For the Development and Wide Use of the Next Generation Innovative Reactors

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Securing Energy Resources and S+3E

- The Sixth Energy Basic Plan (approved by the Cabinet in October 2021) states that "The cornerstone of energy policy is to place priority on energy security (E: Energy security) on the premise of safety (S: Safety), to realise low-cost energy supply by improving economic efficiency (E: Economic efficiency), and at the same time to make maximum efforts to achieve environmental compatibility (E: Environment).
- The Basic Law on Atomic Energy promulgated in December 1955 states that, by promoting the use of nuclear energy, "energy resources should be secured, academic progress should be made and industry should be promoted, thereby contributing to the welfare of human society and the improvement of the standard of living of the people.
- In 1956, the first 'Long-Term Plan for the Development and Use of Atomic Energy' stated: ‘The basic policy is to establish a domestic self-sufficiency system for nuclear fuel and to establish a fuel cycle suited to the actual conditions in our country. The aim was to produce power reactors domestically, and from the perspective of the effective utilisation of nuclear fuel resources and the expectation of lower energy costs, a breeder power reactor’ was chosen.

Environmental Protection and Sustainable Development

- In view of the fact that energy is indispensable for the stabilisation and improvement of people's lives and the maintenance and development of the national economy, and that its use has a significant impact on the regional and global environment, the Government of Japan has established a basic policy and clarified the responsibilities of the State and local governments with regard to measures concerning the supply and demand of energy. The purpose is to promote measures for energy supply and demand in a long-term, comprehensive and systematic manner, thereby contributing to the conservation of the regional and global environment and to the sustainable development of the Japanese and global economies and societies.

Energy and economic security perspectives

Viewpoint of impacts on the local and global environment

Basic Law on Energy Policy (entered into force in June 2002).
https://elaws.e-gov.go.jp/search/elawsSearch/elaws_search/lsg0500/detail?lawId=414AC1000000071

Energy Mix

- Framework for Nuclear Energy Policy (approved by Cabinet in October 2005)
  - In order for nuclear power to continue to make a significant contribution to a stable energy supply and to the fight against global warming, we aim for nuclear power to continue to provide 30-40% of total electricity generation after 2030, which is around the current level or even higher.

- Sixth Energy Basic Plan (approved by Cabinet in October 2021)
  - Energy savings 1,092 billion kWh to 864 billion kWh (21%)

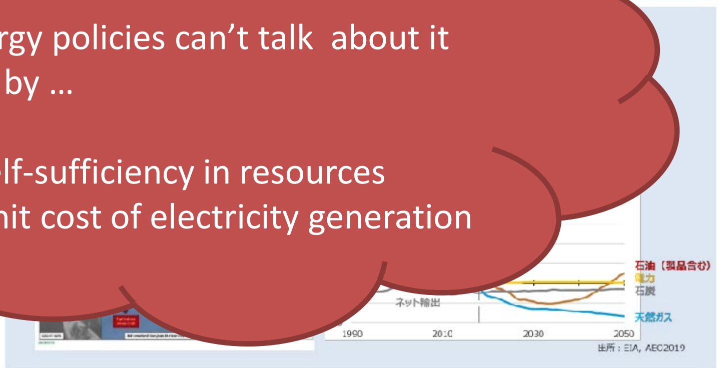
  - Renewable energy 36-38%
  - Nuclear 20-22%
  - Hydrogen and Ammonia 1%
  - Liquefied Natural Gas 20%
  - Coal 19%
  - Petroleum 2%

Diverse Risks to Consider

- Geopolitical risks (amplified by technological change)
  - Risk of fossil resource price volatility
- Geo-economic risk
  - Risk of dependence on other countries for advanced technology
- Risks associated with the power grid
  - Risk of cyber-attacks on the power grid
- Risks of each energy source
  - Natural variability risk of renewable energy systems
  - Accident risk in nuclear systems
  - Geopolitical risks of fossil systems
  - Rare metal risks in energy storage systems
- Risk of inferiority in energy competition
  - Investment in technology development, investment in power generation, investment in transmission network reinforcement, investment in distributed networks, investment abroad

<Natural Disasters>

Blackout by earthquakes
Power grid failure by typhoon



Energy policies can't talk about it just by …

+ Self-sufficiency in resources
+ Unit cost of electricity generation

<Corresponding to Paris Treaty>

Presenting Long-term strategy
Energy/Environment Ministers meeting at G20

Prepared based on the Fifth Basic Energy Plan
https://www.meti.go.jp/press/2018/07/20180703001/20180703001.html

Overall Basic Energy Plan

- An important theme is to set out a path for energy policy to realise the new reduction targets of carbon neutrality in 2050, a 46% reduction in 2030, and the challenge to go higher by 50%.

- Another important theme is overcoming the challenges posed by Japan's energy supply and demand structure. On the basic premise of ensuring safety, efforts will be made to ensure a stable supply and reduce energy costs (S+3E), even as climate change measures are promoted.

48th Meeting of the Basic Policy Subcommittee of the General Resources and Energy Research Council, Document 3, 4 August 2021.

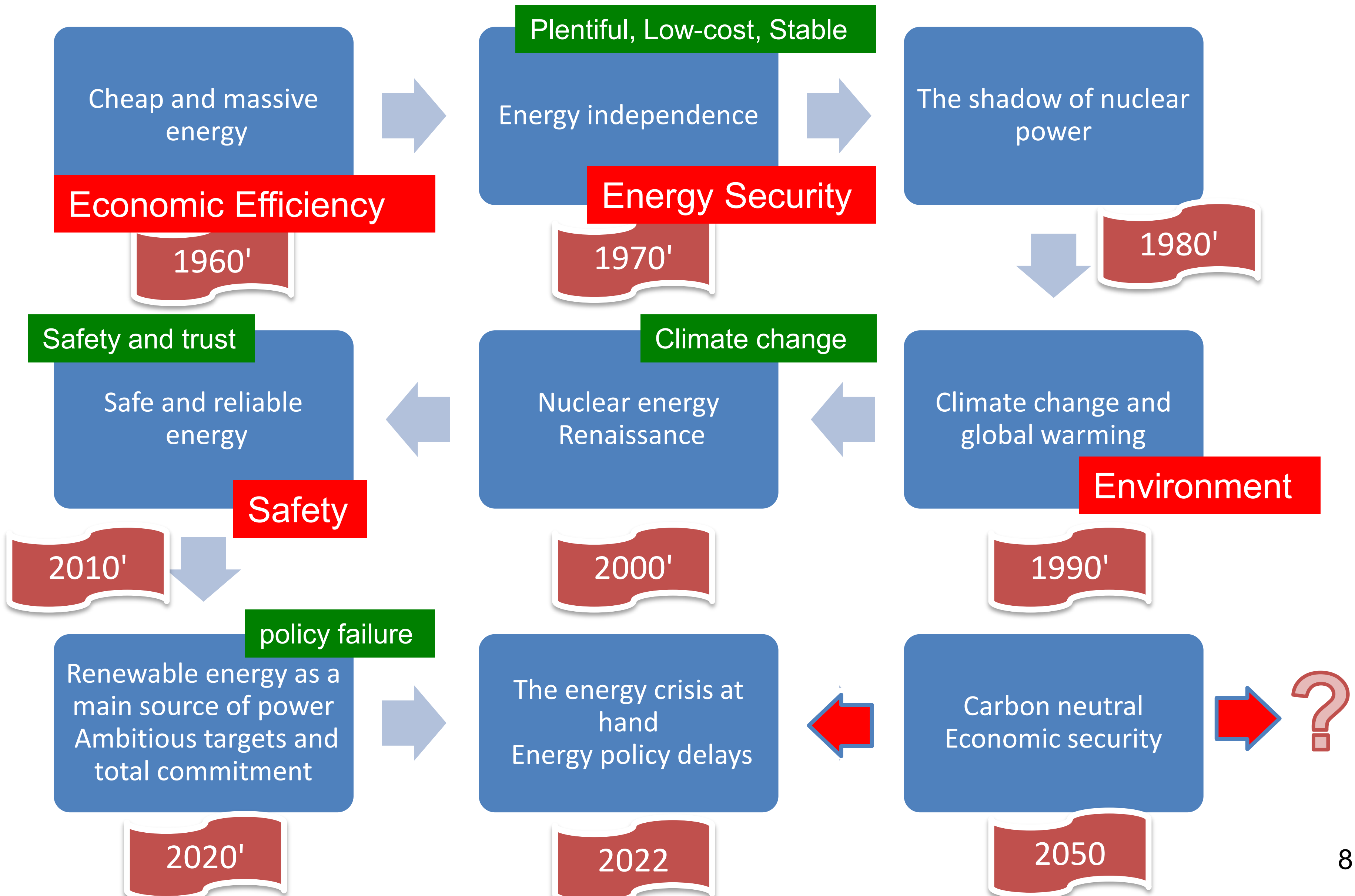
Movements during the First Year after the Basic Energy Plan

- 'Oil and gas market disturbance' caused by Russia's invasion of Ukraine
- The era of 'security-directed energy crises', which could be structural and cyclical
- Global 'fault line fluctuations' in energy

2nd GX Implementation Conference, 24 August 2022

In Japan, the 'Energy crisis at hand' and 'Energy policy delays' are evident

Energy Policy Transition



Logistic Models of Energy Sharing

- If the share accounted for by one energy source is ***F***, the rate of change in ***lnF*** is proportional to the share of other energy sources (***1 - F***) (logistic equation)

$$\frac{1}{F}\frac{dF}{dt} = \frac{dlnF}{dt} = \alpha(1-F)$$

$$ln\left(\frac{F}{1-F}\right)=\alpha t + c$$

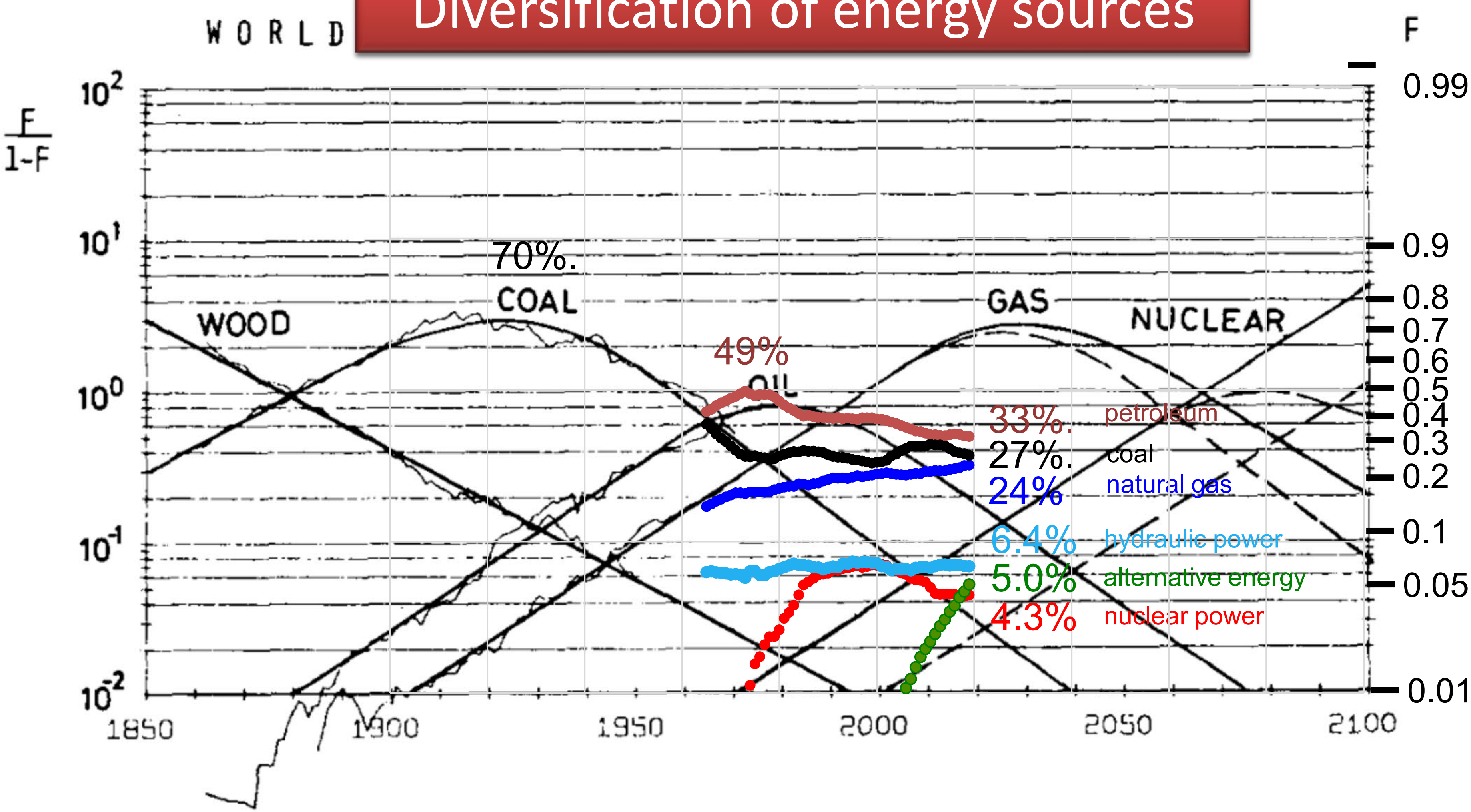
Coal 27.0%
Petroleum 33.1%
Gas 24.2%
Nuclear 4.3
Hydro power 6.4
Renewable energy 5.0

- $ln\left(\frac{F}{1-F}\right)$ is a straight line slope of α with respect to t

  → growing phase, stagnant phase, declining phase
- The sum of the shares of each energy source is $\sum F_i = 1$

Marchetti Energy Forecasts

Diversification of energy sources



C. Marchetti, Primary Energy Substitution Models: On the Interaction between Energy and Society, TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE 10,345-356 (1977)

Prospects for the Future of Energy

- Before 1970, the emergence of new energy technologies replaced the old ones. The following were successively to play a leading role in energy.
  - Firewood (plentiful, low-cost, stable)
  - Coal (plentiful, low-cost, stable)
  - Oil (plentiful, low-cost, stable)
  - Gas (plentiful, low-cost, stable)
  - Nuclear: light water reactors (plentiful, low-cost, stable)
- The oil crisis was an opportunity to diversify power sources.
- In some countries, international interconnection lines and abundant hydropower contributed to plentiful, low-cost and stable stockpiling functions.

- The environment related to the value of energy as 'plentiful, affordable and stable' has changed significantly in the wake of electricity deregulation and climate change response trends.
  - Excessive expectations on renewable energy
  - Lack of business predictability to plentiful, low-cost and stable power sources

Plentiful, Low-cost and Stable ⇒ S+3E ⇒ to 3S+E

- Safety
  - operational safety
  - Assessment and management of accident risks
- Security
  - Self-sufficiency in resources
  - Self-sufficiency in technology
  - Managing risk
- Sustainability
  - Long-term use of resources
  - Protection of the environment
- Economic Efficiency
  - life cycle cost
  - system cost
  - financial risk

Nuclear Policy towards Green Transformation

~Spring 2023 ~Spring 2024 ~2030 years ~2050 years

(Until this winter)

Already restarted]
10 units (western Japan)
● Efforts to shorten construction, adjusting inspection schedules, etc.
→ Securing the operation of **up to nine units**

(i) Acceleration of resumption of operations (emergency measures) (20-22% realised in 2030)
*To accelerate the respective public and private sector responses
Response to be compiled in autumn this year

(next summer/winter ~)

Installation permitted]
7 units (including in eastern Japan)
*Differences exist in construction progress, etc.
● Smooth implementation of safety works and steady resumption of operations **(Takahama 1 and 2, Onagawa 2, Shimane 2)**
● Efforts to secure local understanding **(Kashiwazaki Kariwa, Tokai No. 2)**
-State-fronted response, reform of operational structures, etc.

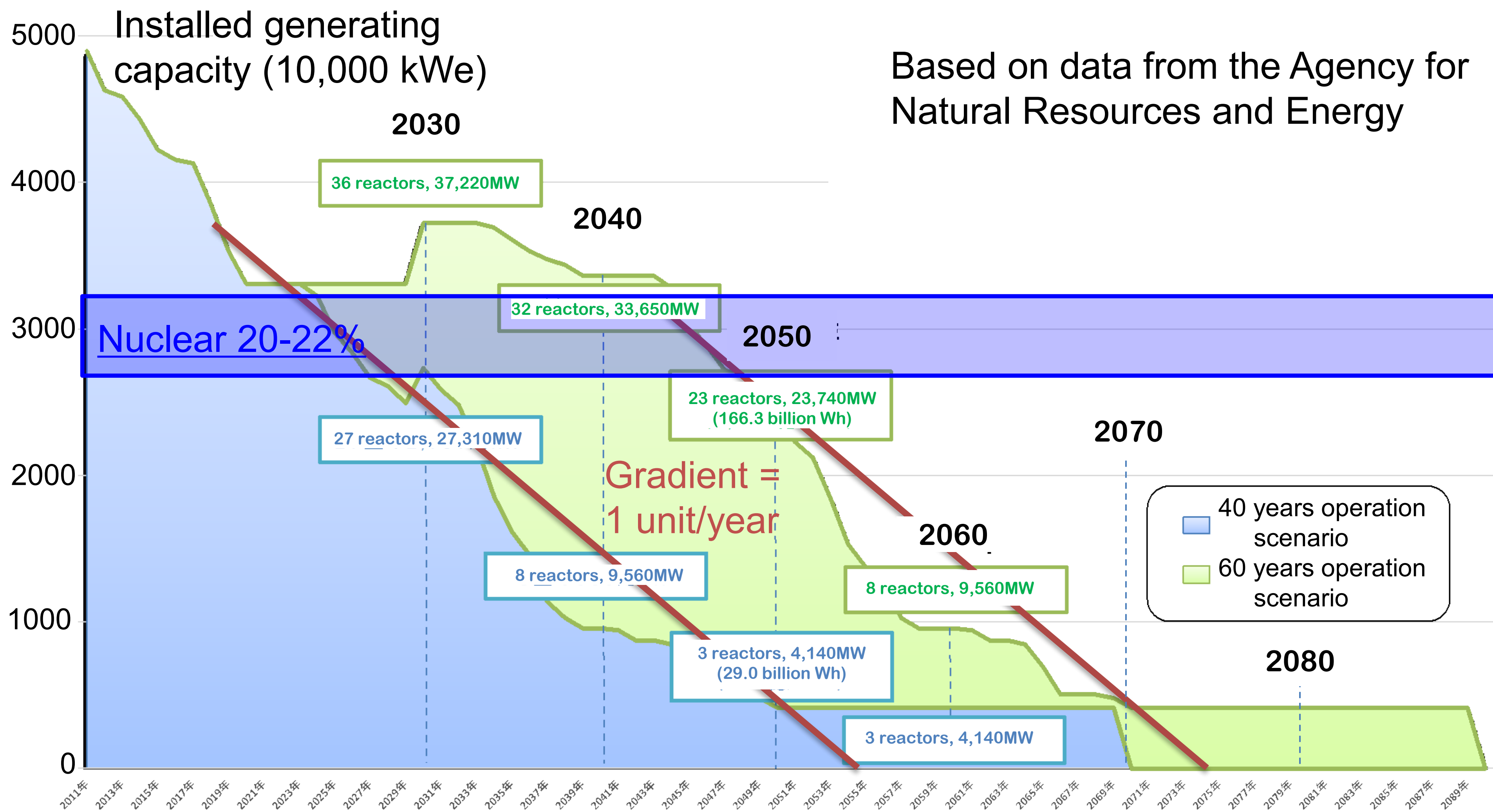
(mid-2000s~)

[Installation permit review]
10 units applied for, 9 units not yet applied for
●Improved mutual communiqués for accurate screening responses.
National efforts to ensure understanding, development of the business environment, etc.

(ii) 2050CN realisation and stable supply (Policy restructuring)
***Compilation of specific issues by the end of this year**

[Structural challenges looking beyond the resumption of operations]
Ensuring options: development and construction of next-generation innovative reactors, extension of operation periods, etc.
Ensuring predictability: national initiatives at the back end, development of the business environment, etc.

Scenarios for Nuclear Power Generation Ratios



Towards 2030. Steady resumption of operations

Towards 2040. Maximum utilisation

Towards 2050. Next generation innovative reactors

Next Generation Innovative (fission) Reactor Development

- Innovative Light Water Reactor
  - Priority is given to the development of innovative LWRs that link the LWR supply chain, have predictable regulatory requirements, have a foreseeable time of realisation and innovative safety improvements.
- Small Light Water Reactor
  - Contributing to international cooperation and supporting the supply chain in acquiring business opportunities, while securing options with future needs in mind, such as investment risk reduction and distributed power supply.
- Fast Reactor
  - Nuclear technology, including existing light water reactors, acquires resource recyclability. Based on discussions in the Fast Reactor Development Council/Strategy Working Group, the development reactor type has been fleshed out. The experience gained from JOYO and MONJU will be utilised to the maximum extent as a strength, and international collaboration will be promoted.
- High Temperature Gas-cooled Reactor
  - Development is being promoted with a view to cogenerating carbon-free electricity, heat and hydrogen for industrial decarbonisation, while also pursuing the possibility of international collaboration. Heat utilisation and hydrogen demonstrations are also being promoted using the test reactor HTTR.

Subcommittee on Nuclear Energy, Subcommittee on Electricity and Gas Industry, General Resources and Energy Research Council (29th meeting, 9 August 2022) Technology roadmap for the development of innovative reactors (draft outline).

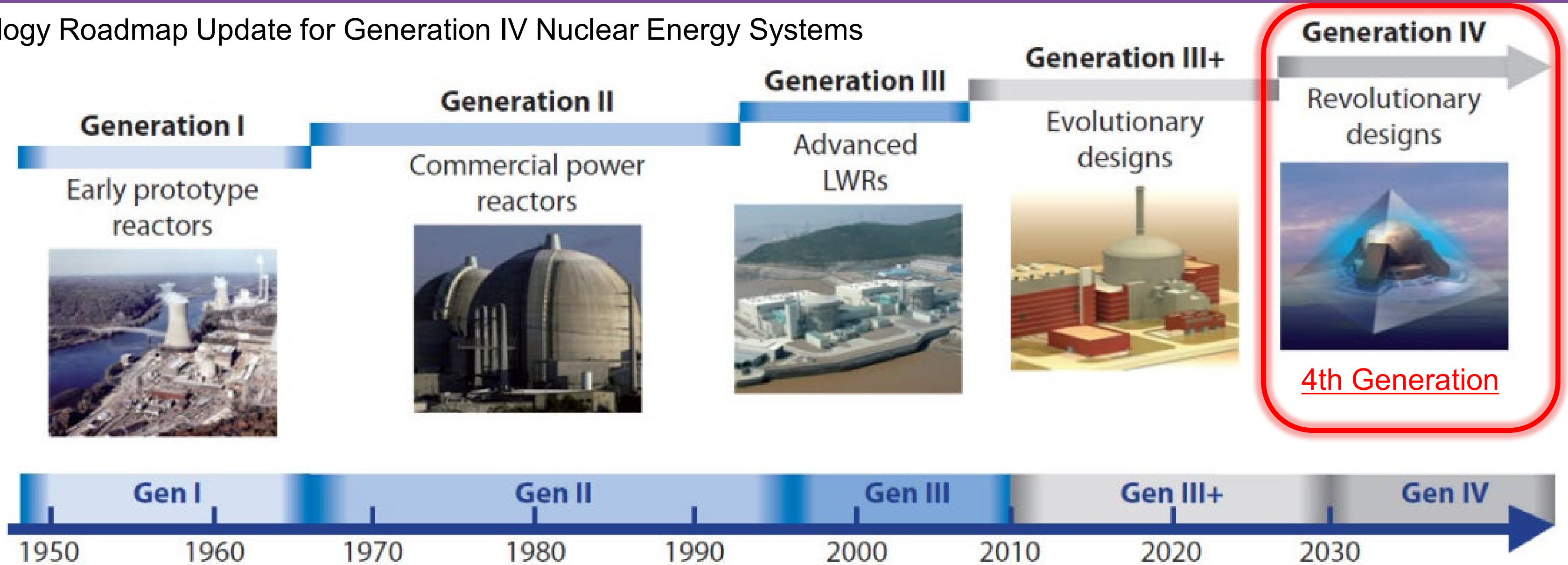
Classification of Small Modular Reactors

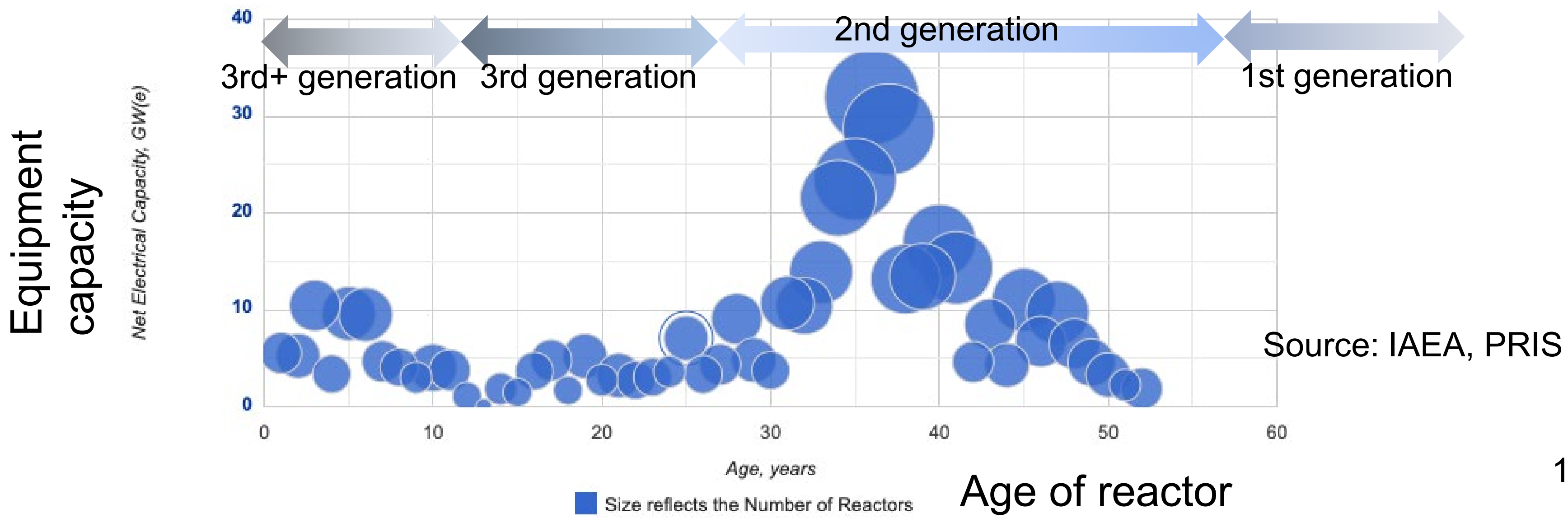
- **light water - monoplane**
  - By already established light water reactor technology and fuels
  - Useful as a successor to small thermal power plants or as a distributed power source
- **light-water - multi-machine**
  - By already established light water reactor technology and fuels
  - Useful as a medium baseload or distributed power source
- **portable**
  - Currently, it uses light water reactor technology and can be easily moved from one location to another
  - Floating reactors are also included
- **4th generation**
  - Using innovative non-light water reactor technology, discussed at the International Generation IV Reactor Forum
  - Enables effective use of resources and high-level waste volume reduction and toxicity reduction
- **Micro-module Reactor**
  - Autonomous operation is possible with power outputs below 10 MW
  - Improved portability, mainly used in remote areas where grid connection is not possible

Small Modular Reactors: Challenges and Opportunities, OECD 2021 NEA No. 7560

What is "Generation" of Nuclear Power Plant?

Technology Roadmap Update for Generation IV Nuclear Energy Systems





Fourth Generation Nuclear Energy Systems

8 objectives in four areas that respond to the economic, environmental and social imperatives of the 21st century

- Sustainability
  - Can provide global, sustainable energy production (clean, long-lasting systems that make good use of fuels)
  - Minimise and manage radioactive waste, particularly to reduce the long-term management burden, thereby improving public health and environmental protection
- Economy (saving money)
  - Clear life cycle cost advantages over other energy sources
  - Its financial risk is at the same level as projects of other energy sources
- Safety and Reliability
  - Excellent safety and reliability during operation
  - Extremely low frequency of core damage occurrence and its impact
  - No off-site emergency response required
- Proliferation Resistance and Physical Protection
  - Increase assurance that material that can be diverted to weapons is highly unattractive and difficult to route for diversion or theft, and enhance protection of nuclear material against acts of terrorism

GIF 2021 ANNUAL REPORT, IAEA, https://www.gen-4.org/gif/

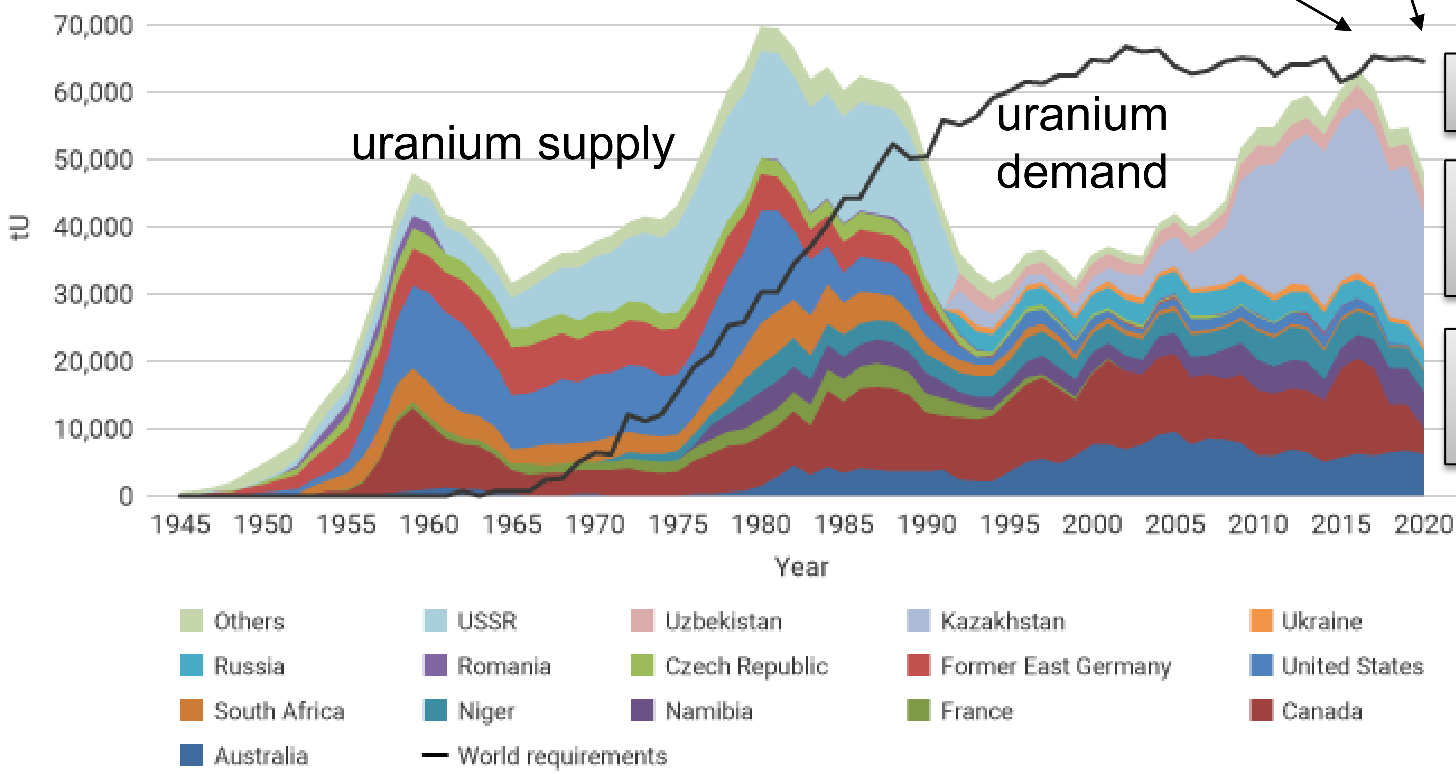
Uranium Supply and Demand, known Resources and Years of Use

cost	Known resources (tU)	Years of use
<USD 260/kgU	8,070,400	129
<USD 130/kgU	6,148,300	98
<USD 80/kgU (reference)	2,007,600	32

uranium supply

2016. 63,207 tU

2020. 47,731 tU



uranium demand Prediction (tU)

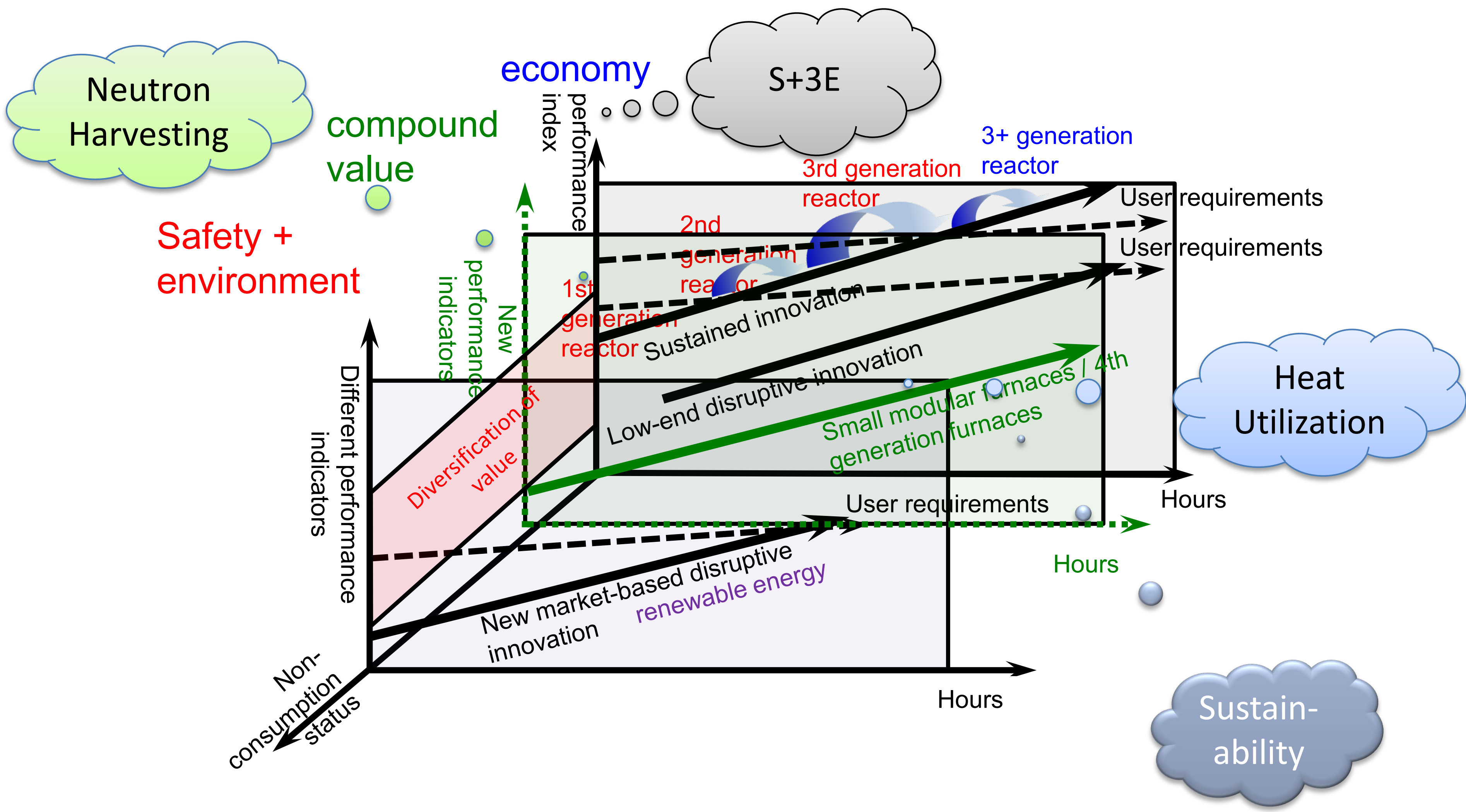
2021 62,500

2030 79,400
70,000 - 99,000

2040 112,300
79,400 - 156,500

Source: World Uranium Mining - World Nuclear Association (world-nuclear.org)
Uranium 2020, Resource, Production and Demand, IAEA

Combined Value-based Innovation



Christensen, The Final Solution to Innovation, Shoei (2014), Figure 1-1

Invention is the Mother of Necessity

- Necessity is the mother of invention - This is an illusion!
  - Does an extraordinary genius take a social need and make a great invention to fulfil it??
- Invention is the mother of necessity - This is the reality!
  - In reality, it improves on the inventions of numerous predecessors
  - A great invention is born when there is an application to which the invention matches, when the application of the invention is found
- Economic efficiency, social status, compatibility with existing systems, straightforward benefits

Continued innovation calls for social needs

Jared Diamond, Guns, Germs, and Steel The Fates of Human Societies, 1997
Jared Diamond, Guns, Germs and Iron, 2000, Soshisha Library

At the End

- Charles Robert Darwin
  - 12 February 1809 - 19 April 1882.

- It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.