Nuclear Power: Benefits and Risks

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Technology options towards a sustainable energy future

- **Improved Energy Efficiency** throughout the energy system
- **More Renewable Energy**
- **Advanced Energy Technologies:**
  - clean fossil fuel technologies including carbon capture & storage (CCS)
  - next generation nuclear technologies
Nuclear power and sustainable development – A controversial issue?

- Exhaustive debate at CSD-9
- Agreement to disagree on nuclear’s role in sustainable development
- But unanimous agreement that choice belongs to countries

NOTE

- There is no technology without risks and interaction with the environment.
- Do not discuss a particular technology in isolation.
- Compare a particular technology with alternatives in a system context and life cycle (LCA) basis.
Pro: Nuclear & Sustainability

- Brundtland\(^1\) about keeping options open
- Expands electricity supplies ("connecting the unconnected")
- Reduces harmful emissions
- Puts uranium to productive use
- Increases human & technological capital
- Ahead in internalising externalities

\(^1\) development that meets the needs of the present without compromising the ability of future generations to meet their own needs
Contra: Nuclear & Sustainability

- No long-term solution to waste
- Nuclear weapons proliferation & security
- Safety: nuclear risks are excessive
- Transboundary consequences, decommissioning & transport
- Too expensive
Economics – Nuclear power

Advantages
- Nuclear power plants are cheap to operate
- Stable & predictable generating costs
- Long life time
- Supply security (insurance premium)
- Low external costs (so far no credit applied)

But…
- High upfront capital costs can be difficult to finance
- Sensitive to interest rates
- Long lead times (planning, construction, etc)
- Long payback periods
- Regulatory/policy/market risks
Range of levelized generating costs of new electricity generating capacities

Source: Adapted from eight recent studies
Externalities of different electricity generating options

- Natural gas technologies
- Nuclear power
- Wind
- Biomass technologies
- Existing coal technologies
  - New coal technologies
  - Existing coal technologies
    - **no gas cleaning**

- Greenhouse gas impacts
- Air pollution (PM$_{10}$) and other impacts

Source: EU-EUR 20198, 2003

IAEA
Cost structures of different generating options

- Nuclear
- Coal
- Natural gas

- Fuel
- O&M
- Capital

uranium
Impact of a doubling of resource prices

The chart illustrates the impact of doubling resource prices on the cost of electricity production. The chart compares the base costs and double resource costs for Nuclear, Coal, and Natural gas.

**Base costs** show the initial cost of production before any increase in resource prices. The **double resource costs** reflect the increased cost after a doubling in resource prices.

- **Nuclear** shows a base cost increase from 50 to 70 US$ per MWh, and a double cost increase from 70 to 110 US$ per MWh.
- **Coal** shows a base cost increase from 40 to 60 US$ per MWh, and a double cost increase from 60 to 90 US$ per MWh.
- **Natural gas** shows a base cost increase from 30 to 50 US$ per MWh, and a double cost increase from 50 to 80 US$ per MWh.

The IAEA logo is visible in the lower left corner, indicating the origin of the document.
Fuel as a percentage of marginal generating costs  

**USA - 2005**

- **Nuclear**
  - Fuel: 74%
  - O&M: 26%

- **Coal**
  - Fuel: 78%
  - O&M: 22%

- **Gas**
  - Fuel: 94%
  - O&M: 6%

- **Oil**
  - Fuel: 91%
  - O&M: 9%

Source: Global Energy Decisions  
Updated: 6/06
Environment – Nuclear power

Advantages

- Low pollution emissions
- Small land requirements
- Small fuel & waste volumes
- Wastes are managed
- Proven intermediary storage

But...

- No final waste repository in operation
- High toxicity
- Needs to be isolated for long time periods
- Potential burden to future generations
Mitigation – Role of nuclear power

Life cycle GHG emissions of different electricity generating options

Nuclear power: Very low lifetime GHG emissions make the technology a potent climate change mitigation option
Range of carbon dioxide reduction costs for electricity technologies

Note: This graph is for illustrative purposes only, actual costs are site specific

Source: World Bank
Impact of CO$_2$ penalty on competitiveness of nuclear power

A relatively modest carbon penalty would significantly improve the ability of nuclear to compete against gas & coal

Source: IEA, 2006
Nuclear Fuel: Small volumes, high energy contents

- 1 pellet produces the energy of 1.5 tonnes of coal
- Each pellet produces 5000 kWh
Wastes in fuel preparation and plant operation

Million tonnes per GWe yearly

- Flue gas desulphurization
- Ash
- Gas sweetening
- Radioactive (HLW)
- Toxic materials

Source: IAEA, 1997
Geological nuclear waste disposal

NATURAL BARRIERS
- Stable rock around the repository
- Stable groundwater in the rocks
- Retention, dispersion and dilution processes in the rock
- Dispersion and dilution processes in the biosphere

ENGINEERED BARRIERS
- Solid waste material
- Waste containers
- Buffer and backfill materials
- Seals

Container
Waste
Buffer or backfill
Seals
Access shafts or tunnels
Disposal tunnels or caverns
Nuclear share of electricity (2006)

- France: 78%
- Belgium: 54%
- Rep. Korea: 40%
- Switzerland: 37%
- Japan: 30%
- Russia: 16%
- USA: 19%
- China: 2%
- S. Africa: 4%
IAEA
Structure of global electricity supply

Global electricity generation in 2005: 18,235 TWh

- Coal 40.3%
- Natural gas 19.7%
- Nuclear 15.2%
- Hydro 16.0%
- Renewables 2.2%
- Oil 6.6%
Structure of OECD North America electricity supply

Electricity generation in 2005: 5,128 TWh

- Coal: 44.7%
- Nuclear: 17.8%
- Gas: 17.6%
- Oil: 4.5%
- Hydro: 12.9%
- Biomass: 1.6%
- Other Ren: 0.8%
Structure of Latin American electricity supply

Electricity generation in 2005: 905 TWh

- Hydro: 68.4%
- Gas: 14.7%
- Oil: 9.3%
- Nuclear: 1.9%
- Coal: 3.4%
- Biomass: 2.1%
- Other Renewables: 0.2%
Nuclear power today:

On 1 January 2008, 439 nuclear power plants (NPPs) operated in 30 countries worldwide, with a total installed capacity of 371,900 MWe.

“Where does nuclear power go from here?”
Reasons for the mid 1980s stagnation:

- Energy efficiency improvements
- Economic restructuring
- Significant drop in electricity demand
- Excess generating capacity
- Electricity market liberalization & privatization
- Oil (traded fossil energy) price collapse
- Advent of the high-efficient cheap gas turbine technology (GTCC)
Reasons for the mid 1980s stagnation:

- Little regard for supply security
- Regulatory interventions after Three Mile Island
- High interest rates
- Chernobyl
- Break up of the Soviet Union

All the above together: New nuclear build out of favour (poor economics and lack of demand)
Development of regional nuclear generating capacities

North America

Western Europe

Eastern Europe & CIS

Asia
Development of regional nuclear generating capacities

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<th>OEA GWe</th>
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<td>2005</td>
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</table>
Annual Incremental Nuclear Capacity Additions and Total Nuclear Electricity Generation

Incremental nuclear power capacity additions in GW \text{e}

Total nuclear power generation in TWh
Global energy availability factor of nuclear power plants

Equivalent to the construction of 34 NPPs of 1,000 MW each
Summary of nuclear power today:

- A proven technology that provides clean electricity at predictable and competitive costs
- Provides 15% of global electricity supply
- More the 13,000 years of accumulated reactor experience
- Operation of nuclear installations have safety as highest priority
- Lessons learned from past mistakes or accidents have been acted on
- Nuclear takes full responsibility its waste
Summary of nuclear power today:

- The industry is alive and vibrant
- Market liberalization served as a wake-up call
- The industry is heavily engaged in innovation
- The political climate towards the technology has begun to change in many countries
- All credible long-term (>> 2030) demand & supply projections show steep increases in nuclear power
Summary of nuclear power today:

- But most importantly the global energy map today is distinctly different from the situation of the mid 1980s
  - Fossil fuel prices
  - Energy security
  - Climate change considerations
  - Demand
  - Aging generating capacities
Rising expectations

- Upwardly revised nuclear projections
- Plans for expansion in a number of countries
- Entry into force of the Kyoto Protocol
- Proven technology that provides clean electricity at predictable and competitive costs
- The industry’s safety record is second to none
- Increasingly favorable commentary from both politicians and the media
Updated nuclear power projections
IAEA: Evolution of low projection

GW(e)

- history
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008

IAEA: Evolution of high projection

GW(e) history

- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008

Nuclear power around the globe

- Countries with operating NPPs
- Countries with operating NPPs & plants under construction
- Countries with a phase out policy
- Countries with operating NPPs
One size does not fit all

Countries differ with respect to:
- energy demand growth
- alternatives
- financing options
- weighing/preferences
  - accident risks (nuclear, mining, oil spills, LNG...), cheap electricity, air pollution, jobs, import dependence, climate change

All countries use a mix. All are different.

Nuclear power per se is not “the solution” to the world’s energy problems and climate change but

It surely can be an integral part of the solution!
...atoms for peace.
The Oklo Mine had a fission reaction... 2 Billion Years Ago
The Oklo Mine fission reaction…

- 15 natural reactors discovered
- 16,000 MW-years
- Used 5 tons uranium
- 5 tonnes waste
- 1.5 tonnes of Pu

*Scientific American, July 1976*
Radio-toxicity of spent nuclear fuel
INNOVATION:
Burning of HLW in Fast Reactor in Reducing Radio Toxicity

Plutonium and minor actinides are responsible for most of the long term hazards.
Do not drive into the future by looking in the rear view mirror:

- Yesterday’s technology is not tomorrow's
- Innovation ongoing
- With each new investment cycle technology tends to get better
Innovation: Nuclear power generation

- 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 & HWRs
  - AP1000, ABWR, System 80+
  - ACR
  - EPR

- Generation III+
  - Evolutionary designs with improved economics and safety for near-term deployment

- Generation IV
  - Highly economical
  - Enhanced safety
  - Minimal waste
  - Proliferation resistant

Timeline:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030
Innovation: AP 1000

- 50% Fewer Valves
- 35% Fewer Safety Grade
- 80% Less Pipe
- 45% Less Seismic Building
- 85% Less Cable
Integral Primary System Reactor (IRIS)

- Simplifies design by eliminating loop piping and external components.
- Enhances safety by eliminating major classes of accidents.
- Compact containment (2 times less power but 9 times less volume, small footprint) enhances economics and security.
Nuclear weapons proliferation:

- The genie is out of the bottle
- Preventing the misuse of nuclear materials for non-peaceful purposes needs special attention
- It is an area where IAEA has a strict mandate
- Non-proliferation is a political problem
- NPT regimes needs strengthening
Nonproliferation and Nuclear Security

Nuclear Nonproliferation: To curb and prevent the spread of nuclear weapons, their delivery means, and related materials and technologies.

Nuclear Security: The prevention and detection of and response to theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances, or their associated facilities.
Elements of nuclear safety: Defense in Depth

1st level: Prevention of failures
2nd level: Detection and control of failures
3rd level: Control of design basis accidents
4th level: Control of severe accidents
5th level: Emergency plans

Robust & proven design
High quality
Appropriate site

IAEA
Source: NEA
A history of mistaken forecasts

“The energy produced by breaking down the atom is a very poor kind of thing. Anyone who expects a source of power from the transformations of these atoms is talking moonshine.”

Lord Ernest Rutherford
1933
A history of mistaken forecasts

“It is not too much to expect that our children will enjoy in their homes [nuclear generated] electrical energy too cheap to meter.”

Lewis Strauss
Chairman
US Atomic Energy Commission
1954
Nuclear Energy and Society

This may well be a good book, but I've got two problems with nuclear power . . .

... I know absolutely nothing about it . . .

... and I don't trust those who know!

Bjorn Wahlström
Nuclear power projections

Maximum mean global temperature change < 2°C
Typical nuclear electricity generation cost breakdown

- Investment: 60%
- O&M: 20%
- Fuel cycle: 20%
- Decommissioning: 1-5%
- Uranium: 5%
- Conversion: 1%
- Enrichment: 6%
- Fuel fabrication: 3%
- Back-end activities: 5%

Source: NEA
## Safety – Nuclear power

### Reality
- Safety is an integral part of plant design & operation
- Nuclear power has an excellent safety record
- Lessons learned from past accidents
- Safety culture, peer reviews & best practices
- No room for complacency

### Perception
- Nuclear power is dangerous
- It can never be made safe
- Safe is not safe enough
- Nuclear plants are atomic bombs
- No public acceptance
Nuclear power safety

- Safety is a dynamic concept
- Upgrading of older generation reactors & life time extensions
- Advanced reactor designs with inherent safety features
- The impact of these ongoing efforts are:
  - Improved availability worldwide
  - Lower radiation doses to plant personnel and fewer unplanned stoppages
Typical barriers confining radioactive materials

1. **1st barrier**: fuel pellet matrix
2. **2nd barrier**: fuel cladding
3. **3rd barrier**: reactor pressure boundary
4. **4th barrier**: containment building
Unplanned scrams per 7000 hours critical

Source: WANO 2006 Performance Indicators
### Industrial accidents at NPPs per 200,000 person-hours worked

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Source: *WANO 2006 Performance Indicators*