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Nuclear fission energy;
a sustainable source?

Sustainable nuclear energy; large scale production with proliferation safety?

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Clarification of the basic position on nuclear energy

- Nuclear (fission) energy,considering its potential, is one of the greatest discoveries of the 20th century science. A potential of environmentally benign and economic energy for many centuries cannot be neglected and left undeveloped.
- Military or terorrist abuse of nuclear energy is one of the greatest threats to humanity. Installations required for peaceful uses of nuclear energy (enrichment, reprocessing) can be abused for production of nuclear explosives.
- Socially responsible scientists and engineers promoting the use of nuclear energy must also promote measures for controlling and preventing the possibility of abuse.

More on basic position

- Following the spirit of Washington declaration of November 15,1945 by President of US and Prime Ministers of Britain and Canada for elimination of atomic weapons, aware of both potentials and dangers, top US scientists and industrialists (Leading author R.Oppenheimer) produced a proposal for the safe peaceful use of nuclear energy, presented in 1946 in UN as Baruch plan.

- Its rejection by SSSR marked the beginning of nuclear arms race.

  Important years 1949, 1952, 1953

- Major alarms about 1954. Since 1957 independent world scientists united to act through the so called Pugwash movement initiated by Russel and Einstein. The aim is to ban and eliminate nuclear weapons. Important results achieved. Nobel peace price for 1995.

- Another chance for nuclear disarmament was lost in 1990 after the break up of SSSR. This time the blame is on the other side.

Present status, technology

- 437 reactors in operation
- 55 reactors in construction
- large number of reactors in planning phase

Since “Three Mile Island” accident in 1979 technical safety improved by several orders of magnitude (in terms of CM probability and probability of radiation subsuquently penetrating through containment building into the environment). NPP Chernobyl (accident 1986) did not have a containment.

European Union

- The EU has the largest number of commercial Nuclear Power Plants in the world (146 in the EU – 437 worldwide);
- Nuclear provides around 1/3 of the EU electricity generation;
- Growing majority of EU Member States is choosing nuclear energy for power generation.

EU recent projects

- **Romania: Cernavoda 2 (connected in 2007)**
- **Finland: Olkiluoto 3 (under construction)**
- **France: Flamanville 3 (under construction)**
- **Slovakia: Mochovce 3-4 (under construction)**
- *Bulgaria: Belene ?*
- *Romania: Cernavoda 3-4 ?*

Renewed interest for nuclear energy in the European Union

- Announced new reactors:
  - Italy (8); United Kingdom (8); Poland (5); Romania (3); France (2); Bulgaria (2); Czech Republic (2); Finland (2); Hungary (2); Lithuania (2); Slovakia (1); Slovenia (1).

- Evolution of nuclear energy *policies*:
  - Belgium (phase-out *reversed*)
  - Germany (phase-out being *reconsidered*)
  - Italy (new build *decided*)
  - Sweden (phase-out *reversed*)
  - United Kingdom (new build *decided*)

"EU 2050 Roadmap":

- **By 2050**, ~100-250 GWe new EU nuclear capacity could be necessary (133 GWe today),
  - *i.e. more than 100 new reactors*
- This implies that from today onwards 3-5 large NPPs would have to be constructed every year.

Nuclear technology, future

Generation 4 in development, main aims:

- further improvement in safety, more passive systems
- better economy, reduction of investment costs per unit power.
- proliferation resistance

Proliferation control and safety,present status

- Main international mechanism NPT, Israel, India, Pakistan and North Korea outside.
- Initial NW states: US, SSSR, China, France, UK
- Additional NW states: India, Pakistan, Israel, North Korea
- Temporary NW state: South Africa
- Potential NW state: any country in posession of enrichment or reprocessing installations. There are now 9 such countries (without SA and Iraq, including Iran) other then five inital NW states. Four of them have acquired nuclear weapons

Sustainability of nuclear fission energy?

Large scale and long term use of nuclear energy depends on three main issues:

- Sufficiency of uranium resources
- Acceptable reactor safety
- Proliferation safety

Storage on nuclear waste is not in the same category, acceptable technical solution exist.

In view of the high reactor safety standards of Generations 3+ and 4 we may conclude that nuclear fission energy can be considered sustainable if the answer on the questions on uranium resources and proliferation safety are positive.

Proliferation safety

- Nuclear explosives can be produced in uranium enrichment installations (highly enriched uranium) and in reprocessing of spent fuel (plutonium 239).

Enriched uranium required for most present and future reactors

Solutions:

Enriched uranium supply through IAEA fuel bank without any kind of political bias. International enrichment centres under IAEA supervision (example:agreement between Russia,Khazakstan and Ukraine)

Agreement on and application of Fissile Materials Cutoff Treaty (FMCT)

Proliferation safety, reprocessing installations

- Reprocessing of spent fuel will be required should the uranium resources be inadequate for large scale long term nuclear development. With plutonium fuel fast breeders can utilize uranium 238 and the amount of nuclear fission energy becomes practicaly inexhaustible.

- Increased number of reprocessing installations with spent fuel and plutonium containing fresh fuel moving between breeder reactors and reprocessing installations would present additional proliferation risk.

- US Nuclear Non-proliferation Act of 1978 attempts to stop plutonium recycle. Not accepted by uranium less rich countries

Can reprocessing be avoided or postponed until better political environment is created and reliable controls agreed upon and applied?

- Answer depends on the sufficiency of uranium resources for the future nuclear power build-up.

- Nuclear fission is the largest carbon free energy source with 5.7% share in total world energy production. For essential impact on carbon emission considerably larger share in increased future consumption will be required.

Quantitative assesment is necesary

Uranium resources

Present (Red book 2008) estimates of uranium resources recoverable under 130 USD/kg

- Identified resources 5,47 million tons
- Prognosticated resources 2,77
- Speculative resources 7,77

Total conventional resources 16,01 million tons

Unconventional resources

- Phosphates
- Seawater ~4 billion tons

Uranium, present and future consumption

With about 440 reactors in operation annual uranium consumption is about 70 000 t (see WNA for details).

Nuclear energy contribution to total energy production is less than 6% (5,7 IAEA, May 2010), too small for essential reduction of carbon emission

For increased nuclear share of about 25% in the future energy production, larger by factor of two, nuclear energy production should be almost ten times larger while the annual uranium consumption would approach 700 000 t.

Another look on the Red book data shows that a large scale production of fission energy could not be covered for a long time with presently estimated conventional uranium resources.

Is then nuclear fission energy unsustainable?

Obvious technical solution

- Stated uranium consumption follows from the characteristics of the present reactors (mainly light water thermal reactors) and the use of once-through fuel cycle without reprocessing and without recycle of plutonium and uranium.

- By introduction of fast breeders uranium 238 can be effectively burnt, in theory extending uranium resources indefinitely.There are many years of experience with fast breeders.

However, reprocessing and plutonium use would create additional proliferation risk in present unfavourable political environment.

Do we need reprocessing and and when? This is an important question for future energy policy.

Assumptions for quantitative assessment on the need of reprocessing and plutonium use

- We want to establish whether a nuclear build-up covered by presently estimated uranium resources, used with **once-through fuel cycle without reprocessing,** can give **effective** and **timely** contribution to the reduction of carbon emission

- **Once-through fuel cycle, no reprocessing**: to avoid risks associated with large scale plutonium use

- **Timely**: critical period 2025-2065 (CCS,solar, nuclear fusion)

- Present estimates of uranium resources by the Red book 2008
  Uranium consumption per unit energy produced typical for present mix of nuclear power reactors

- **Effective:** maximum nuclear build-up under stated constraints
  gives maximum carbon emission reduction – can the nuclear contribution be much larger then present 5,7% in future total energy production?

Maximum build-up strategies in the years 2025-2065

- Scenario 1: **Exponential growth**
- Scenario 2: **Linear growth**

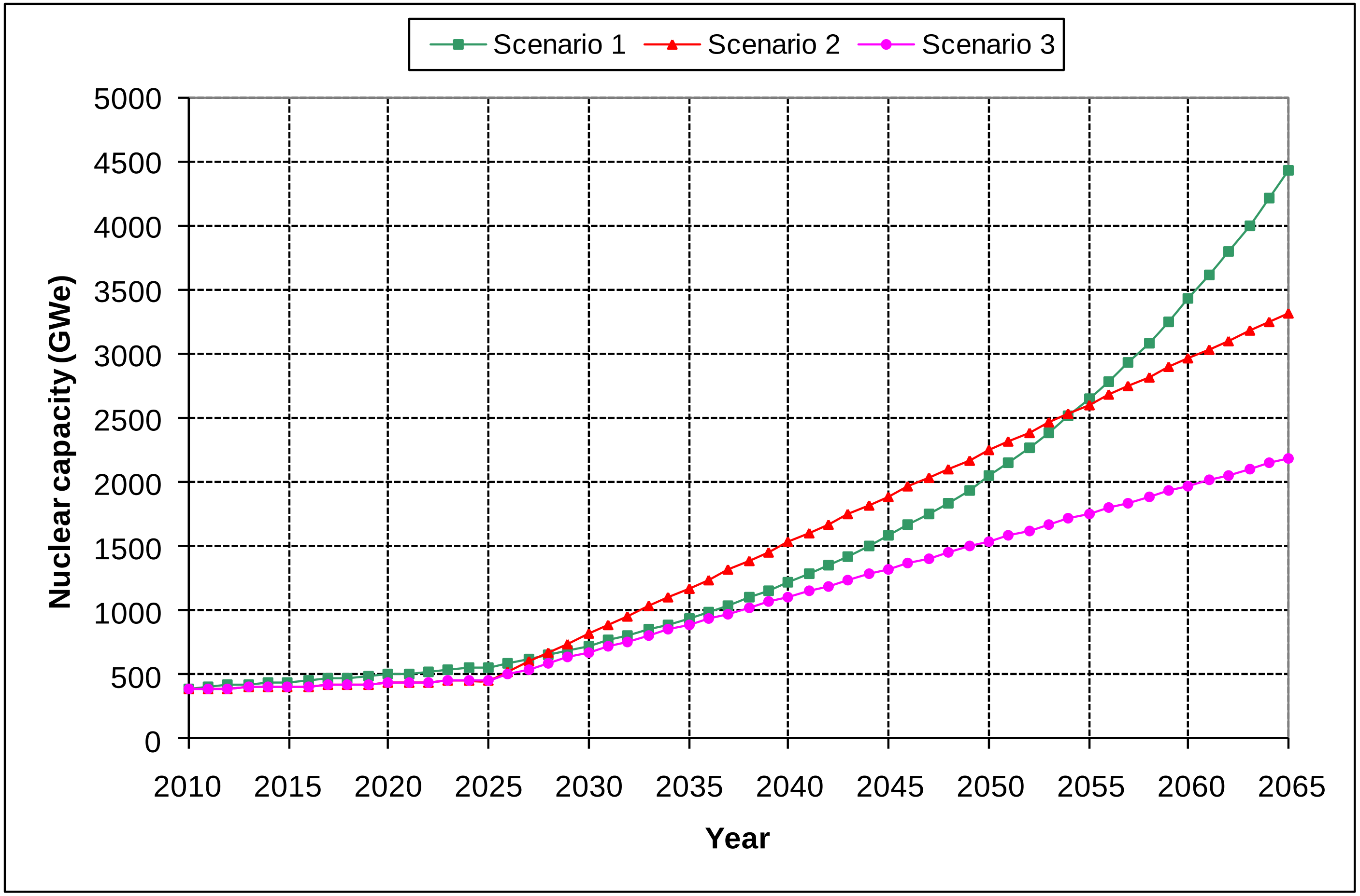
Maximum growth rates determined by request that presently estimated uranium resources (16 million tons) be consumed by 2065

Reduced growth strategy

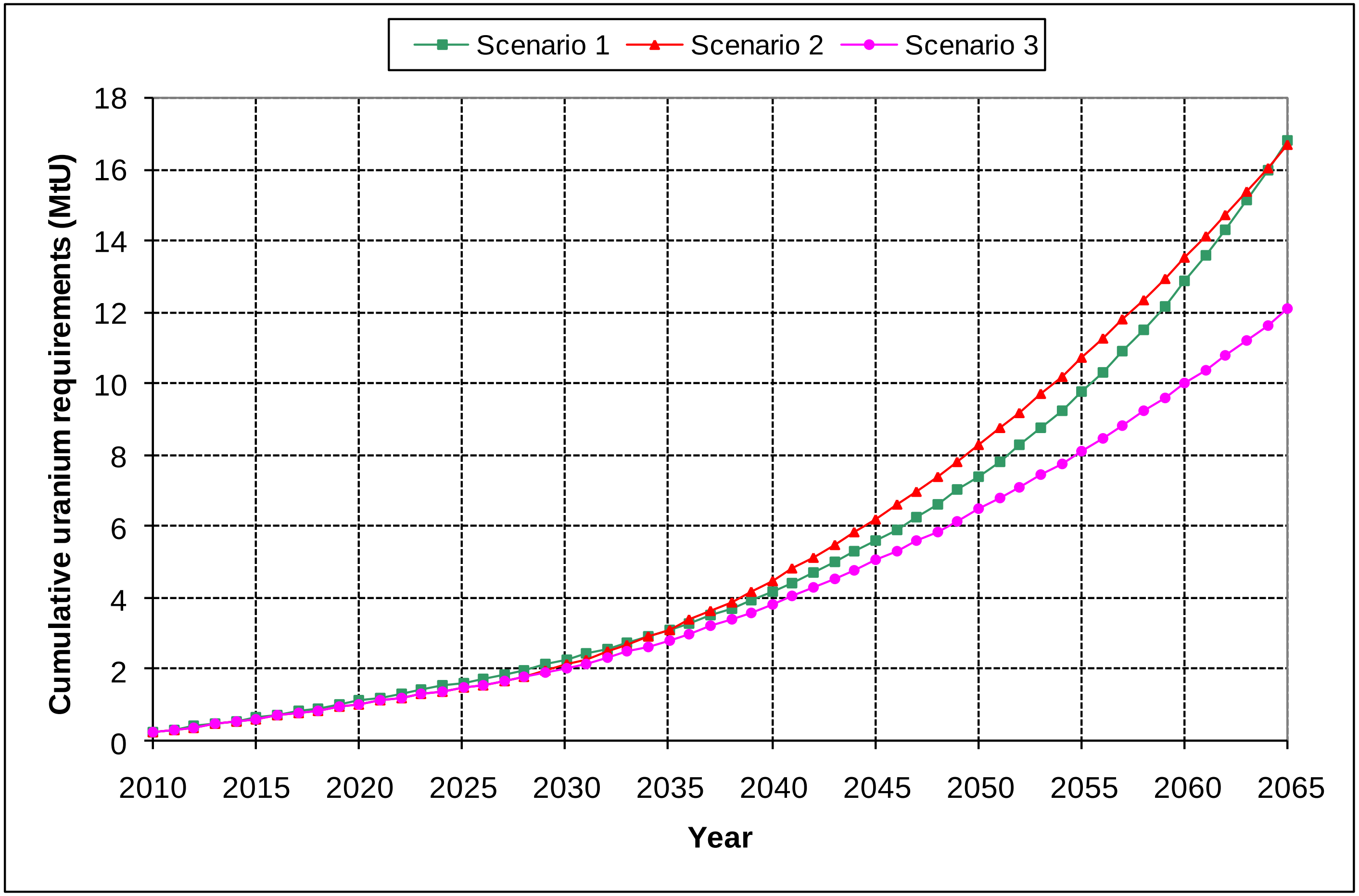
- Scenario 3: **Replacement after 2025 of all retiring non-CCS coal plants with nuclear power plants**

Coal power plants electricity production in 2025 from WEO 2009

. The nuclear generating capacity for all three scenarios to the year 2065

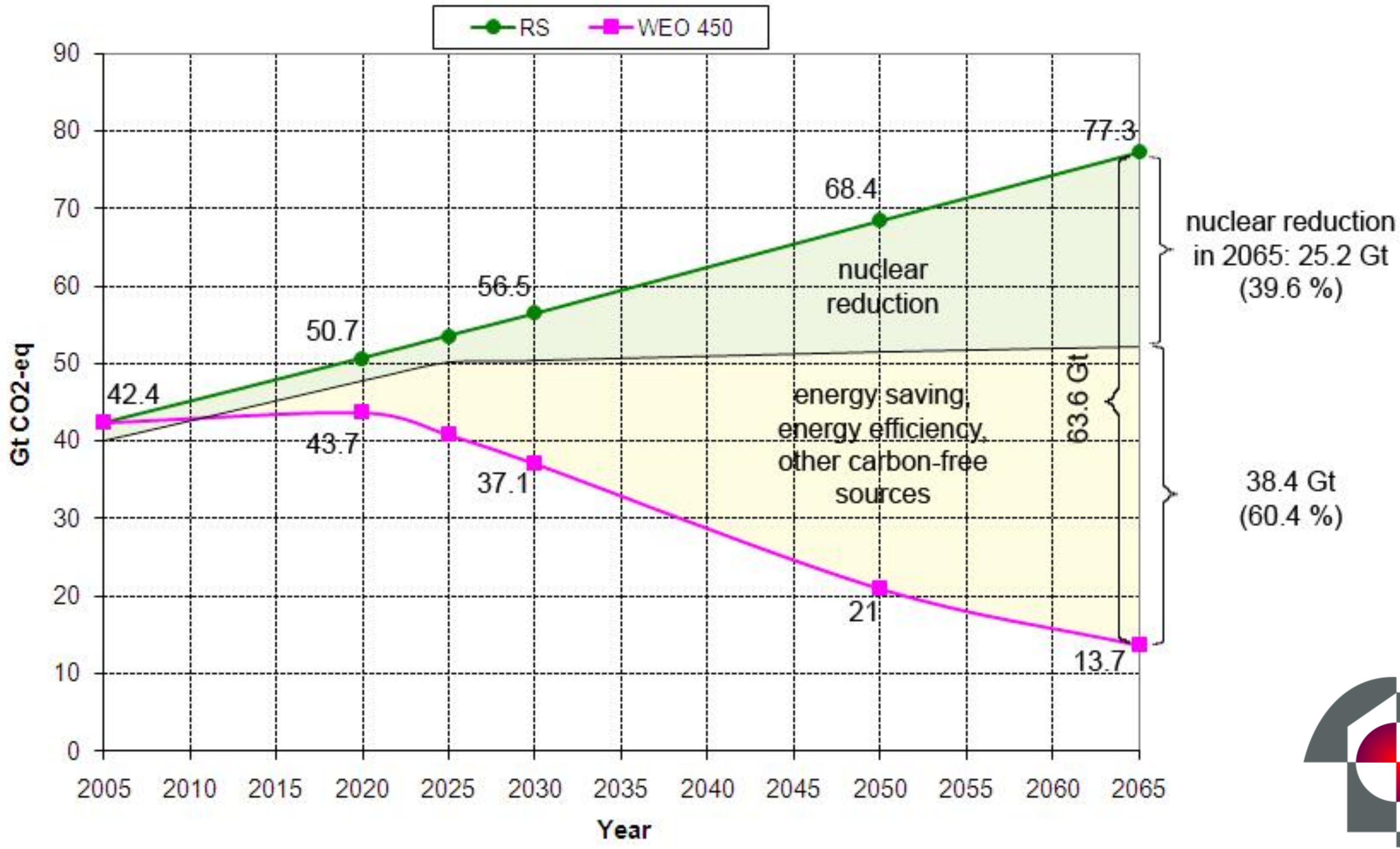


The cumulative uranium requirements for all three scenarios to the year 2065



Emission reduction by nuclear build-up

(linear growth Scenario 2) in GtCO2. The upper and bottom curves are the total anthropogenic emissions according to the WEO 2009.

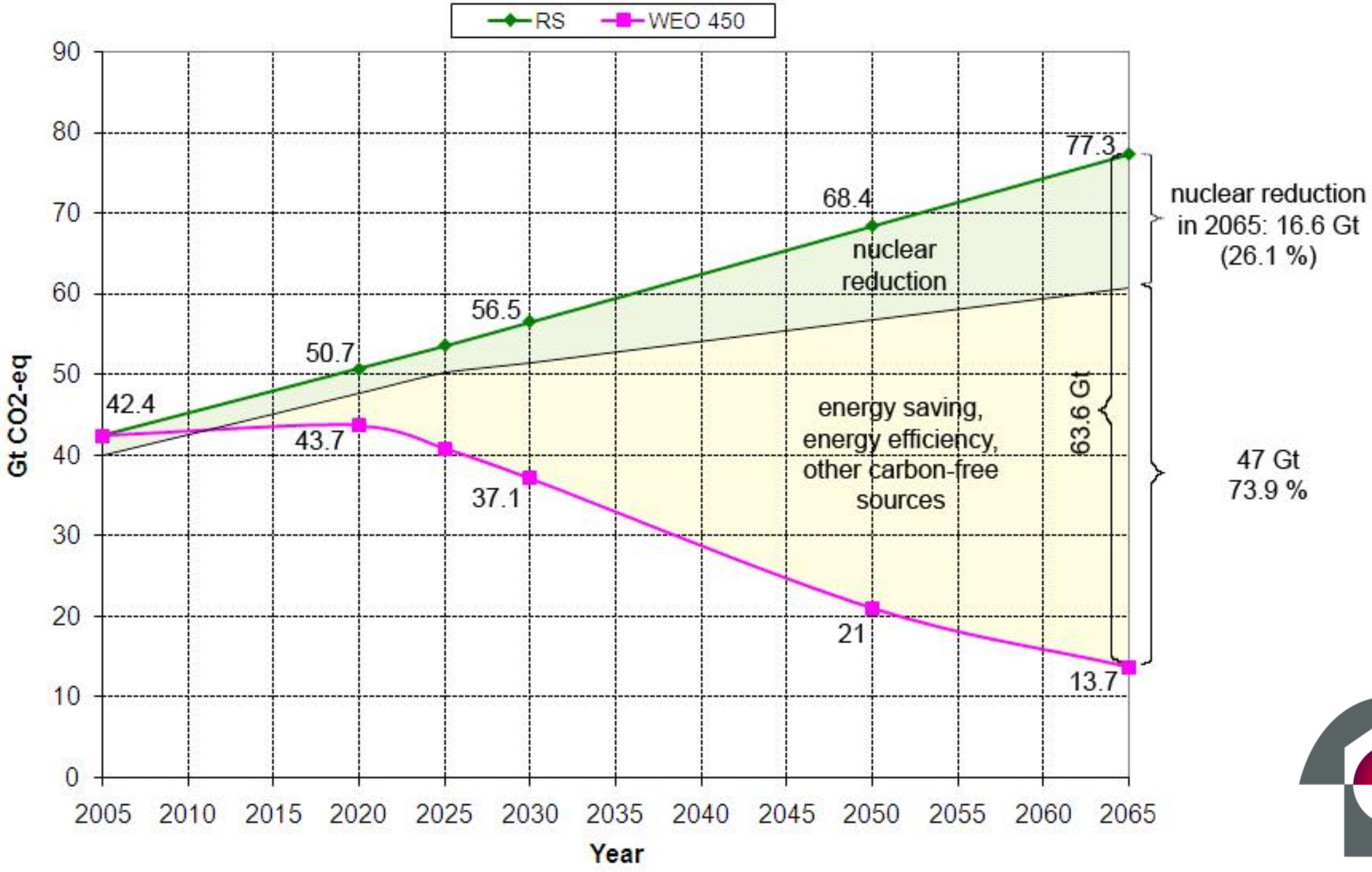


. Emission reduction by nuclear build-up

(intermediate Scenario 3), in $GtCO_2$.

The upper and bottom curves are the total anthropogenic emissions according to the WEO 2009 Reference Scenario and WEO 450 Scenario.

The 2065 values are extrapolated from predictions up to 2050.



Comments:what would happen after 2065?

(strategies 1 and 2 consume by 2065 all uranium resources of 2008)

- Lower strategies selected, more years to exhaustion
- Increased conventional resources
- Development of unconventional sources:

  -Phosphates

  -Seawater uranium
- Pu 239 or U 233 production by accelerator or fusion neutrons irradiation of U 238 or Th 232

- Failing all above, plutonium in spent fuel sufficient for another 15 years of operation on the 2065 power level

- By 2080 large scale CCS or nuclear fusion could be developed

Some comments on the techno-industrial aspects

Upper limit linear strategy would require annual construction of 71.8 GW/y through 2025-2065 reaching 3330 GW in 2065 from 459 GW in 2025.

Lower, CPP replacement strategy, would mean construction rate of 43.4 GW/y in the same period

Construction of 50-70 reactors/y can be compared with annual construction (at present) of about 70 million cars and light trucks

In the years 1980-1990 about 200 GW of nuclear power was constructed with maximum about 30 GW/y

Recent proposal by IEA and NEA (OECD) argues for and considers requirements for a nuclear program to reach 1200 GW by 2050, not much bellow CPP replacement strategy above

Some comments on finances

WEO 2009 Reference scenario; total investment in energy supply infrastructure in 2008-2030: 25.5 trillion USD.

Emission in 2030: 56.5 GtCO2eq

WEO 2009 450 Scenario additional cost of 10.5 trillion affecting emission reduction by 19.4 GtCO2eq in 2030 (estimated offset by health benefits, energy security, energy saving: 8.6 trillion USD).

Nuclear build-up 2025-2065 (2871 GW in the upper limit linear growth scenario) would cost 10-15 trillion USD and reduce emission by 25.2 GtCO2 in 2065

Conclusions

- **Essential nuclear contribution to carbon emission reduction is possible using once-through fuel cycle without fuel reprocessing at least until 2065**.

- **Strategies considered would give 50 years or more to prepare the technical and institutional requirements for the safe use of plutonium, if needed, after 2065.**

- **Considered nuclear build-up would give time for development of other carbon free sources and technologies, which together with nuclear contribution could limit the global temperature increase to 2 °C.**