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

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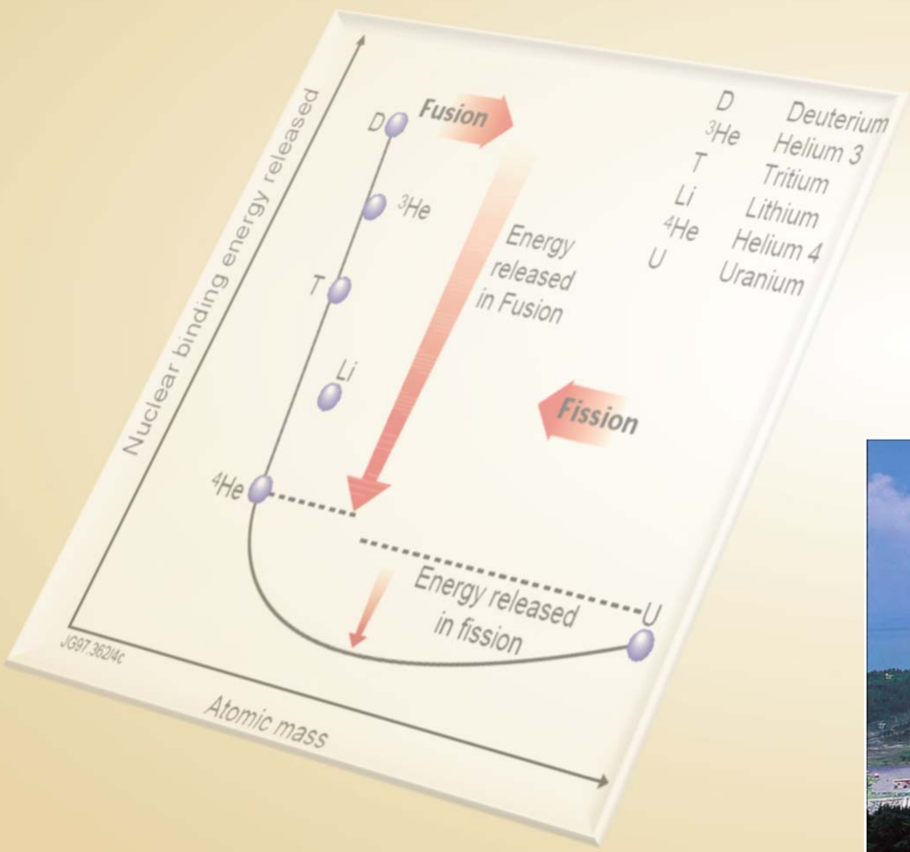

Nuclear Energy

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

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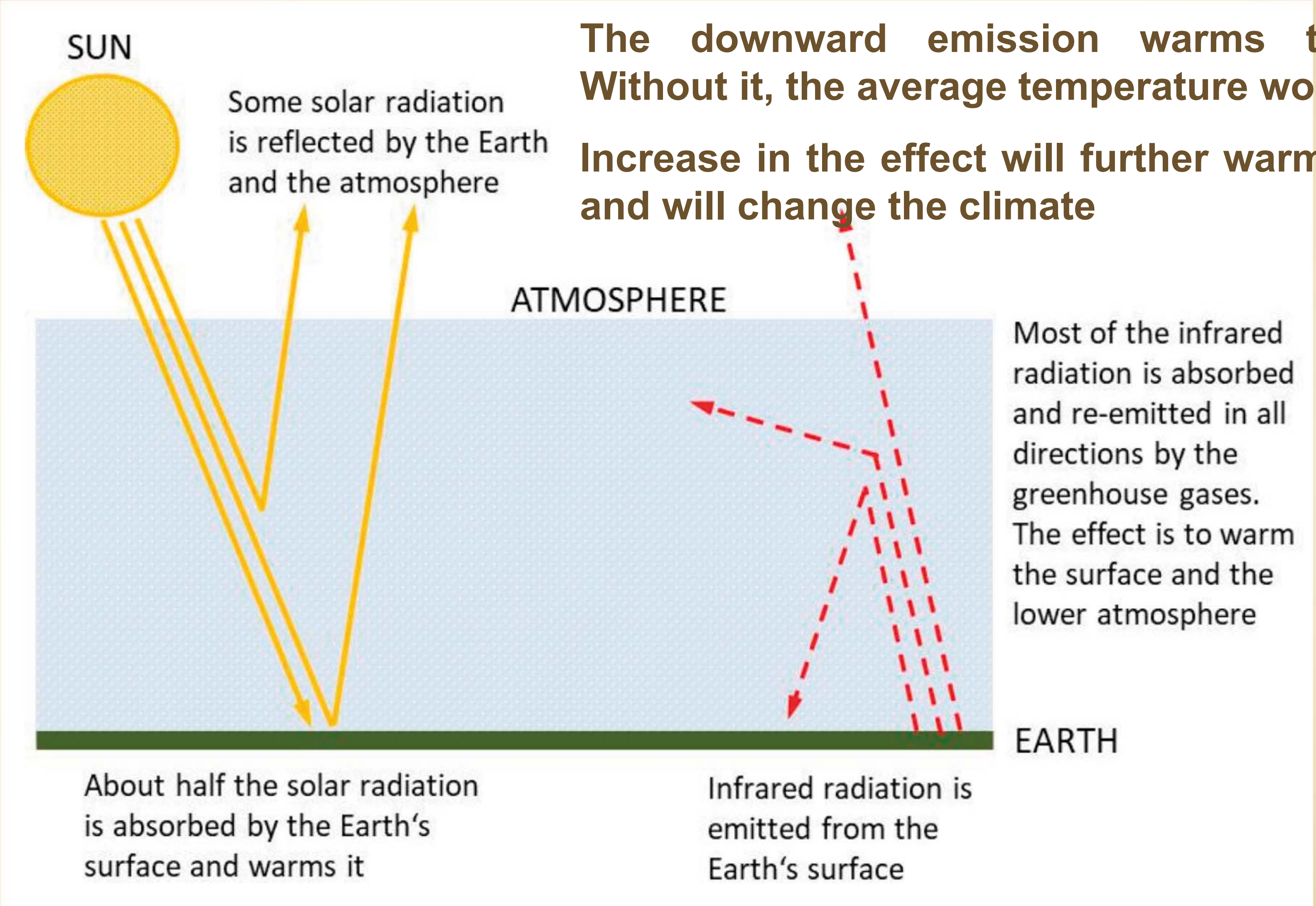
Part 1:

Global Warming Challenge

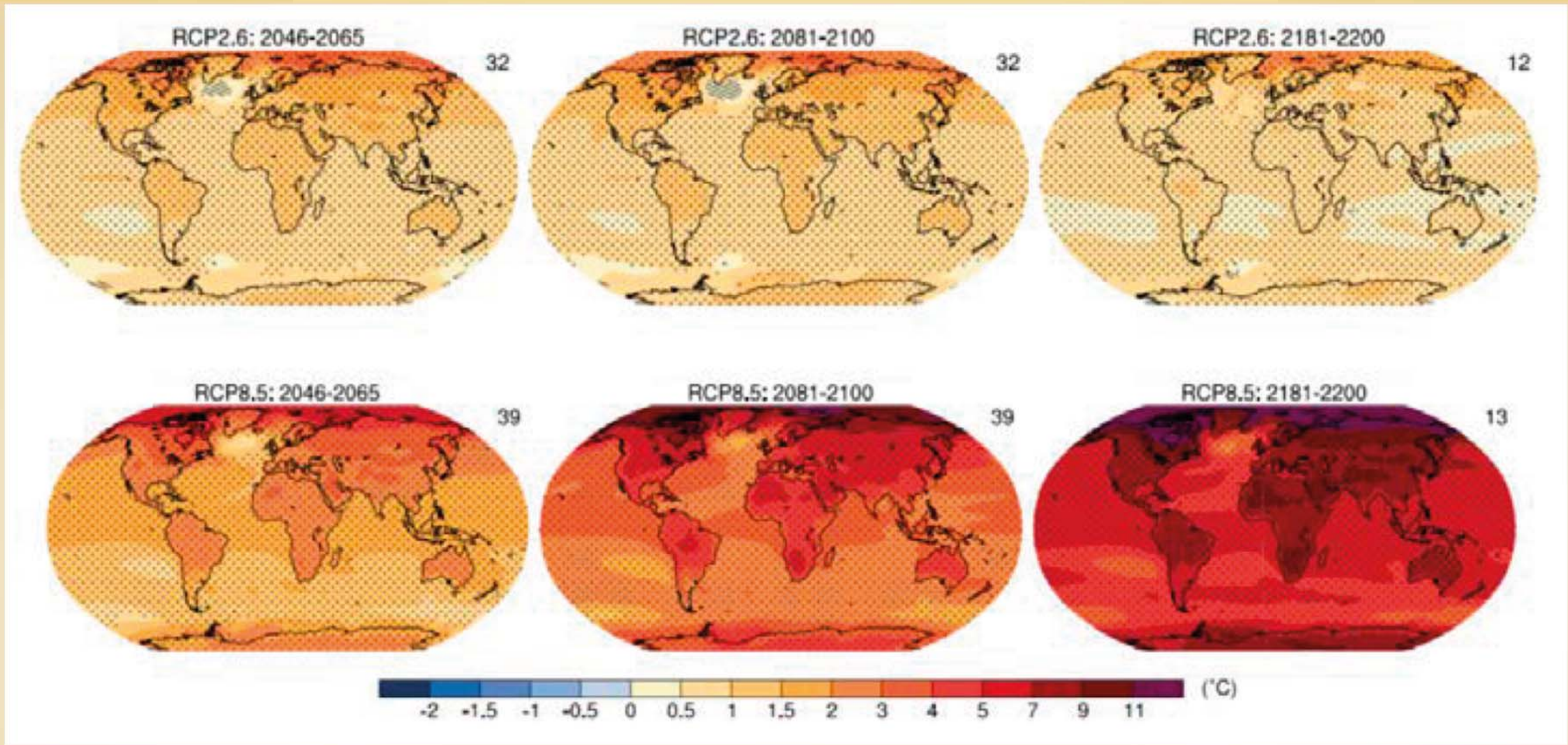
Greenhouse Effect

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



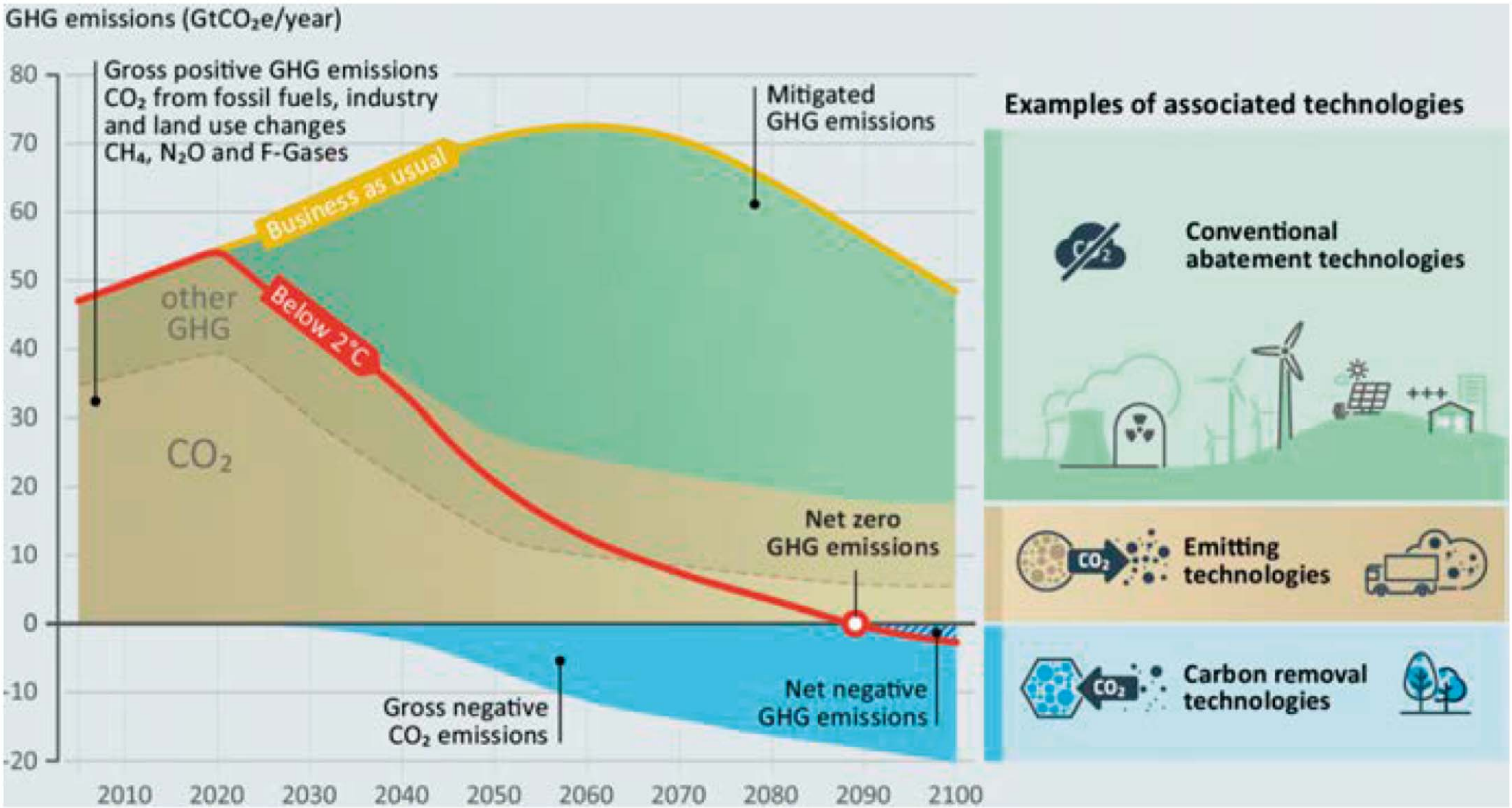
Greenhouse Effect



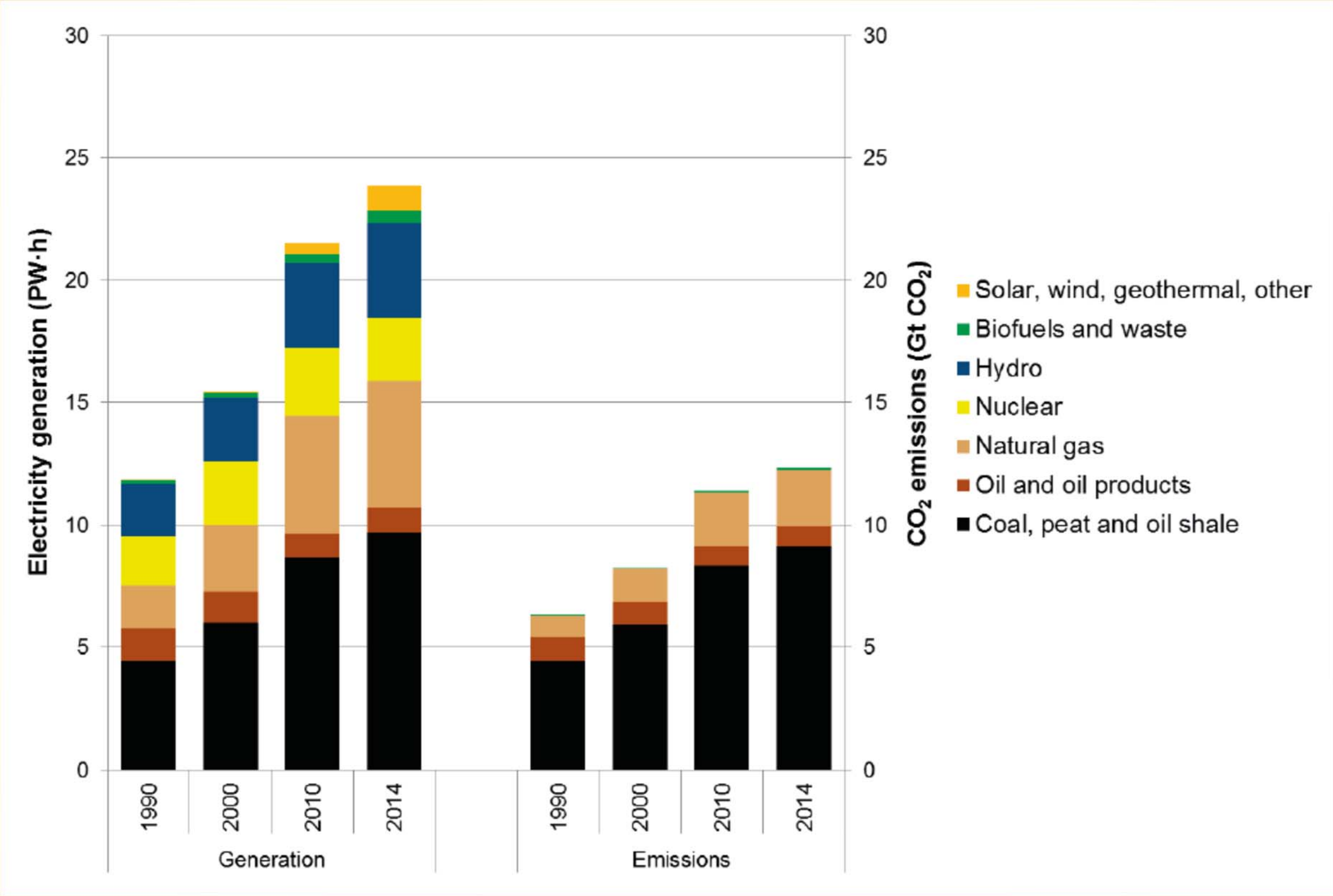
Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels would significantly reduce the risks and impacts of climate change

Mitigation target of the Paris Agreement, Article 2

Global Warming Challenge



Global Warming Challenge



Global Warming Challenge

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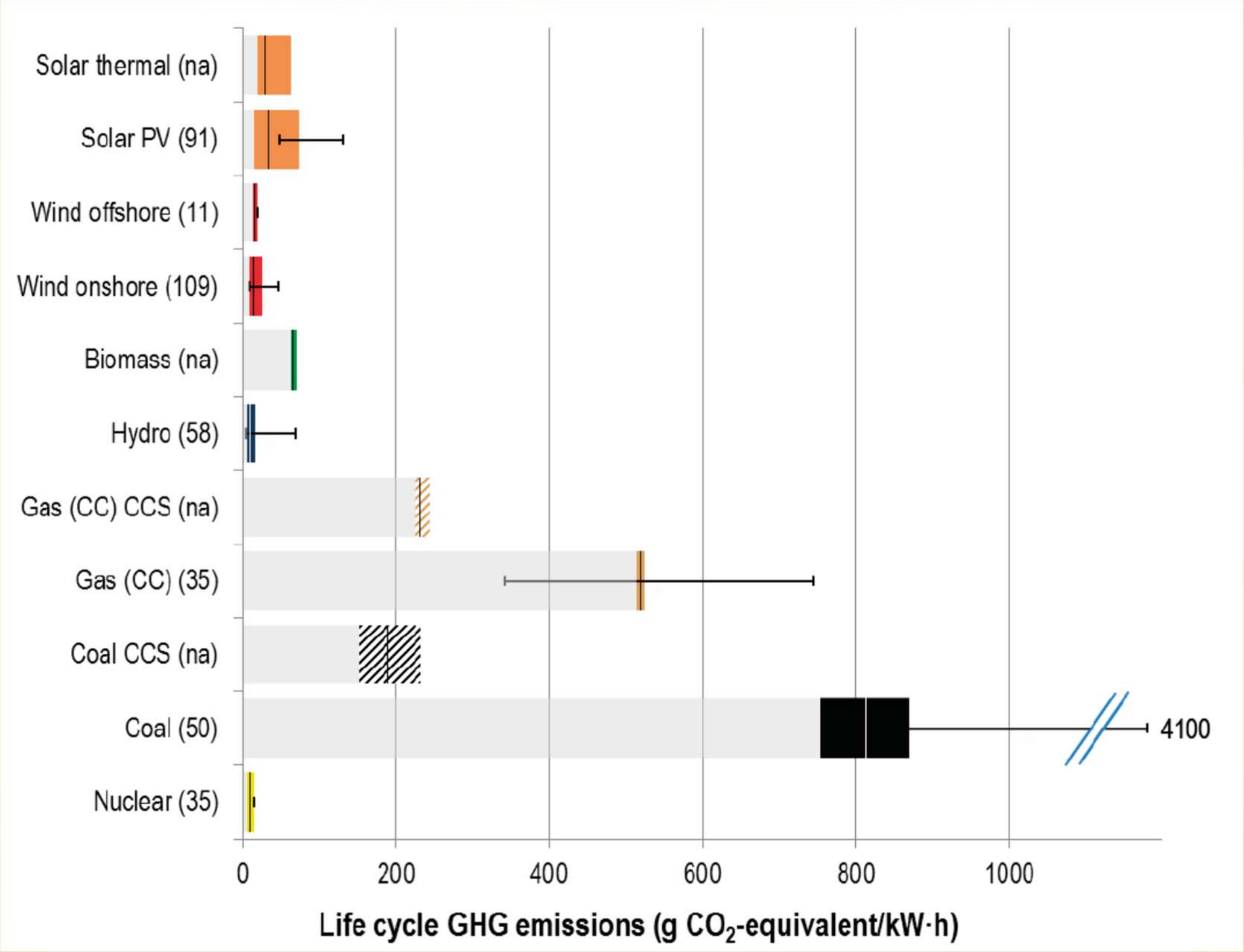
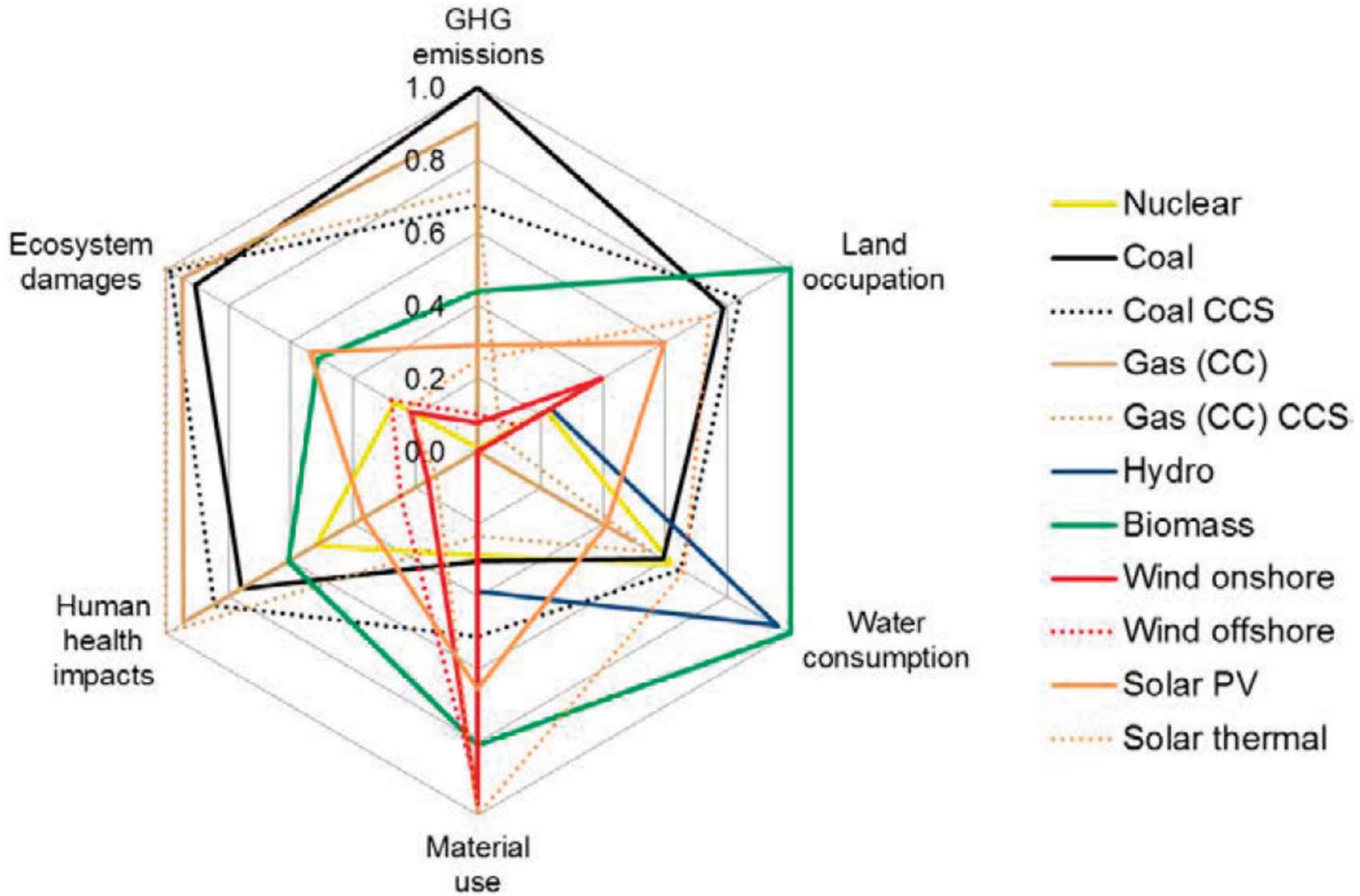
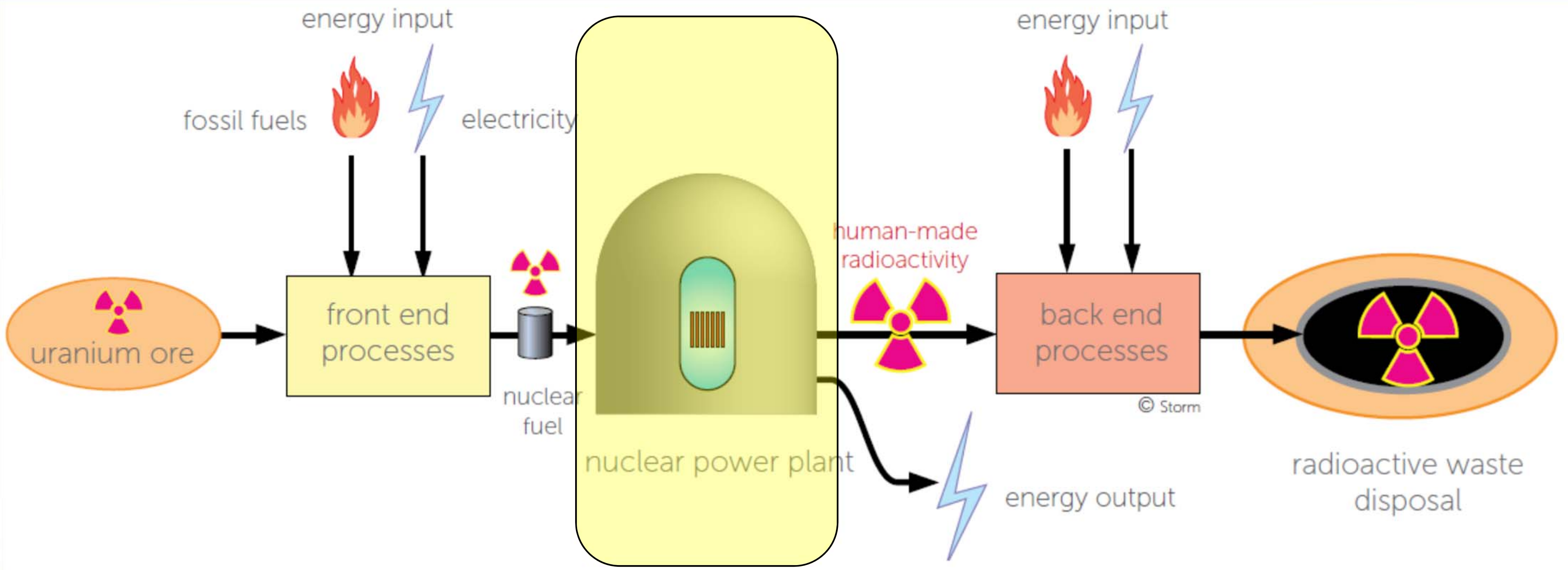


Global Warming Challenge



0 = lowest impact; 1 = highest impact (log normalized)

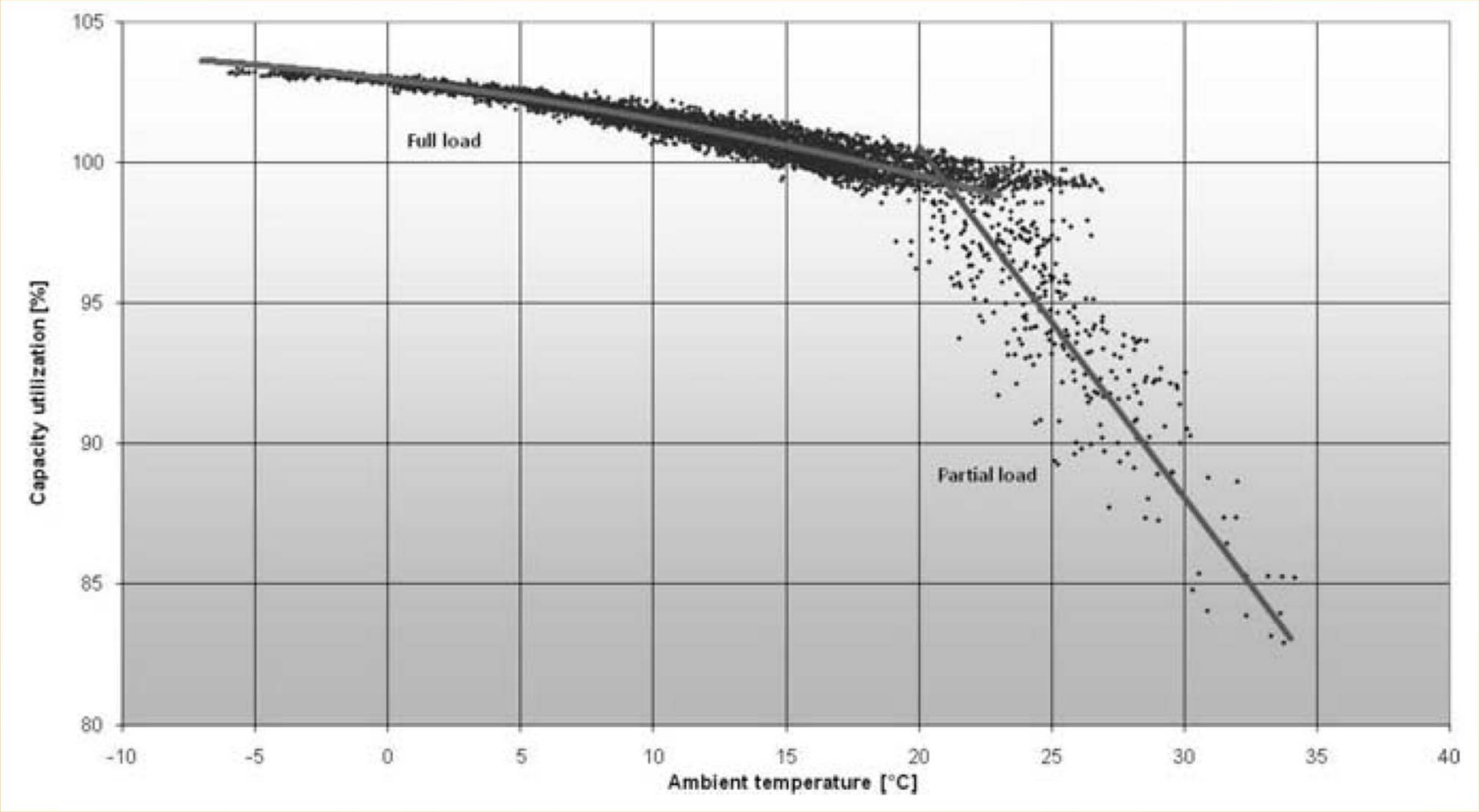
Global Warming Challenge



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

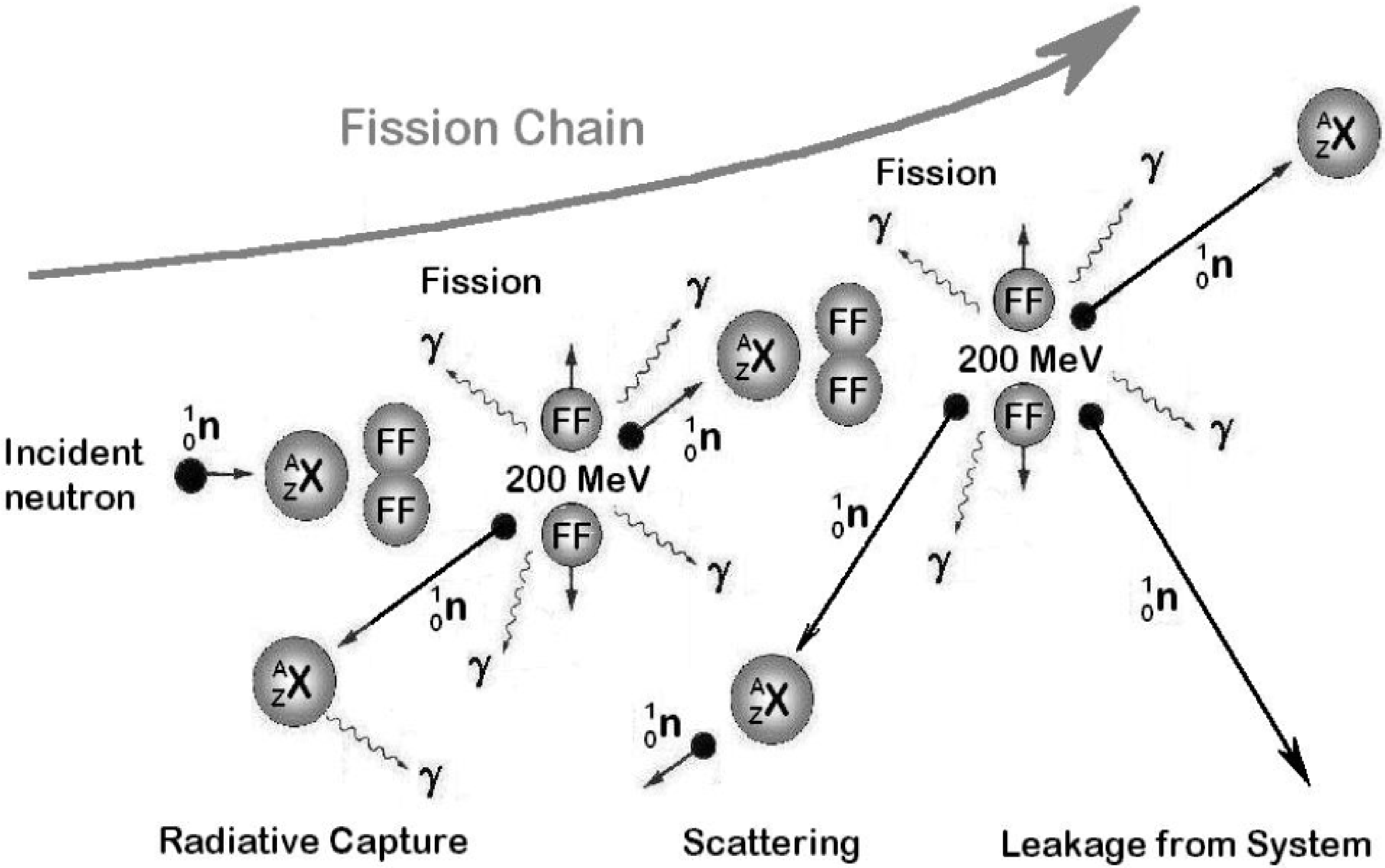
Light nuclei (hydrogen, helium) release energy when they **fuse (Nuclear Fusion)**

The **product nuclei** weigh **less** than the parent nuclei

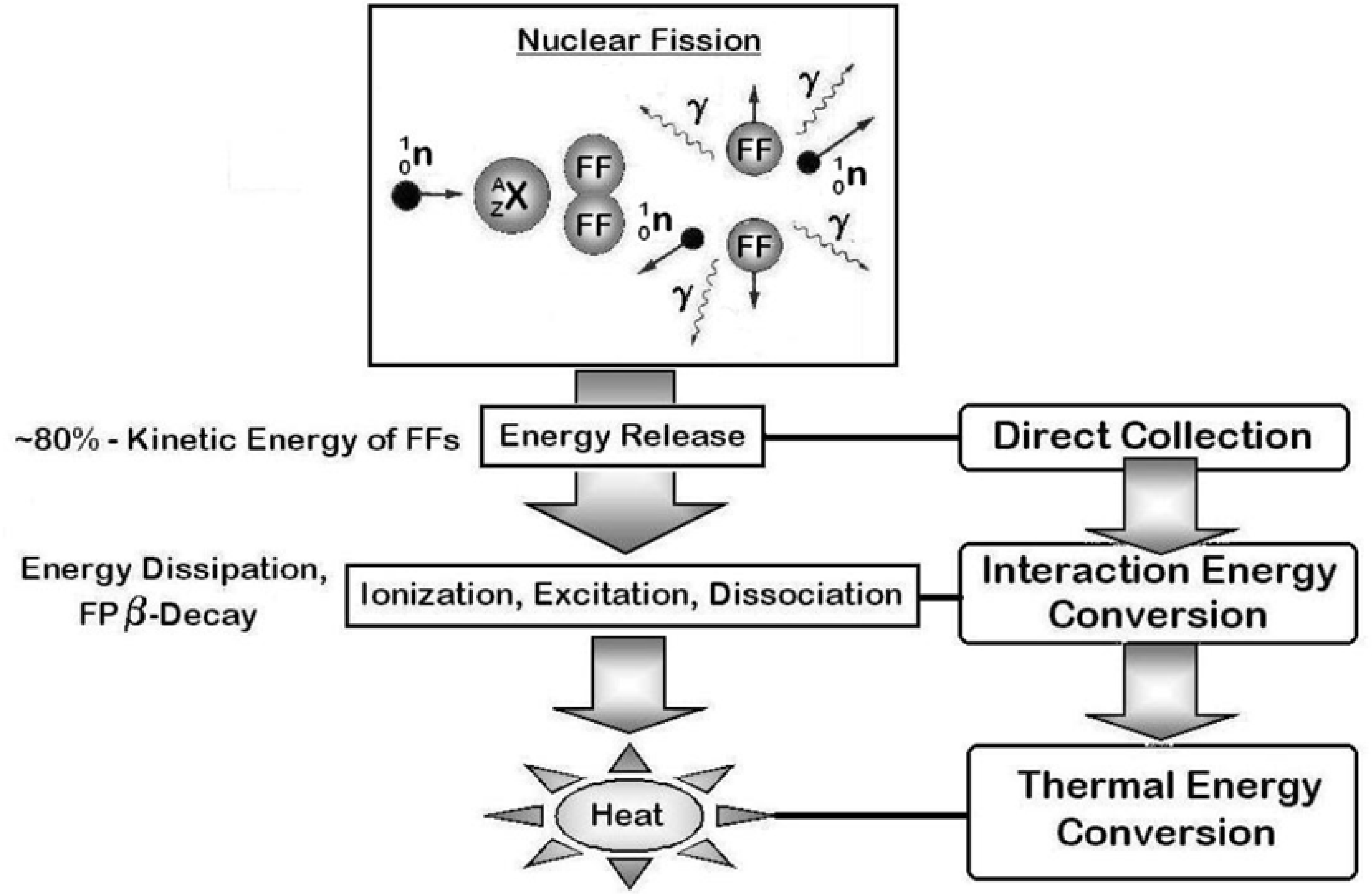
Heavy nuclei (Uranium) release energy when they **split (Nuclear Fission)**

The **product nuclei** weigh **less** than the original nucleus

Nuclear Energy



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

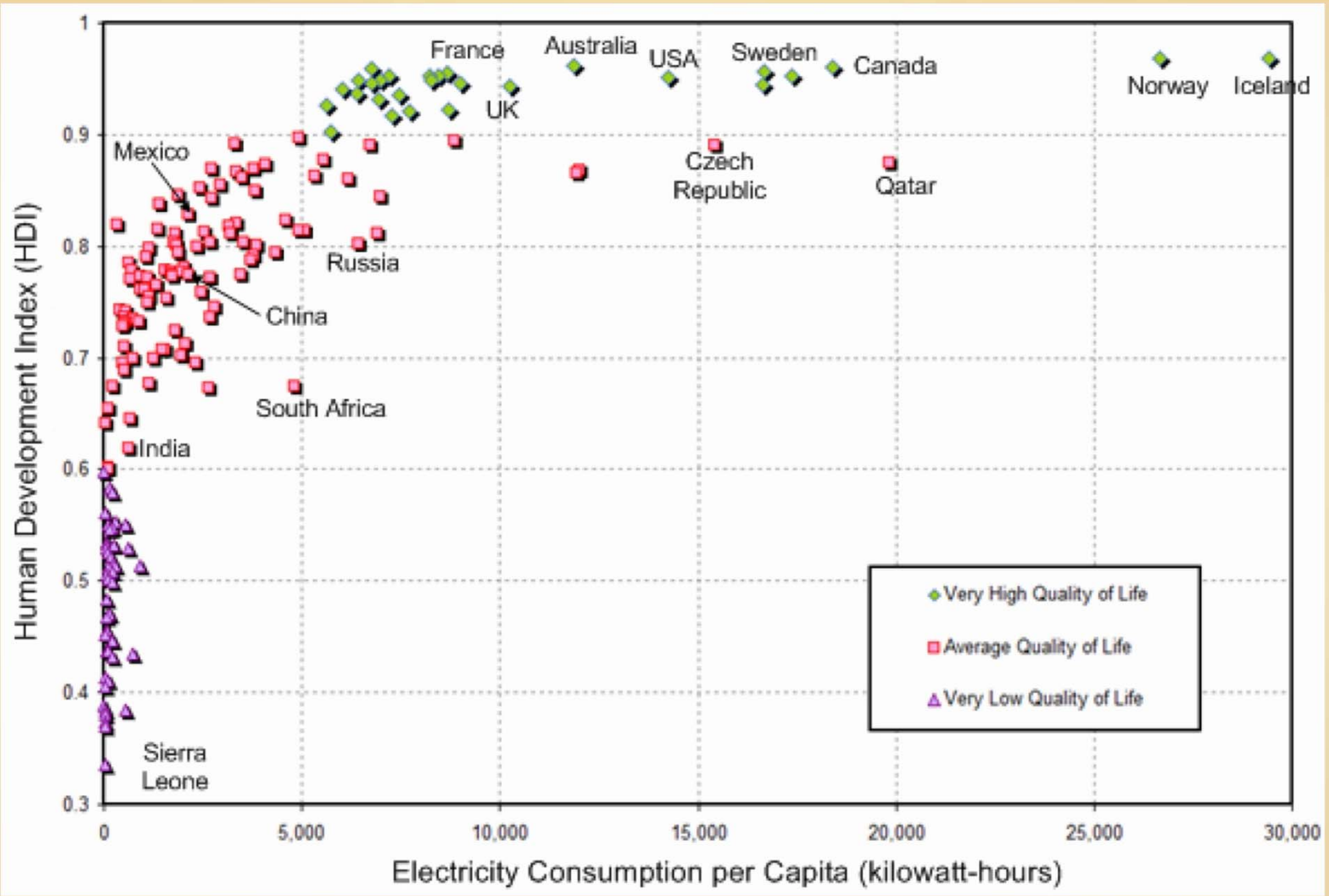
Engineering:

- Highly regulated safety design leading to low probabilities for accidents with high consequences
- Nuclear waste management
- Security

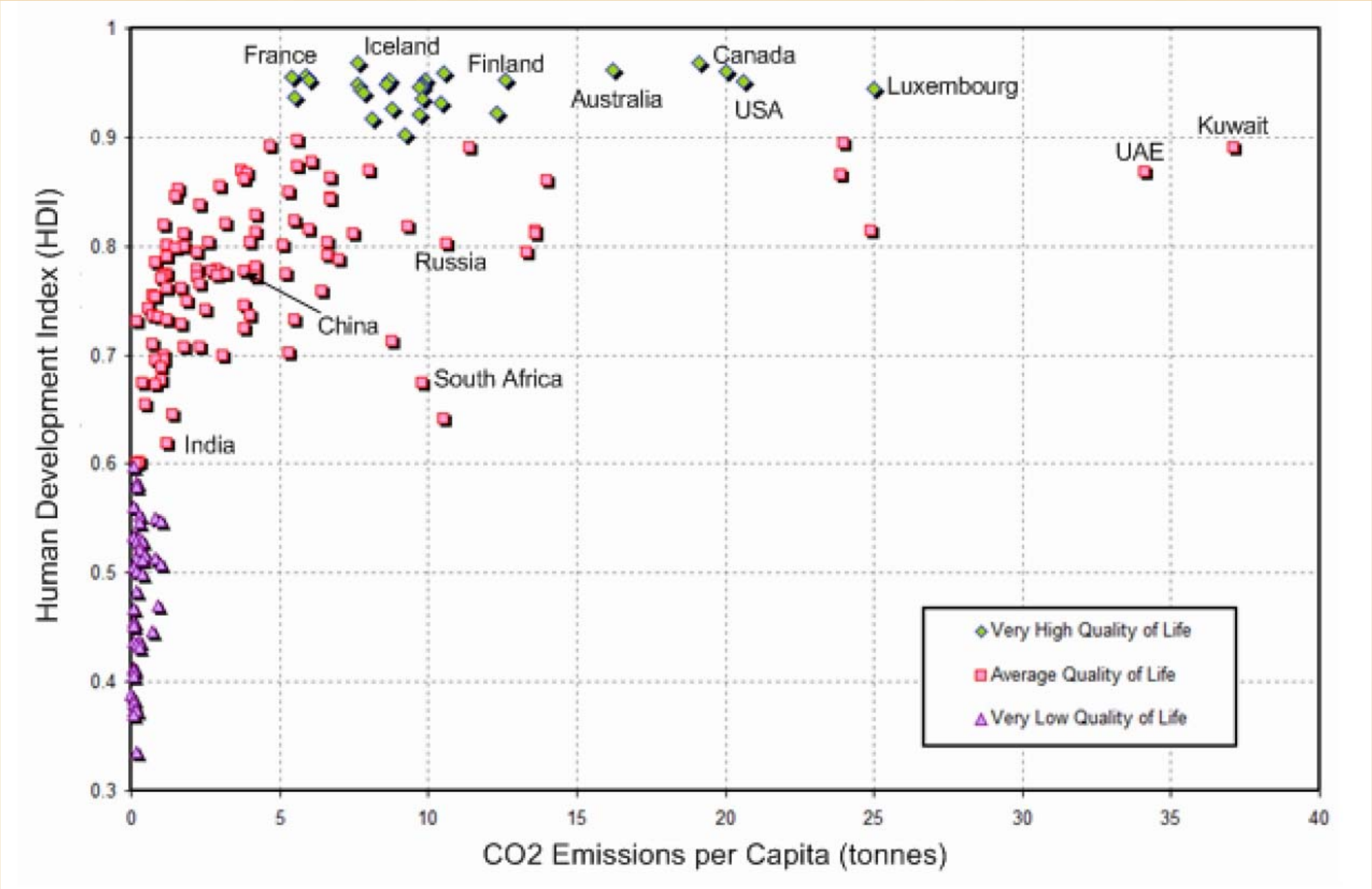
Part 3:

Energy Supply and Demand

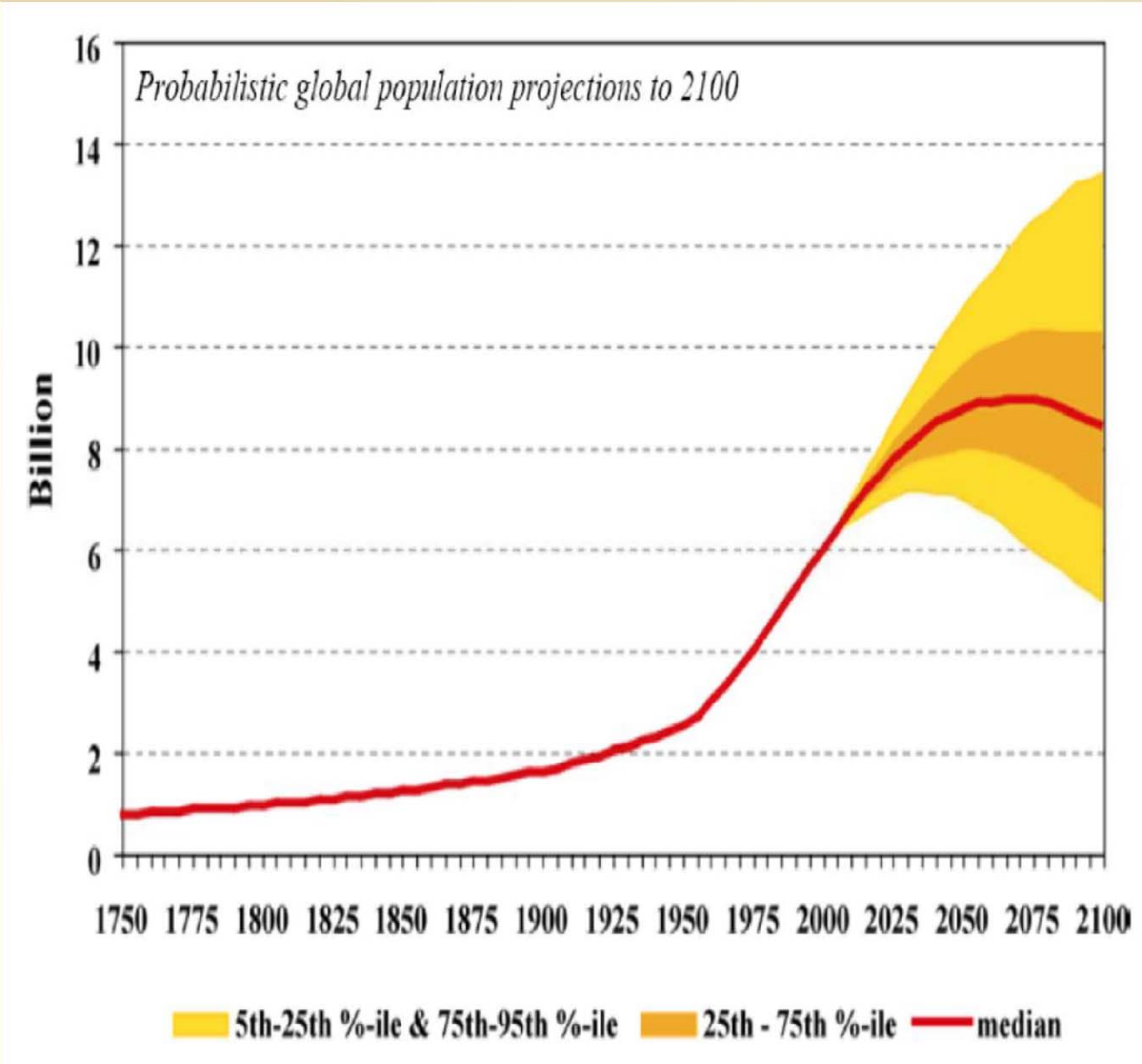
Energy Supply and Demand

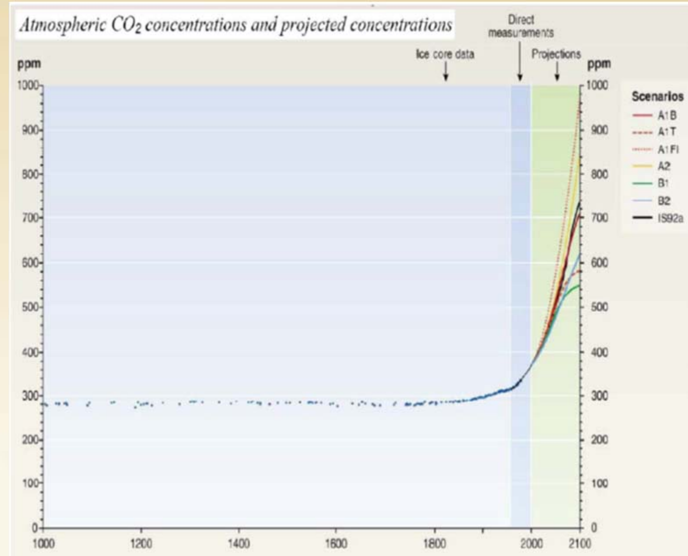


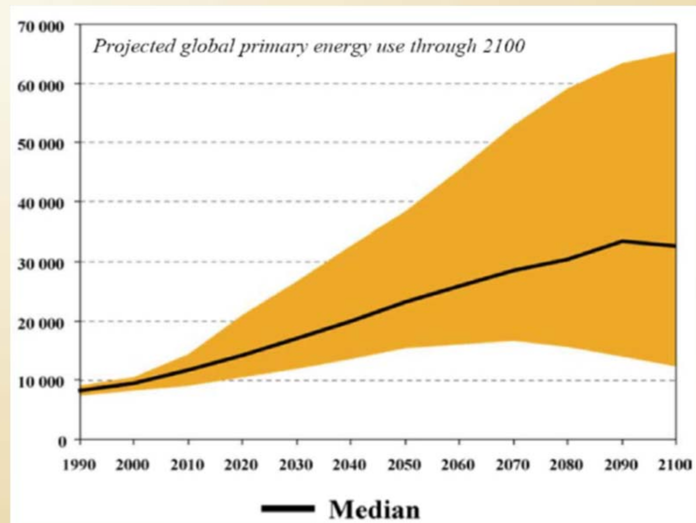
Energy Supply and Demand



Energy Supply and Demand







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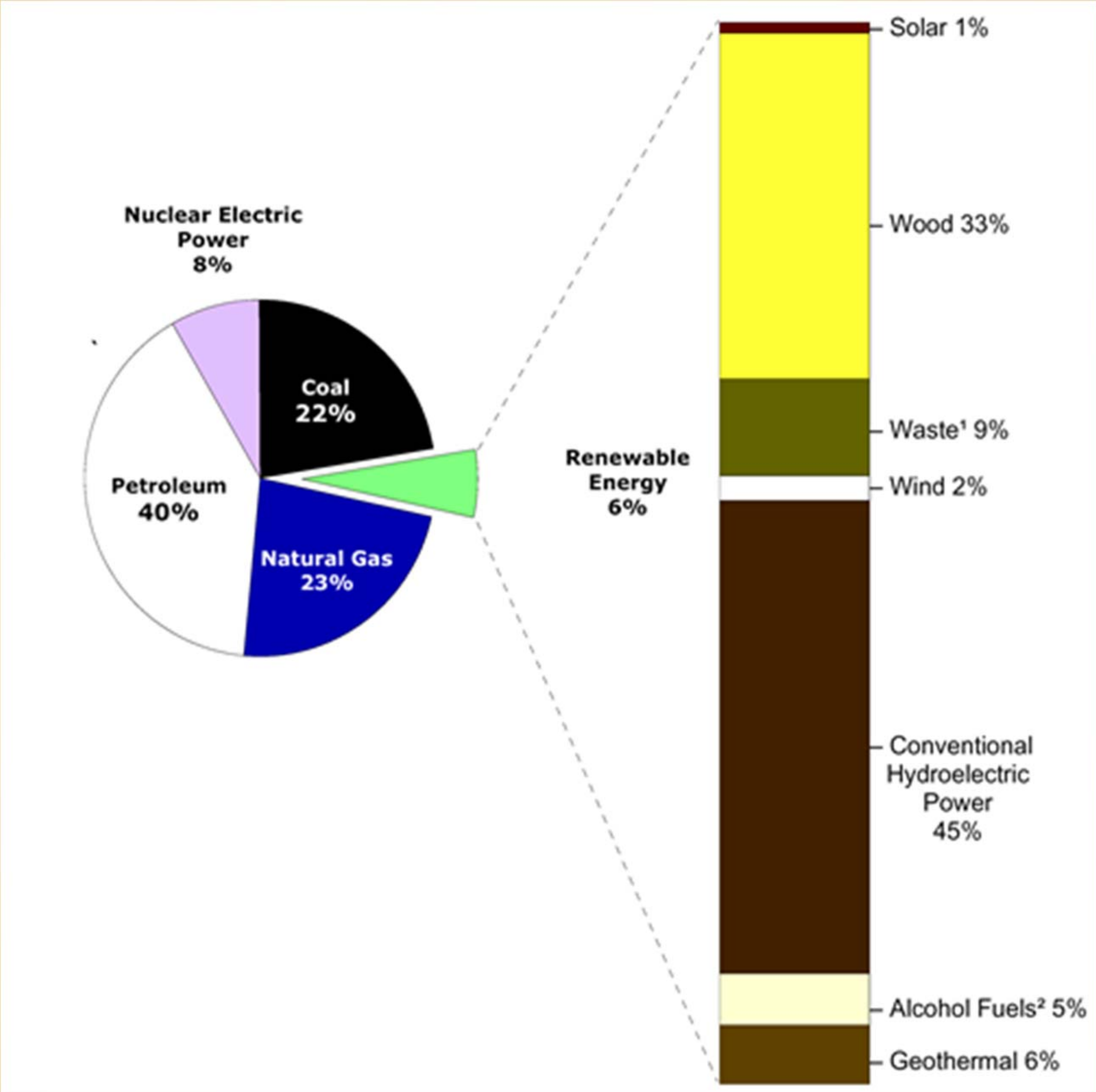
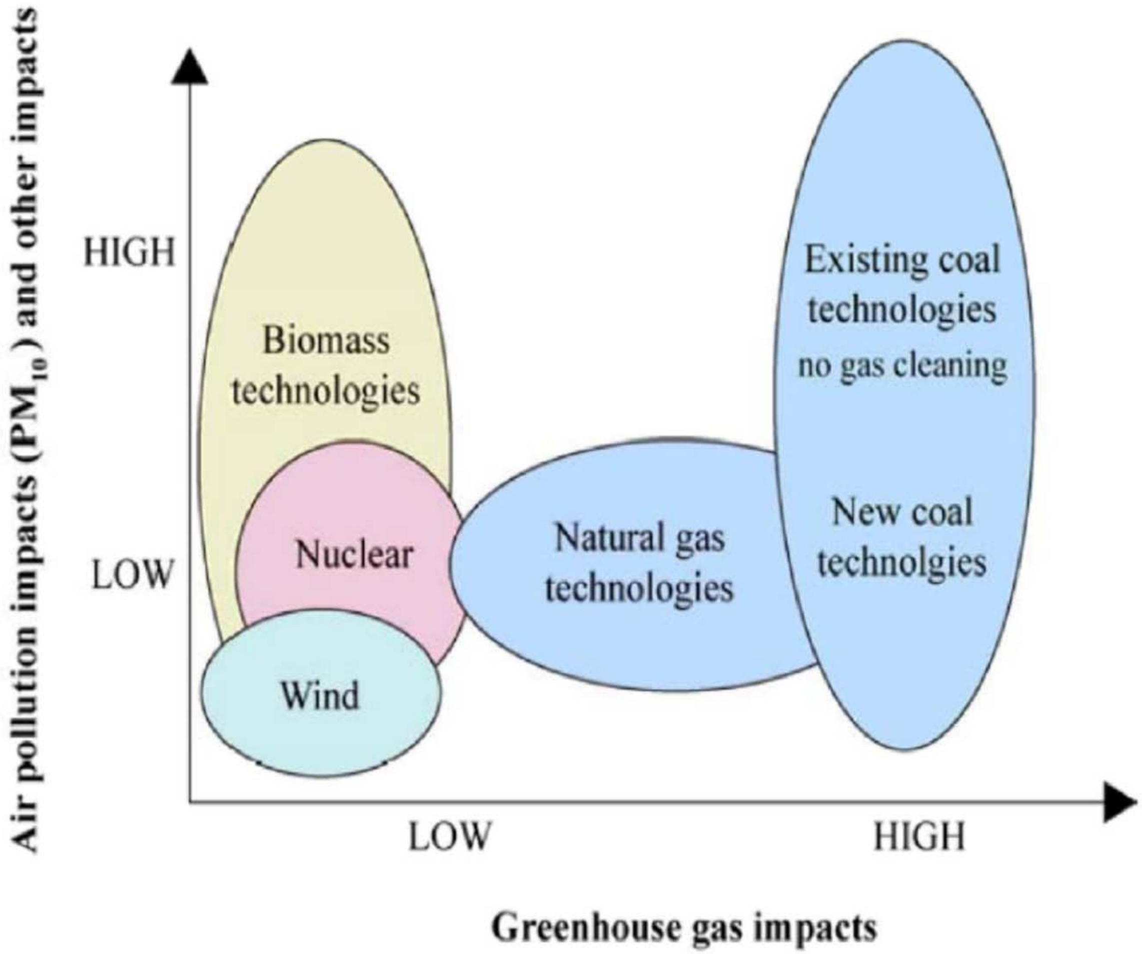
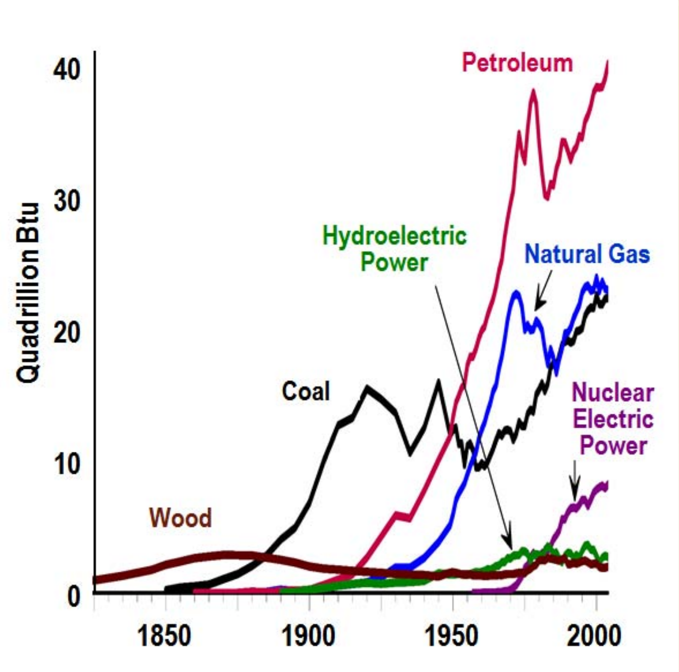


Energy Supply and Demand



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)

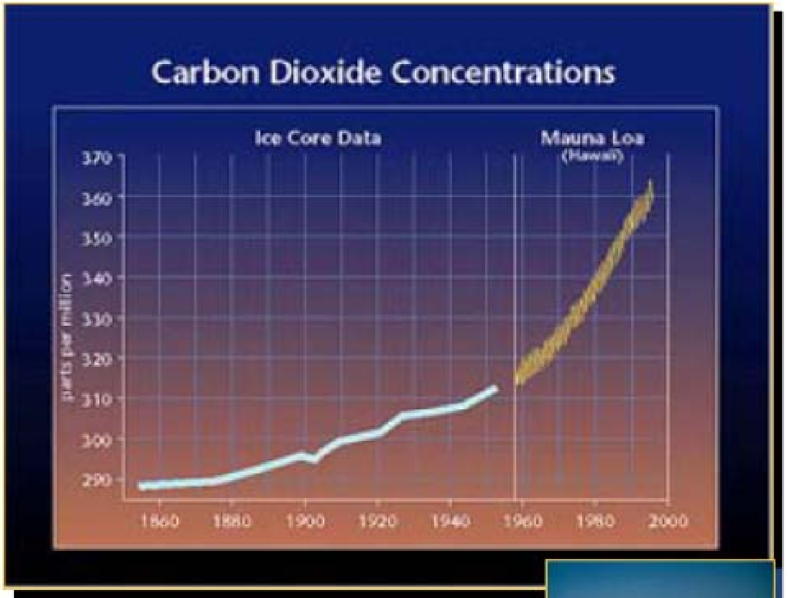
Fuel Cycle Scenario	Conventional Resources (years)	Total Resources (years)
Once-through fuel cycle with LWRs	80	270
Closed fuel cycle based on pure recycling in FRs	4,800–5,600	16,000–19,000

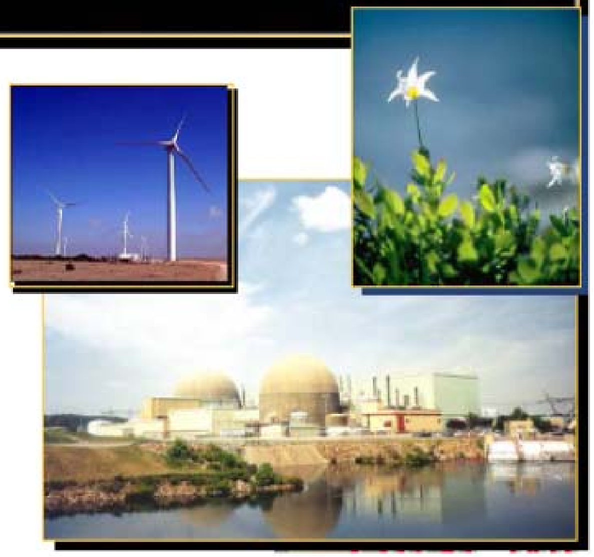
Part 4:

Nuclear Power

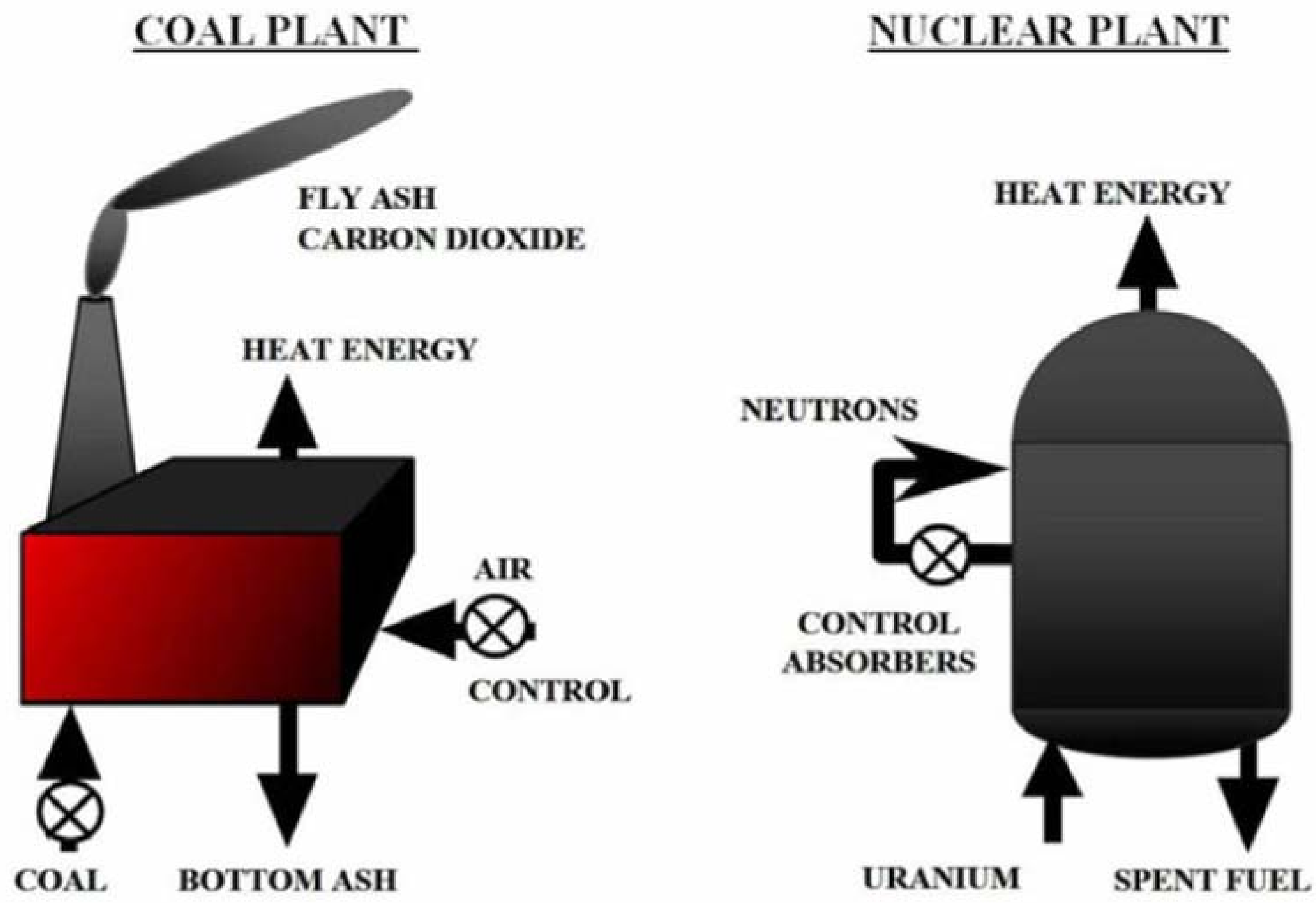
Nuclear Power

- 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





Nuclear Power



Coal and nuclear power plants.

Nuclear Power

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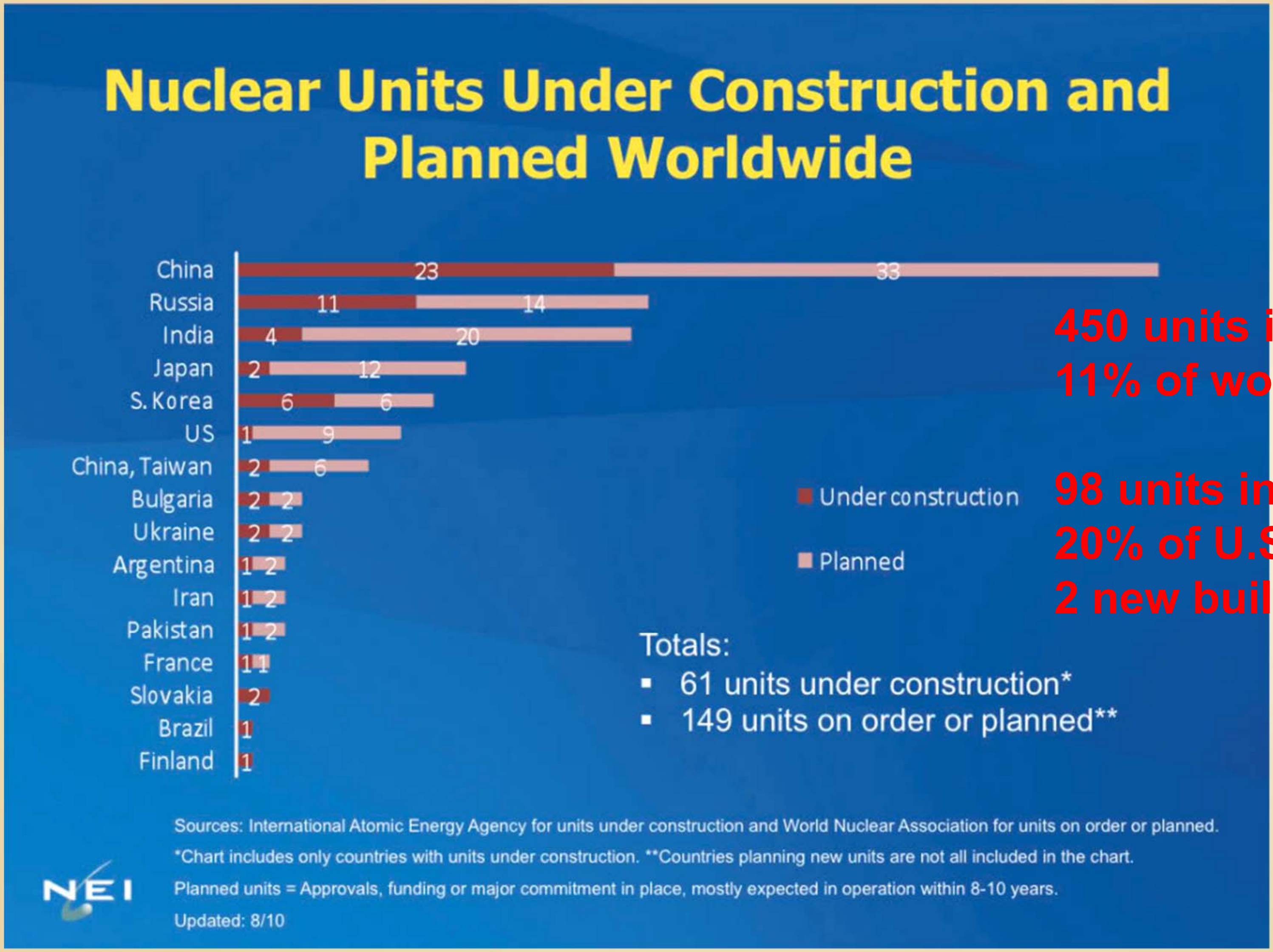
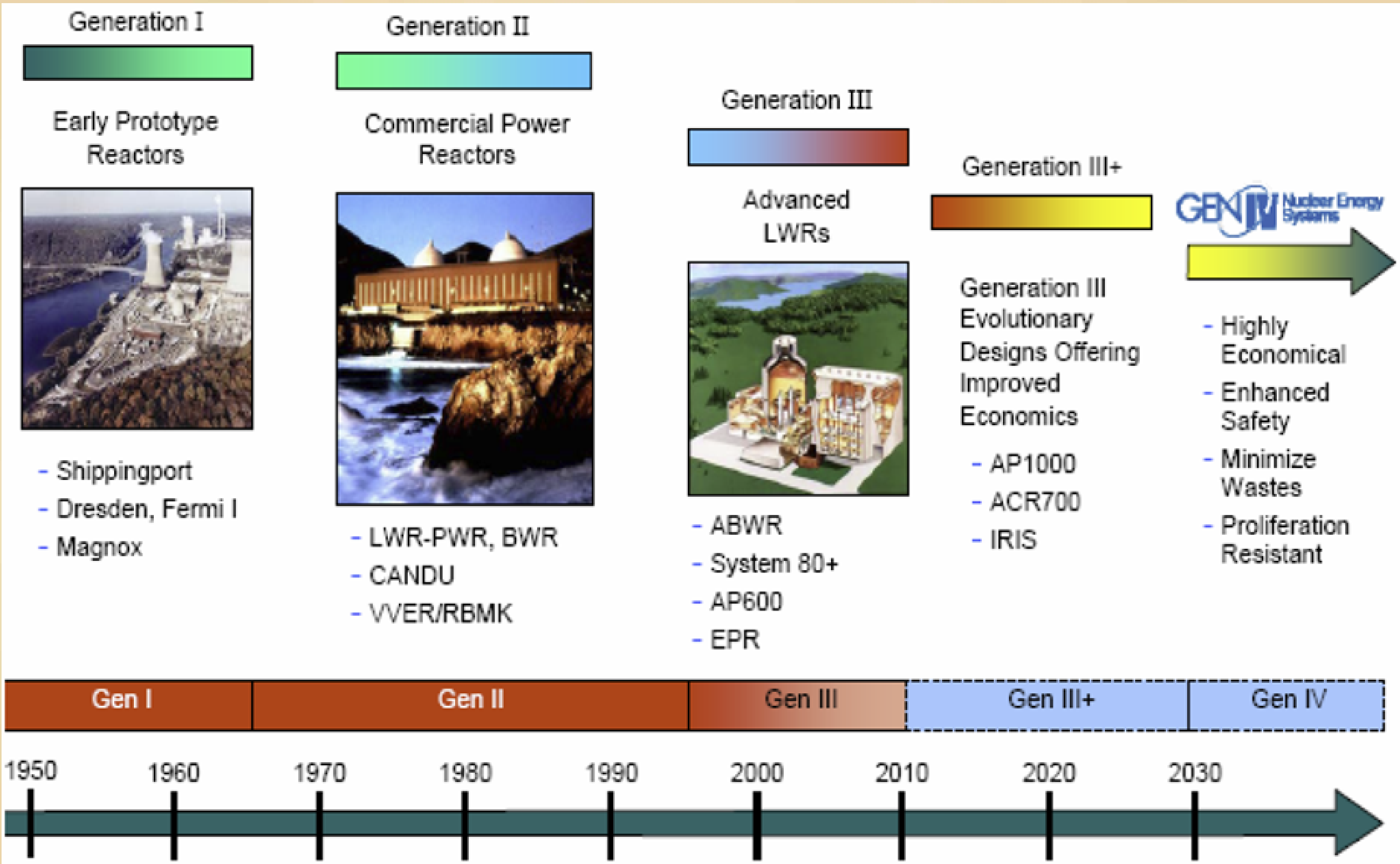


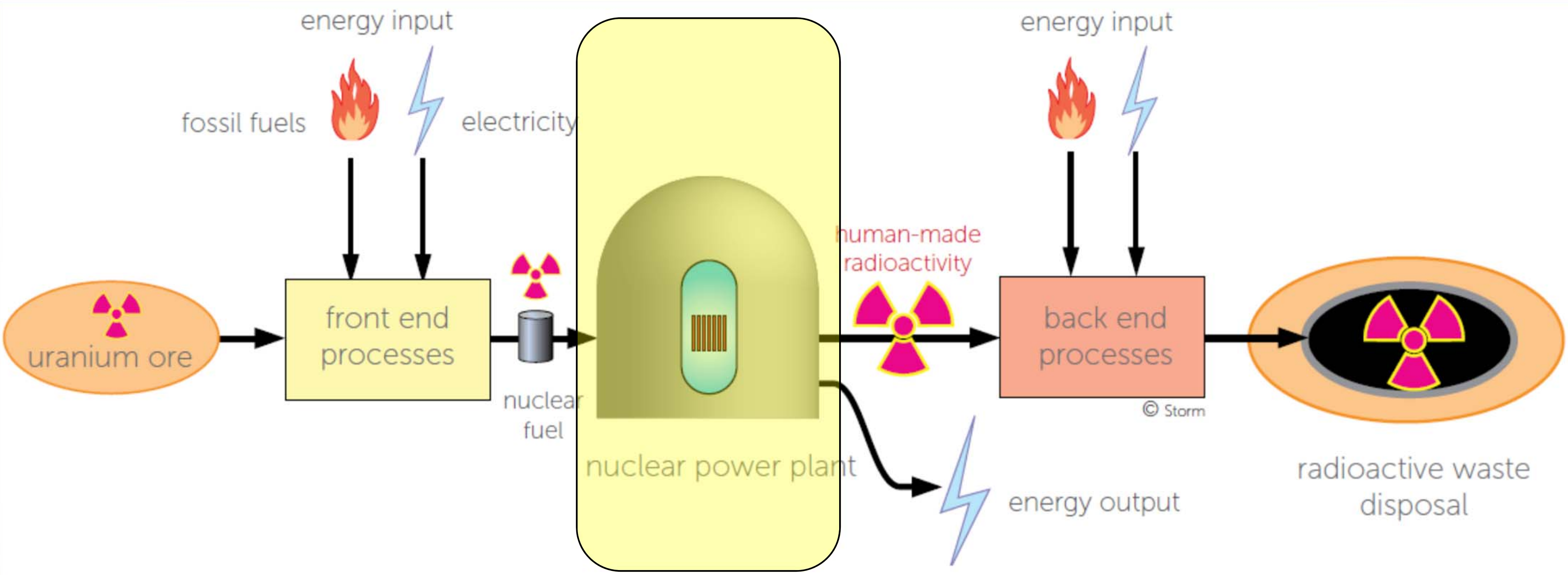
450 units in operation
11% of world's electricity

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

Nuclear Power



Nuclear Power



Mitigation Potential of Nuclear Power

Nuclear Power

Goals for Generation IV Nuclear Energy Systems

Sustainability-1

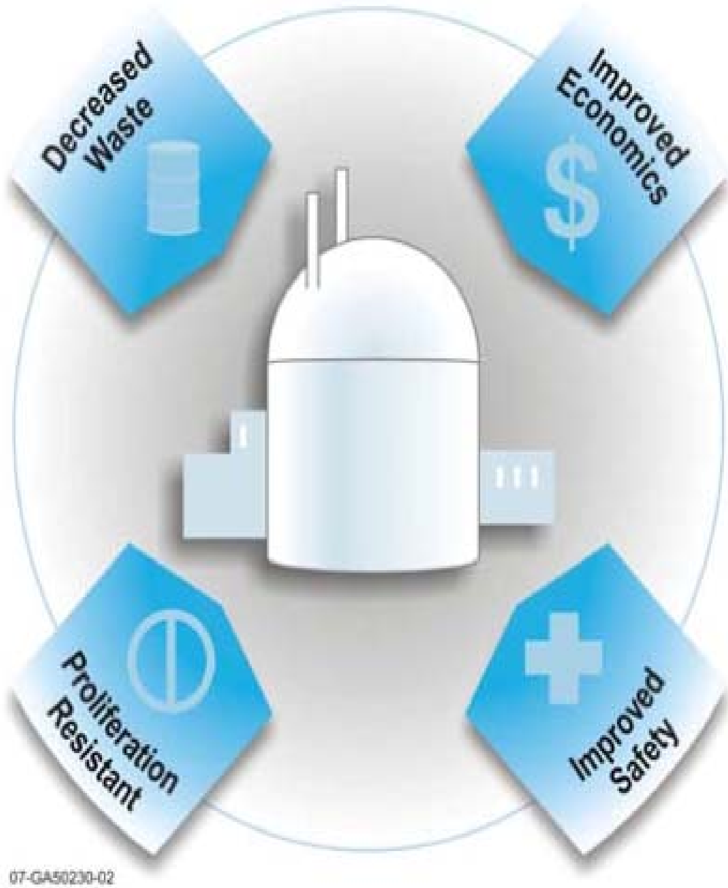
Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.

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 weapons-usable 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.

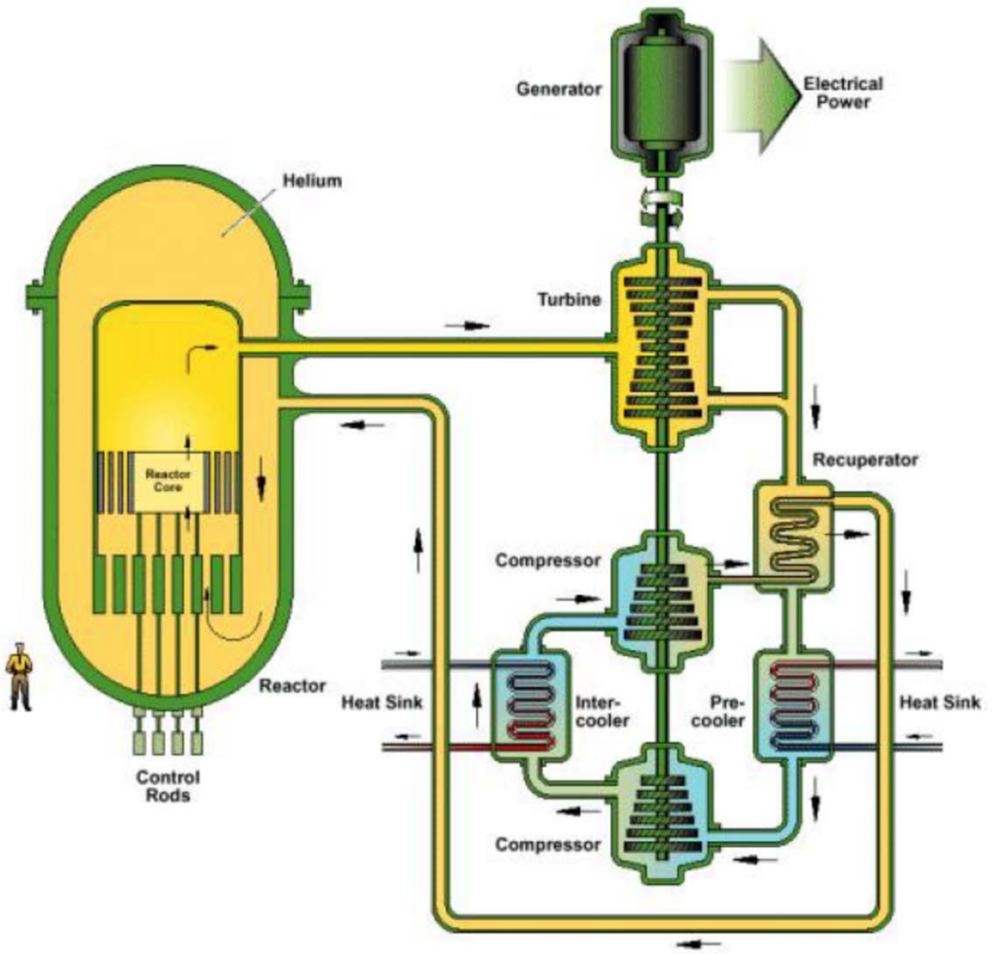
Nuclear Power

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);
6. Molten Salt Reactor (MSR).

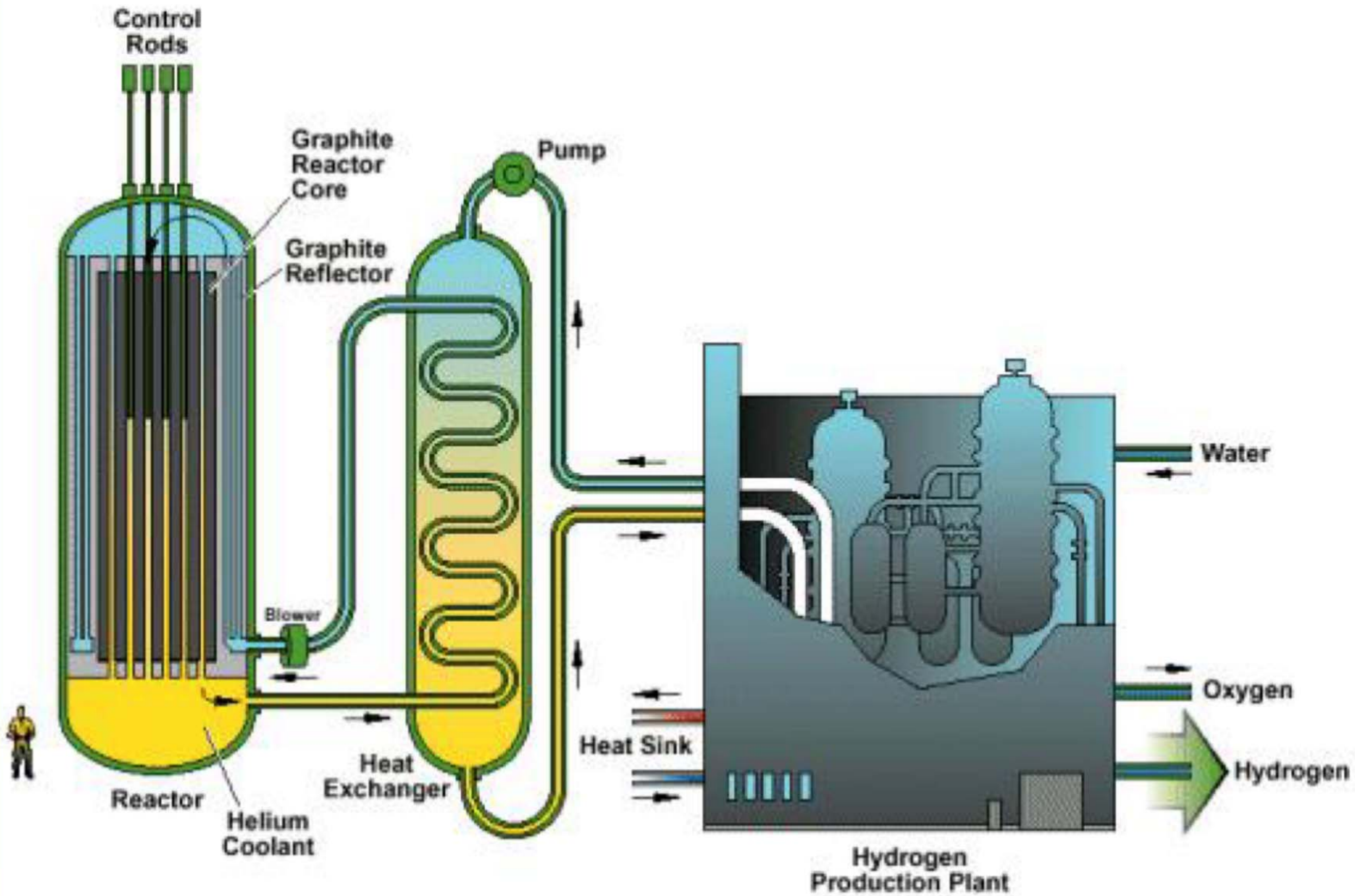
Nuclear Power

1. Gas-Cooled Fast Reactor (GFR)

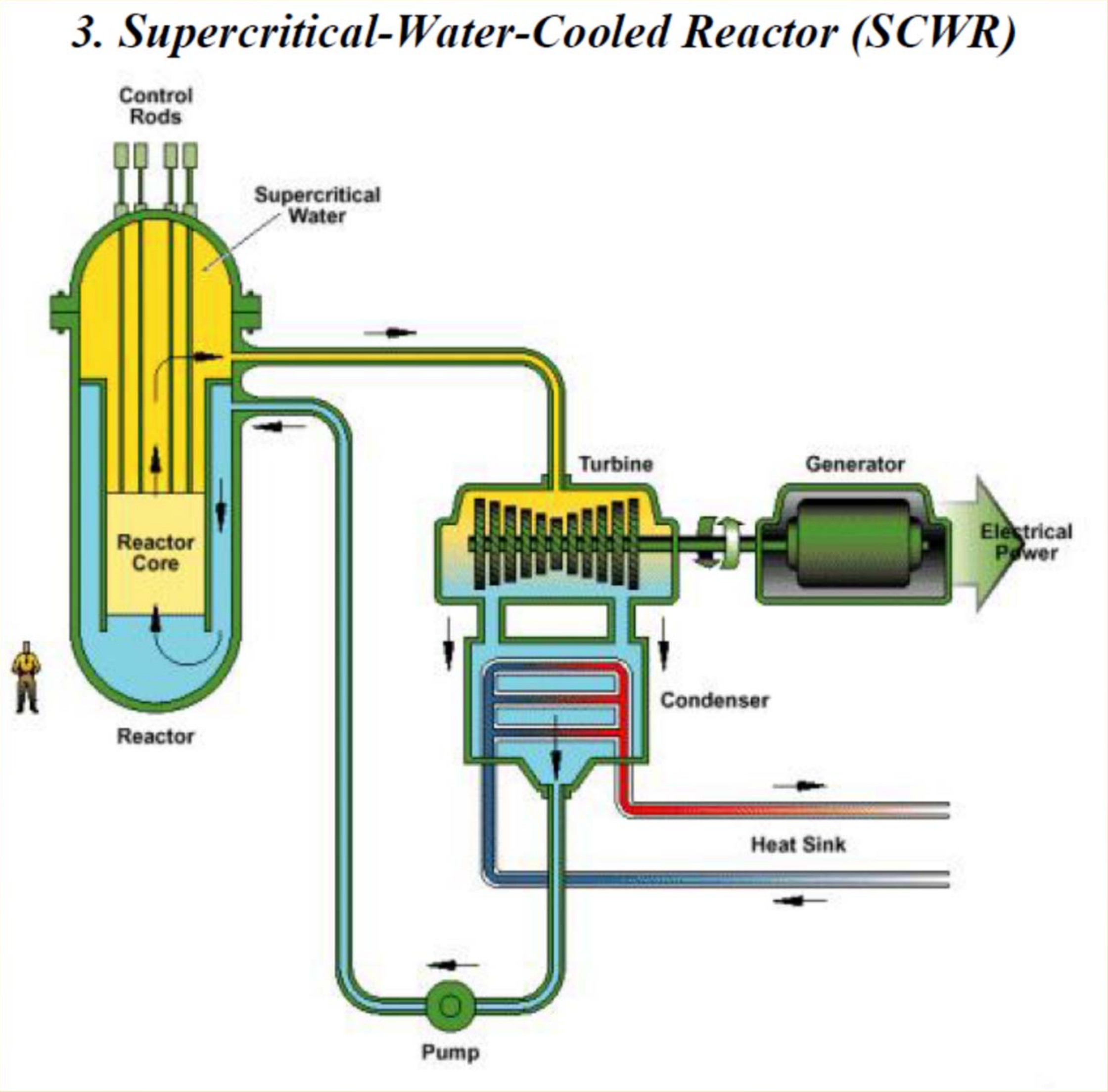


Nuclear Power

2. Very-High-Temperature Reactor (VHTR)

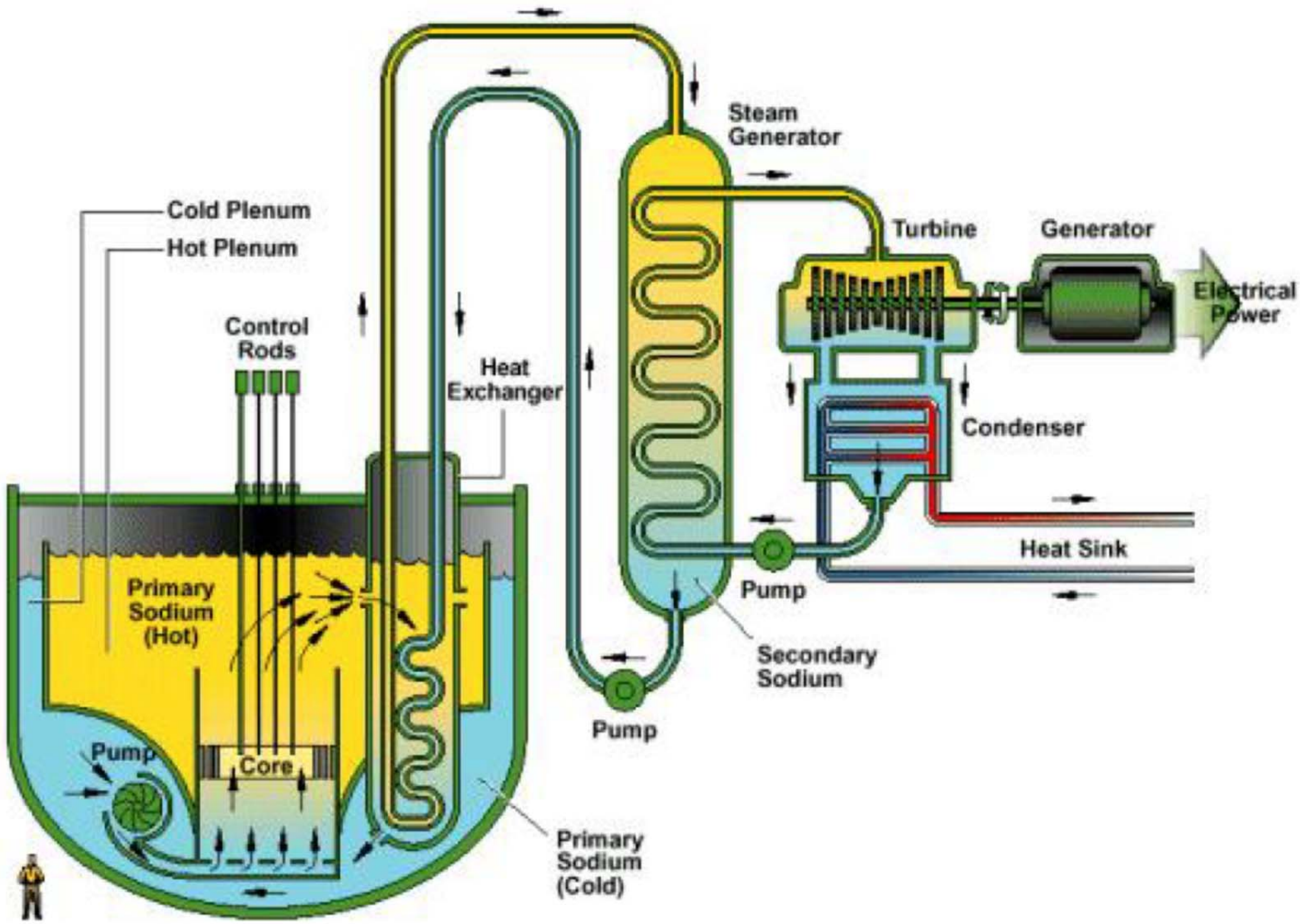


Nuclear Power



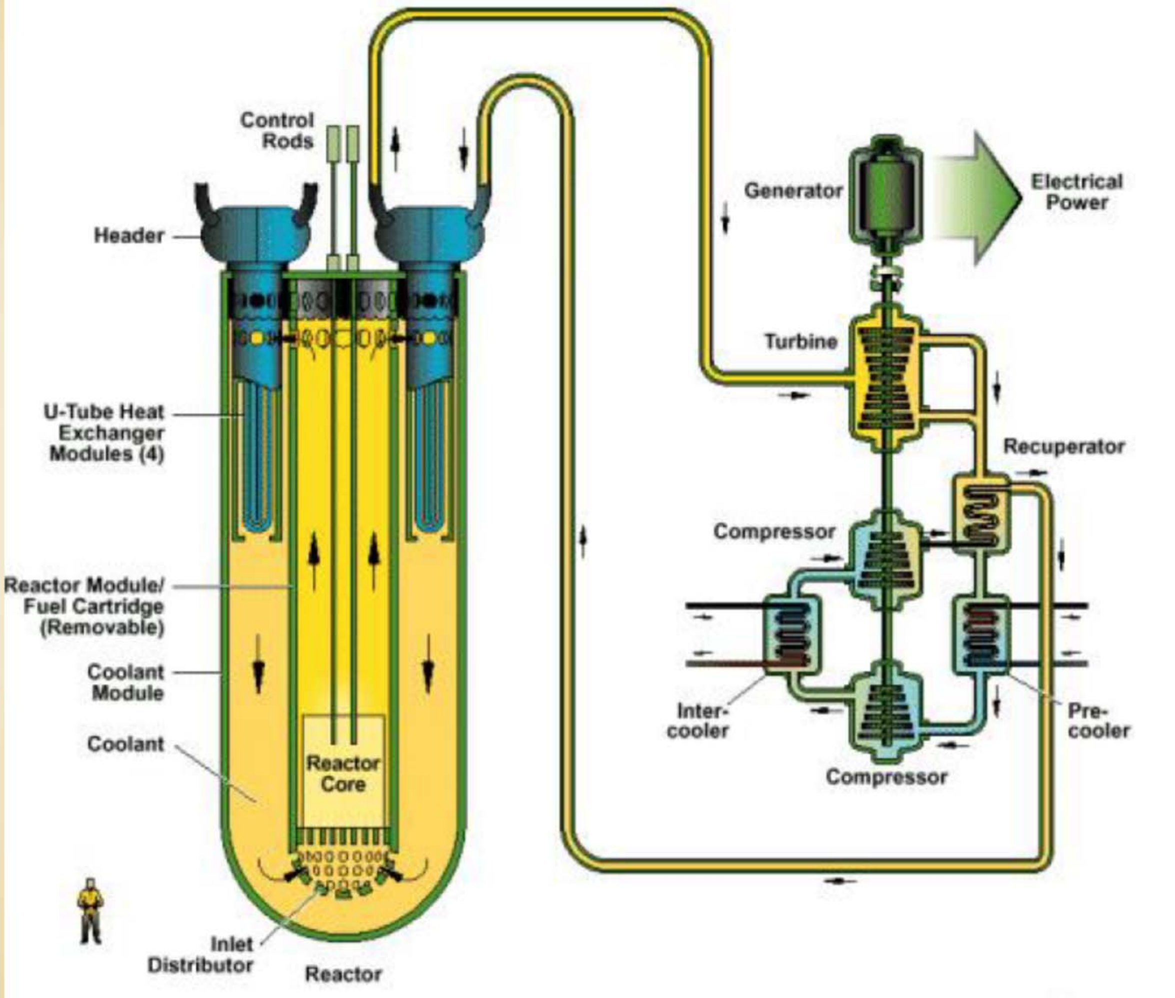
Nuclear Power

4. *Sodium-Cooled Fast Reactor (SFR)*



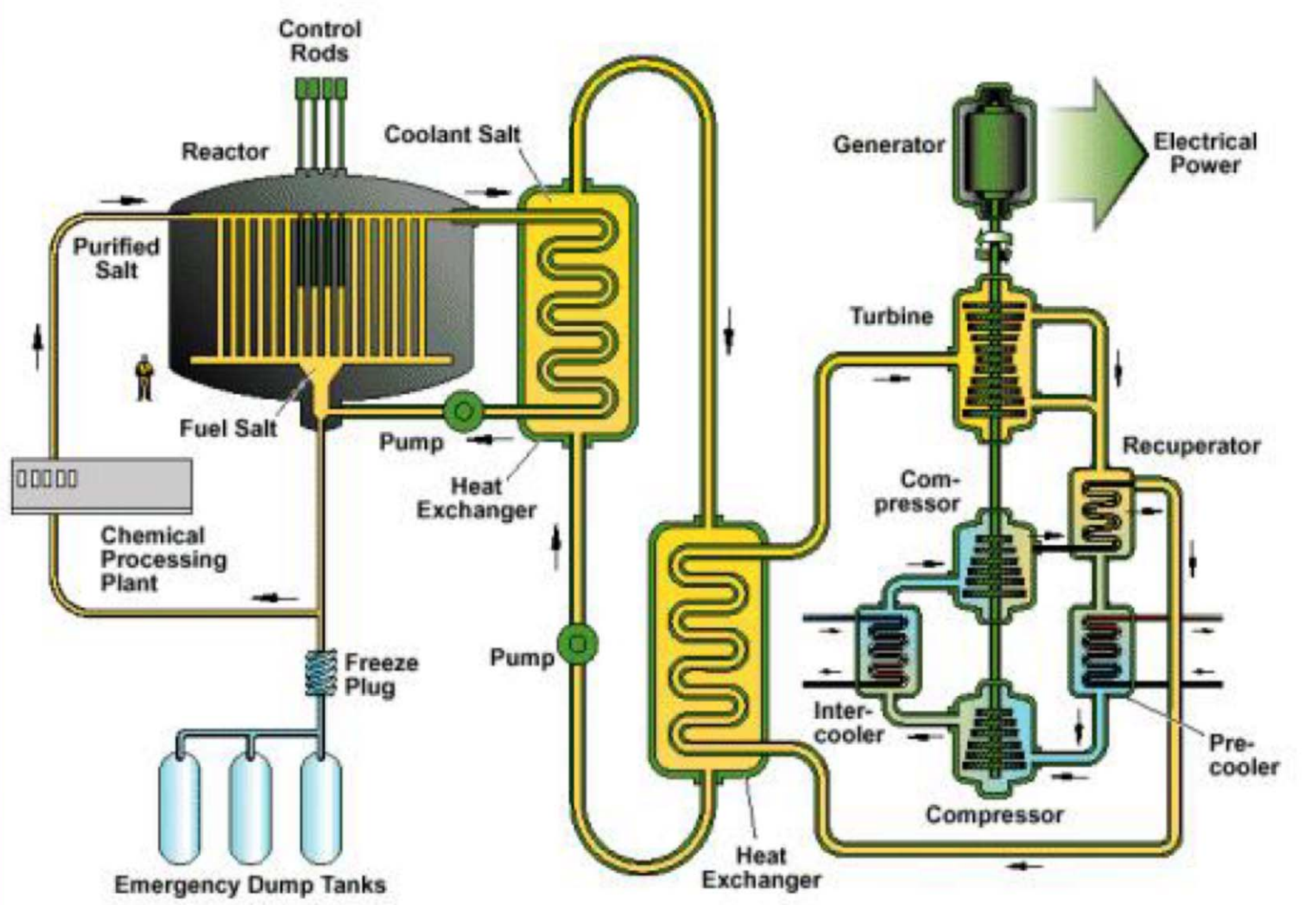
Nuclear Power

5. Lead-Cooled Fast Reactor (LFR)

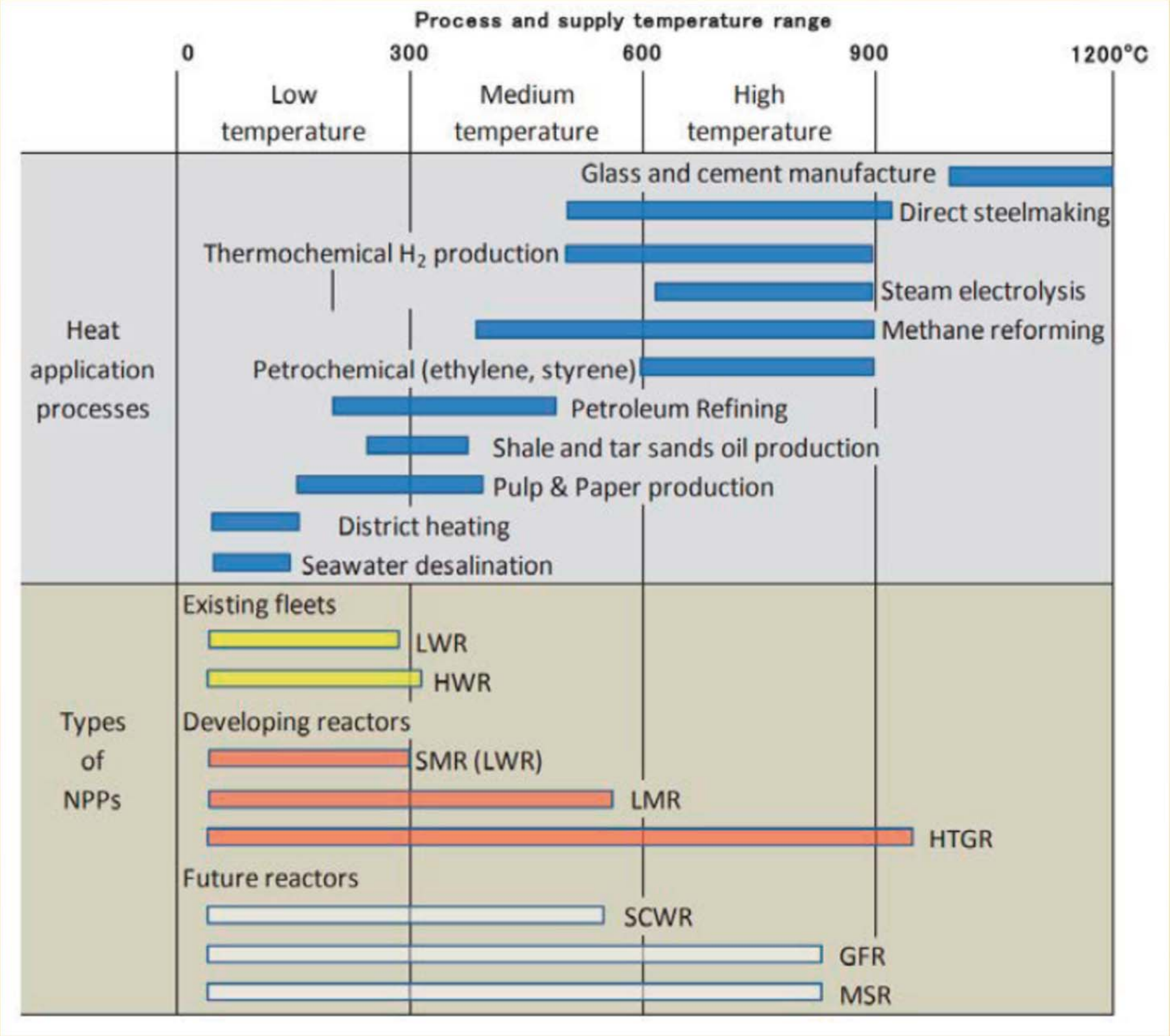


Nuclear Power

6. *Molten Salt Reactor (MSR)*



Nuclear Power



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 ($^{238}U \varnothing ^{239}Pu$-based)

Thermal Breeder ($^{232}Th \varnothing ^{233}U$-based)

Nuclear Power

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

Nuclear Power – Fusion?

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

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]

Sustainability

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)

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

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

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

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)

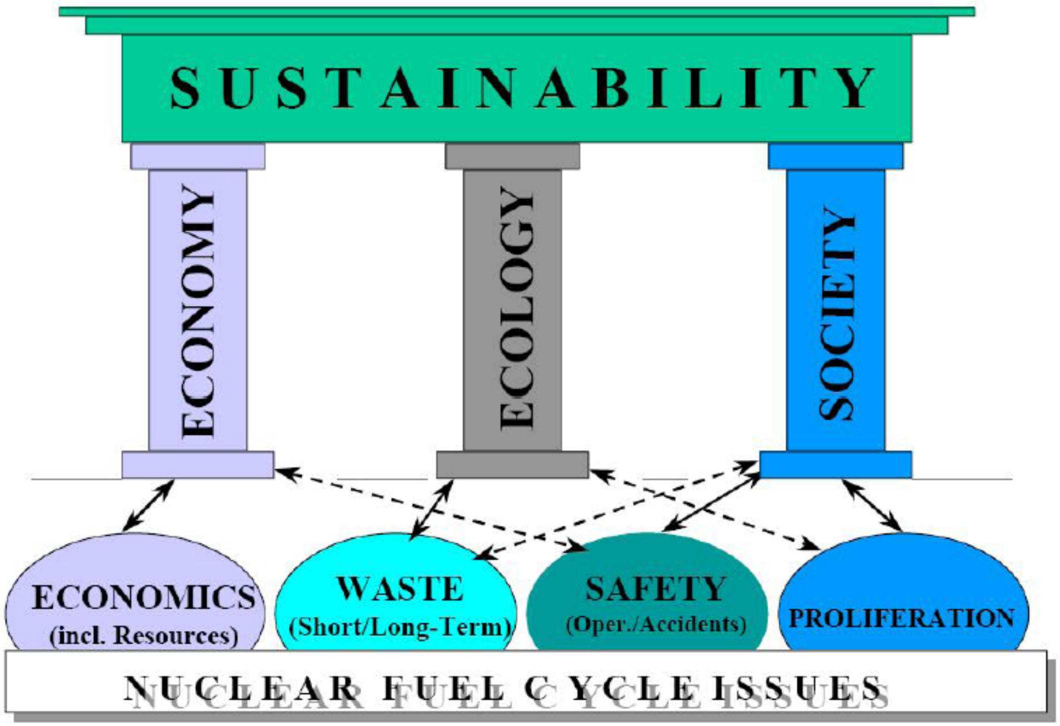
Sustainability

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?

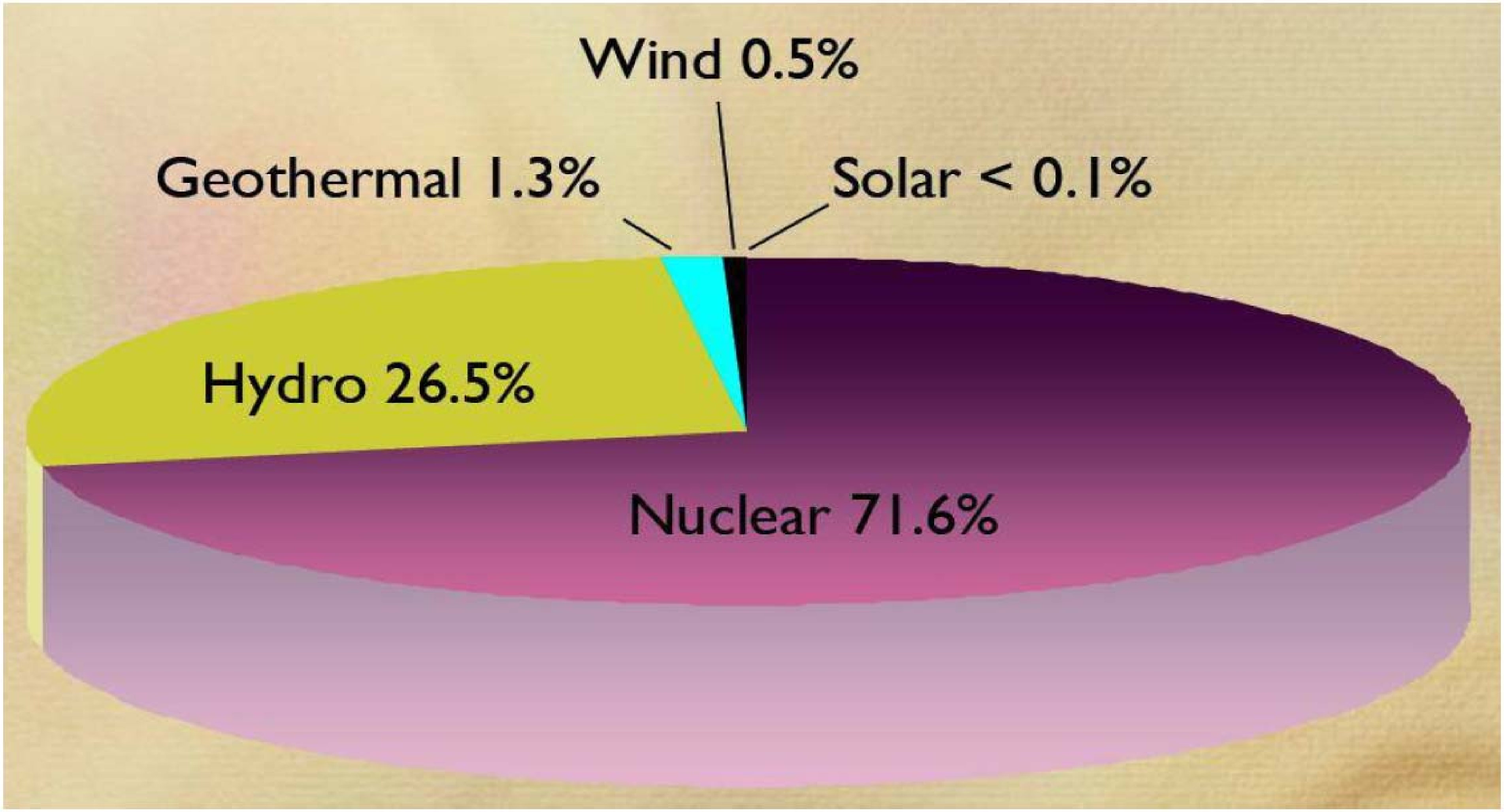
Sustainability

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)

Fuel Cycle Scenario	Conventional Resources (years)	Total Resources (years)
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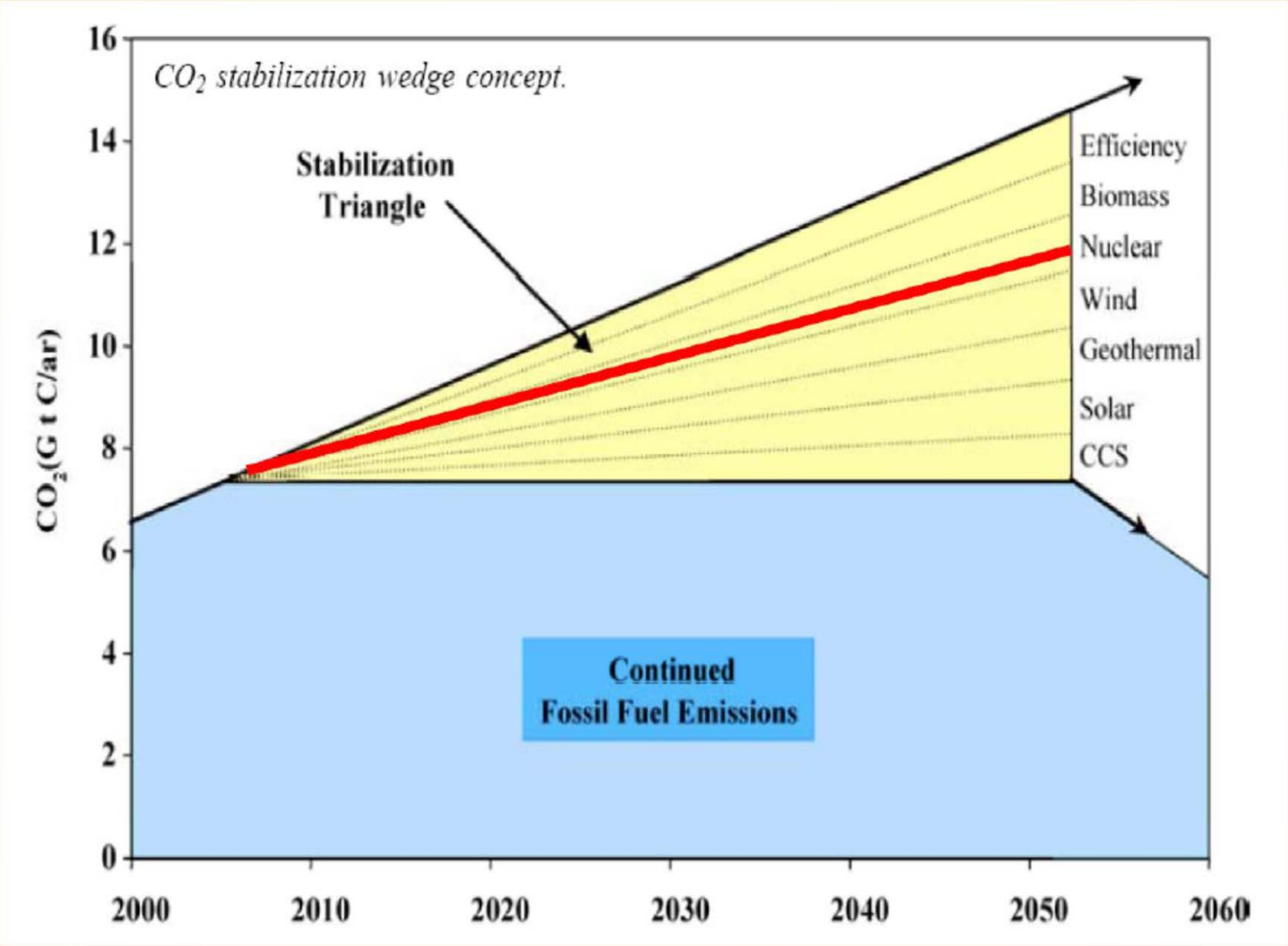
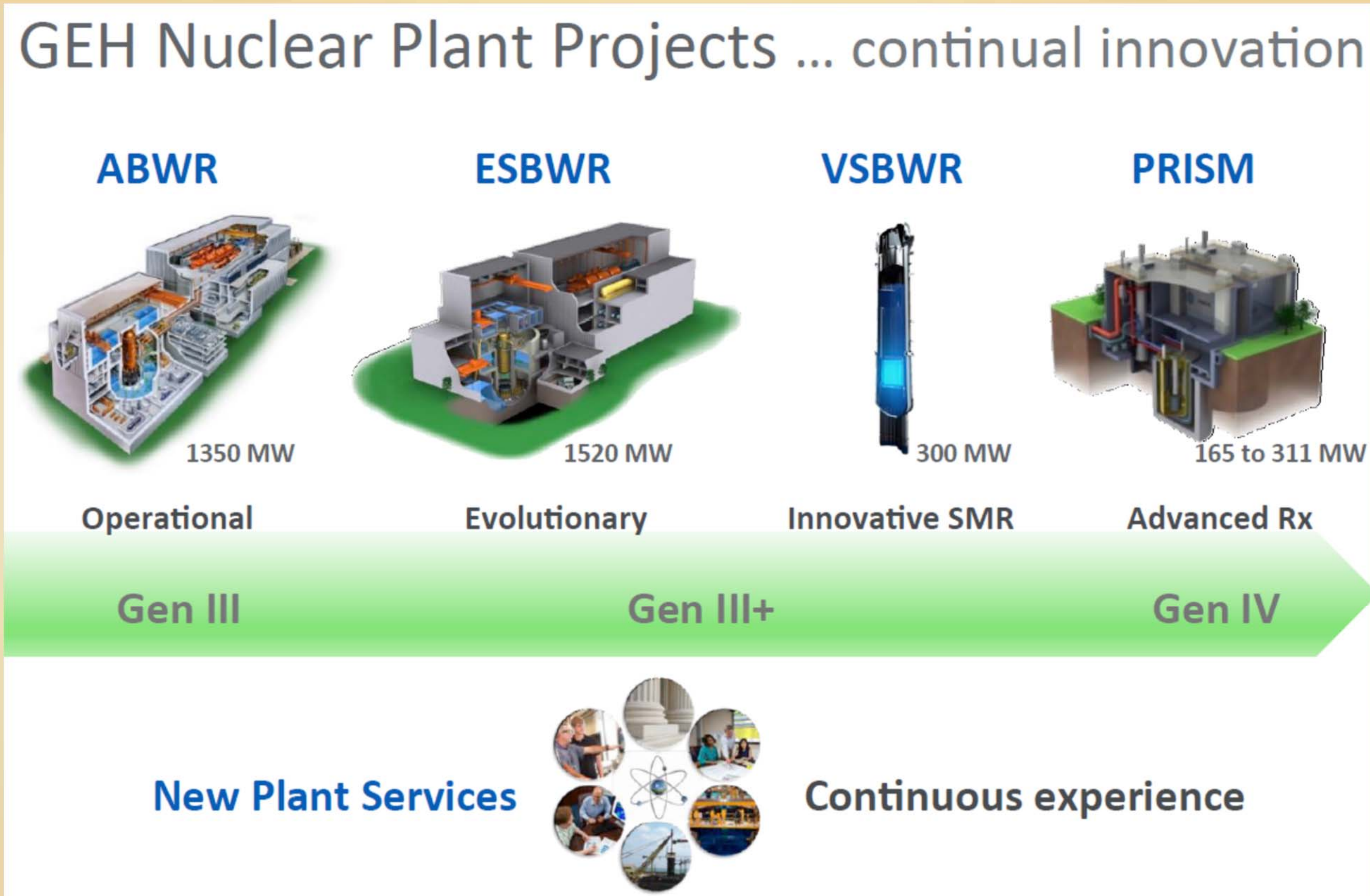
Sustainability



New Nuclear Example



New Nuclear Example

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Generation IV International Forum

Steady Progress:
- Economic competitiveness
- Safety and reliability

Nuclear Power for centuries
- Resource saving
- HL Radwaste minimisation
- Non-prolifération

New applications

Hydrogen, drinkable water, heat

Industrial deployment ~2040

Multilateral cooperation with 3 levels of agreements:

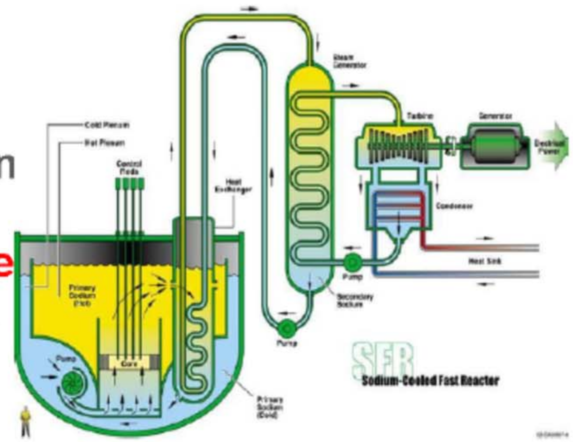
✓ *Intergovernmental*
✓ *Systems (x 6)*
✓ *R&D Projects (3 à 6 / System)*

New requirements to support a sustainable development

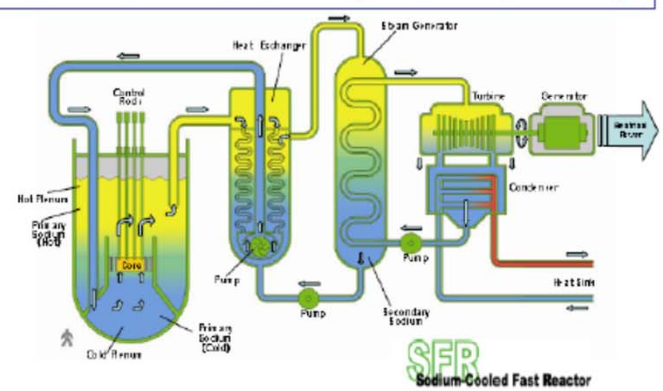
New Nuclear Example

Sodium Fast Reactor *(SFR)*

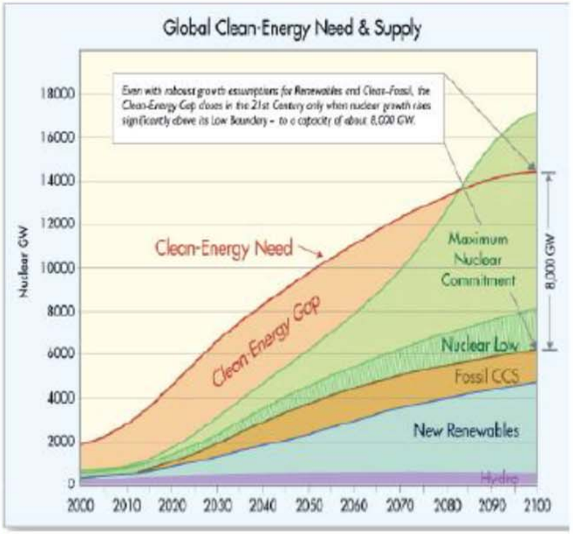
- A new generation of sodium cooled Fast Reactors
- Reduced investment cost
  Simplified design, system innovation
  (Pool/Loop design, ISIR – SC CO_2 PCS)
- Towards more passive safety feature
  + Better managt of severe accidents
- Integral recycling of actinides
  Remote fabrication of TRU fuel

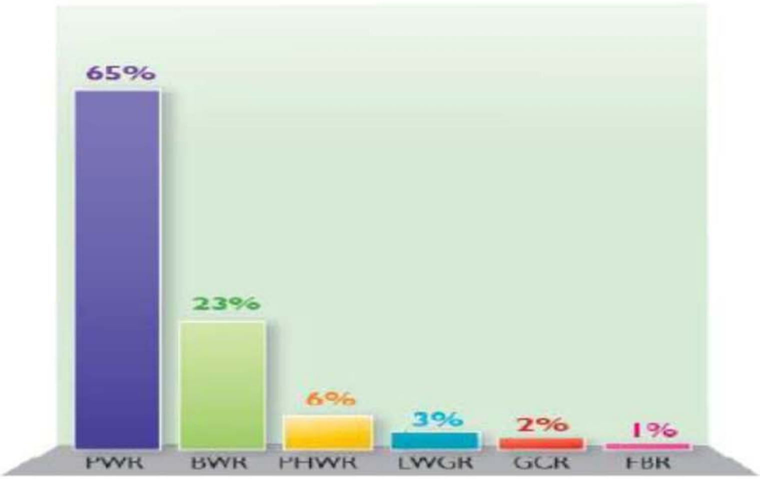


→ 2009/15: Feasibility/Performance → 2020+: Demo SFR *(FR, US, JP…)*

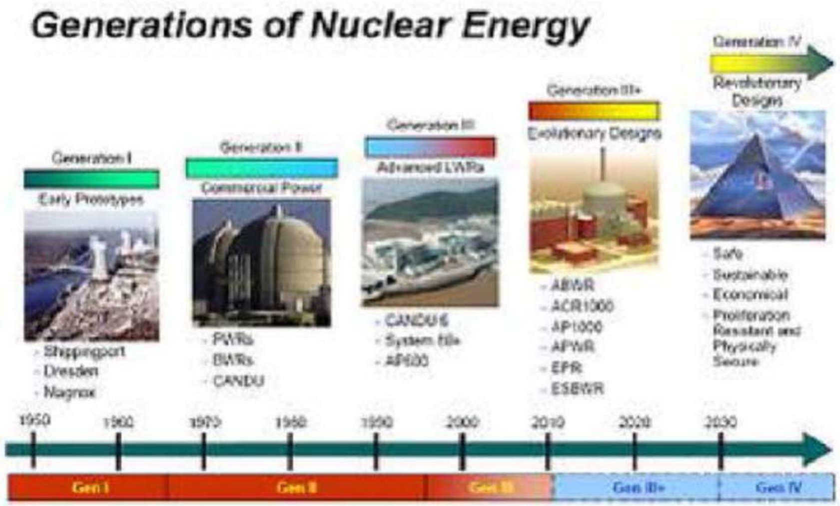


New Nuclear Example





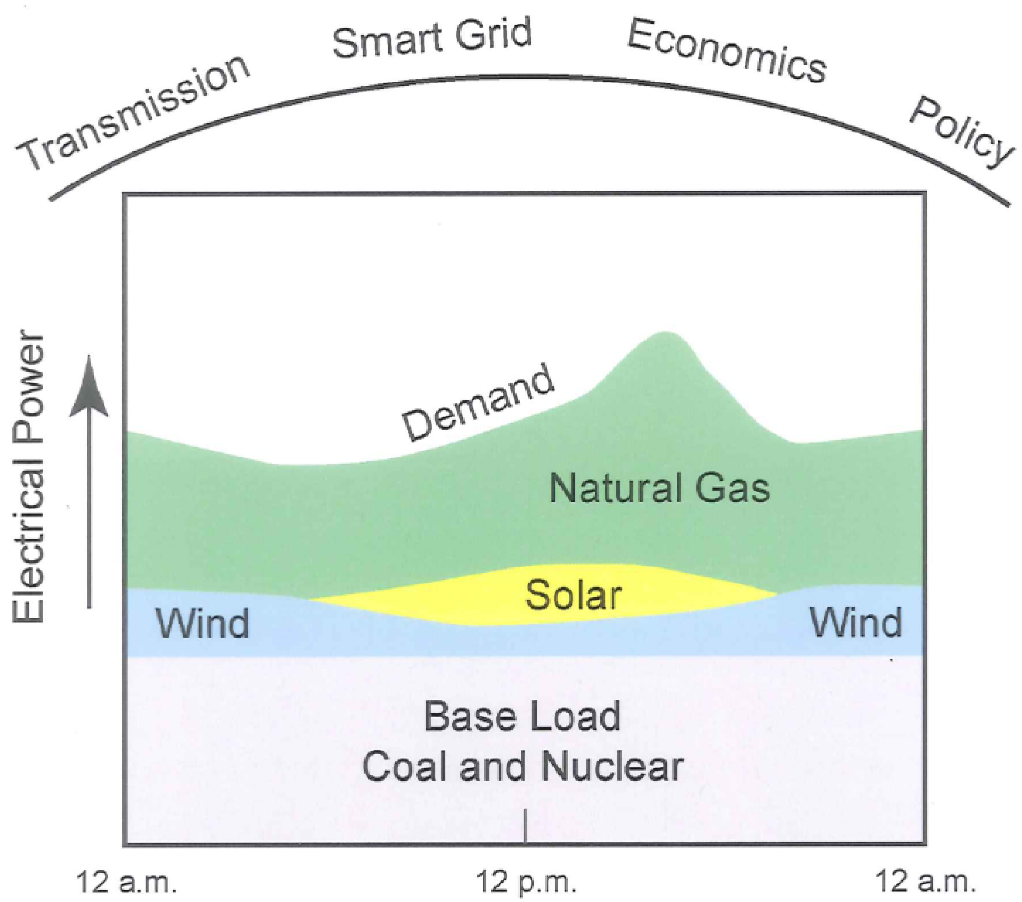
World nuclear power generation by reactor type, 2008



GEN IV reactors are mainly FR systems

Sustainability

Clean Energy Business Plan



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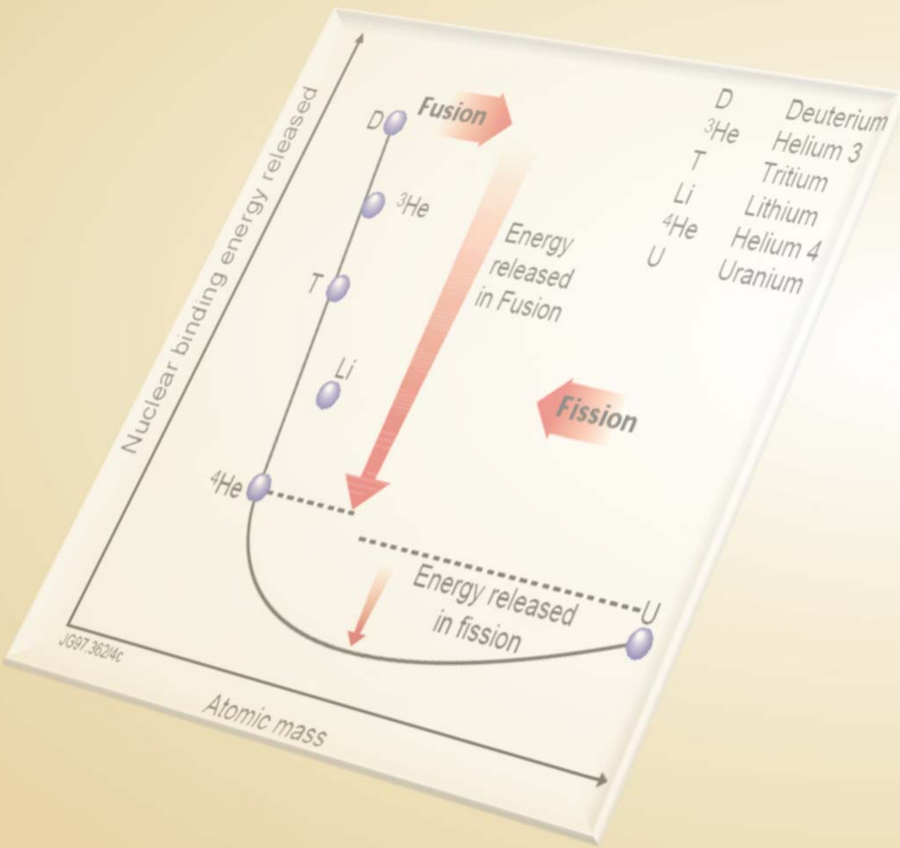

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QUESTIONS?

April's Pop Quiz

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

In U.S.

A – over 10,000
B – about 100
C – 50

98 to be exact
in 30 states
(20% of domestic energy)

Worldwide

A – over 100,000
B – about 1000
C – about 500

450 to be exact
(11% of world electricity)