1- Global Scenarios for Nuclear Energy and future of Innovative NES

Expanding nuclear energy. Focus on resources: options to meet the needs

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Joint IAEA-ICTP Workshop on

Physics and Technology of Innovative Nuclear Energy Systems for Sustainable Development

20-24 August 2018

ICTP, Miramare - Trieste, Italy

IAEA
International Atomic Energy Agency
Atoms for Peace

Where are we today?

Climate goals call for speedier expansion of nuclear power

"The rate of new grid connections will have to increase significantly to support global economic growth, alleviate energy poverty and provide enough clean energy to meet agreed climate change targets. WNA"

Achieving a vision of a substantial role for nuclear power in our energy requires:

- **Continued long-term operation of existing fleet of nuclear power plants**
- **Deployment of new nuclear plants, including a mixture of – Large LWRs – SMRs – Advanced Reactors**

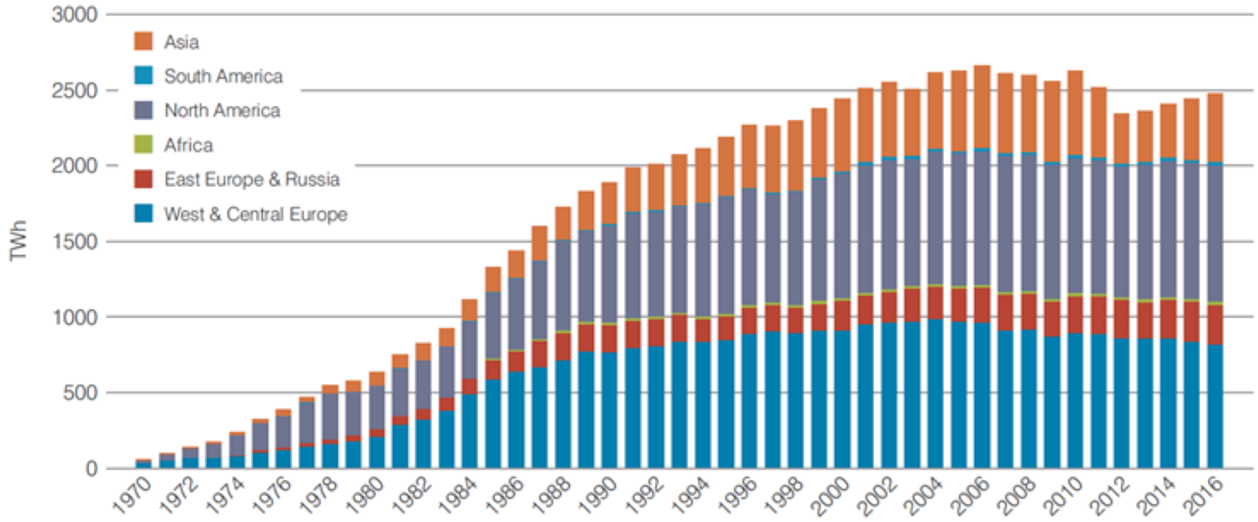
The World Nuclear Association considers that, in order to meet the goals, there should be 1000 GWe of new nuclear build by 2050, with nuclear generation supplying 25% of global electricity demand.

Around 11% of the world's electricity is generated by about 450 nuclear power reactors.

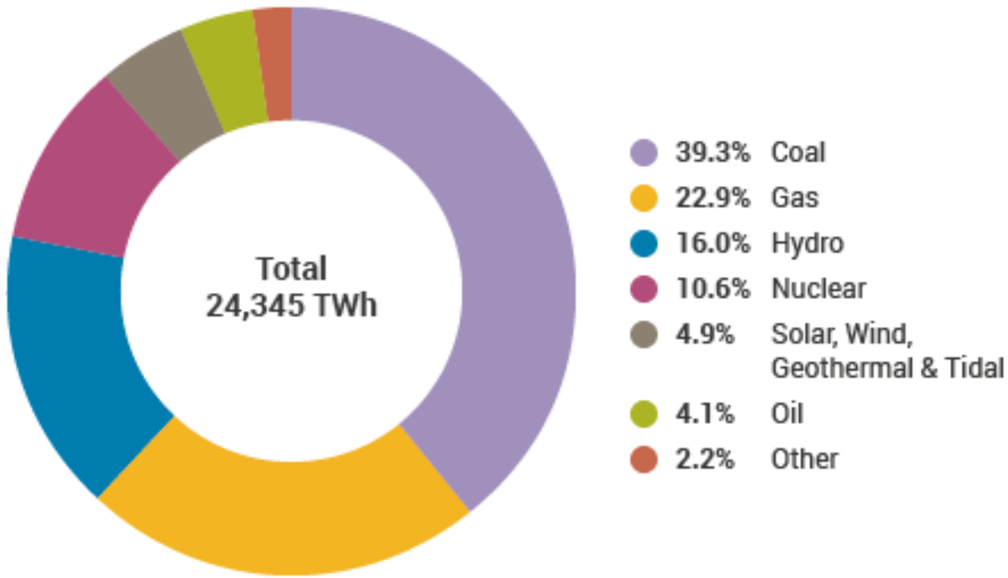
About 60 more reactors are under construction, equivalent to 16% of existing capacity, while an additional 150-160 are planned, equivalent to nearly half of existing capacity.

In 2016 nuclear plants supplied 2476 TWh of electricity, up from 2441 TWhe in 2015.

This is the fourth consecutive year that global nuclear generation has risen, with output 130 TWhe higher than in 2012.



Source: World Nuclear Association, IAEA Power Reactor Information Service (PRIS)



Source: IEA Electricity Information 2017

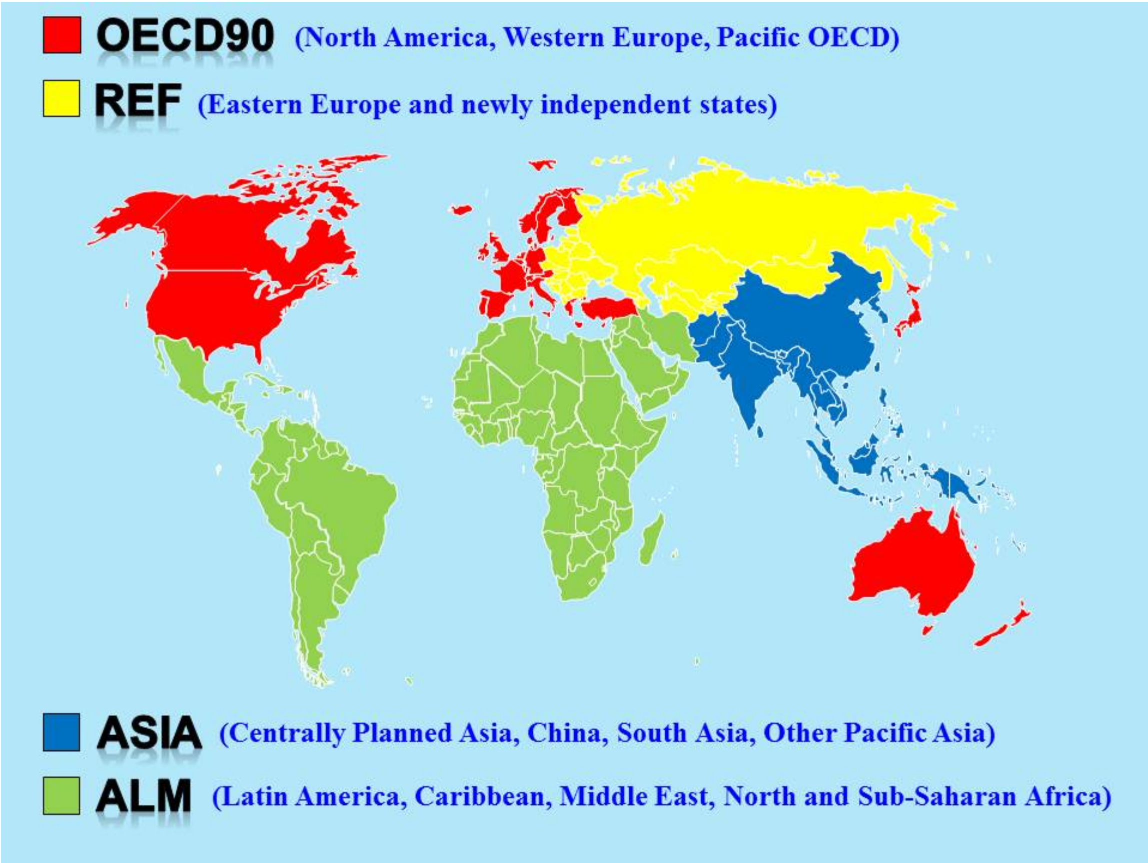
1- Expanding nuclear energy. Focus on resources: fuel cycles to meet the needs

- **If a significant increase in *nuclear energy demand* could be expected in the long term, some important issues about uranium resources and availability of infrastructures are likely to result, within a frame of enhanced safety requirements.**

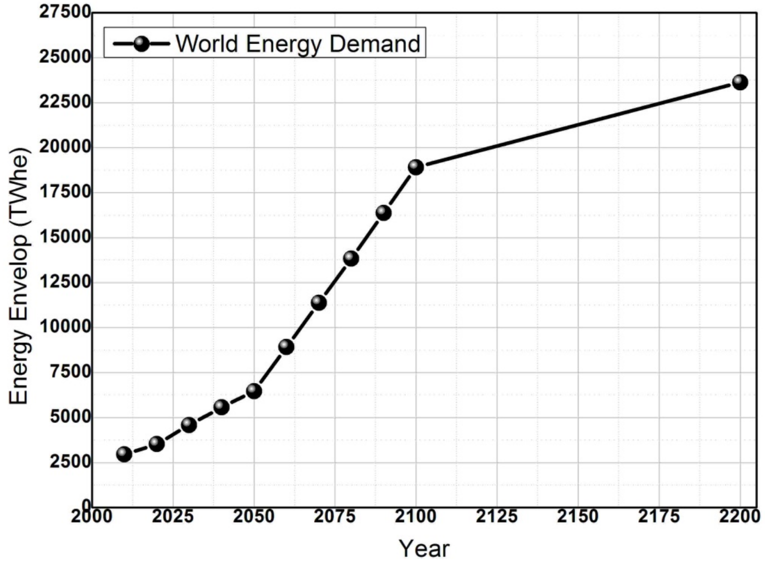
- **Fuel cycle choices have both long and short term impacts and a holistic assessment of their characteristics, cost and associated safety issues is of paramount importance.**

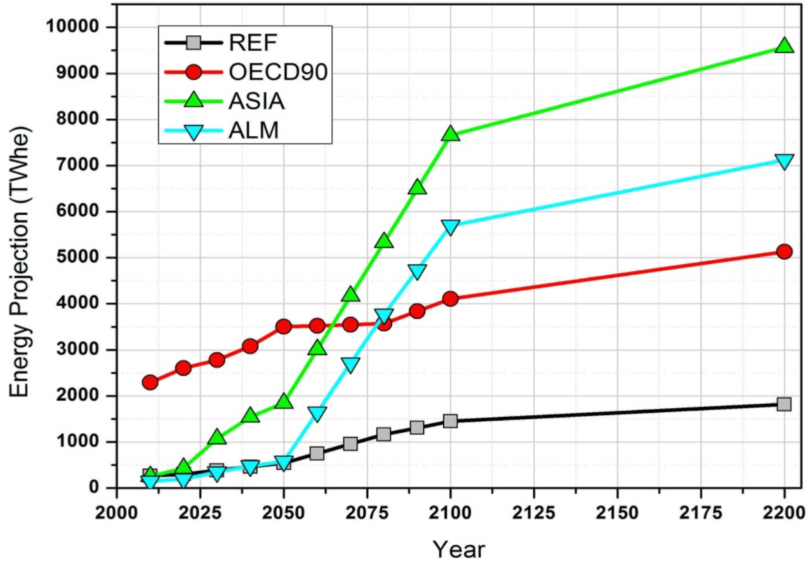
Development scenarios

To investigate development scenarios and their impact, one can make use of a « uniform» world representation or of a « regional » representation, dividing the world in regions such as:



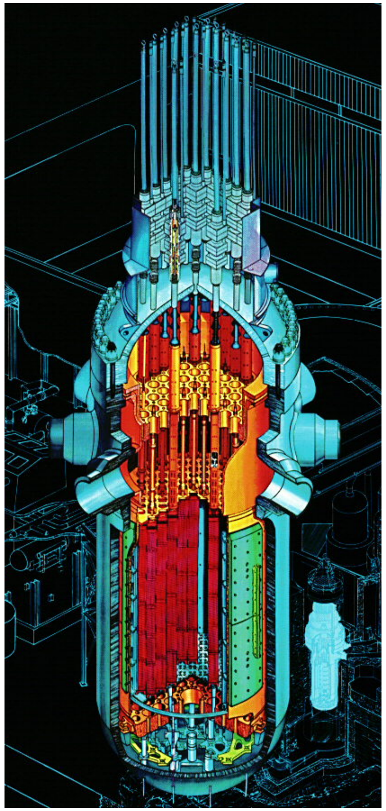
Numerous studies (IAEA, IEA, etc.) have made predictions of nuclear energy growth. Among the most recent ones (IPCC, IIASA) is the following:





	Nuclear Energy Projections (TWhe)				
	OECD90	REF	ASIA	ALM	WORLD
2016					2476 (*)
2030	2780	383	1072	348	4583
2050	3502	542	1846	580	6472
2070	3547	955	4170	2706	11380
2090	3836	1307	6494	4733	16371
2100	4104	1451	7655	5698	18908
2200	5130	1814	9569	7122	23634

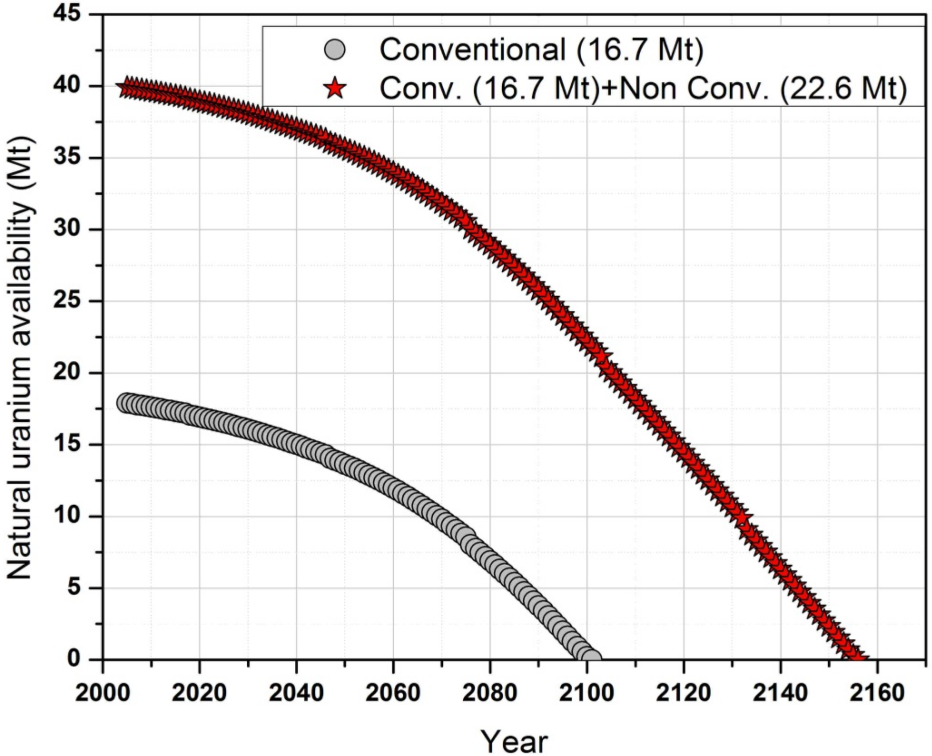
Uniform World Scenario: PWRs to Meet Energy Demand



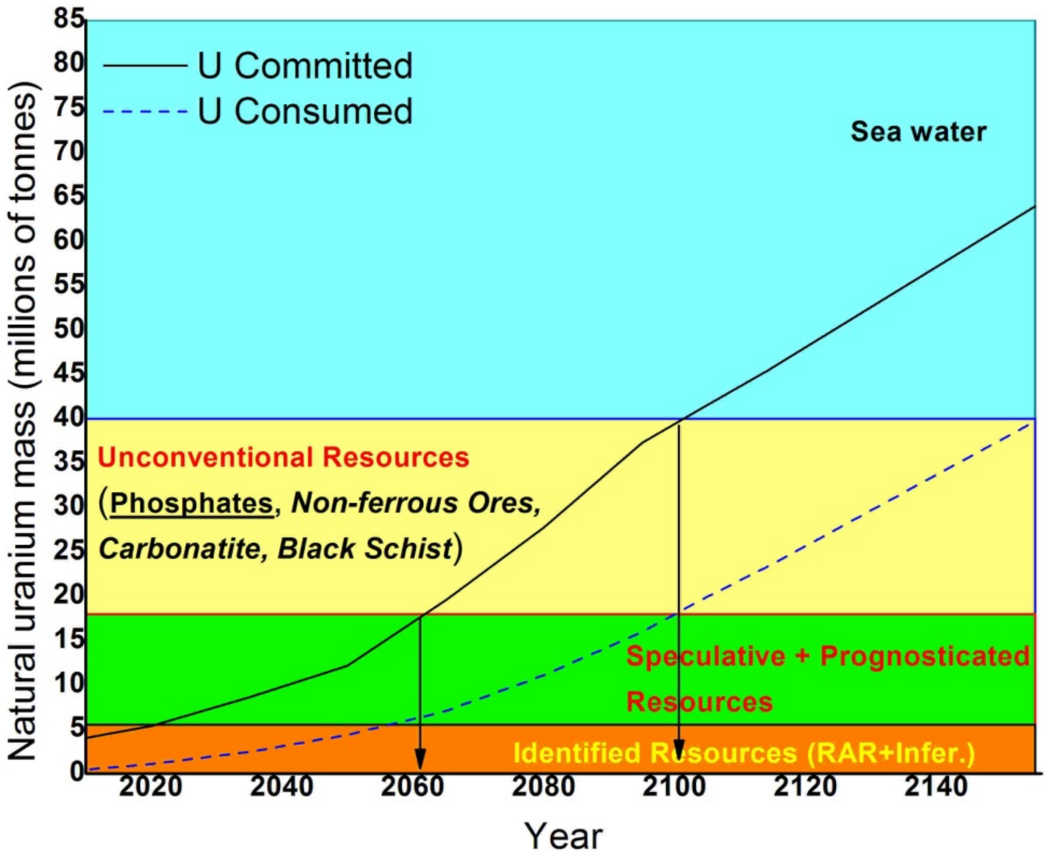
The reference case studied considers that the world nuclear energy demand is met by PWRs only (4.2% U enrichment and 50 GWd/tHM burnup)

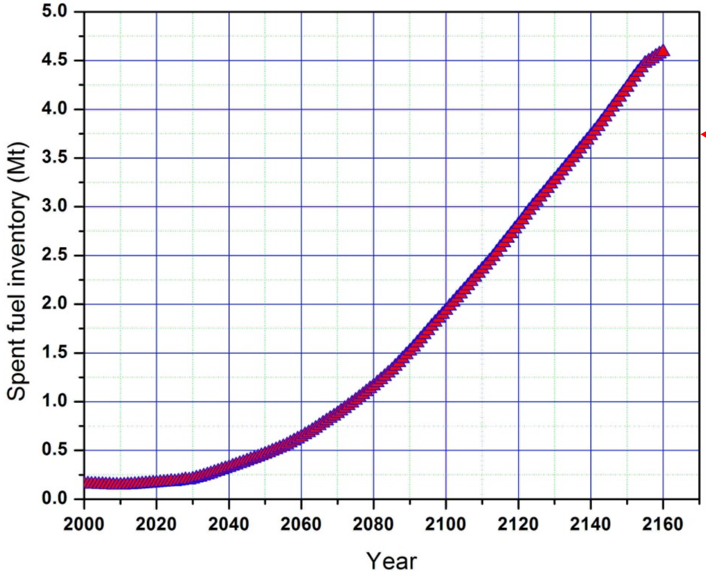
For the PWR-based fuel cycle, the simulations show that the conventional uranium resources, according to most recent evaluations, will be exhausted by the end of the present century, while the non-conventional ones will run out at around ~2150

Stress on resources will appear some decades prior to the predicted exhaustion date if the committed uranium (*i.e.*, natural uranium amount required to feed a power plant during its complete lifetime) issue is addressed.

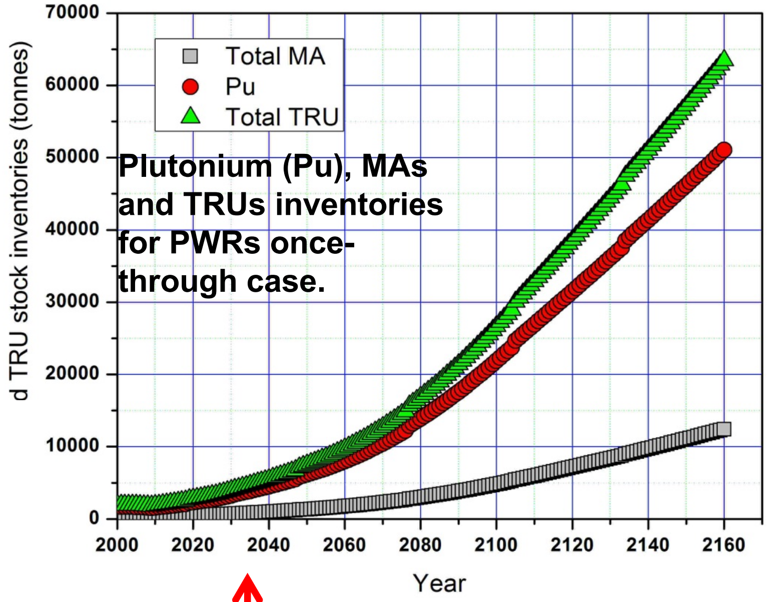


Only PWRs deployed world-wide, without distinction among countries/world regions:

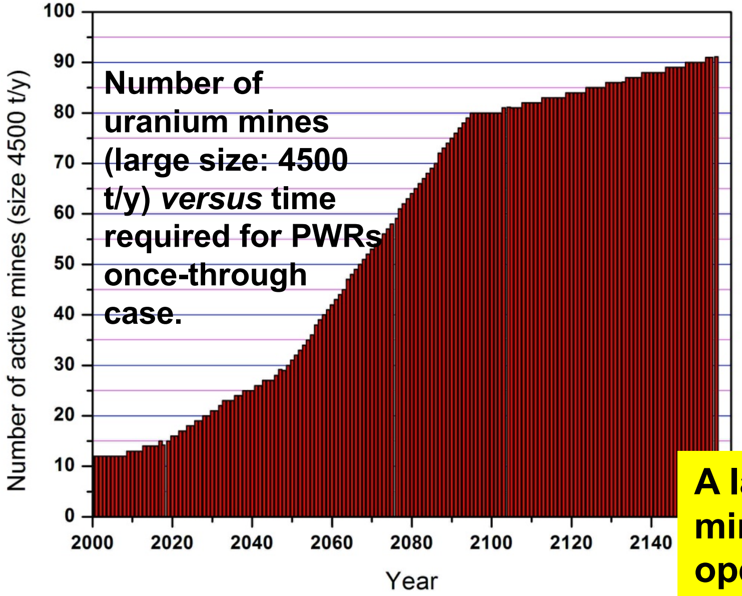




As a consequence of a once-through world fuel cycle, a large amount of spent fuel will also build-up worldwide.

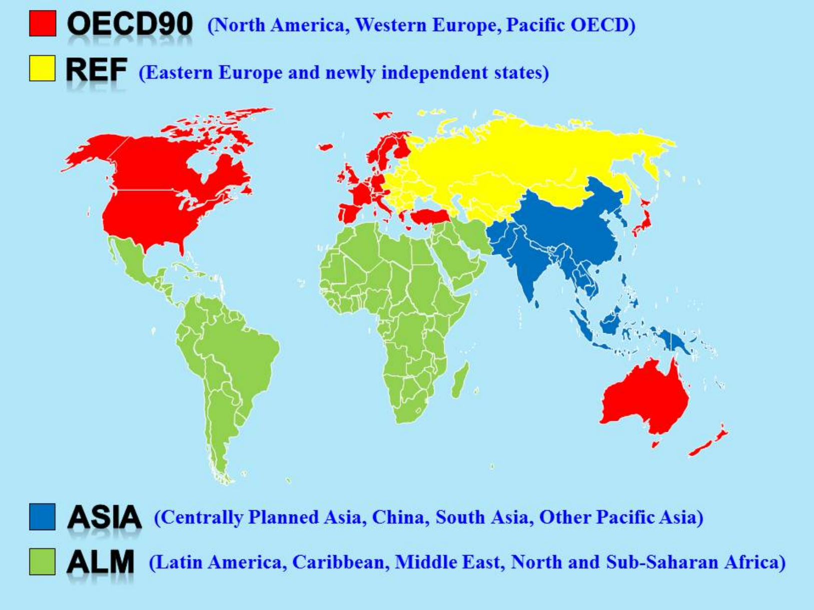


The spent fuel composition in 2150 corresponds to roughly 65,000 tons of TRU, with ca. 50,000 tons of Pu and ca. 11,000 tons of MA



A large number of new U mines should be opened and operated.

World Scenario: Regional Approach



The uniform world scenario does not take into account potential differences in nuclear energy demands, technology development and required rates of deployment in different regions that can be accounted in a regional approach

For the regional scenario the hypotheses are:

- **OECD90 and REF deploy break-even fast reactors (*"isogenerators"*, *i.e.*, breeding ratio close to one) in 2040;**

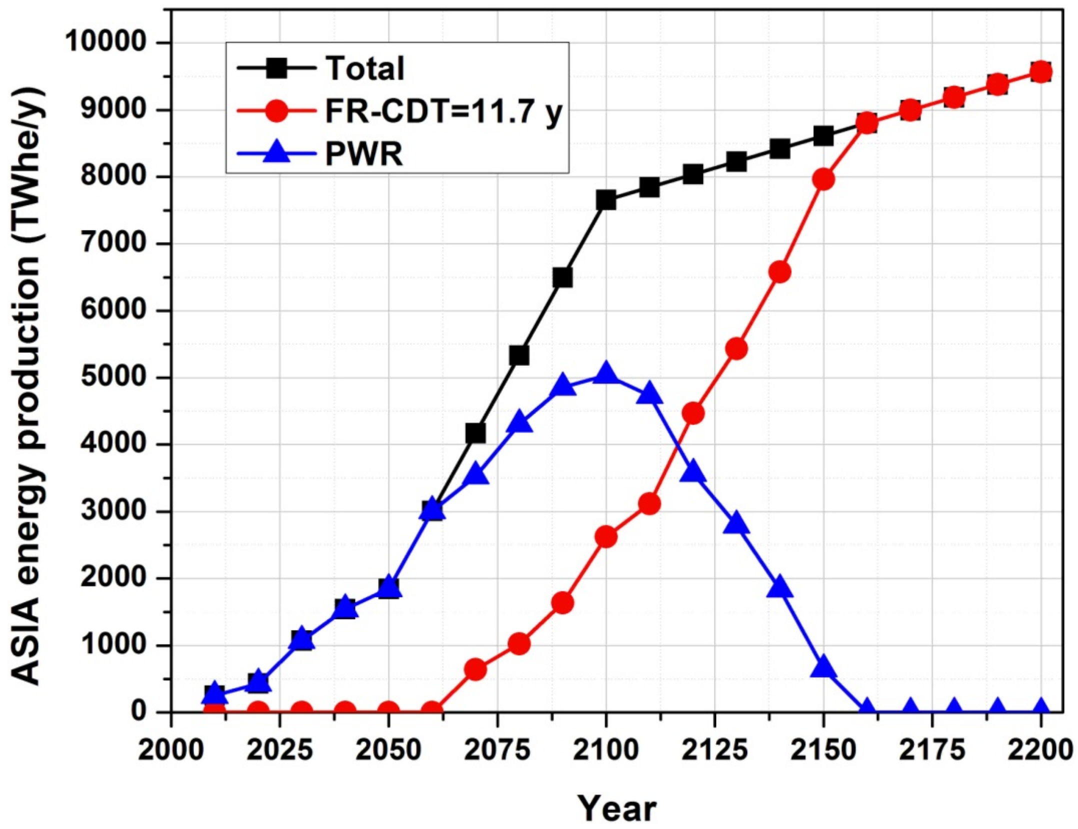
- **ASIA and ALM deploy high performance breeder reactors starting from 2060 and 2080, respectively.**

- **The spent fuel legacy was subdivided, due to the lack of published data, according to the nuclear energy production share of each region in the reference year 2000, resulting in the following distribution: OECD90 ~83%, REF ~10%, ASIA ~6%, and ALM ~1%**

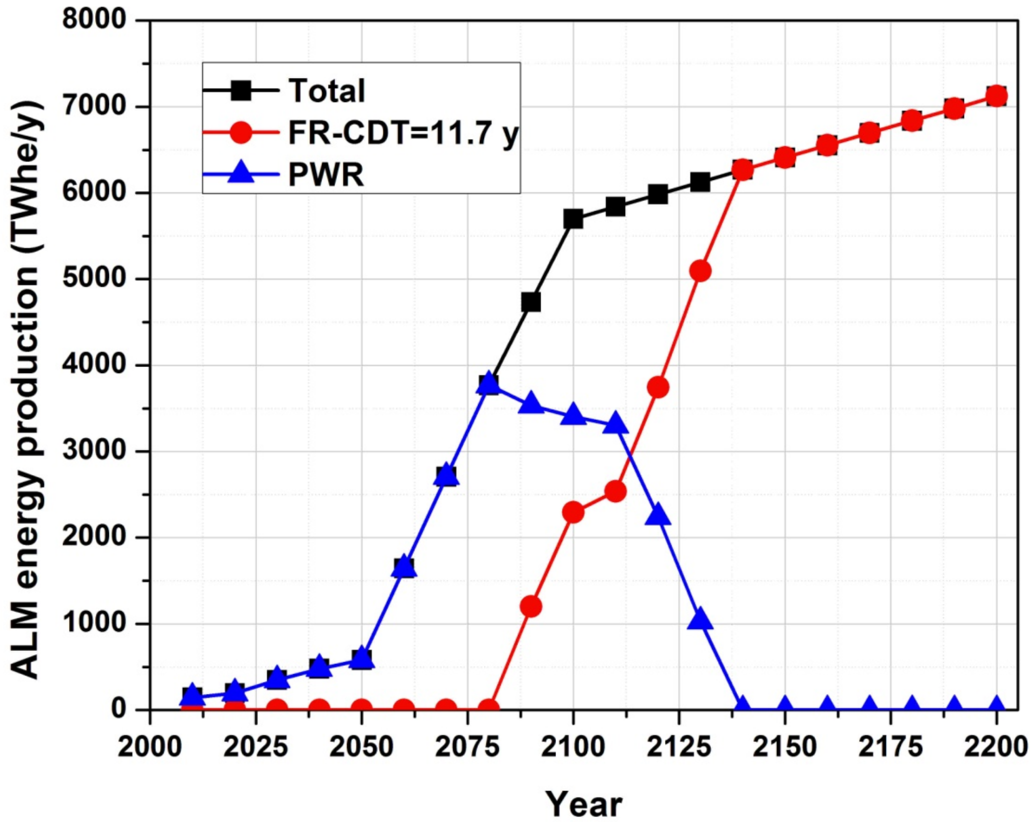
Results (1)

Transition from a regional scenario based only on the once-through PWR fuel cycle to a fully closed fuel cycle (by the deployment of fast systems in all regions)

Nuclear energy production share in ASIA (PWRs and breeder FR).

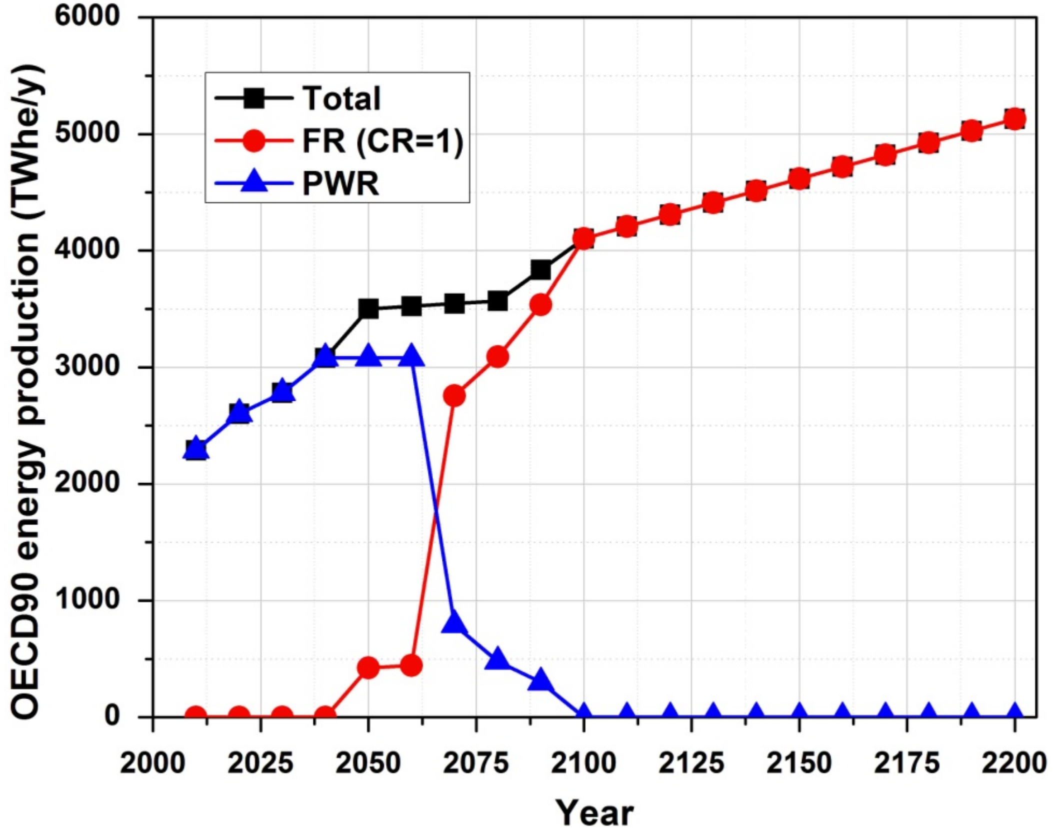


Nuclear energy production share in ALM (PWRs and breeder FR).

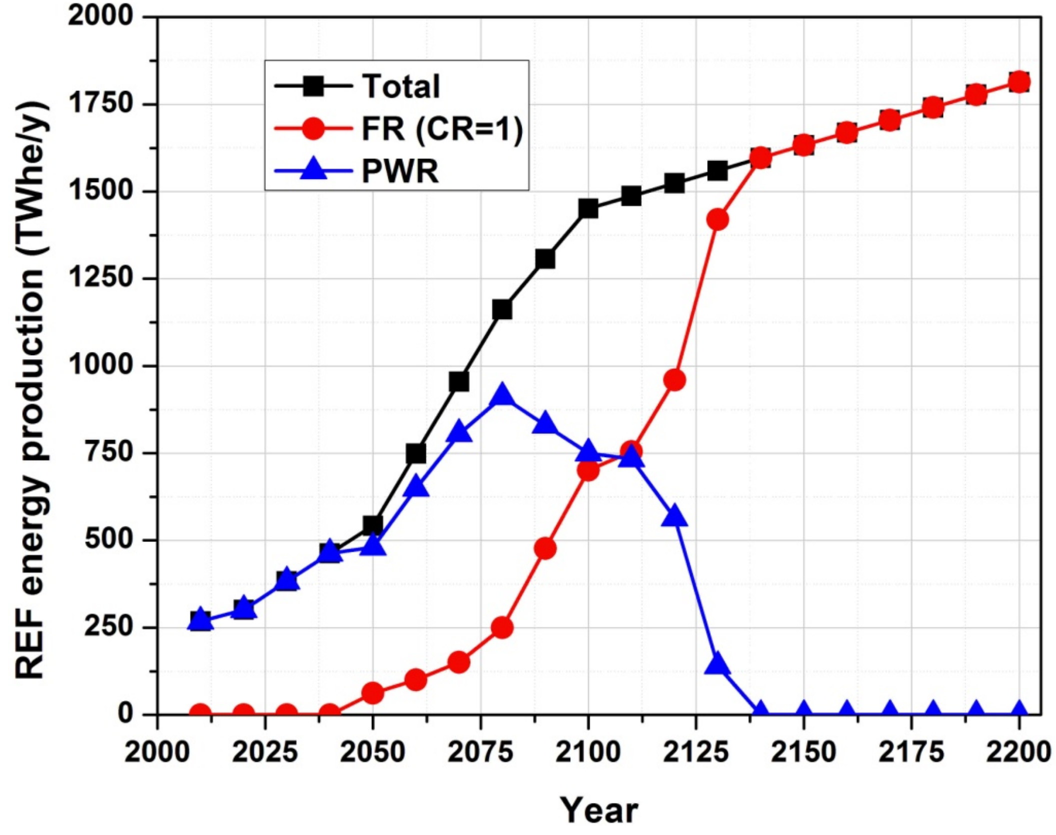


Results (2)

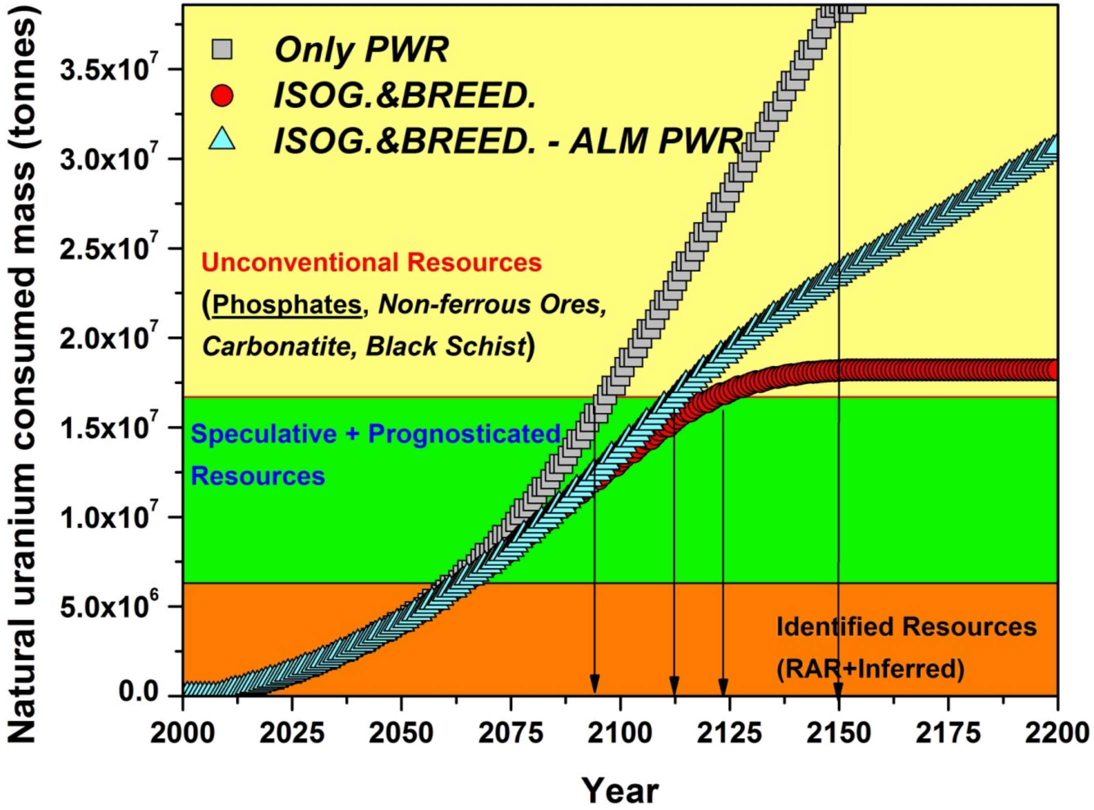
Nuclear energy production share in OECD90
(PWRs and break-even FR).



Nuclear energy production share in REF
(PWRs and break-even FR).



The figure below shows the variation of natural uranium consumption rate with time **for three fuel cycle options: (1) *PWRs "once-through"* fuel cycle, (2) the *PWRs transition to FRs in all world regions*, and (3) the *PWRs transition to FR in all regions except ALM* where the nuclear energy needs are met only by PWRs operating in an open cycle:**



(■) Fuel Cycle option 1: only PWRs with open cycle; (●) option 2: ASIA and ALM (breeders) + OECD90 and REF (isogenerators) (▲) option 3: ASIA (breeders) + OECD90 + REF (isogenerator) + ALM (only PWRs).

- The increase of both fuel fabrication and of reprocessing capacities will be very significant and a large increase in capacity of these facilities will be required in fast growing regions (ASIA and ALM).

- In fact, ASIA and ALM will require a UOX fabrication capacity of ~10,000 tons by ~2067 and ~2077 respectively

- As a result of the FR implementation strategy envisaged in the scenarios, the UOX fabrication capacity requirement will decrease after a few decades and a sharp increase of the FR fuel fabrication is then expected: ~18,000 tons in ASIA by ~2140 and ~14,000 tons by ~2130 in the ALM group of countries.

- When compared with the existing world annual reprocessing capacity, ~3800 tons/year, a value of ~6 times higher is expected in ASIA and a value of ~4 times higher in ALM by ~2130.

- In practice, this would mean that the ALM and ASIA reprocessing capacities should be increased by about 1130 tons/year every 10 years (*i.e.*, equivalent to the development of a La Hague-size reprocessing plant every 15 years).

What we learn from these studies

- It can be shown that the potential future scarcity of uranium resources can be a serious issue for regions of the world where the energy demand growth is and will continue to be high, and where nuclear energy is expected to (partially) meet that demand.
- In the case of an open cycle, an increased pressure on the uranium market is to be expected towards the end of the current century. Moreover, the increase of mining needs of unequally distributed resources is a further factor of uncertainty.
- The main objective in all cases studied (i.e. *"uniform" or "regional"* world approaches, Supply-N scenario), was to deploy fast reactors as rapidly as possible and to replace the thermal reactor fleet to minimize the uranium resource consumption and to cope with steeply increasing global world energy demand.
- Even with a significant deployment of fast reactors, the uranium resources can remain a crucial issue, unless very high breeding ratio (and low doubling times) fast reactors are deployed.
- A few more power fast reactors are soon expected to be deployed. However, very little experimental capabilities are available or planned (MBIR) world-wide to cope with innovative concepts challenges

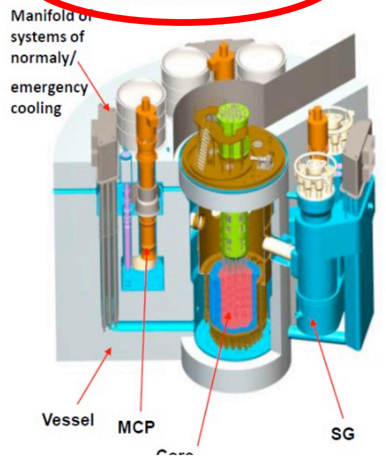
Fast reactor demonstrations, deployment and operation is underway in India, China but in particular in Russia:

BN-800

The upper part of the reactor vessel for MBIR (Image: AEM-Technology)

Main elements and technical characteristics of the reactor unit

RU BREST-OD-300 prototype of commercial reactor units



Heat power, MWt	700
The amount of the loops	4
The primary coolant	lead
Max (hydrostatic) pressure of the coolant in the primary circuit, MPa	1,17
Average temperature of lead coolant at the entrance/exit of the core, °C	420/535
The amount of fuel assemblies	169
Fuel charge, t	20,6
Electric power , MWt	300
The average temperature of the working fluid at the entrance/exit of the steam generator, °C	340/505
The pressure at the outlet of the steam generator, MPa	17
Steam productivity, t/h	1500
Efficiency coefficient, %	43,5

❑ **It will be, in any case, a very significant challenge to develop suitable fuel cycle infrastructures especially in the world regions that presently have limited (or no) nuclear power plants.**

In fact, the needed fuel fabrication and spent fuel reprocessing capacities will be required to increase by at least one order of magnitude over the next decades.

The results of these studies are obviously very much related to the hypotheses made, in particular in terms of energy demand growth. However, some general trends have a general value, and if they can motivate further studies, one should not hide the urgency of the issues at stake.