次世代原子力技術の概観

CIGS　地球温暖化シンポジウム　2016
地球温暖化問題における原子力エネルギーの役割

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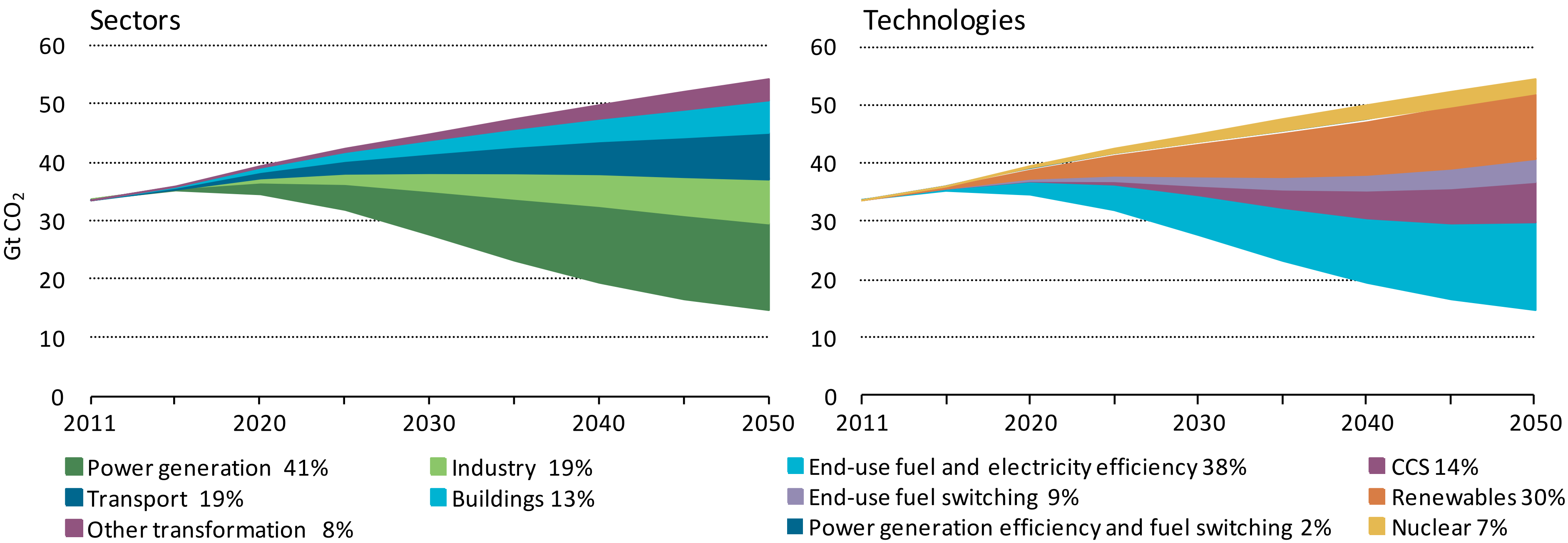
The Institute of Applied Energy

IEA Flagship Publication, Energy Technology Perspectives



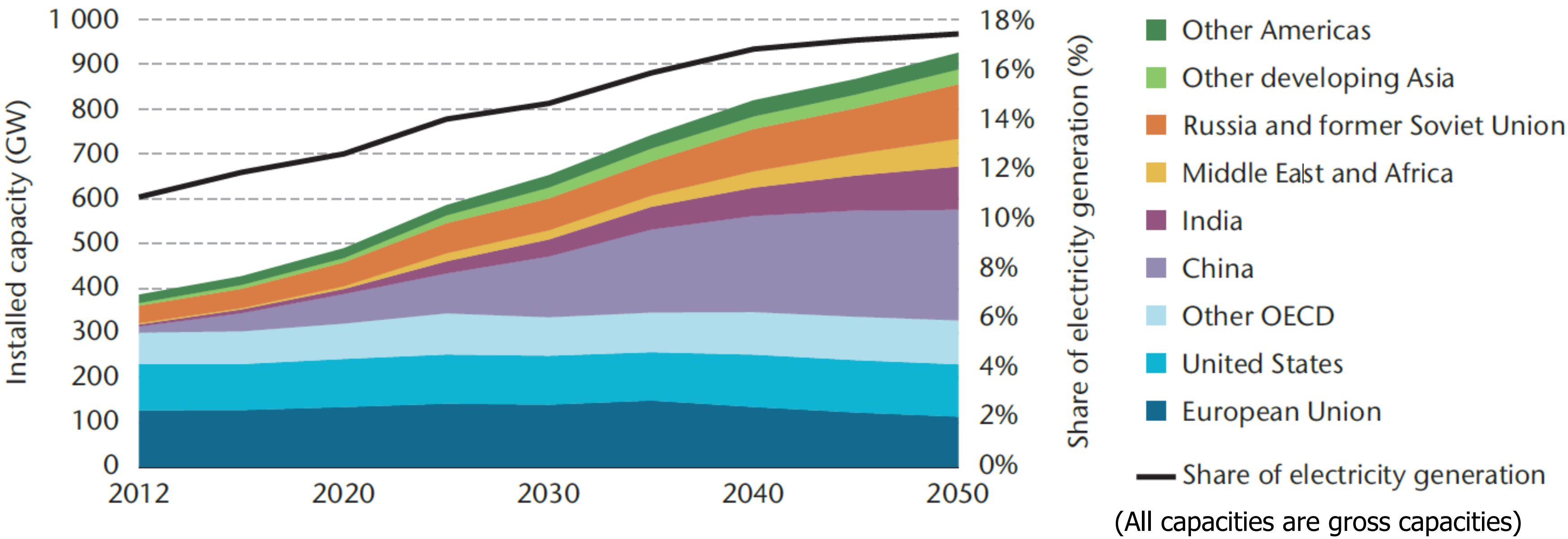
Source: Energy Technology Perspectives 2014

- **6° C Scenario – business-as-usual; no adoption of new energy and climate policies**
- **2° C Scenario - energy-related CO_2-emissions halved by 2050 through CO_2-price and strong policies**

Technology Roadmap / Nuclear Energy /2015, NEA&IEA

Nuclear in the 2°C Scenario (2DS)

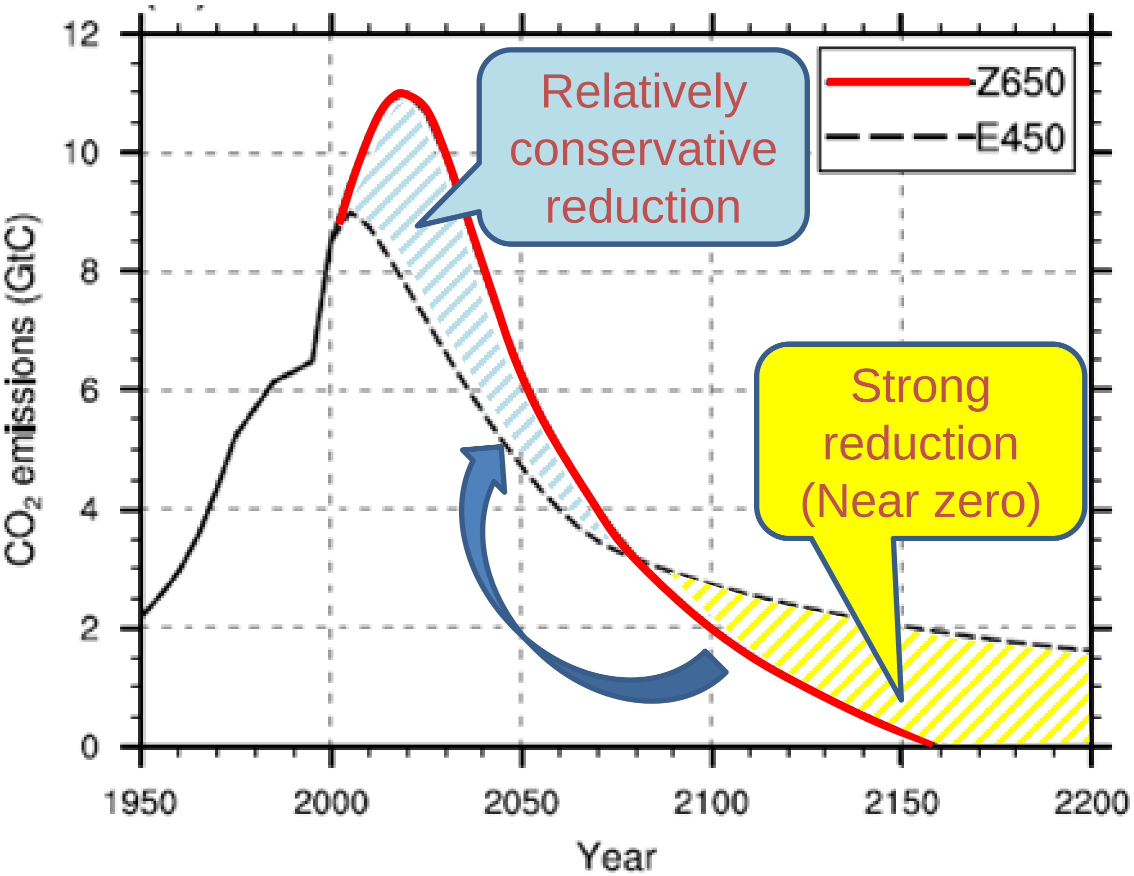
Technology Roadmap / Nuclear Energy /2015, NEA&IEA



- **930 GW by 2050 (down from 1200 GW)**
- **17% share electricity (down from 24%)**
- **But still a formidable challenge (multiply current capacity by 2.3 in 35 years)**

CO_2 reduction target from Climate Science

- Integrated value is more important than pathway.



GRAPE standard scenario:

Z650

(650Gt-C before Zero emission is achieved)

By Taroh MATSUNO, Koki MARUYAMA, and Junichi TSUTSUI, Proc. Jpn. Acad., Ser. B 88 (2012) 368

Energy model in this analysis

GRAPE* model is mainly used in this analysis

Society

Population
GDP

Scenario

Final Energy consumption

Input

Optimization:
Minimizing Energy cost

Input

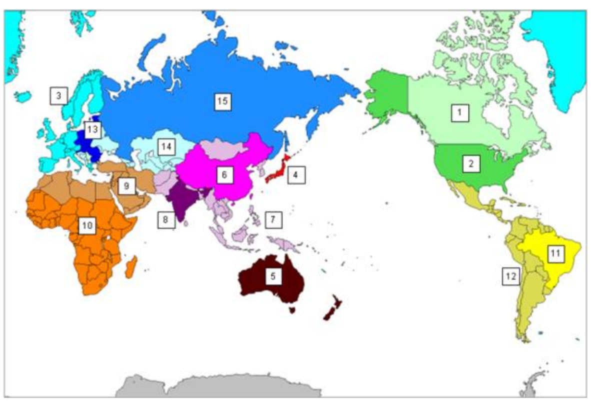
- CO_2 limit
- Potential and unit cost
- transportation and delivery cost
- Plant construction cost

,etc.

Output

Energy supply, transfer

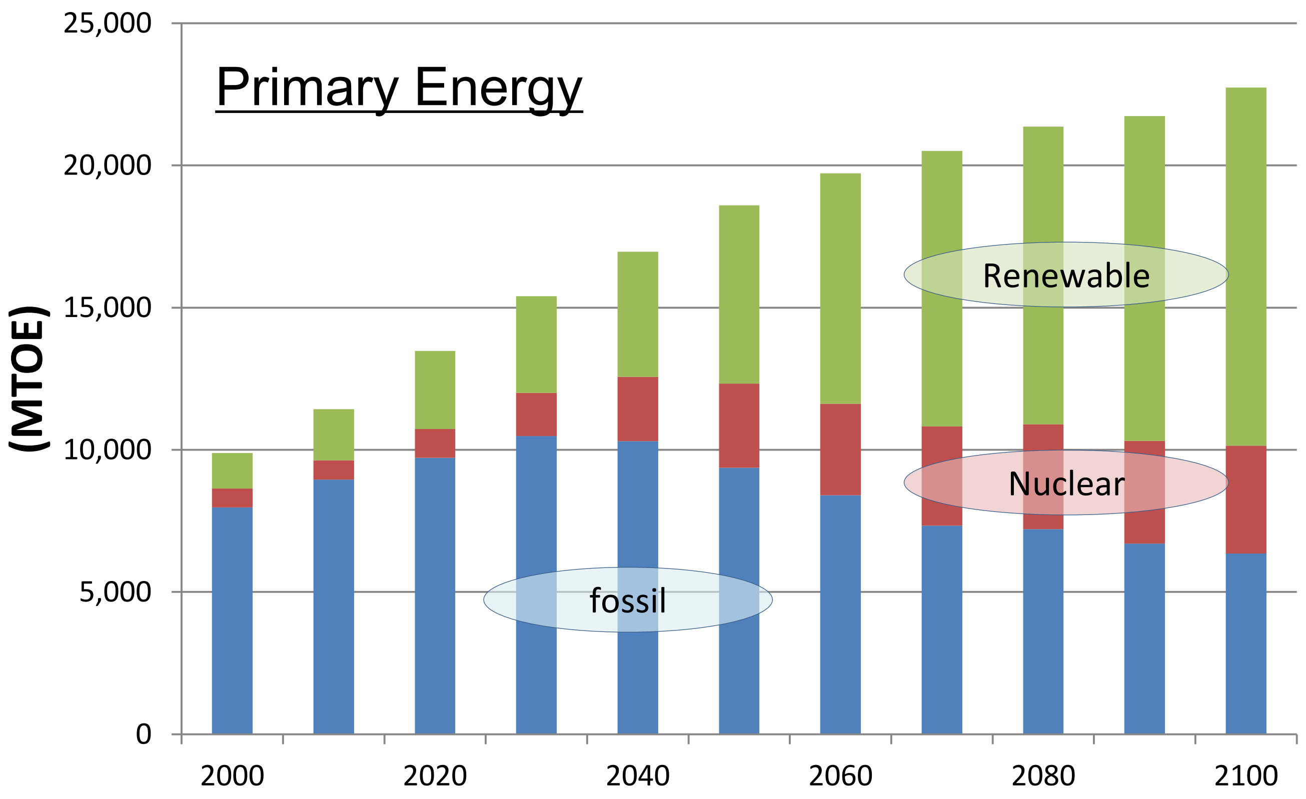
※Fifteen region



*** Global Relationship Assessment to Protect Environment**
Kurosawa et.al., Energy Journal, 157-175 (Kyoto Special Issue)

Energy portfolio to realize Z650

- Share of nuclear and renewable increases.
  - Fossil : Nuclear : Renewable = 5 : 2 : 3 (2050)
  - 3 : 2 : 5 (2100)
- Fossil fuel will play important roll up to 2100.



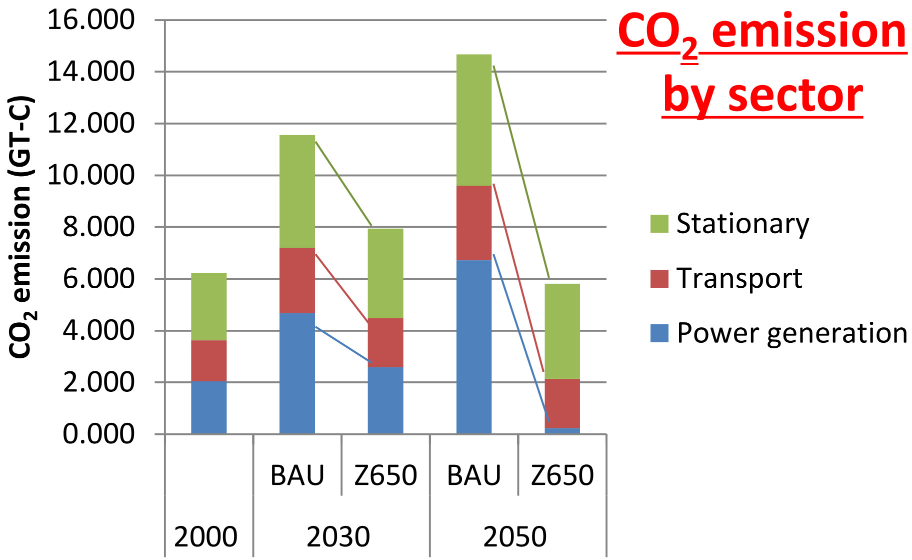
Power generation is most important

- Drastic increase of Nuclear and renewable
  Nuclear : 36GW/year
  Wind : 90GW/year

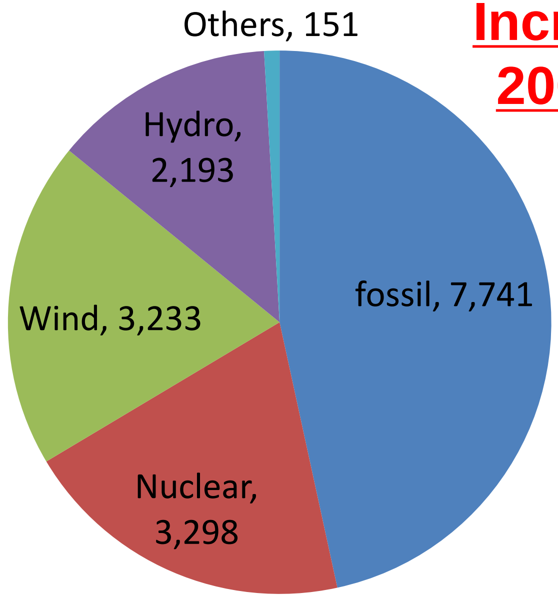
- Improvement of the efficiency is also important especially around 2030.

- CCS is key technology for drastic reduction by almost all new thermal plant after 2030

CO_2 emission by sector



Increase from 2000 to2030 （TWh）

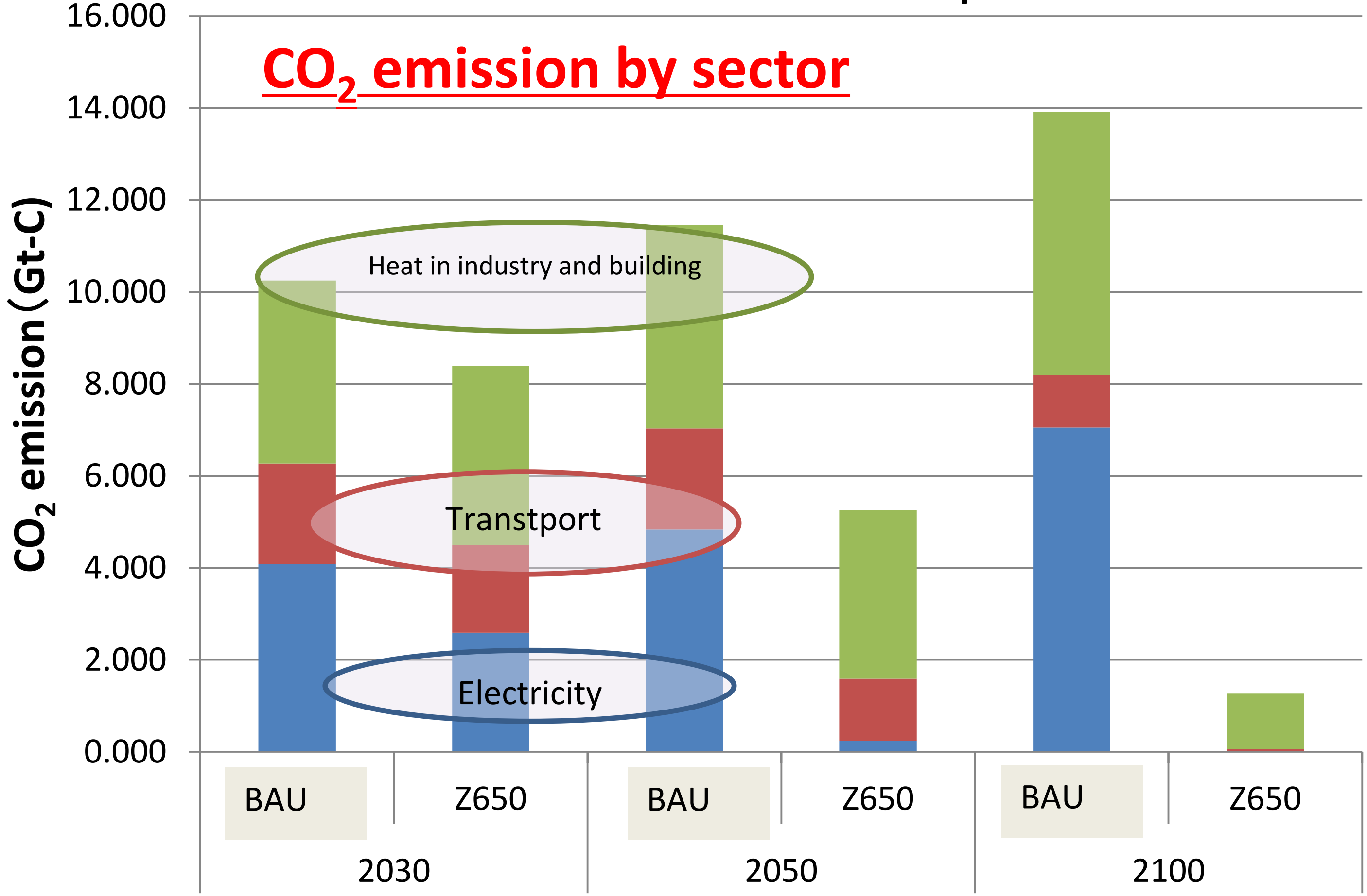


Long term issues

2050 : zero emission in power generation sector

2100 : zero emission in transport sector

remarkable reduction in heat production



Electric power generation

- **Achievement of near zero emission (before 2050)**
  Nuclear, renewable, and CCS

- **Preservation of zero emission**
  Technological development is necessary as follows
  - **Nuclear**
    - ✓ **Uranium resources is not so abundant**
      - **in GRAPE almost all the new construction nuclear plant after 2050 is fast breeder reactor (FBR).**
      - **Other possibility : Uranium from ocean, Thorium, Nuclear Fusion!**
  - **Renewable**
    - ✓ **Instability of output: Battery, hydrogen, and network**
    - ✓ **Land use: Efficiency**
  - **CCS**
    - ✓ **Potential storage sites have to be found.**

GRAPE Analysis Messages

- ***Even for the relatively conservative target like Z650, strong effort will be required to realize.***
  - *Nuclear*
  - *Renewable (mainly wind turbine and photovoltaic)*
  - *Carbon Capture and Storage (CCS)*
  - *Energy conservation*

- ***Drastic decrease of CO_2 emission is unavoidably necessary in the end of this century. Thus continuous development of the key technologies is really important.***
  - *Nuclear : Fuel cycle with recycling and waste management, with presumption of robust safety*
  - *Renewable : Energy storage, network*
  - *Transport : battery, fuel cell, biofuel*
  - *Industry : steel, chemicals, cement, etc.*

Reactor technology evolution

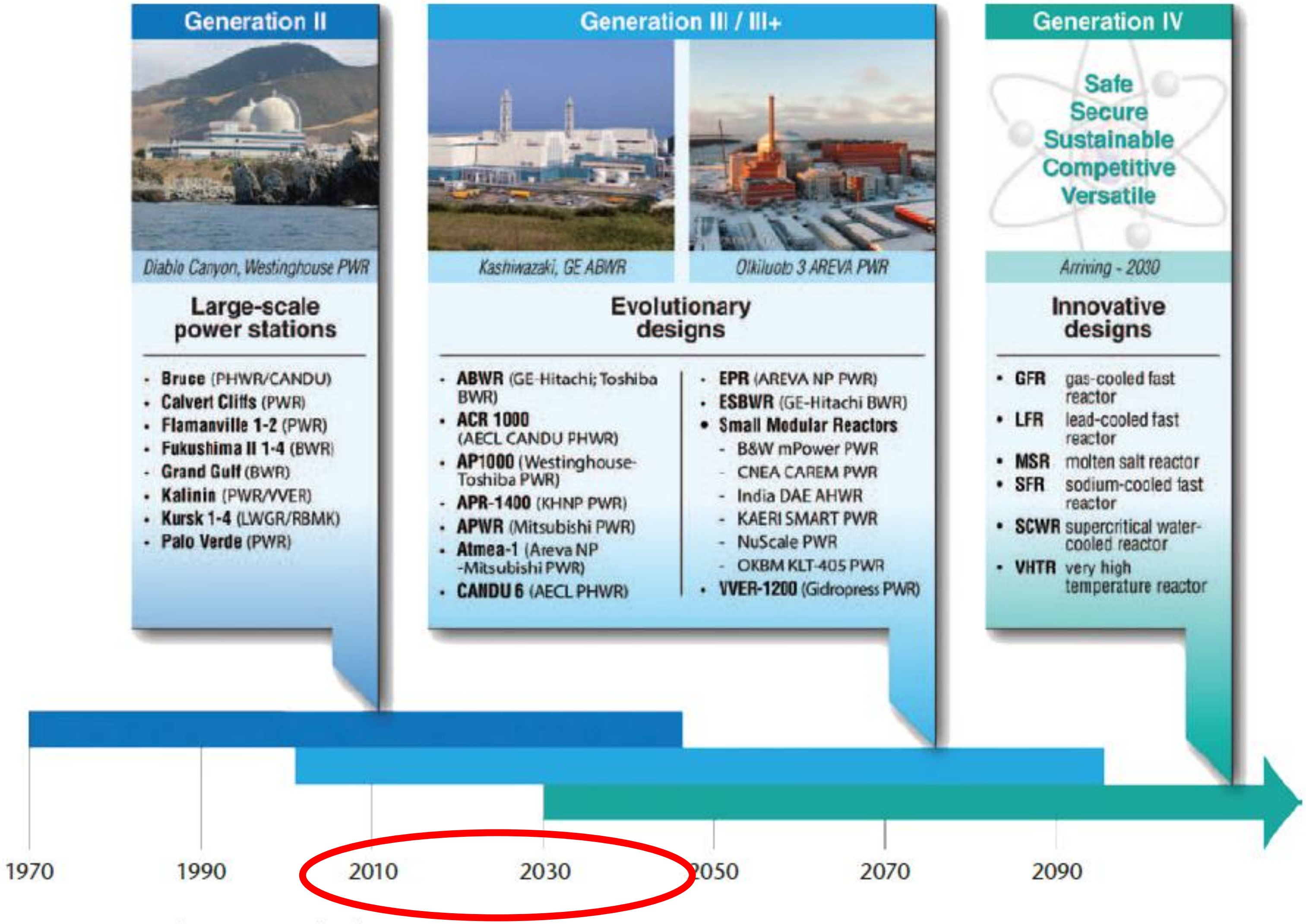
Technology Roadmap / Nuclear Energy /2015, NEA&IEA

- **Safety upgrades & Long Term Operation of existing fleet**
- **Continuous evolution of Gen III/III+ designs:**

- **Small Modular Reactors**
- **Operational aspects**
- **Generation IV (Fast Neutron Reactors)**
- **Cogeneration / non-electric applications**

Reactor technology evolution

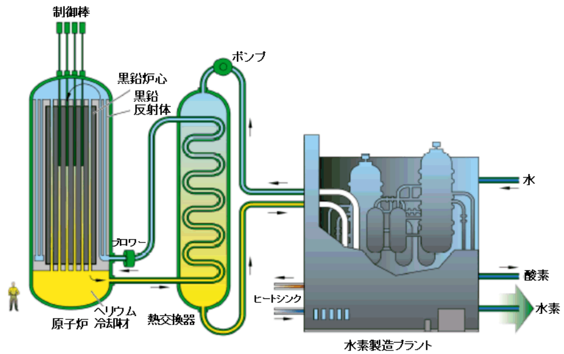
Technology Roadmap / Nuclear Energy /2015



Source: Generation IV International Forum, www.gen-4.org.

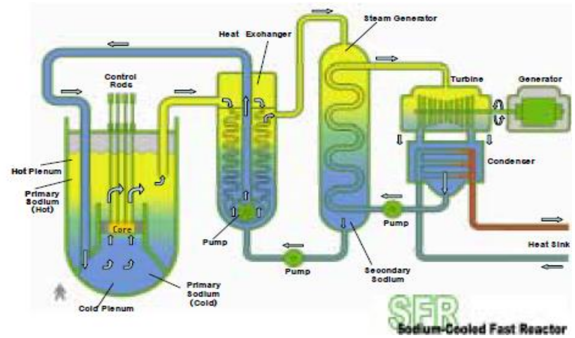
GIF選定6炉型

VHTR,LFR等では、発電以外の用途として水素製造・産業への熱利用、海水淡水化の可能性についても検討している。



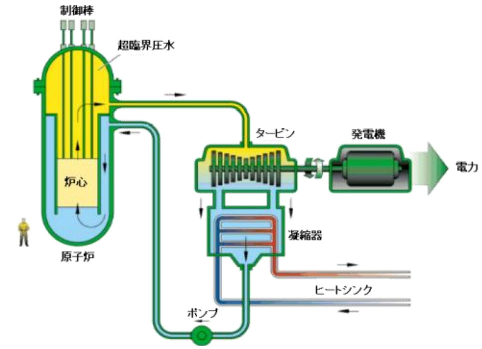
超高温ガス炉（VHTR）

中性子スペクトル：熱中性子
冷却材：ヘリウム
出口温度：900-1000℃
燃料サイクル：オープン
出力：250-300MWe



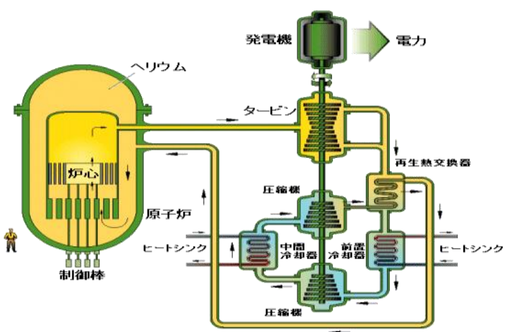
ナトリウム冷却高速炉（SFR）

中性子スペクトル：高速中性子
冷却材：ナトリウム
出口温度：500-550℃
燃料サイクル：クローズド
出力：50-1500MWe



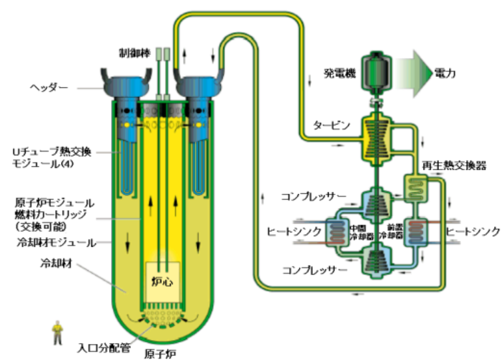
超臨界圧水冷却炉（SCWR）

中性子スペクトル：熱中性子/高速中性子
冷却材：水
出口温度：510-625℃
燃料サイクル：オープン/クローズド
出力：300-1500MWe



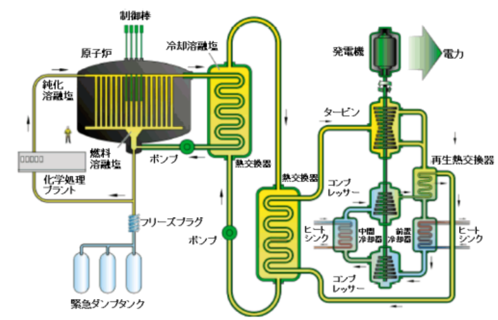
ガス冷却高速炉（GFR）

中性子スペクトル：高速中性子
冷却材：ヘリウム
出口温度：850℃
燃料サイクル：クローズド
出力：1200MWe



鉛冷却高速炉（LFR）

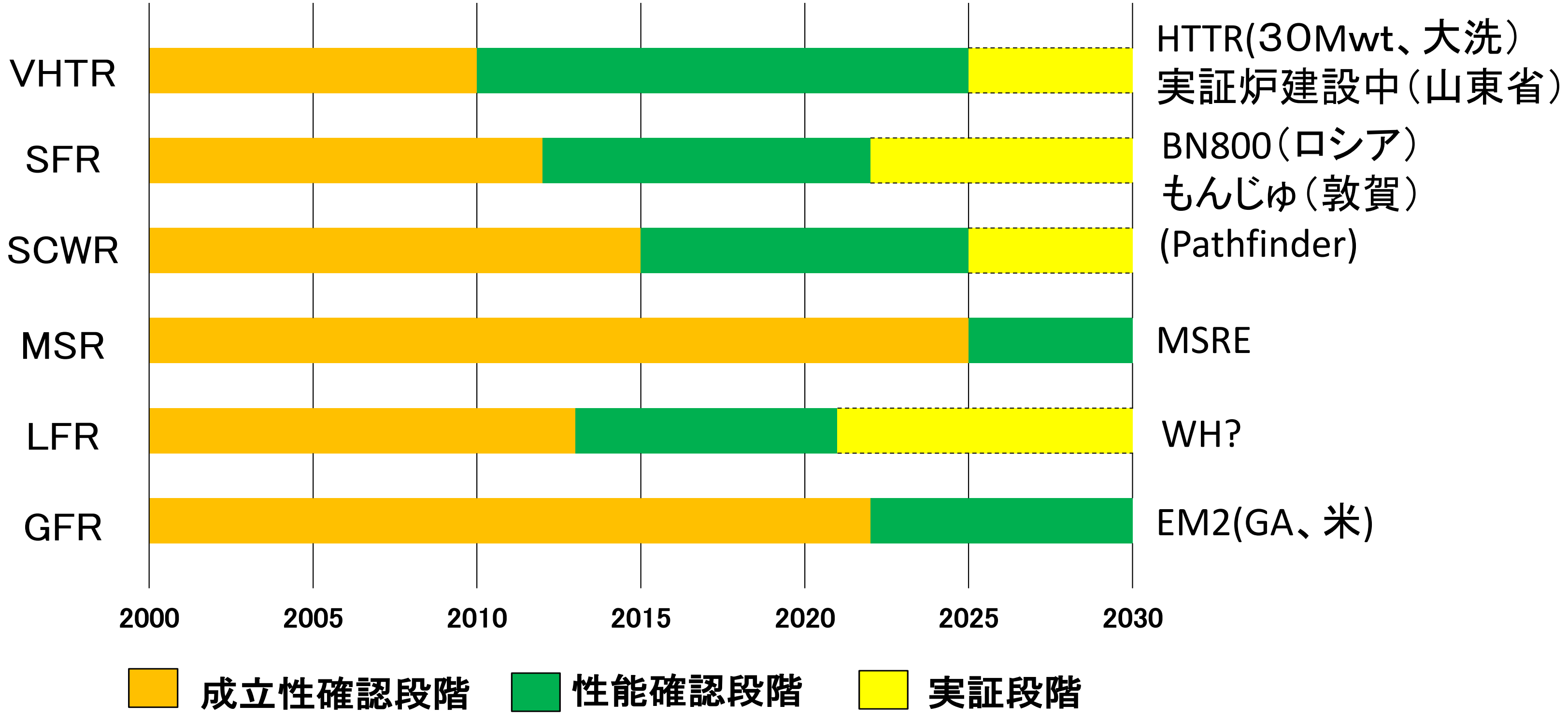
中性子スペクトル：高速中性子
冷却材：鉛
出口温度：480-570℃
燃料サイクル：クローズド
出力：20-1200MWe



溶融塩炉（MSR）

中性子スペクトル：熱中性子/高速中性子
冷却材：フッ化物塩
出口温度：700-800℃
燃料サイクル：クローズド
出力：1000MWe

各炉型の開発展望


VHTR
SFR
SCWR
MSR
LFR
GFR
HTTR(30Mwt、大洗)
実証炉建設中(山東省)
BN800(ロシア)
もんじゅ(敦賀)
(Pathfinder)
MSRE
WH?
EM2(GA、米)
2000
2005
2010
2015
2020
2025
2030
成立性確認段階
性能確認段階
実証段階

Gen IV Concepts

a private observation @Paris, 2009

- VHTR was the most popular one among GIF concepts by member states because of Hydrogen
- SFR, once lame duck, becomes a champion if a Gen-IV has to be demonstrated in 2020's
- SCWR, only one light water cooled reactor, needs to clarify material challenge in super critical water environment
- LFR was once a window for Russian and small scale reactor development
- GFR why?
- MSR interesting but unpopular, maybe another window for Thorium?

Generation IV?

- Originally from Dream Vision
  - Who would survive after 2030?
  - GE showed no interest
  - Different dreams in the same bed by members
- FBR came back from lame duck through the flame of MA burning
  - How deadly need it for global sustainability
    - Effect to ease waste disposal legacy
    - Exhaustible resource of Uranium or
  - Would it be anything to help for Low or Zero Carbon Society in 2050?

Generation IV? continued

- Japan, US and France declared the demo plant in 2020s
  - Where and who do what? ***ASTRID!***
  - Any innovative idea or technology?
  - Just an economic compatibility? What are the safety assessment?
  - Who buys and operates it?
- Spare some resources for the alternatives
- Institutions
  - MDAP⇒MDEP, *"safety designs internationally accepted"*
  - Security and proliferation resistance
  - CDM

Questions?

- Innovative or Next generation reactors: are they not Fast Breeder Reactors? Paradigm to claim FBR is still valid?
- Is it Ultimate super safe small?
- Where and when will be Potential market?
- Who share development in liberalized market?
- The world finally accept nuclear for Zero Carbon Society?
- Can we get rid of excessive regulation?
- Experts regretted what to be regretted?

Features of SMR designs

High Temperature Gas Cooled Reactor

- Inherent Robust Safety
  - Solid confinement of fuel and radioactivity
  - Strong resistance to loss of coolant flow, SBO
  - Possible elimination of core melt accident
- Utilization of high temperature to industrial application; hydrogen, etc.
- Possible utilization of Thorium

LWR

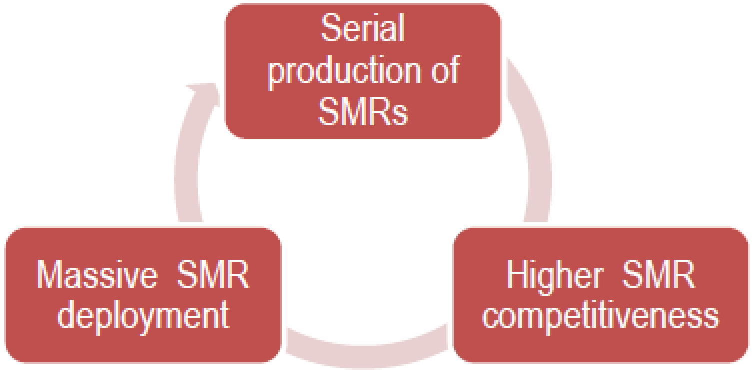
- Based on proven LWR technologies
- Common fuel and fuel cladding
- Simplification by application of passive safety system
- Possible utilization of large water pool for long term cooling

Fast Reactor

- Long life core without refueling
- Possible application for proliferation resistant system with closed fuel cycle (IFR)
- Possible elimination of core destructive accident
- Possible utilization of natural convection cooling

Development of small nuclear reactors (SMRs)

- SMRs, including multi-module plants, generally have higher generation costs than NPP with large reactors.
- The generation costs for SMR might decrease in case of **large scale serial production** which is very important for proving competitiveness of SMR
  - Large initial order is needed to launch the process. Who can be the first customer?
  - How many SMR designs will be really deployed?



Need to fortify specific features of each concept and designs for segregation and competition

- In summary, **SMR could be competitive with many non-nuclear technologies for generating electricity in the cases when NPP with large reactors are, for whatever reason, unable to compete**
- *The challenges facing SMRs are: Licensing, siting, multiple units/modules on the same site, the number of reactors required to meet energy needs (and to be competitive), and the general public acceptability of new nuclear development.*

Modified the presentation of Alexey Lokhov, OECD/NEA-NDD, 2013

Challenges

- **A lot of markets, but who take the first**
- **Economics depend on Investment, its return and risk, keeping fairness wrt externality and LCA.**
- **Possible to reduce nuclear waste, but trade off among preference and economics of fuel cycle**
- **Recycle as Valley of Death needs long range development with public and international commitment and consensus**
- **No single solution for proliferation resistance, but deadly needs for world thousands of reactors**
- ***Finally, but at most, safety challenges and renaissance of public trust to nuclear in general***

Key actions for the next 10 years

Technology Roadmap / Nuclear Energy /2015, NEA&IEA

- **Offer same level playing field to all low C technologies (electricity markets)**
- **Industry to build on time and to budget, FOAK →NOAK**
- **Enhance standardisation, harmonise C&S and regulatory requirements**
- **Continue to share information & experience (among regulators and among operators) to improve safety**
- **Public acceptance must be strengthened (post F safety upgrades, fact-based information)**
- **Develop long-term strategy for radwaste management**