New vision on development of nuclear energy generation of Ukraine

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Nuclear energy as part of a national energy mix

**RIVNE NPP**
- Installed capacity: 2,835 MW
- 2 Units WWER-440
- 2 Units WWER-1000

**KHMELNITSKY NPP**
- Installed capacity: 2,000 MW
- 2 Units WWER-1000
- 2 Units

**ZAPORIZHZHYA NPP**
- Installed capacity: 6,000 MW
- 6 Units WWER-1000

**SOURTH-UKRAINE NPP**
- Installed capacity: 3,000 MW
- 3 Units WWER-1000
Nuclear energy as part of a national energy mix

Structure of installed capacity
- Thermal: 63.0%
- Hydro: 10.9%
- NPPs: 26.1%

Structure of electricity generation
- Thermal: 41.2%
- Hydro: 10.1%
- NPPs: 48.7%

Structure of output to electricity market
- Thermal: 37.4%
- Hydro: 12.4%
- NPPs: 50.2%
Nuclear energy as part of a national energy mix

Life time extension

- **Realized (3 Units)**
  - **Rivne NPP №1 WWER-440/213 shut down - 2030**
  - **Rivne NPP №2 WWER-440/213 shut down - 2031**
  - **South-Ukraine №1 WWER-1000/302 shut down - 2023**

- **Under realization (3 Units)**
  - **South-Ukraine №2 WWER-1000/338 shut down – 12.05.2015**
  - **ZAPORIZHZHYA №1 WWER-1000/320 shut down - 23.12.2015**
  - **ZAPORIZHZHYA №2 WWER-1000/320 shut down - 19.02.2016**

- **In near time (9 Units)**
  - **Life time will be completed to 2020 (6 Units)**
    - **ZAPORIZHZHYA №3 WWER-1000/320**
    - **ZAPORIZHZHYA №4 WWER-1000/320**
    - **ZAPORIZHZHYA №5 WWER-1000/320**
    - **Khmelnitsky №1 WWER-1000/320**
    - **Rivne №3 WWER-1000/320**
    - **South-Ukraine №3 WWER-1000/320**
  - **Life time will be completed after 2020 (3 Units)**
    - **ZAPORIZHZHYA №6 WWER-1000/320**
    - **Khmelnitsky №2 WWER-1000/320**
    - **Rivne №4 WWER-1000/320**
## Nuclear energy as part of a national energy mix

**Life time extension**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Capacity, MWe</th>
<th>Operational</th>
<th>Replacement to 2035 (plan)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Khmelnitsky NPP</strong></td>
<td>WWER</td>
<td>1000</td>
<td>1987</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td><strong>Rivne NPP</strong></td>
<td>WWER</td>
<td>402</td>
<td>1980</td>
<td>2031</td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>417</td>
<td>1981</td>
<td></td>
</tr>
<tr>
<td><strong>South Ukraine NPP</strong></td>
<td>WWER</td>
<td>1000</td>
<td>1986</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td><strong>Zaporizhzhya NPP</strong></td>
<td>WWER</td>
<td>1000</td>
<td>1989</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>1984</td>
<td>2034</td>
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<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>1985</td>
<td>2035</td>
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<td></td>
<td>WWER</td>
<td>1000</td>
<td>1986</td>
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<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>1987</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>1989</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WWER</td>
<td>1000</td>
<td>1995</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>13819</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Phases of implementation:
- 2000 – 2005 – designing and licensing
- 2006 – 2010 – 6 LTA on 4 years exploitation of first experience party FAs at South-Ukraine NPP (Unit 3 WWER-1000 (B-320)).
- 2010 - 42 FA-Westinghouse (FA-W)
- Approved of new design – FA-WR
- 2015 – exploitation of 42 FA-WR

Calculations and tests:
- Hydraulic tests of the FA-WR and its elements
- Static and dynamic tests of distance grid on damage
- Testing on vibration
- Imitation of FAs management (handling) on reactor
### Nuclear energy as part of a national energy mix

**Diversification of nuclear fuel supply**

<table>
<thead>
<tr>
<th></th>
<th>TVSA</th>
<th>Westinghouse</th>
<th>FAs WWER-440</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass of UO$_2$, t</strong></td>
<td>0.495</td>
<td>0.545</td>
<td>0.126</td>
</tr>
<tr>
<td><strong>Average maximum enrichment of fuel loads, %</strong></td>
<td>4.32</td>
<td>3.9 – 4.0</td>
<td>4.35</td>
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<tr>
<td><strong>Average maximum enrichment of FA, %</strong></td>
<td>4.38</td>
<td>4.2</td>
<td>4.38</td>
</tr>
<tr>
<td><strong>Average time of fuel company, eff. days</strong></td>
<td>320</td>
<td>320</td>
<td>310</td>
</tr>
<tr>
<td><strong>Maximum burnup, MWd/kg U</strong></td>
<td>55.0</td>
<td>60.0</td>
<td>50.9</td>
</tr>
<tr>
<td><strong>Quantity of reloaded FAS</strong></td>
<td><strong>42</strong></td>
<td><strong>42</strong></td>
<td><strong>72</strong></td>
</tr>
</tbody>
</table>

Top nozzle, Bottom nozzle, Distance grid – stainless steel Road, Thimble tube - ZIRLO

Westinghouse fuel assembly
Nuclear energy as part of a national energy mix

Nuclear fuel cost

Front-end

- Uranium mining and milling
  - ~ 2200 – 2400 tU

- Conversion
  - ~ 2200 – 2400 tU

- Enrichment
  - ~ 1,5 – 1,8 mln SWU
  - ~ 540 – 560 FAs WWER-1000
  - ~ 130 – 140 FAs WWER-440

- Fabrication

Cost breakdown:

- Uranium mining and milling: ~ 300 mln $
- Conversion: ~ 30 mln $
- Enrichment: ~ 230 mln $
- Fabrication: ~ 150 mln $

Total: ~ 700 mln $ annual
Spent nuclear fuel VVER-1000 of Rivne NPP, South-Ukraine NPP and Khmelnitsky NPP (6 Units, annual - 107 tHM) is sent for long term storage and reprocessing (before 2025) to RF. Reprocessing waste will be sent back to Ukraine. South-Ukraine NPP (1 Unit) FAs-W storage in reactor pool (reprocessing in AREVA is under consideration -2020).

Spent nuclear fuel VVER-1000 of Zaporizhzhya NPP is being stored in dry SNF storage facility at the site of Zaporizhzhya NPP. Capacity – 380 casks. 50 years storage.

Spent nuclear fuel VVER-440 of Rivne NPP is sent for the reprocessing to RF (annual - 14.4 tHM). RAW will be obtained since 2017.

A centralized Dry SNF storage facility for spent nuclear fuel of WWER type reactors is under construction in the Chernobyl exclusion zone. The commissioning of CSNFDSF is scheduled in end of 2017. Since end of 2016 – not shipping SNF. The design capacity is 16 529 spent nuclear fuel assemblies (480 casks HI-STORM), including 12 010 spent nuclear fuel assemblies of WWER-1000 and 4 519 spent nuclear fuel assemblies of WWER-440. Time storage – 100 years.

Waste management. Waste treatment (evaporation of liquid RAW, sorting and compaction of solid RAW) is performed on-site. Facilities on deep reprocessing of RAW is under deployment. In future RAW may be transported to the “Vector” for the storage.
Nuclear energy as part of a national energy mix
Spent nuclear fuel management

SE NNEGC “Energoatom”

ZNPP  SU NPP  KhNPP  RNPP

On-site fuel pools (FP)

FP  FP  FP  FP

SF storage facility at ZNPP
Storage period – 50 years
9 120 SFAs

CSNFDSF:
Storage period – 100 years
12,010 SFAs WWER-1000
4,519 SFAs WWER-440
Annual loading capacity:
504 SFAs WWER-1000 and 192 SFAs WWER-440

Start-up complex:
2,511 SFAs WWER-1000
1,105 SFAs WWER-440

Long-term storage (“wait and see”)

Technological cooling and reprocessing of SF at enterprises of the Russian Federation

Decision-making:

SF reprocessing

SF final disposal
Nuclear energy as part of a national energy mix
Spent nuclear fuel management

Total annual SNF accumulation – 246.4 tHM (232 tHM of WWER-1000 and 14.4 tHM of WWER-440).

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity FAs</th>
<th>Annual tHM</th>
</tr>
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<tbody>
<tr>
<td>1996</td>
<td>564</td>
<td>231.8</td>
</tr>
<tr>
<td>1997</td>
<td>450</td>
<td>186.6</td>
</tr>
<tr>
<td>1998</td>
<td>564</td>
<td>233.3</td>
</tr>
<tr>
<td>1999</td>
<td>330</td>
<td>136.6</td>
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<tr>
<td>2000</td>
<td>408</td>
<td>165.3</td>
</tr>
<tr>
<td>2001</td>
<td>264</td>
<td>108.6</td>
</tr>
<tr>
<td>2002</td>
<td>342</td>
<td>137.7</td>
</tr>
<tr>
<td>2003</td>
<td>144</td>
<td>57.9</td>
</tr>
<tr>
<td>2004</td>
<td>186</td>
<td>76.2</td>
</tr>
<tr>
<td>2005</td>
<td>132</td>
<td>54.2</td>
</tr>
<tr>
<td>2006</td>
<td>204</td>
<td>82.2</td>
</tr>
<tr>
<td>2007</td>
<td>324</td>
<td>130.3</td>
</tr>
<tr>
<td>2008</td>
<td>204</td>
<td>82.8</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>132</td>
<td>53.1</td>
</tr>
<tr>
<td>2011</td>
<td>144</td>
<td>57.9</td>
</tr>
<tr>
<td>2012</td>
<td>204</td>
<td>82.1</td>
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<tr>
<td>2013</td>
<td>288</td>
<td>117.1</td>
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<tr>
<td>2014</td>
<td>300</td>
<td>122.5</td>
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<tr>
<td>2015</td>
<td>300</td>
<td>130.5</td>
</tr>
<tr>
<td>2016</td>
<td>300</td>
<td>130.5</td>
</tr>
<tr>
<td>2017</td>
<td>300</td>
<td>130.5</td>
</tr>
</tbody>
</table>
* Energy Strategy of Ukraine up to 2030 (approved in 2006, first strategy)

* Updated Strategy of Ukraine up to 2030 (2013) – old and legal strategy

* Energy Strategy of Ukraine up to 2035 (White book of Energy policy) (approve was announced up to 15 July 2015. not approved)

* New energy strategy of Ukraine: safety, energy efficiency, competition (under consideration)
**Goals**

*Energy sufficiency to 2035 (in case of natural gas mining realization, energy safe technology development and deep energy resource diversification)*

*no more then 30% from one supplier*

*energy intensity decreasing from 0,35 to 0,12 t o.e./$1000*

**Gas**

*gas consumption decreasing from 34,8% in 2012 to 28% in 2025 (2013 – 50 billn m3, 40 billn m3 in 2015)*

*40 billn m3/year = 20 billn m3/year DOMESTIC + 20 billn m3/year IMPORT (5 billn m3/year RF + 15 billn m3/year from Slovak, Poland, Hungary)*

**Coal**

*5% share decreasing in 2020 comparison to 2012 due to increase renewable and nuclear.*

**Renewable**

*From 2% to 5,2% increasing share in 2020 and to 20% in 2035 due to decreasing of gas and coal consumption*

**Nuclear**

*nuclear generation is the basis of energy structure*

*46 – 50% share in electricity generation with load factor 78%*

*diversification of nuclear fuel supply for 3 Units (3*42 Westinghouse FAs annual reloading)*

*construction*

* of 2 new nuclear units on Khmelnitsky NPP
* fuel fabrication plant
* Centralize of Dry Storage Facility
* new nuclear units after 2030 according to requirements of IAEA and Euroatom
* connect to **ENTSO-E**
Nuclear energy scenario and strategy

Energy intensity of Ukraine
(Key World Energy Statistics 2013, MEA)

Consumption of initial resource in 2012 and 2020, %

Electricity generation in 2012 and 2020, %
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
<td>2030 base</td>
<td>2030 min</td>
<td>2030</td>
</tr>
<tr>
<td>GDP, billion.$</td>
<td>83</td>
<td>257</td>
<td>306</td>
<td>390</td>
</tr>
<tr>
<td>Total electricity installed capacity, GW</td>
<td>52</td>
<td>88.5</td>
<td>56.7</td>
<td>65.5</td>
</tr>
<tr>
<td>Part of NPPs in total installed capacity, %</td>
<td>26</td>
<td>33.3</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>Part of NPPs in total electr.generation, %</td>
<td>47.9</td>
<td>52.1</td>
<td>50</td>
<td>48.8</td>
</tr>
<tr>
<td>Total electr.generation, billion kWh</td>
<td>185.2</td>
<td>420.1</td>
<td>234</td>
<td>272</td>
</tr>
<tr>
<td>Total installed capacity NPPS, GW</td>
<td>13.8</td>
<td>29.5</td>
<td>15.8</td>
<td>17.8</td>
</tr>
<tr>
<td>Life time extension, years</td>
<td>15</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Electricity generation by NPPs in 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| NPPs electricity generation scenarios in 2030, billion kWh |               |                       |                      | 219.0         | 118           | 133           | 141            | 126.0         | 122.0
Nuclear energy scenario and strategy

Population prognosis UNO, mln people

Relative electricity demand, kWh

Electricity demand prognosis to 2100, billn kWh
Nuclear energy scenario and strategy

- SNF shipping to RF up to 2016
- Long term storage
- Reprocessing
- FP return
- NPPs
- CSNFDSEF
- ZNPP_SNFDSF (time storage to 2051)

Timeline:
- 2015
- 2017
- 2018
- 2020
- 2025
- 2035
- 2040
- 2050
- 2100

- Disposal
- Storage
- Burn in HWR
- Life time extension
- SNF GD
- Reprocessing
### Nuclear energy scenario and strategy

<table>
<thead>
<tr>
<th>NFC element</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural uranium capacity (deposit)</td>
<td>500 000 tHM</td>
</tr>
<tr>
<td>Conversion</td>
<td>10 USD/kg</td>
</tr>
<tr>
<td>Enrichment</td>
<td>130 USD/SWU</td>
</tr>
<tr>
<td>Fabrication</td>
<td>300 USD/kgHM - LWR 1500 USD/kgHM MOX 200 USD/kgHM – ReU HWR</td>
</tr>
<tr>
<td>Reprocessing</td>
<td>2 000 USD/kgHM</td>
</tr>
<tr>
<td>Dry storage</td>
<td>300 USD/kgHM UOX - LWR, MOX – LWR, ReU</td>
</tr>
<tr>
<td>Geological disposal</td>
<td>1000 USD/kgHM</td>
</tr>
<tr>
<td>Capital cost</td>
<td>5000 USD/kWe - LWR 4500 USD/kWe – HWR</td>
</tr>
</tbody>
</table>

**Type of NPP: LWR 1000-1200 MW, HWR – 730 MW**

- NPPs life time LWR: 20 years extension – old, 60 years – new
- NPPs life time HWR: 30 years
- Number of reloaded FAs LWR: 42 (4 years fuel cycle)
- Dry storage VVER-1000 (380 casks). No expanded. Time storage – 50 years
- CDSF LWR since 2018 (480 casks). Can be expanded
- Geological disposal: after 2035
- No differences between TVSA and FAs Westinghouse
Open Nuclear Fuel Cycle and GD

max

base

min
Partially Closed Open Nuclear Fuel Cycle and ReU

$max$  

$base$

$min$
1. The results are preliminary (trends).

2. **Up to 2040:**
   - 120 TWh for all NFC scenarios electricity production from nuclear power plants will exceed
   - until 2025 – build Khmelnitsky Unit 3-4 (type LWR-1000, 2 GW)
   - between 2030 and 2040 for a 50% share must be commissioned 11 GWe of new units;
   - will be accumulated SNF 8 000 tHM (6 000 tHM must be removed in CSNFDSF)
   - CSNFDSF-2 commissioned
   - *in the case of reprocessing* since 2025 the 1 GW HWR is rational for build up to 2030. 20 tHM of Pu have been accumulated
   - *in the case of geological disposal* - since to 2035 will need GD capacity of 4 000 tHM
3. In the period from 2040 by 2060
- For all the nuclear fuel cycle production of electricity from nuclear power plants will be 90 TWh
- 2 GWe LWR and 1 GWe HWR will be commissioned
- the accumulation of spent nuclear fuel - up to 13 000 tHM (3876 tHM – Z_SNFDSF)
- in the case of reprocessing since 2025 (100 tHM/y) all SNF which was shipped on RF shall be reprocessed. have been accumulated:
  - 100 tHM of Pu
  - 500 tHM of FP
- in the case of geological disposal - since to 2035 will need GD capacity of 8 000 tHM
  (4 000 tHM – Z_SNFDSF)

4. Up to 2100
- 25 000 tHM accumulated
- in the case of reprocessing - capacity RP 200 tHM/y, 200 tHM Pu, 1000 tHM – FP, 3 GWe commissioned (2 HWR, 1 LWR)
- in the case of geological disposal - 15 000 tHM in GD
<table>
<thead>
<tr>
<th>Element of NFC</th>
<th>Direction of collaboration</th>
<th>Old status</th>
<th>New status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front end</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining and milling</td>
<td>30% Ukr – 70% RF</td>
<td>30% Ukr – 70% (RF+Fr)</td>
<td></td>
</tr>
<tr>
<td>Conversion, enrichment</td>
<td>RF</td>
<td>RF+Fr</td>
<td></td>
</tr>
<tr>
<td>U-fuel assemblies fabrication (design, fabrication plant)</td>
<td>RF</td>
<td>RF + Westinghouse</td>
<td></td>
</tr>
<tr>
<td>Implementation of new design of FAs</td>
<td>RF</td>
<td>RF + Westinghouse</td>
<td></td>
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<tr>
<td>Requirements</td>
<td>RF + Ukr</td>
<td>Ukr (RF)</td>
<td></td>
</tr>
<tr>
<td><strong>Operation of Nuclear Reactor</strong></td>
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<tr>
<td>Reactors</td>
<td>RF</td>
<td>(RF) – Westinghouse – Fr + other</td>
<td></td>
</tr>
<tr>
<td>Life time extension</td>
<td>RF</td>
<td>Ukr - (RF) – Westinghouse – Fr</td>
<td></td>
</tr>
<tr>
<td>Supply of main equipment</td>
<td>RF + Ukr</td>
<td>Ukr (RF) + other</td>
<td></td>
</tr>
<tr>
<td>Enhanced of fuel management (economics of NFC, FAs reliability)</td>
<td>RF + Ukr</td>
<td>RF + Ukr + Westinghouse</td>
<td></td>
</tr>
<tr>
<td>Scientific support of nuclear units operation (nuclear safety analysis, licensing)</td>
<td>RF + Ukr</td>
<td>Ukr (RF) + other</td>
<td></td>
</tr>
<tr>
<td>Requirements</td>
<td>RF + Ukr</td>
<td>Ukr (RF)</td>
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</tr>
<tr>
<td><strong>Back end</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Long term storage</td>
<td>USA + Fr</td>
<td>USA + Fr</td>
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</tr>
<tr>
<td>Reprocessing</td>
<td>RF</td>
<td>RF + Fr</td>
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<tr>
<td>Scientific support</td>
<td>RF + Ukr</td>
<td>RF + Fr + Westinghouse</td>
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<tr>
<td>Requirements</td>
<td>RF + Ukr</td>
<td>RF + Ukr</td>
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Thank you for the attention!