Generation IV Nuclear Power: Nuclear Energy Approach in the 21st Century to Global Warming Challenge

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Nuclear Energy

- Part 1: Global Warming Challenge
- Part 2: Nuclear Energy
- Part 3: Energy Supply and Demand
- Part 4: Nuclear Power
- Part 5: Sustainability
Part 1:
Global Warming Challenge
Greenhouse Effect

The downward emission warms the surface. Without it, the average temperature would be -18°C. Increase in the effect will further warm the surface and will change the climate.
Greenhouse Effect

Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels would significantly reduce the risks and impacts of climate change.

Mitigation target of the Paris Agreement, Article 2
Global Warming Challenge
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Global Warming Challenge

0 = lowest impact; 1 = highest impact (log normalized)
Global Warming Challenge

Mitigation Potential of Nuclear Power
Global Warming Challenge

Nuclear Capacity Utilization and Ambient Temperatures

Impact of Climate Change on Contemporary Nuclear Power Supply
Part 2:

Nuclear Energy
Energy Released by Nuclear Reactions

**Light nuclei** (hydrogen, helium) release energy when they **fuse** (**Nuclear Fusion**) 
The **product nuclei** weigh **less** than the parent nuclei

**Heavy nuclei** (Uranium) release energy when they **split** (**Nuclear Fission**) 
The **product nuclei** weigh **less** than the original nucleus
Nuclear Energy

Energy transformation processes accompanying nuclear fission.
Nuclear Energy

Advantages (under normal operation scenarios):

- Specific energy yield from fission
- The energy process is a nuclear reaction, not a chemical process.
- Potential for long-term operation on a single batch of fuel
- Potential autonomy of operation
- Emissions are limited to the controlled thermal pollution
- Ability to deliver electricity and industrial heat

Engineering:

- Highly regulated safety design leading to low probabilities for accidents with high consequences
- Nuclear waste management
- Security
Part 3:
Energy Supply and Demand
Energy Supply and Demand
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Energy Supply and Demand

Relative environmental impacts from emissions of different electricity generating technologies.
Energy Supply and Demand

- Energy consumption today
- Energy needs through the 21st century
- Energy sources and end-use sectors in the U.S.
- Fossil fuel reserves
- Nuclear and renewable energy
- Energy and the environment
- Meeting our energy challenges in a new era of science

Years of Uranium Availability for Nuclear Power (IAEA 2006)

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Part 4:

Nuclear Power
Nuclear Power

- Advantages:
  - Energy and National security
  - Environmentally friendly
  - Global affluence and stability
  - Resource availability

- Concerns:
  - Global nuclear materials management
    - Proliferation
    - Waste management
  - Capital cost, R&D cost
  - Resource availability without reprocessing
  - Public perception of safety
Coal and nuclear power plants.
Nuclear Power

450 units in operation
11% of world’s electricity

96 units in U.S.
20% of U.S. electricity
2 new builds in progress

Nuclear Units Under Construction and Planned Worldwide

- China: 23 units under construction, 33 planned
- Russia: 14 units under construction, 11 planned
- India: 20 units under construction, 11 planned
- Japan: 12 units under construction, 2 planned
- S. Korea: 6 units under construction, 6 planned
- US: 9 units under construction, 1 planned
- China, Taiwan: 6 units under construction, 2 planned
- Bulgaria: 2 units under construction, 2 planned
- Ukraine: 2 units under construction, 2 planned
- Argentina: 2 units under construction, 1 planned
- Iran: 1 unit under construction
- Pakistan: 1 unit under construction
- France: 1 unit under construction
- Slovakia: 1 unit under construction
- Brazil: 1 unit under construction
- Finland: 1 unit under construction

Totals:
- 61 units under construction*
- 149 units on order or planned**

Sources: International Atomic Energy Agency for units under construction and World Nuclear Association for units on order or planned.

*Chart includes only countries with units under construction. **Countries planning new units are not all included in the chart.

Planned units = Approvals, funding or major commitment in place, mostly expected in operation within 8-10 years.

Updated: 8/10
Nuclear Power

Generation I
- Early Prototype Reactors
  - Shippingport
  - Dresden, Fermi I
  - Magnox

Generation II
- Commercial Power Reactors
  - LWR-PWR, BWR
  - CANDU
  - VVER/RBMK

Generation III
- Advanced LWRs
  - ABWR
  - System 80+
  - AP600
  - EPR

Generation III+
- Generation III Evolutionary Designs Offering Improved Economics
  - AP1000
  - ACR700
  - IRIS
- Highly Economical
- Enhanced Safety
- Minimize Wastes
- Proliferation Resistant

Generations Timeline:
- Gen I: 1950-1960
- Gen II: 1960-1980
- Gen III+: 2000-2030
Nuclear Power

Mitigation Potential of Nuclear Power
Nuclear Power

Goals for Generation IV Nuclear Energy Systems

Sustainability-1
Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.

Sustainability-2
Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden thereby improving protection for the public health and the environment.

Proliferation Resistance and Physical Protection-1
Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weaponsusable materials and provide increased physical protection against acts of terrorism.

Economics-1
Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.

Economics-2
Generation IV nuclear energy systems will have a level of financial risks comparable to other energy projects.

Safety and Reliability -1
Generation IV nuclear energy systems operations will excel in safety and reliability.

Safety and Reliability -2
Generation IV nuclear energy systems will have a very low likelihood and degree of reactor damage.

Safety and Reliability -3
Generation IV nuclear energy systems will eliminate the need for offsite emergency response.
Six system concepts chosen by the United States Department of Energy’s Nuclear Energy Research Advisory Committee and the Generation IV International Forum to be researched:

1. Gas-Cooled Fast Reactor (GFR);
2. Very-High-Temperature Reactor (VHTR);
3. Supercritical-Water-Cooled Reactor (SCWR);
4. Sodium-Cooled Fast Reactor (SFR);
5. Lead-Cooled Fast Reactor (LFR);
Nuclear Power

1. Gas-Cooled Fast Reactor (GFR)
Nuclear Power

2. Very-High-Temperature Reactor (VHTR)

Diagram of a Very-High-Temperature Reactor (VHTR) showing the reactor core, graphite reflector, heat exchanger, and hydrogen production plant.
Nuclear Power

3. Supercritical-Water-Cooled Reactor (SCWR)
Nuclear Power

4. Sodium-Cooled Fast Reactor (SFR)
Nuclear Power

5. Lead-Cooled Fast Reactor (LFR)
Nuclear Power

6. Molten Salt Reactor (MSR)
Nuclear Power
Nuclear Power

PLAUSIBLE TRENDS IN REACTOR TECHNOLOGY EVOLUTION

CURRENT/SHORT TERM
Light Water Reactors (LWRs)
- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR)
- Pressurized Heavy Water Reactor (CANDU)

INTERMEDIATE TERM (>20 years)
Brayton Cycle Gas (He) Cooled Reactor (GCR-GT)

LONG TERM (>50 years)
Fast Breeder ($^{238}\text{U} \otimes ^{239}\text{Pu}$-based)
Thermal Breeder ($^{232}\text{Th} \otimes ^{233}\text{U}$-based)
Areas where use of nuclear energy is essential:

- Navy carriers and civilian nuclear fleet applications
- Portable nuclear power for remote regions without reliable fuel supply chains
- Deep space missions

Areas where use of nuclear energy is beneficial:

- Base load electricity generation
- Potable water production
- Industrial heat applications
- District heating
- Control and minimization of greenhouse gas emissions
Fusion reaction is difficult to start!

High temperatures (Millions of degrees) in a pure High Vacuum environment are required

Technically complex and high capital cost reactors are necessary

More Research and Development is needed to bring concept to deployment

The physics is well advanced but requires sustained development on a long time scale (20 to 40 years)
Part 5: Sustainability
Sustainability

- The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. [Bruntland, 1987]
- Preservation of productive capacity for the foreseeable future. [Solow, 1992]
- Biophysical sustainability means maintaining or improving the integrity of the life support system of earth. [Fuwa, 1995]
Intergenerational Principles

- Trustee: Every generation has obligation to protect interests of future generations
- Chain of obligation: Primary obligation is to provide for the needs of the living and succeeding generations. Near term concrete hazards have priority over long term hypothetical hazards
- Precautionary Principle: Do not pursue actions that pose a realistic threat of irreversible harm or catastrophic consequences unless there is some compelling or countervailing need to benefit either current or future generations
Sustainability

Affordable energy reduces poverty (SDG 1) and inequality (SDG 10), and supports health (SDG 3), education (SDG 4), industry (SDG 9) and economic growth (SDG 8).

Energy for all fosters peace and justice (SDG 16), and partnerships (SDG 17).

Sustainable energy is crucial for climate action (SDG 13), ecosystems (SDG 14, 15), agriculture (SDG 2), water (SDG 6, 14) and reducing waste (SDG 12).

Reliable energy is essential for industry (SDG 9), agriculture (SDG 2), health (SDG 3) and education (SDG 4).

Modern energy supports clean communities (SDG 11), health (SDG 3) and gender equality (SDG 5).
Sustainability

Big Energy Questions

- Can we satisfactorily reduce emissions and remediate wastes residing in our water and air basins?
- Can we offset changes being introduced by our consumption of fossil fuels?
- Can we significantly reduce our dependence on imported oil?
- Can nuclear, renewable, and other non-fossil energy resources be deployed quickly enough to make a difference?
Sustainable Development and Nuclear Technology

Sustainability - development that meets the needs of the present without compromising the ability of future generations to meet their own needs
Sustainability

U.S. sources of emission-free electricity.
### Sustainability

#### Years of Uranium Availability for Nuclear Power (IAEA 2006)

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Sustainability

CO₂ stabilization wedge concept.

Stabilization Triangle

Continued Fossil Fuel Emissions

Efficiency
Biomass
Nuclear
Wind
Geothermal
Solar
CCS

CO₂ (Gt C/yr)

2000  2010  2020  2030  2040  2050  2060
New Nuclear Example

GEH Nuclear Plant Projects ... continual innovation

**ABWR**
Operational
1350 MW

**ESBWR**
Evolutionary
1520 MW

**VSBWR**
Innovative SMR
300 MW

**PRISM**
Advanced Rx
165 to 311 MW

Gen III

Gen III+

Gen IV

New Plant Services

Continuous experience
New Nuclear Example

**Generation IV International Forum**

**Steady Progress:**
- Economic competitiveness
- Safety and reliability

**Nuclear Power for centuries**
- Resource saving
- HL Radwaste minimisation
- Non-proliferation

- **New applications**
  - Hydrogen, drinkable water, heat

- **Industrial deployment** ~2040

- **Multilateral cooperation with 3 levels of agreements:**
  - Intergovernmental
  - Systems (x 6)
  - R&D Projects (3 à 6 / System)

New requirements to support a sustainable development
New Nuclear Example

Sodium Fast Reactor (SFR)

- A new generation of sodium cooled Fast Reactors
- Reduced investment cost
- Simplified design, system innovation
  (Pool/Loop design, ISIR – SC CO₂ PCS)
- Towards more passive safety feature
  + Better management of severe accidents
- Integral recycling of actinides
  Remote fabrication of TRU fuel


SFR Steering Committee

- France
- Japan
- U.S.A.
- Euratom countries
- Russia
- China
- South Korea
New Nuclear Example

Global Clean Energy Need & Supply

Generations of Nuclear Energy

World nuclear power generation by reactor type, 2008

GEN IV reactors are mainly FR systems
Sustainability

Clean Energy Business Plan

Transmission → Smart Grid → Economics → Policy

Electrical Power

Demand

Natural Gas

Wind

Solar

Wind

Base Load
Coal and Nuclear

12 a.m. 12 p.m. 12 a.m.
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QUESTIONS?
April’s Pop Quiz

How many nuclear plants are in operation in U.S. and worldwide?

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<th>In U.S.</th>
<th>Worldwide</th>
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<tr>
<td>A – over 10,000</td>
<td>A – over 100,000</td>
</tr>
<tr>
<td>B – about 100</td>
<td>B – about 1000</td>
</tr>
<tr>
<td>C – 50</td>
<td>C – about 500</td>
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98 to be exact in 30 states
(20% of domestic energy)

450 to be exact
(11% of world electricity)