WNA Worldwide Overview on:

Nuclear’s Health, Safety and Environmental (HSE) Issues and Challenges

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Director for Environment and Radiological Protection
World Nuclear Association

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# Qualitative Overview of HSE Issues

## Front-End

<table>
<thead>
<tr>
<th>H&amp;S – Health &amp; Safety</th>
<th>Mining</th>
<th>Milling</th>
<th>Conversion</th>
<th>Enrichment</th>
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<td>Open Pit</td>
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</table>

H&S = Health & Safety
U/G mine = Underground mine
U sol = Uranium solution; U conc = Uranium concentrate
LLW = Low level waste
ILW = Intermediate level waste
HLW = High level waste
UNF = Used Nuclear Fuel
Qualitative Overview of HSE Issues

Front-End

Occupation H&S
• Conventional risk and radiation risk higher for underground mines

Environment
• Chemical risk higher for conversion and enrichment

Waste
• LLW amounts higher for open-pits and mill tailings
## Qualitative Overview of HSE Issues

**Nuclear Fuel, Nuclear Power and Back-End**

<table>
<thead>
<tr>
<th>Occupational H&amp;S</th>
<th>Fuel Fabrication</th>
<th>Nuclear Power</th>
<th>Reprocessing/Recycling</th>
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<tbody>
<tr>
<td></td>
<td>UO2</td>
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</tbody>
</table>
Qualitative Overview of HSE Issues
Nuclear Fuel, Nuclear Power and Back-End

Occupation H&S
• Radiation risk higher for nuclear power and reprocessing/recycling

Environment
• Nothing particular

Waste
• Risk higher for used nuclear fuel (though not a waste) and for HLW
HSE Issues Outlook

No key HSE issues are foreseen for the global expansion of nuclear fuel cycle and power

• Greater performance is expected from plant upgrades and new plants

Overcoming a few key HSE challenges would greatly facilitate this expansion
HSE Challenges

1. World Challenge on Environmental-Health Protection
   a) Reality check: Main HSE Drivers
   b) Reality check: Energy->Climate Change->HSE
   c) Overall protection benefits from nuclear energy in this challenge

2. Reposition already safe nuclear technologies as the Main Driver for the deployment of nuclear energy
   • No need for a priori set safety criteria that unduly challenge technologies beyond the notion of protection

3. Convey integrated HSE management - including an harmonized and integrated set of IAEA safety standards
HSE Challenges

4. Fix imbalanced RP policies for public exposure at very low doses (<1mSv/y)
   - RP stringency for nuclear industry only is not sound

5. Clearer Communications on:
   - Major nuclear accident
   - Radiation risk
   - Nuclear waste
   - Non-proliferation

There are high public expectations that nuclear industry management can clearly articulate “easy to understand” views on these topics

6. Better address new uranium projects in countries without sufficiently developed regulatory regimes
## HSE Challenges

1a. Reality Check: Main HSE Drivers

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.</td>
<td><strong>Climate change</strong></td>
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<tr>
<td>2.</td>
<td>Air pollution (all kinds)</td>
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<td>3.</td>
<td>Water pollution (all kinds)</td>
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<td>4.</td>
<td>Intense industrial activities (chemical, oil/gas, agriculture, fishery, forestry, etc.)</td>
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<tr>
<td>5.</td>
<td>Urban developments</td>
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...  

100 th? **Exposure to radiation** => localised and inconsequential  

‘n’ th? **Nuclear waste management and disposal** => “ “ “ “ “
What do you know about the world challenge on **Energy & Climate Change**, and the related planet-wide public health and environmental protection consequences?

- Clearer views, especially on the realistic orientations to take on board for progressing, is paramount.
- Due to the urgency to act, cannot afford to hide behind dogma, or to only offer ambiguous and superficial views.
The **Biggest** Broad Challenge
A new challenging era

We are in a new era where growing 

Energy needs

are the key challenges...

...the two are closely interconnected...

... Energy & Climate Change and Environmental-Health Issues must be tackled together
The **Biggest Broad Challenge**
Securing energy and electricity generation supplies over the long term

Average growth (2006-2030) ≈ 1.6% per year
+45% over 2006-2030 from ≈ 12,000 to 17,000 Mtoe

**World population:**
1950: 2.5 billions; 2009: 6+ billions; 2050: 9 billions

Average growth (2006-2030) ≈ 2.5% per year
+75% over 2006-2030 from ≈ 19,000 to 33,000 TWh

Mtoe - Million tonnes of oil equivalent
TWh - Terawatt hour

Source: International Energy Agency (IEA) 2008, Reference Scenario
The **Biggest Broad Challenge**
Securing energy and electricity generation supplies over the long term

**World primary energy demand in the Reference Scenario: this is unsustainable!**

*World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise*

Going from 12,000 to 17,000 Mtoe over 2006 to 2030
The **Biggest Broad Challenge**
Securing energy and electricity generation demands over the long term

IEA’s Presentation to Press: 4/12/08

**Energy-related CO₂ emissions in the Reference Scenario**

- **Giga tonnes**
  - 1980: 5
  - 1990: 20
  - 2000: 35
  - 2010: 45
  - 2020: 55
  - 2030: 70

- **97% of the projected increase in emissions between now & 2030 comes from non-OECD countries – three-quarters from China, India & the Middle East alone**

Going from 28 to 41 Gt of CO2 energy-related emissions over 2006 to 2030

Gt : Gega tonnes = 1 billion tonnes
The **Biggest Broad Challenge**
Long-term Climate Change Consequences from Greenhouse Gases

**Projections of Surface Temperatures**

2020 – 2029 ≈ current

2090-2099 ≈ 100 years

Scenario B1

Scenario A1B

Scenario A2

Source: IPCC AR4
The **Biggest Broad Challenge**
Long-term Climate Change Consequences from Greenhouse Gases

**Multi-Model Averages and Assessed Ranges for Surface Warming**

Source: IPCC AR4
In the nearer term, let’s also not forget air quality

Already quite deteriorated in many major cities (1 - 10+ M people)

Frequent heavy smog that can just get worse if GHG continue growing

A reminder of history: London 1954 Big Smog due to heavy coal combustion (1+ M people)

Just 4 days of a cold big smog
8,000 fatalities in the following weeks and months
At the core of this World Challenge:

1. Choices in low-carbon Energy Sources
2. Climate Change
3. Environmental and Health Protection

International organisations such as the UN and the OECD as well as governments are urged to act/help:
- UN/IAEA and OECD/NEA are of particular relevance for nuclear energy

UN - United Nations
IAEA - UN’s International Atomic Energy Agency
OECD - Organisation for Economic Co-operation and Development
NEA - OECD’s Nuclear Energy Agency
Main outcomes of the:

- **Intergovernmental Panel on Climate Change (IPCC)**
  - Series of comprehensive studies
  - [http://www.ipcc.ch/ipccreports/assessments-reports.htm](http://www.ipcc.ch/ipccreports/assessments-reports.htm)

- **International Energy Agency (IEA)**
  - World Energy Outlook 2008
  - [http://www.worldenergyoutlook.org/](http://www.worldenergyoutlook.org/)

Recognizing that such comprehensive knowledge is fundamental to overall efficiency in planet-wide human health and environmental protection
IPCC Statements
Intergovernmental Panel on Climate Change (IPCC)

Over Two Decades, a Series of 4 Key IPCC Comprehensive Studies

1) FAR 1990: “little observational evidence of a detectable anthropogenic influence on climate”


3) TAR 2001: “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.”

4) AR4 2007: “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level”.

Gt CO$_2$-eq

<table>
<thead>
<tr>
<th>Year</th>
<th>CO$_2$</th>
<th>CH$_4$</th>
<th>N$_2$O</th>
<th>F-Gases</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>1970</td>
<td>28.7</td>
<td>4.0</td>
<td>1.5</td>
<td>0.4</td>
<td>34.6</td>
</tr>
<tr>
<td>1980</td>
<td>35.3</td>
<td>4.5</td>
<td>1.9</td>
<td>0.6</td>
<td>42.3</td>
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<tr>
<td>1990</td>
<td>39.4</td>
<td>5.0</td>
<td>2.2</td>
<td>0.8</td>
<td>47.4</td>
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<tr>
<td>2000</td>
<td>44.7</td>
<td>5.5</td>
<td>2.5</td>
<td>1.1</td>
<td>53.9</td>
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<tr>
<td>2004</td>
<td>49.0</td>
<td>6.0</td>
<td>2.8</td>
<td>1.4</td>
<td>60.2</td>
</tr>
</tbody>
</table>

Gt: Gega tonnes = 1 billion tonnes; GHG: Greenhouse Gases

Source: IPCC AR4
2004 Anthropogenic GHG Emissions by GHG

- **CO₂** from fossil fuel use: 56.6%
- **CO₂** (deforestation, decay of biomass, etc.): 17.3%
- **N₂O**: 7.9%
- **F-gases**: 1.1%
- **CH₄**: 14.3%
- **CO₂** (other): 2.8%

**Source:** IPCC AR4

- Total CO₂ –eq = 49 Gt
- Total CO₂ of GHG = 76.7% = 37.6 Gt
- Total C of GHG = 10.3 Gt

- CO₂ fossil fuel use = 27.2 Gt of CO₂
- or = 7.4 Gt of C
Observed Trends: Atmospheric CO₂ Concentrations

Changes in CO₂ from ice core and modern data

Pre and post-industrial: 280 and 380 ppm

Similar graphs for other GHG: CH₄ and N₂O
Observed Trends: Global Average Mean Temperature

Approximate temperature increase since 1900 ≈ 0.7°C

Source: IPCC AR4
Observed Trends: Global Average Mean Temperature

Rate of temperature increase (per decade) is much higher for last 25 years:
• Absolute increase of 0.5-0.6°C; increase rate now at 0.177°C per decade
20th century estimates show that global average sea level rose at a rate of 1.7 mm/yr. Based on more global and accurate data, since 1993 sea level has been rising at a rate of 3 mm/yr.
Predictions: Increased Global Mean Temperature
Best estimate and ranges = Function (GHG atmospheric concentration)

<table>
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<tr>
<th>Equilibrium CO$_2$–eq (ppm)</th>
<th>Temperature Increase (°C)</th>
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<tr>
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<td>Best Estimate</td>
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<td>350</td>
<td>1.0</td>
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<tr>
<td>450</td>
<td>2.1</td>
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<tr>
<td>550</td>
<td>2.9</td>
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<tr>
<td>650</td>
<td>3.6</td>
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<td>750</td>
<td>4.3</td>
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<tr>
<td>1000</td>
<td>5.5</td>
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<tr>
<td>1200</td>
<td>6.3</td>
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+2°C at 450 ppm, +3°C at 550 ppm

Source: IPCC AR4
### Predictions: Sea Level Rise
Function of global mean temperature (best estimate and ranges)

<table>
<thead>
<tr>
<th>Case</th>
<th>Temperature Change (°C at 2090-2099 relative to 1980-1999)</th>
<th>Sea Level Rise (m at 2090-2099 relative to 1980-1999)</th>
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<tbody>
<tr>
<td></td>
<td>Best estimate</td>
<td>Likely range</td>
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<tr>
<td>Constant Year 2000 concentrations</td>
<td>0.6</td>
<td>0.3 – 0.9</td>
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<tr>
<td>B1 scenario</td>
<td>1.8</td>
<td>1.1 – 2.9</td>
</tr>
<tr>
<td>A1T scenario</td>
<td>2.4</td>
<td>1.4 – 3.8</td>
</tr>
<tr>
<td>B2 scenario</td>
<td>2.4</td>
<td>1.4 – 3.8</td>
</tr>
<tr>
<td>A1B scenario</td>
<td>2.8</td>
<td>1.7 – 4.4</td>
</tr>
<tr>
<td>A2 scenario</td>
<td>3.4</td>
<td>2.0 – 5.4</td>
</tr>
<tr>
<td>A1FI scenario</td>
<td>4.0</td>
<td>2.4 – 6.4</td>
</tr>
</tbody>
</table>

+0.2 to 0.6 metres (≈ 100 years relative to currently)!

Source: IPCC AR4
Past and Future CO$_2$ Emissions Evolution Paths = Function (Atmospheric GHG Concentrations: CO$_2$ eq.)

Source: IPCC AR4
Predictions: Temperature Rise = Function (Atmospheric GHG Concentrations: CO$_2$ eq.)

Source: IPCC AR4
Future of human prosperity depends on how successful we tackle two central challenges

• Securing the supply of reliable and affordable energy
• Effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply

Preserving catastrophic and irreversible damage to the global climate ultimately requires a major decarbonisation of the world energy

The 15th Conference of the Parties, to be held in Copenhagen in November 2009 (Nov 30-Dec 11), provides a vital opportunity to negotiate a new global climate-change policy regime for beyond 2012
Primary energy demand and CO2 energy-related emissions are unsustainable

World primary energy demand in the Reference Scenario: this is unsustainable!

Going from 12,000 to 17,000 Mtoe over 2006 to 2030

Going from 28 to 41 Gt of CO2 energy-related emissions over 2006 to 2030

World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise
Increase in primary energy demand: => Coal and Non-OECD countries prevail

The continuing importance of coal in world primary energy demand

Demand for coal has been growing faster than any other energy source & is projected to account for more than a third of incremental global energy demand to 2030
Oil demand driven by China, Middle East and India

Change in oil demand by region in the Reference Scenario, 2007-2030

All of the growth in oil demand comes from non-OECD, with China contributing 43%, the Middle East & India each about 20% & other emerging Asian economies most of the rest.
Renewable: Most of it is hydro (10-20% of electricity generation) and the rest is much smaller (<<10%)
+$26 trillion of investment (≈ 50% in power)

Cumulative energy-supply investment in the Reference Scenario, 2007-2030

Investment of $26 trillion, or over $1 trillion/year, is needed, but the credit squeeze could delay spending, potentially setting up a supply-crunch once the economy recovers.
Three scenarios considered over 2006-2030:
1) fossil-fuel “business as usual” energy growth
2) 550 and 450 ppm: stabilization of atmospheric CO2 concentrations

<table>
<thead>
<tr>
<th></th>
<th>Reference Scenario</th>
<th>550 ppm Scenario</th>
<th>450 ppm Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary energy demand (2006-2030)</td>
<td>+1.6%/y</td>
<td>+1.2%/y</td>
<td>+0.8%/y</td>
</tr>
<tr>
<td>Temperature increase (-&gt;2100)</td>
<td>Up to +6°C</td>
<td>+3°C</td>
<td>+2°C</td>
</tr>
<tr>
<td>CO2 energy-related emissions by 2030</td>
<td>41 Gt</td>
<td>33 Gt</td>
<td>26Gt</td>
</tr>
<tr>
<td>Carbone capture and storage (CCS) by 2030</td>
<td>negligible</td>
<td>160 Gw</td>
<td>350 Gw</td>
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</table>
Two scenarios considered to stabilize CO$_2$ atmospheric concentrations: ie. 550 and 450 ppm

<table>
<thead>
<tr>
<th>Key results of the post-2012 climate-policy analysis</th>
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<tbody>
<tr>
<td><strong>550 Policy Scenario</strong></td>
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<tr>
<td>• Corresponds to a c.3°C global temperature rise</td>
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<tr>
<td>• Energy demand continues to expand, but fuel mix is markedly different</td>
</tr>
<tr>
<td>• CO$_2$ price in OECD countries reaches $90/tonne in 2030</td>
</tr>
<tr>
<td>• Additional investment equal to 0.25% of GDP</td>
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<tr>
<td><strong>450 Policy Scenario</strong></td>
</tr>
<tr>
<td>• Corresponds to a c.2°C global temperature rise</td>
</tr>
<tr>
<td>• Energy demand grows, but half as fast as in Reference Scenario</td>
</tr>
<tr>
<td>• Rapid deployment of low-carbon technologies – particularly CCS</td>
</tr>
<tr>
<td>• Big fall in non-OECD emissions</td>
</tr>
<tr>
<td>• CO$_2$ price in 2030 reaches $180/tonne</td>
</tr>
<tr>
<td>• Additional investment equal to 0.6% of GDP</td>
</tr>
</tbody>
</table>
A major decarbonisation of the world’s energy system is needed. The Copenhagen conference (Nov-Dec 09) must deliver a credible post-2012 climate regime.

Summary & conclusions

- Current energy trends are patently unsustainable — socially, environmentally, economically
- Oil will remain the leading energy source but...
  - The era of cheap oil is over, although price volatility will remain
  - Oilfield decline is the key determinant of investment needs
  - The oil market is undergoing major and lasting structural change, with national companies in the ascendancy
- To avoid "abrupt and irreversible" climate change we need a major decarbonisation of the world’s energy system
  - Copenhagen must deliver a credible post-2012 climate regime
  - Limiting temperature rise to 2°C will require significant emission reductions in all regions & technological breakthroughs
  - Mitigating climate change will substantially improve energy security
- The present economic worries do not excuse back-tracking or delays in taking action to address energy challenges
World Energy Outlook 2008
Power generation - CO2 emissions

With 41% of CO2 energy-related emissions (2006), power generation mix offer CO2 reduction opportunities.

In short, this change means more renewable and nuclear, with less fossil fuel (CCS equipped).

![CO2 emissions (Gt) from power generation](image)

Reducing CO2 emissions from 11 Gt down to ??? over 2006-2030.
World Energy Outlook 2008
Power generation - Delivered

To achieve CO2 reduction by 2030, nuclear and renewable will increase, and fossil fuel will stay flat or decrease. The upside is more limited for hydro than nuclear.

Electricity Generation (TWh)
2006 versus 2030 scenarios

Going from ≈ 19,000 to 30,000 TWh over 2006 to 2030

Over 2006-2030:
Renewable ≈ x4
Nuclear ≈ x 2
Fossil fuel ≈ flat
To achieve CO2 reduction by 2030, nuclear and renewable will increase, and fossil fuel will stay flat or decrease.

An extra 312 Gw of nuclear is already foreseen by IEA.

**Power Generation Capacity (Gw)**

2006 versus 2030 scenarios

- **2006:**
  - Renewables: 4,434 Gw
  - Nuclear: 956 Gw
  - Gas: 1,124 Gw
  - Oil: 514 Gw
  - Coal: 1,382 Gw

- **Ref. Scen. 2030:**
  - Renewables: 7,484 Gw
  - Nuclear: 2,397 Gw
  - Gas: 1,695 Gw
  - Oil: 287 Gw
  - Coal: 433 Gw

- **550 ppm 2030:**
  - Renewables: 7,022 Gw
  - Nuclear: 2,850 Gw
  - Gas: 1,623 Gw
  - Oil: 228 Gw
  - Coal: 522 Gw

- **450 ppm 2030:**
  - Renewables: 6,987 Gw
  - Nuclear: 3,773 Gw
  - Gas: 1,800 Gw
  - Oil: 208 Gw
  - Coal: 1,101 Gw

Note: $312 = 680 - 368$ Gw = 8 to 13 new nuclear power plants (NPPs) per year.
World Energy Outlook 2008
Electricity generation and CO2 emissions

What if the challenges of CCS for fossil fuel and of the great expansion of renewable cannot be met in time? Is ‘ready-to-deploy’ nuclear sufficiently accounted for?

Going from ≈ 19,000 to 30,000 TWh over 2006 to 2030

Over 2006-2030:
Renewable ≈ x4
Nuclear ≈ x 2
Fossil fuel ≈ flat

Reducing CO2 emissions from 11 Gt down to ??? over 2006-2030

Electricity generation (TWh)
2006 versus 2030 scenarios

CO2 emissions (Gt) from power generation
2006 versus 2030 scenarios
Already, an extra 312 Gw of nuclear power by 2030 would help meeting the world CO2 reduction goal (450 ppm)

- The expected rate of new nuclear build is 8 to 13 NPP/y
- This would save 2.5 Gt of CO$_2$ emissions per year

In comparison to further deploying nuclear, the greatest challenges are:
- Developing and widely applying CCS to fossil fuel energy
- Considerably expanding renewable energy (hydro and others)

Achieving this within two decades adds to the challenge
New nuclear build: Overall protection benefits

The option of further increasing ‘ready-to-deploy’ nuclear energy beyond 680 Gw (5,400 TWh) by 2030 is key: e.g.

<table>
<thead>
<tr>
<th>TWh</th>
<th>Gt CO2</th>
<th>Gw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>1</td>
<td>125</td>
</tr>
<tr>
<td>2,000</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>3,000</td>
<td>3</td>
<td>375</td>
</tr>
</tbody>
</table>

An extra 10 to 15 new NPPs/y over 2006-30

Would allow to overcome shortcomings concerning CCS for fossil fuel energy and the expansion of renewable energy
What would be the energy mix and CO₂ emissions if an extra 3,000 TWh (+375 Gw) of nuclear is added by 2030:
- Total nuclear : 8,500 TWh (1,055 Gw: 680 + 375)
- Equivalent reduction of 2,000 TWh from fossil fuel and of 1,000 TWh from renewable

New nuclear build: Overall protection benefits
Climate Change & Environmental-Health Protection

As CO2 reduction targets should not be missed, by 2030, nuclear energy can reach up to 1,000 Gw (8,000 TWh)

• With 8 Gt of CO2 emission savings

This would help to overcome any shortcomings in developing CCS and in expanding renewable energies
Towards a major decarbonisation => nuclear power

Aiming for a more balanced mix of electricity generation by 2030: fossil fuel, renewable and nuclear (each 10,000 TWh)

Post-2030, decarbonisation will continue to augment with steadily increasing energy and power generation demands

Accounting for diverse clean-energy needs (electricity, heating, desalination, hydrogen, etc.), nuclear energy upside can be:
- 4,000 GW by 2050, and 8,000 Gw by 2100

• WNA Nuclear Century Outlook: [http://www.world-nuclear.org/outlook/clean_energy_need.html](http://www.world-nuclear.org/outlook/clean_energy_need.html)

Thank you for your attention
Questions?
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