Market perspectives and challenges for GEN-4 systems

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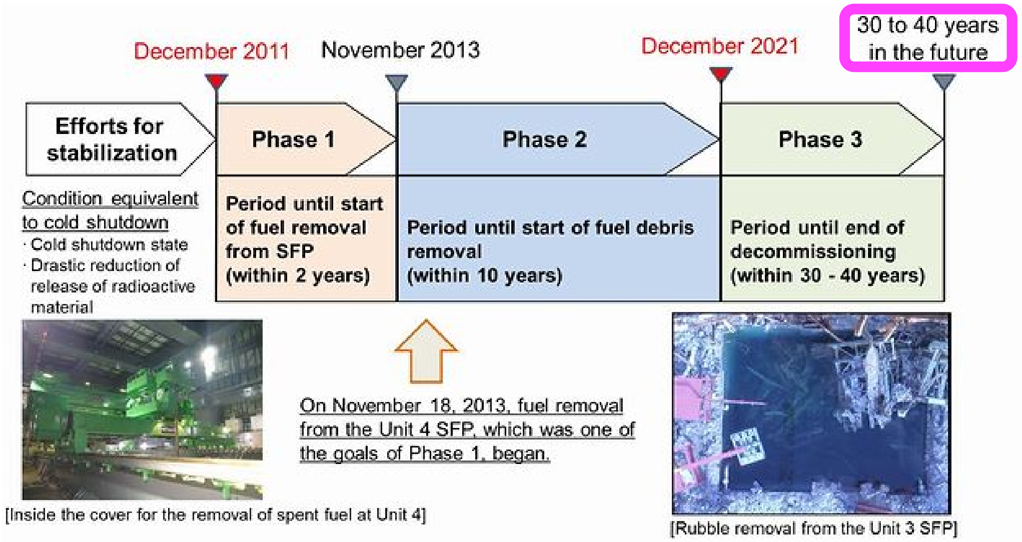
Current status of Fukushima Daiichi Nuclear Power Station (NPS)

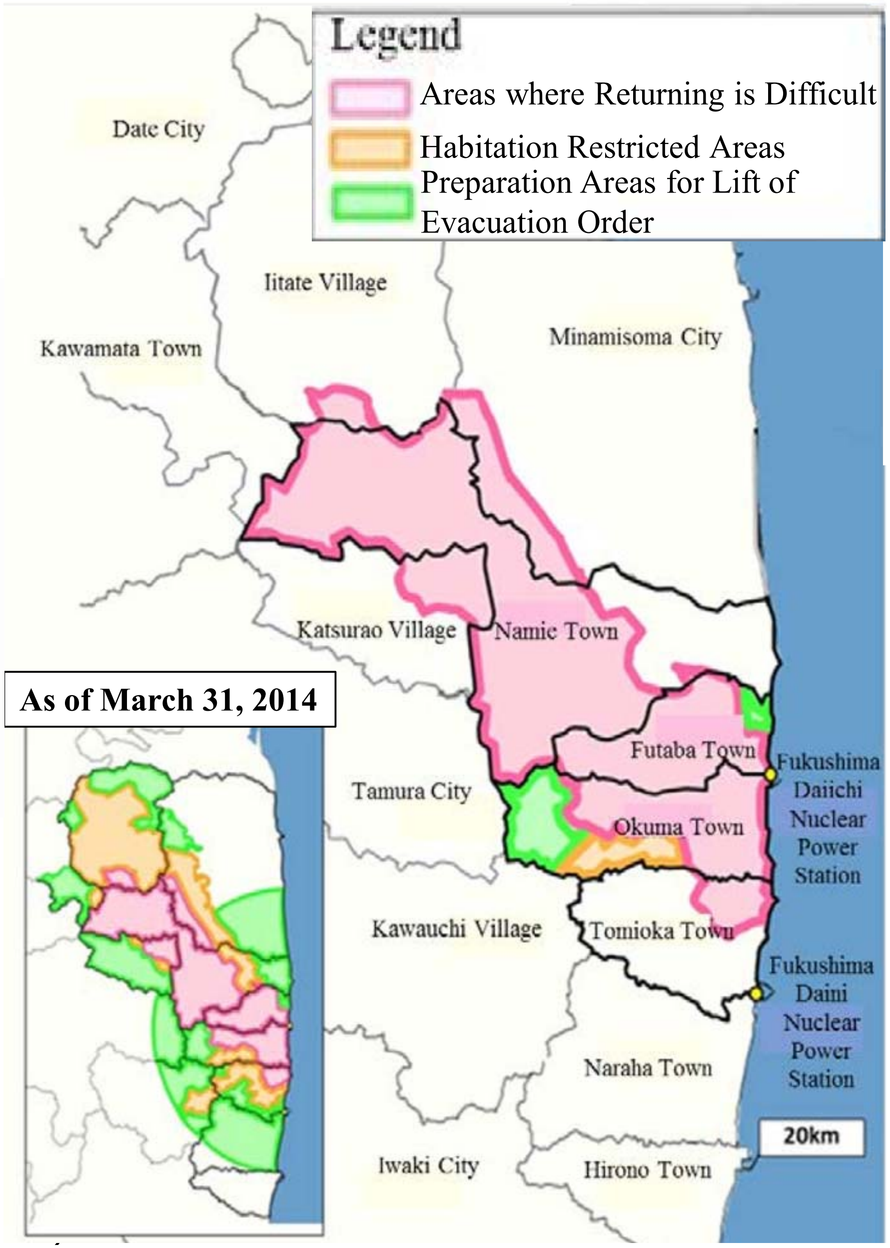
Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station



[Inside the cover for the removal of spent fuel at Unit 4]
[Rubble removal from the Unit 3 SFP]

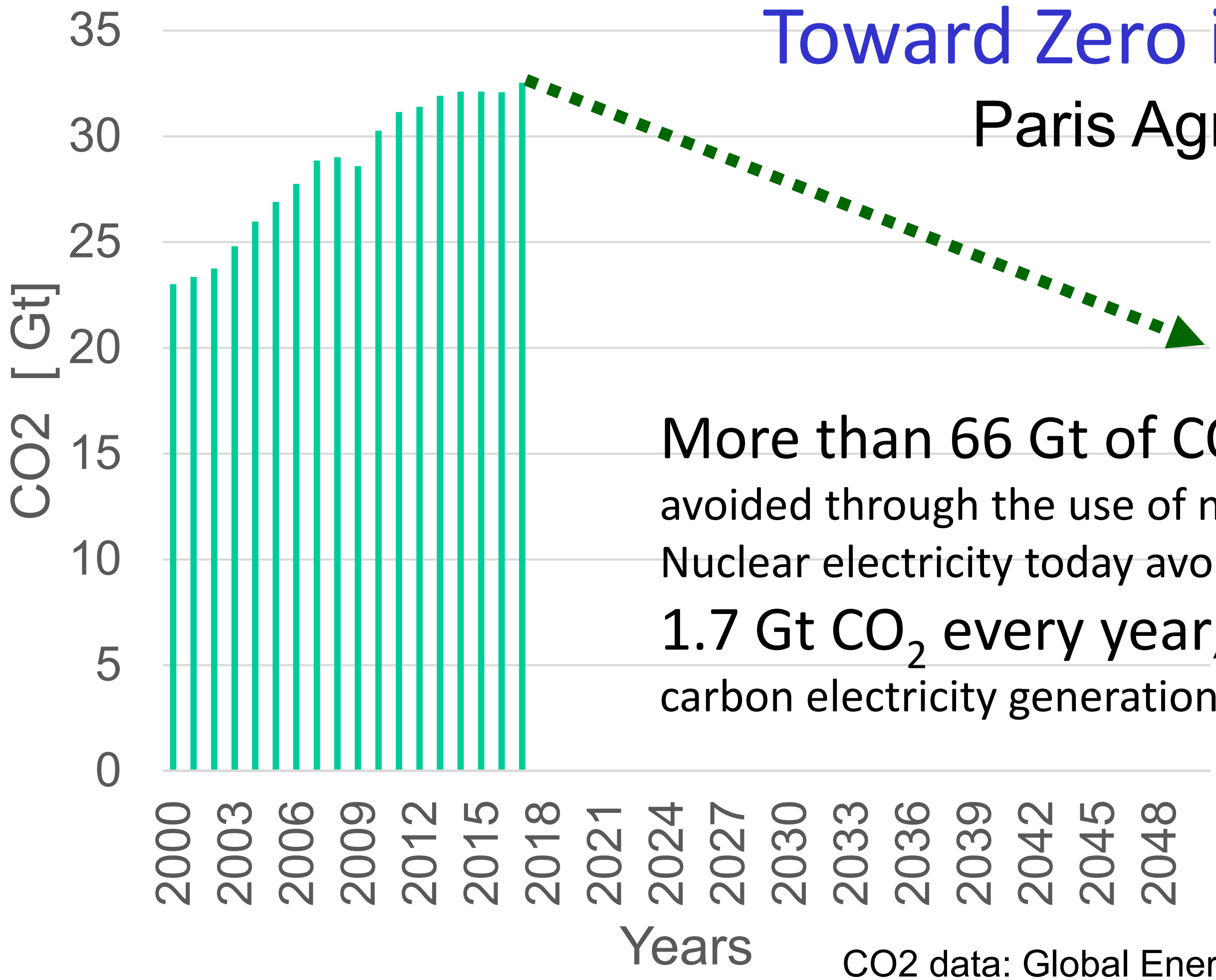
- 30-40 years for decommissioning
- 43,700 of people are still evacuated.

Conceptual diagram of areas under evacuation orders (As of April 1, 2017)



http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/index.html
http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20180827_roadmap.pdf

Needs for CO2-free Energy: Global warming & Decarbonized society



Toward Zero in 2100

Paris Agreement (COP21)

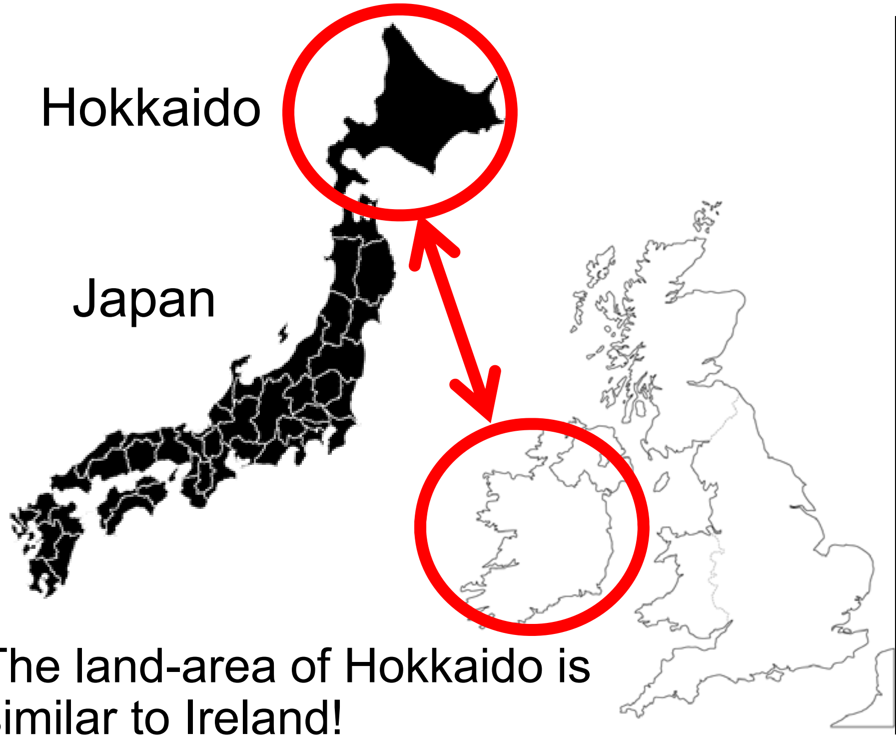
II

-0.4Gt every year

More than 66 Gt of CO_2 emissions have been avoided through the use of nuclear energy since 1971. Nuclear electricity today avoids global emissions of about 1.7 Gt CO_2 every year, accounting for 40% of low carbon electricity generation worldwide.

CO2 data: Global Energy & CO2 Status Report 2017, IEA

Earthquake in Hokkaido and Blackout



The land-area of Hokkaido is similar to Ireland!

- An Earthquake in this summer resulted in Blackout of electricity in the entire area of Hokkaido for several days long.
- Large thermal power reactor, which covers half of Hokkaido, was shutdown by the Earthquake.
- Total of 2.95 million households* lost the electricity.
- Such large-scale blackout is the first time in Japan. Reliability of the Grid is high-lighted.

Widespread blackouts occurred all over the world

North America(1989,2003), South America(2009), Moscow(2005)

Europe(2003,2005), Asia(2011,2017)

Stable and Reliable Grid is a significant issue of electricity supply.

*Source: Reuter News:
September 7, 2017 https://www.reuters.com/article/us-japan-quake-power/power-returning-to-hokkaido-but-quake-exposes-flaws-of-japan-grid-idUSKCN1LN1EM

Goals for Generation IV Reactor systems in GIF

Four rigid pillars

Sustainability	Safety & Reliability	Economics	Proliferation Resistance & Physical Protection
☐ Clean air and effective use of U ☐ Minimize waste and burden	☐ Very low likelihood of Core Damage ☐ No need of Offsite emergency response	☐ Life cycle cost ☐ Financial risks	☐ Unattractive diversion ☐ Physical protection

Examples of Emerging influence factors

- Low carbon society, Hybrid systems
- Stakeholders, Society
- Drivers from market
- Private sectors
- Grid reliability
- National status, Historical circumstance
- Commercialize pathway
- National policy

Pathways to commercialize

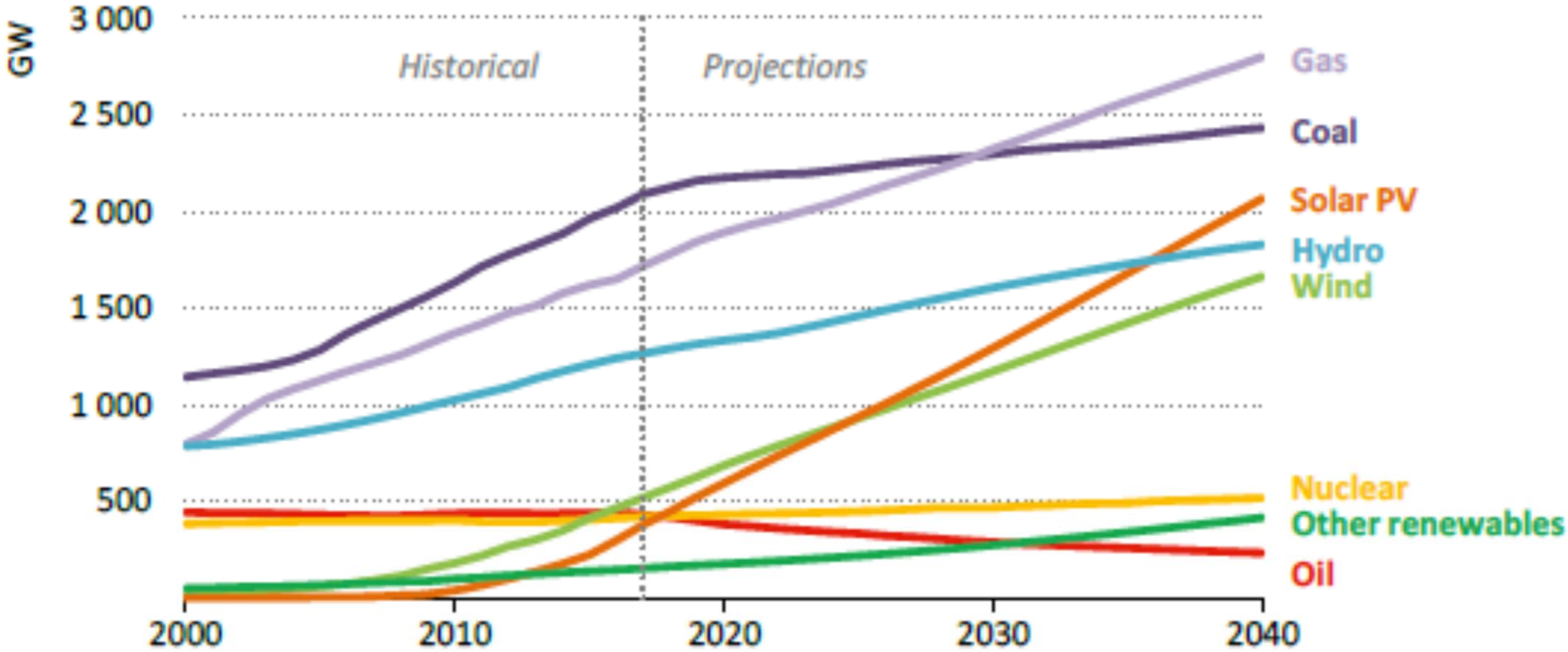
Six reactor systems to achieve GIF goals

SFR	LFR	MSR	GFR	SCWR	VHTR
Technical issues	***Technical issues***	***Technical issues***	***Technical issues***	***Technical issues***	***Technical issues***

Common attributions and Challenges

- Reliable and Sustainable power supply in Decarbonized Society (Combination with other CO2 free energy systems)
- Safety enhancement depended on reactor types
- Cost competitive with these attributions
  - ***Enhancement of R&D Collaborations on these issues***

World 2˚C energy policy scenario by IEA

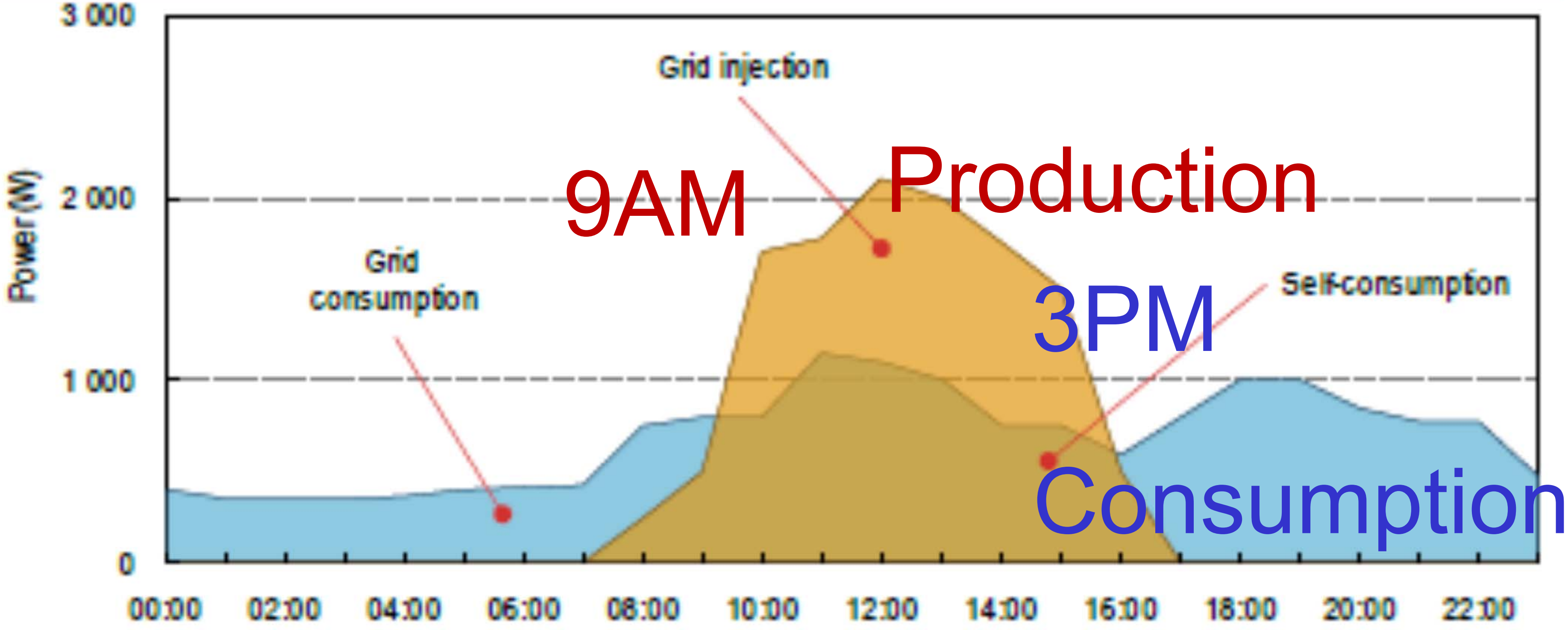


IEA, WORLD ENERGY OUTLOOK-2017,P244

Intermittent renewables emerging rapidly in the world, but even so Stable zero CO2 energies are 20%, Intermittents are 30%

Example of daily intermittent patterns (Germany)

Figure 7 • Two-way flows of power from embedded solar PV capacity



Key point • When production exceeds own consumption, electricity flows reverse.

Getting Wind and Sun onto the Grid, p.35-36 OECD/IEA(2017)

CO_2 emission depended on power supply systems: 2015

	Sweden	France	Washington	Denmark	California	Germany	Japan
	11 gCO2/kWh	46 gCO2/kWh	106 gCO2/kWh	174 gCO2/kWh	282 gCO2/kWh	450 gCO2/kWh	540 gCO2/kWh
Stable	88%	88%	76%	15%	26%	25%	12%
Renewables	53%	11%	69%	15%	16%	11%	11%
Nuclear	35%	78%	7%	0%	9%	14%	1%
Intermi-ttent	10%	5%	6%	51%	14%	18%	4%
Solar	0%	1%	0%	2%	8%	6%	3%
Wind	10%	4%	6%	49%	6%	12%	1%
Fossil energy	2%	7%	17%	34%	60%	56%	85%

IEA CO2 emissions from fuel combustion 2017

GEN IV International Forum

Multiple pathways to Commercialization

SFR **LFR** **MSR** **GFR** **SCWR** **VHTR**

Example of contributions / attributions

Hybrid systems **Sustainability** **Cost Competitive**

Reliable grid: Load following, Heat storage
Heat usage for hydrogen, Water desalination.
Effective Use of Uranium Resources
Minimize radioactive waste and burden

R&Ds on Innovative systems
Cost challenges based on recent Gen III+ experiences

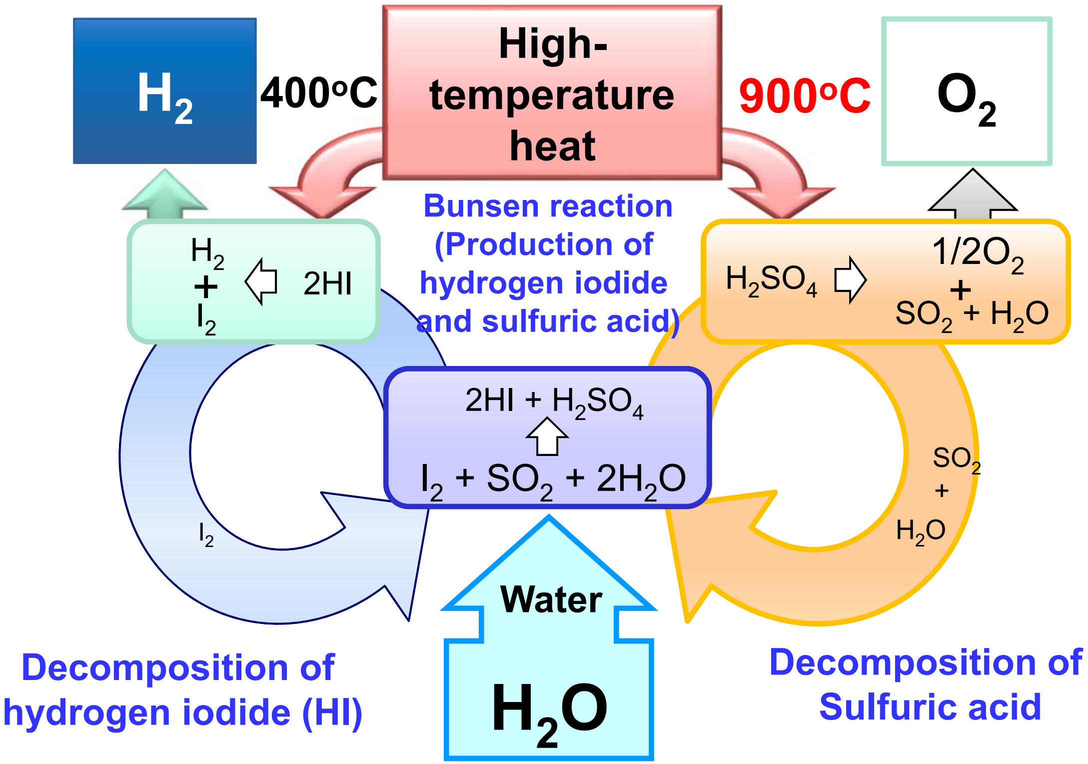
Safety

Passive features of feedbacks, Passive shutdown systems, Passive decay heat removals, Natural circulations, etc.
Safety Design Criteria for International Safety Standards

Example of H_2 Production Technology

Decarbonized technology

IS process decomposes water with heat of ca. 900°C using chemical reactions of iodine (I) and sulfur (S).

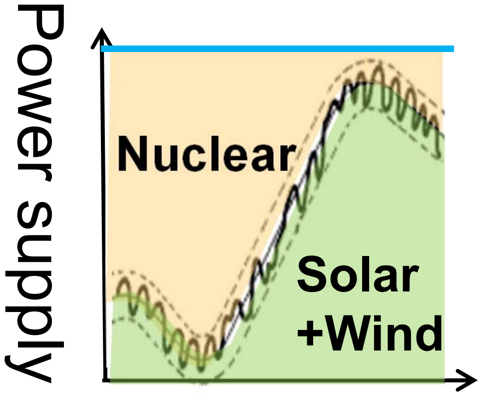


JAEA website: https://www.jaea.go.jp/04/o-arai/nhc/en/research/intro/is/index.html

Example of Hybrid system

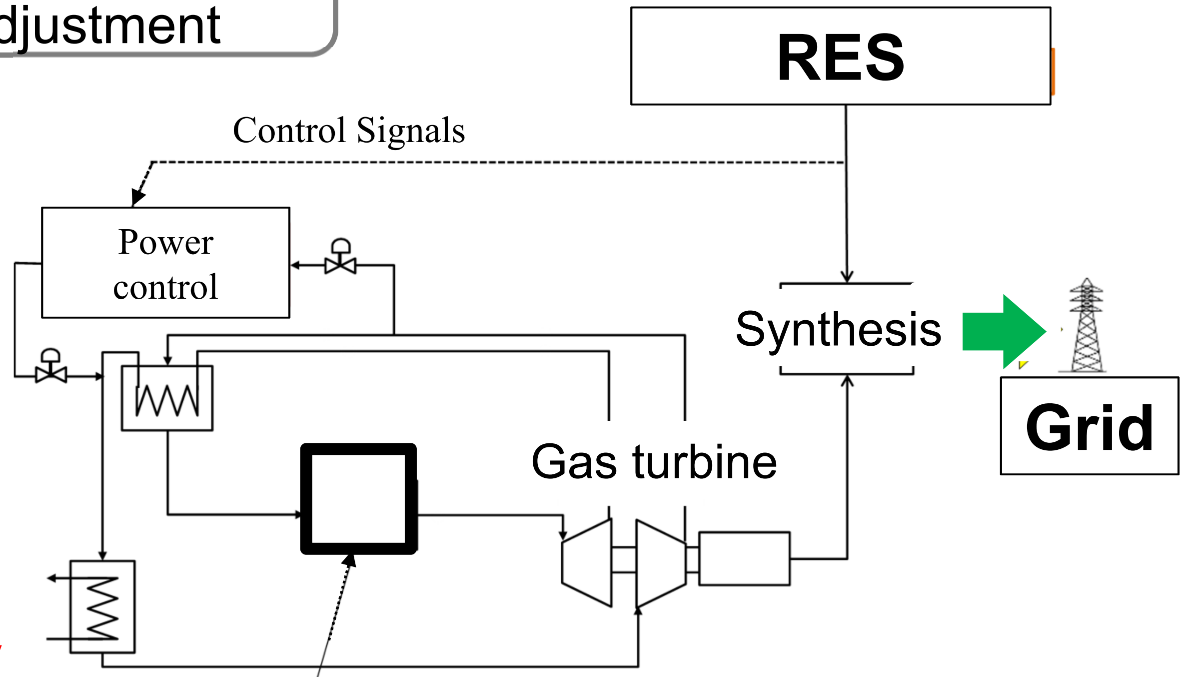
+

Nuclear Power output adjustment → Constant Power supply



Time

Nuclear power output adjustment by gas pressure and turbine inertia without adjusting reactor fission power.



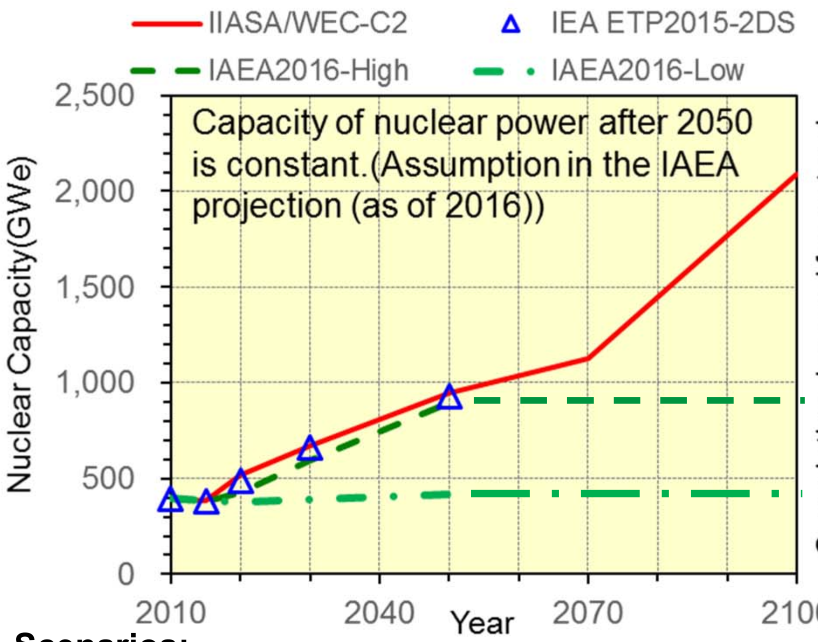
Very High Temperature Reactor (VHTR)

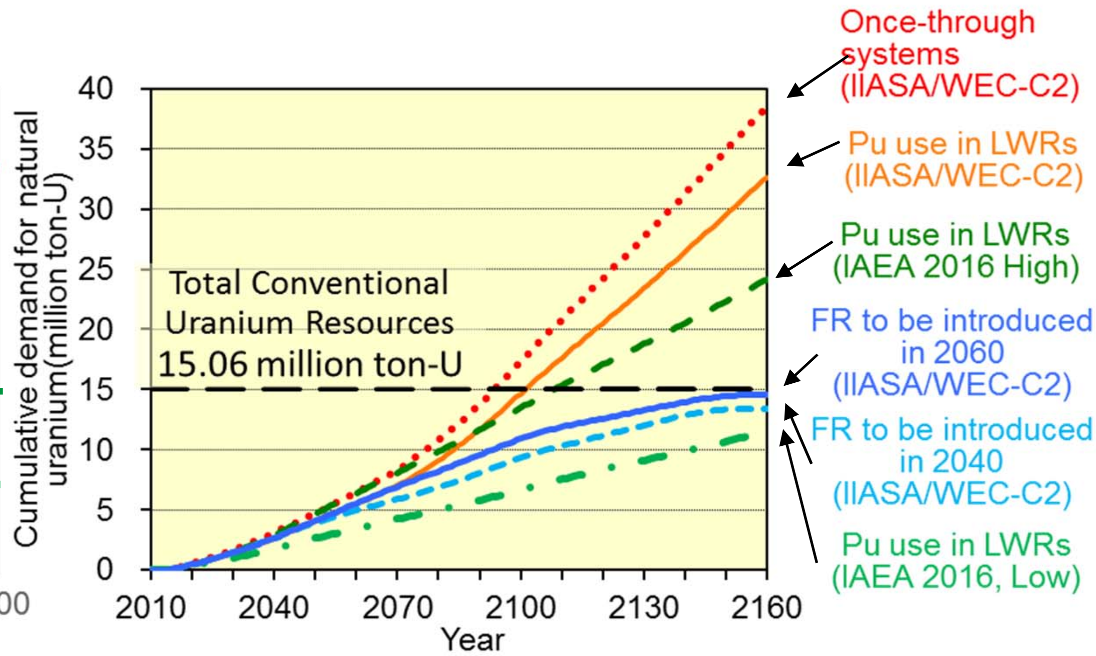
VHTR + RES hybrid system

JAEA website: https://www.jaea.go.jp/04/o-arai/nhc/jp/research/intro/heat/heat_03.html [in Japanese]

Effective Use of Uranium Resources for Sustainability

The period of natural Uranium use can be extended by Fast Reactor (FR)





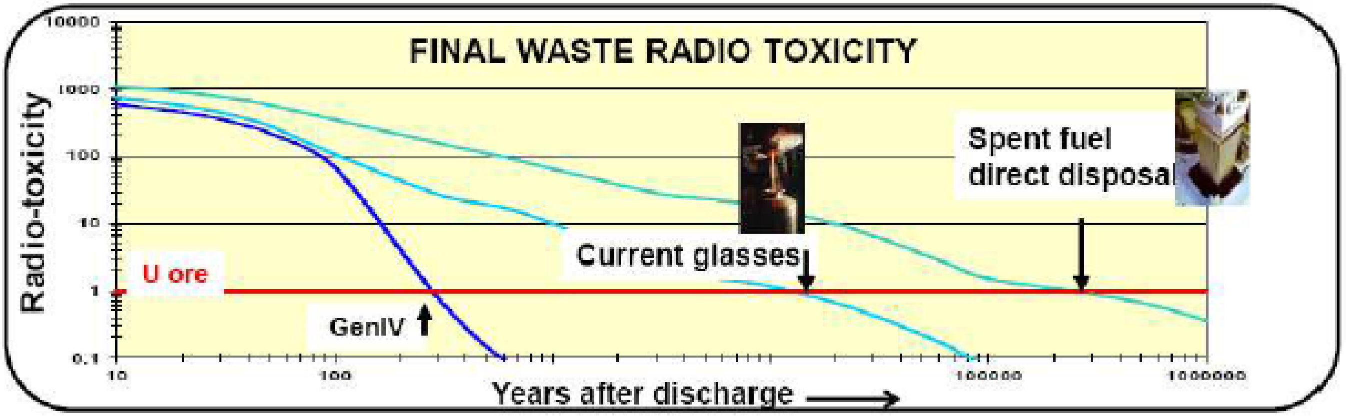
Scenarios:

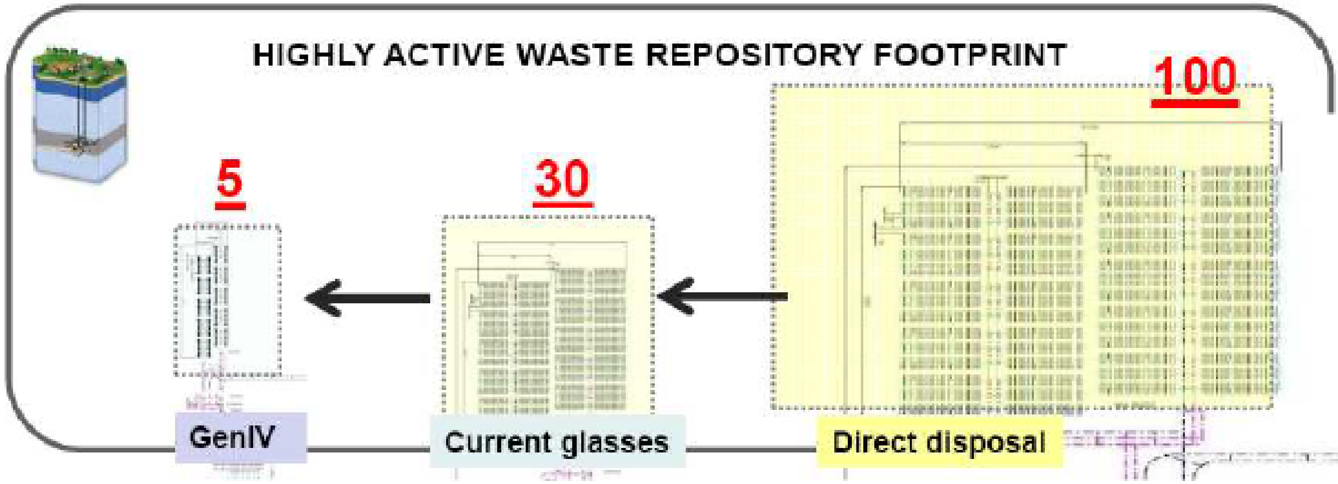
- **IIASA/WEC-C2:** “Ecologically-driven” scenario. Renewable energy and small reactor would be used as global warming countermeasures.
- **IEA ETP2015-2DS:** Greenhouse gas would be reduced and sustainable energy systems would be used.
- **IAEA 2016 (High case):** The current rates of economic and electricity demand growth, particularly in the Far East, would continue, and policy on the climate change would be shifted.
- **IAEA 2016 (Low case):** Current market, technology, and resource trends would continue. Increase in nuclear output might not be achieved.

Y. Sagayama, “Generation IV Reactors,” Lecture at the university of Tokyo, Oct. 15, 2018.

Minimize radioactive waste by Gen-IV systems

- Burning and Transmutation of Pu and Minor Actinides by Fast Reactors

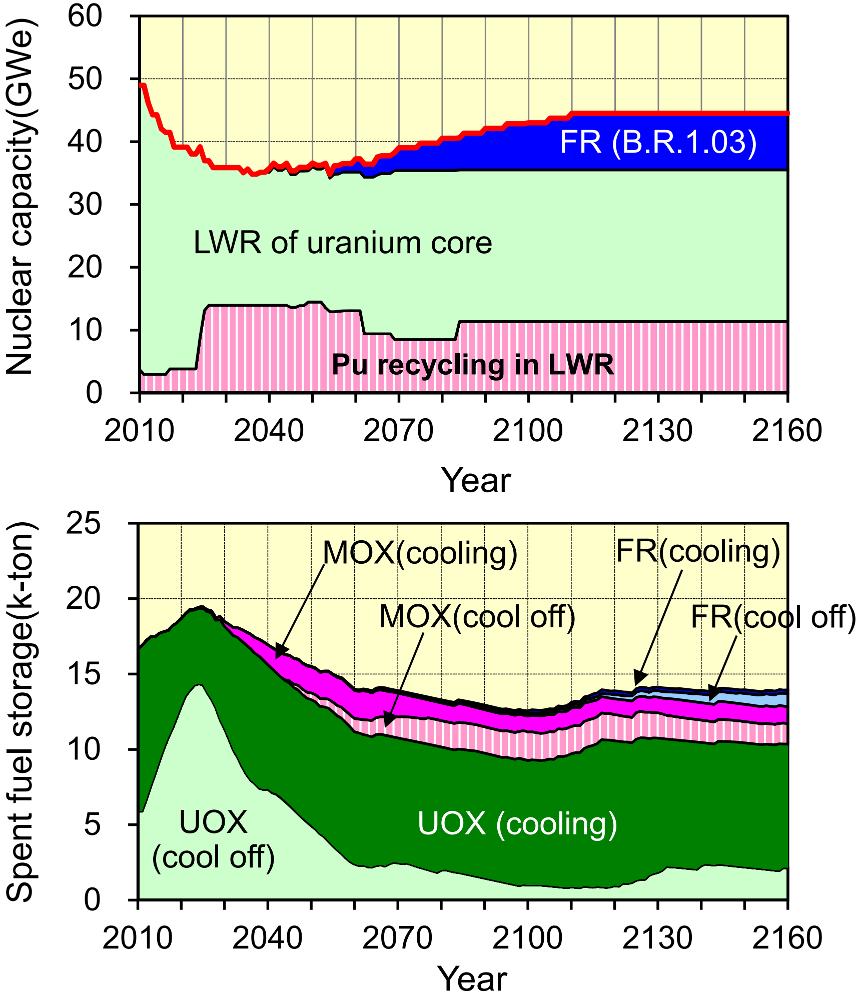




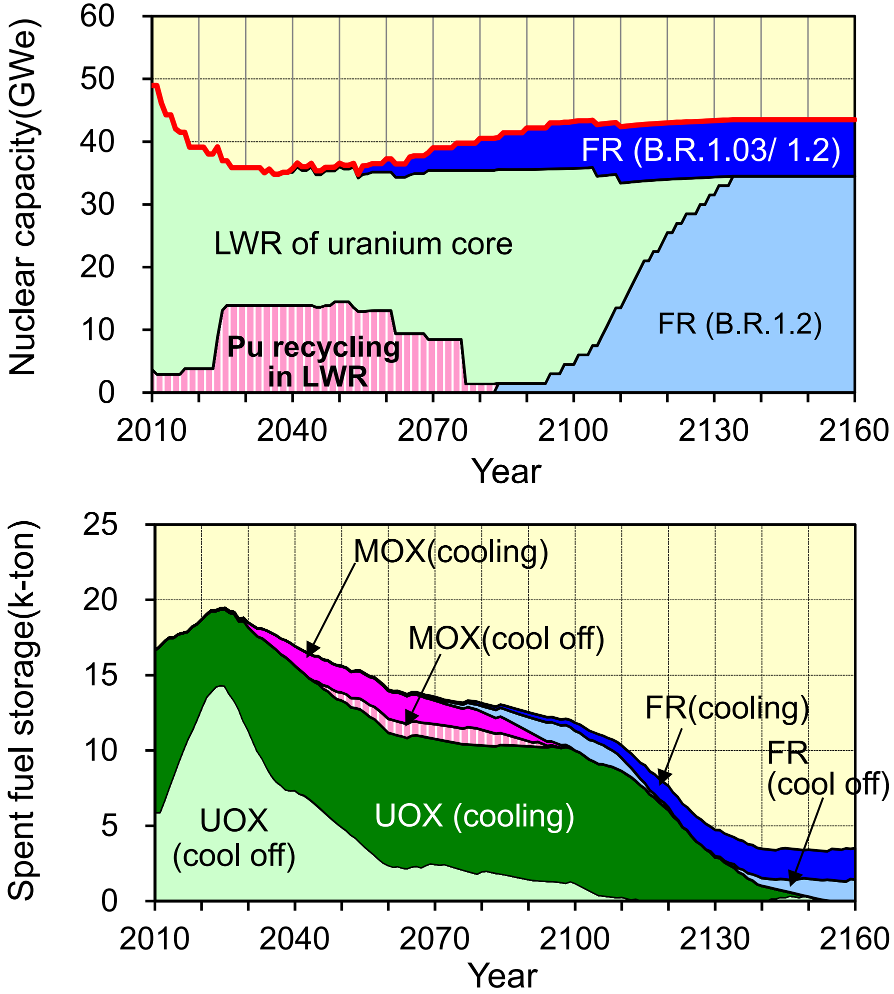
GEN IV reactors and the ASTRID Project, P. Le Coz, ENYGF Paris 24/6/2015

Flexible Plutonium management by Fast Reactor

Combination of LWR-MOX and FR



Transition from LWR to FR



B.R. (Breeding Ratio): Ratio of Fissile amount after/before the reactor use

Viewpoints Toward Commercial Deployment of a Gen-IV System

To cross a deep valley from “Prototype” to “Commercial Use”

Combination (Balance) or Choice of following Factors

a)	Government	<Developer>	Private Companies
b)	Policy Oriented	<Motive Force>	Market Mechanism
c)	Sustainability	<Goal>	Economics
d)	Long-term	<Time Span>	Short-term
e)	Large Scale	<Plant Size>	Small / Modular
f)	Independently	<R&D>	International Collaboration

Benefit of International Collaboration

Improvement of Predictability on Regulation for Reactor Deployments

"Global Standard of safety regulation for Gen-IV system"

R&D Collaboration in GIF, OECD NEA

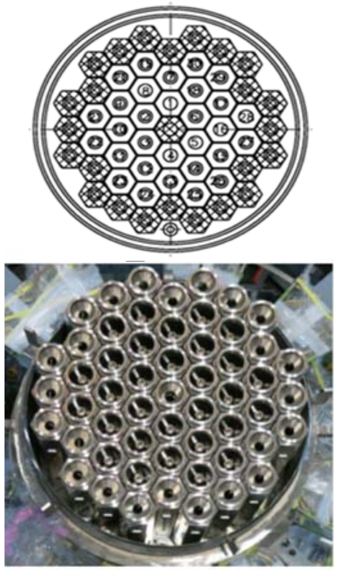
New TF on R&D Infrastructure in GIF

- Promote international utilization of large infrastructures

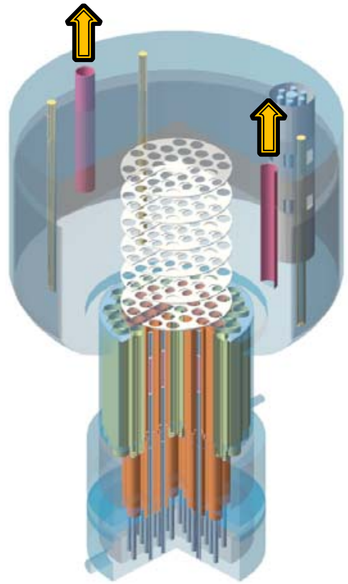
NI2050 in OECD NEA

- International collaboration on demo. of key technologies

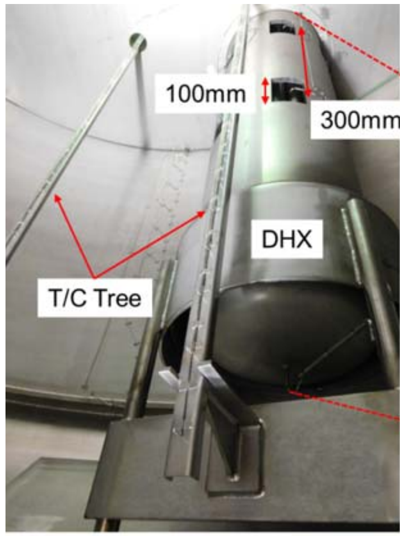
- ☐ Passive decay heat removal system
- ☐ Core thermal hydraulics under natural circulation



Top view of Core



PLANDTL-2 Test Sectioı



Inside of Upper Plenum

Heat Transfer Tube

Concluding Remarks

- Higher safety on Severe Accidents
- Gen-IV Goals: Safety, Sustainability, Economy and PRPP
- Not only Renewable Energy but combination with Nuclear
  - for Decarbonized Society against Global Warming
  - for Stable and Reliable Grid
  - by Load following, Heat usage, Storage of products, Hybrid-System
- Sustainability with Economy by Gen-IV Fast reactors
  - Higher efficiency of Uranium use
  - Minimize high level radioactive waste and burden by Pu, MA burning
- Key Factors on Deployment of Gen-IVs
  - Policy supports with Market for Sustainability of long term & clean air
  - International Collaboration on R&D of above issues (red color)

Thank you