Energia nucleare: una risorsa o un problema?

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Movimento

20-60%

100%

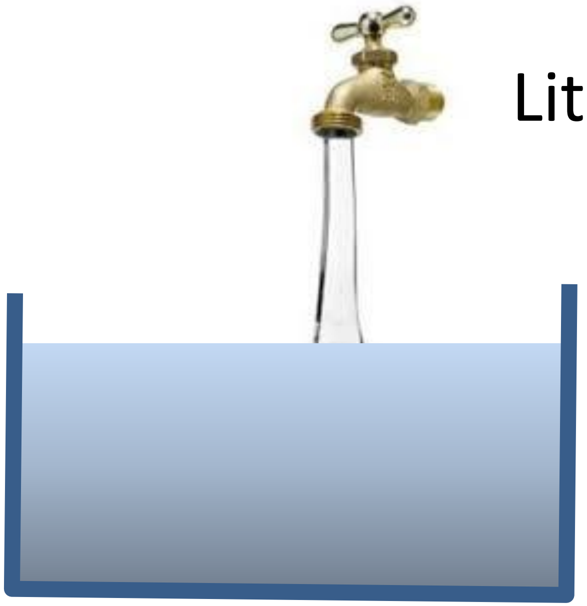
Energia

Energia termica

massa

radiazione

kW and kWh



Litri per secondo-> kW (= 1000 J/s)

litri raccolti-> kWh (= 3.6 milioni of J)

1 kWh_e circa 0.2-0.4 €

Quanta acqua?

peresempi, **2** kW per **3** hours = **6** kWh

1.2-2.4 €

1 kWh

90-120g
benzina
Gasso animale
carbone

7 kg

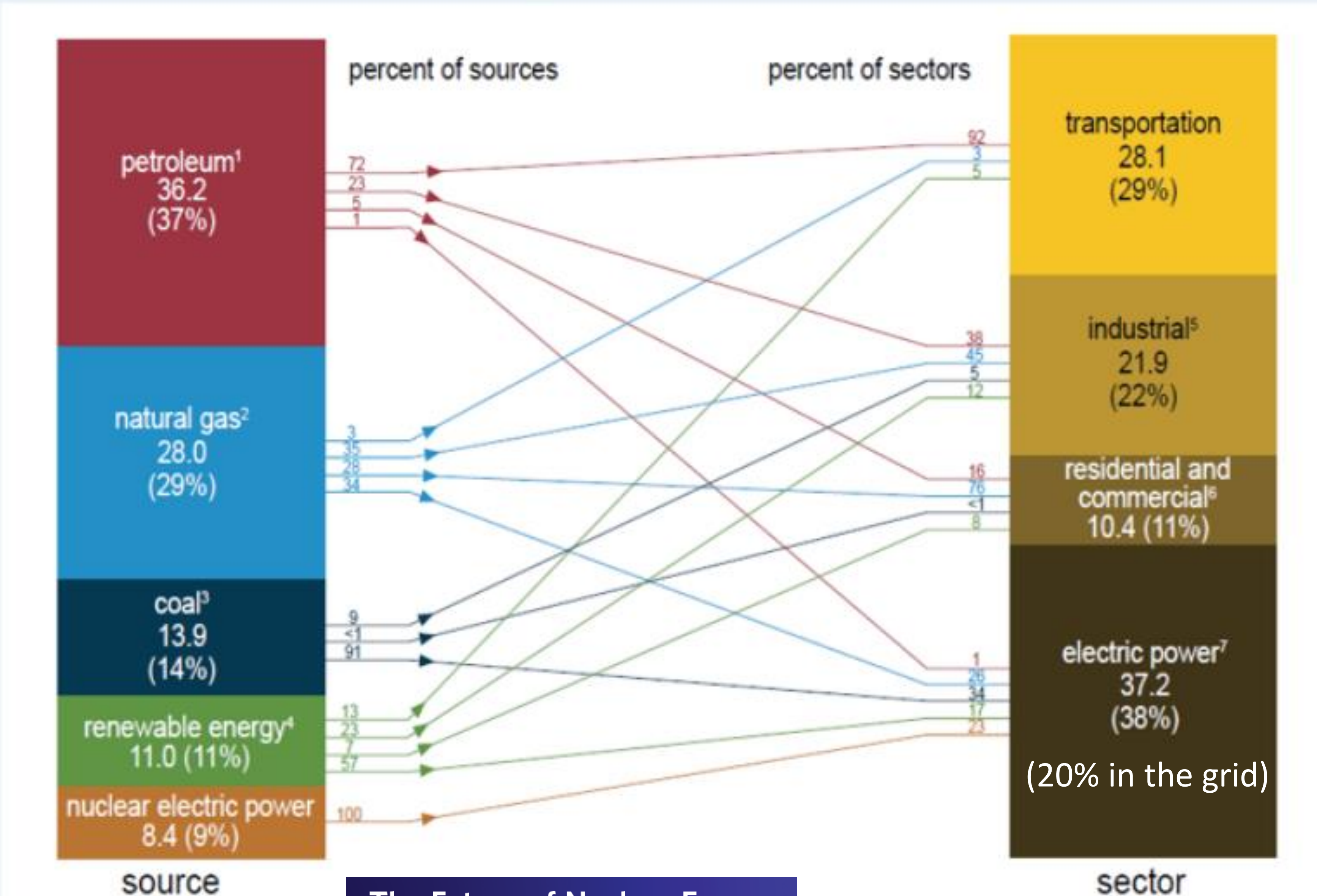
30-60 g
20-100 l
idrogeno
Metno

22 mg uranio
naturale

0.3 kg
Legna
secca

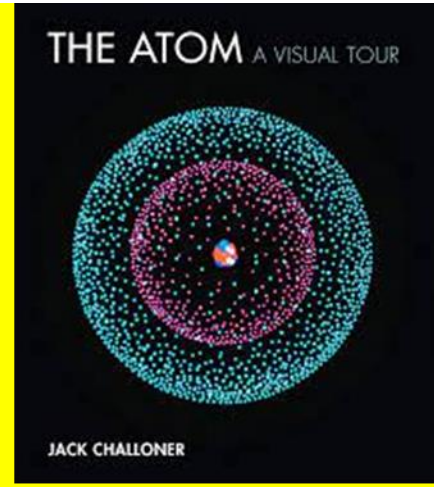
8 m2
celle
solari

Figure F.3: 2014 primary U.S. energy consumption by source and sector



The Future of Nuclear Energy in a Carbon-Constrained World

MIT study 2018



Atom: 10^{-8}cm

Nucleus: 10^{-13}cm

Reazioni chimiche

- $C + O_2 = CO_2 + Q \qquad Q = 3.6\,eV$

Metano

- $CH_4 + 2O_2 = CO_2 + 2H_2O + Q \qquad Q = 9.2\,eV$

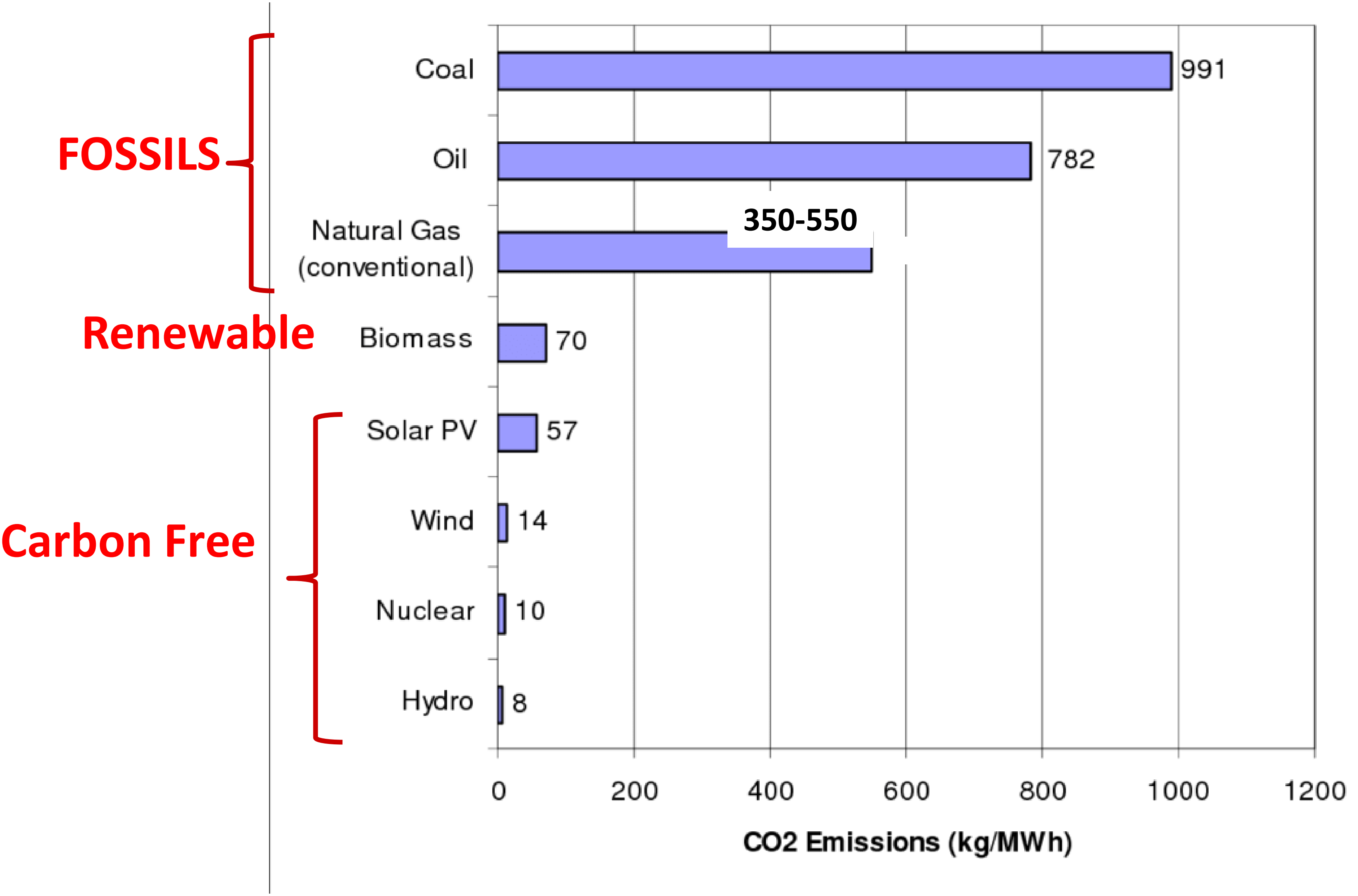
Fissione Nucleare

x 23'000'000

- ${}^{235}U + n = F_1 + F_2 + \nu n + Q \qquad Q = 211.5\,MeV$

Fusione nucleare

- ${}^{2}H + {}^{3}H = {}^{4}He + n + Q \qquad Q = 17.6\,MeV$

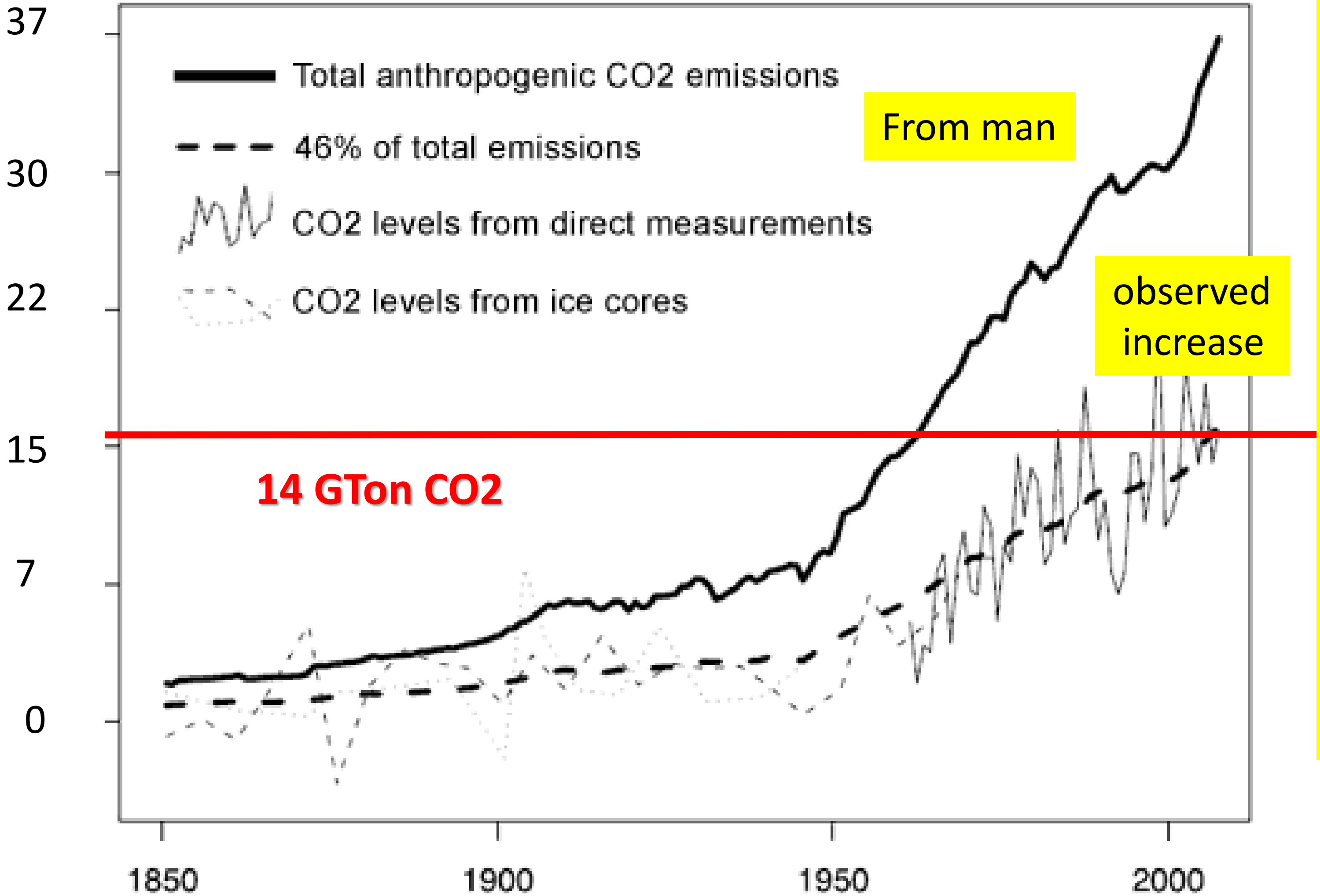


Fonts

Frank, Matthew & Goodward, Jenna & Ladislaw, Sarah & Zyla, Kate. (2022). Crossing the Natural Gas Bridge.

L. Maugeri *Con tutta l'energia possibile* Sperling Kupfer 2008

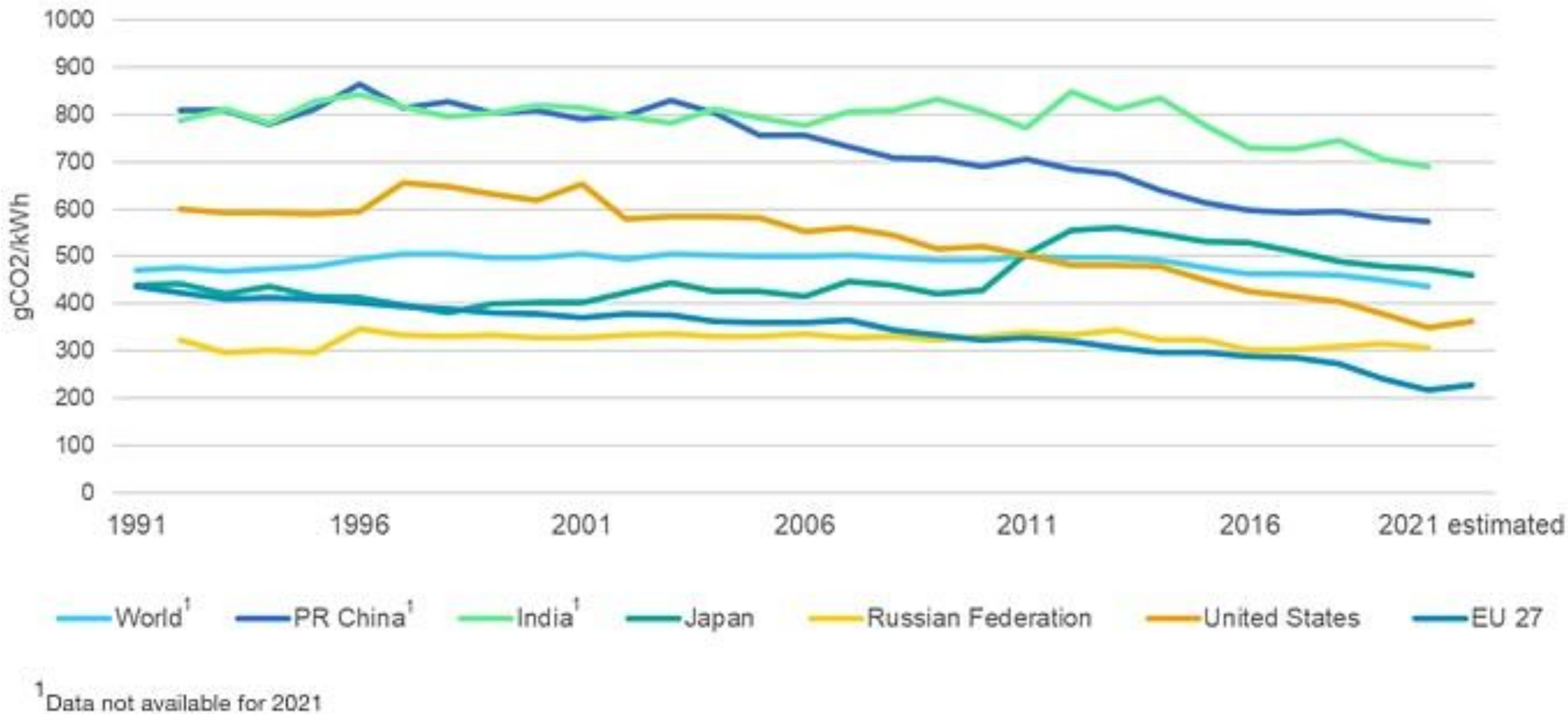
CO2 emissions versus CO2 levels



Total CO2 in atmosfera: 2000 Gton.
Emissioni annuali antropiche: 37 Gton CO2
Incremento annuale osservato: 17 Gton CO2

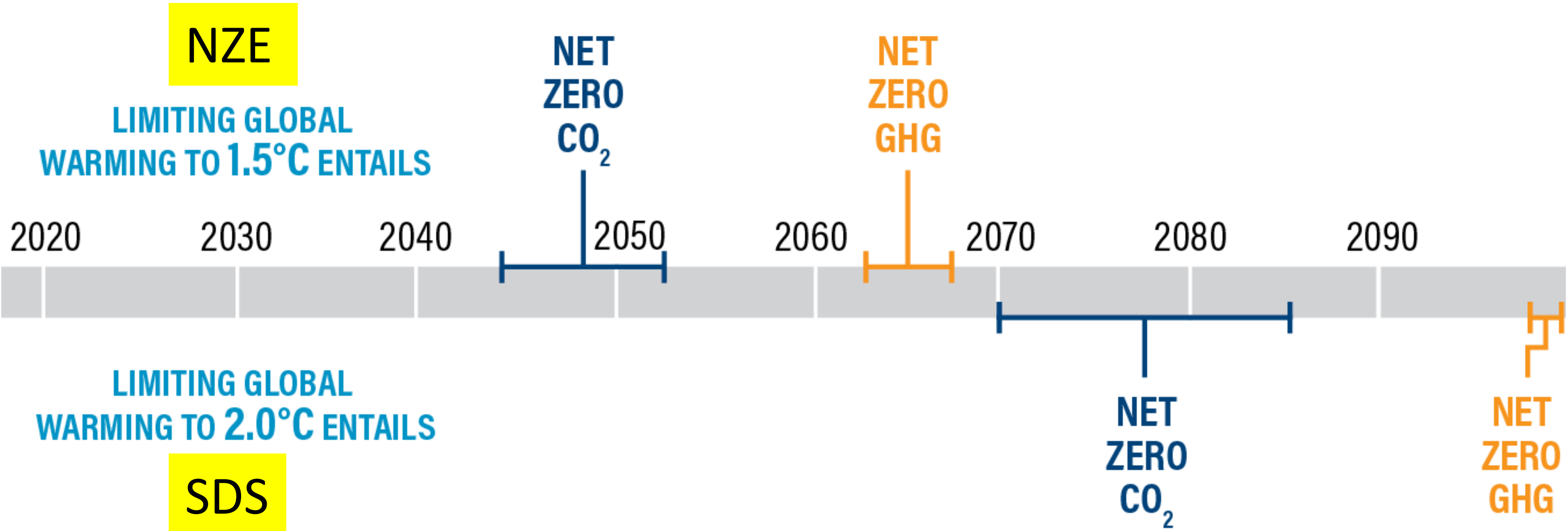
10 Gtons = 100 laghi di Garda l'anno nella atmosfera; se questo volume fosse spalmanto sull'Italua, avrebbe un spessore di 16 m

w. Knorr, GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L21710, doi:10.1029/2009GL040613, 2009



IEA releases 'Emissions Factors' and
'Greenhouse Gas Emissions from Energy' databases (september 2022)

Global timeline to reach net-zero emissions



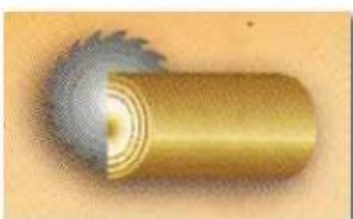
Source: IPCC Special Report on Global Warming of 1.5°C

WORLD RESOURCES INSTITUTE

Pastiglia di uranio (4% of U235)

5 g (4800 kWh)

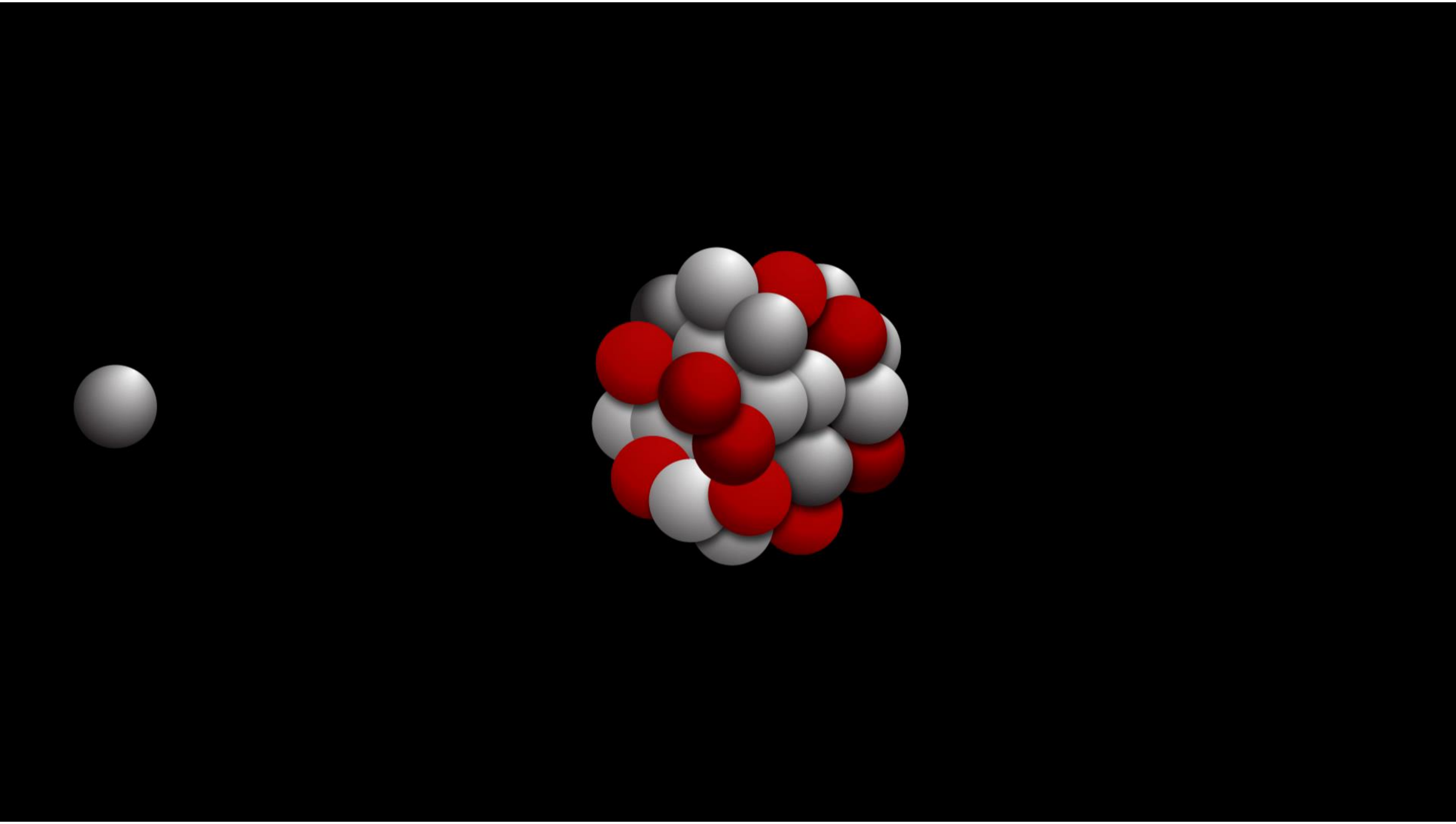
=

			
1600 kg	436 m^3	450 kg	500 *l*
legna secca	metano	carbone	petrolio

neutron

Proton +

+ $U = {}^{235}_{92}U$



Come funziona un reattore?

Punti cruciali

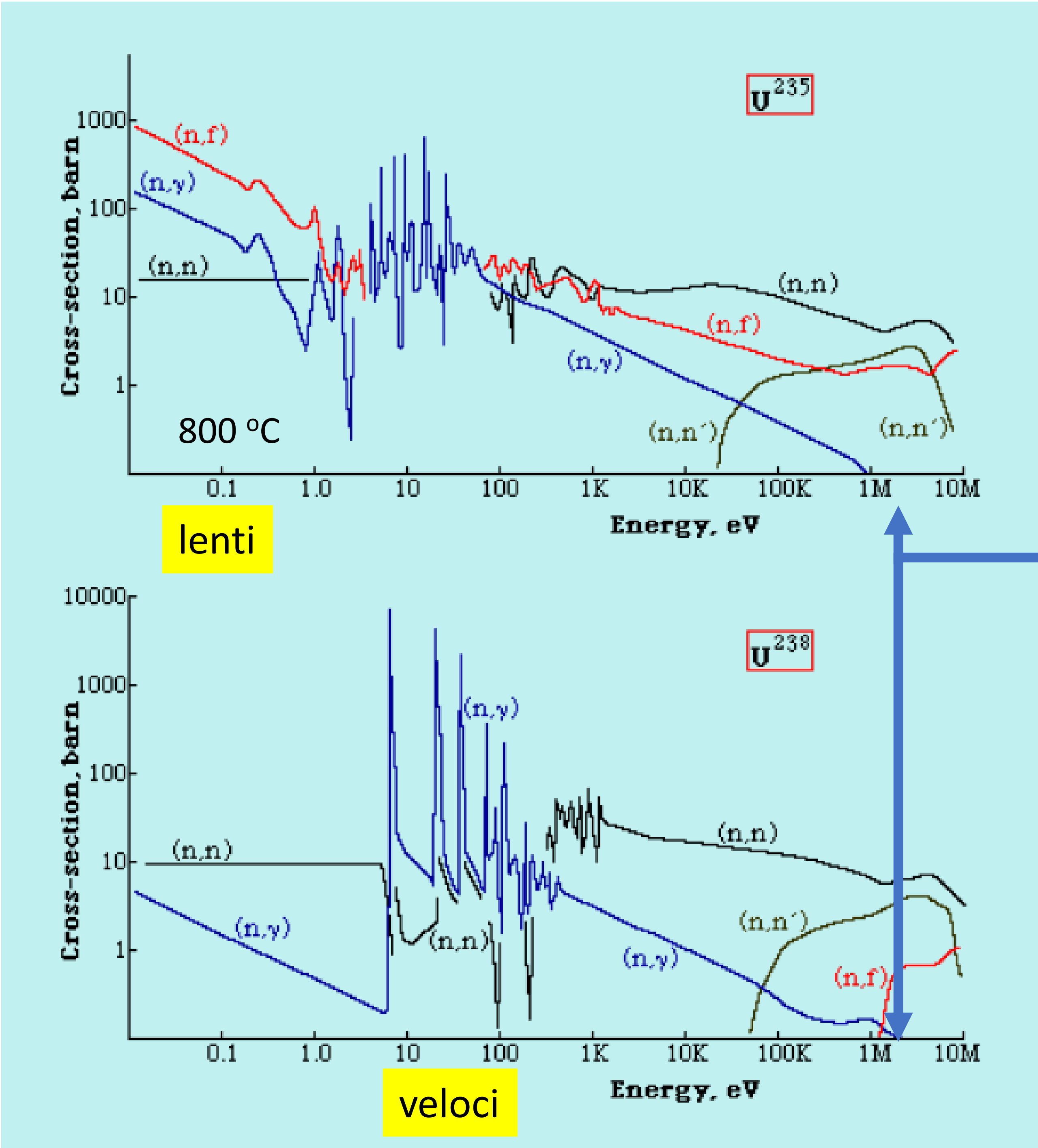
Nuclei Fissili (^{233}U, ^{235}U, ^{239}Pu): assorbono un neutrone e si spaccano in due o tre frammenti rilasciando energia

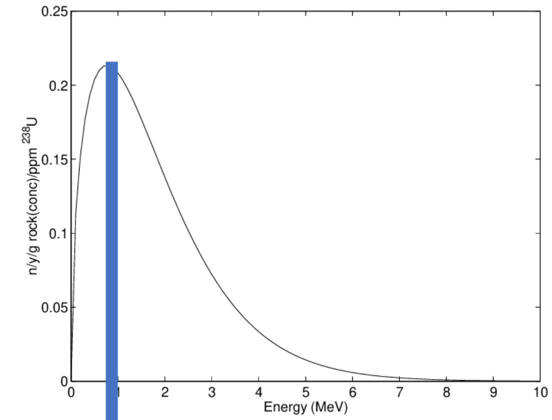
- Nuclei Fertili (^{232}Th, ^{238}U): assorbono un neutrone e si trasformano in un nucleo fissile ($^{232}Th + n \rightarrow {}^{233}U$, $^{238}U + n \rightarrow {}^{239}Pu$)

- L'assorbimento di un neutrone e la probabilità di fissione (cross sections) dipendono fortemente dall'energia del neutrone

- **I frammenti di fissione perdono la loro energia in meno di 1 mm nelle barre di metallo o nel combustibile. La barra si scalda.**

Questa è la srgente di energia di un reattore

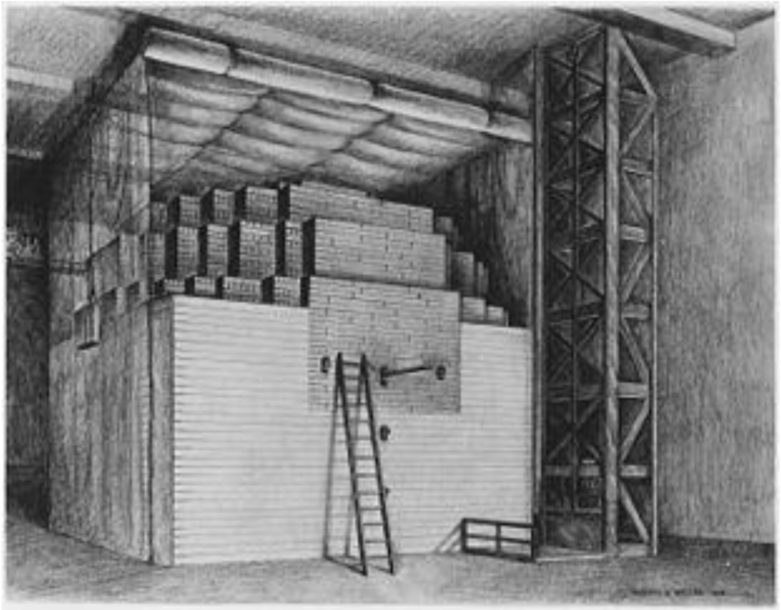




Fissione di ^{235}U:
Neutroni lenti.
Reattori termici

Assorbimento neutronico di ^{238}U:
Neutroni veloci.
Reattori veloci

L'idea di Fermi



La prima pila a uranio
1941-42

La percentuale di ^{235}U nell'uranio naturale è 0.7% and ^{235}U assorbe neutroni lenti
I neutroni veloci emessi da ^{235}U sono rallentati da nuclei di grafite
Questo rese possibile la prima reazne a catena (decembre 1942).
Questo tipo di reattore produsse il plutonio per la bomba di Nagasaki

Dopo la guerra

Come prdurre calore in md controllato?

Soluzione: usare l'acqua sia per rallentare i neutroni sia come reffrigerante.
Ma l'acqua assorbe parte dei neutroni.
Questo può essere compensato arricchendo l'uranio

arricchimento

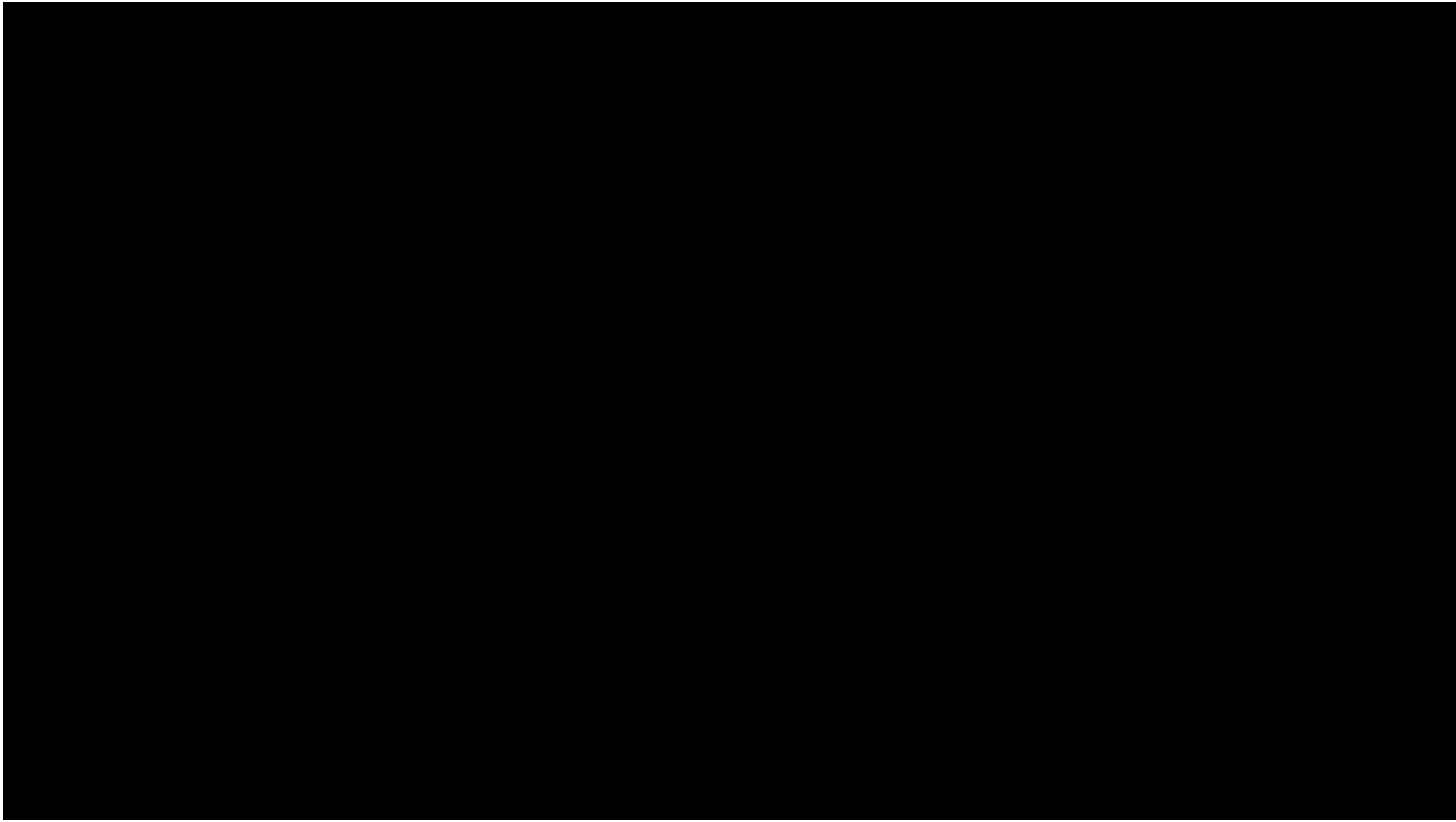
1 Kg of ^{235}U rilascia una energia di 18 ktons di TNT. Questa è l'energia elettrica consumata dall'Italia in ½ora.

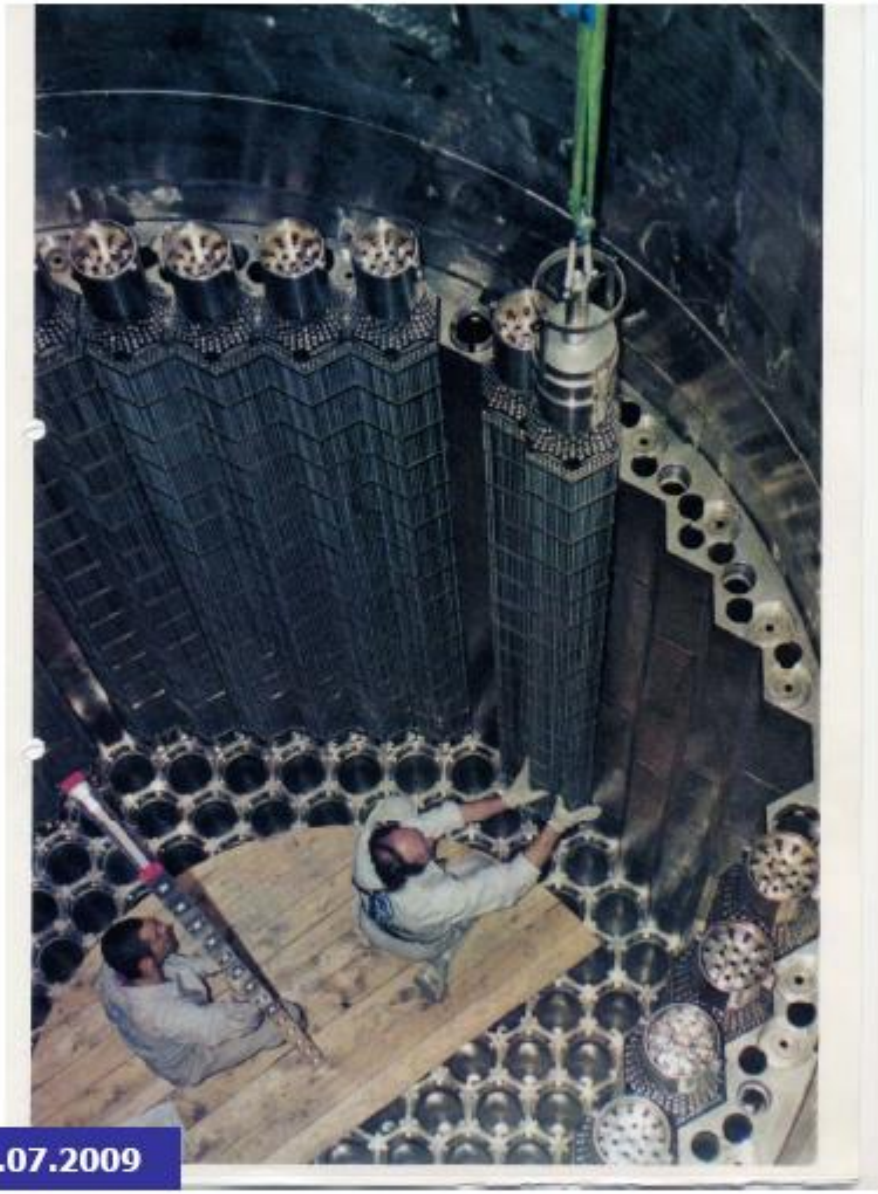
^{235}U è "diluito" nell'uranio naturale (0.7 % ^{235}U, 99.3% ^{238}U).

Sia per reattori (4-10%) sia per bombe (>90%)

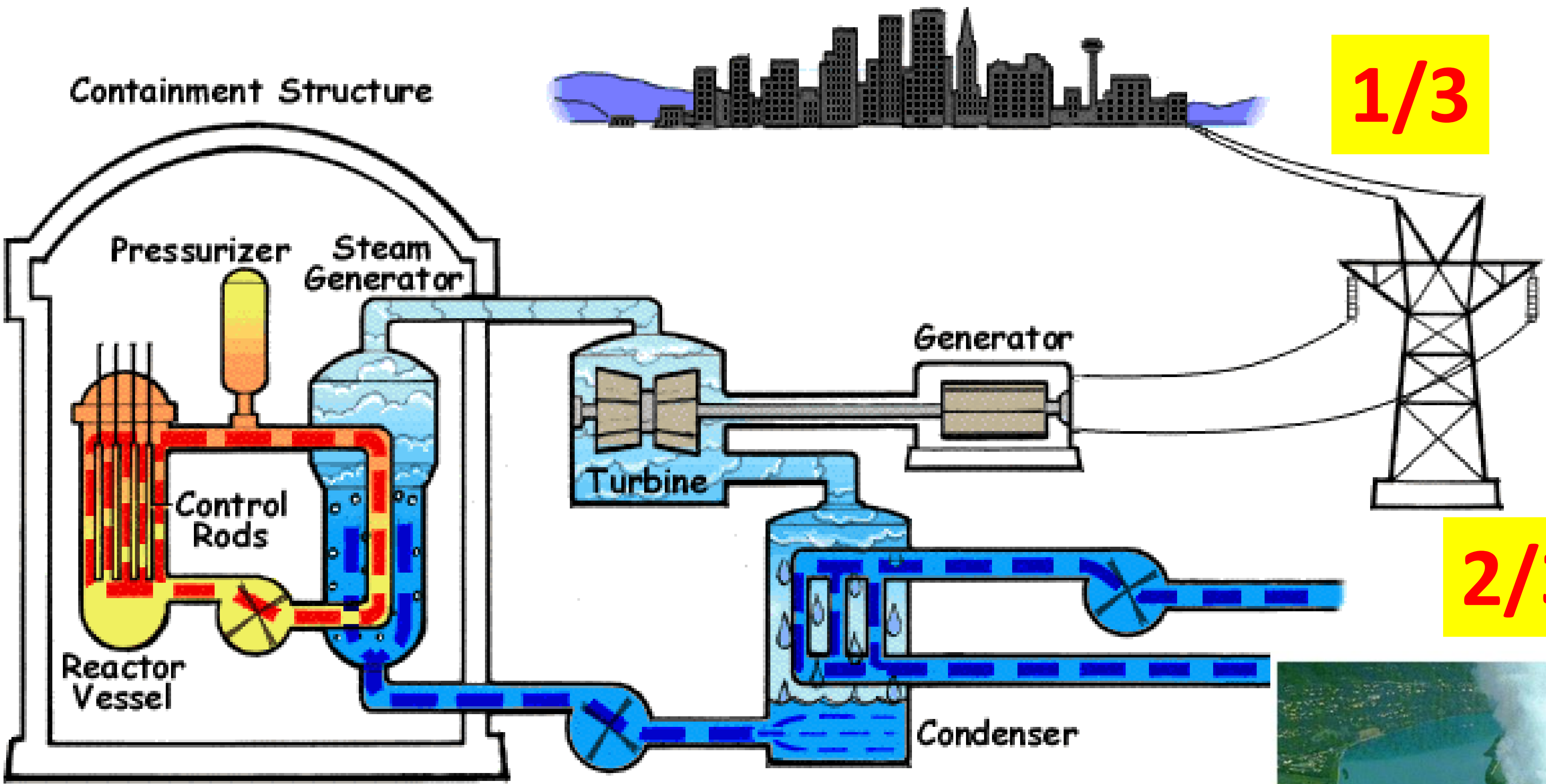
Il minerale viene arricchito

La procedura è la stessa





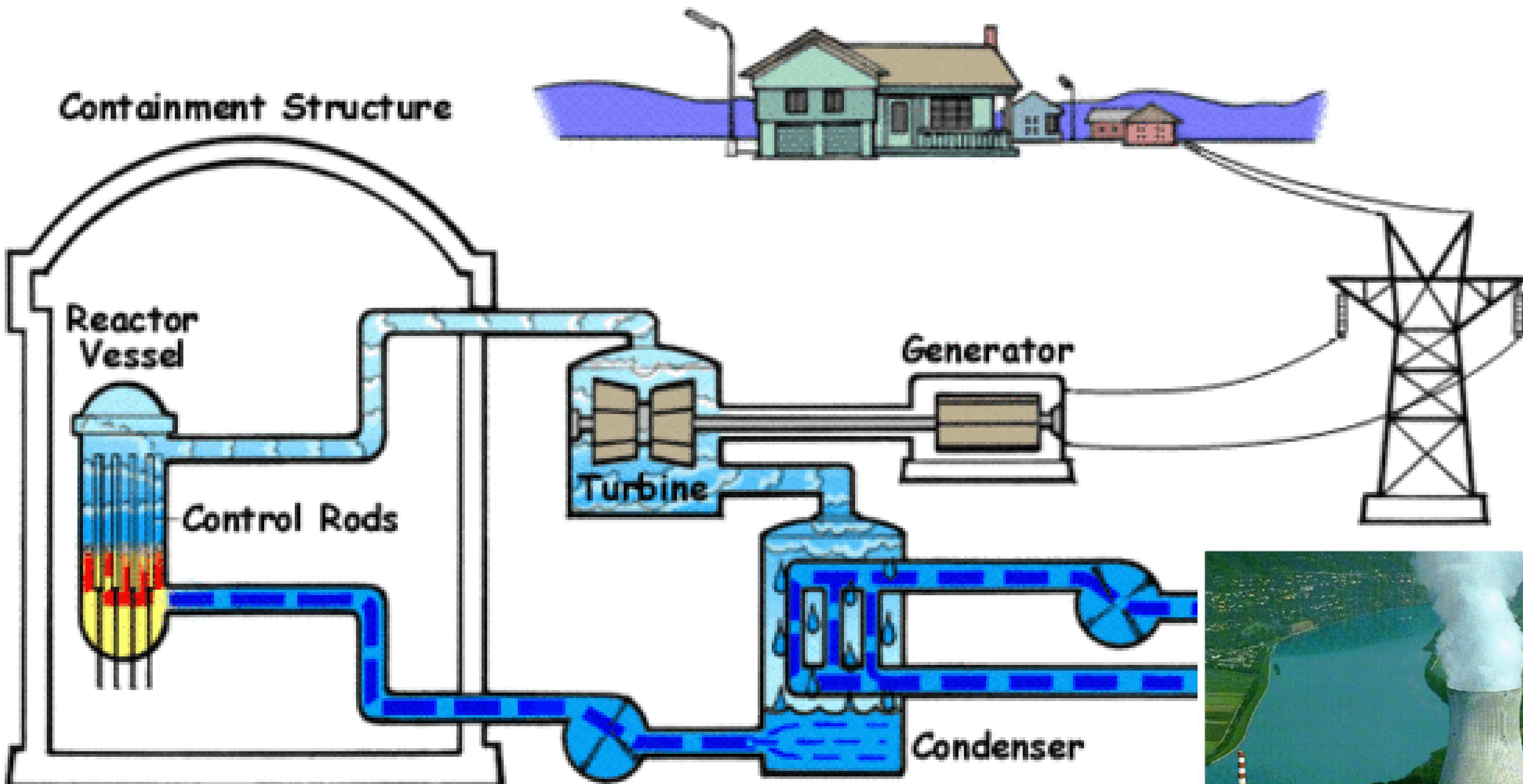
Reattore PWR-280 nel mondo

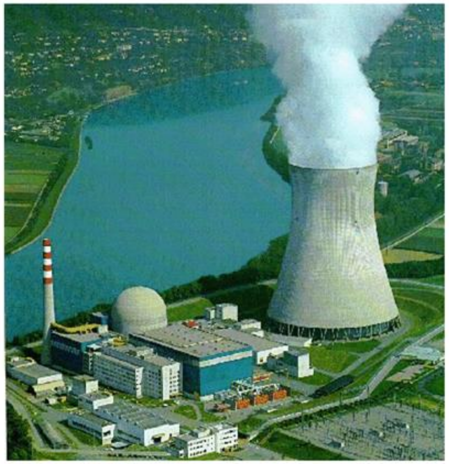


1/3

2/3

Reattore BWR - 70 nel mondo





Light water reactors (LWR)

- Light water reactors use ordinary water to moderate and cool the reactors.
- Water is light, cheap, and does not burn.
- However it eats neutrons ($p+n \rightarrow d + \gamma$) and Uranium has to be enriched, to about 3 per cent for reaching criticality.
- When at operating temperature, if the temperature of the water increases, its density drops, and fewer neutrons passing through it are slowed enough to trigger further reactions. **That negative feedback** stabilizes the reaction rate.
- Also, if the moderator/coolant is lost, neutrons are not slowed down. Rather they are captured by ^{238}U and the reactor stops.

After the shutdown, 6% of the power remains as radioactive heat
Decay heat removal problem (3 GW->180 MW)

- There are some 359 LWR in in 27 countries, with a global generating capacity of some 330 GW.
- 27 reactors are in construction

CANDU= CANadian Deuterium Uranium

- Light water reactors need enriched Uranium, and thus the (expensive) technology for Uranium enrichment .
- Canada has developped a system which can burn natural Uranium, by employing as moderator and coolant (expensive) heavy water.
- The use of heavy water moderator is the key to the CANDU system, enabling the use of natural uranium as fuel (in the form of ceramic UO_2), which means that it can be operated without expensive uranium enrichment facilities.
- Compared with light water reactors, a heavy water design is "neutron rich". This makes the CANDU design suitable for "burning" a number of alternative nuclear fuels. To date, the fuel to gain the most attention is mixed oxide fuel (MOX). MOX is a mixture of natural uranium and plutonium, such as that extracted from former nuclear weapons.
- Today there are 18 CANDU reactors in use in Canada 10 in the rest of the world, and a further 13 "CANDU-derivatives" in use in India (these reactors were developed from the CANDU design after India detonated a nuclear bomb in 1974 and Canada stopped nuclear dealings with India).

LWR	
Moderator	H_2O
Coolant	H_2O
Fuel	UO_2 (3-4.5%)
Fuel bundle	Zircalloy 4
Working temp UO_2	1300-1500 °C
Efficiency	33%
Pressure	150 bar
Coolant temp	300 °C

CANDU	
Moderator	D_2O
Coolant	D_2O
Fuel	UO_2 (0.7% nat)
Fuel bundle	Zircalloy 4
Working temp UO_2	2000 °C
Efficiency	29%

I pro dei rettori termici

- Mantenimentdelle competenze nucleari
- Produzione di energia continua e concentrata
- Ottimizzati per la produzione elettrica
- Nessuna emissione di CO2
- Dispnibilità di combustibile
- Stabilità dei prezzi
- Piccoli volumi di scorie

…. I pro

Source: Comparison between Doel Nuclear Plant and Kristal Solar Park in Lommel. If operated at 85% capacity factor, Doel's 570 megawatt (net) capacity would produce 22 terawatt-hours per year on an approximate land area of 1.1 square kilometers, for a density of 20 terawatt-hours per square kilometer. Kristal Solar Park has a power density of 0.07 terawatt-hours per square kilometer.

ENVIRONMENTAL PROGRESS

1 GW di potenza elettrica =
3 GW di potenza totale

1500 turbine a vento of 3 MW
50 km^2 di celle solari

continua

intermittente

… i pro

UNA centrale a carbone per 45 anni:
12 Milioni di tonnellate di rifiuti tossici!
volume: 1kmx 1km x 12m di acqua

Sapevate che… (… i pro)

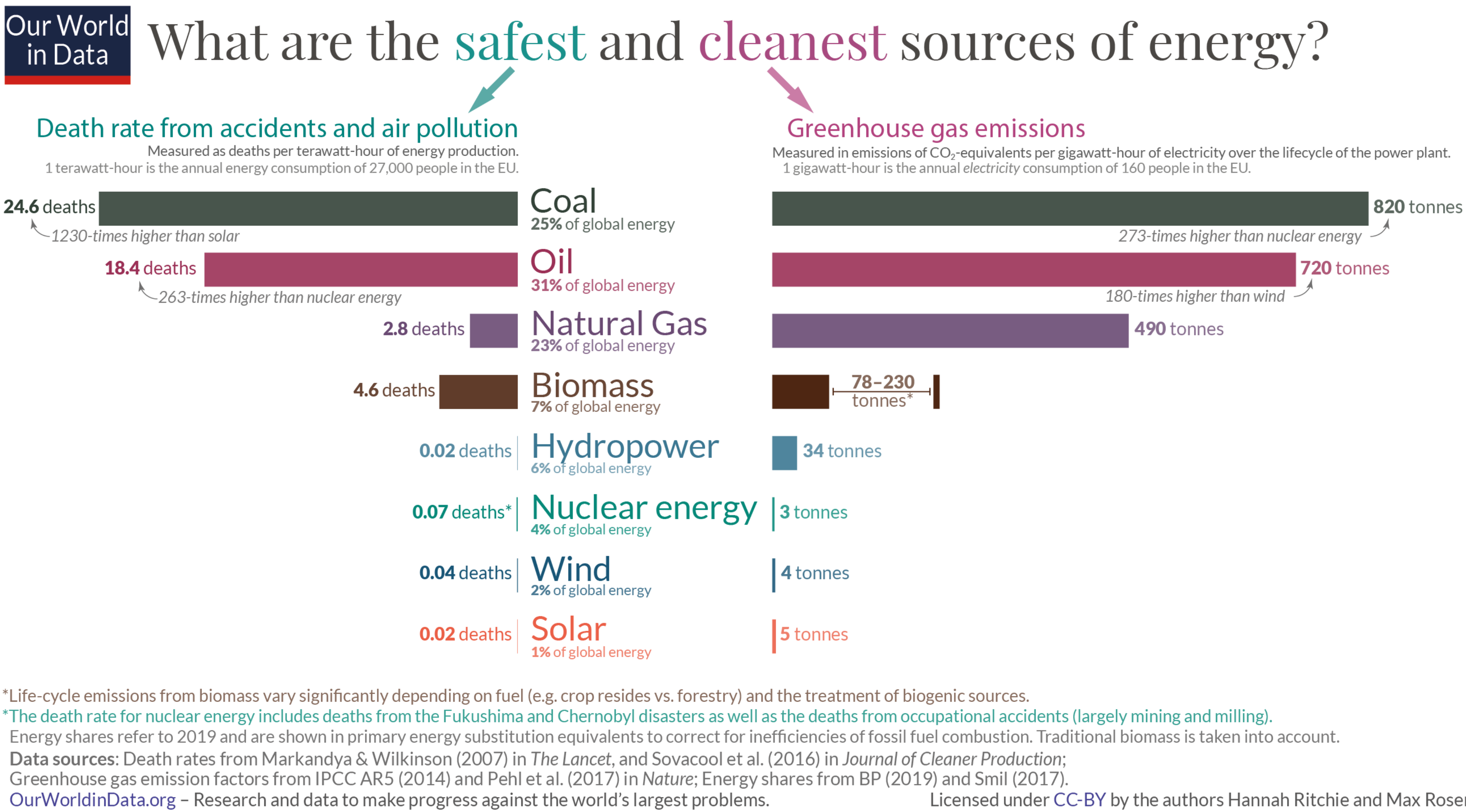
	centrale da 1000 MWe in un ann carbone	nucleare
Fuel	1-2 milini di tonnellate 45.000 vagoni	20 tonnellate 2 vagoni
Scorie	in sito e dispersi	in sito
Scorie totali	7.000.000 tonnellate	30 tonnellate
Tossiche	--------	2 tonnellate
da gestire	250.000 tonnellate	20 tonnellate
Scorie radioattive	50 GBq	2 GBq

Scorie:

Carbone: bassa tossicità, ingestibili e delocalizzate

Nucleare: alta tossicità, gestibili e localizzate

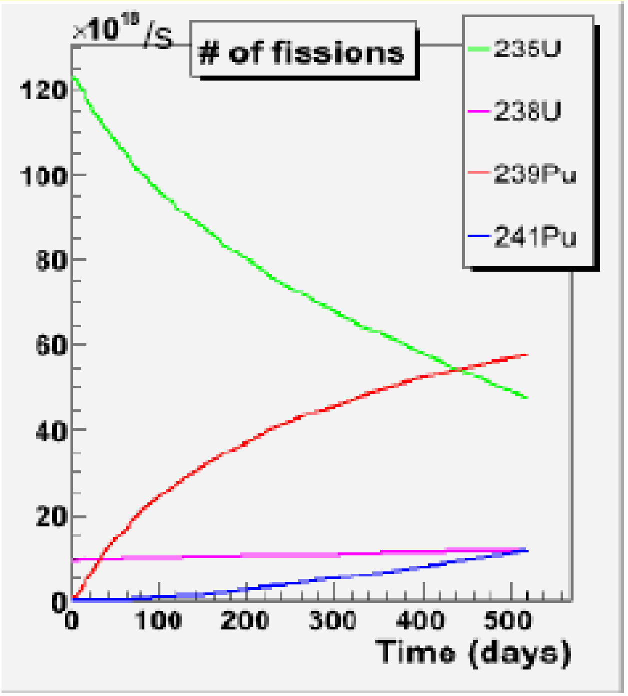
…. I pro


Our World in Data
What are the safest and cleanest sources of energy?
Death rate from accidents and air pollution
Measured as deaths per terawatt-hour of energy production.
1 terawatt-hour is the annual energy consumption of 27,000 people in the EU.
Greenhouse gas emissions
Measured in emissions of CO_2-equivalents per gigawatt-hour of electricity over the lifecycle of the power plant.
1 gigawatt-hour is the annual electricity consumption of 160 people in the EU.
24.6 deaths
1230-times higher than solar
Coal
25% of global energy
820 tonnes
273-times higher than nuclear energy
18.4 deaths
263-times higher than nuclear energy
Oil
31% of global energy
720 tonnes
180-times higher than wind
2.8 deaths
Natural Gas
23% of global energy
490 tonnes
4.6 deaths
Biomass
7% of global energy
78–230 tonnes*
0.02 deaths
Hydropower
6% of global energy
34 tonnes
0.07 deaths*
Nuclear energy
4% of global energy
3 tonnes
0.04 deaths
Wind
2% of global energy
4 tonnes
0.02 deaths
Solar
1% of global energy
5 tonnes
*Life-cycle emissions from biomass vary significantly depending on fuel (e.g. crop resides vs. forestry) and the treatment of biogenic sources.
*The death rate for nuclear energy includes deaths from the Fukushima and Chernobyl disasters as well as the deaths from occupational accidents (largely mining and milling).
Energy shares refer to 2019 and are shown in primary energy substitution equivalents to correct for inefficiencies of fossil fuel combustion. Traditional biomass is taken into account.
Data sources: Death rates from Markandya & Wilkinson (2007) in The Lancet, and Sovacool et al. (2016) in Journal of Cleaner Production;
Greenhouse gas emission factors from IPCC AR5 (2014) and Pehl et al. (2017) in Nature; Energy shares from BP (2019) and Smil (2017).
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.

I contro dei reattri termici (II and III gen)

- Cattivo uso del combustibile
- Grande consumo di acqua
- Bassa efficienza di produzione elettrica (30%)
- Da risolvere: deposito per lescorie ad alta attività
- Difficoltà a trattare la radioattività in caso di incidente
- Alta complessità tecnica (tempi e costi)
- Proliferazione nucleare
- **Un reattore nucleare non si spegna mai del tutto**
- **Il nucleare dipnde in modo cruciale dal tipo di società che lo ospita**

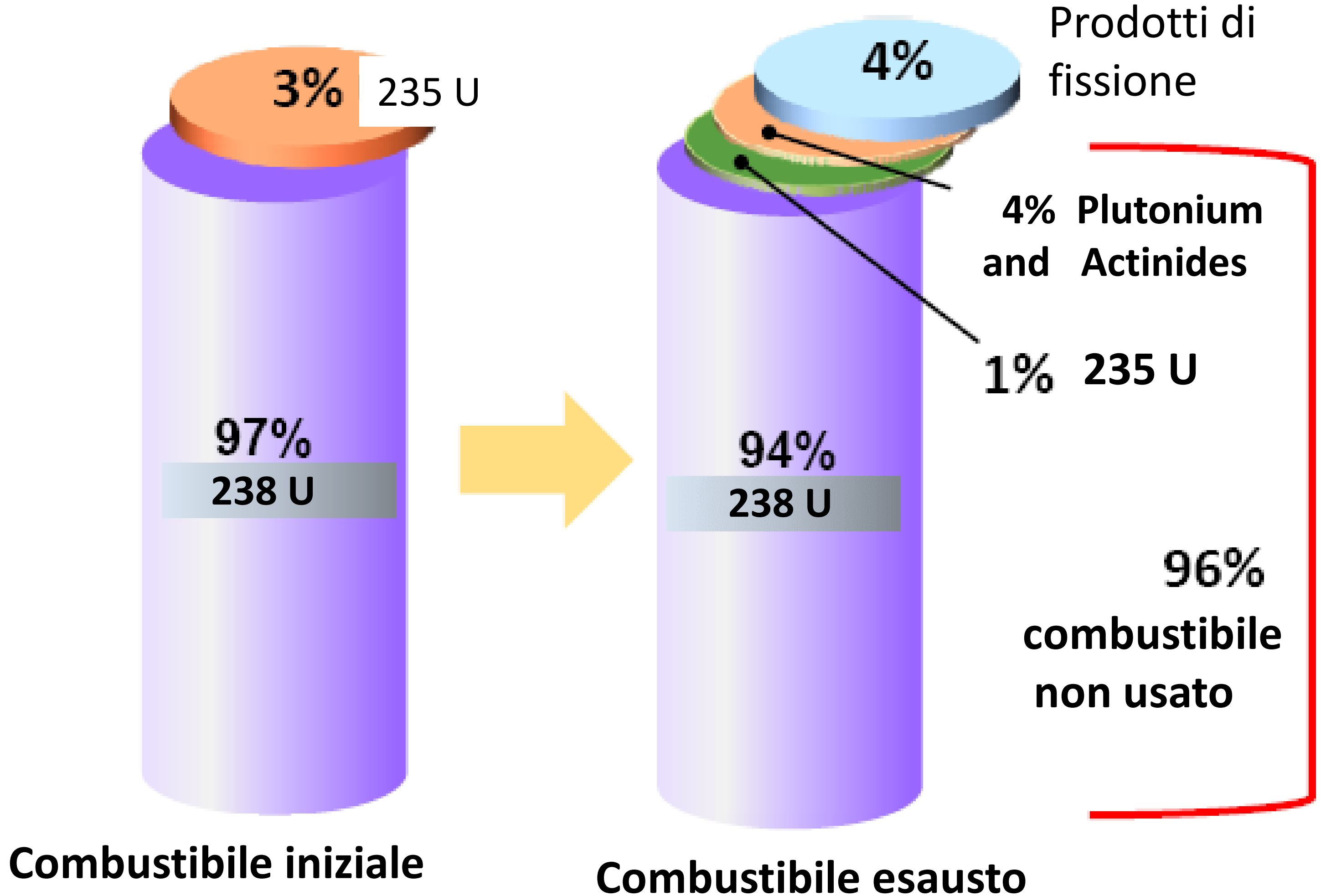
Fuel budget (… i Contro)



- Consider a reactor which at burn up contains a critical mixture of 235U and 238U.
- Of course, the main ingredient is the fissile ^{235}U, where fission is indiced by thermalized neutrons
- A non negligible fraction arises from ^{238}U, due to the fast neutrons, before they are slowed down
- Note also the role of Plutonium, which at later times even passes the role of 235U.

(Modern reactors are built so that they can burn since the beginning admixtures of U and Pu (MOX) since there is "abundance" of Pu, from nuclear weapons which are being dismantled as the consequence of international treaties…)

Fuel budget II (… i contro)



Se si utilizzasse ^{238}U per produrre energia, risorse sufficienti per 3000 anni !!

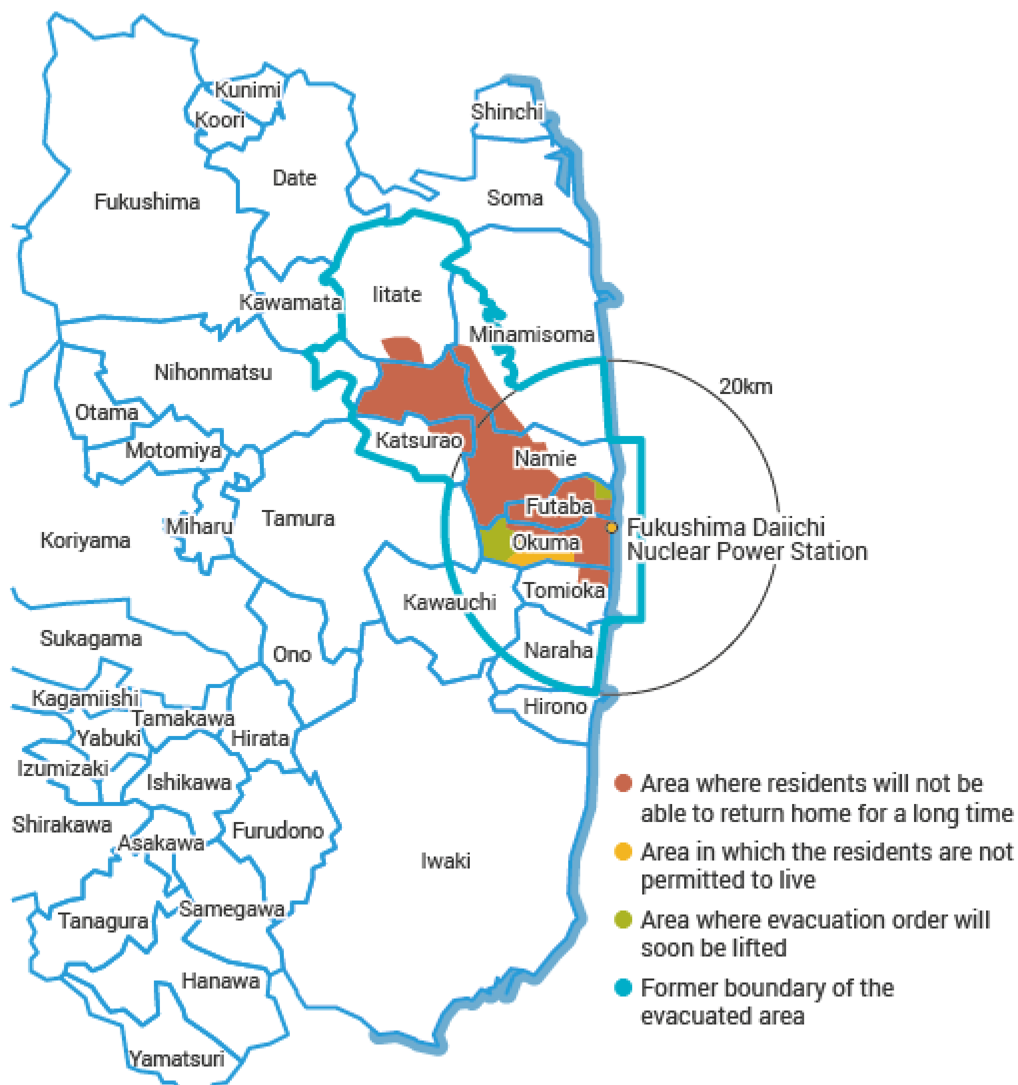
Fukushima 2011-2021 (…i contro)

Marzo 2021

la zona proibita ora occupa circa 337 km^2, il 30% di quella massima iniziale, ed è equivalente a metà dell'area del centro di Tokyo.

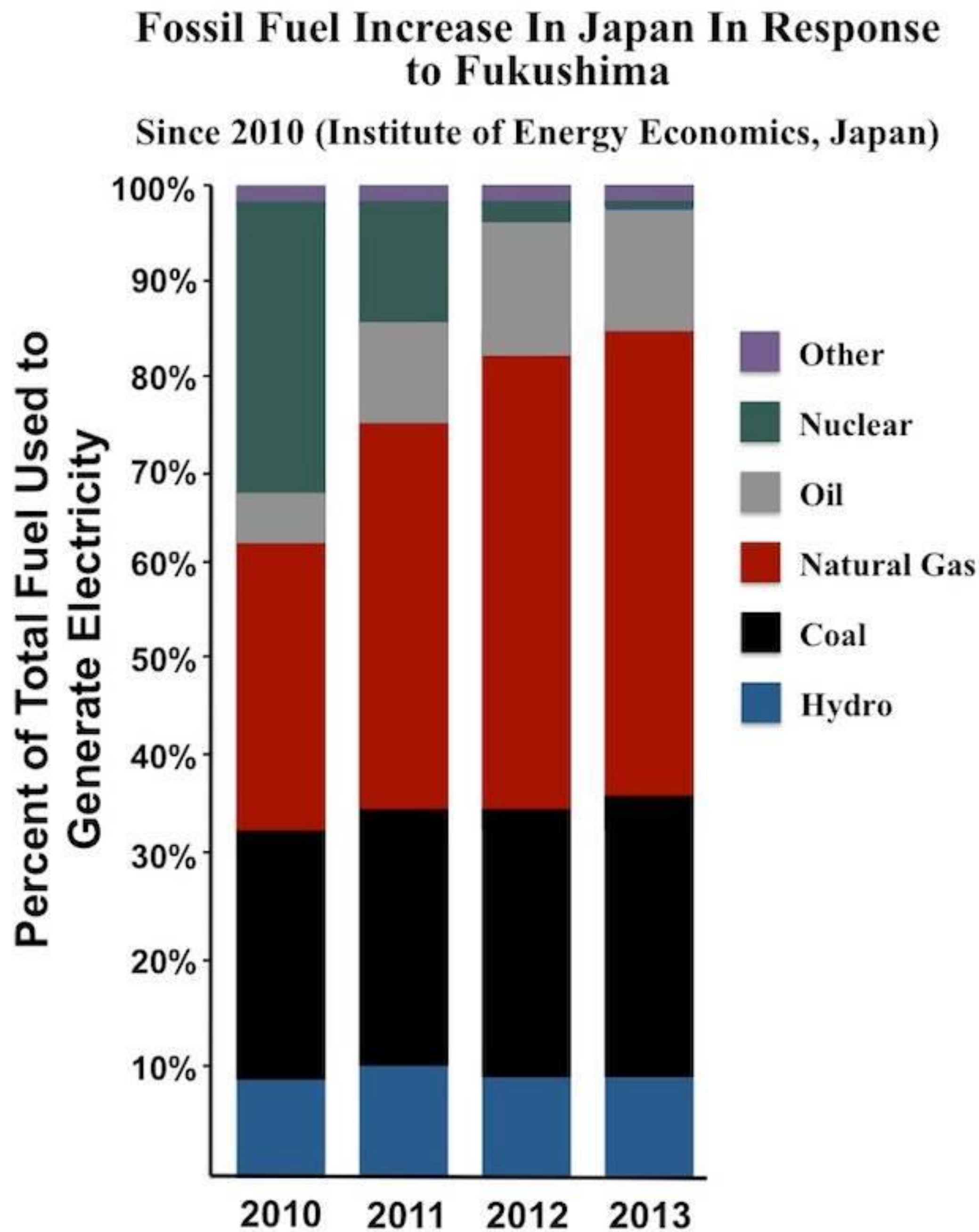
Le aree in 7 municipalità rimangono zone off limits a causa dei lively di radiazione. Non si sa quando queste restrizioni saranno rimosse.

State of Reconstruction of Fukushima Prefecture



Source: METI

World Nuclear Association website



Fossil Fuel Increase In Japan In Response to Fukushima
Since 2010 (Institute of Energy Economics, Japan)
Percent of Total Fuel Used to Generate Electricity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
2010
2011
2012
2013
Other
Nuclear
Oil
Natural Gas
Coal
Hydro

Olkiluoto3: il disastro (... i contro)

17 Feb. 2005	the Finnish cabinet approves the construction application
July 2005	**start of construction**
2009	Siemens withdraws from the joint venture with Areva
Jan. 2009	reactor pressure vessel and vessel head arrive on site
May 2009	main control room lifting in Safeguard Building 2
summer 2009	polar crane installation, dome installation
Sep. 2009	EPR dome installed
June 2011	Anne Lauvergeon leaves her position as CEO of Areva
July 2012	delay in start of production to no earlier than 2015 announced
December 2012	**Areva estimates that the full cost of building the reactor will be about €8.5 billion, or almost three times the delivery price of €3 billion**
February 2014	Areva shutting down construction due to dispute over compensations and unfinished automation planning. Operation estimated to be delayed until 2018–2020.[27]
December 2015	**The operational automation systems began to be delivered and installed. Commercial operation is estimated for Dec 2018.**
January 2016	Testing of the operational automation systems begins.
December 2022	The connection to the grid after 17 year from starting

Table 8.2: Construction costs of recent FOAK Generation III/III+ projects

Type	Country	Unit	Construction start	Initial announced construction time	Ex-post construction time	Power (MWe)	Initial announced budget (USD/kWe)	Actual construction cost (USD/kWe)
AP 1000	China	Sanmen 1, 2	2009	5	9	2 x 1 000	2 044	3 154
	United States	Vogtle 3, 4	2013	4	8/9*	2 x 1 117	4 300	8 600
APR 1400	Korea	Shin Kori 3, 4	2008	5	8/10	2 x 1 340	1 828	2 410
EPR	Finland	Olkiluoto 3	2005	5	16*	1 x 1 630	2 020	>5 723
	France	Flamanville 3	2007	5	15*	1 x 1 600	1 886	8 620
	China	Taishan 1, 2	2009	4.5	9	2 x 1 660	1 960	3 222
VVER 1200	Russia	Novovoro-nezh II-1 & 2	2008	4	8/10	2 x 1 114	2 244	**

* Estimate. ** No data available.

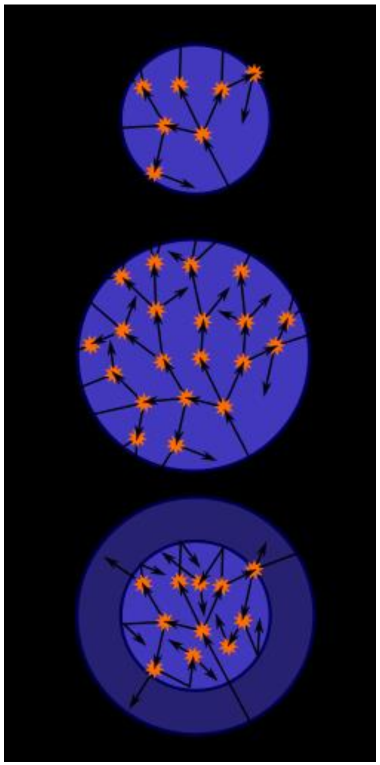
Notes: MWe = megawatt electrical capacity. kWe = kilowatt electrical capacity.

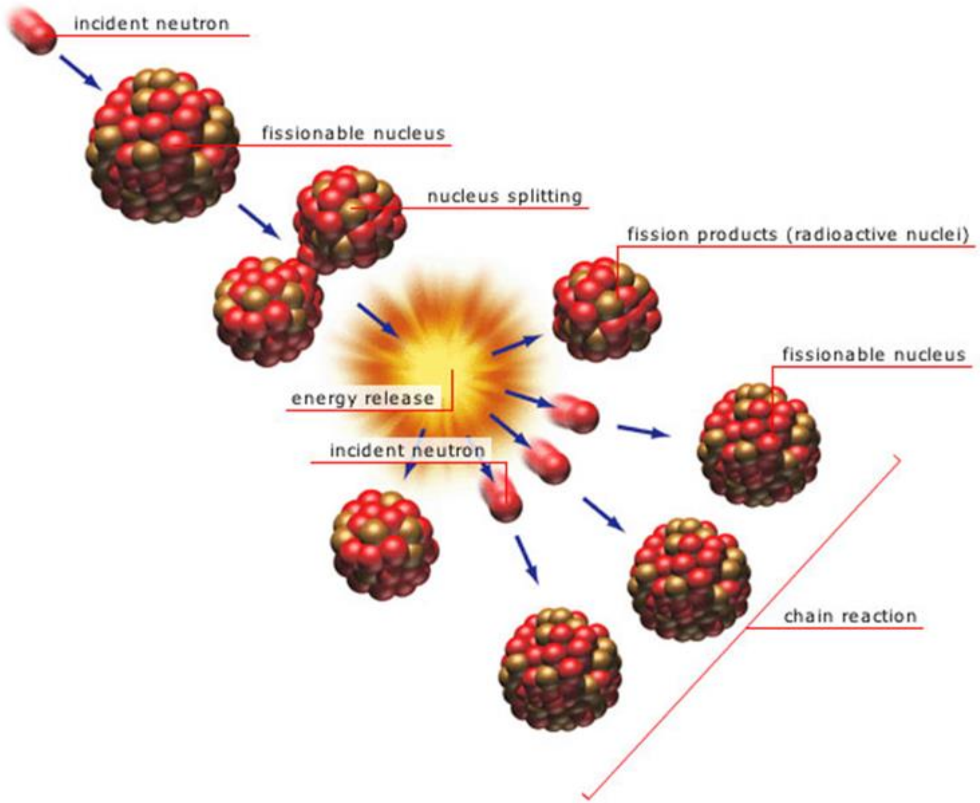
Source: NEA (2020).

[Taishan-1 EPR resumes operation a year after shutting down after reactor damage fears (Aug 2022)]

CNN then reported erroneously on the situation based on what was disclosed in Framatome's memo about an "imminent radiological threat." …..the issue posed no public health risk, the news cycle moved on, and on July 30, China General Nuclear, majority owner of Taishan Nuclear Power, took the reactor off line to look for the cause of the damage to fuel rods and perform maintenance.

Proliferazione nucleare: la massa critica di ^{235}U
Arricchita >90%   (instead of 5%)

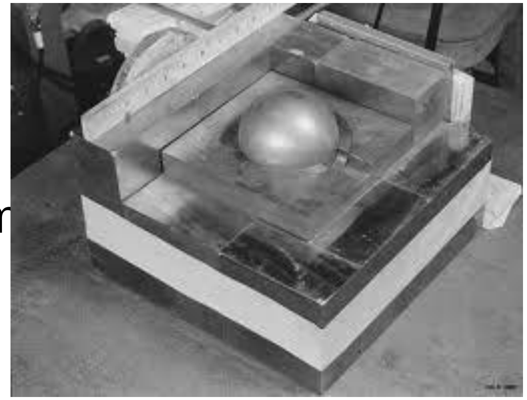




per ^{235}U la massa critica è circa 15 kg

Esplosione: rilascio rapido di grandi quantità di energia

plutonum

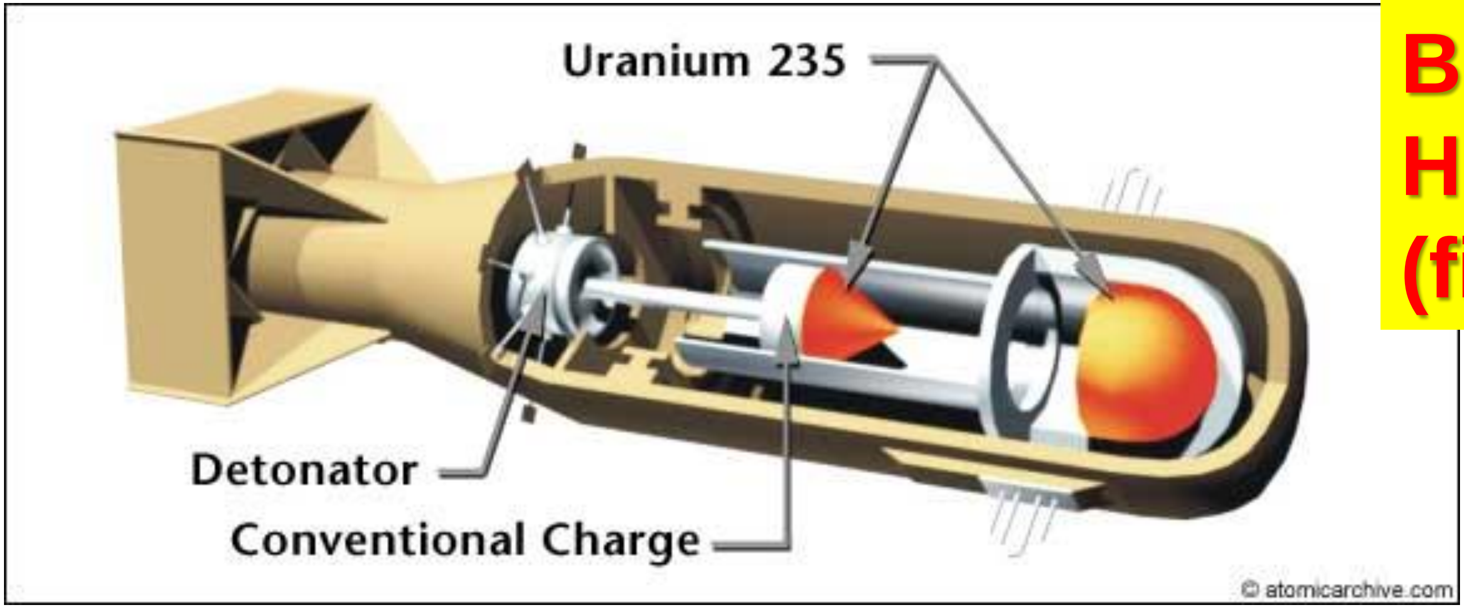


Uranium 235

1+2+4+8+16 = 31

1+2+4+8+16 +32= 63

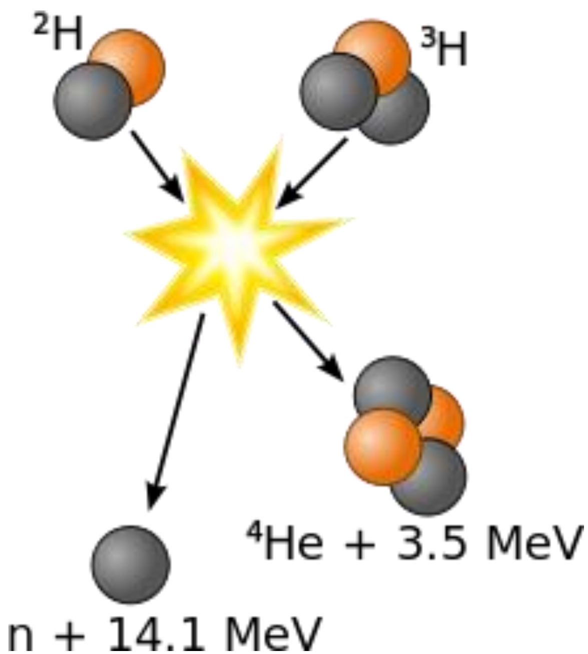
99.9% è rilasciata nelle ultime 7 generazioni:
In un tempo rapido, 0.07 milionesimi di secondo, si crea la massa critica

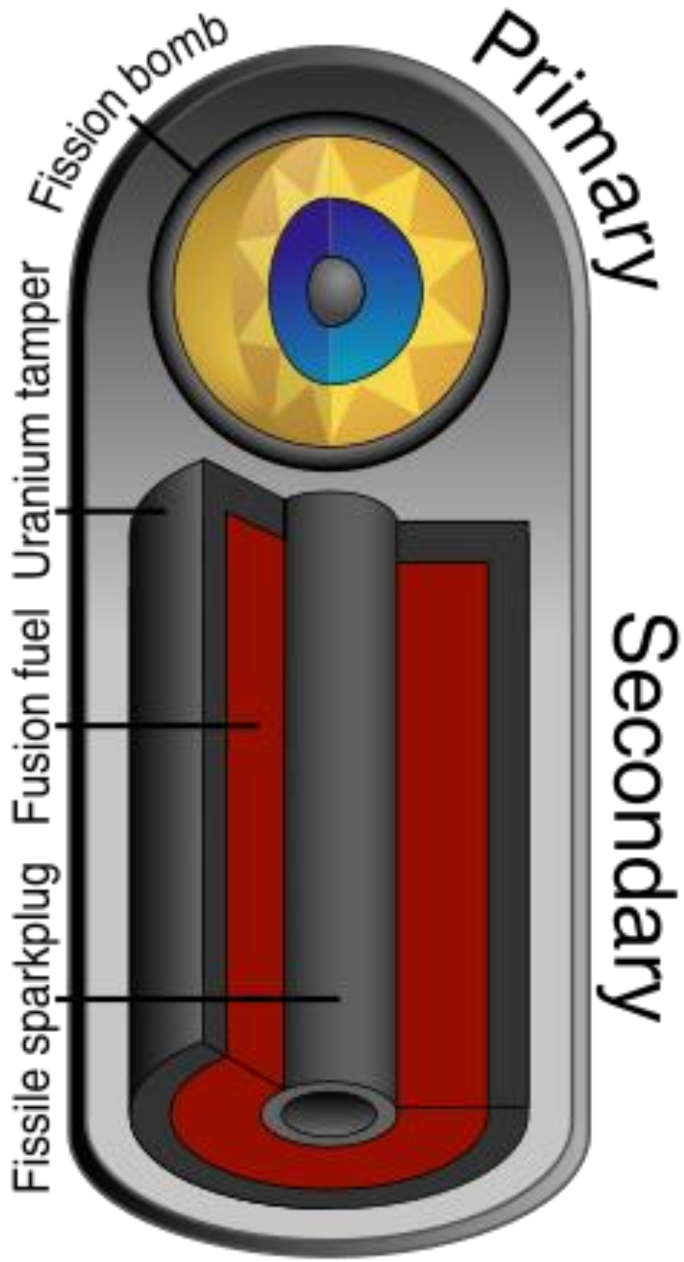


Bomba di Hiroshima (fissione)

- Lunghezza: 3 m
- peso: 4 Ton.
- esplosivo: 60 kg of 70% enriched U
- solo 650-700 g sono stati usati
- Energia rilasciata: 13 KTon di TNT
- Esplosione a 550 m di altezza

Bomba a fusione





- peso: 82 Ton.
- cilindro
- 2,0m diametr 6,20m altezza

- *Tecnlogia segreta e complicata*

Fissione 15 kTon - Fusione 500 kTon (standard), massimo 60.000 kTon

Nuclear proliferation (cons)

trattato
di non
proliferazione

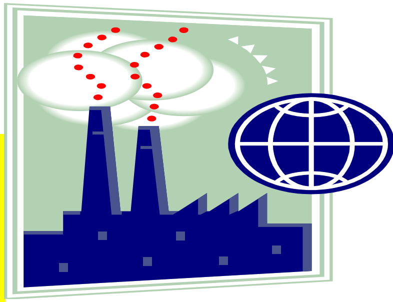
deposito

Scorie
trattate

Uranio
5%

plutonio

Impianti di
trattamento



reattori
civili

Scorie e
barre

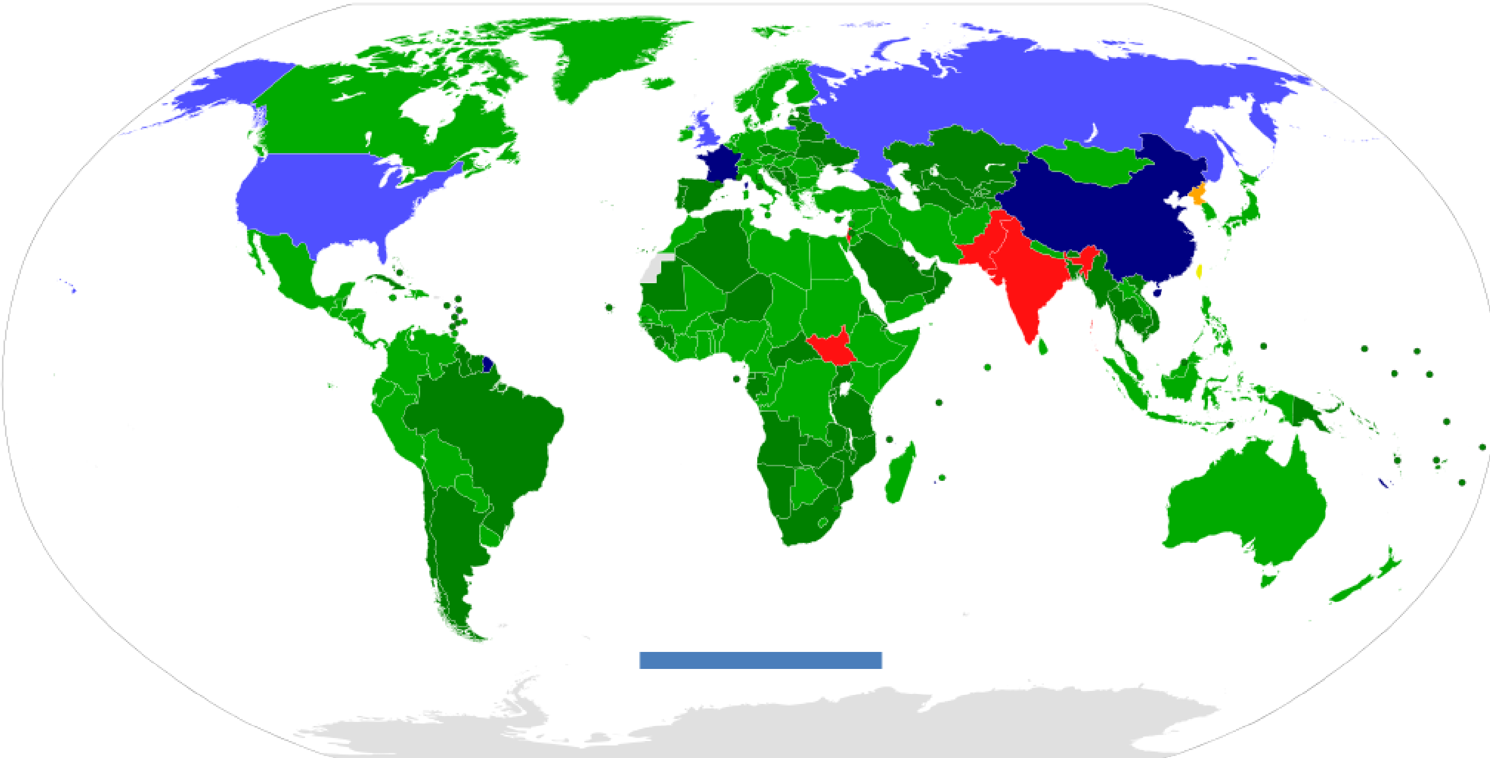
United Nations

Firmat nel1968, il tratto entra in vigore nel 1970

Nel Maggio 1995, il trattato èprrogato indefinitamente

Un ttale di 191 Stati hanno firmato il trattato, inclusi 5 stati nucleari

Il trattato è quello più firmato in assoluto tra quelli elative al disarmo

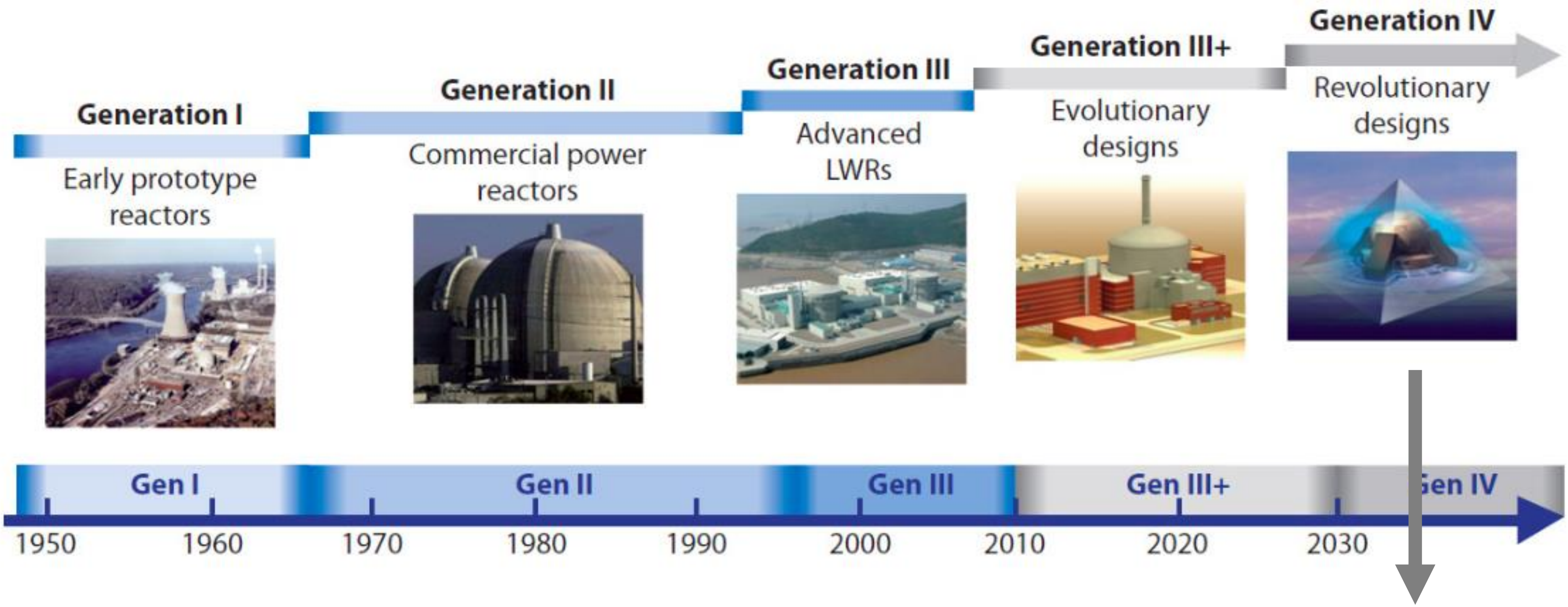


Paesi «nucleari» che lo hanno riconsciuto

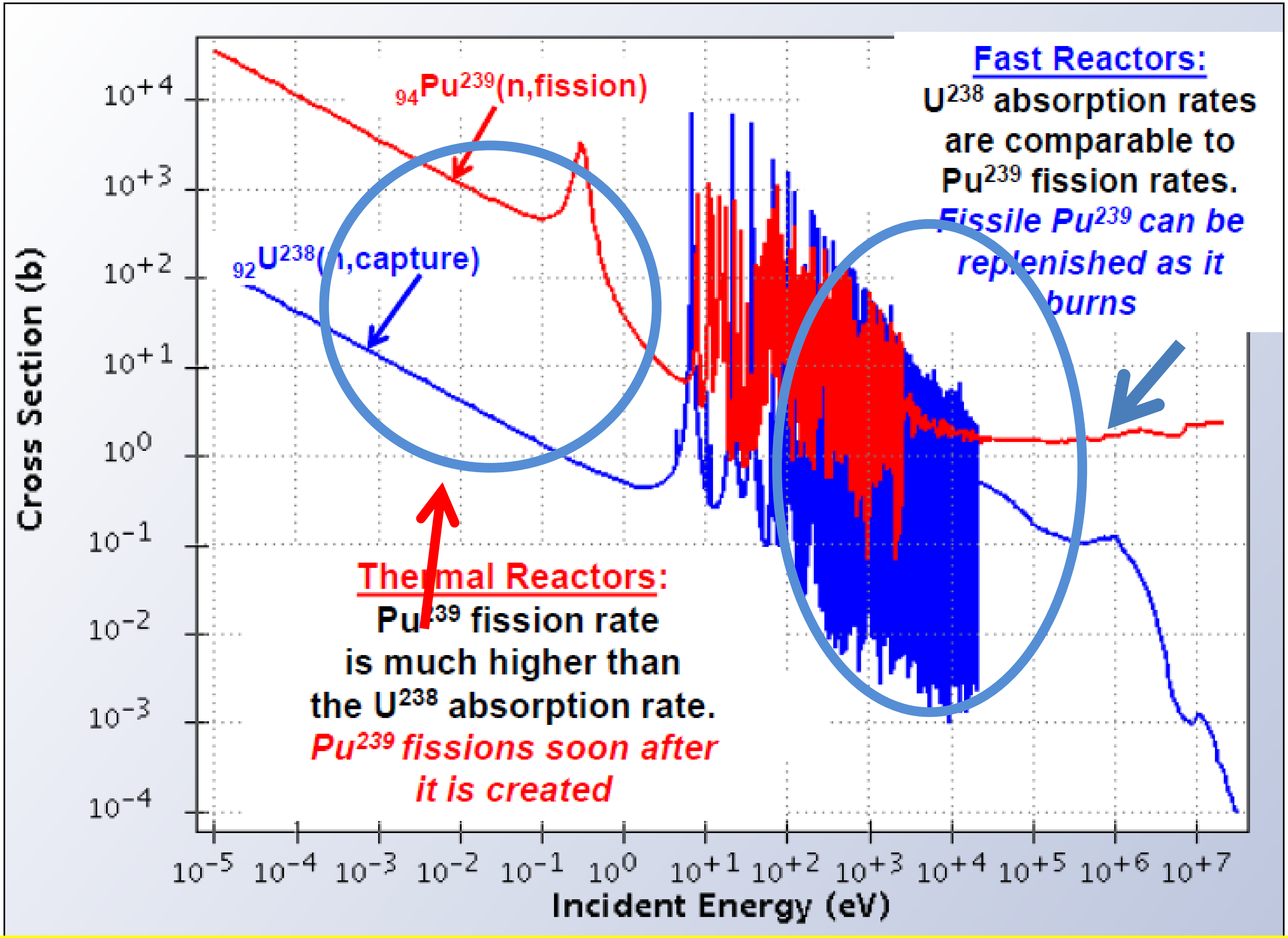
Paesi che non hanno firmato (India, Israel, Pakistan, North Korea, Sudan)

Paesi che hanno firmat

Reattori di IV generazione



Miglior uso del combustibile
Efficienza termica
Miglire sicurezza
Scrie ridotte



Pe rmigliorare l'uso del combustibile si usano neutroni veloci per craere il fissile ^{239}Pu.

Qundi non si può usare l'acqua come moderatore.

Cosa usare per il raffreddamento??

Storia dei reattori veloci

- **FERMI-1 costruito nel 1960, solo 61 Mwe**

–fusion delle barre nel 1966, ripartito nel 1970

–fermato nel 1972

- **Reattore russo BN-600 (600 MWe) operative dal 1980**

–eccellente record operativo ~75% di fattore di capacità per 40 anni

–estensione fino al 2025 (45 years) oppure al 2040 (60 years)

- **Reattre francese SUPERPHENIX (1242 MWe) partito nel 1986**

–ha funzionato con Potenza limitata per problem di raffreddamento

–chiuso nel 1998 per ragioni politiche

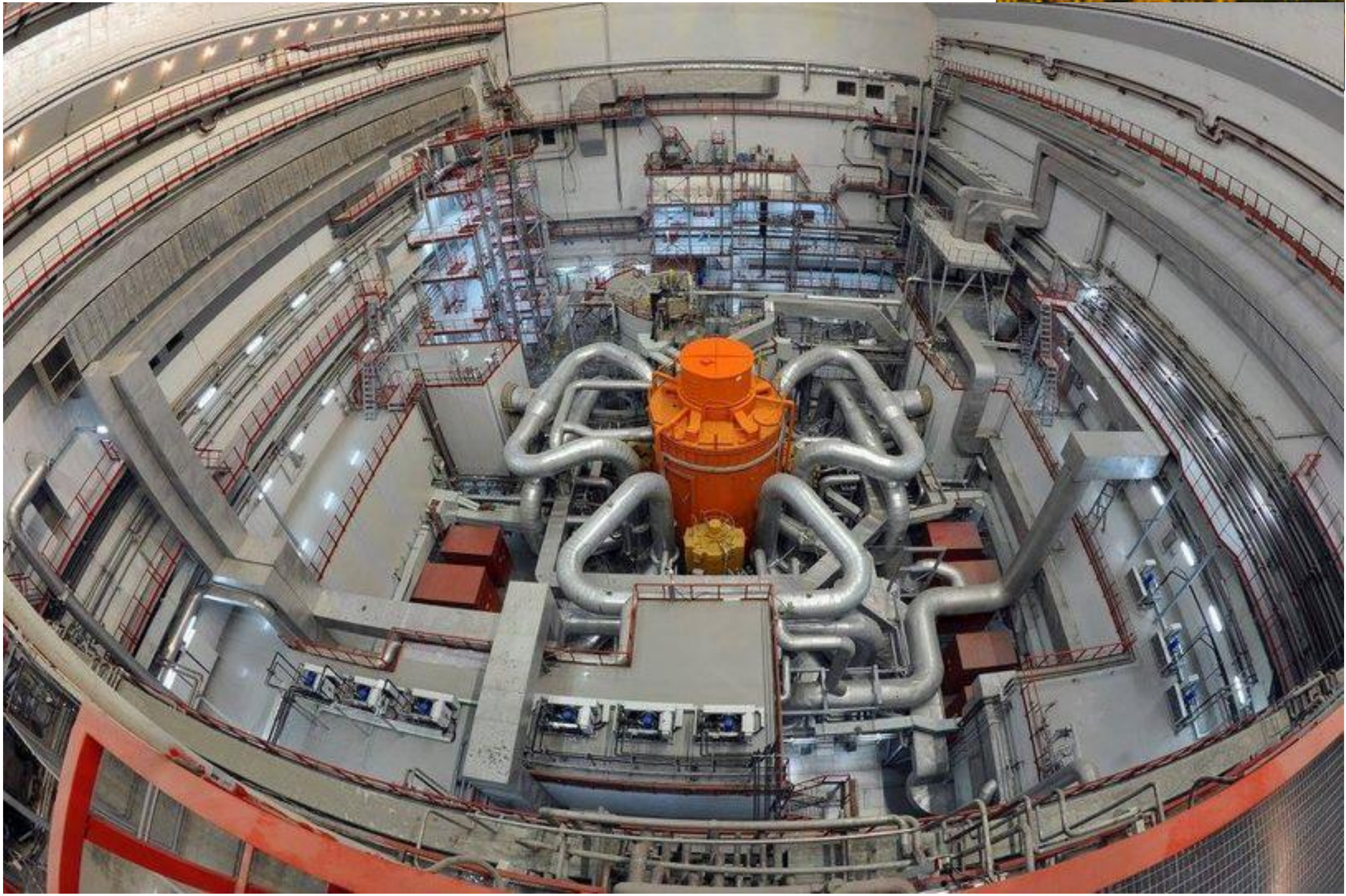
- **Reattore giapponese MONJU (280 MWe) partito nel 1995**

–Perdita di sodio nel 1995

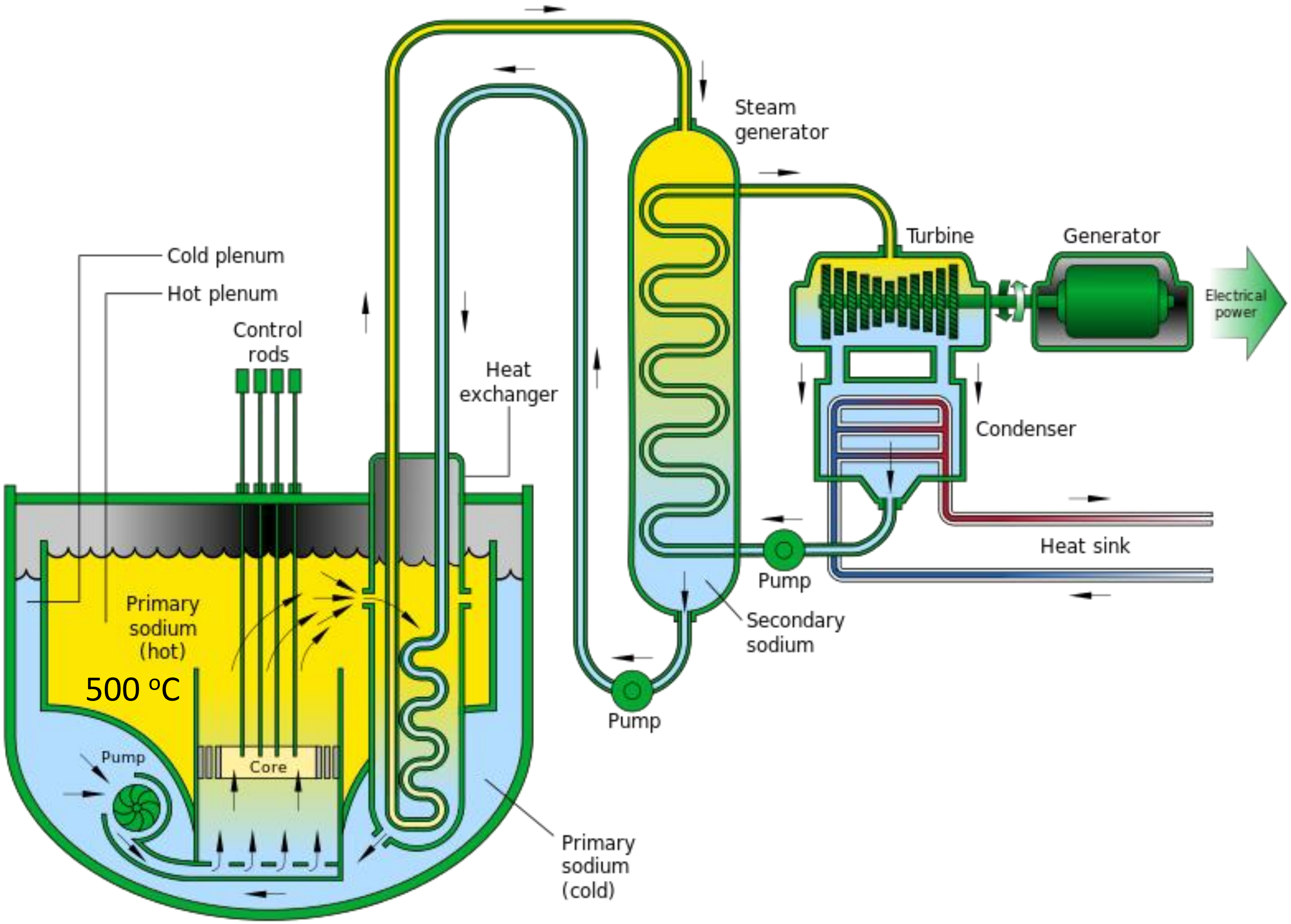
–Ripartito nel in 2010; incidente nel rifornimrnto di combustibile nel 2010

–chiuso nel 2016, forse anche in seguito a Fukushima

Il reattore veloce BN-800



Il reattore BN-800



Il reattore BN-800

- Operativo dal 2014 a Beloyarsk.
- **800 MW di potenza elettrica, , 2300 di termica**
- brucia ^{235}U e ^{239}Pu e produce il fissile ^{239}Pu partendo da ^{238}U
- Questo rreattore usa fino al 98% di Uranium (la III generatione usa solo il 0,72%!), e può anche bruciare scorie nucleari, che contengono fino al 90% di ^{238}U
- Come refrigenrante us sodio liquido. Questo material esplode a contatto con l'aria e quindi vanno osservate molte precauzioni

La IV generazione nel mondo

- **Il nuovo -BN-800 (880 MWe) Russo**

– opersativo dal 2014

– connesso alla rete nel dicembre 2015

– incluso nel Sistema elettrico russo dal 2016

– 82% di capacità dal 2020

- **PFBR (500 MWe) in India**

– completata ka costruzione

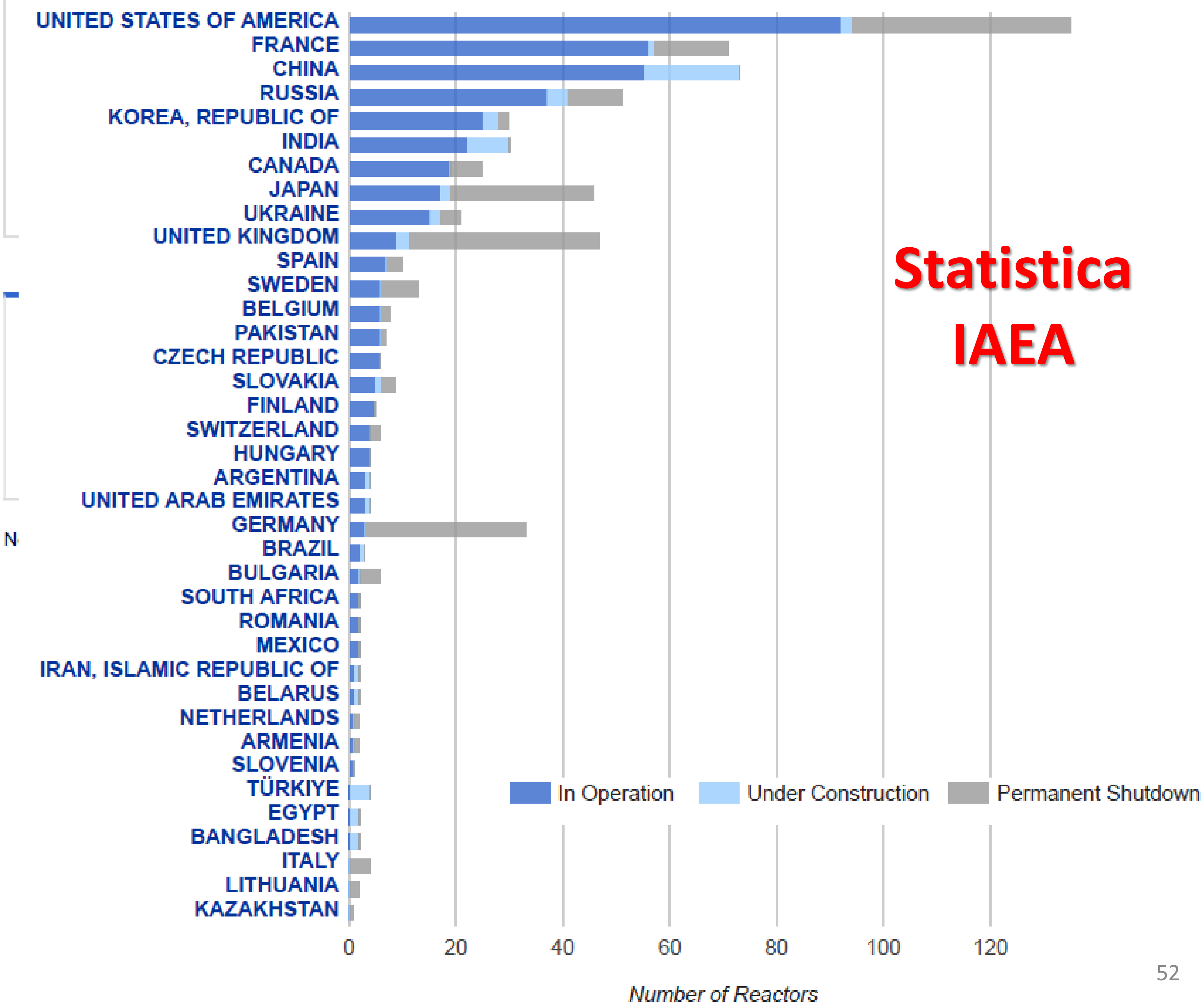
– dovrebbe artire nel 2024

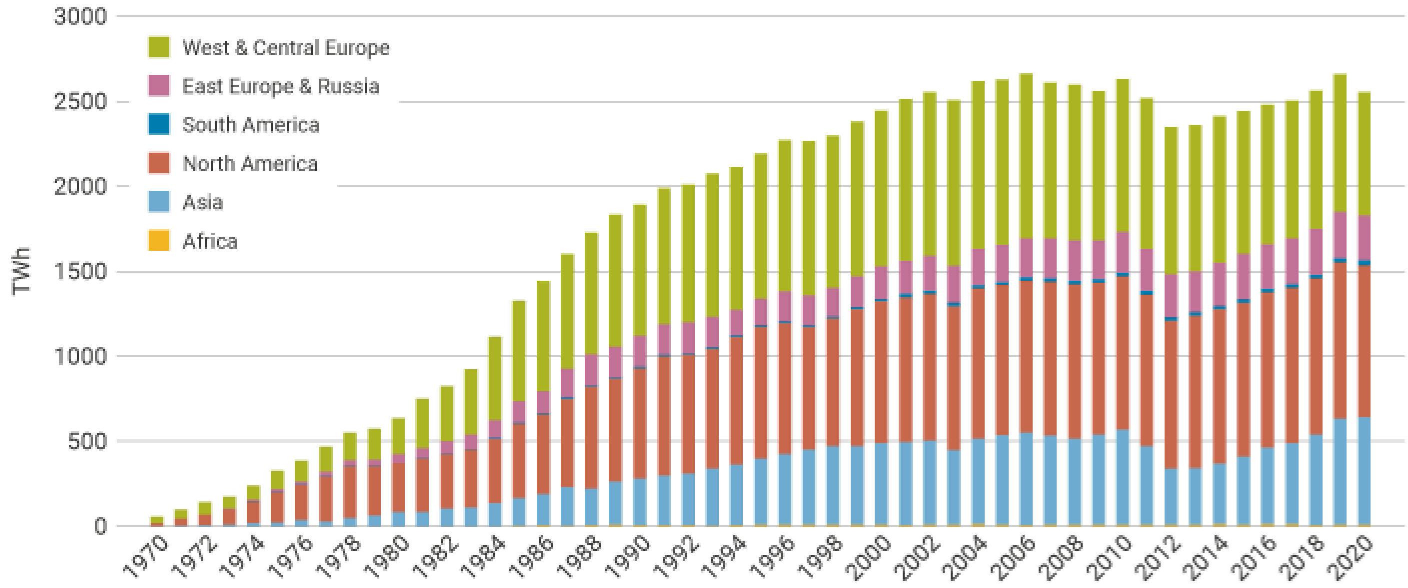
- **Altri progetti di reattori dimostrativi**

–CFR600 cinese sotto test.

prototipo commerciale per 2028-2034

–in fase autorizzativa il rettore Natriumin USA


UNITED STATES OF AMERICA
FRANCE
CHINA
RUSSIA
KOREA, REPUBLIC OF
INDIA
CANADA
JAPAN
UKRAINE
UNITED KINGDOM
SPAIN
SWEDEN
BELGIUM
PAKISTAN
CZECH REPUBLIC
SLOVAKIA
FINLAND
SWITZERLAND
HUNGARY
ARGENTINA
UNITED ARAB EMIRATES
GERMANY
BRAZIL
BULGARIA
SOUTH AFRICA
ROMANIA
MEXICO
IRAN, ISLAMIC REPUBLIC OF
BELARUS
NETHERLANDS
ARMENIA
SLOVENIA
TÜRKIYE
EGYPT
BANGLADESH
ITALY
LITHUANIA
KAZAKHSTAN
Statistica IAEA
In Operation
Under Construction
Permanent Shutdown
0
20
40
60
80
100
120
Number of Reactors



In 10 years **66** nuovi reattori son stati ultimati e
50 sono stti chiusi
Pari ad un aumento di **18** GW in 10 anni a fronte di un aumento dei consumi di 250 GW

Pwr soddisfare la domanda elettrica, sarebbero necessari **50** nuovi reattori all’anno per i prossimi 60 anni

The Future of Nuclear Energy in a Carbon-Constrained World

AN INTERDISCIPLINARY MIT STUDY **2018**

Findings:

The cost of new nuclear plants is high, and this significantly constrains the growth of nuclear power under scenarios that assume 'business as usual' and modest carbon emission constraints. In those parts of the world where a carbon constraint is not a primary factor, fossil fuels, whether coal or natural gas, are generally a lower cost alternative for electricity generation. Under a modest carbon emission constraint, renewable generation usually offers a lower cost alternative.

As the world seeks deeper reductions in electricity sector carbon emissions, the cost of incremental power from renewables increases dramatically. At the levels of 'deep decarbonization' that have been widely discussed in international policy deliberations—for example, a 2050 emissions target for the electric sector that is well below 50 grams carbon dioxide per kilowatt hour of electricity generation (gCO_2/kWh)—including nuclear in the mix of capacity options helps to minimize or constrain rising system costs, which makes attaining stringent emissions goals more realistic (worldwide, electricity sector emissions currently average approximately 500 gCO_2/kWh).

Lowering the cost of nuclear technology can help reduce the cost of meeting even more modest decarbonization targets (such as a 100 gCO_2/kWh emissions target).

....fusione?

Reazini chimiche

- $C + O_2 = CO_2 + Q \qquad Q = 3.6\ eV$

Metano

- $CH_4 + 2O_2 = CO_2 + 2H_2O + Q \quad Q = 9.2\ eV$

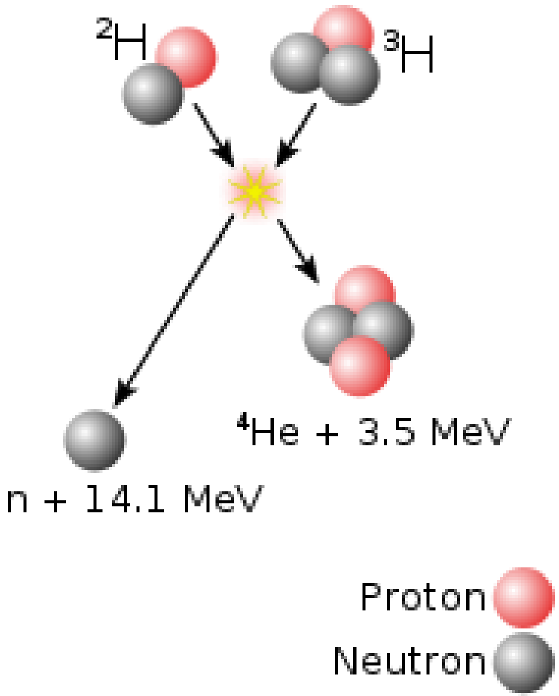
Fissine nucleare

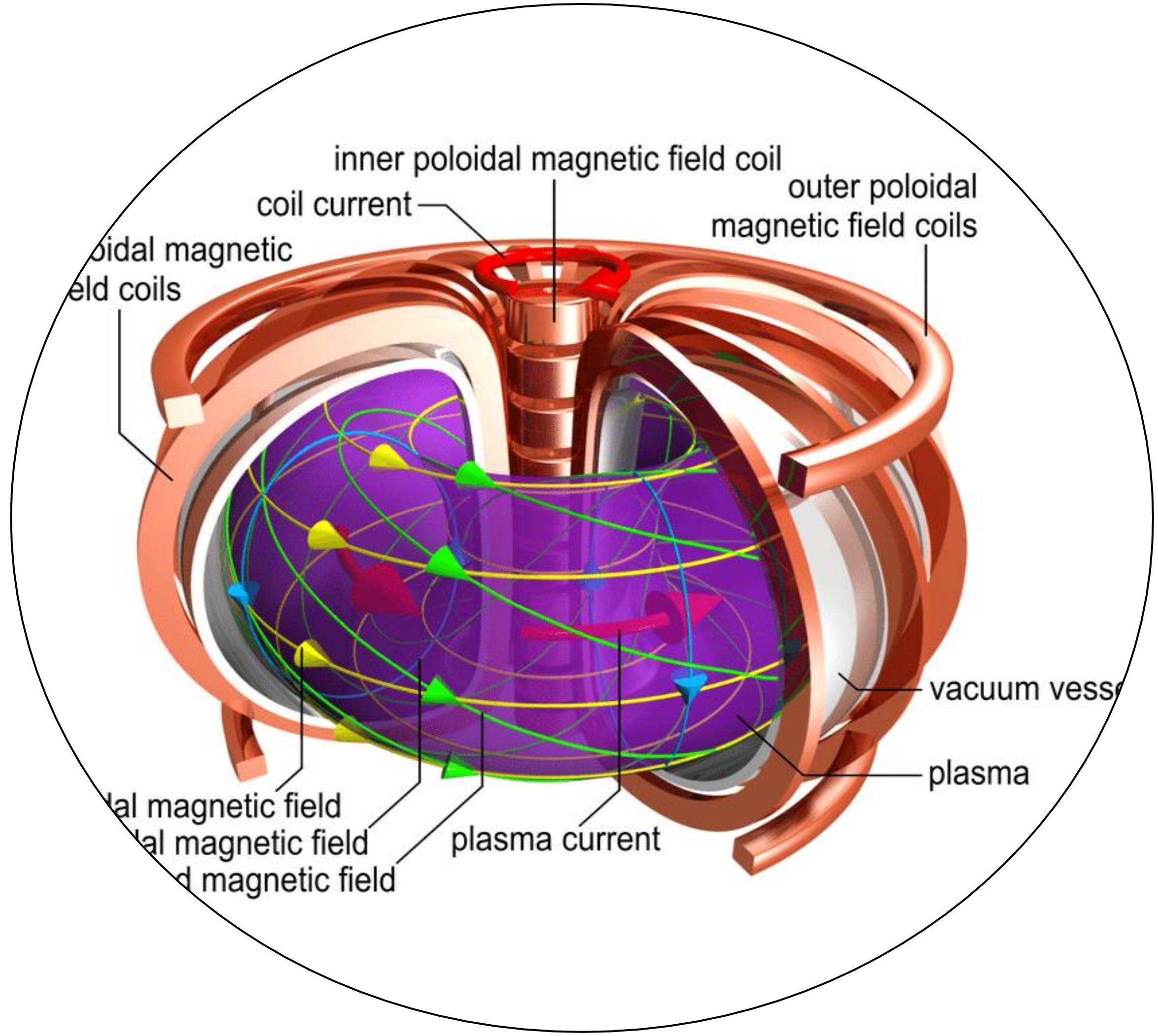
- ${}^{235}U + n = F_1 + F_2 + \nu n + Q \qquad Q = 211.5\ MeV$

Fusione nucleare

- ${}^{2}H + {}^{3}H = {}^{4}He + n + Q \qquad Q = 17.6\ MeV$

fusione


^{2}H
^{3}H
^{4}He + 3.5 MeV
n + 14.1 MeV
Proton
Neutron


inner poloidal magnetic field coil
coil current
outer poloidal
magnetic field coils
vacuum vess
plasma
plasma current

1) ottenere il plasma deuterio-trizio plasma che si autosostiene con la sua energia interna

2) Generare 500 MW di Potenza da fusion (Q=10)

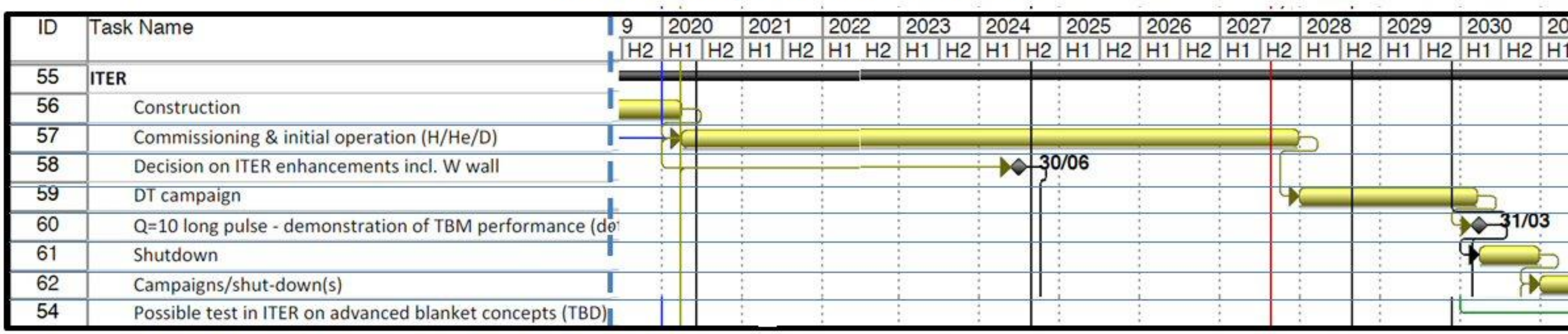
3) dimostrare che la tecnologia è in grado di controllare la fusione

4) mantenere la produzione di trizio

5) dimostrare la sicurezza dell'impianto

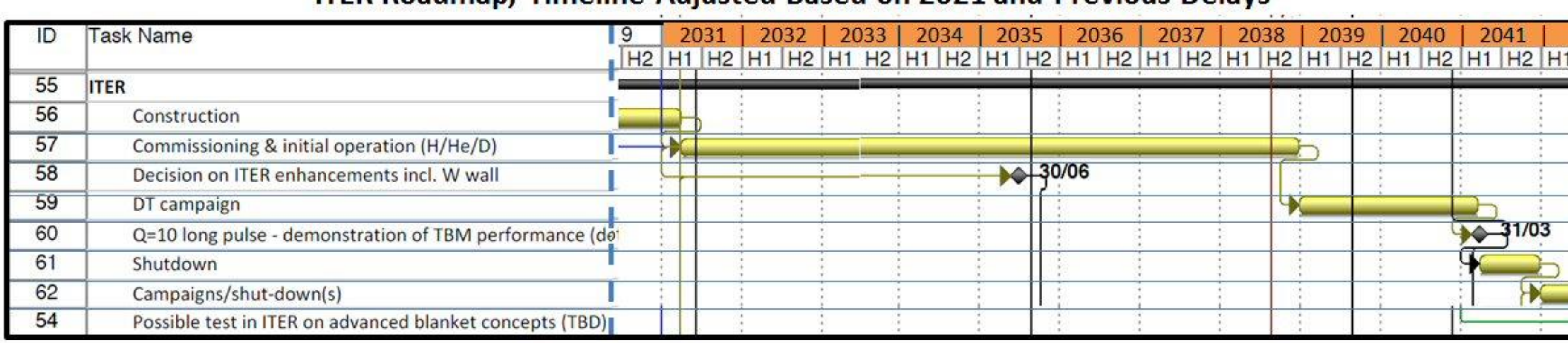
the ITER project (31 nations!)

ITER Roadmap, Timeline as of 2012



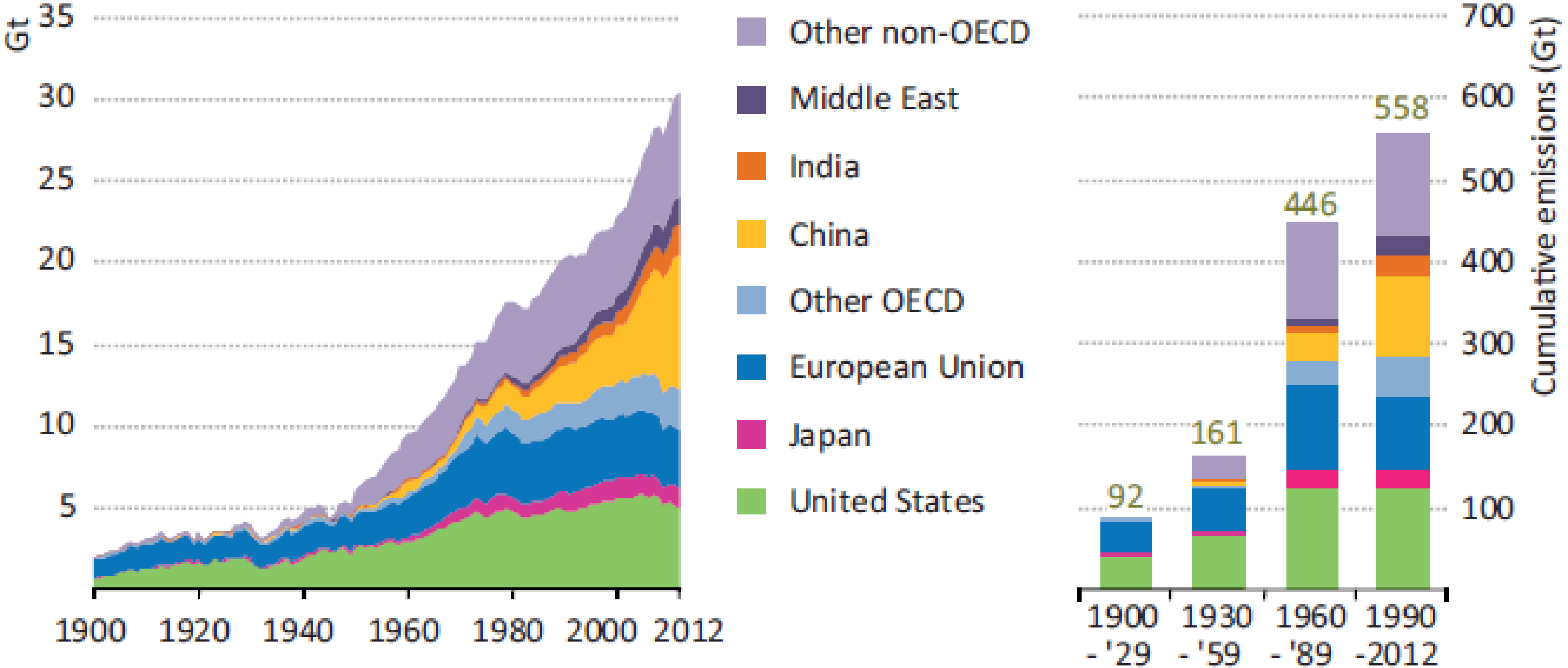
Source: EFDA "Fusion Electricity A Roadmap to the Realisation of Fusion Energy", 2012

ITER Roadmap, Timeline Adjusted Based on 2021 and Previous Delays



Source: EFDA "Fusion Electricity A Roadmap to the Realisation of Fusion Energy", 2012 | Projected Dates Adjusted by Steven Krivit, Oct. 25, 2021

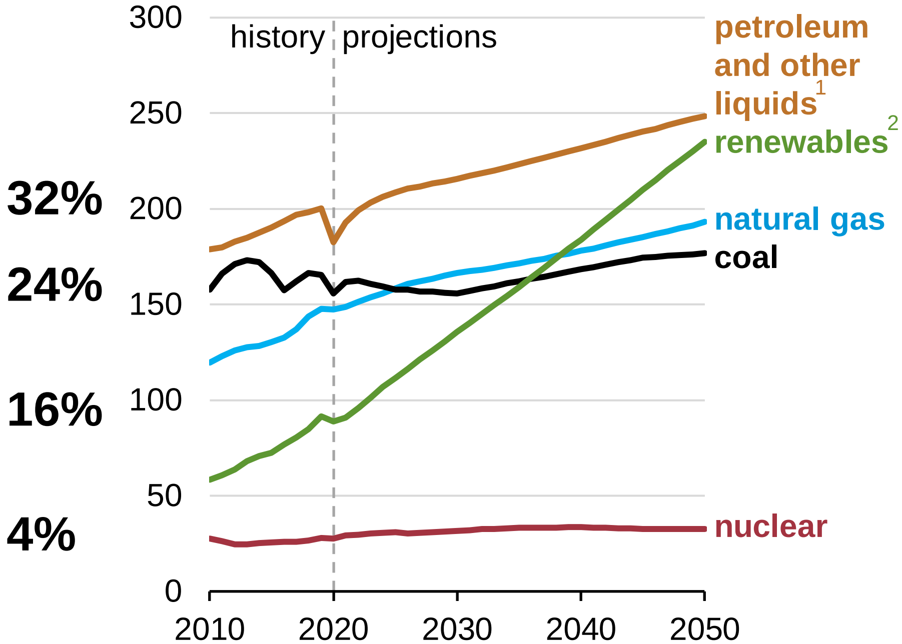
Figure 1.11 ▷ **Energy-related CO_2 emissions by country**



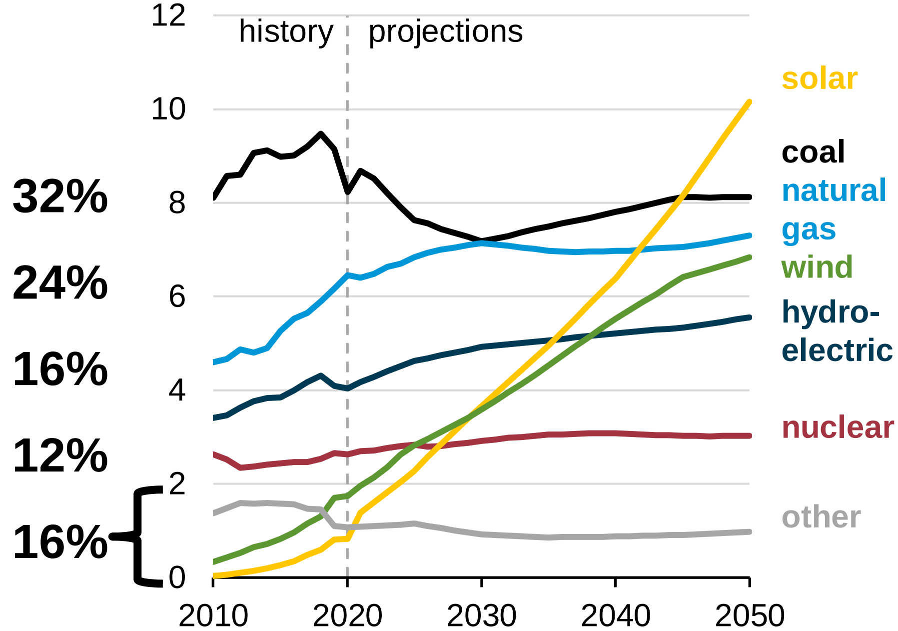
Sources: IEA databases and analysis; Boden *et al.*, (2013).

Consumo di energia totale nel mondo

Total energy (QBTU)



Electric energyTWh

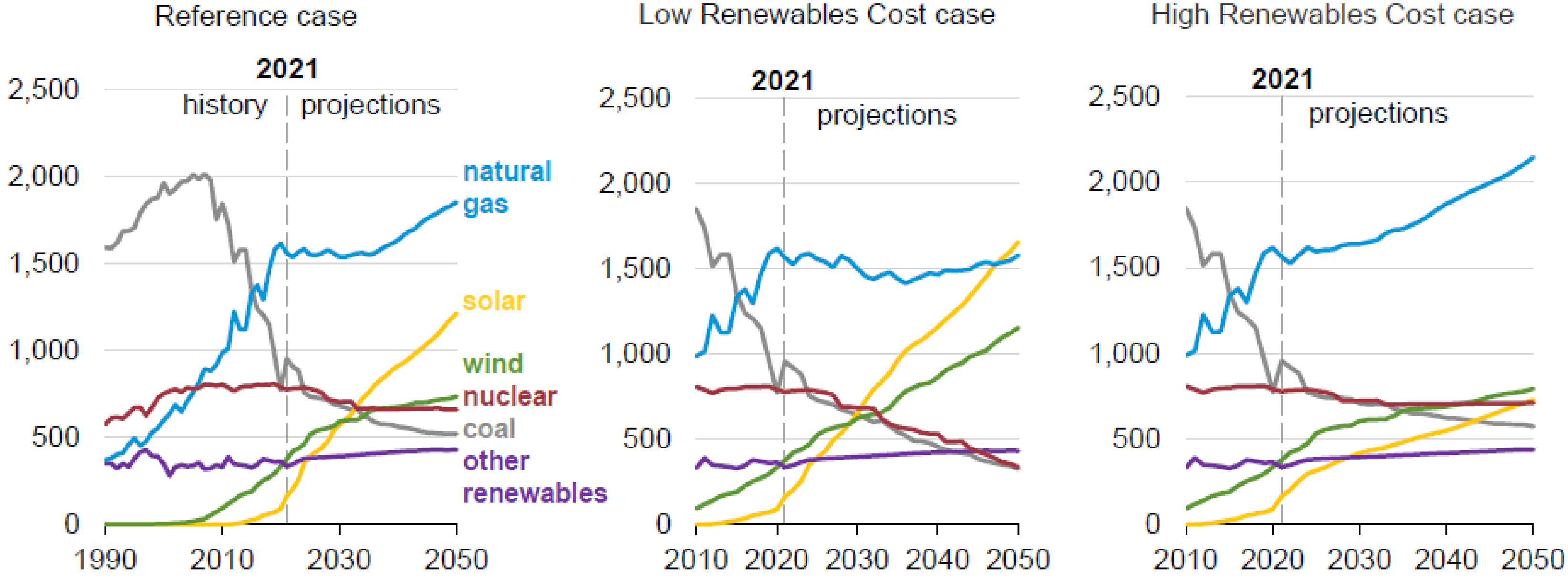


[1] *Includes biofuels*
[2] *Electricity generation from renewable sources is converted to Btu at a rate of 8,124 Btu/kWh*

consumo di energia elettrica nel mondo

Renewables consumption for electricity generation grows significantly in all cases, even as it trades off with nuclear, coal, and natural gas

U.S. electricity generation
billion kilowatthours

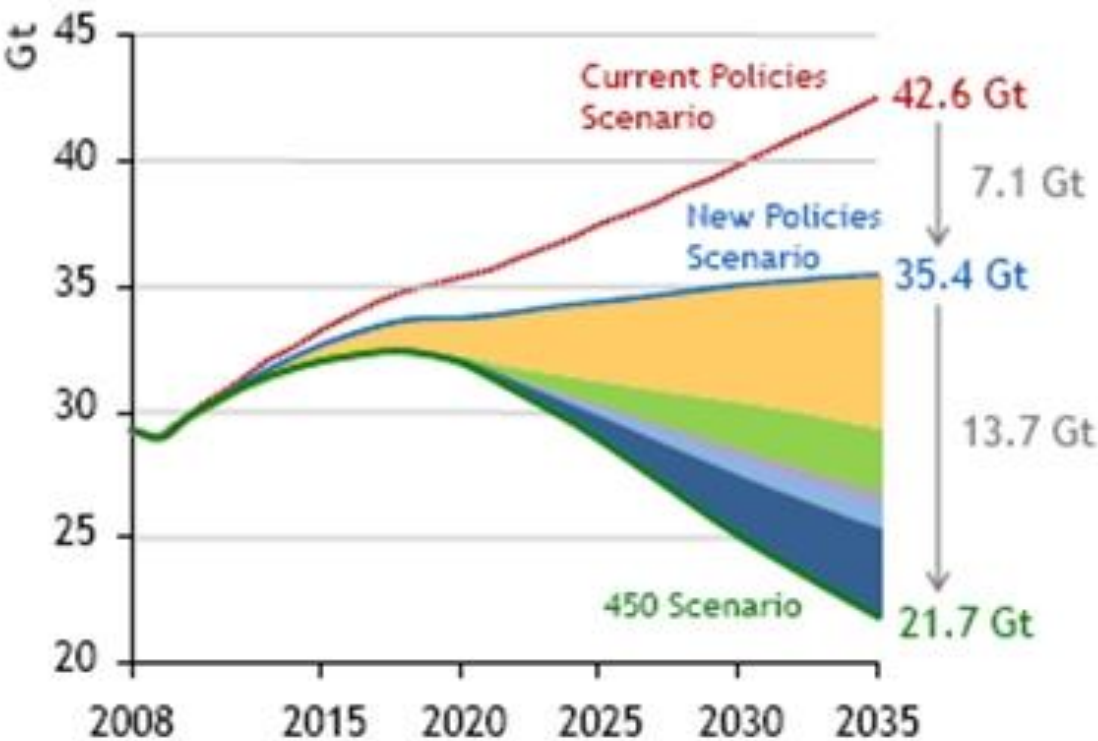


Note: Other renewables category includes electricity generation from hydroelectric, geothermal, wood, and other biomass sources.

International Energy Agency

450 Scenario: A scenario presented in the *World Energy Outlook* that sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2.

World energy-related CO2 emission savings by technology in the 450 Scenario relative to the New Policies Scenario



Share of cumulative abatement between 2010-2035	
Efficiency	50%
Renewables	18%
Biofuels	4%
Nuclear	9%
CCS	20%

La fonte energetica più importante: la efficienza energetica

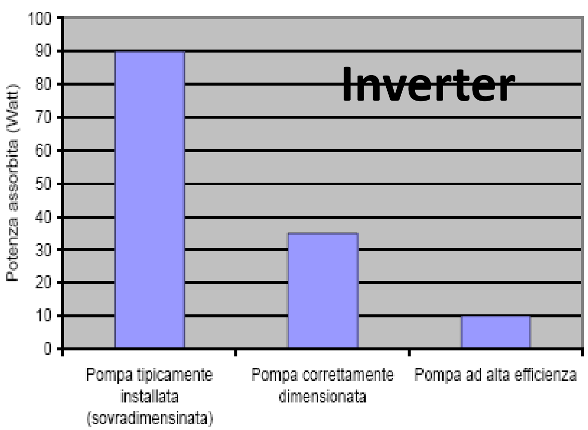
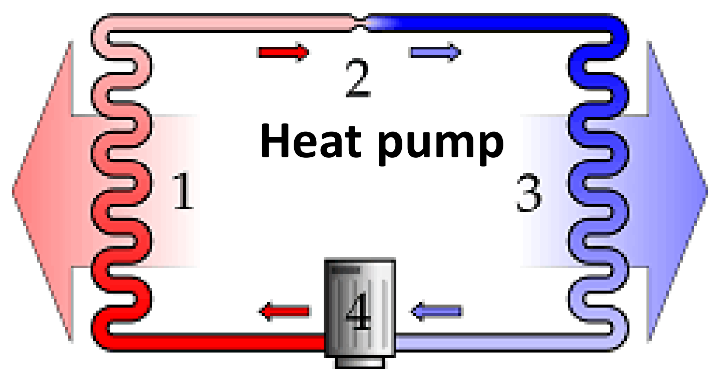


Fig. 14.6: Consumi di pompe di circolazione dell'acqua (*fonte: eERG, Politecnico Milano*).

10%

14%

LED



30%

Un possibile ruolo per il nucleare

- nel 2050 l'Italia dovrà produrre almeno 600 TWh/anno di elettricità con meno di 60 gCO_2/kWh

- Questo corrisponde a una potenza effettiva di 70 GW, cioè 450 GW /5000 km^2 di celle solari o 280 GW/80.000 turbine eoliche di 3 MW

- Ora abbiamo 22 GW di celle solari (240 km^2) e 11 GW di turbine eoliche (7000 pale) e l'aumento è di circa 1GW/anno per entrambe. Per stare al passo col programma EU dovemmo aumentare la nostra capacità di realizzare rinnovabili di 10 volte

- Inoltre, ci vogliono almeno 40 GW di impianti di stoccaggio di energia (ora abbiamo 7 GW non utilizzati)

- Un programma di 40 GW di energia nucleare (25-30 reattori in 4 o 5 siti) permetterebbe di tagliare del 60% le energie rinnovabili necessarie senza ricorrere a impianti di stoccaggio

- Per questo occorre un nuovo Piano Energetico Nazionale (PNIEC) di durata 30ennale approvato in modo bipartisan

Conclusioni I

Limiti dei reattori attuali:

- **- alta produzione di scorie**
- **- uso inefficiente dell'uranio**

- la IV generazione prevede reattori a ciclo chiuso che **ottimizzano l'uso del combustibile**

- i reattori di IV generazione possono bruciare anche una gran parte delle scorie attuali

- molti nuovi tipi di reattori sono allo studio

Conclusioni II

L'energia nucleare

- Presenta pro e contro
- Dipende dalle condizioni geo-politiche
- Durante la transizione verde condividerà il mercato col gas (con CCS?) come alternativa alle tecnologie carbon free
- La complessità, tecnica, i costi e la paura della radioattività allungano i tempi e ne ostacolano la diffusione
- L'energia nucleare sarà importante ma non sarà sufficiente da sola per soddisfare la domanda di energia elettrica
- L'energia da fusione è ancora molto lontana

Thank you