the power plant.

1 gigawatt-hour is the annual electricity consumption of 150 people in the EU.

820 tonnes

273-times higher than nuclear energy

720 tonnes

180-times higher than wind

490 tonnes

78-230 tonnes

34 tonnes

4 tonnes

3 tonnes

5 tonnes

Death rates from fossil fuels and biomass are based on state-of-the-art plants with pollution controls in Europe, and are based on older models of the impacts of air pollution on health. This means these death rates are likely to be very conservative. For further discussion, see our article: [OurWorldinData.org/safest-sources-of-energy](https://ourworldindata.org/safest-sources-of-energy). Electricity shares are given for 2021. Data sources: Markandya & Wilkinson (2007); UNSCEAR (2008; 2018); Sovacool et al. (2016); IPCC AR5 (2014); Pehl et al. (2017); Ember Energy (2021).

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Licensed under CC-BY by the authors Hannah Ritchie and Max Roser.