Tsuruga Summer Institute on Nuclear Energy
Wakasa Wan Energy Research Center

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Nuclear Energy Development Towards the Future Society

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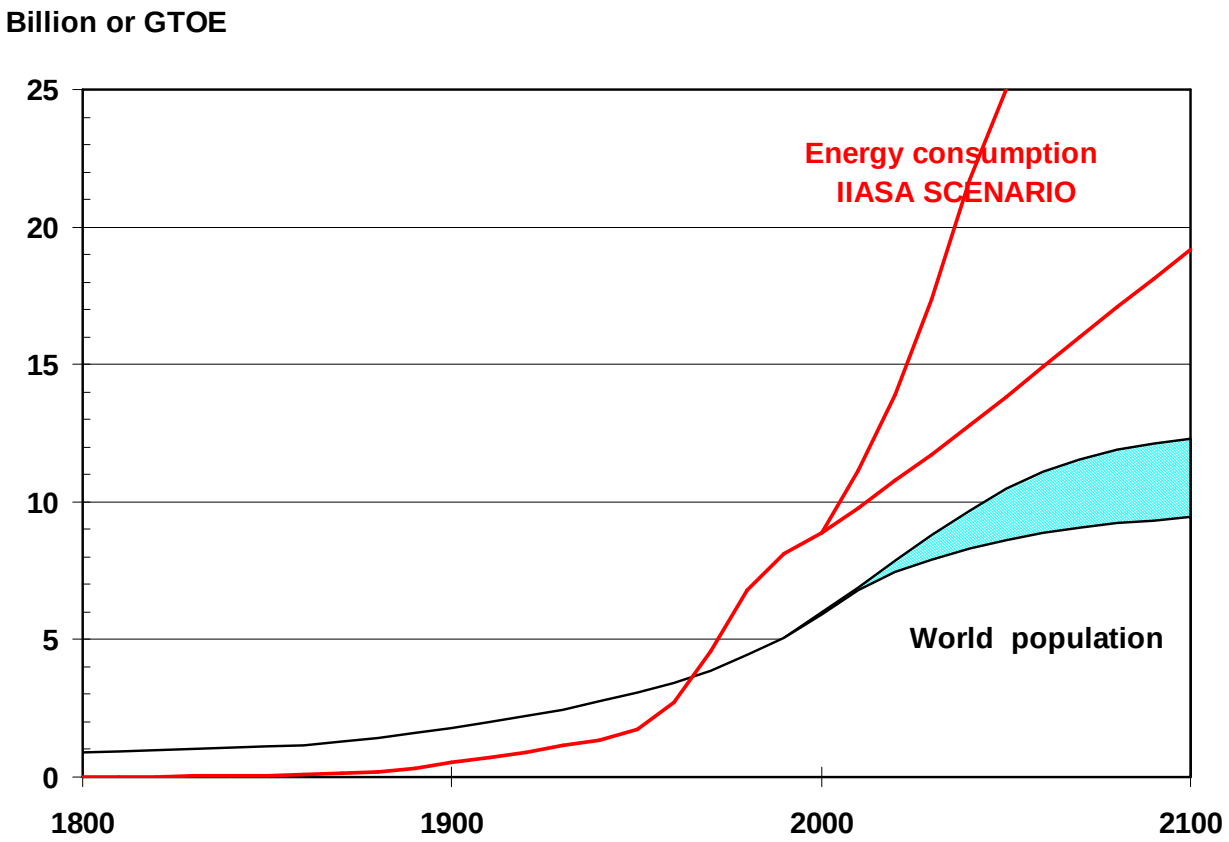
Energy as a factor of development

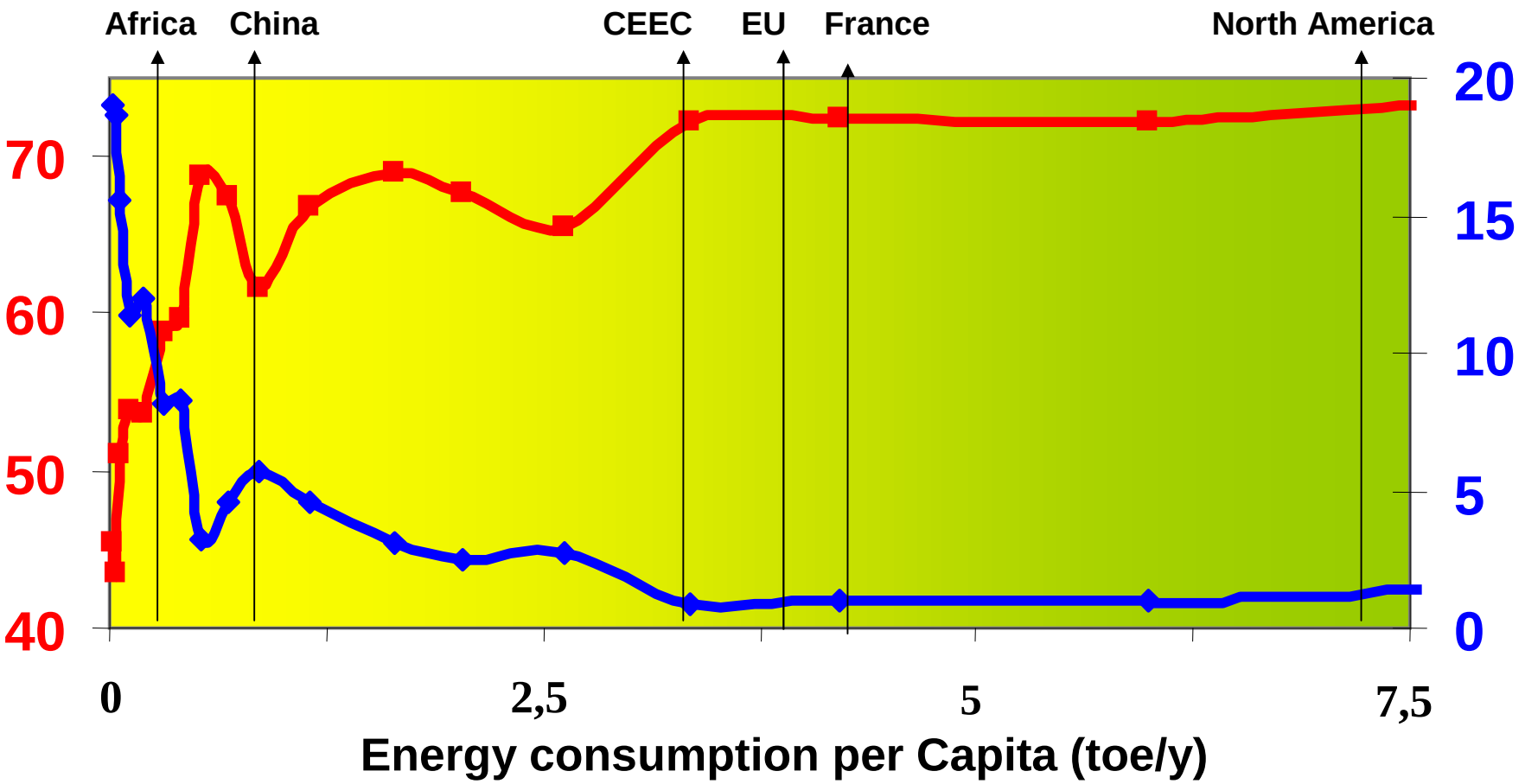
Energy is a factor of development
(An afghan use 300 times less energy than an US citizen)

20 % of the population consume 60% of the energy

2 billion people still have no electricity



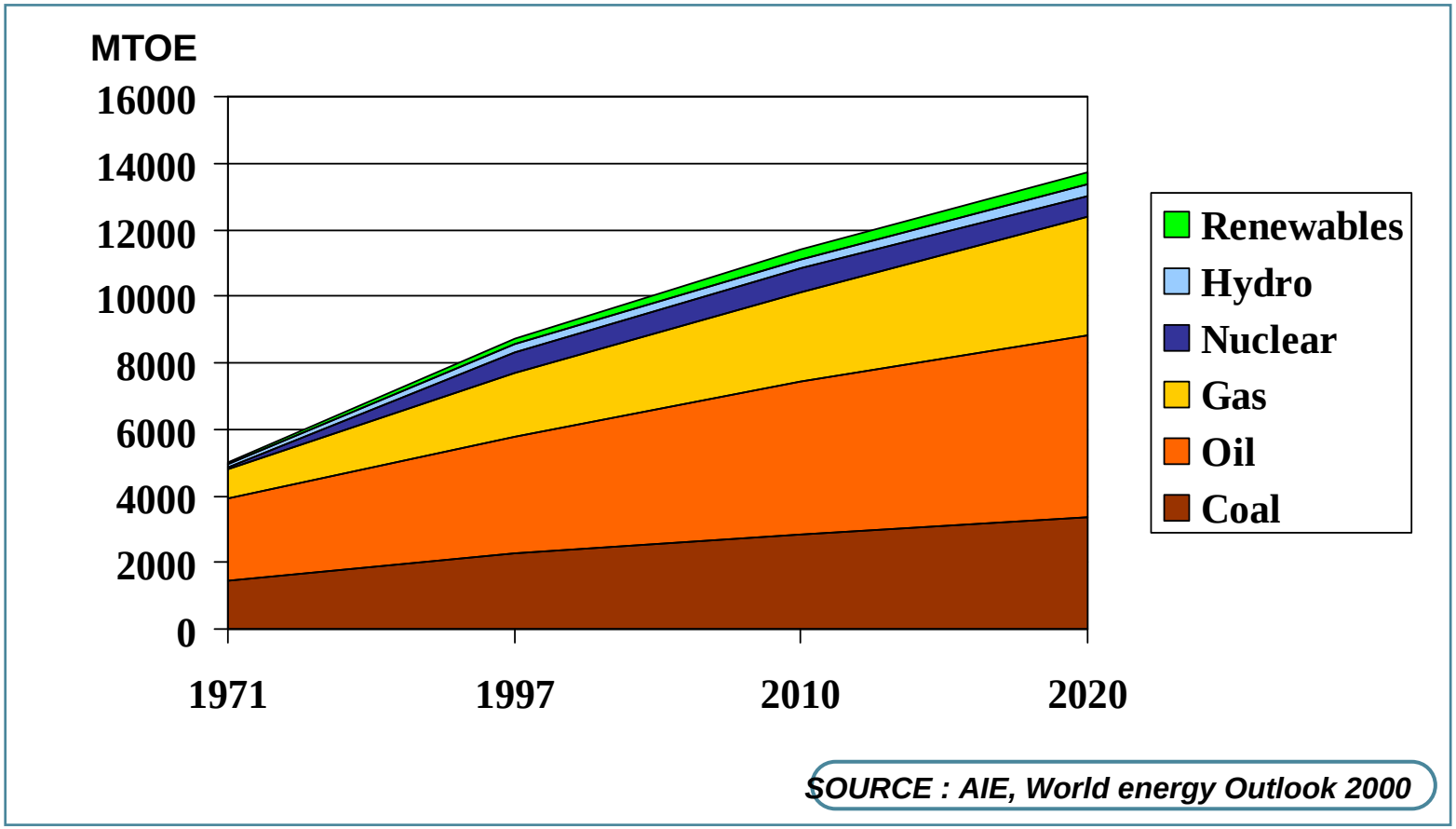
Energy is necessary for Life



Energy consumption per capita

(tons of oil equivalent)

A strong dependency on fossil fuels

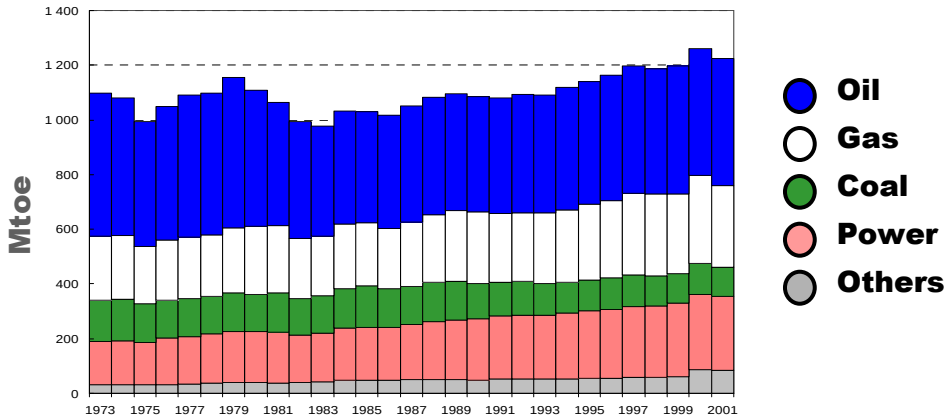


SOURCE : AIE, World energy Outlook 2000

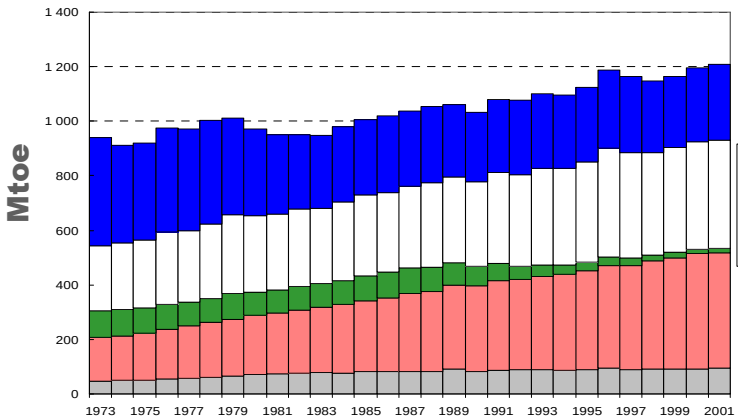
87% of the energy consumption come from fossil fuels

Energy for transportation

Industry

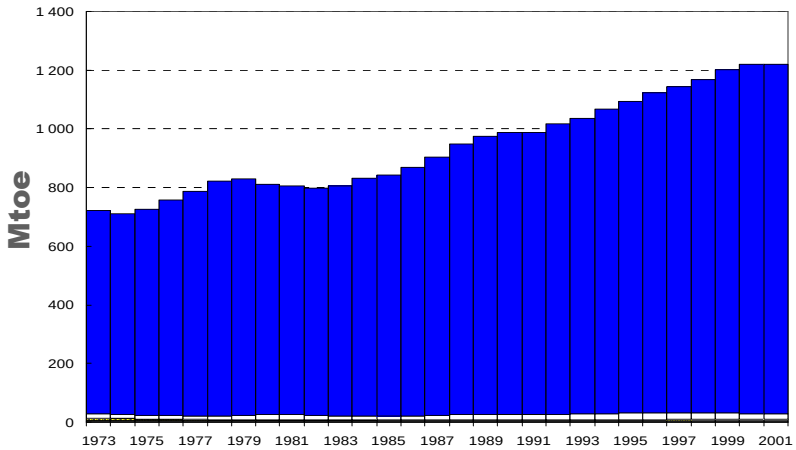


Households/Services



(source IEA)

Transports

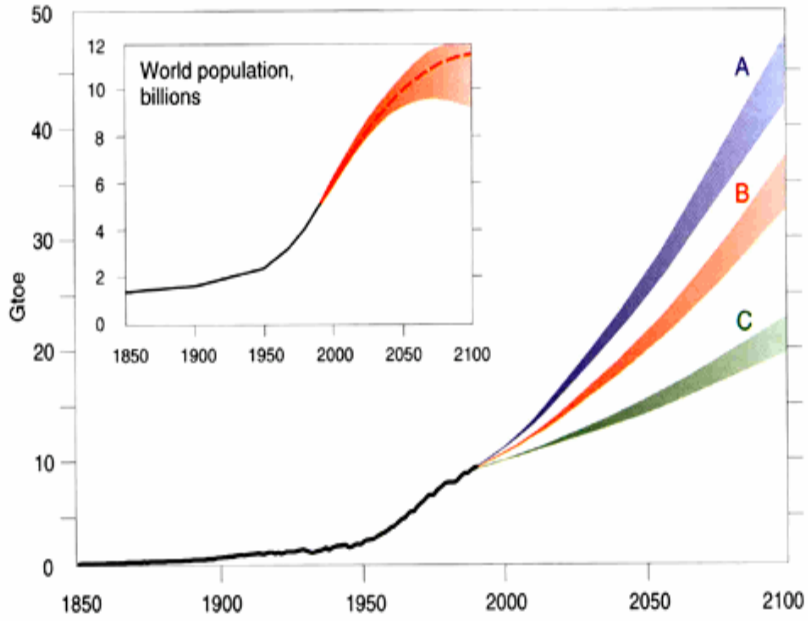


Transports :

- **a still increasing consumption**
- **a dependence rate on oil > 95%**

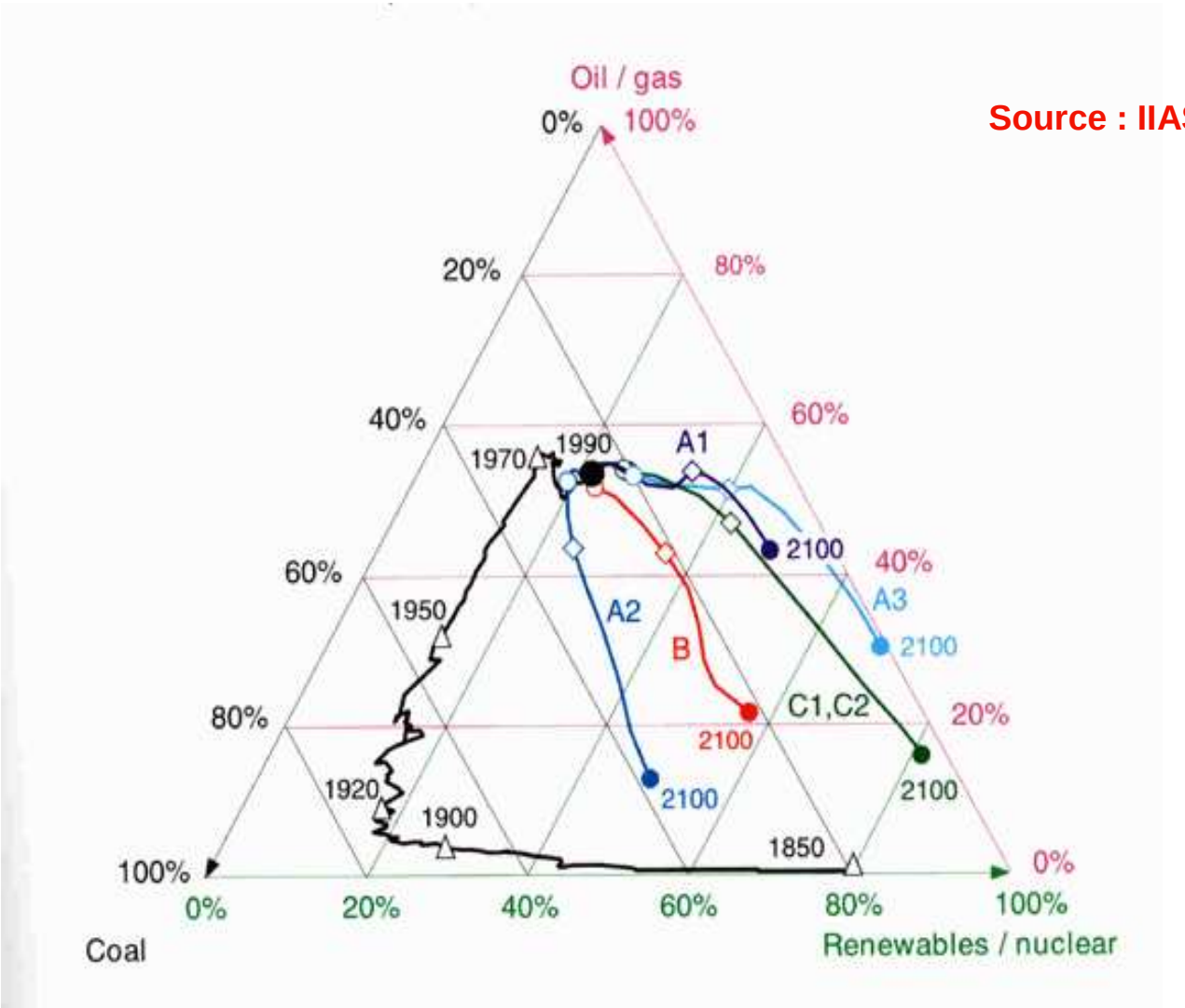
Needs for Energy during the 21st Century

- Increasing energy demand in the world by 2050
- Need of a better equity in the access to energy
- Threat of increasing climate desorders due to green house gases emissions, in particular CO2



- Increasing needs to secure energy supply, higher geo- political tensions around the access to fossil fuels
- Energy savings and renewables are necessary but will not be sufficient
- New needs : Hydrogen, heat, desalinated water …

Evolution of the Primary Energy Structures

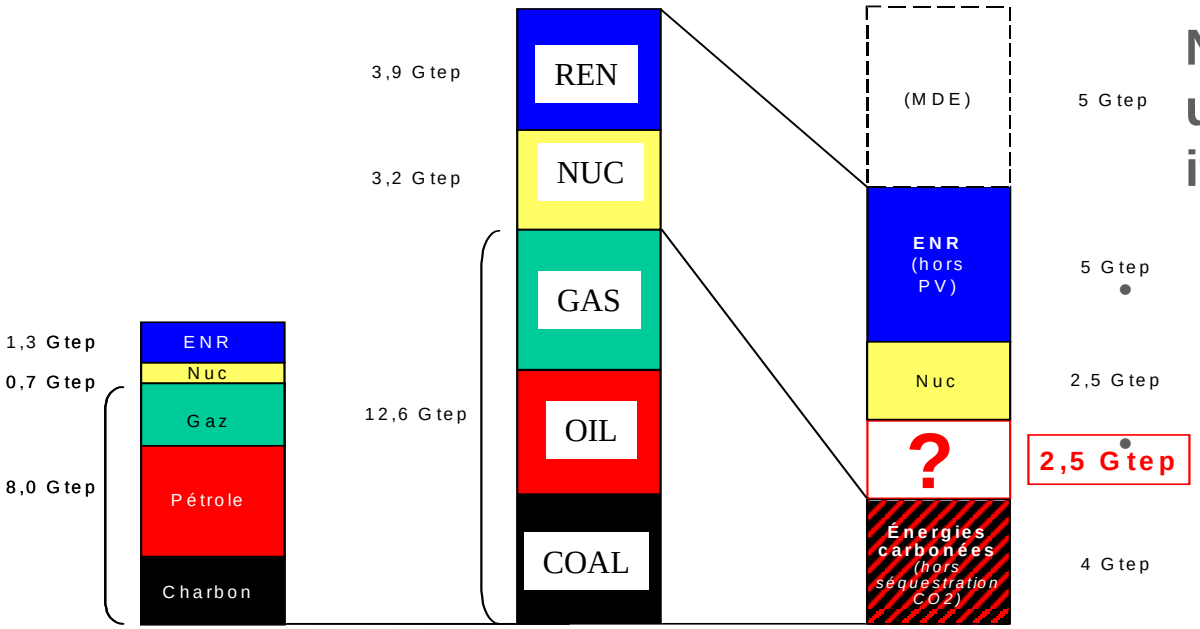


Source : IIASA/ WEC

What should be a sustainable scenario ?

To satisfy an increasing energy demand in the world by 2050, but also

- **Limitation of CO2 emissions**
- **Energy supply security**



Nuclear energy could be used even more extensively if:

- **The 2.5 GTOE of primary energy not yet allocated cannot be obtained from fossil fuels**
- **The obligations imposed in terms of energy management (MDE) and renewable energies (ENR) cannot be met**

Nuclear Energy is abundant

- Fission of 1 g of uranium gives the same energy as the combustion of 2 tons of oil
- There is plenty of uranium on earth (#5 billions tons in sea waters)

- But…

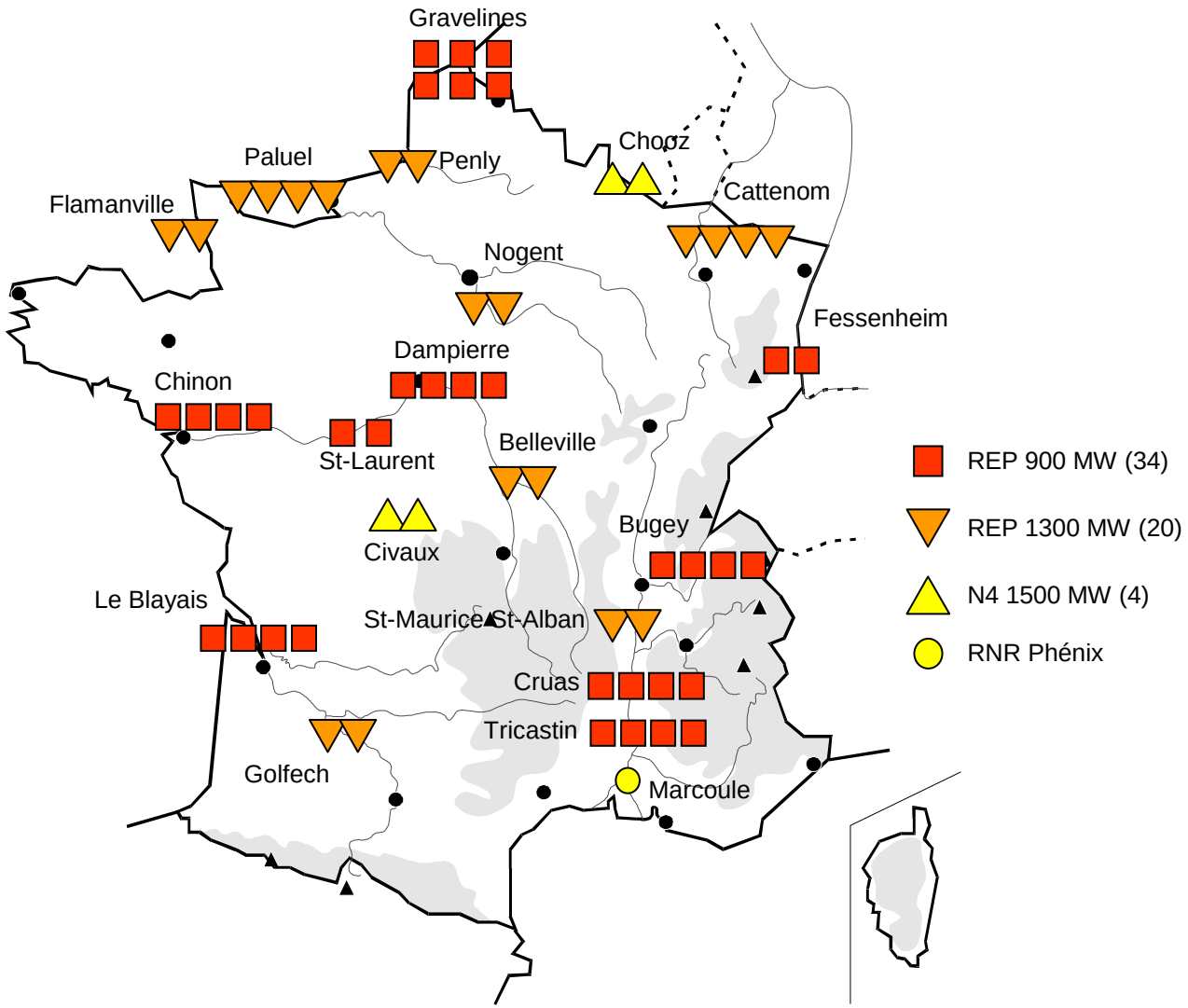
- Uranium resources at low cost are limited
- Light Water Reactors cannot use more than 1% of natural uranium
- The development of fast reactors has been slowed down during twenty years and is only restarting in the frame of Generation IV programs

Nuclear Power Plants (2004)

- LWR are dominant, 87% of total capacity
- # 70 tons of plutonium produced every year
- Most of it is in spent fuel stored in pools or dry storages

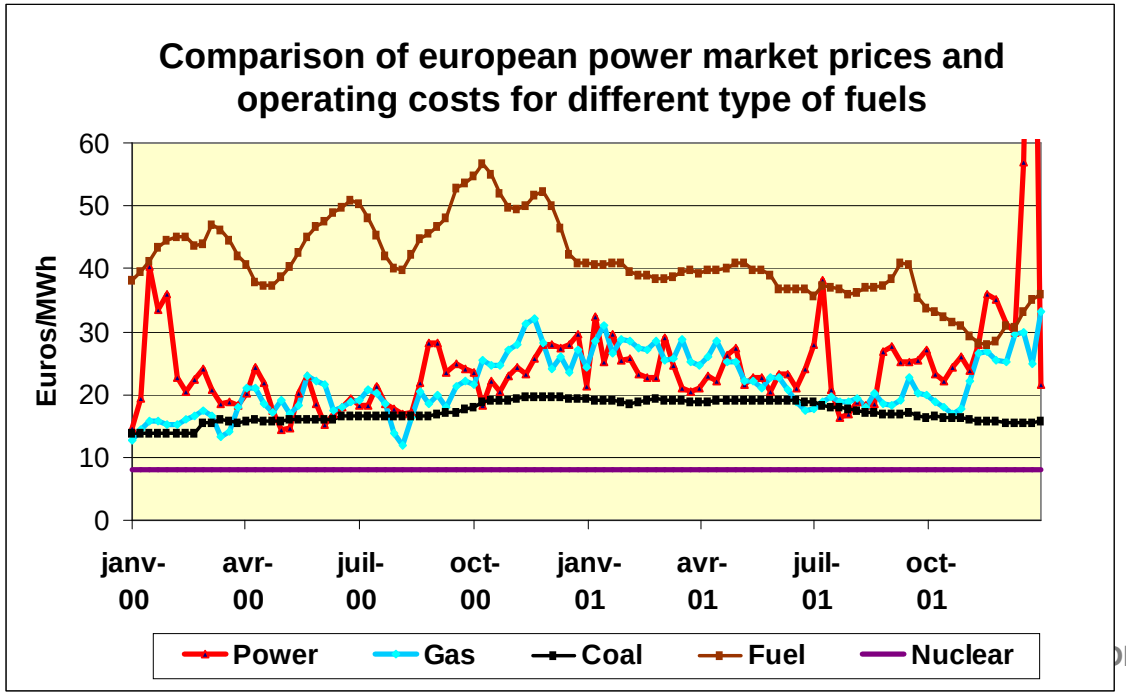
Type	Nb of units	Total Capacity (GWe)
PWR	263	236
BWR	92	81
PHWR	38	19
GCR	26	11
LWGR	17	13
FBR	3	1
Total	439	361

The 58 nuclear power plants & Phénix



Nuclear : an affordable energy

- Affordable
- Competitive
- Stable and predictable costs



- **High capital costs : what incentives for utilities to make the necessary investment at the right time with reasonable returns for investors ?**

Nuclear energy competitiveness

- Several European studies issued over the last 6 years
- Real costs based on more than 1000 years x reactor of experience in France

1997 : French Ministry of industry report (DIGEC)
1998 : International OECD study, (9 countries)
1999 : French Parliament report,
2000 : French report to the Prime Minister (Charpin, Pellat, Dessus),
Belgian report issued from the Ampere Commission,
Finnish study in view of building the fifth nuclear reactor,
2003 : French Ministry of industry report (DIDEME)

€/MWh*	Nuclear	Gas Turbine CCGT
Total cost of generation	22 to 32	26 to 57
Cost of impact on environment	2 to 7	5 to 35
Total	24 to 39	31 to 92

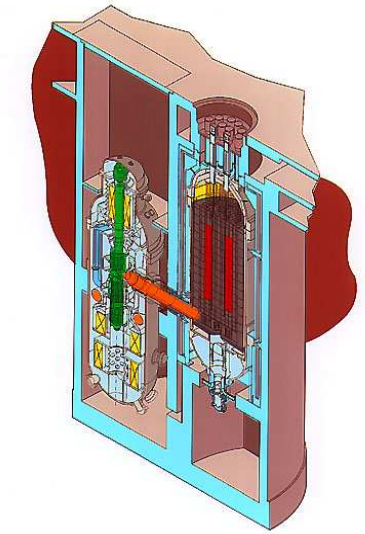
* Real discount rates from 5% to 10% for power generation and 3% for external costs.

Existing reactors have improved their performances for the last three decades (life time, load factor and availability, burn-up, fuel cost…)

New European units may be at least 20% cheaper than CCGT

Nuclear tomorrow : even more competitive

- **Prospects of internalization of the greenhouse gas emission cost in the kWh should boost the competitiveness of nuclear against gas plants**
- **The cost of fossil fuels will remain at high values**
- **Nuclear energy costs will decrease due to prospects of large deployment worldwide (mass production, standardization…)**



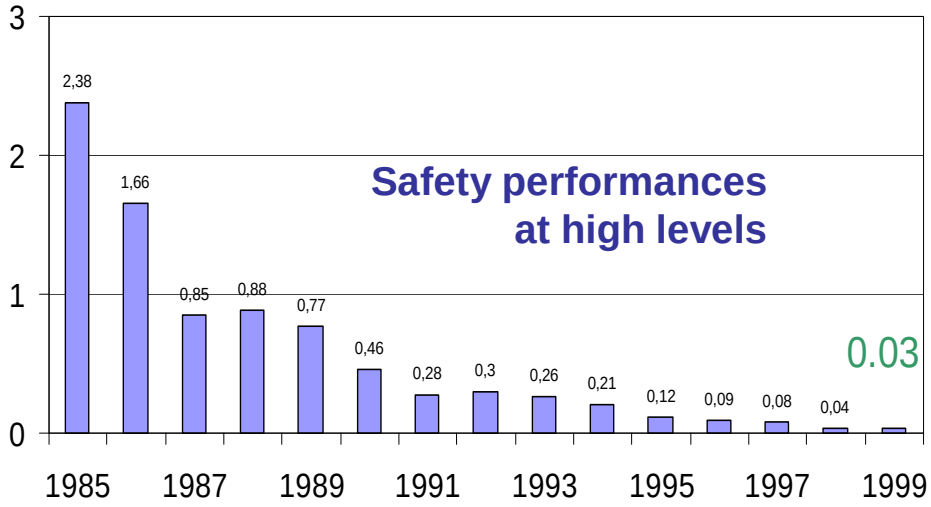
- **GEN IV** target :
- To reduce both Capital and O&M costs

- Construction cost **< 1000 $/kWe**
- production cost **< 20 $/MWh**

Nuclear : a safe and reliable energy

Safety :

- Gen II : satisfactory data for 15 years



- A new step with Gen III reactors (EPR for instance)

→ Gradual improvements to be pursued for Gen IV reactors

Nuclear Energy is clean

- No emission of greenhouse gases;
- Very low gaseous or liquid release of chemical or radioactive elements;
- Small amount of highly radioactive solid waste.

But…

- There is always the residual risk of a severe accident, even if the probability is very low;
- Mitigation measures developed for Generation III reactors should be taken into account for Generation IV systems.

Nuclear Waste : Low quantities

Some figures : (France, per year & per capita)

- **Domestic waste : 2200 kg**
- **Industrial waste : 800 kg**
  (i/c toxic waste 100kg)
- **Nuclear waste : 1 kg**

Short lives, low activities:
>90% in volumes,
< 1% of activity

Long lives, high activities:
<1% in volumes
>90% of activity

Plutonium Recycling in Light Water Reactors

An industrial reality

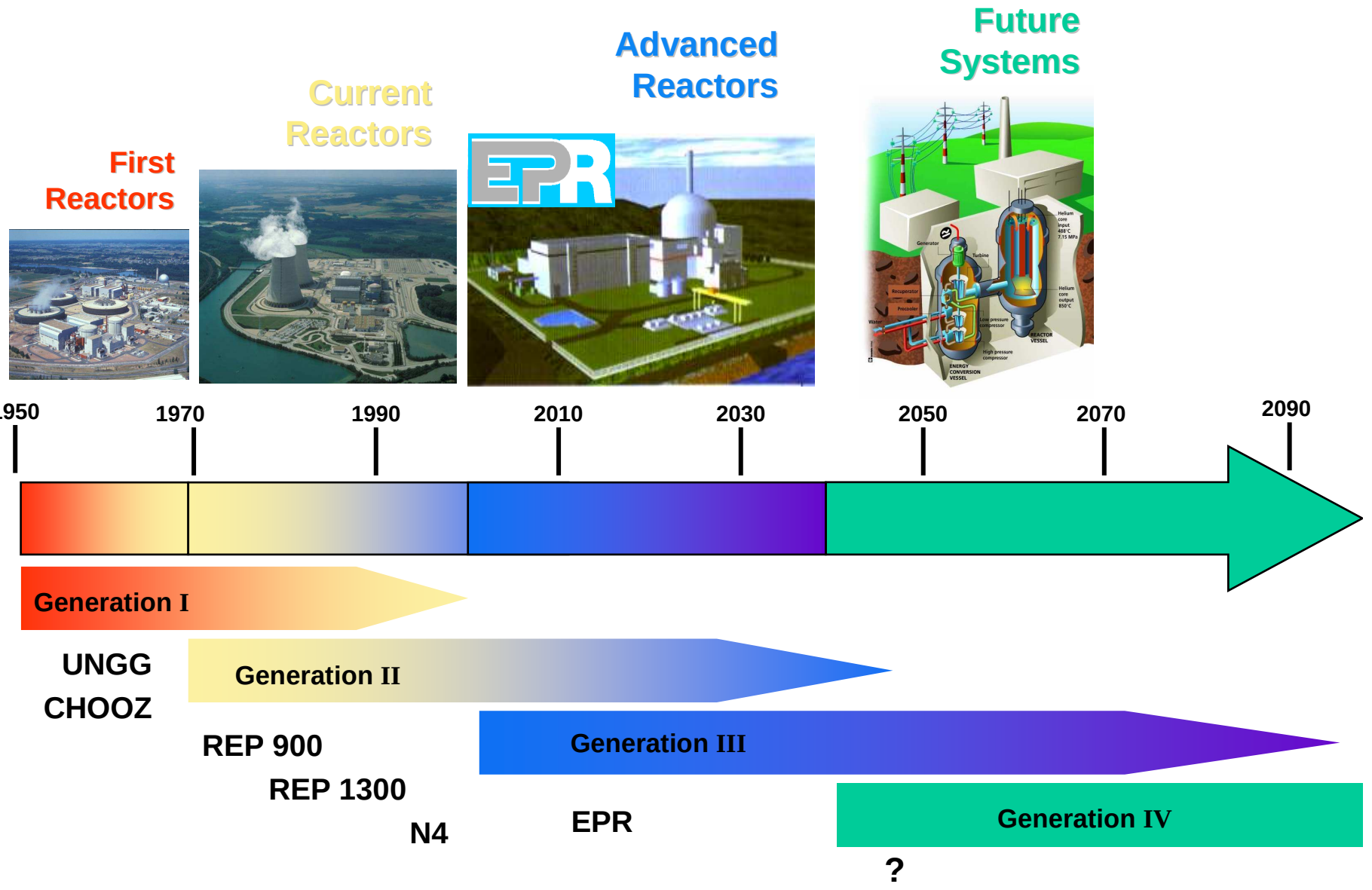
The future of Nuclear Energy

Ensure a large part of energy needs are met without emitting greenhouse gases

- The world energy needs will still increase during the next decades.
- Besides renewable sources, nuclear energy is necessary to limit the use of fossil fuels.
- Nuclear industry is offering 3rd generation reactors which rely on the large experience with LWRs and bring new improvements in particular for safety.
- Generation IV systems should be developed to allow a sustainable use of nuclear energy, saving resources, minimizing waste and ensuring the best security.

International Ministerial Conference - IAEA - Paris, 21-22 March « Nuclear Power for the 21st Century »

The Evolution of Nuclear Power Systems



Generation III : Advanced Reactors

Near term deployment of industrial reactors

- **A new generation of reactors which design takes benefit of the large experience acquired in the operation of Gen II plants and of the lessons coming from TMI;**

- **Light Water Reactors are still dominating;**

- **To make new improvements in safety while keeping economic competitiveness have been the main objective;**

- **Different approaches have been studied and are still competing in the industrial offer :**
  - **small vs. large reactors,**
  - **passive vs. active safety systems;**

- **Mitigation of severe accident consequences is a major step.**

Generation III : Market prospective

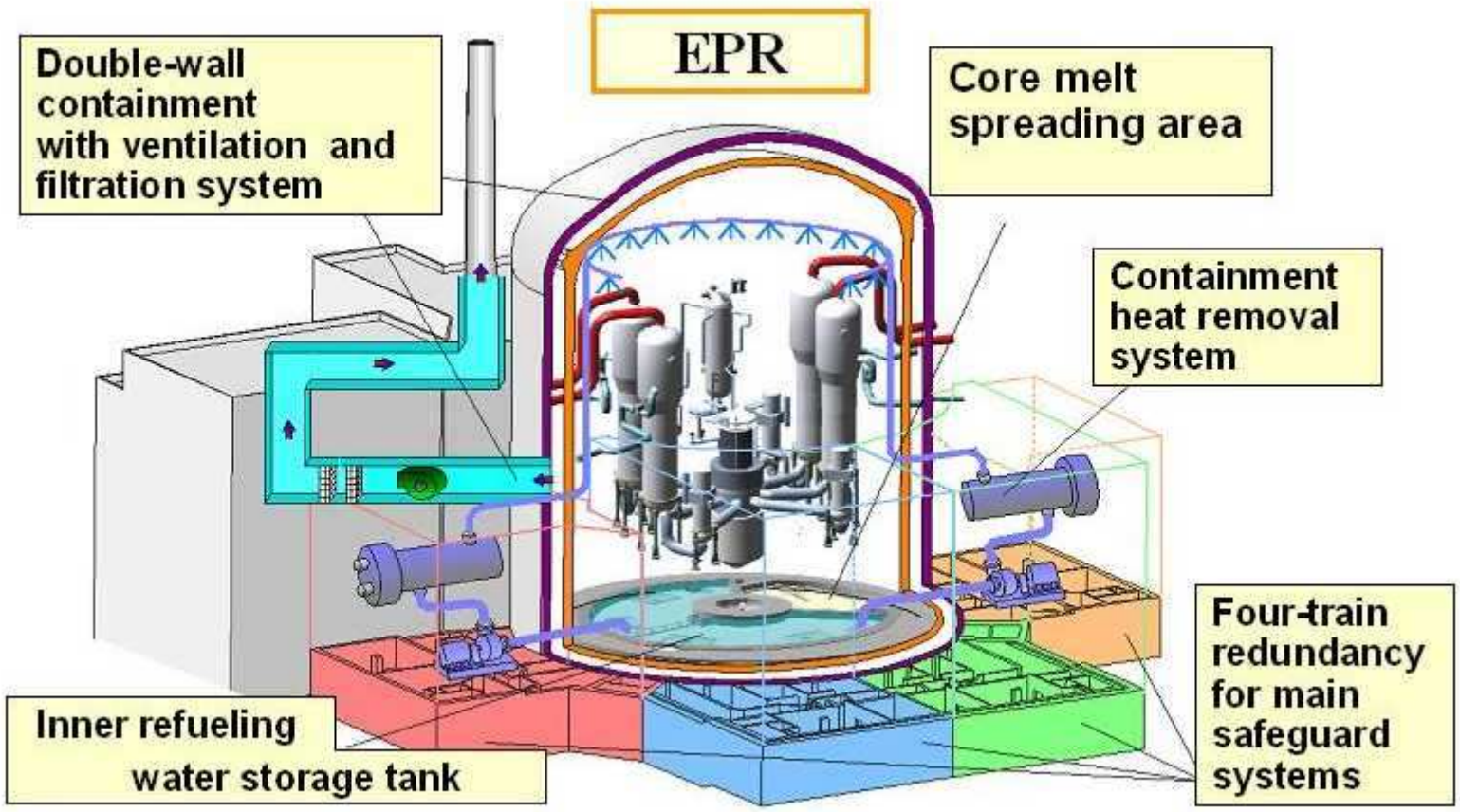
- **Besides the renewal of existing power plants, there are many plans for new realizations (USA, China, India…);**

- **The nuclear production capacity could grow from 400 GWe to 1000 - 1500 GWe by 2050.**

- **Most of the new nuclear plants in the three or four coming decades will be Gen III systems.**

Light Water Reactors : Generation III

Framatome – ANP : EPR



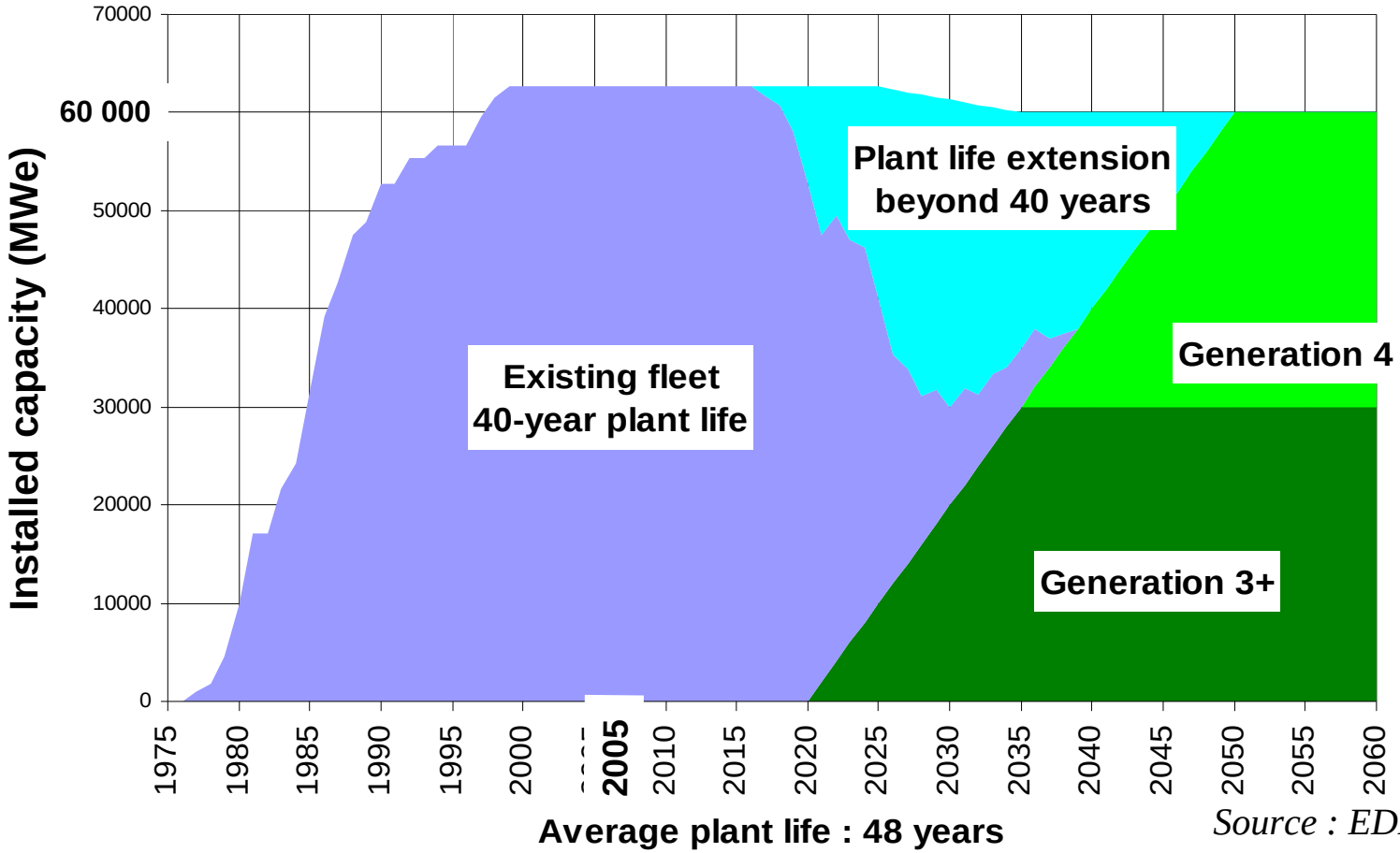
EPR in Finland

Okiluoto 3 under construction

FLAMANVILLE 3 : EPR in FRANCE

Scenario for the renewal of French power reactors

- Major role of LWRs over the 21st century
- 2035-2040 : Transition from PWRs to Gen IV Fast reactors

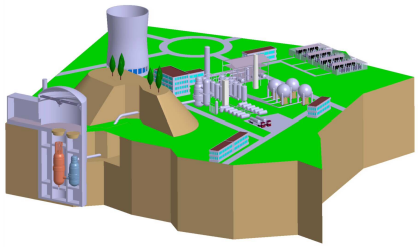


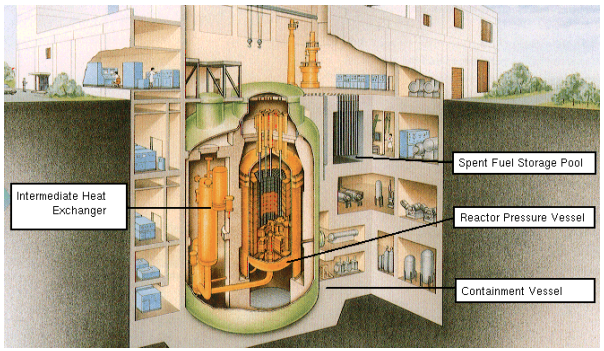
Source : EDF

Gen IV : paves the way for a sustainable nuclear energy

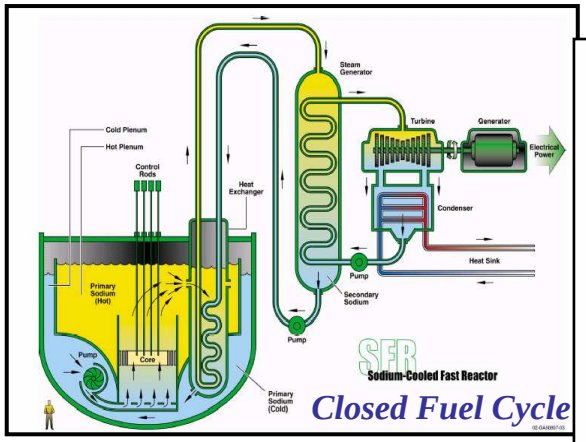
Ensure energy needs are met in the long term without emitting greenhouse gases

- **Gradual improvements**
  - Economic competitiveness
  - Safety and reliability
- **Significant steps forward:**
  - Saving of natural resources
  - Waste minimization
  - Security: non-proliferation, physical protection
- **An opening to other applications:**
  - High temperature heat for industry
  - Hydrogen vector
  - Drinking water

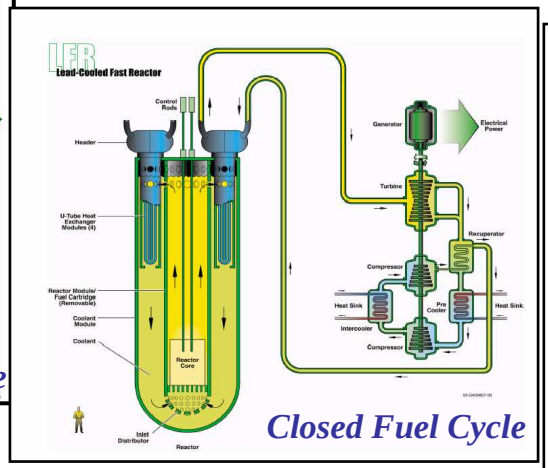




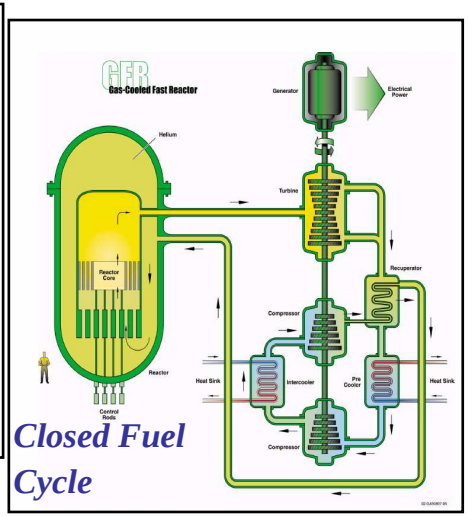
Six Innovative concepts with technological breakthroughs



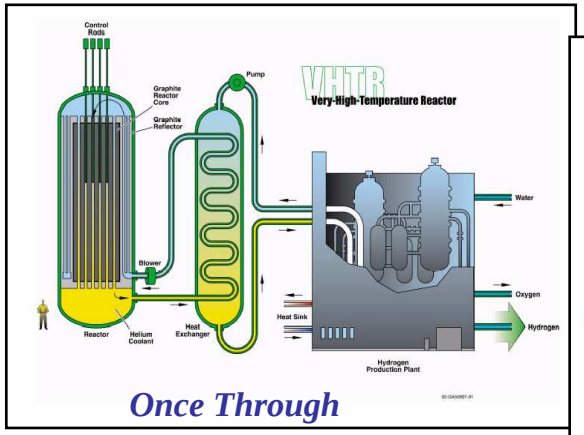
Sodium Fast reactor



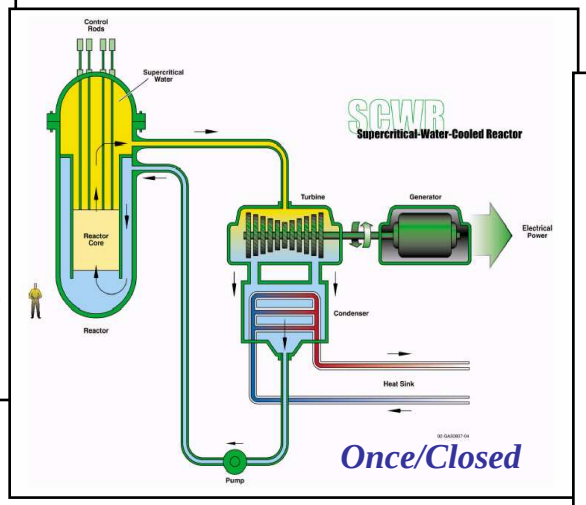
Lead Fast Reactor



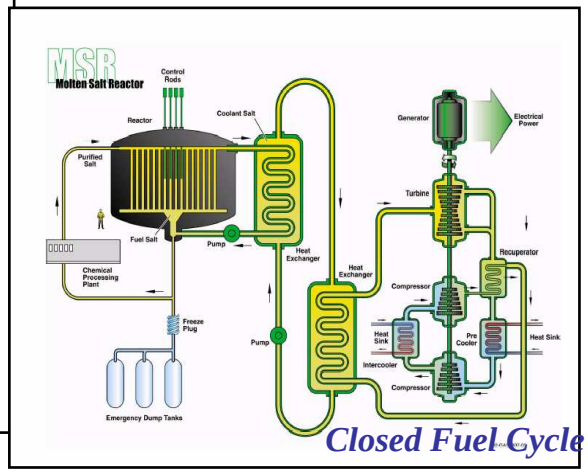
Gas Fast Reactor



Very High Temperature Reactor



Supercritical Water Reactor



Molten Salt Reactor

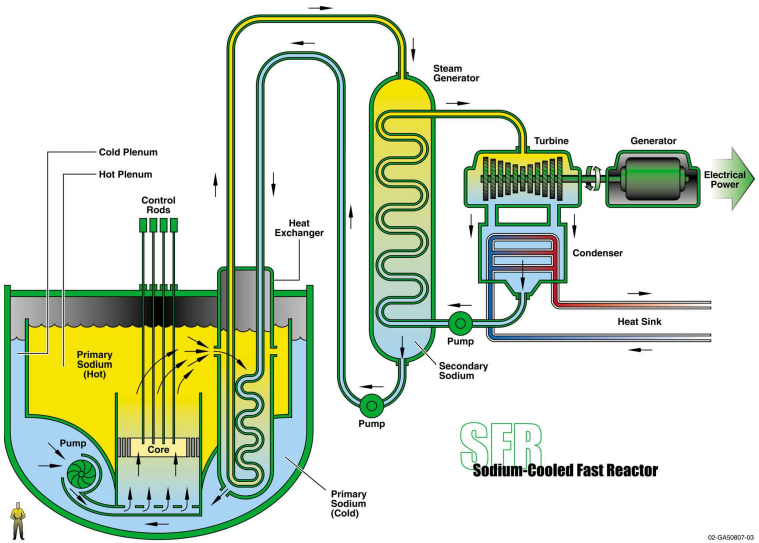
Generation IV main objectives

- **SUSTAINABILITY**
  - Saving of natural resources
  - Waste minimization
  - Security: non-proliferation, physical protection

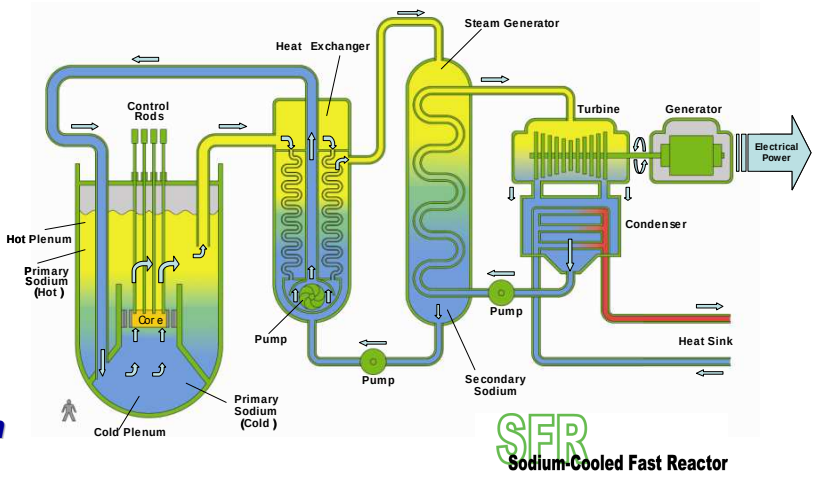
- **DIVERSITY**
  - High temperature heat for industry
  - Hydrogen vector
  - Drinking water

Sodium Fast Reactor (SFR)

- A new generation of sodium cooled Fast Reactors
- Reduced investment cost –
  Simplified design, system innovations
  (Pool/Loop design, ISIR – SC CO_2 PCS)
- Towards a passive safety approach
- Integral recycling of actinides
  Remote fabrication of TRU fuel



→ 2009 : Feasibility – 2015 : Performance → 2020+ : SFR Demo

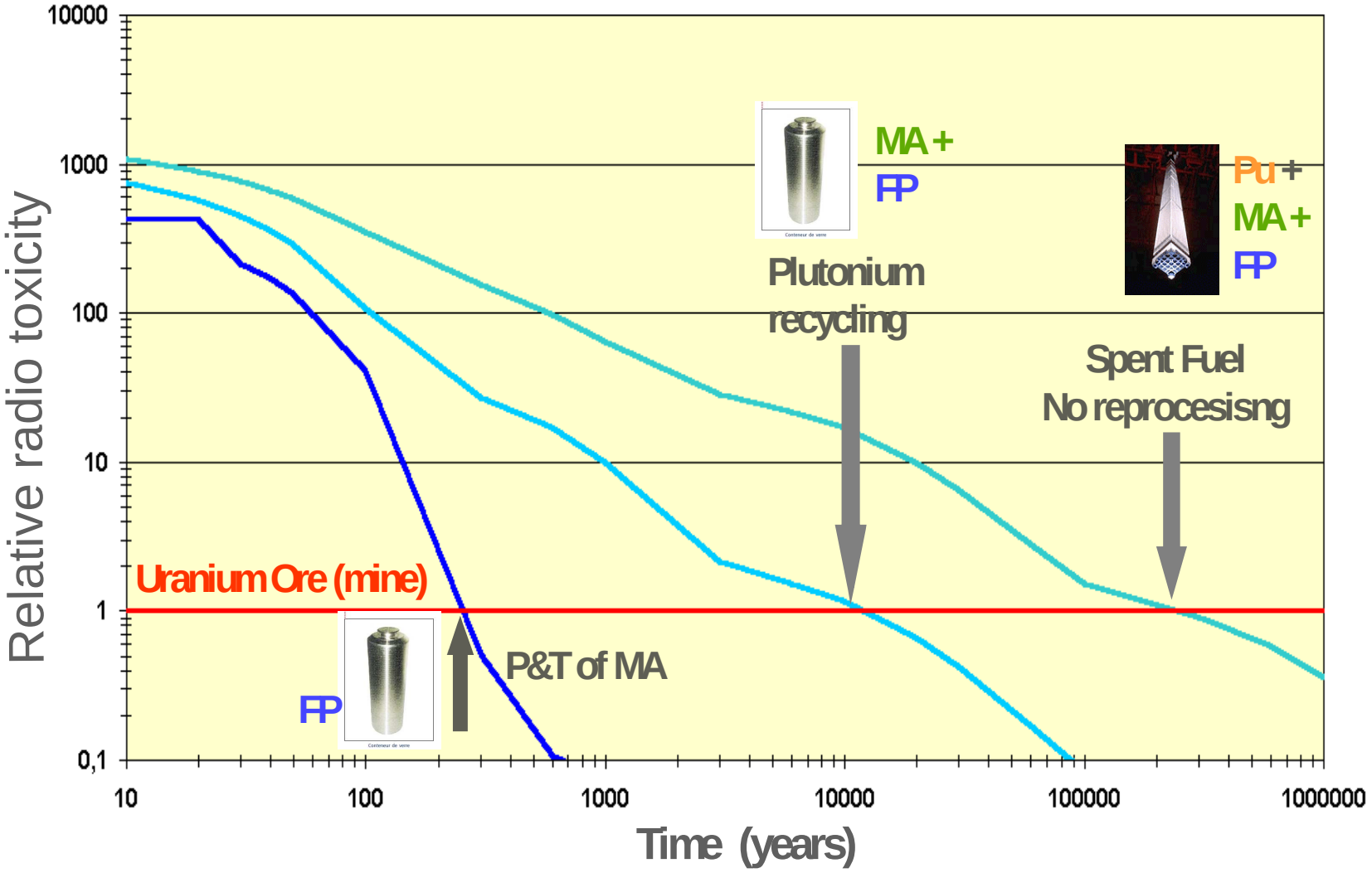


SUPERPHENIX

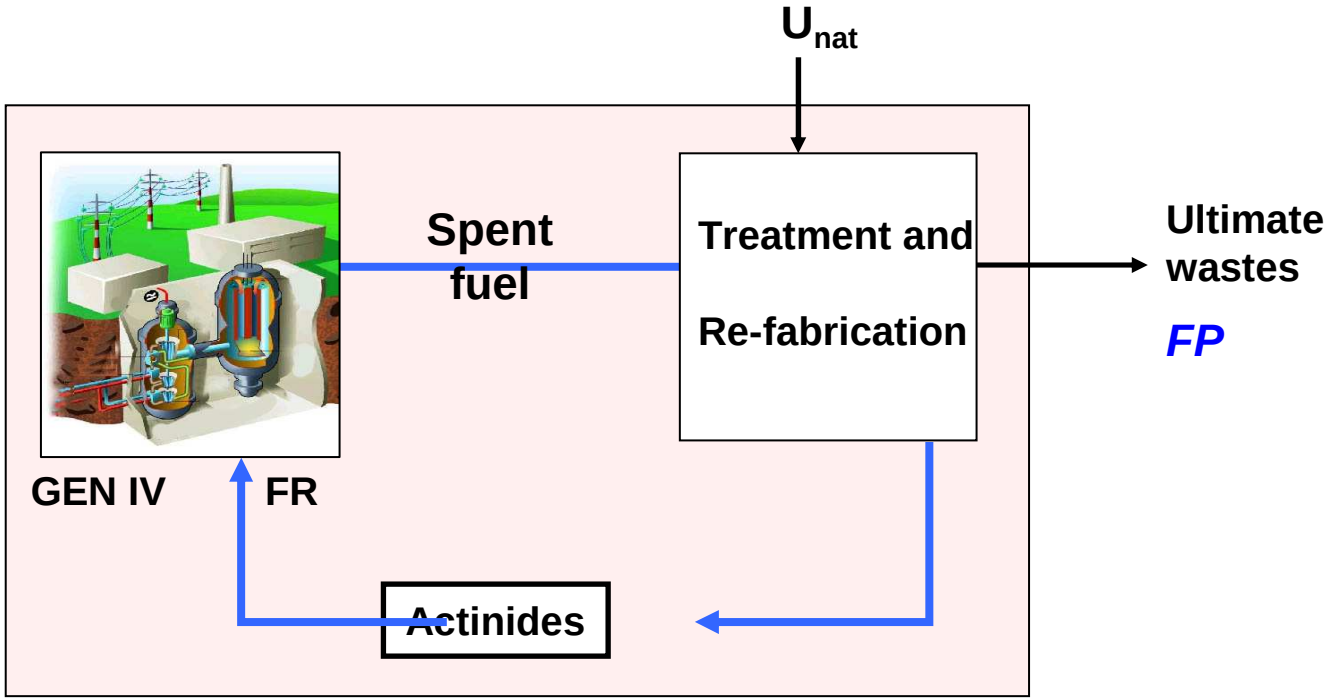
A 1200 MWe plant built at Creys-Malville (France)
First criticality: 1985; Shutdown: 1997

Fast Reactor Prototypes

Minimizing waste



Global Actinide Recycling



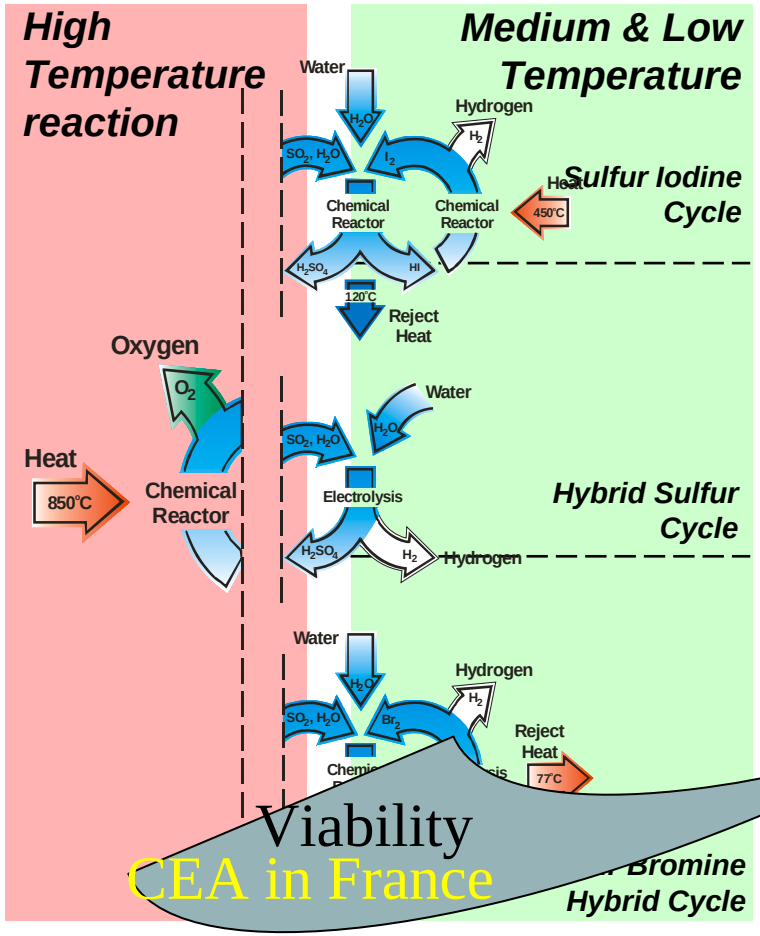
- Saving uranium resources
- Minimizing waste heat and radiotoxicity
- Ensuring a strong proliferation resistance

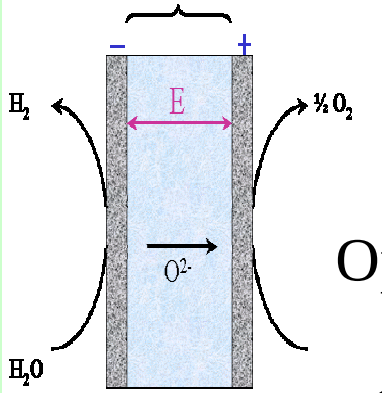
FBR Prototype MONJU

An opening to other applications : H2 production

Sulfur Family

HTE





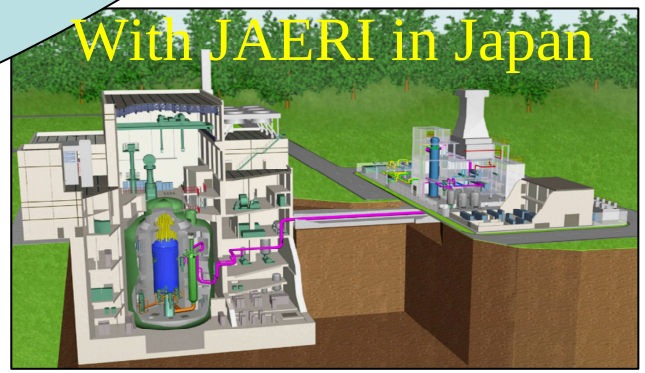
Demonstration

Optimization

Innovation

Viability

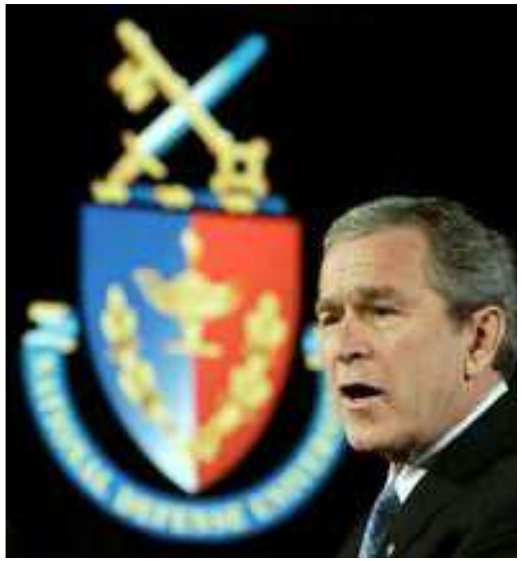
CEA in France



Key GNEP Program Elements

(source US DOE)

- Expand use of nuclear power
- Minimize nuclear waste
- Demonstrate recycle technology
- Demonstrate Advanced Burner Reactors
- Establish reliable fuel services
- Demonstrate small, exportable reactors
- Enhanced nuclear safeguards technology



"To build a secure energy future for America, we need to expand production of safe, clean nuclear power"

President Bush, 06/2004

The Russian President Initiative

- Various offers of nuclear power services
- Fuel leasing with back end operations in Russia
- Interim storage of spent fuel before reprocessing

A French prototype by 2020

President Chirac statement :

« A number of countries are working on future generation reactors, to become operational in 2030-2040, which will produce less waste and will make a better use of fissile materials.
I have decided to launch, starting today, the design work by CEA of a prototype of the 4th generation reactor, which will be commissioned in 2020.

We will naturally welcome industrial or international partners who would like to get involved… »