DE LA RECHERCHE À L'INDUSTRIE

# PLACE OF THE NUCLEAR POWER IN THE ELECTRICITY PRODUCTION IN THE XXI$^{st}$ CENTURY:

## WHAT IS DESIRABLE, WHAT IS FEASIBLE?

Anne Baschwitz Gilles Mathonnière

CEA I-tésé

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# SUMMARY

- The GRUS model
- What is desirable ?
  - Global nuclear energy prospective scenarios
  - FRs are essential
  - FRs with ambitious features
- What is feasible ?
  - depending on Plutonium and Uranium availability
- Conclusion

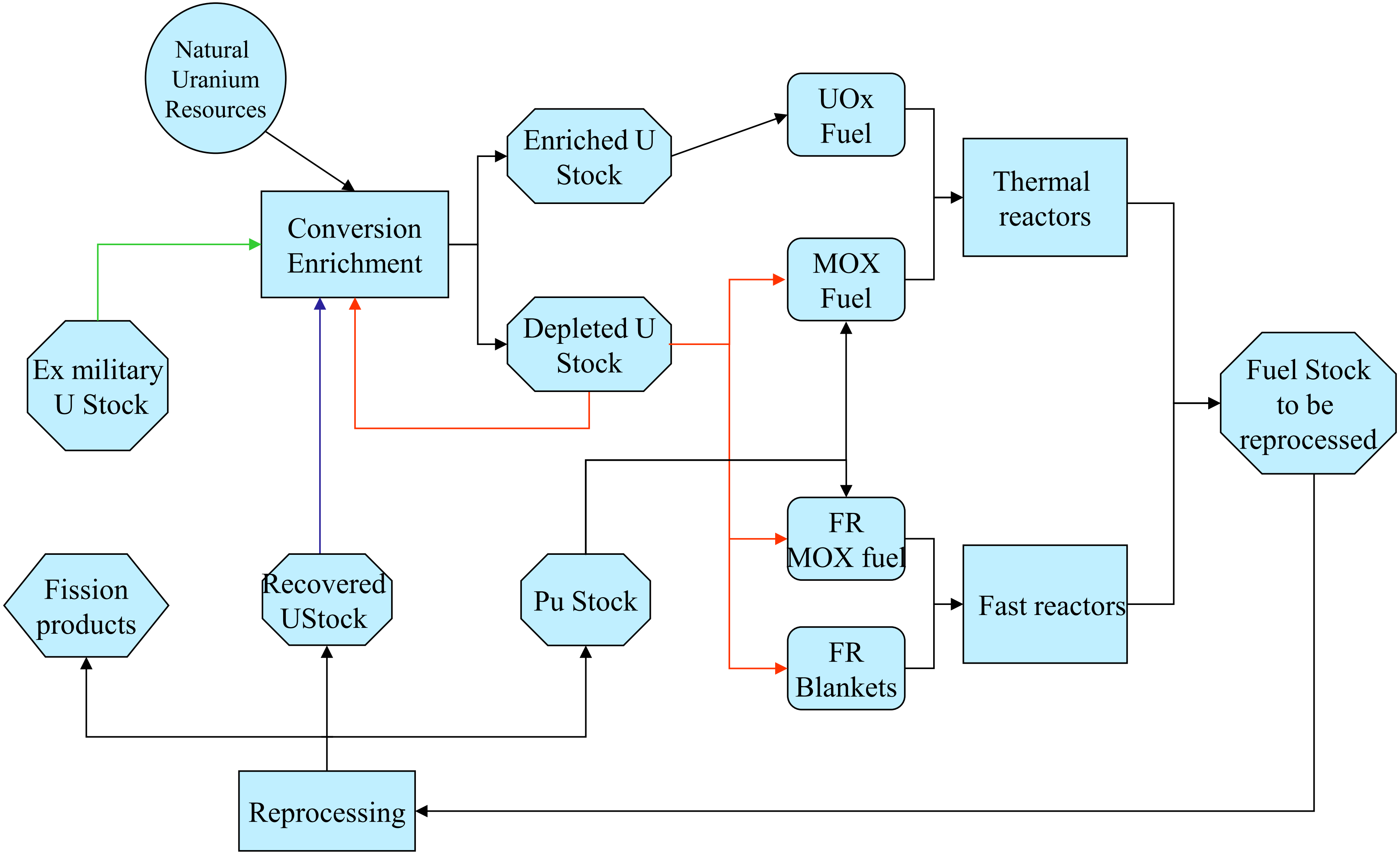
# GRUS

**“Gestion des ressources en uranium avec STELLA”**

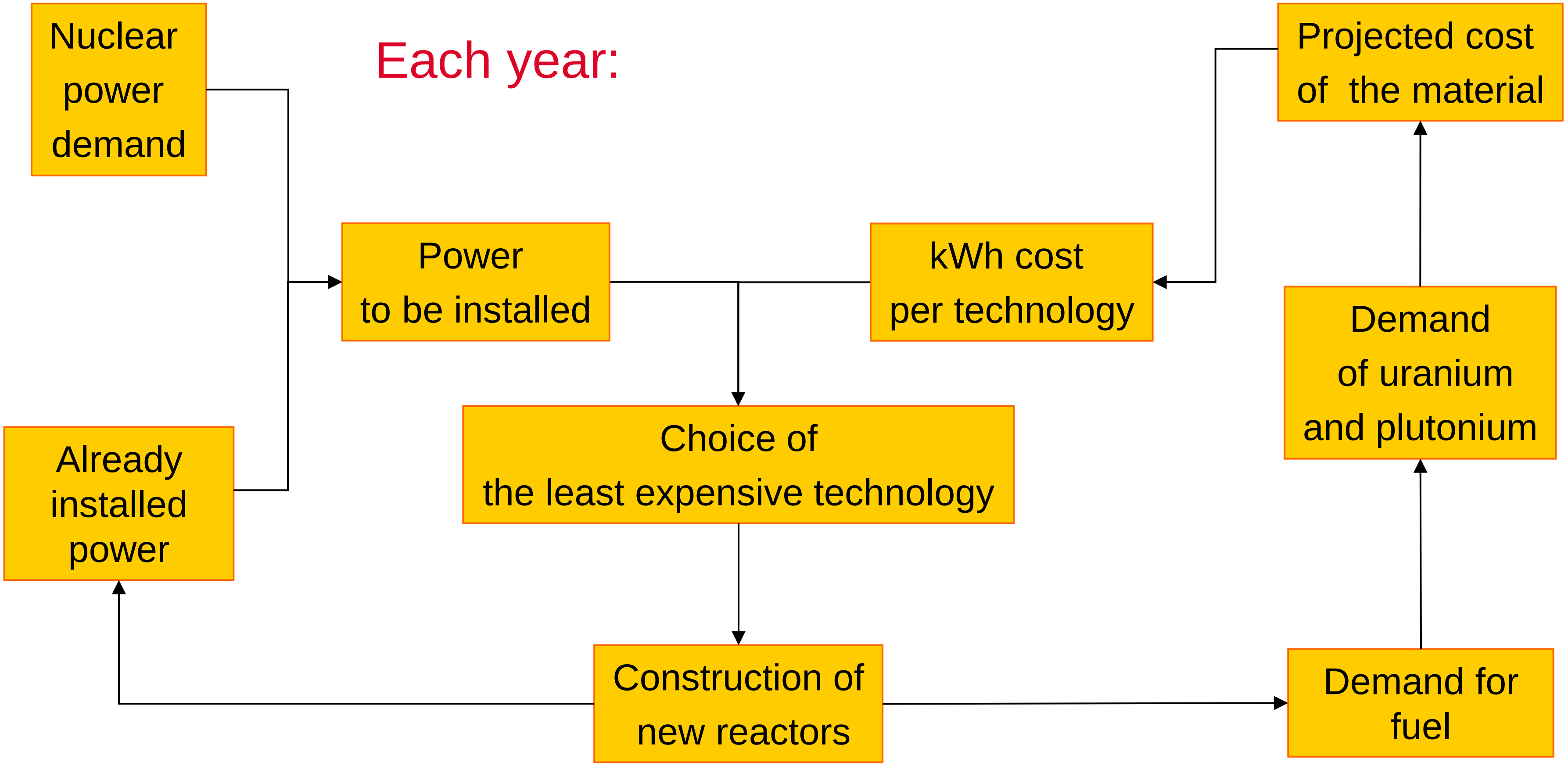
so in English

**“Uranium resources management using STELLA software”**

# MAIN FLOWS TAKEN INTO ACCOUNT IN GRUS



# PRINCIPLE OF THE SIMULATION IN GRUS



# HOW IS THE SIMULATION PERFORMED?

We define:

- The initial conditions of stocks (material stocks, number of each kind of reactors, capacities of factories).
- The key parameters of the model (technical characteristics of reactors, investment and operating costs of a reactor, process costs, resource prices).
- The electricity demand versus time
- Every year we calculate the need in new capacity

↳ The simulation will determine the nuclear fleet which will meet the demand in electricity according to the availability of the resources and diverse costs.

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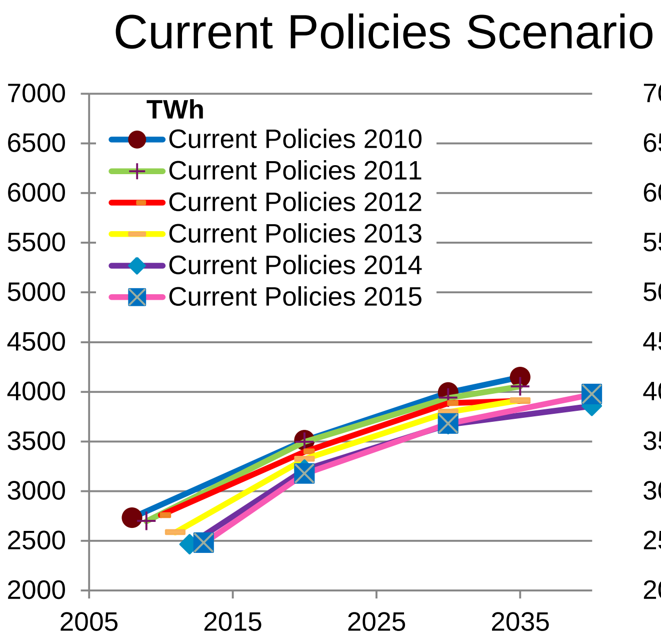
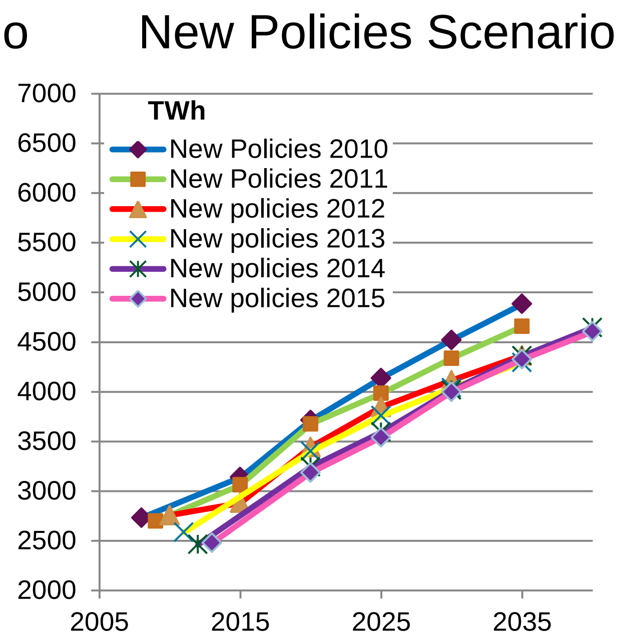
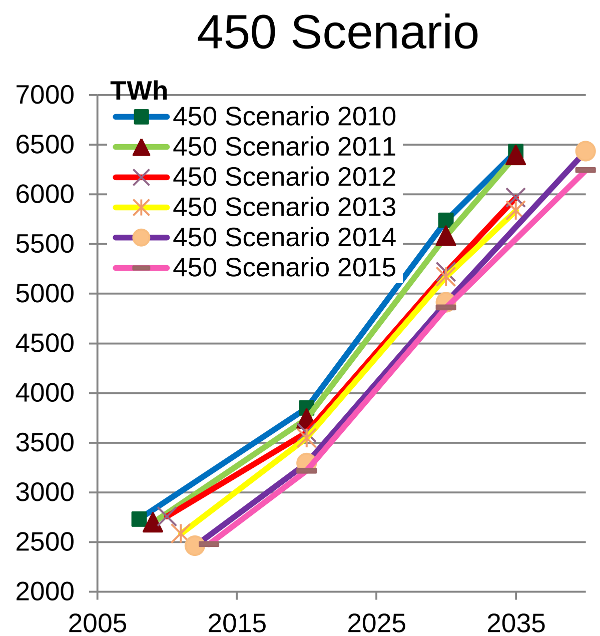
# NUCLEAR SCENARIOS OF THE WORLD ENERGY OUTLOOK UP TO 2040



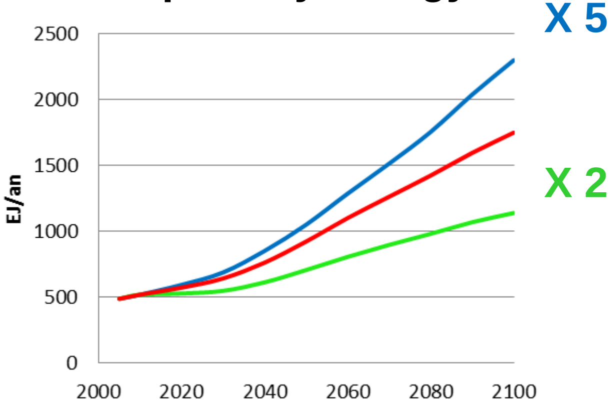




Scenarios up to 2040 : slightly lower previsions after Fukushima

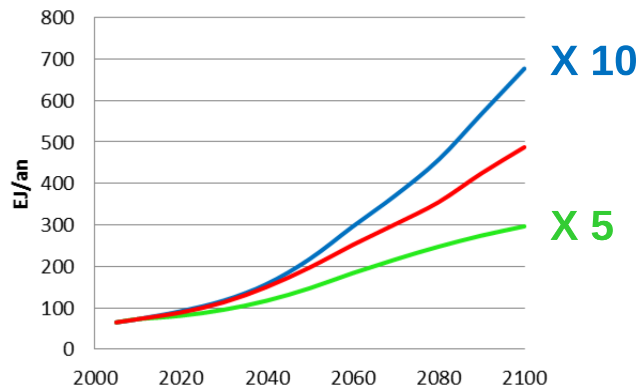
# IIASA SCENARIOS: GLOBAL ENERGY ASSESSMENT

## Total primary energy

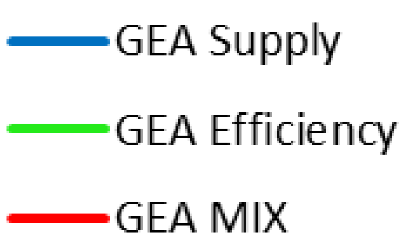



A global energy demand growing strongly

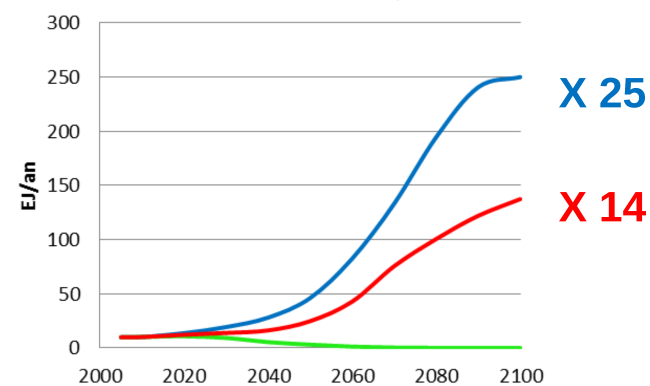
## Secondary energy: electricity




Electricity being used increasingly as an energy carrier

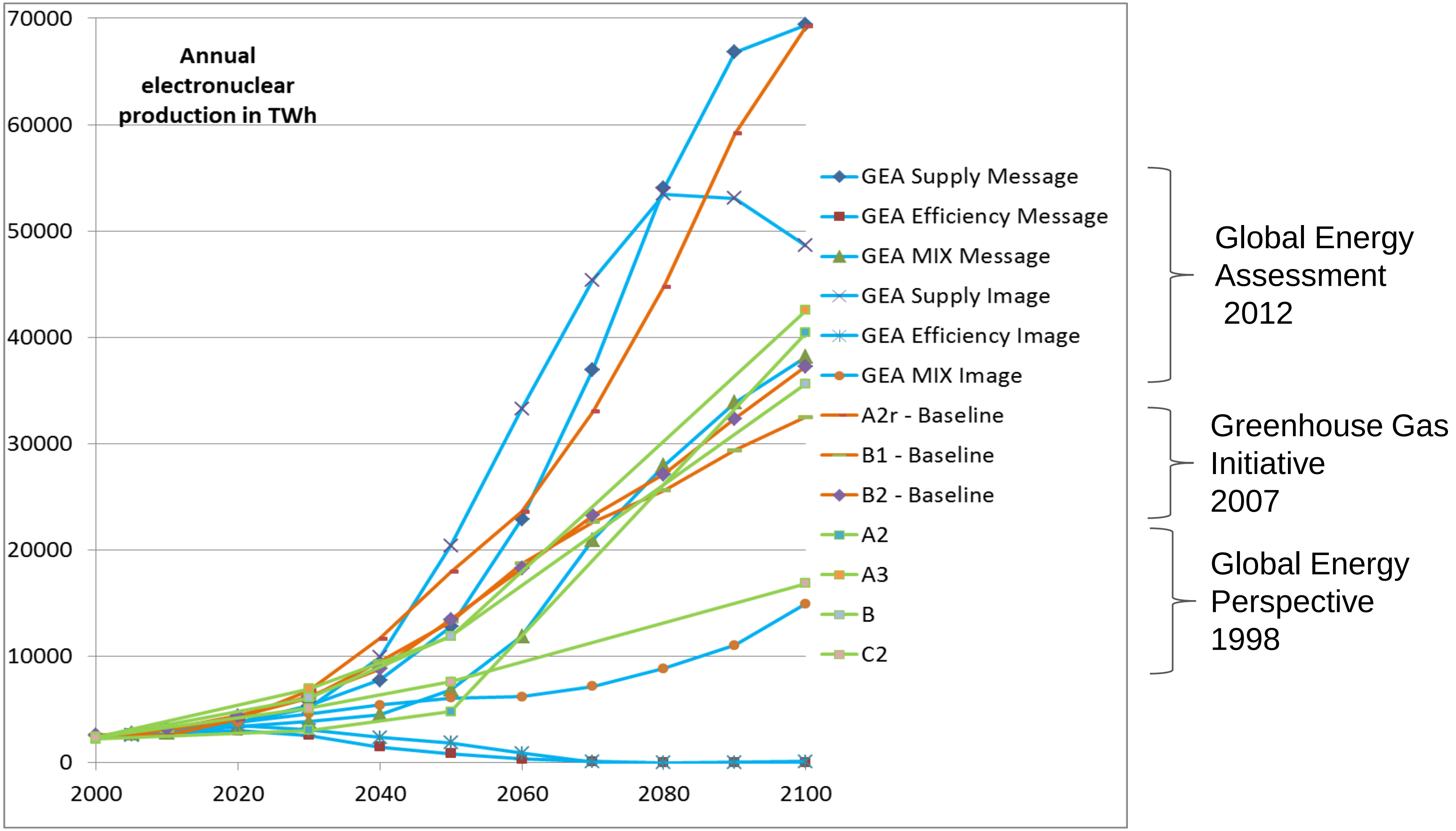



## Secondary energy: nuclear




A strong growth of the nuclear share whenever the energy policy is nuclear-friendly

# IIASA SCENARIOS UP TO 2100



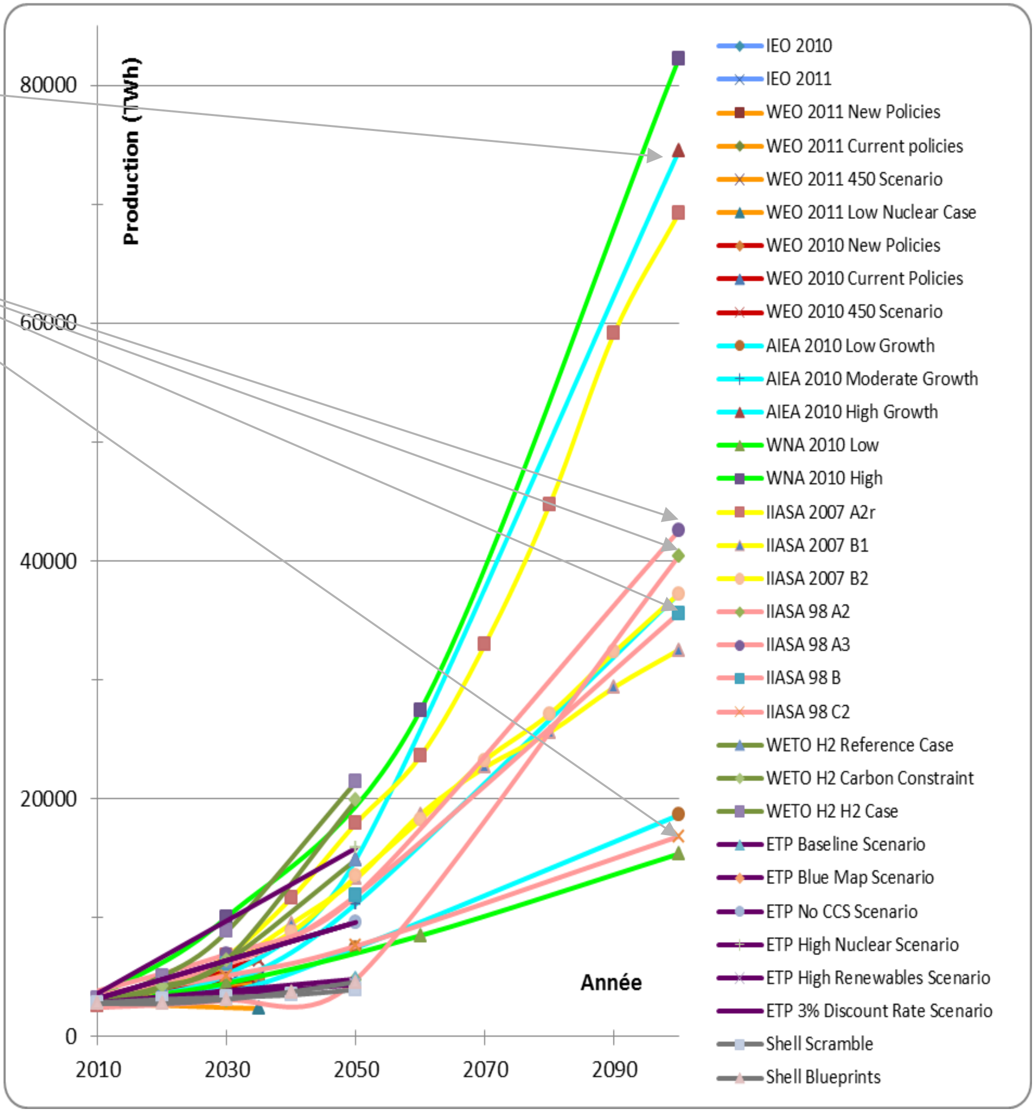

Long-term scenarios are always high

# GLOBAL NUCLEAR SCENARIOS

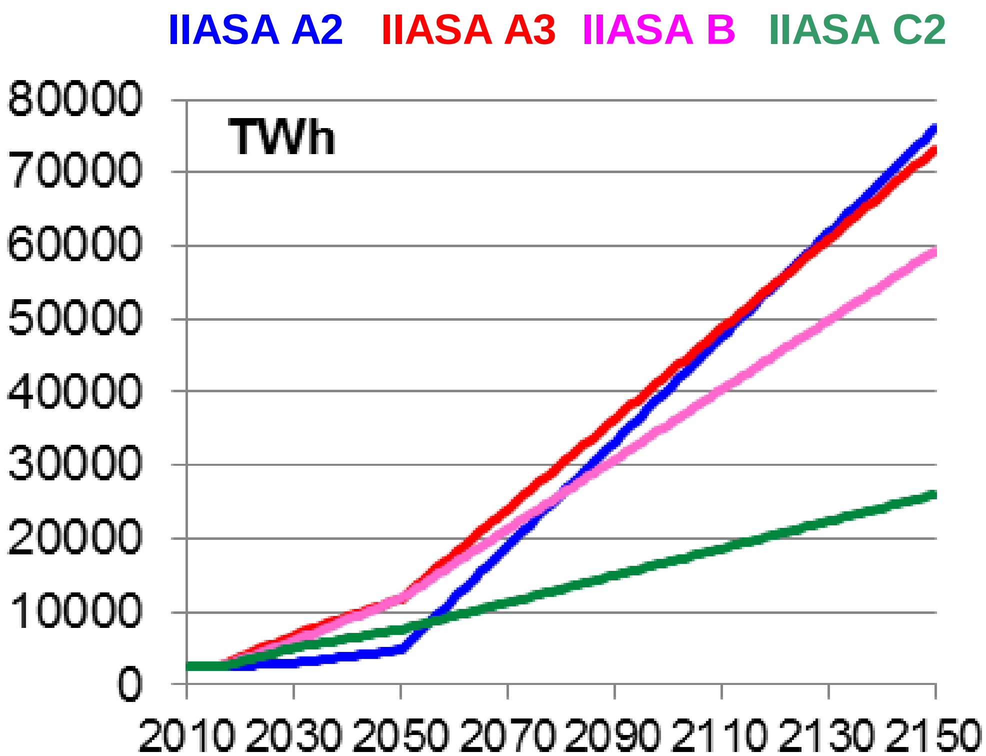
IAEA 2010 High growth scenario

IIASA 1998 Scenarios

- Lot of organisations making energy forecasting
- Different time horizon (2035, 2050, 2100)
- Different assumptions (demographics, GDP, energy intensity, political decisions)
- Different models
- Various objectives (CO2 content, deployment of hydrogen as an energy carrier ...)



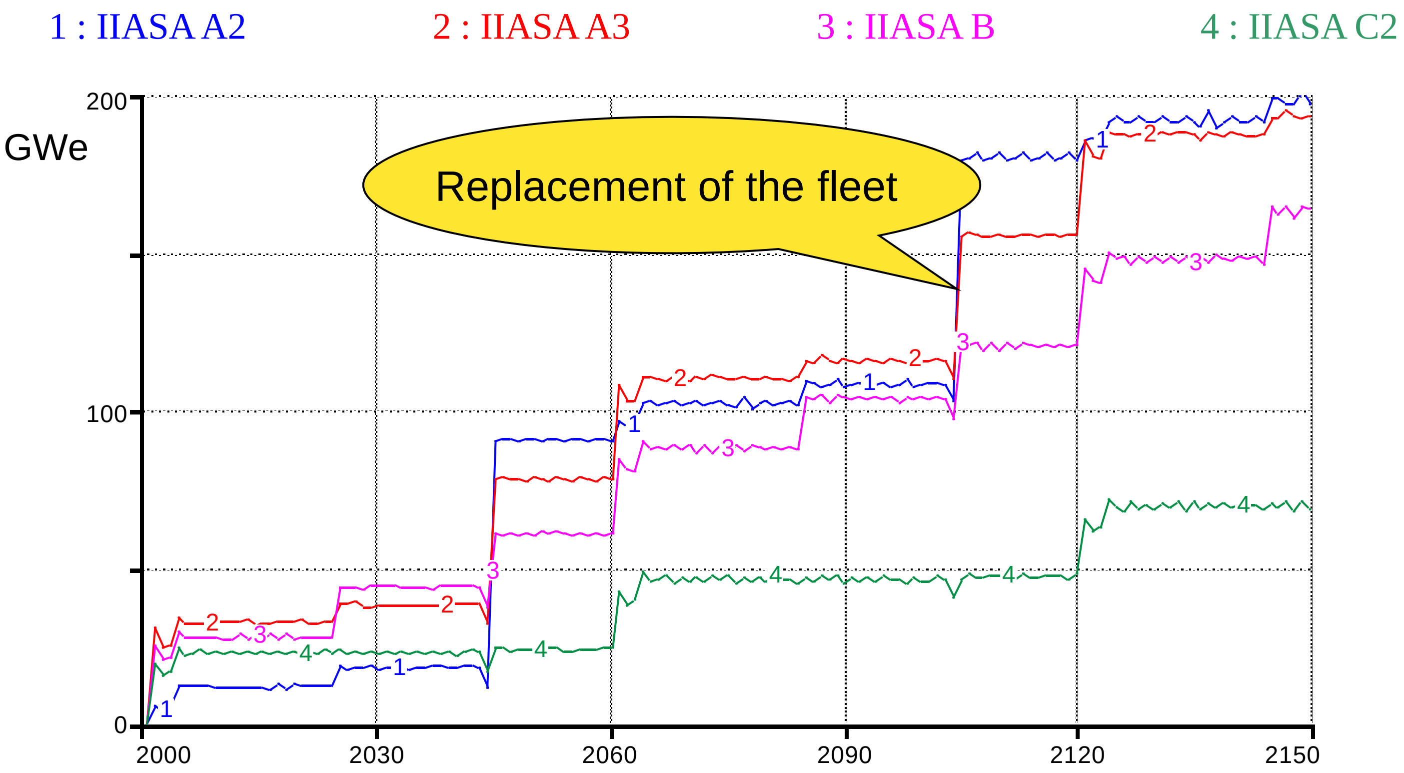
# ELECTRONUCLEAR PRODUCTION




Multiplying factor

| | 2050/2000 | 2100/2000 |
|---|---|---|
| A2 | 2 | 16 |
| A3 | 5 | 17 |
| B | 5 | 14 |
| C2 | 3 | 7 |

# NUCLEAR POWER TO BE INSTALLED



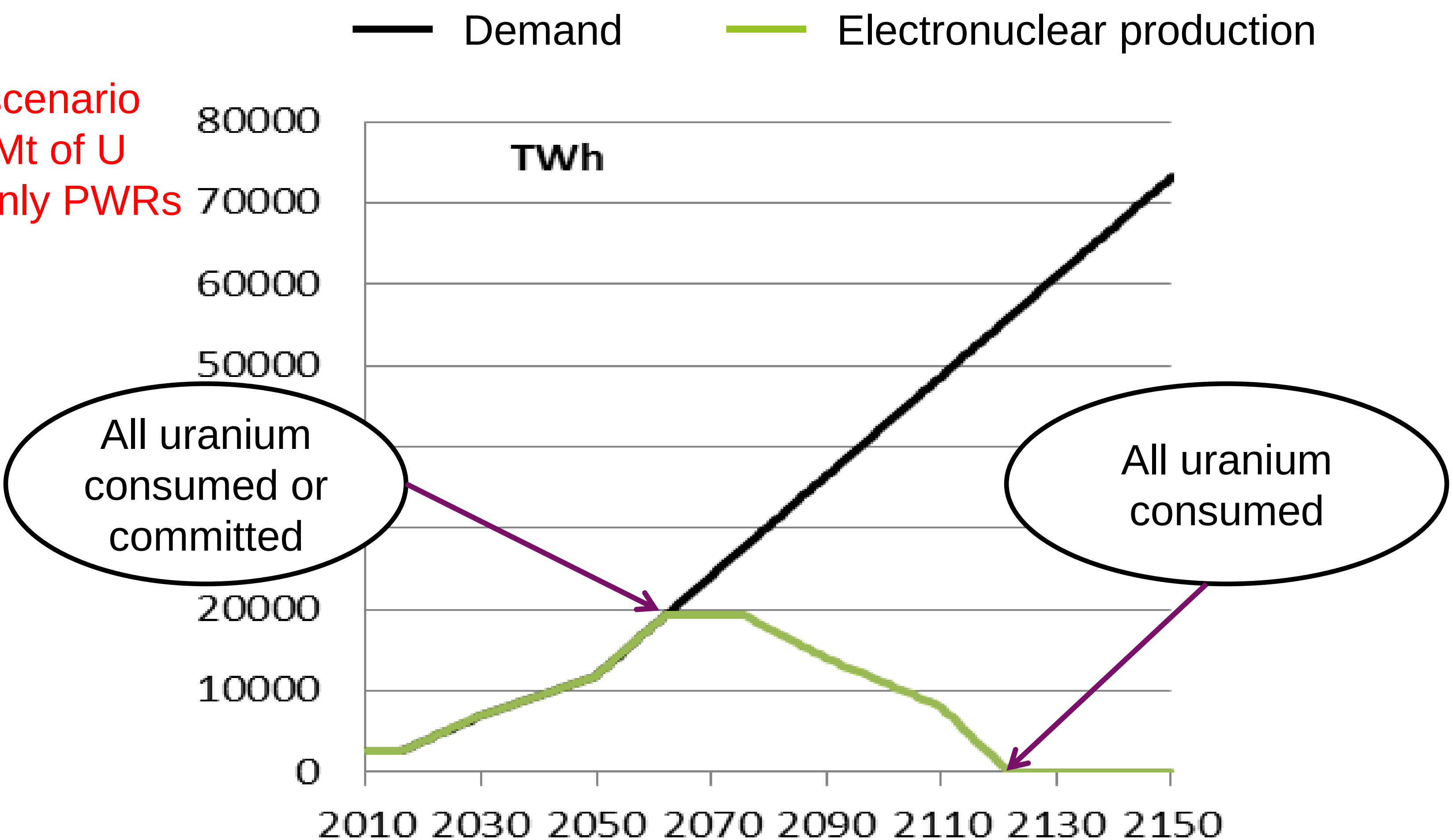

Net power to be installed every year

# AVAILABLE QUANTITIES OF URANIUM

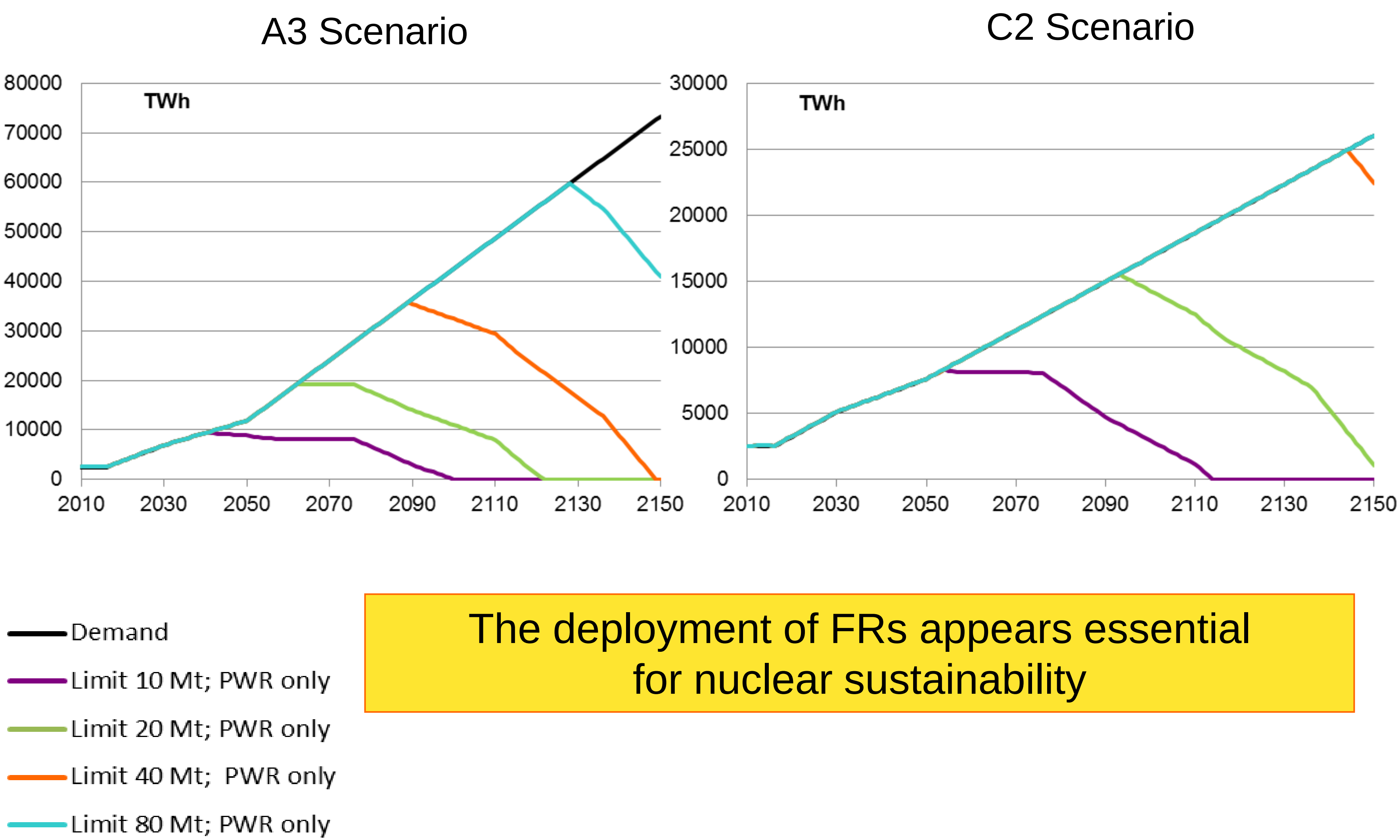
- **We consider the available quantities of natural uranium as limited**
  - ↳ A study case to clearly define the issues related to the necessary resources
- **Four values are considered for a parametric study**
  - **10 Mt** ≈ identified conventional uranium resources = pessimistic view
  - **20 Mt** ≈ conventional resources + 4 Mt extracted from phosphates
    ↳ realistic view
  - **40 Mt** = optimistic view
  - **80 Mt** = very optimistic view
- **When the committed uranium (i.e. taking into account the needs of operational reactors throughout their service lives) exceeds one of the limits in question, only FRs can be deployed**

# « DEMAND AND NUCLEAR PRODUCTION »

A3 scenario
20 Mt of U
With only PWRs



# DEPLOYMENT OF EPRs ONLY




The deployment of FRs appears essential for nuclear sustainability

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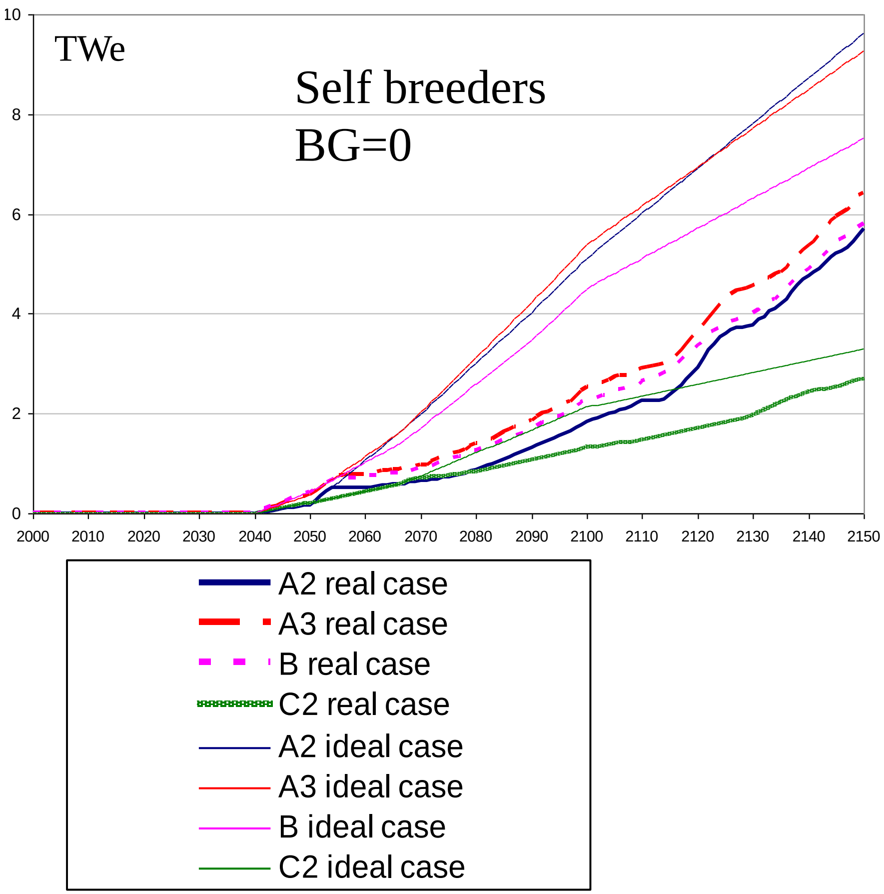
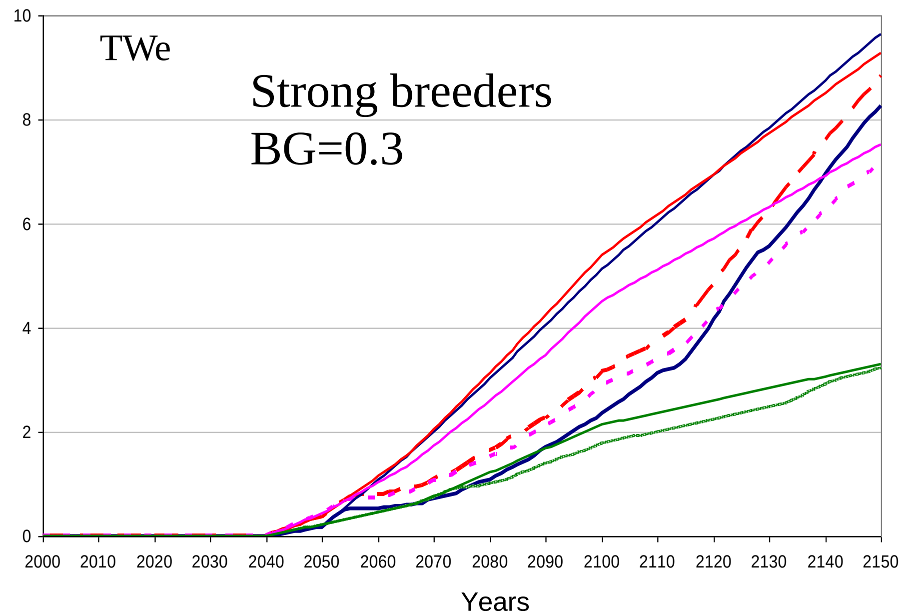
# FR INSTALLED CAPACITY TAKING INTO ACCOUNT PU AVAILABILITY

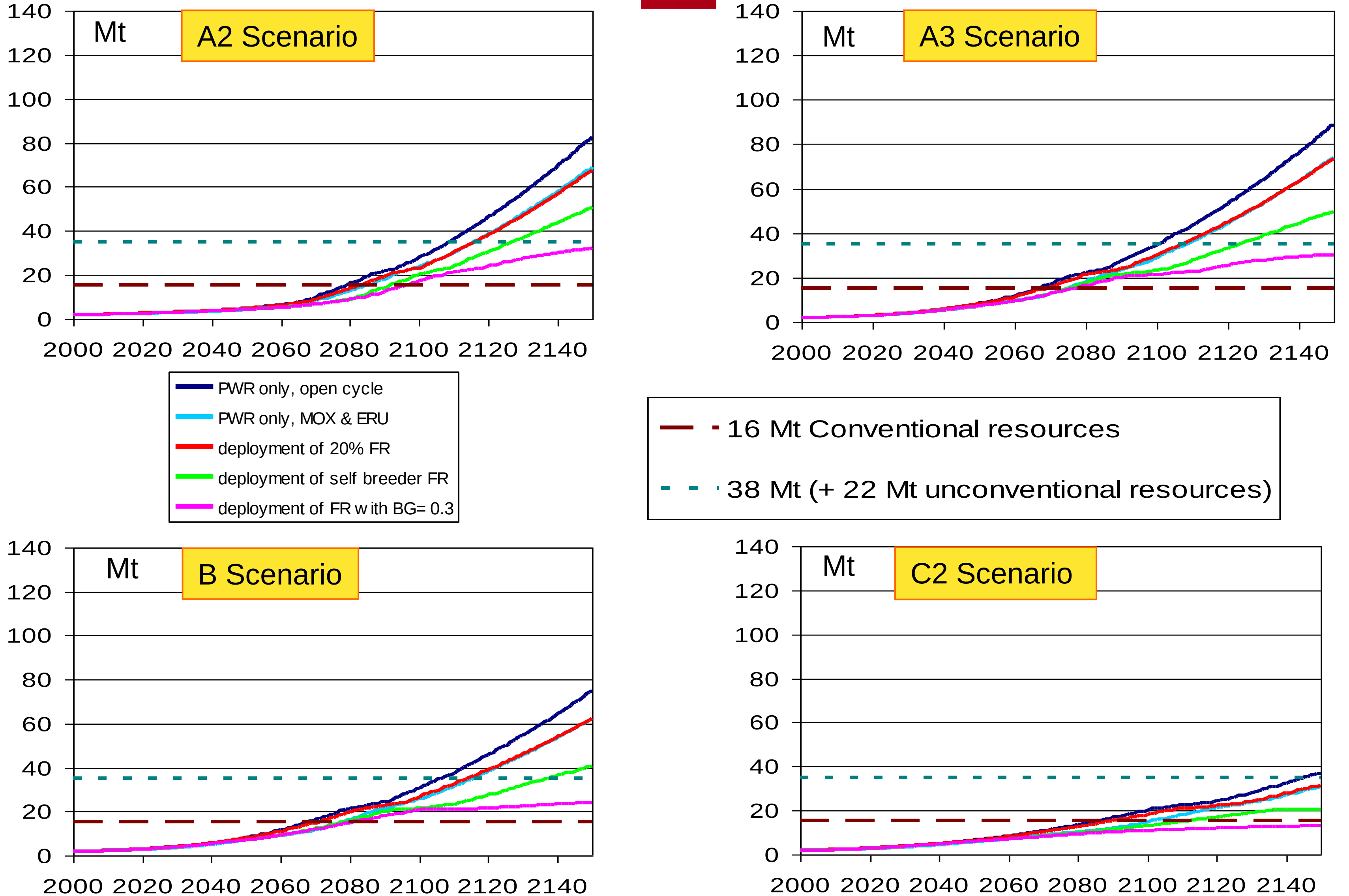



Throughout the period, the installation rate of FR fleet is driven by Pu availability rather than by energy demand.




The impact of the breeding will be significant after a first FR fleet generation, thus from the next century.

# CUMULATIVE NATURAL URANIUM NEED IN MT

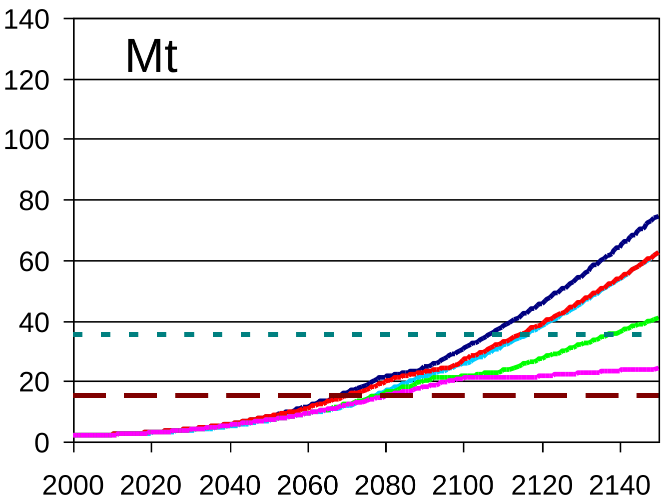


# IIASA B SCENARIO

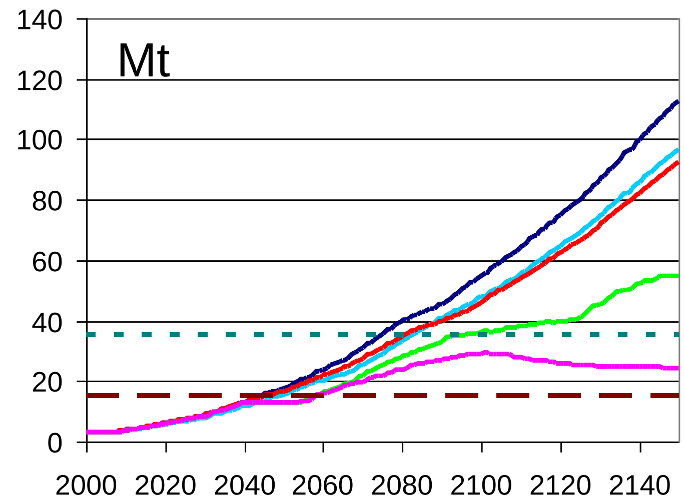
- PWR only, open cycle
- PWR only, MOX & ERU
- deployment of 20% FR
- deployment of self breeder FR
- deployment of FR with BG= 0.3

- 16 Mt Conventional resources
- 38 Mt (+ 22 Mt unconventional resources)

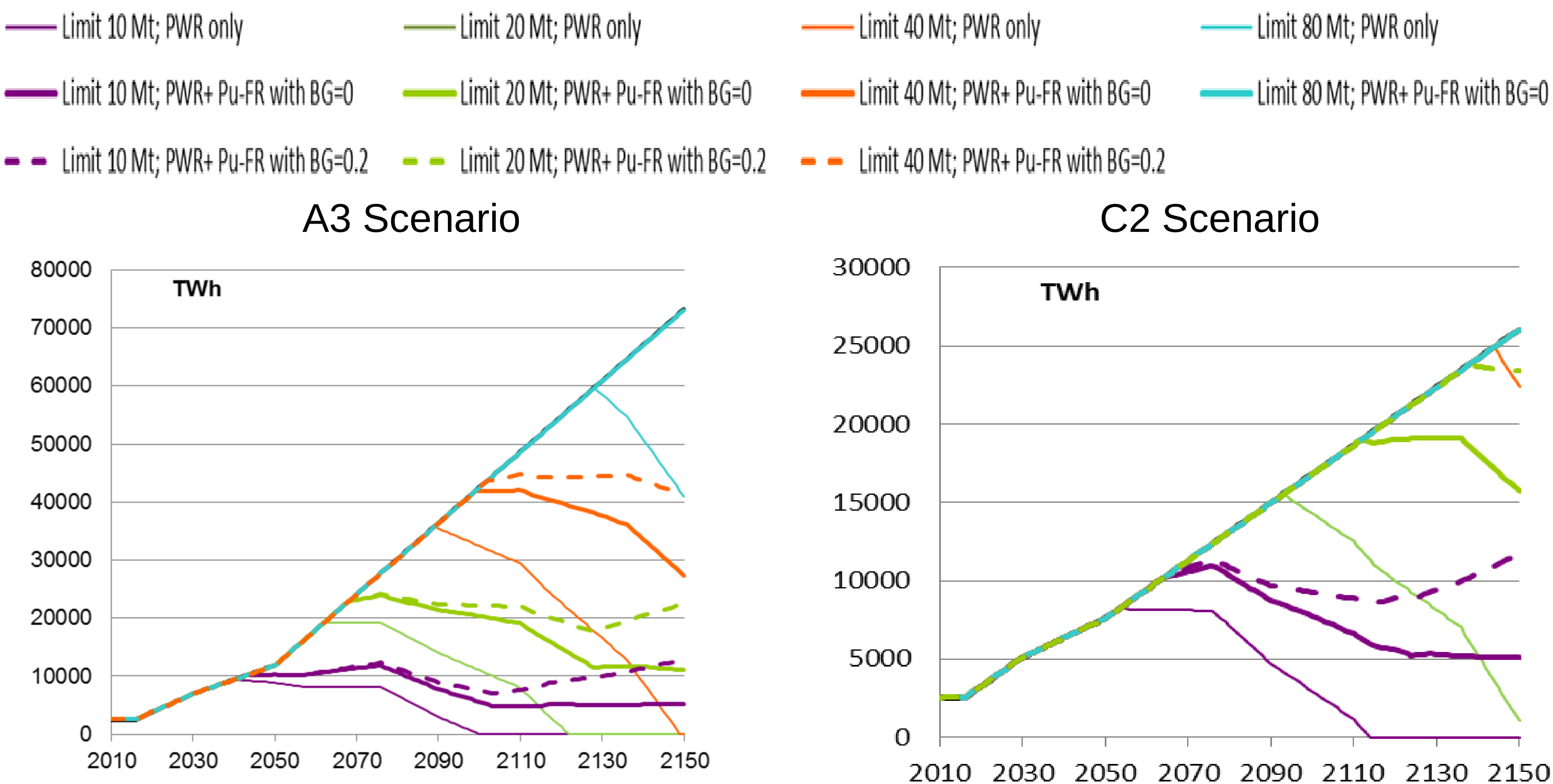
**Consumed Uranium**




**Consumed and committed Uranium**

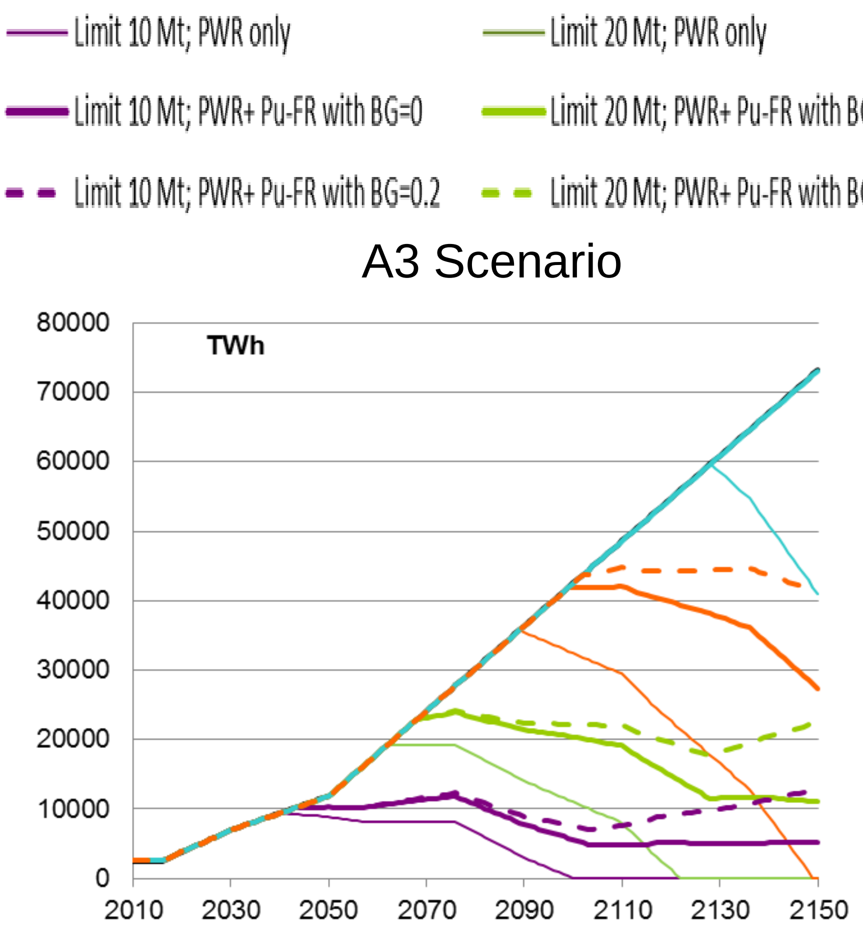



Committed Uranium: future uranium consumption
for the already installed reactors for their remaining life time



Limit 10 Mt; PWR only
Limit 20 Mt; PWR only
Limit 40 Mt; PWR only
Limit 80 Mt; PWR only
Limit 10 Mt; PWR+ Pu-FR with BG=0
Limit 20 Mt; PWR+ Pu-FR with BG=0
Limit 40 Mt; PWR+ Pu-FR with BG=0
Limit 80 Mt; PWR+ Pu-FR with BG=0
Limit 10 Mt; PWR+ Pu-FR with BG=0.2
Limit 20 Mt; PWR+ Pu-FR with BG=0.2
Limit 40 Mt; PWR+ Pu-FR with BG=0.2
A3 Scenario
TWh
80000
70000
60000
50000
40000
30000
20000
10000
0
2010 2030 2050 2070 2090 2110 2130 2150
C2 Scenario
TWh
30000
25000
20000
15000
10000
5000
0
2010 2030 2050 2070 2090 2110 2130 2150

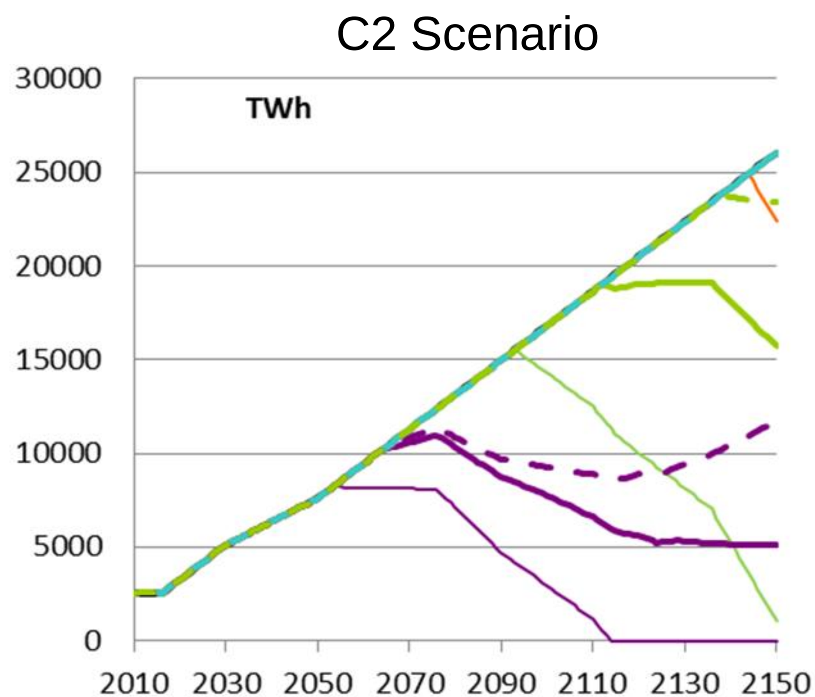
# A3 SCENARIO, PWRs AND PU-FRs




- With FRs it would be possible to maintain nuclear production
- With self-sufficient reactors, an installed power plateau is reached
- Production is increased by breeders but demand is not met
- 80 Mt and self-sufficient reactors are needed

# C2 SCENARIO, PWRs AND Pu-FRs

Limit 10 Mt; PWR only
Limit 20 Mt; PWR only
Limit 40 Mt; PWR only
Limit 80 Mt; PWR only
Limit 10 Mt; PWR+ Pu-FR with BG=0
Limit 20 Mt; PWR+ Pu-FR with BG=0
Limit 40 Mt; PWR+ Pu-FR with BG=0
Limit 80 Mt; PWR+ Pu-FR with BG=0
Limit 10 Mt; PWR+ Pu-FR with BG=0.2
Limit 20 Mt; PWR+ Pu-FR with BG=0.2
Limit 40 Mt; PWR+ Pu-FR with BG=0.2




- A less constrained scenario
- More than 20 Mt with breeder reactors are needed
- Or 40 Mt with self-sufficient reactors

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# CONCLUSION 1/2

- A large increase of the nuclear installed capacity in the prospective scenarios (up to 2100 from 5 to 20 times that of today)
  - ↳ a challenge for nuclear technology
- Constraints on uranium resources?
  - ↳ Nuclear is not sustainable with only LWRs
  - ↳ The fourth generation is therefore essential
- Constraints on Plutonium availability
  - ↳ The installation rate of the FR fleet is limited by the Pu availability

# CONCLUSION 2/2

- Importance of uranium resources
  - importance of mining exploration
- Importance of research on the fourth generation of reactors
  - FRs with highly performing technological characteristics (breeding gain, core size, cooling time, FRs started up with enriched uranium…)

**Will nuclear be able to develop as the prospective scenarios foresee?**

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**Thank you for your attention**