The World Nuclear Energy Picture

Ian Hore-Lacy

Head of Communications,
World Nuclear Association

June 2009

World Perspective

World:	1800	2000	2050
Population - billion	1	6	10
GDP – trillion $ (1990)	0.3	30	85-110
Primary energy - EJ	13	420	600-1000
CO_2 emissions – Gt carbon	0.3	6.4	5-15
Mobility – km/person/day	0.04	40	120-160

WEC 2004

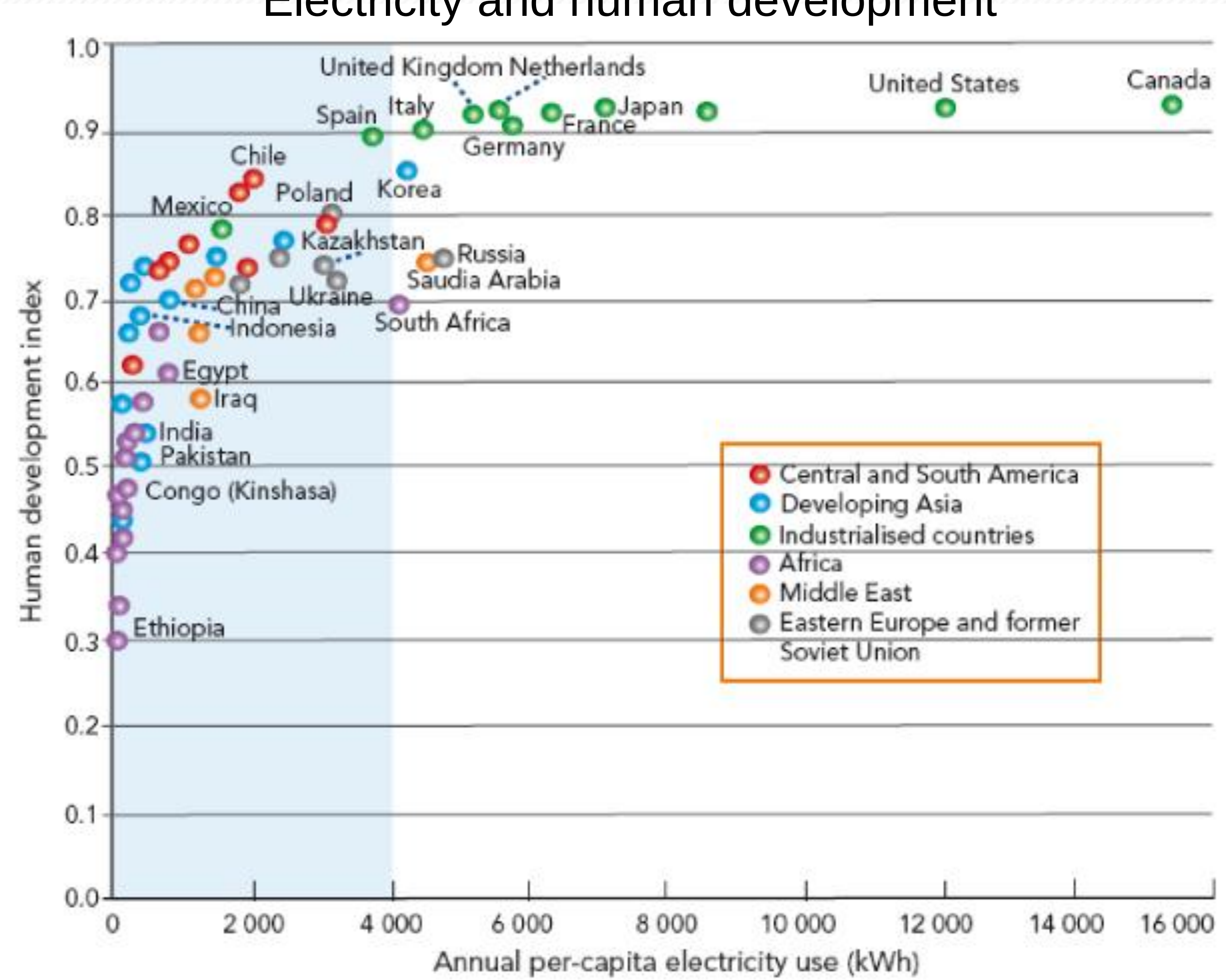
World Nuclear Association

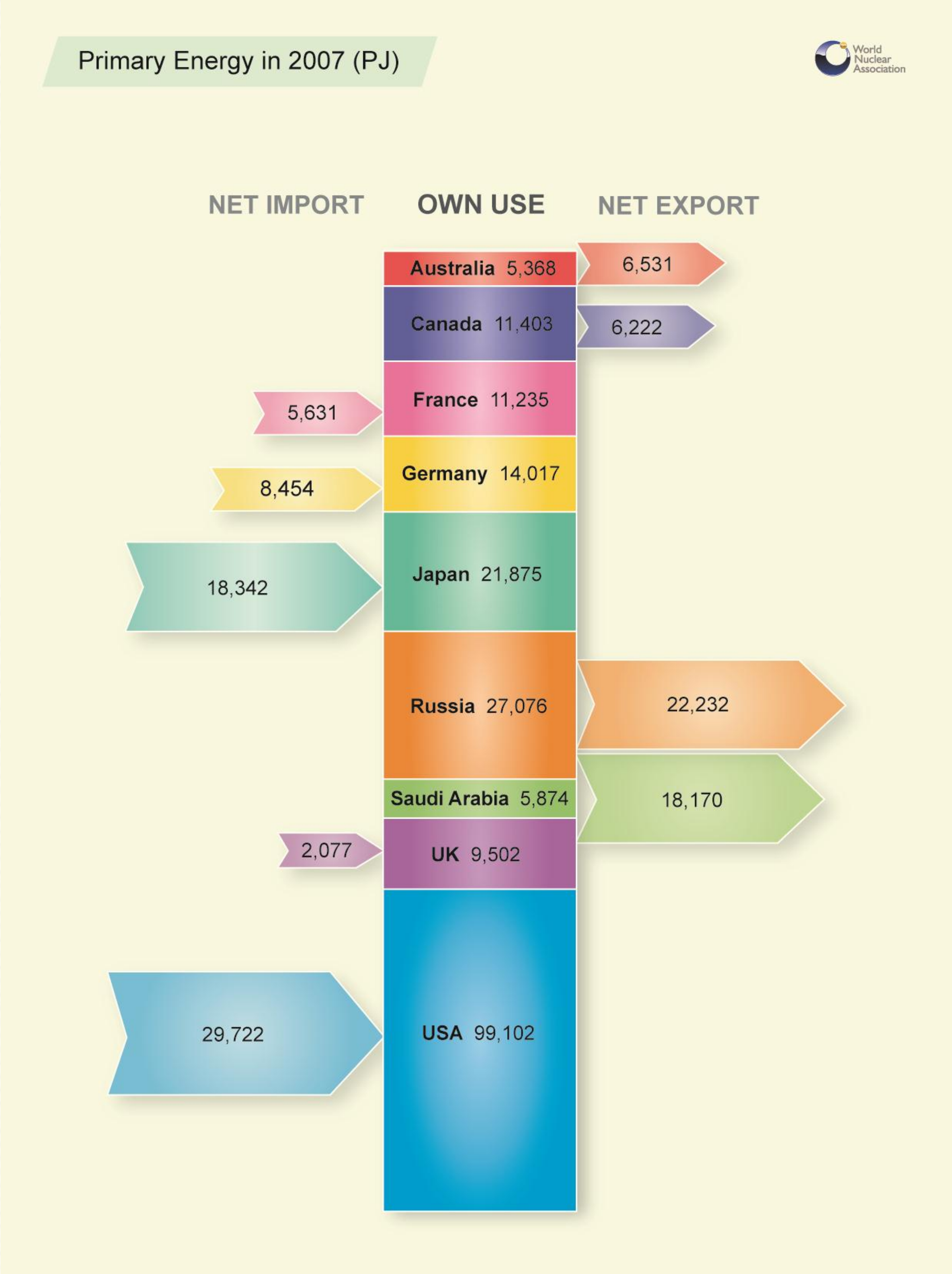
Perspective of God's Providence

- Abundant nuclear fuel, for centuries
- Large-scale continuous reliable power
- Physics enables control of both moderated and fast neutron reactors
- Mature technology (14,000 reactor years)
- Timely availability due to carbon constraints
- Liberal provision for human needs

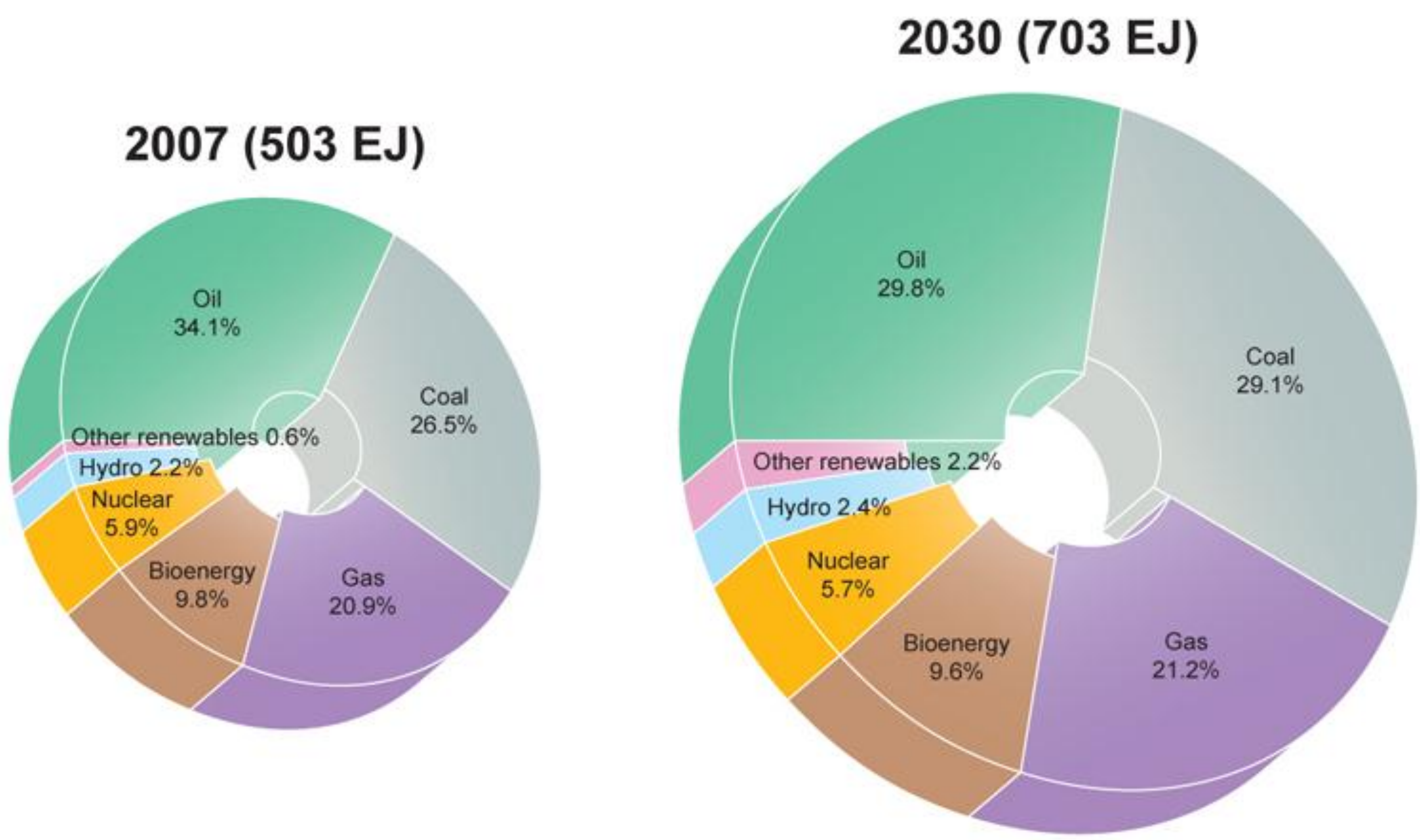
World Nuclear Association

Electricity and human development




Primary Energy in 2007 (PJ)
NET IMPORT
OWN USE
NET EXPORT
Australia 5,368
6,531
Canada 11,403
6,222
5,631
France 11,235
8,454
Germany 14,017
18,342
Japan 21,875
Russia 27,076
22,232
Saudi Arabia 5,874
18,170
2,077
UK 9,502
29,722
USA 99,102

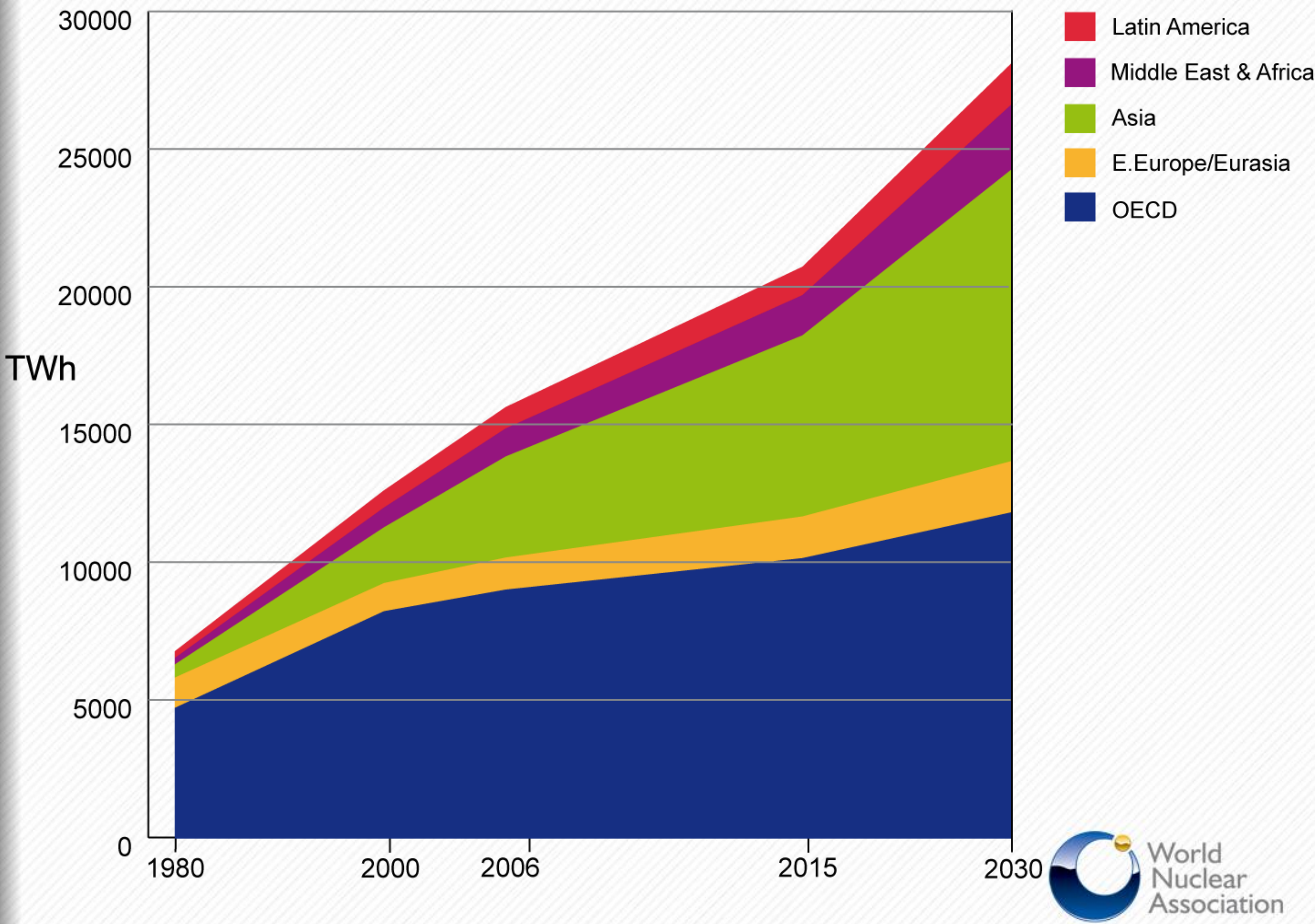
World Primary Energy



World Energy Outlook 2009: reference scenario

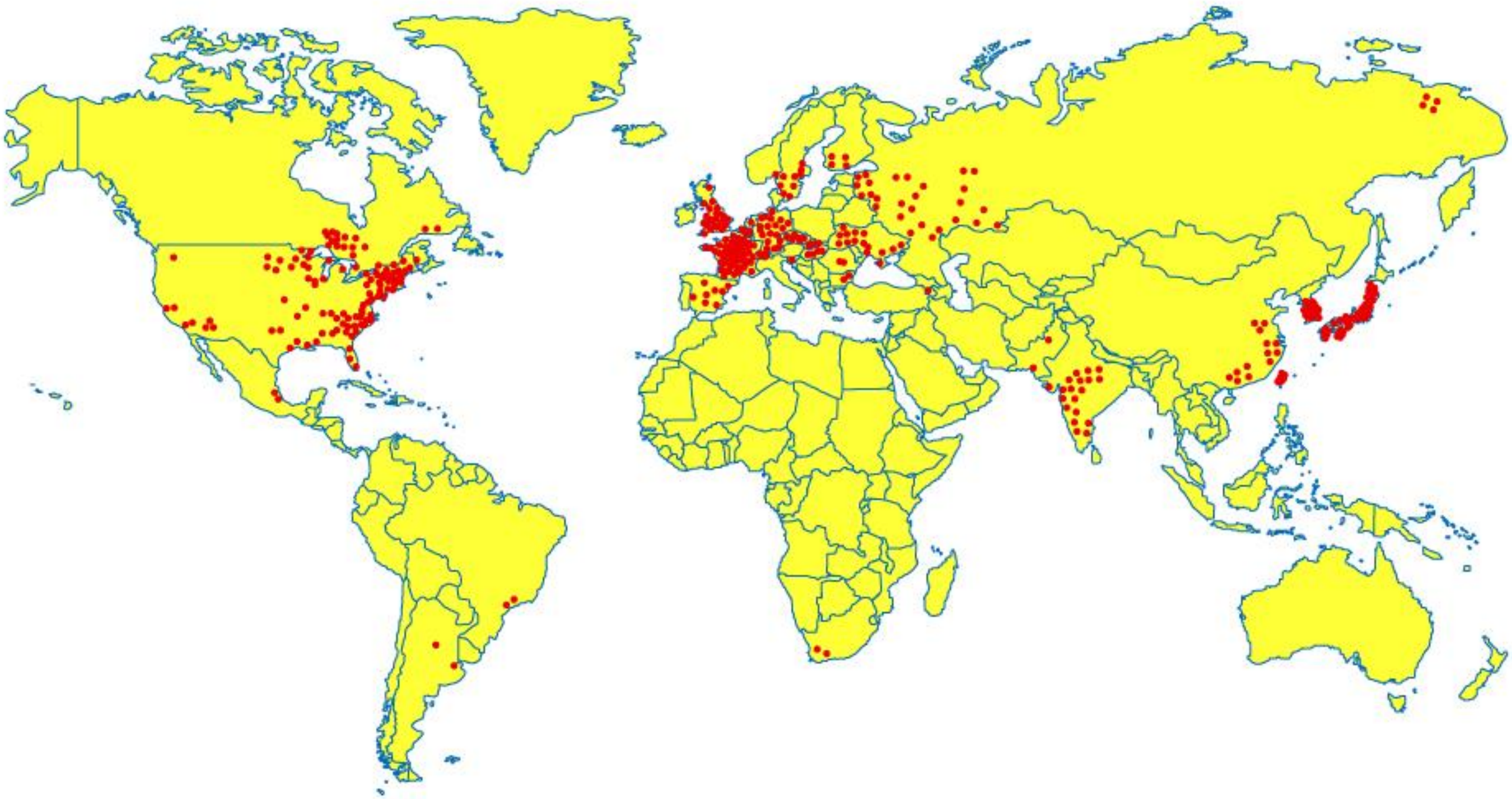
World Nuclear Association

World Electricity Consumption by Region



Source: World Energy Outlook 2008

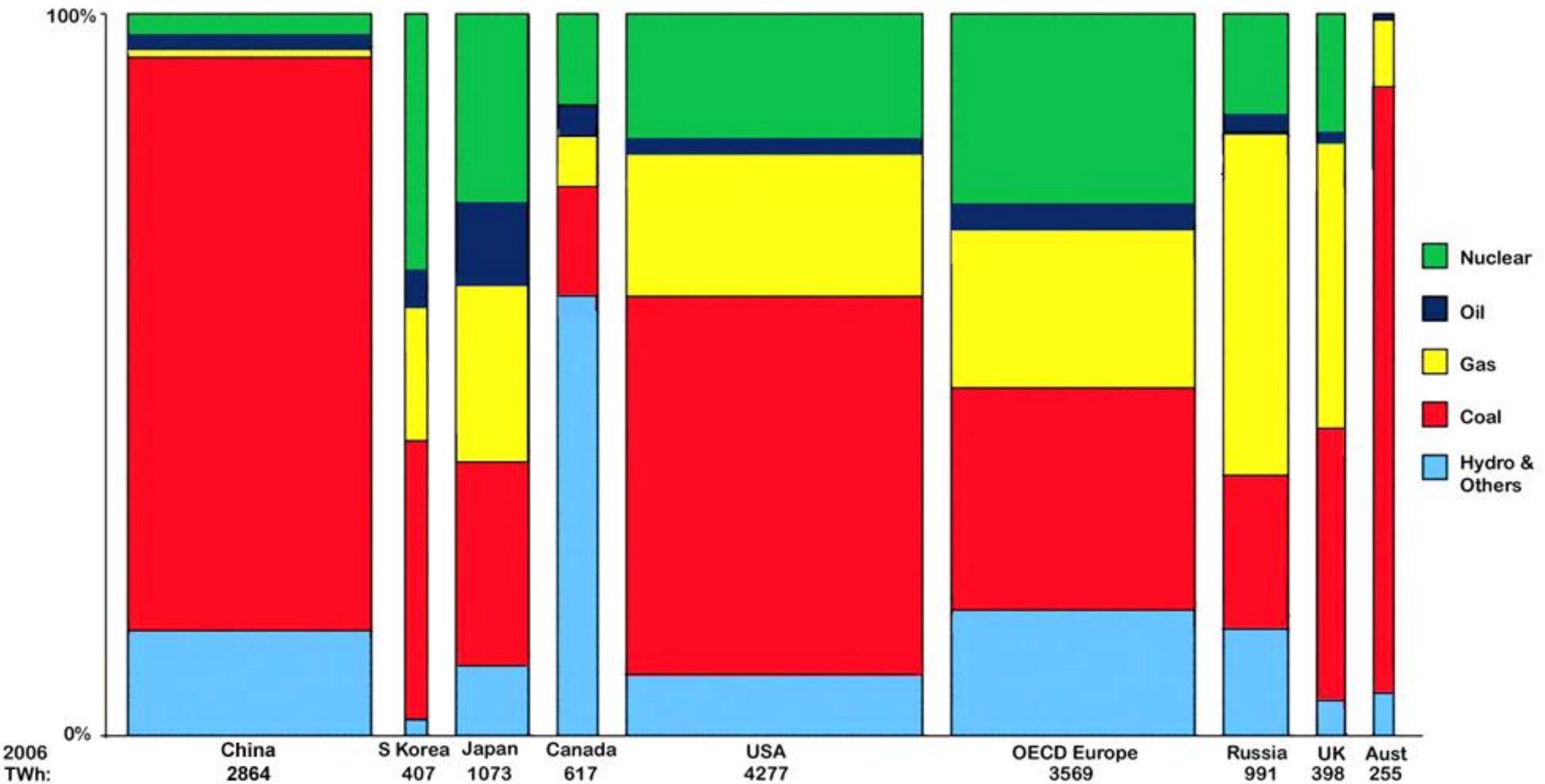
World Nuclear Power Reactors



Total 443 operating nuclear power reactors, 62 under construction, 150+ firmly planned. 14% of world electricity, total 378 GWe.

Locations approximate

Fuel for Electricity Generation (%)



Width of each bar is indicative of gross power production

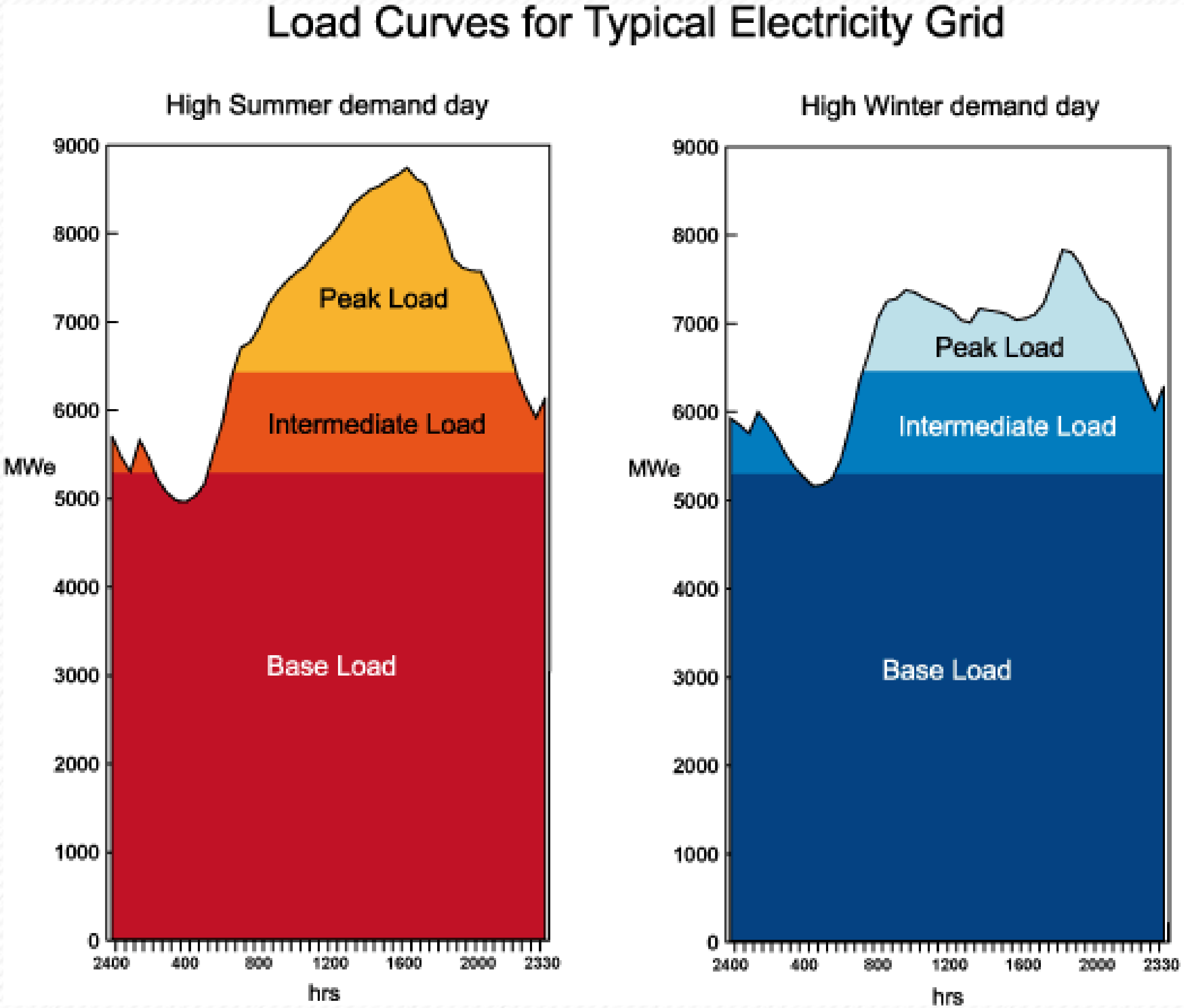
Main Source: OECD Electricity Information 2007

World Nuclear Association

Main Drivers for nuclear expansion:

- Basic economics,
including increased fossil fuel prices
- Prospect of carbon emission costs
- Insurance against future fuel price increases
- Energy security - geopolitical

World Nuclear Association



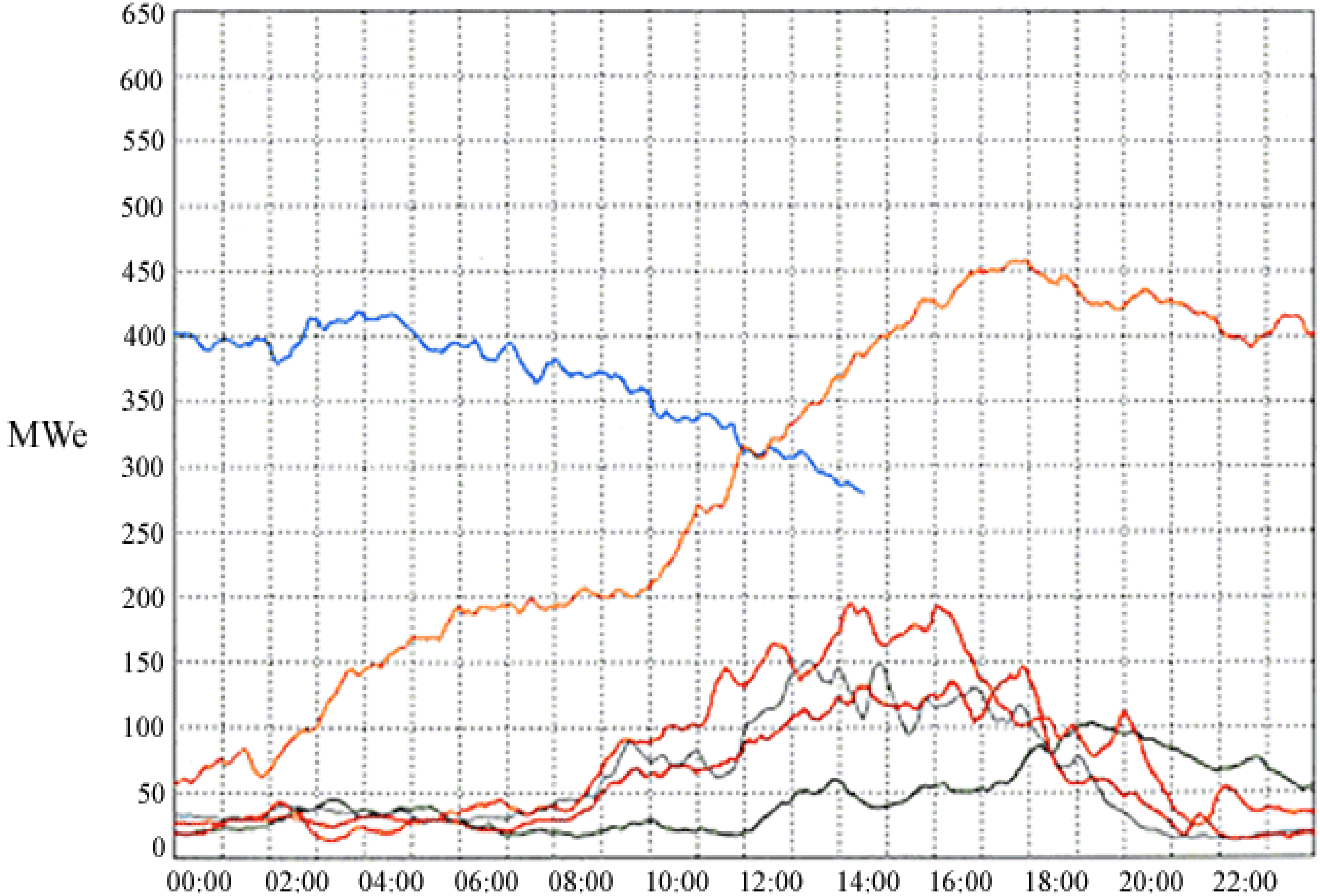
Most demand is for continuous, reliable supply

Wind is low-carbon, but …

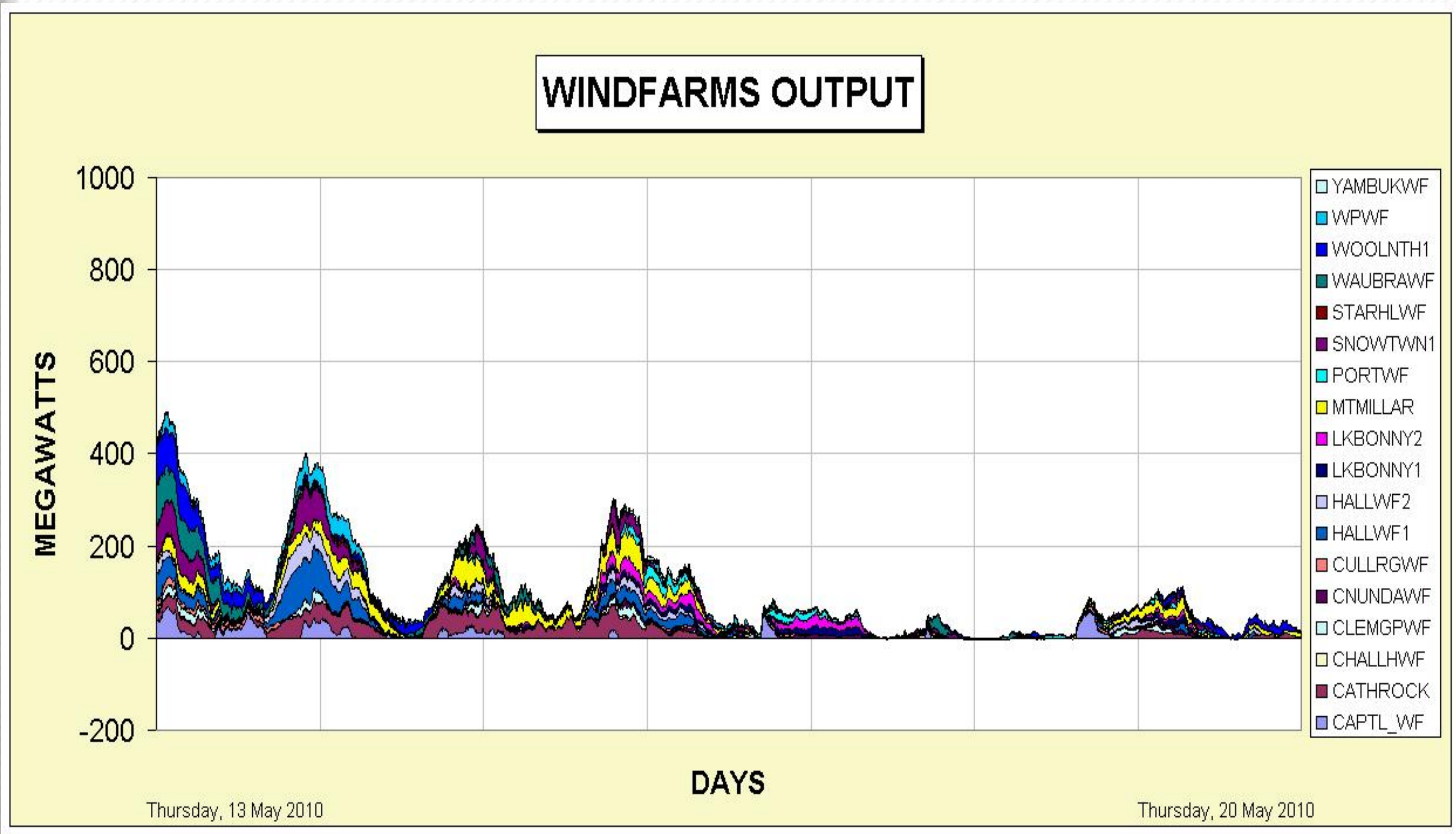
World Nuclear Association

Wind Energy production during One Week in Western Denmark

is one day, capacity 650 MWe.



Danish Wind Energy Association



All SE Australian wind farms, 830 MWe, one week 5/2010.

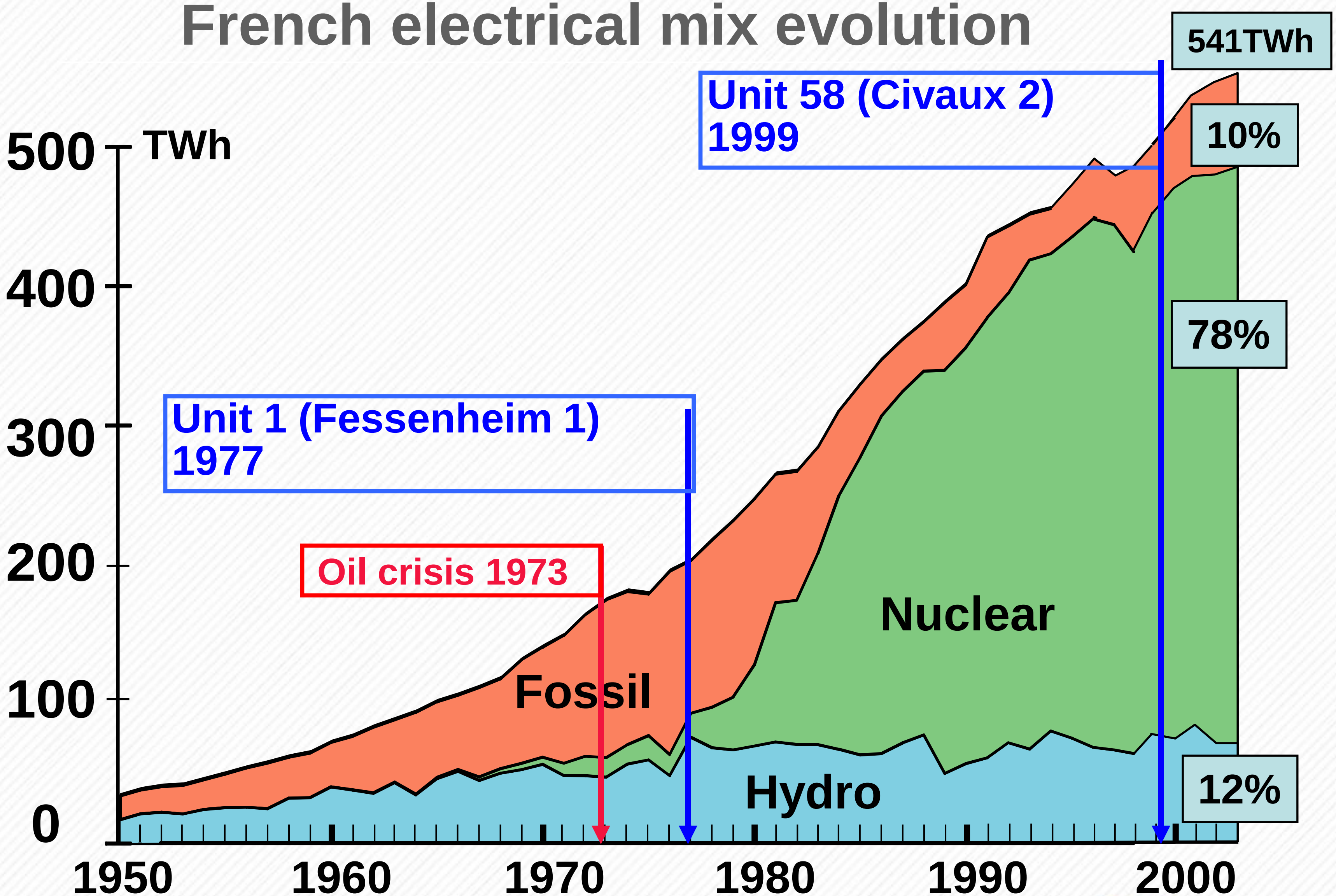
Qinshan III nuclear power plant, China

World Nuclear Association

Diablo Canyon nuclear power plant, USA

World Nuclear Association

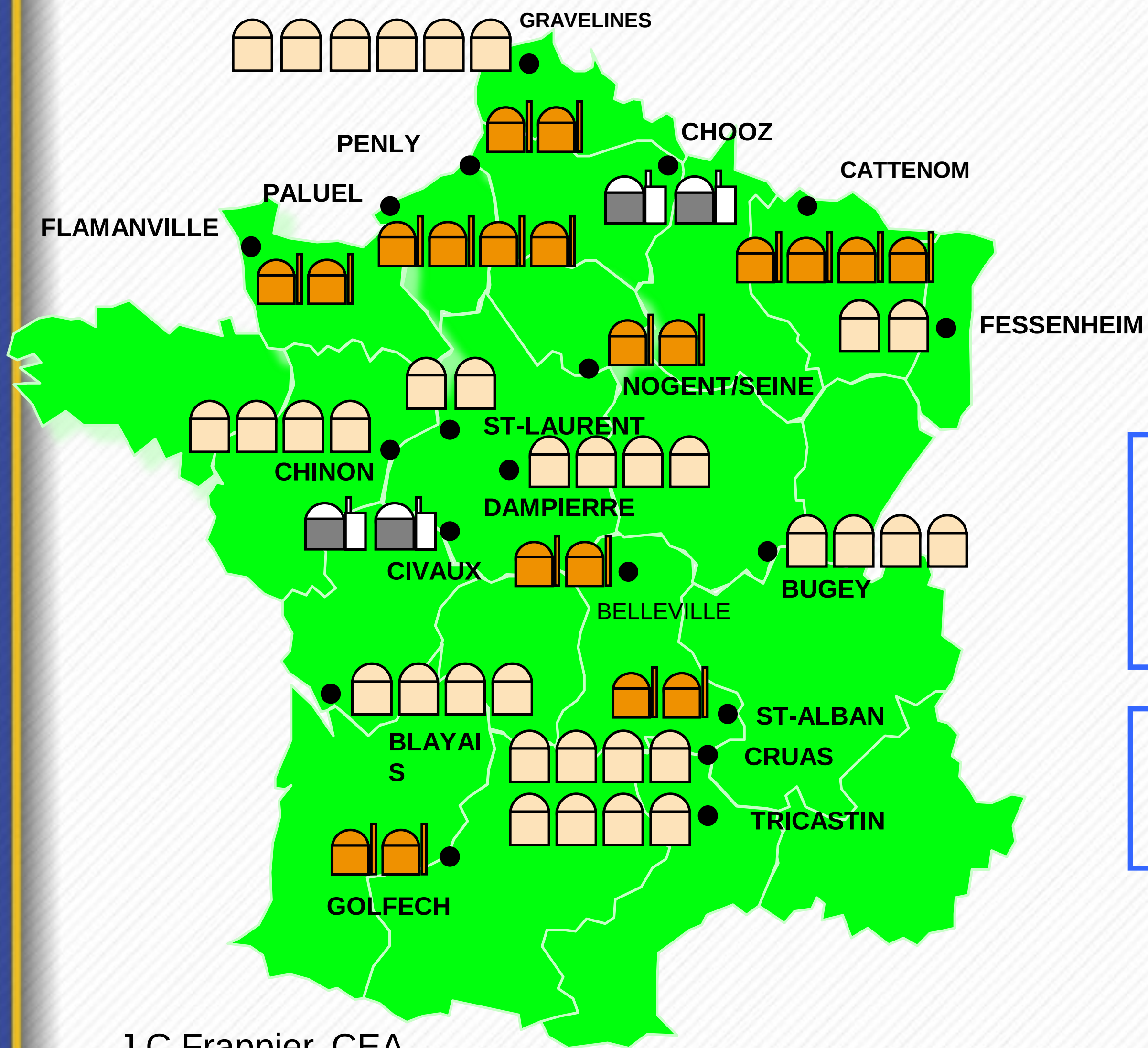
French electrical mix evolution



J C Frappier, CEA

The nuclear reactor fleet in France

58 units in operation on 19 sites



900 MWe (34 Units)

1300 MWe (20 Units)

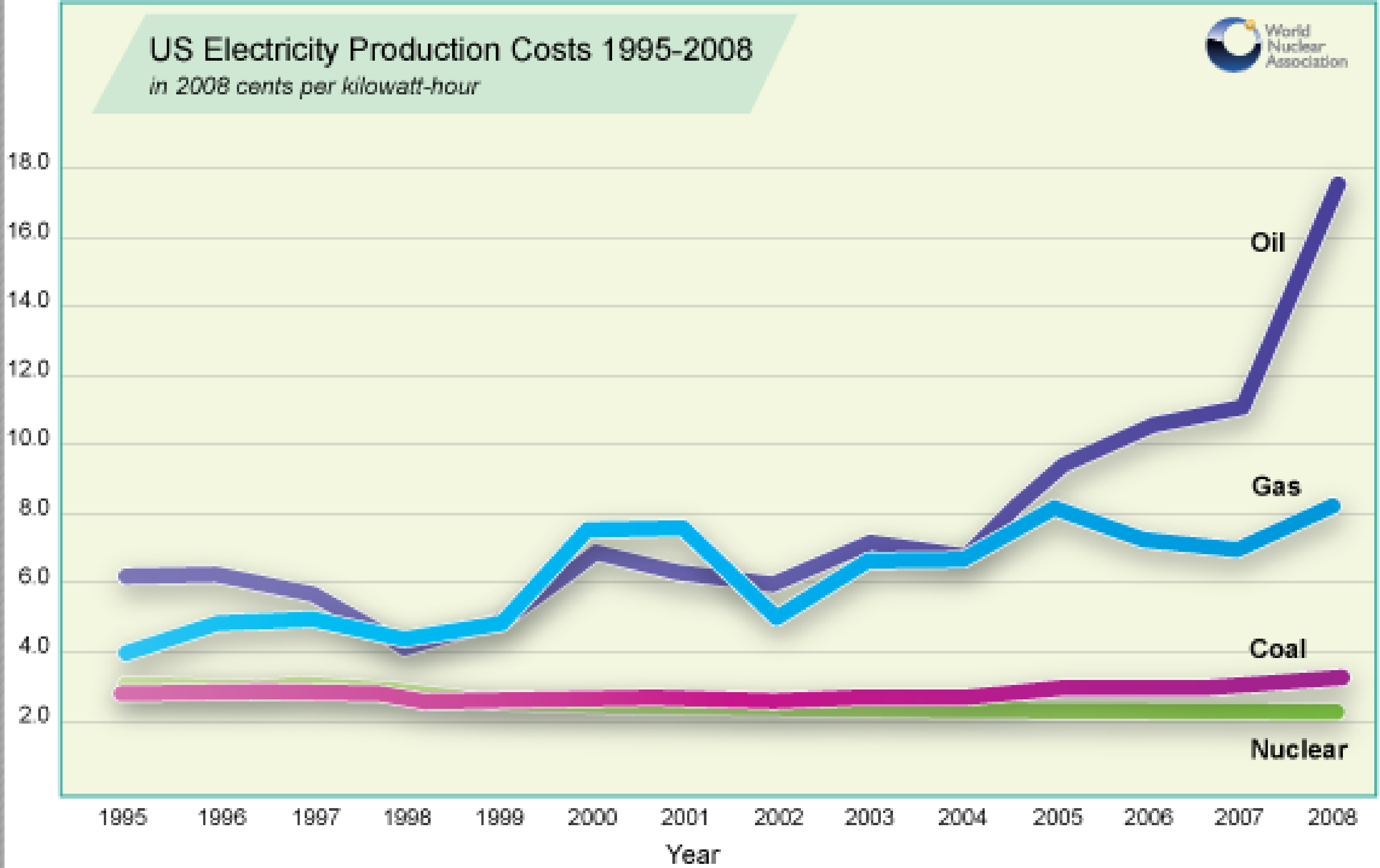
1500 MWe (4 Units)

80% of electricity from nuclear power

The cheapest KWh in Europe

J C Frappier, CEA

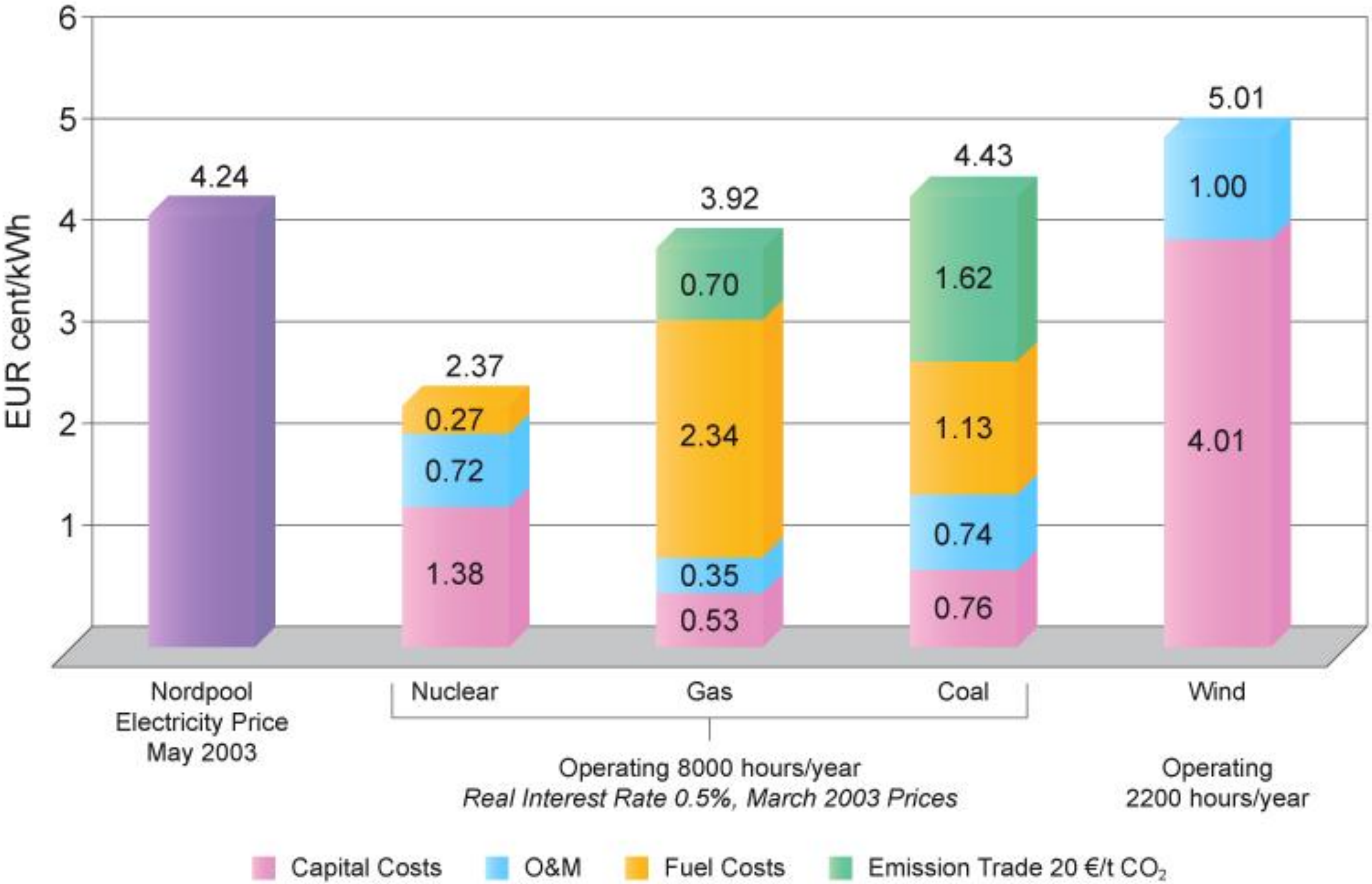
World Nuclear Association



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

Source: *Ventyx Velocity Suite, via NEI*

Projected Electricity Costs for Finland 2003 - cent/kWh



Source: R. Tarjanne & K. Luostarinen, Lappeenranta University of Technology 03.07.2003

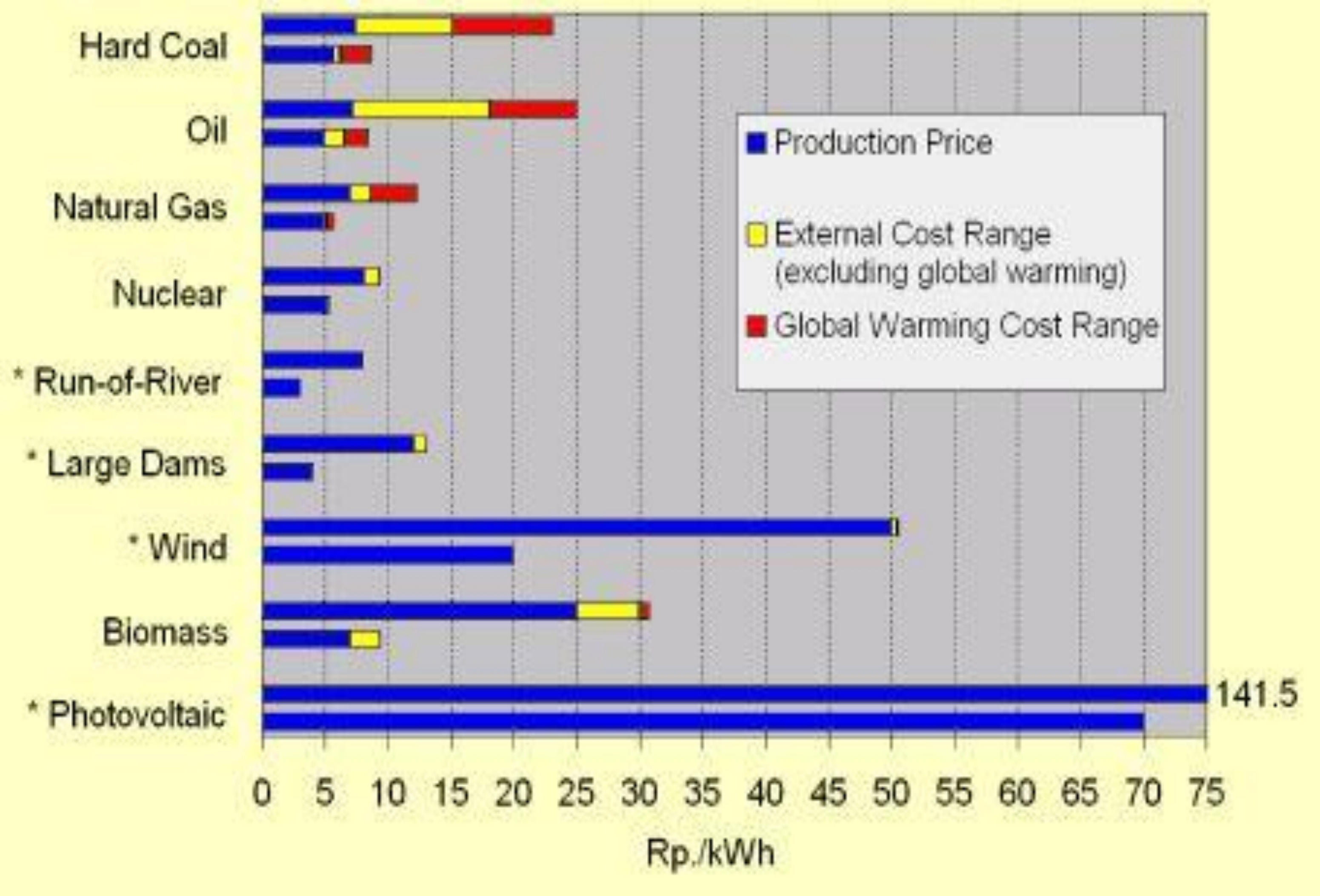
Energy Subsidies and taxes

From/ to governments:
- US production tax Credit – paid to generators, per kWh
- Levy on specified sources – nuclear in Sweden, Belgium, Germany, Finland

From consumers: (mandated by government)
- Feed-in tariff: set price paid by grid company and passed on to consumers.
- Renewables obligation, RET: set proportion at offered price paid by grid company and passed on to consumers

World Nuclear Association

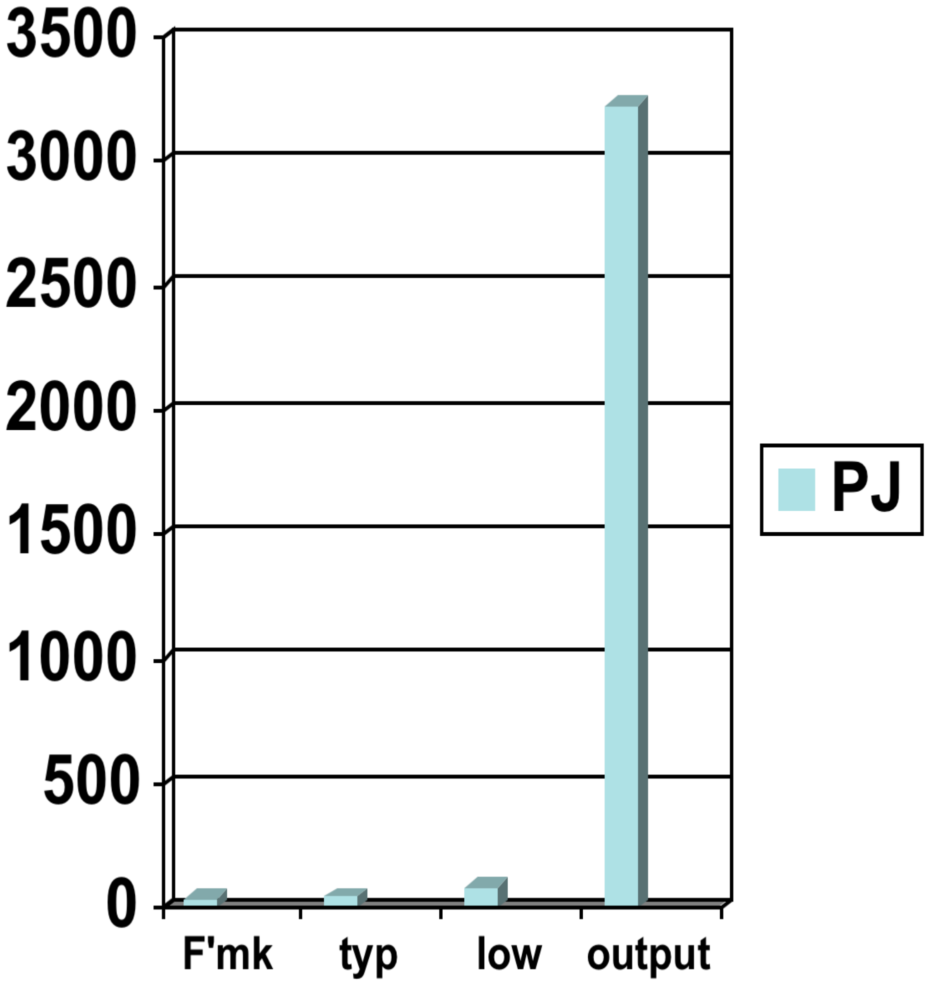
Total costs of electricity generation in Switzerland



Paul Scherrer Inst. Twin bars indicate range

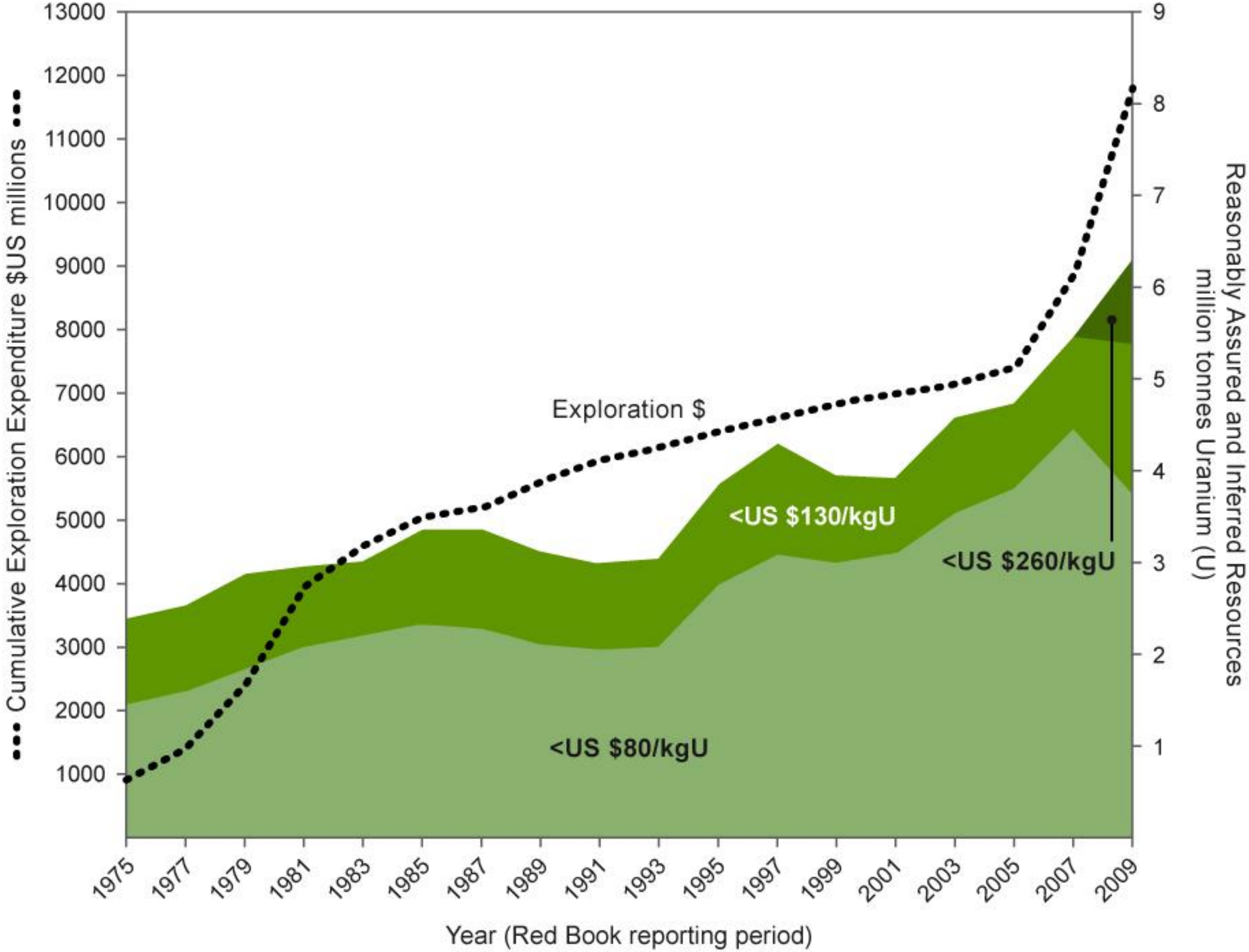
Energy accounting

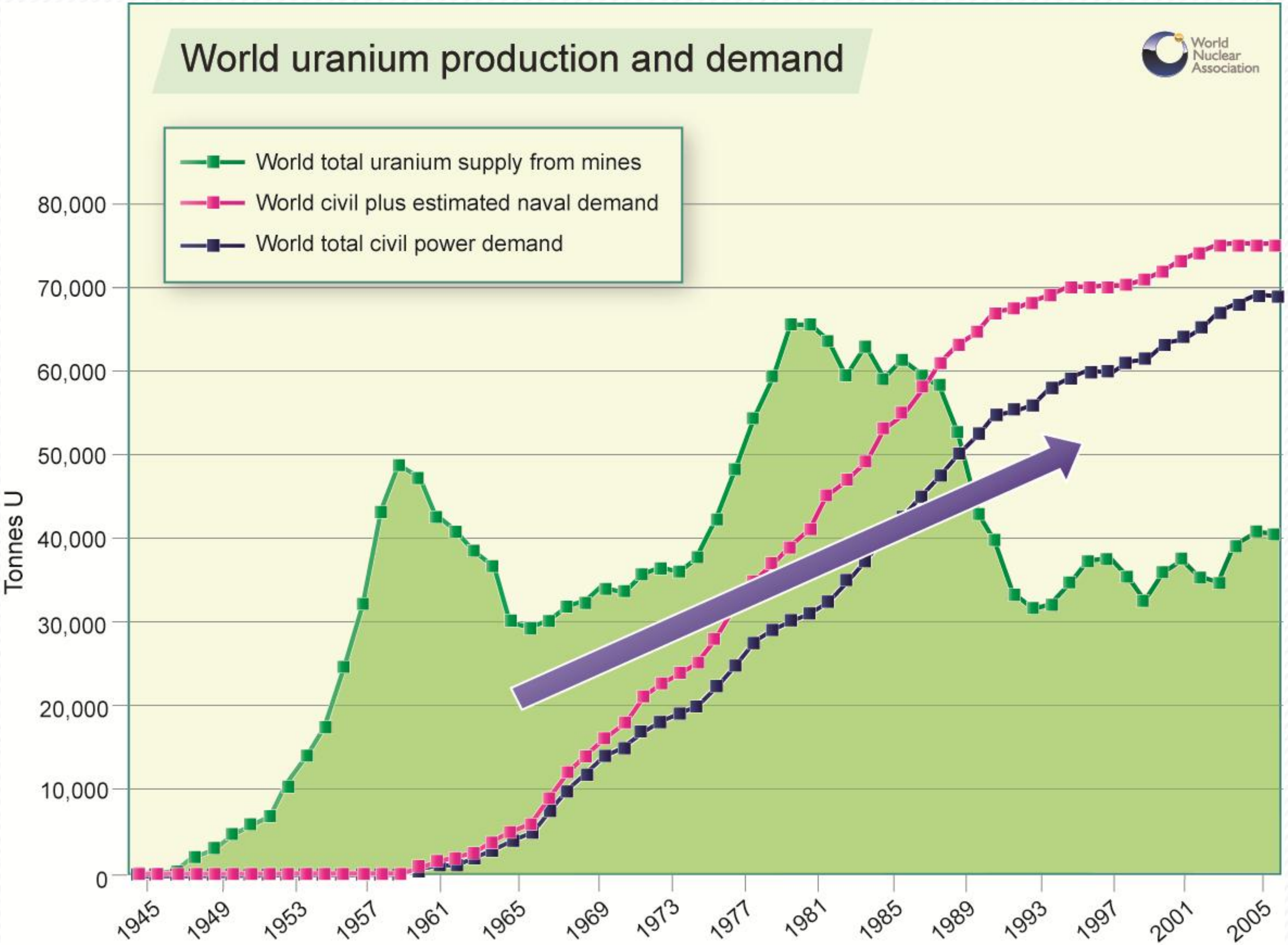
- Vattenfall Forsmark audited LCA: input is 1.35% of output.
- Typical: 1.7% of output.
- Very low grade ore: 2.9% of output.
- Hence negligible CO_2



Output: 40 years for 1 GWe

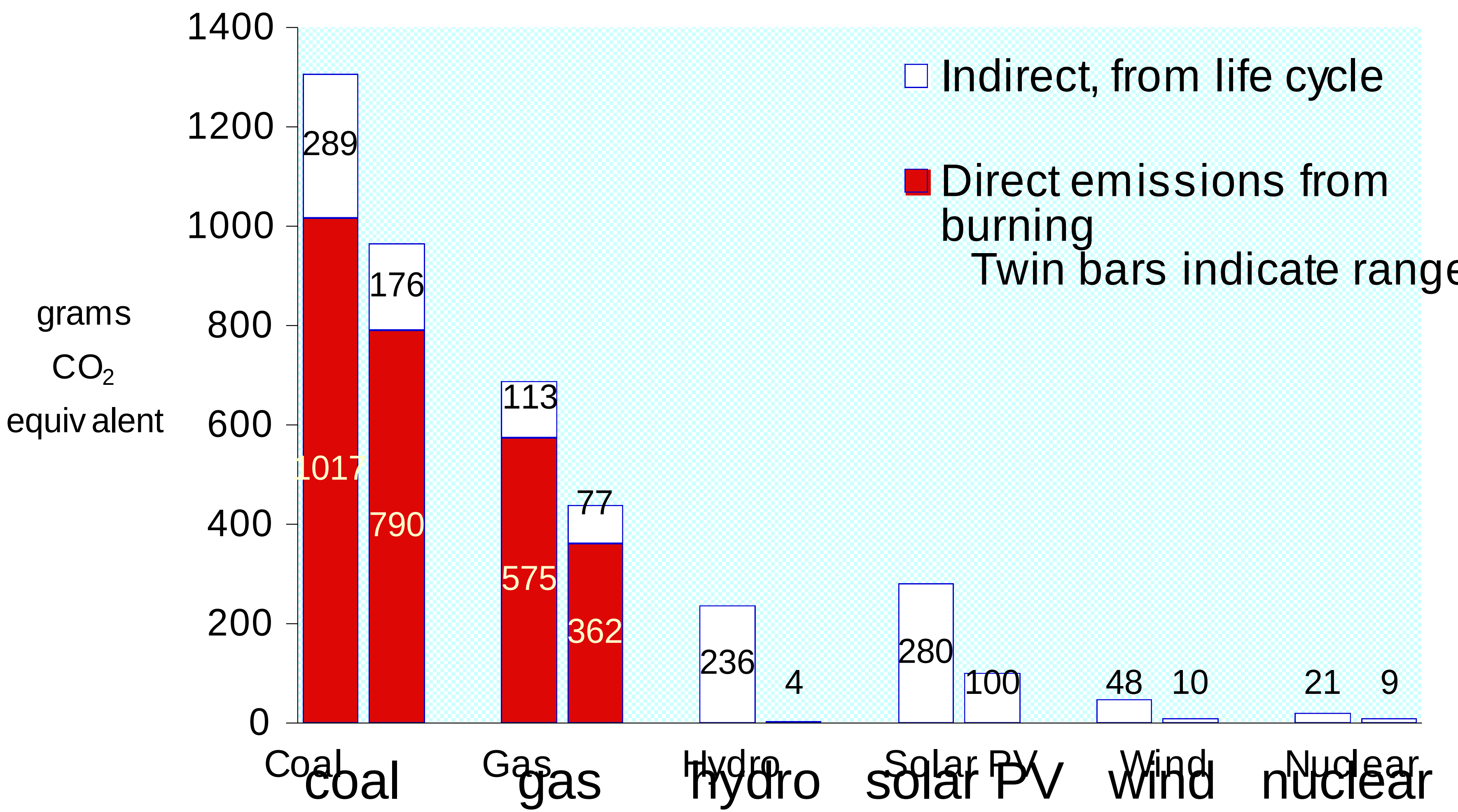
Known Uranium Resources and Exploration Expenditure





World Nuclear Association

Greenhouse Gas Emissions from Electricity Production



Source: IAEA 2000

IAEA 2000

EVERY 26 TONNES U_3O_8

USED SAVES

1 MILLION TONNES CO_2

RELATIVE TO COAL!

Nuclear-powered Icebreaker *Yamal,* 23,500 dwt

Powered by two 170 MWt reactors ➔ 54 MW at propellers

World Nuclear Association

Nuclear submarines use reactors up to 200 MWt

World Nuclear Association

First Russian floating nuclear power plant

With 2 x 40 MWe reactors

Sites for Russian FNPPs

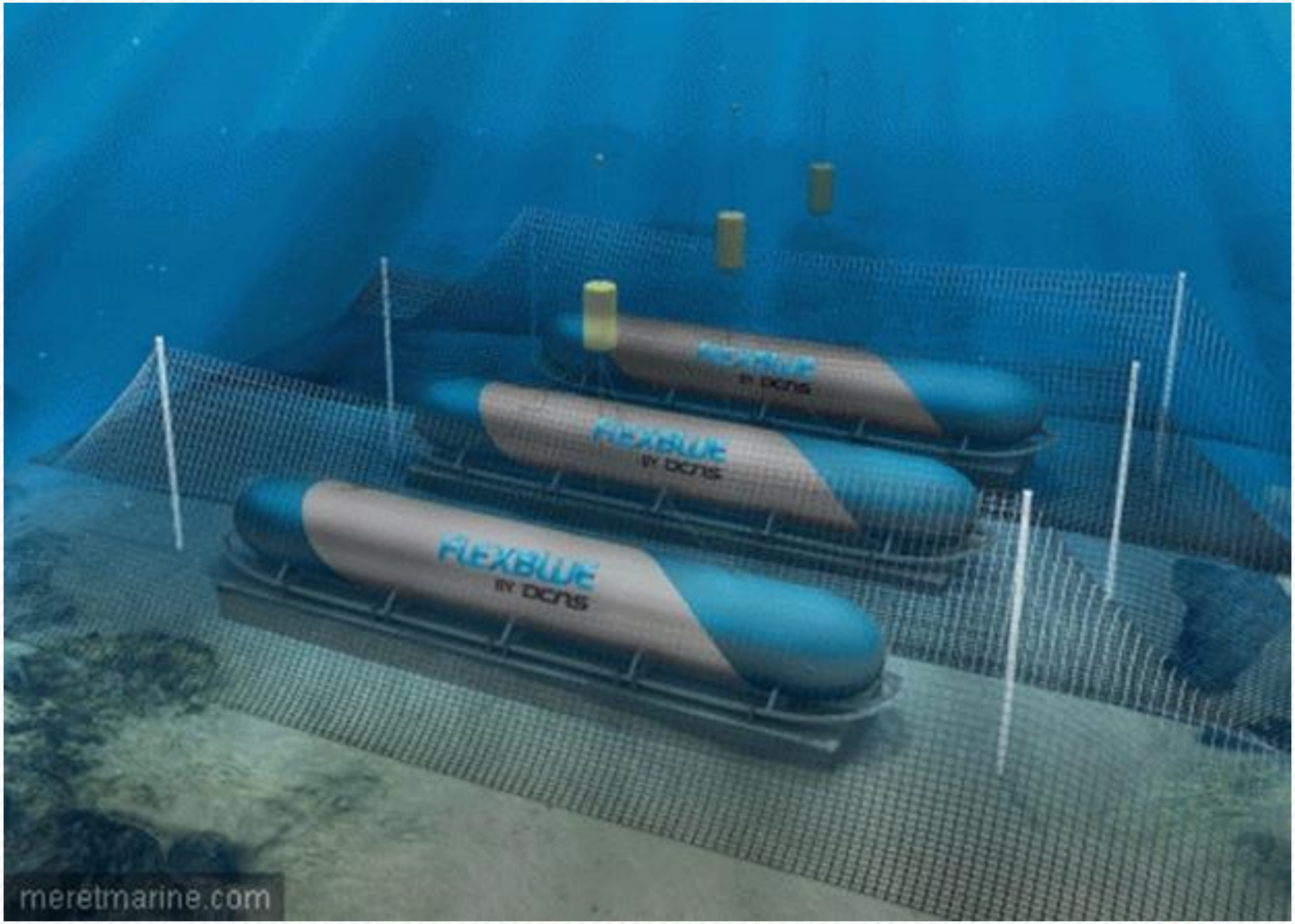
First Floating Nuclear Power Plant

(U.S. Army Corps of Engineers photo)

1967-1976, *USS Sturgis*, Panama Canal Zone

World Nuclear Association

Flexblue SMR farm on seabed - France



50 to 250 MWe PWR reactor in each

World Nuclear Association

Nuclear Desalination

Reverse osmosis –
use electric pumps off-peak

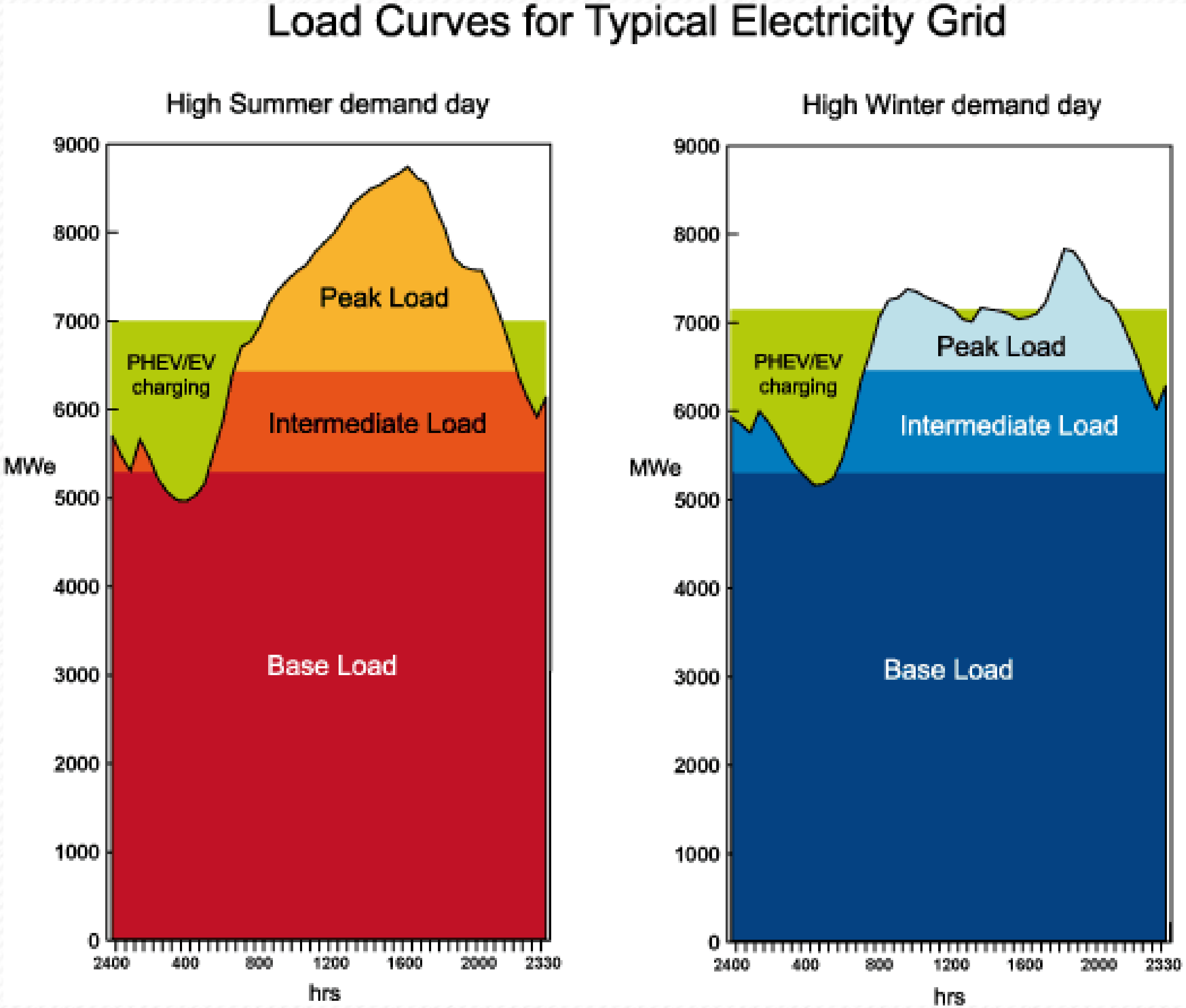
Distillation - scope for cogeneration

Transport: electromobility

- Plug-in Hybrid Electric Vehicles & EVs
- Charge off-peak

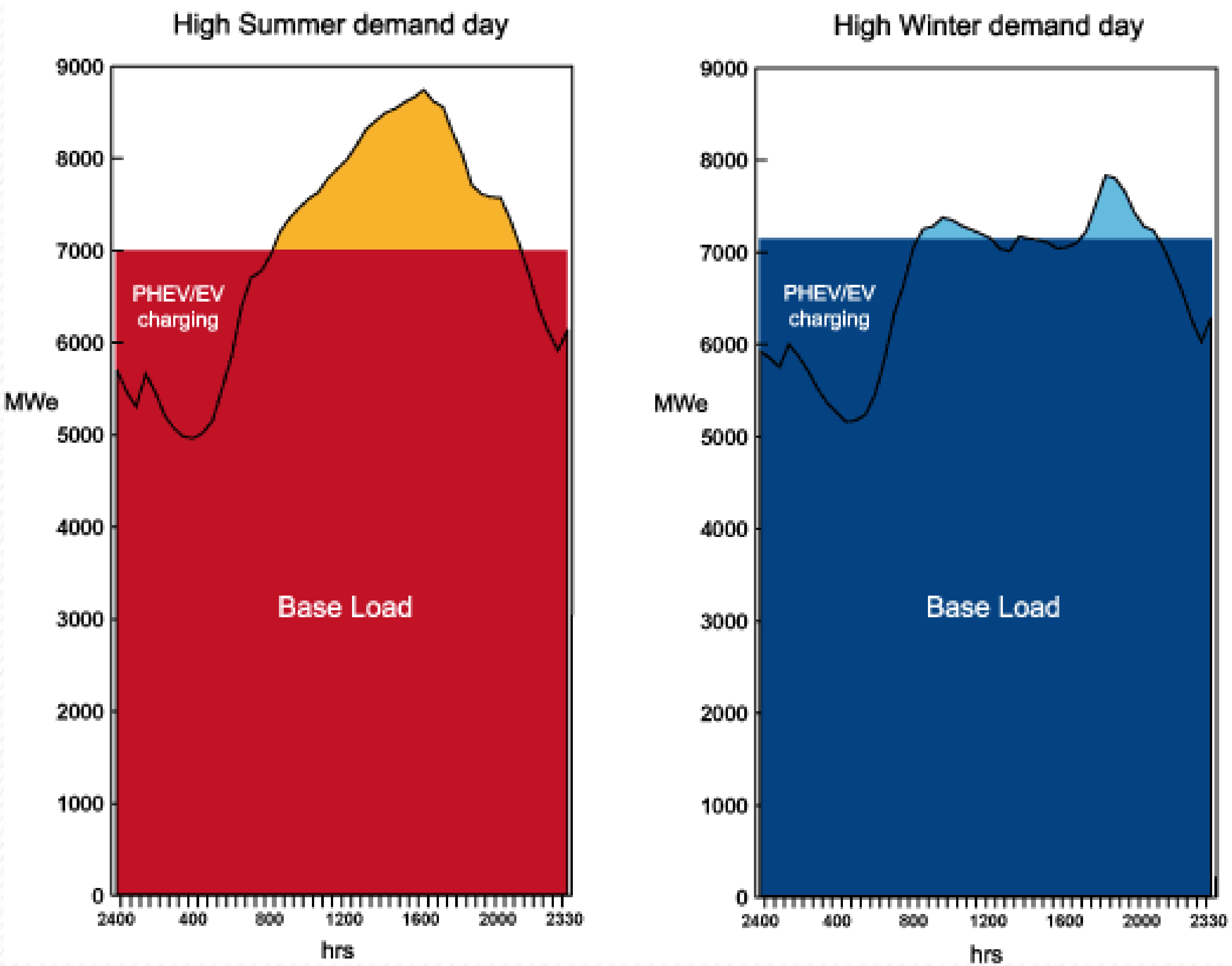
➔ Increase proportion as base-load

World Nuclear Association



With overnight charging of EVs

Load Curves For Typical Electricity Grid



Higher base-load proportion ➔ reduced kWh cost

World Nuclear Association

Nuclear Process Heat

Synthetic crude oil from coal

- A nuclear source of hydrogen + nuclear process heat

➔ double the liquid hydrocarbons

and eliminate most CO_2 emissions

Liberate oil from tar sands

World Nuclear Association

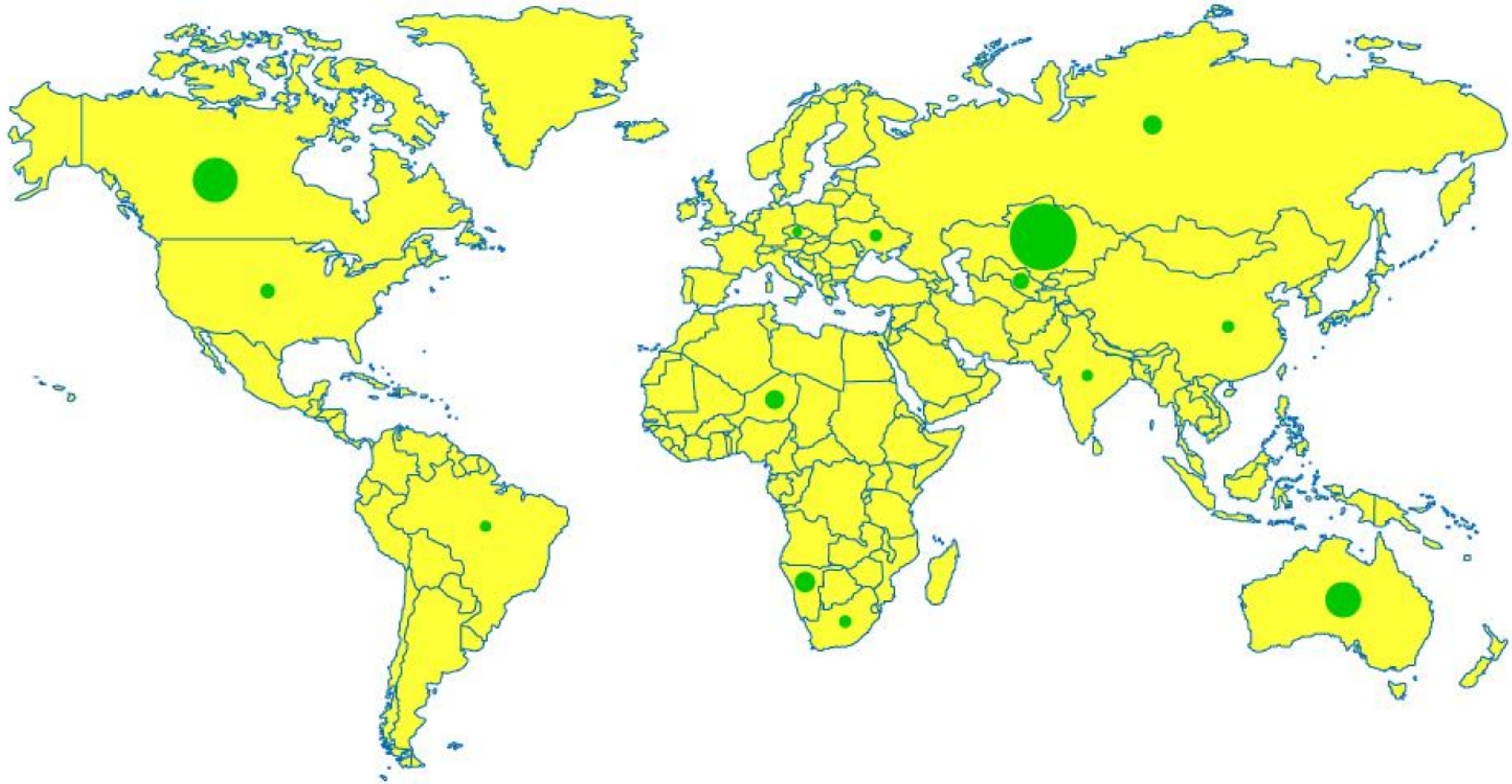
Hydrogen Economy

- Now: 50 million tonnes per year hydrogen made, for oil production
- future: 1000 Mt/yr + for use in fuel cells

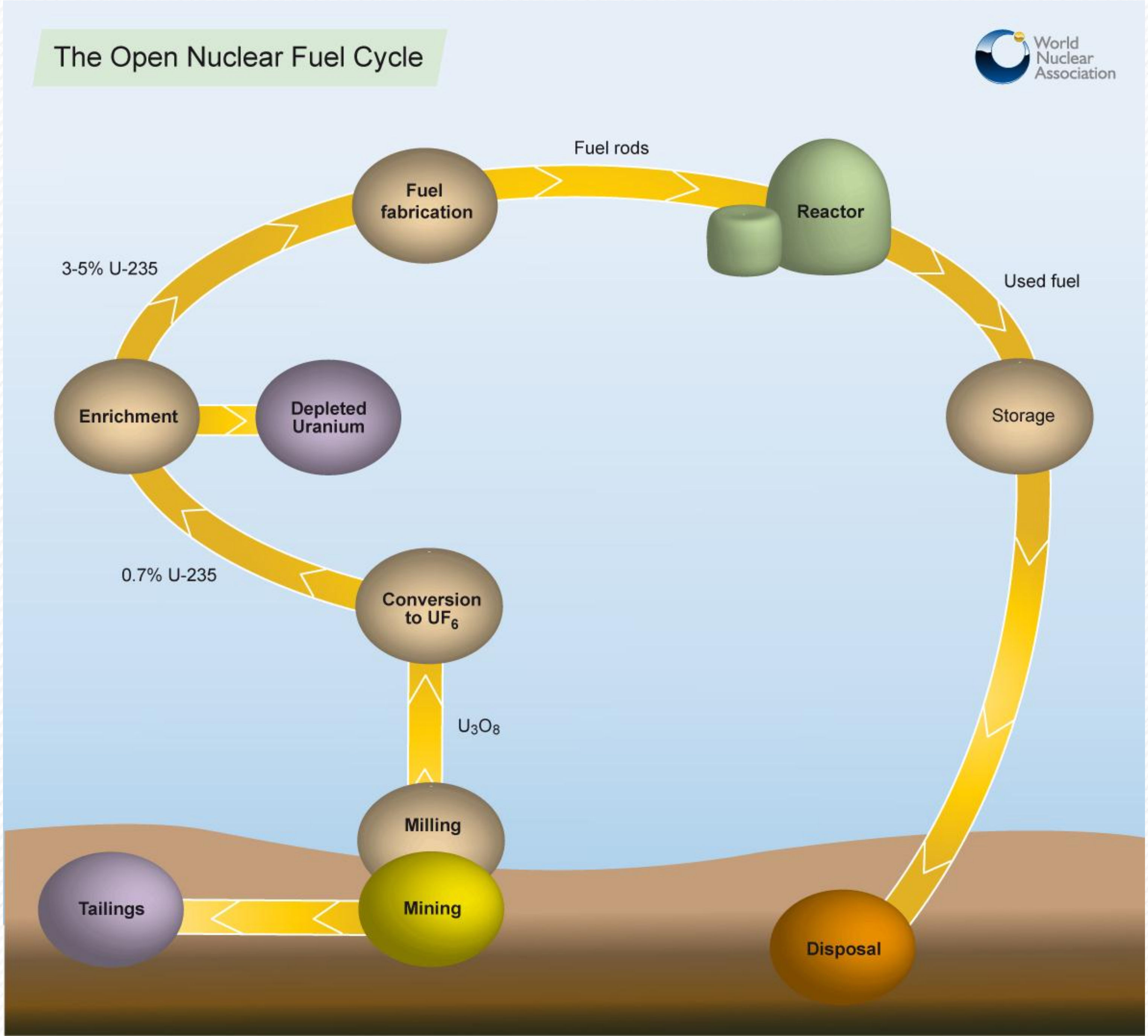
- Now: steam reforming of natural gas
- High temperature electrolysis of water
- **Thermochemical production** from water using nuclear heat - needs 950ºC

World Nuclear Association

World Sources of Mined Uranium

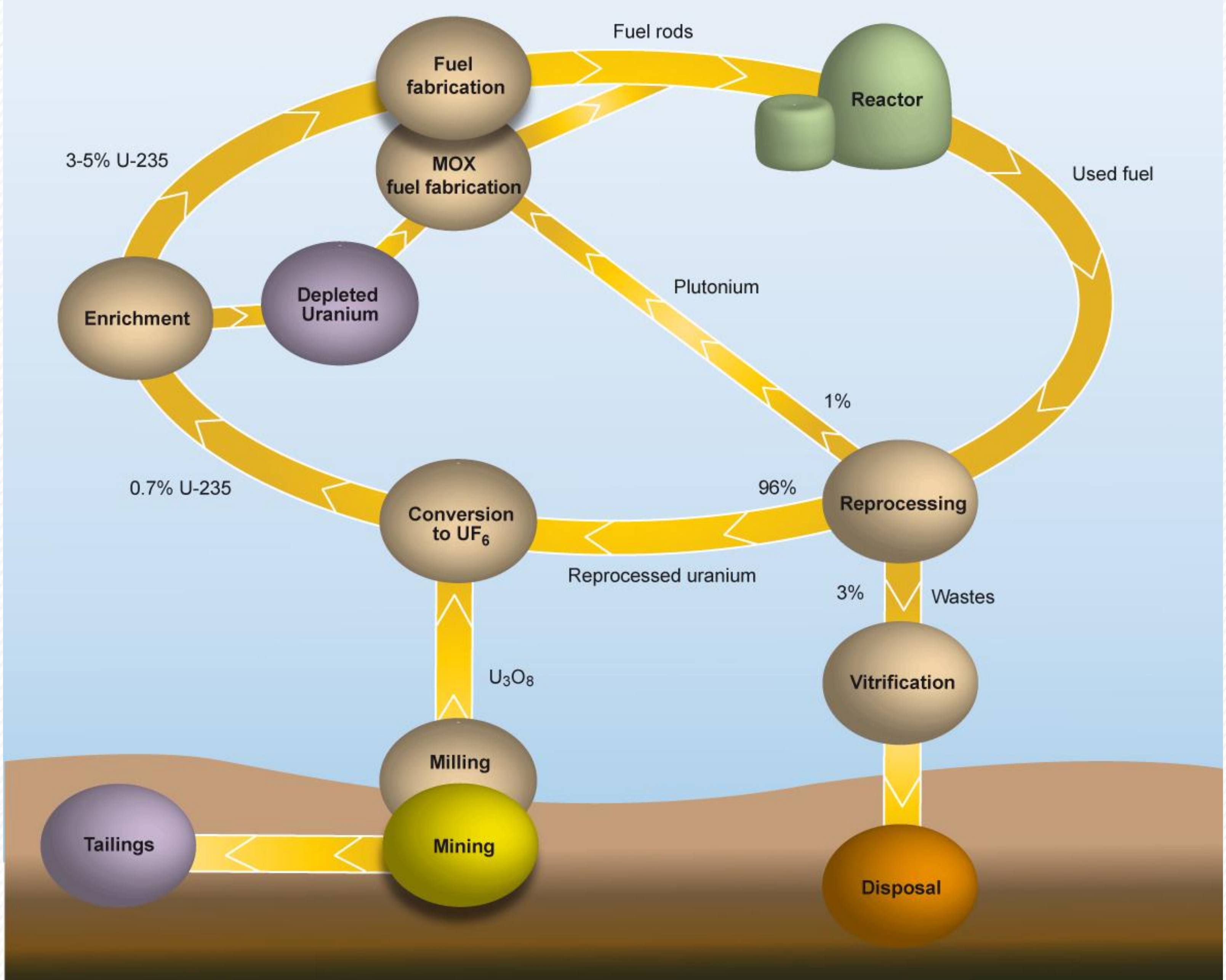


World Nuclear Association

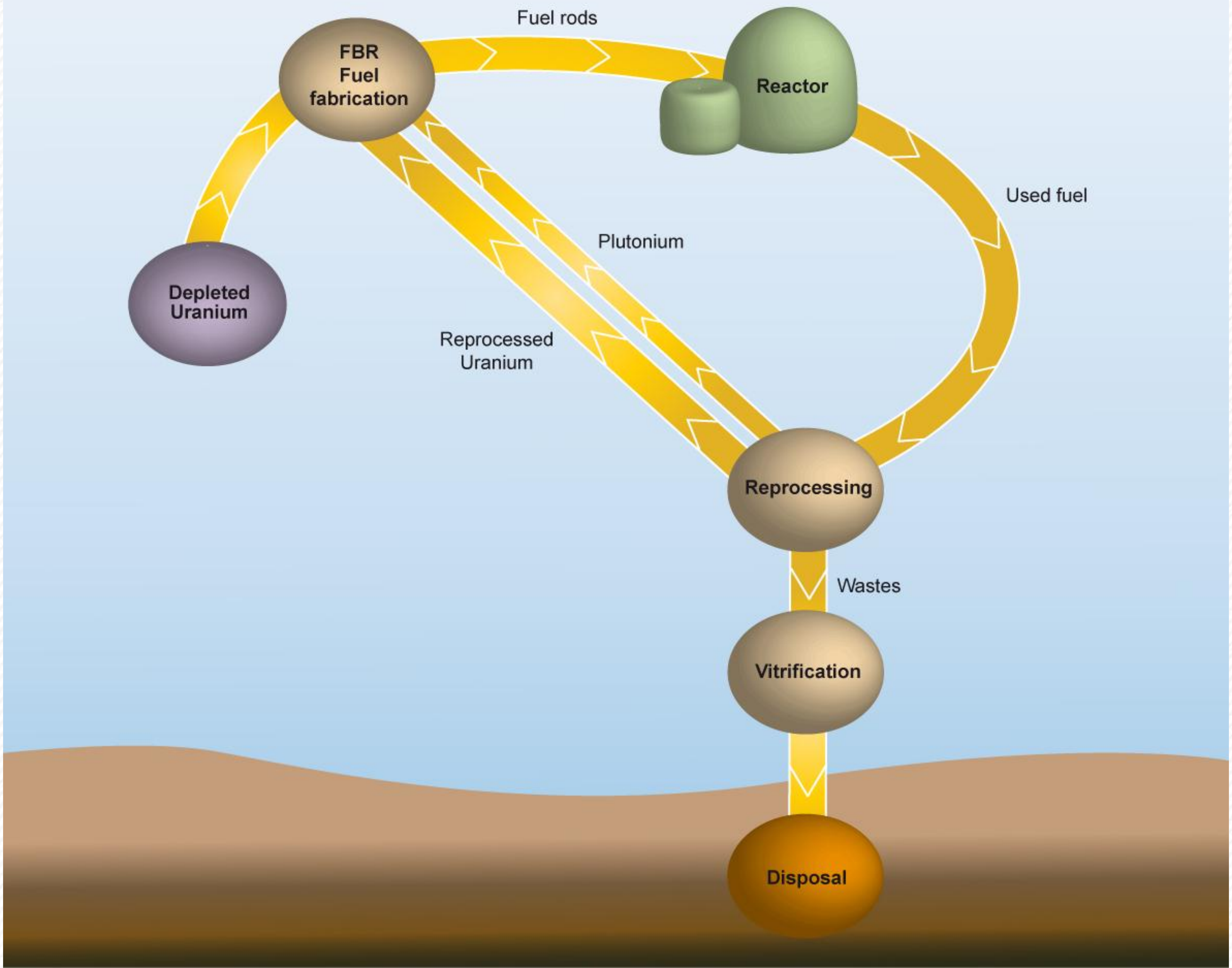


The Open Nuclear Fuel Cycle
World Nuclear Association
Fuel rods
Fuel fabrication
Reactor
3-5% U-235
Used fuel
Enrichment
Depleted Uranium
Storage
0.7% U-235
Conversion to UF_6
U_3O_8
Milling
Tailings
Mining
Disposal

The Closed Nuclear Fuel Cycle



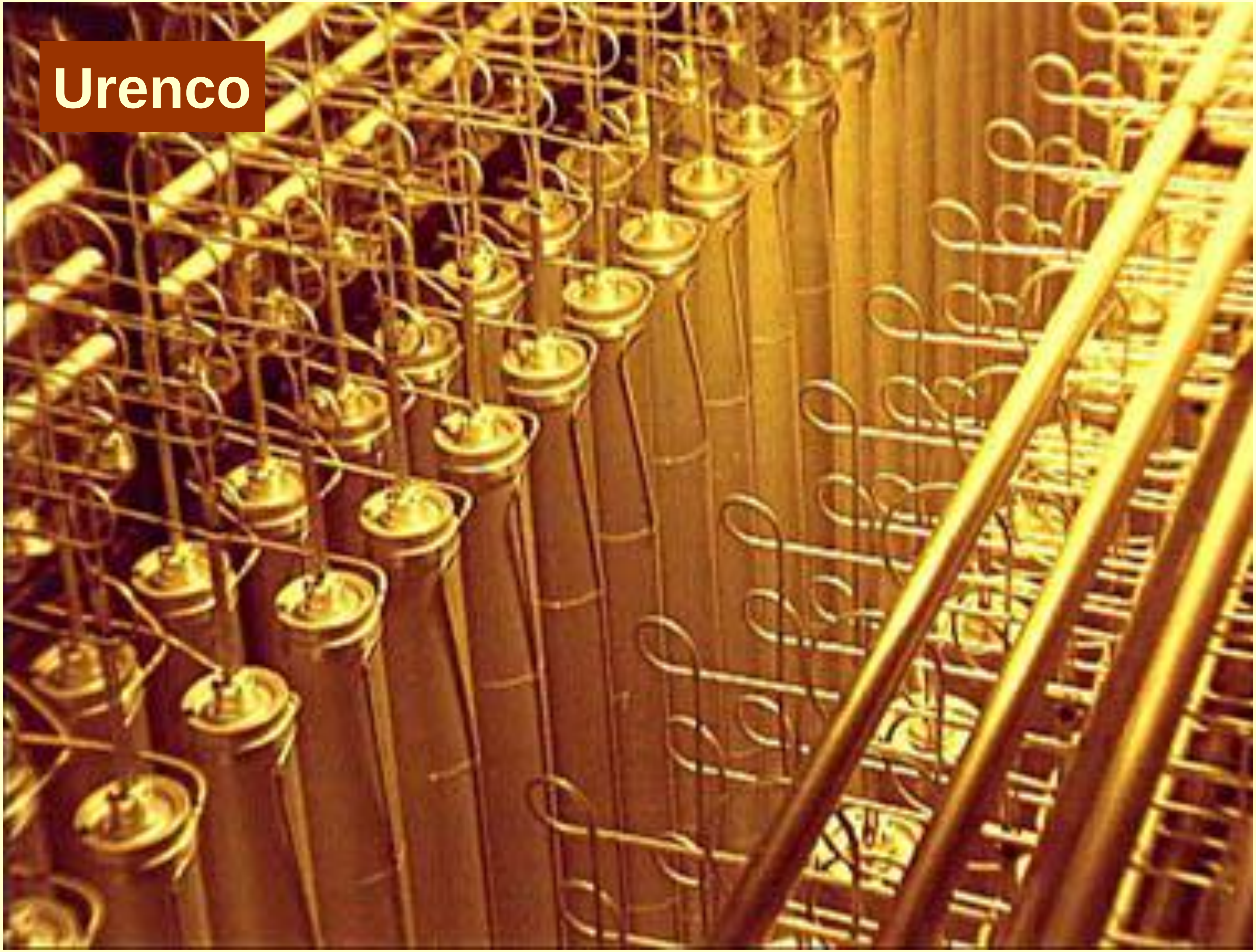
The Fast Breeder Nuclear Fuel Cycle



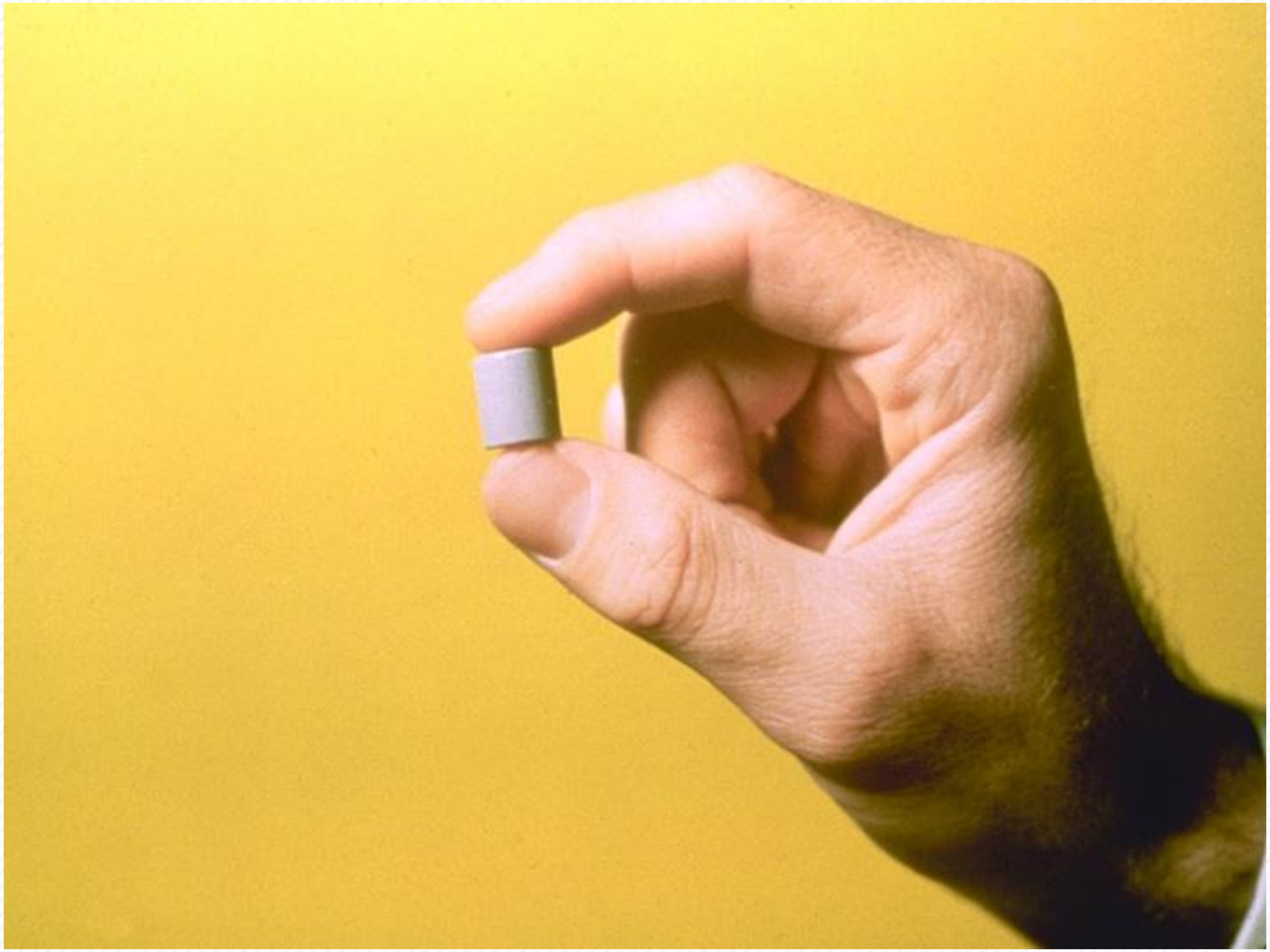
Uranium conversion

Port Hope
Inside UF_6 plant.

Source: Cameco


Urenco

Fuel Pellet - uranium oxide

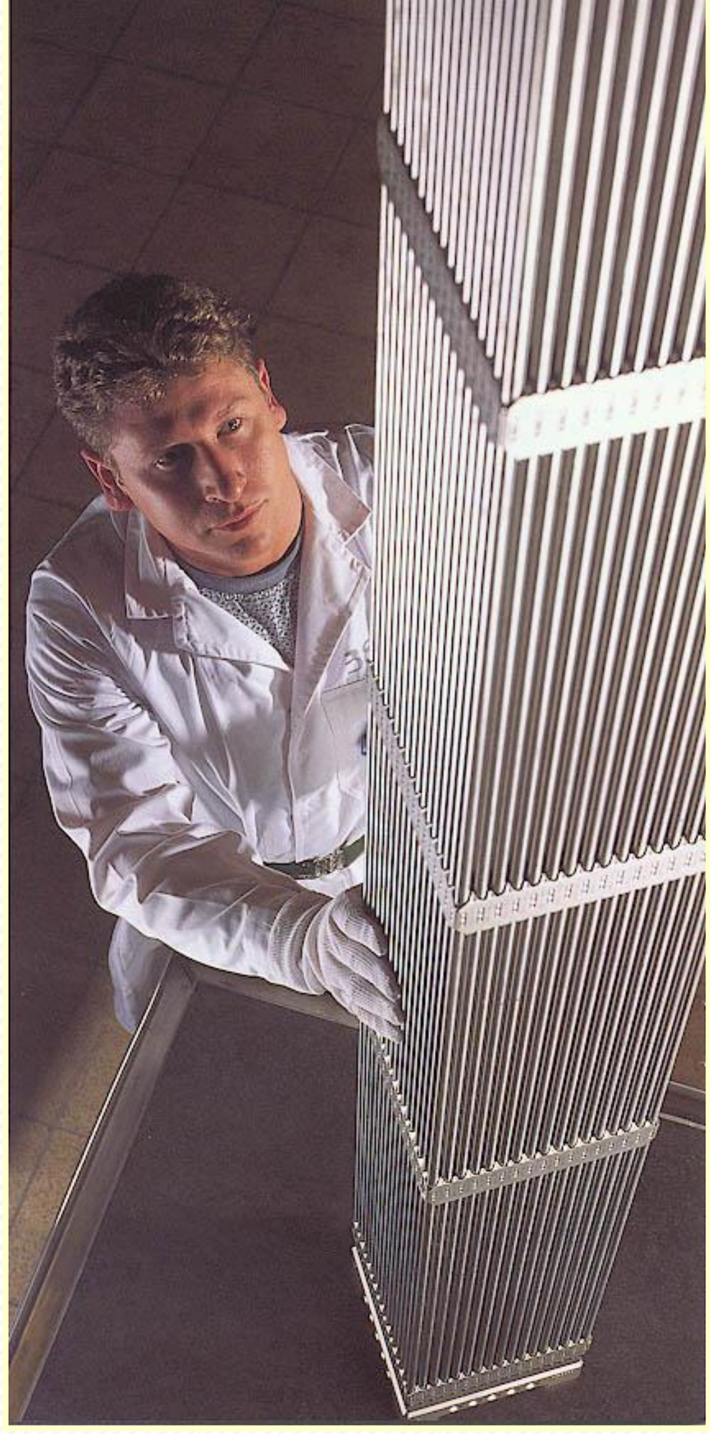


= 700 cubic metres of natural gas

= 950 kg of coal

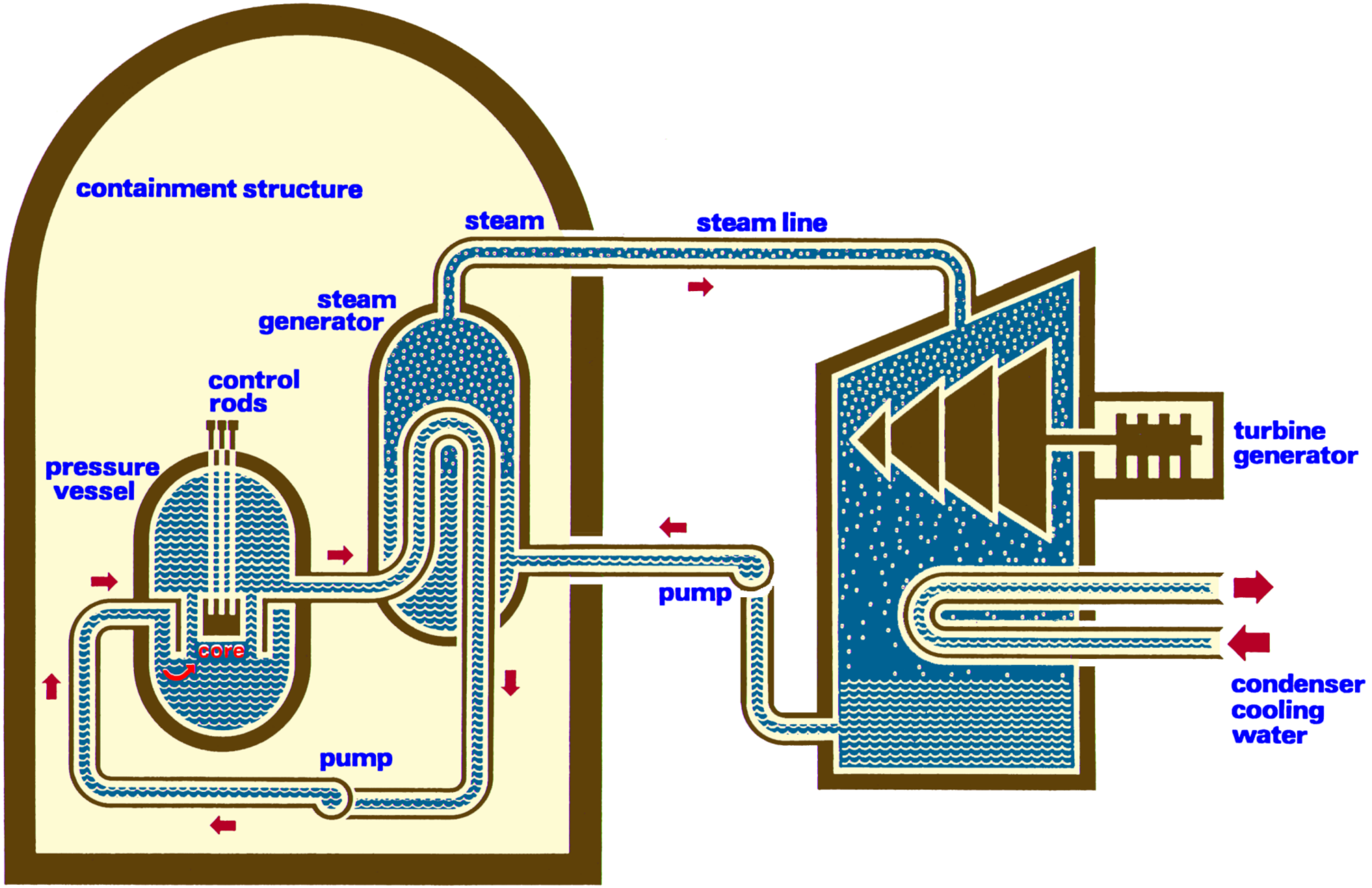
World Nuclear Association

Fuel Assembly for Nuclear Reactor

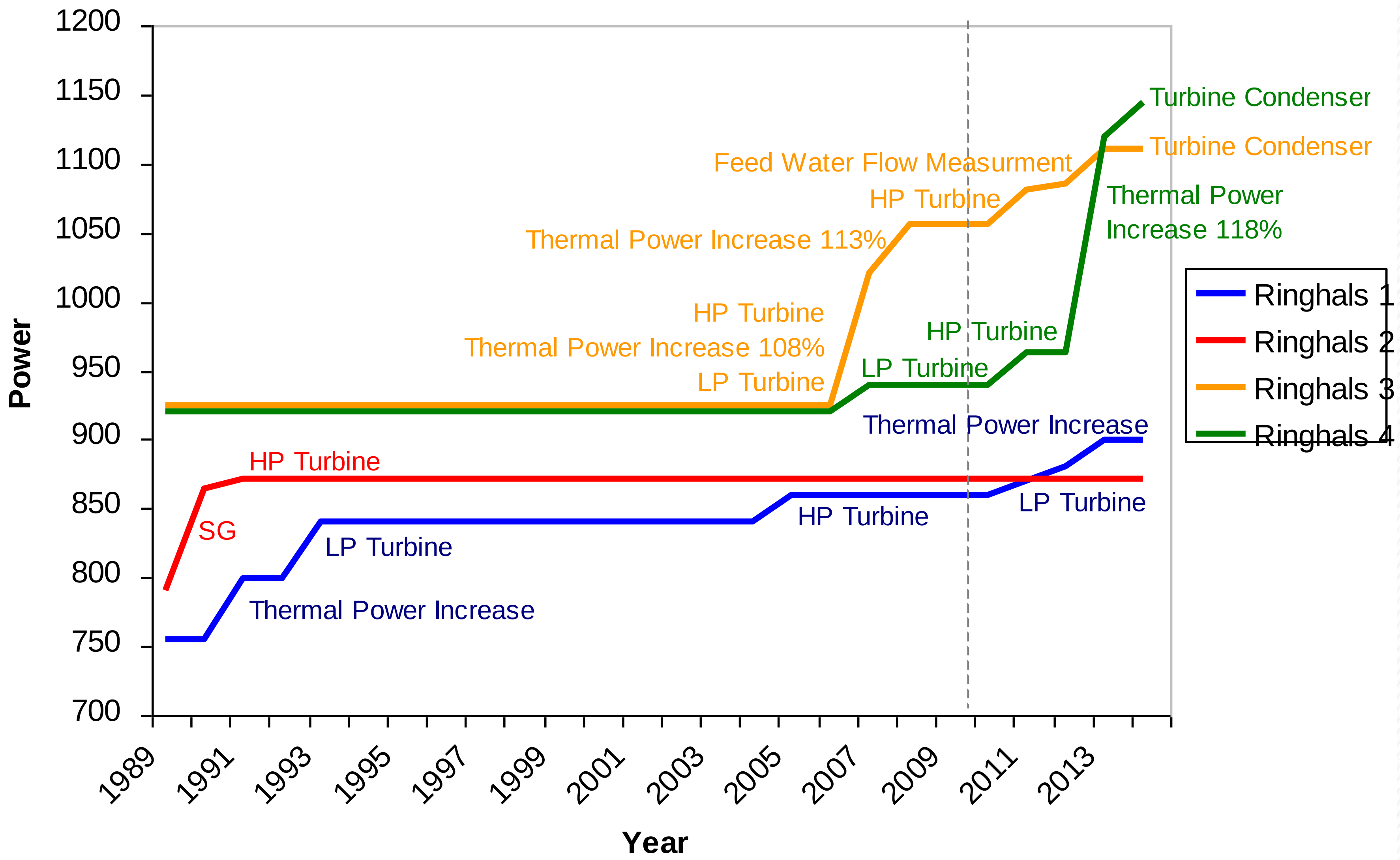


World Nuclear Association

Pressurized water reactor (PWR)



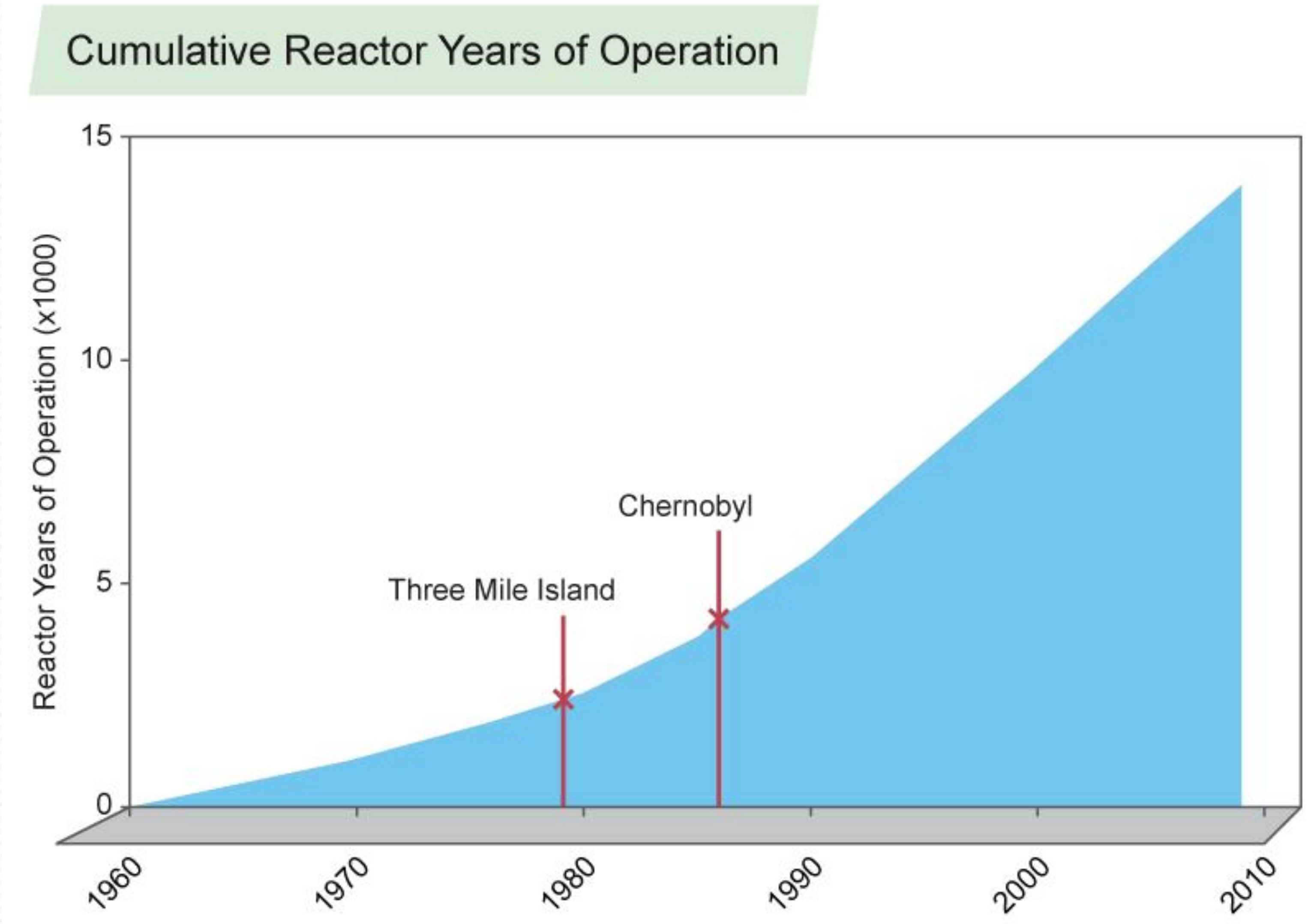
Ringhals uprates - total from 2004: over 450 MWe



Nuclear Association

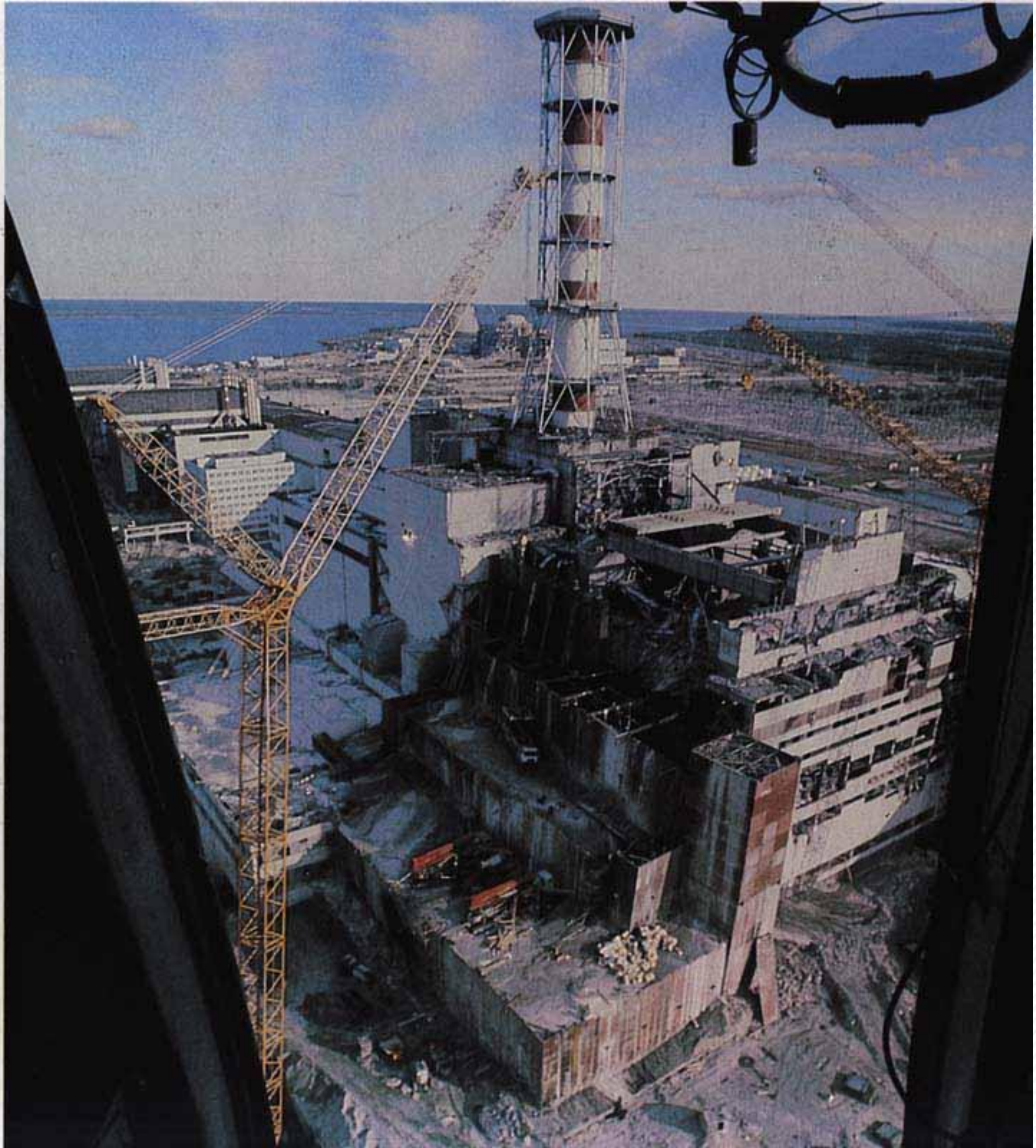
L. Eliasson, Vattenfall

Sizewell B nuclear power plant, UK - a PWR



A safety record unmatched by any major technology!
14,000+ reactor-years civil, similar for naval

World Nuclear Association



Chernobyl unit 4

soon after the accident

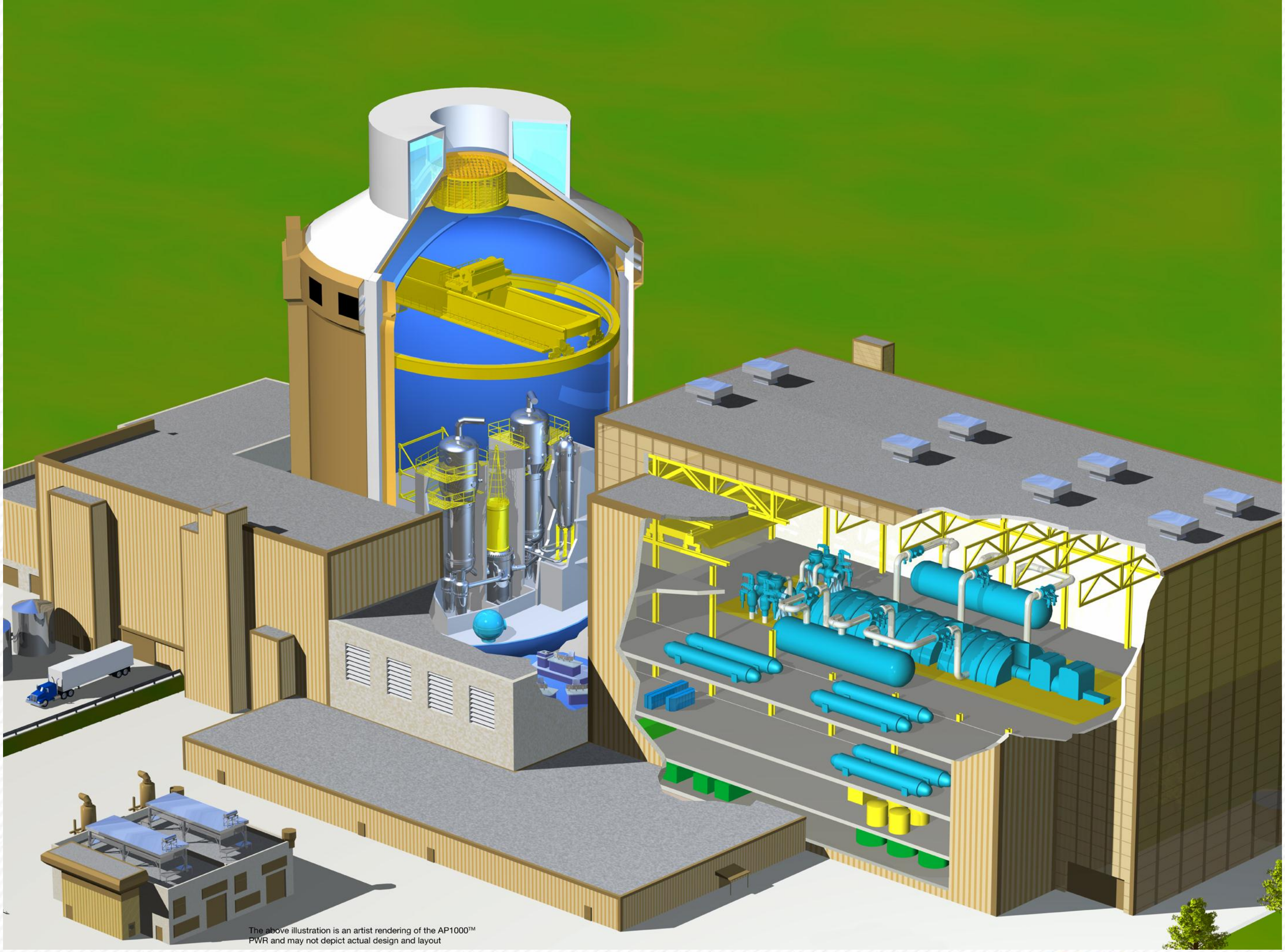
World Nuclear Association

More people are killed every 2 days in the world's coal mines than died as a result of the Chernobyl accident

World Nuclear Association

Generation III: Kashiwazaki Kariwa 6 & 7, Japan

World Nuclear Association



W
e

World Nuclear Association

Sanmen-1
Dec 2009

Containment
vessel bottom

World Nuclear Association

Olkiluoto 3, February 2010

World Nuclear Association

Main 3rd generation nuclear reactors:

- Areva NP **EPR** - 1700 MWe
- Westinghouse **AP1000** - 1200 MWe
- GE Hitachi/Toshiba **ABWR** - 1350 MWe
- Gidropress **AES-2006** – 1200 MWe
- Korea HNP **APR-1400** - 1450 MWe
- Mitsubishi **APWR** - 1500 MWe
- GE Hitachi **ESBWR** - 1600 MWe
- AECL **ACR-1000** - 1100 MWe
- Chinergy **HTR-PM** – 2x105 MWe

World Nuclear Association

Small & Medium Reactors (SMR)

- Increasing interest:
- - For progressively-constructed large plants
- - For small grids
- - For isolated sites
- Many innovative designs
- Range of sizes from 10 MWe to 300 MWe (small), & to 700 MWe (medium)
- Diverse possible uses

World Nuclear Association

Fast neutron reactors

- About 300 reactor-years of experience
- Many are and will be operated as breeders
- BN-600, BN-800 in Russia, sold to China
- Phenix & Super Phenix in France
- Monju in Japan
- Many small reactor designs are FNR
- Role in burning actinides from use LWR fuel

World Nuclear Association

Monju fast reactor, Japan

Generation IV Reactors

	Neutron spectrum	Coolant, Temp	pressure	Fuel	Uses
Gas-cooled	Fast	Helium 850 C	High	U-238+	Electricity & hydrogen
Lead-cooled	Fast	Lead 480-800 C	Low	U-238+	Electricity & hydrogen
Molten salt	Fast	Fluoride, 700-800 C	Low	Thorium, U-238+	Electricity & hydrogen
Molten salt – Advanced HT reactor	Slow	Fluoride, 750-1000 C	Low	UO2 in prism	hydrogen
Sodium-cooled	Fast	Sodium 550 C	Low	U-238 & MOX	electricity
Super-critical	Fast or slow	Water 510-625 C	Very High	U-235	electricity
High-temp gas-cooled	Fast	Helium 900-1000 C	High	U-235	Hydrogen & electricity

World Nuclear Association

Military provenance of civil nuclear power

- Power reactors in UK pre 1960, also some in Russia & India: dual use
- Submarine PWR technology
- Naval experience people to civil sector
- Military high-enriched uranium ➔ LEU for civil use
- Military plutonium ➔ MOX fuel for civil use
- No reverse flow

World Nuclear Association

Two routes to bombs

- Uranium enrichment – to 90%+
- Plutonium production – low burn-up fuel, short time in reactor
- (Hiroshima and Nagasaki respectively)

World Nuclear Association

NPT Safeguards

- Under Nuclear Non-Proliferation Treaty
- Accounting and audit internationally
- Through whole progression and transformation of fissile materials
- Reinforced by intrusive inspection
- Backed by Nuclear Suppliers' Group

World Nuclear Association

Australian and Canadian

NUCLEAR SAFEGUARDS POLICIES

1. **Selected countries**

   Non-weapons states must be party to NPT and must accept full-scope IAEA safeguards applying to <u>all</u> their nuclear-related activities.
   Weapons states to give assurance of peaceful use, IAEA safeguards to cover the material.

2. **Bilateral agreements are required**

- IAEA to monitor compliance with IAEA safeguards and Australian or Canadian requirements
- Fallback safeguards (if NPT ceases to apply or IAEA cannot perform its safeguards functions)
- Prior consent to transfer material or technology to another country
- Prior consent to enrich above 20% U-235
- Prior consent to reprocess
- Control over storage of any separated plutonium
- Adequate physical security

3. Materials exported to be in a form attracting full IAEA safeguards.

4. Commercial contracts to be subject to conditions of bilateral agreements.

5. Both countries will participate in international efforts to strengthen safeguards.

6. Both countries recognise the need for constant review of standards and procedures.

World Nuclear Association

Nuclear weapons vs civil programs

- **With nuclear weapons**
- USA, Russia, UK, France, China, India, Pakistan, Israel
- None from civil program
- 1960s: expectation of over 30 countries

- **Proliferation concerns**
- Iran - via enrichment, North Korea - via plutonium,
- (formerly: Iraq, Libya, S.Africa)

World Nuclear Association

Nuclear weapons vs civil programs

- **Controlled civil use**
- 28 countries plus Taiwan - under NPT
- + India, Pakistan - partly under NPT

- **Proliferation concerns**
- Not related to civil program
- Iran, North Korea

Clearly need to focus on problems. But how?

World Nuclear Association

Nuclear liability (3rd party)

- Strict liability of operator
- Exclusive liability of operator
- Operator must insure
- Compensation regardless of location
- Liability limited in amount and time

Vienna & Paris Conventions as amended
Convention on Supplementary Compensation 1977
USA: Price-Anderson Act, to $10 B

World Nuclear Association

The Nuclear Future

- Mature technology – electricity since 1956
- Increasingly competitive as fuel costs rise
- Environmental drivers – carbon emissions & clean air
- Energy security drivers - EU & USA
- Part of future supply more widely

World Nuclear Association

www.world-nuclear.org

> Information papers

Providential features in the physics:

Concentrated energy from little material

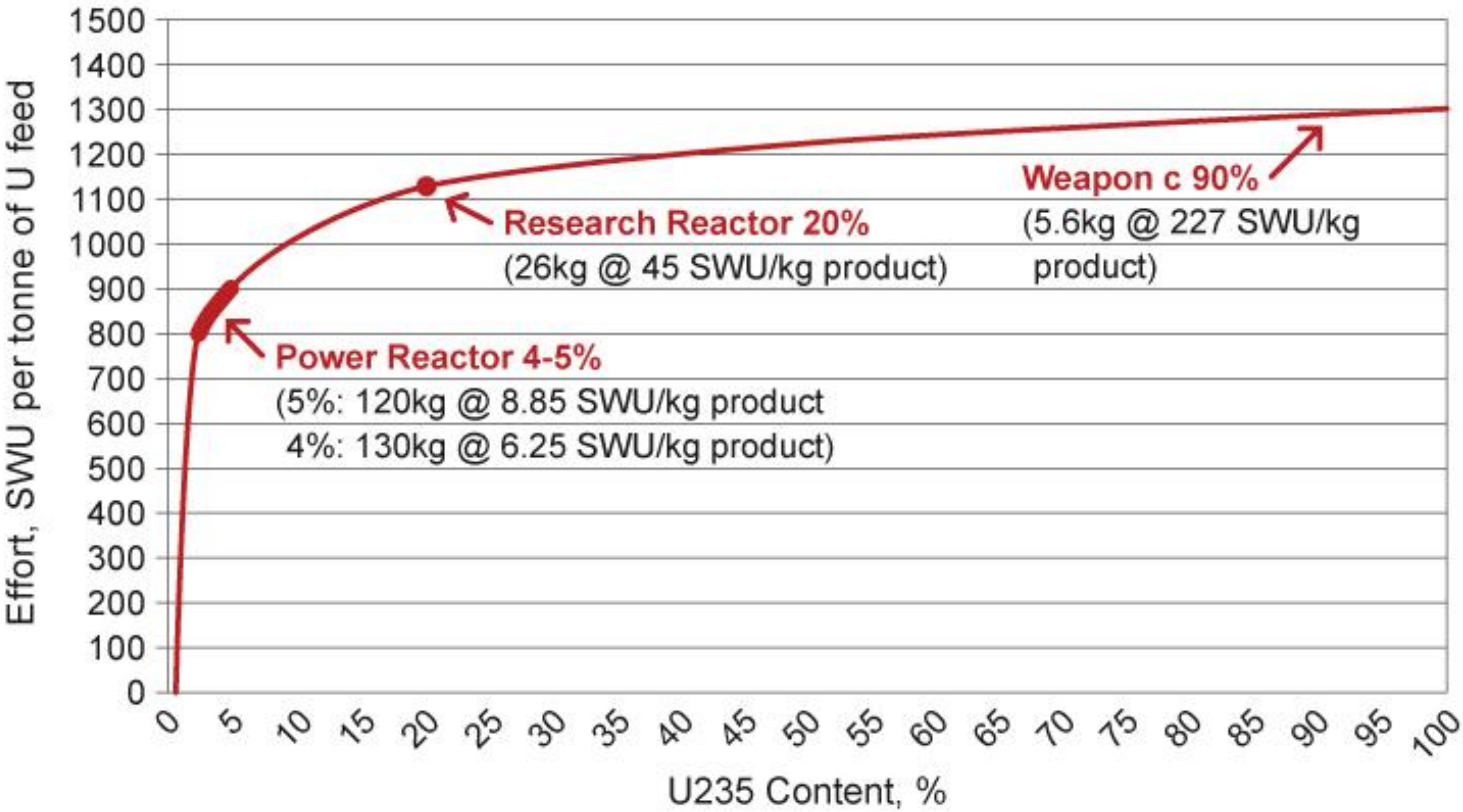
Delayed neutron release – controllable

Negative fuel temperature coefficient
Negative void coefficient

Plutonium production and consumption

Fast neutron reactor able to use U-238

Uranium Enrichment and Uses



ASNO 2010 & DOE
Mass quantities are from one tonne of natural uranium feed.
0.22% tails assay

World Nuclear Association

Wind as base-load?

Ultimately we <u>have</u> to fit it in, if legally it has to be accepted into the grid preferentially to other sources!

So, somehow fit this underneath this