Nuclear Fuel Diversification in CEE

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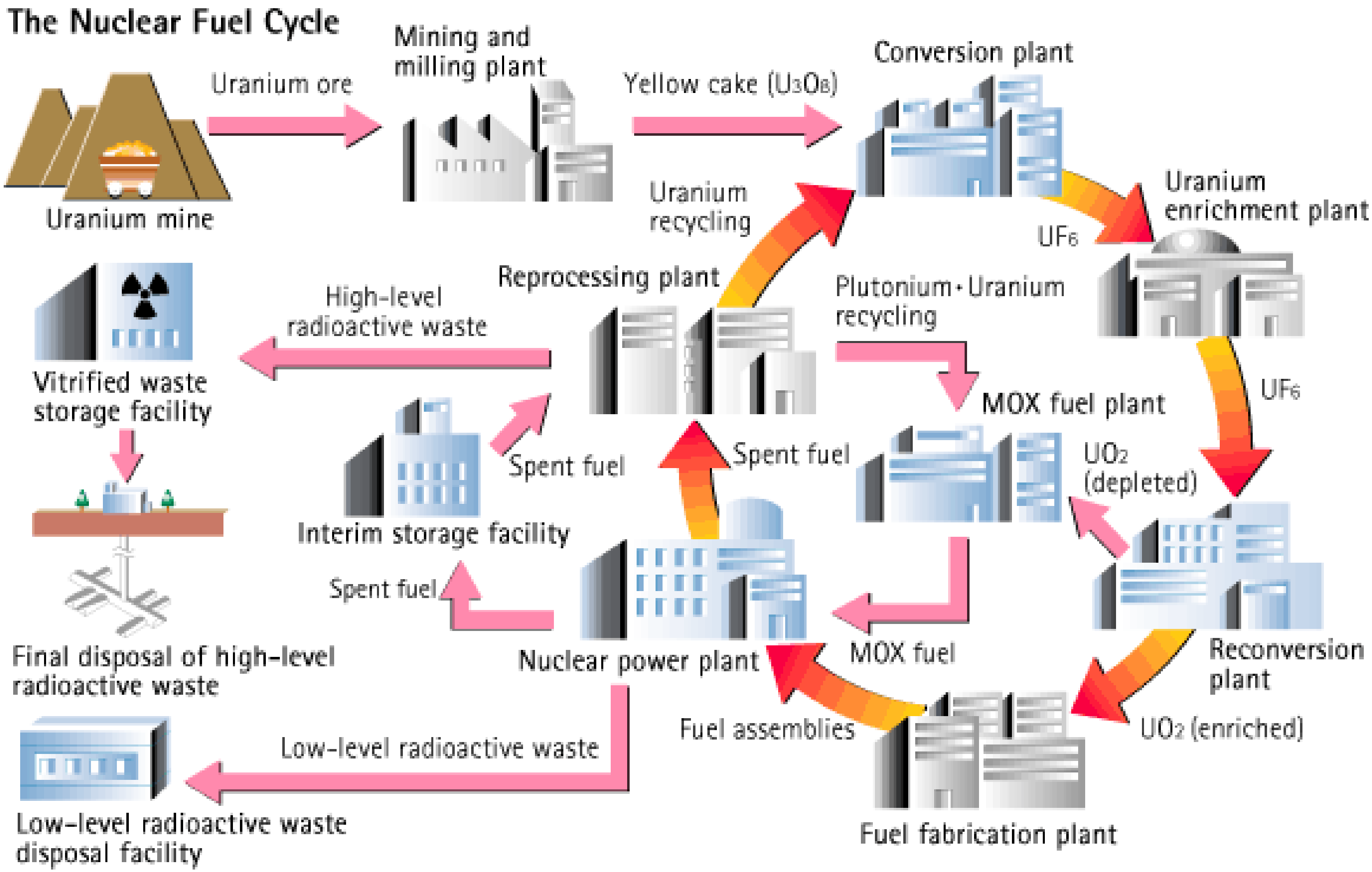
OP Vzdělávání pro konkurenceschopnost

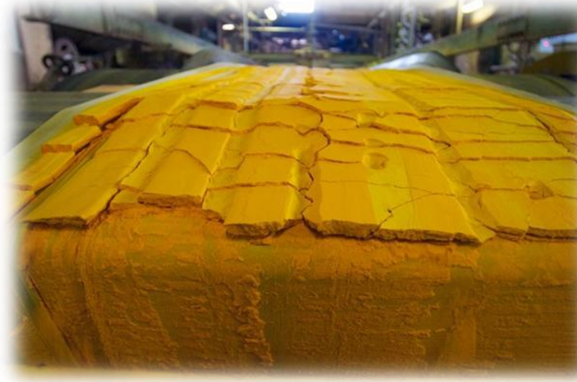
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Introduction

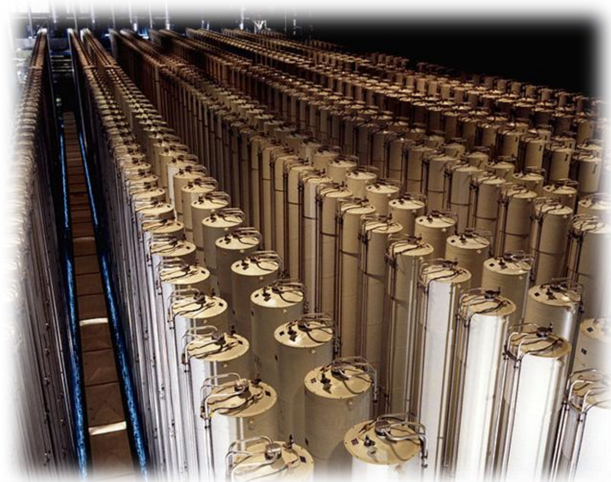
- **European Energy Security Strategy** (May 2014) - utilities to diversify their nuclear fuel supply sources
- Euratom opened call NFRP-16-2015 to **support the licensing of Western nuclear fuel** for reactors in VVER units in December 2013, with an application deadline of November 2014
- Six months later, **Westinghouse Electric Company LLC** led a group that won €2 million in backing from the EU to diversify nuclear fuel supplies to these reactors, with a focus on licensing alternative nuclear supplies for Russian-designed pressurized water reactors operating inside the EU
- The Euratom Supply Agency understands the importance of the security of supply, mandating that there should always be at least two alternative fuel designs from two different suppliers qualified for each reactor

Nuclear Fuel Cycle






RADIOACTIVE MATERIAL
URANIUM HEXAFLUORIDE
GB/3572/H(U)-96
TYPE IP 2
Max. wt.=15200 kg



Front End Price Break-down (2013)

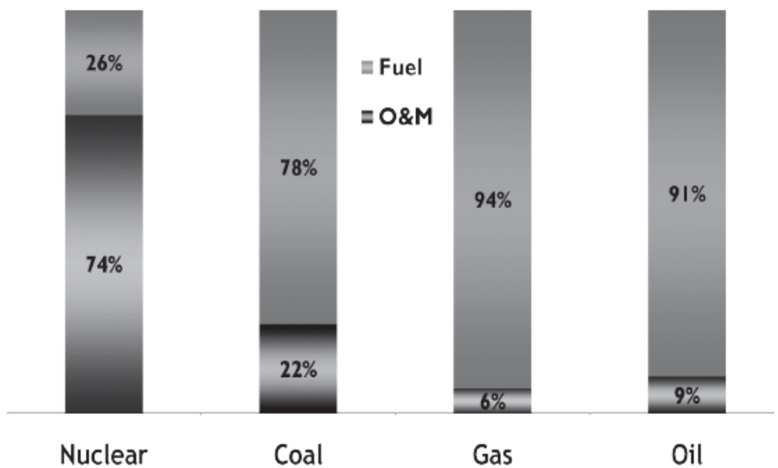
Uranium	9.0 kg U3O8	$ 50 per lb	**$ 990**
Conversion	7.6 kg U	$ 13 per kg	**$ 99**
Enrichment	7 SWU	$ 150 per SWU	**$ 1050**
Fabrication	1 kg	$ 300 per kg	**$ 300**
Total			**$ 2439**

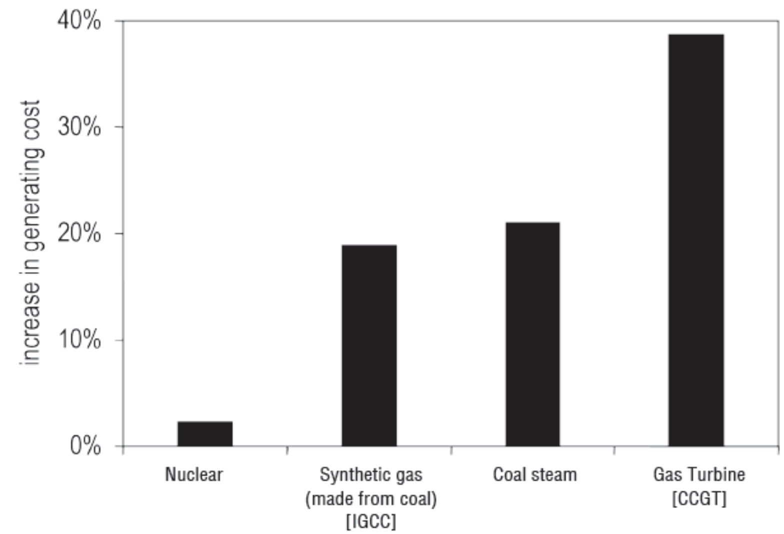
Need about 20 tonnes of enriched uranium for an average large reactor refuel, so cost will be about **$ 50 million**

Total front end world market is now worth about **$ 25 billion** annually

Source: Steve Kidd, World Nuclear Association

Nuclear Fuel Economy





The reactor fuel buyers fight hard to save every last cent because this is cost they feel they can influence. It has however minor role on the NPP operating costs.

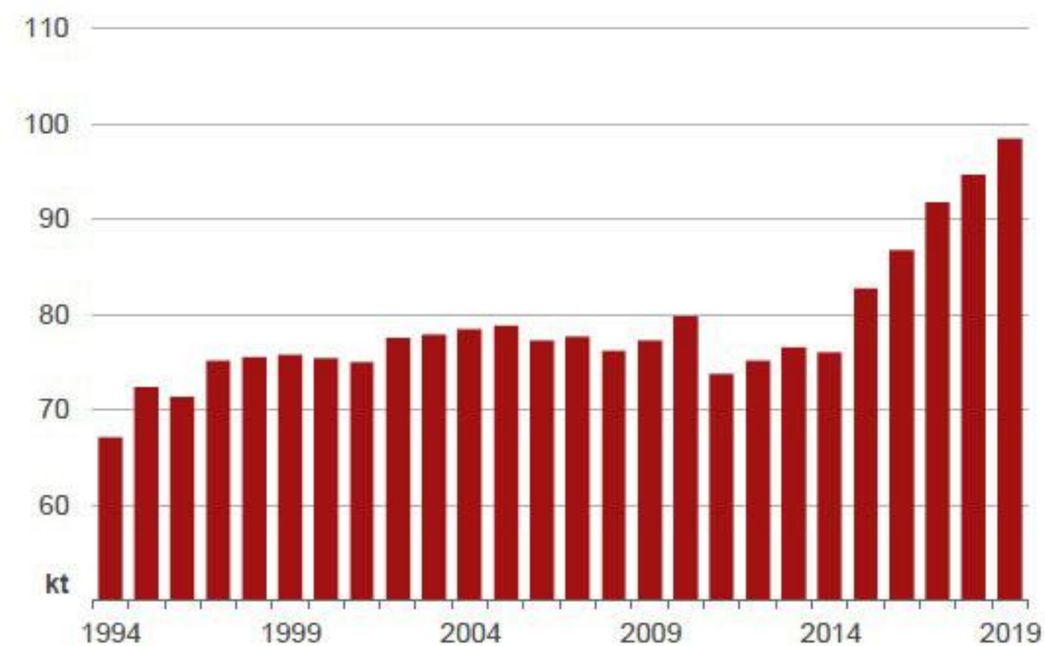
Impact of 50 % increase in fuel costs on generating costs

Source: Global Energy Decisions, ERI, Inc.; IEA WEO 2006; in Steve Kidd, 2010, Nuclear Fuel: Myths and Realities

Uranium

According to WNA, as of 31 December 2014 there were **437 nuclear reactors** operational in 30 countries generating 377.8 GWe of electricity. There were **70 nuclear reactors** under construction in 14 countries (52 in top five: China, Russia, India, South Korea and USA).

Figure 8.5: World uranium consumption (U_3O_8)



Sources: IEA; WNA; BREE.

Agency / Year	Low / GWe	High / GWe
IAEA 2030	435	722
IEA 2040	620	
OECD NEA 2035	399	678

Uranium

Region/country	Production 2014 (estimate)	Production 2013 (final)	Share in 2014 (%)	Share in 2013 (%)	Change 2014/13 (%)
Kazakhstan	23 127	22 451	41	38	3
Canada	9 134	9 331	16	16	– 2
Australia	5 001	6 350	9	11	– 21
Niger	4 057	4 518	7	8	–10
Namibia	3 255	4 323	6	7	– 25
Russia	2 990	3 135	5	5	– 5
Uzbekistan	2 400	2 400	4	4	0
United States	1 919	1 792	3	3	7
China	1 500	1 500	3	3	0
Ukraine	926	922	2	2	0
Others	963	985	2	2	– 2
South Africa	576	531	1	0	8
Malawi	369	**1 132**	**0**	**2**	**– 67**
Total	**56 217**	**59 370**	**100**	**100**	**– 5**

Source: Data from WNA and specialised publications (totals may not add up due to rounding).

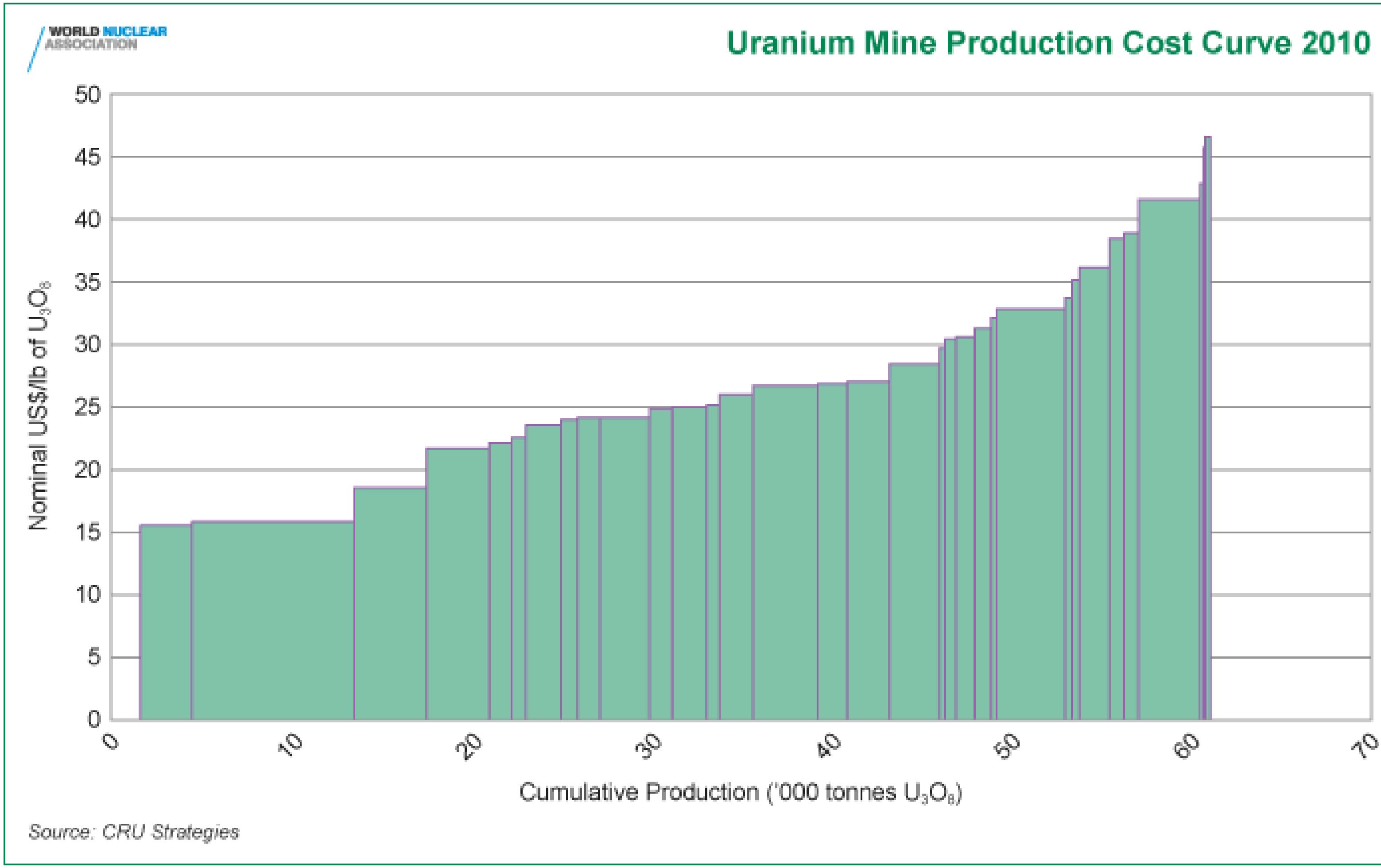
Uranium Production Perspective

- Rising NPP capacity factors (10 % in 1990s)
- Rising enrichment levels (up to 5 % U235)
- Uranium price levels limit usable deposits exploration and extraction (proven reserves vs. pure guesses) – U from oceans
- According to Red Book, there is 7,635 Mt of Identified resources of U, not counting resources with current production price above 260 USD/1 kg
- 400 junior uranium companies emerged recently (largely still in exploration stage)

- Stockpiles of natural and enriched uranium
- RepU (expensive U = pressure on reprocessing)
- P239 (Spent fuel, weapons)
- Down-blended weapons-grade uranium
- Re-enriched uranium tails assay (currently 0.25-0.3% U235)
- Higher enrichment (expensive U = pressure on higher enrichment/U235 extraction)
- Breeder reactors (U238 to P239)
- Fusion (?)

- Extreme short-term measures (lowering NPP production output means longer fuel campaigns)

Uranium Production Perspective



Source: CRU Strategies

Conversion

Table 3: Commercial UF_6 conversion facilities (tonnes of uranium/year)

Company	Nameplate capacity in 2014 (tU as UF_6)	Share of global capacity (%)
Atomenergoprom (Rosatom) (Russia)	25 000 (*)	35
Cameco (Canada)	12 500	18
ConverDyn (United States)	15 000	21
Comurhex (AREVA) (France)	15 000	21
CNNC (China)	3 650	5
Ipen (Brazil)	40	0
Total nameplate capacity	71 190	100

Source: WNA, The global nuclear fuel market — Supply and demand 2013–30.
(*) Operating capacity estimated at 10 000 tU/y.

Source: Euratom Supply Agency

-China´s capacity is expected to grow considerably in 2025 and beyond

-Plan to develop Ulba plant in Kazakhstan (12 000 tU)

Enrichment

World enrichment capacity – operational and planned (thousand SWU/yr)

Country	Company and plant	2013	2015	2020
France	Areva, Georges Besse I & II	5500	7000	7500
Germany-Netherlands-UK	Urenco: Gronau, Germany; Almelo, Netherlands; Capenhurst, UK.	14,200	14,400	14,900
Japan	JNFL, Rokkaasho	75	75	75
USA	USEC, Piketon	0*	0	0
USA	Urenco, New Mexico	3500	4700	4700
USA	Areva, Idaho Falls	0	0	0
USA	Global Laser Enrichment, Paducah	0	0	0
Russia	Tenex: Angarsk, Novouralsk, Zelenogorsk, Seversk	26,000	26,578	28,663
China	CNNC, Hanzhun & Lanzhou	2200	4220	7520
Other	Various: Argentina, Brazil, India, Pakistan, Iran	75	100	170
	Total SWU/yr approx	**51,550**	**57,073**	**63,526**
	Requirements (*WNA reference scenario*)	49,154	47,285	57,456

Source: World Nuclear Association Nuclear Fuel Report 2013 & 2105, Areva 2014 Reference Document for most 2013 figures.

SWU calculator: http://www.wise-uranium.org/nfcue.html

Fabrication

Difference to every other step:

- 1) Fabrication is a highly specialised service rather than commodity (barrier for newcomers enetring the market)
- 2) TVEL offers full front end process as a product (i.e. fuel) vs. steps in the fuel cycle
- 3) Main technology (NPP) suppliers are also main fuel producers
- 4) Fuel is manufactured according to public tenders specifing the product in details
- 5) VVER technology was developed paralelly with western technology (legacy of cold war)
- 6) Markets were opened 25 years ago with no experience on both sides
- 7) The nuclear fuel quality is critical for NPP production. The financial implications of reduced plant performance would quickly outweigh any benefit from potentially lower fuel prices

Fabrication

Table 1: World LWR fuel fabrication capacity, tonnes/yr

	Fabricator	Location	Conversion	Pelletizing	Rod/assembly
Brazil	INB	Resende	160	160	240
China	CNNC	Yibin	400	400	450
		Baotou	200	200	200
France	AREVA NP-FBFC	Romans	1800	1400	1400
Germany	AREVA NP-ANF	Lingen	800	650	650
India	DAE Nuclear Fuel Complex	Hyderabad	48	48	48
Japan	NFI (PWR)	Kumatori	0	360	284
	NFI (BWR)	Tokai-Mura	0	250	250
	Mitsubishi Nuclear Fuel	Tokai-Mura	450	440	440
	Global NF-J	Kurihama	0	750	750
Kazakhstan	Ulba	Ust Kamenogorsk	2000	2000	0
Korea	KNFC	Daejeon	700	700	500
Russia	TVEL-MSZ*	Elektrostal	1450	1200	1200
	TVEL-NCCP	Novosibirsk	250	200	400
Spain	ENUSA	Juzbado	0	500	500
Sweden	Westinghouse AB	Västeras	600	600	600
UK	Westinghouse**	Springfields	950	600	860
USA	AREVA Inc	Richland	1200	1200	1200
	Global NF-A	Wilmington	1200	1000	1000
	Westinghouse	Columbia	1500	1500	1500
Total			**13908**	**14618**	**12972**

** Includes approx. 220 tHM for RBMK reactors*

*** Includes approx. 200 tHM for AGR reactors*

Source: WNA Market Report 2013. NB the above figures are about 40% above operational capacities, which meet demand.

Fabrication

Table 2: World PHWR fuel fabrication capacity, tonnes/yr

	Fabricator	Location	Rod/Assembly
Argentina	CONUAR	Cordoba & Eizeiza	160
Canada	Cameco	Port Hope	1200
	GNF-Canada	Peterborough	1500
China	CNNC China Northern	Baotou	200
India	DAE Nuclear Fuel Complex	Hyderabad	435
Pakistan	PAEC	Chashma	20
Korea	KEPCO	Taejon	400
Romania	SNN	Pitesti	240
Total			**4320**

Source: World Nuclear Association Market Report 2013, from IAEA.

Table 3: World MOX fuel fabrication capacity, tonnes/yr

	Fabricator	Location	Pelletising	Rod/assembly
France	Areva NC	Marcoule	195	195
India	DAE Nuclear Fuel Complex	Tarapur	50	50
Japan	JARA	Tokai-Mura	5	5
	JNFL	Rokkasho-Mura*	130	130
USA		Savannah River**	100	100
Total			480	**480**

** Operational by 2016*

*** Operational by 2018*

Source: World Nuclear Association Market Report 2013

Operating VVER Design Nuclear Units Outside Russian Federation						
Country	**Reactor**	**Type**	**In Operation From**	**End of Life-Cycle**	**Fuel Supplier**	**Fuel Contract Until**
Armenia	Metsamor 2	VVER-440/V-270	1980	2026	OAO TVEL[B]	2026
Bulgaria	Kozloduy 5	VVER-1000/V-320	1987	2017[A]	OAO TVEL	2020
	Kozloduy 6	VVER-1000/V-320	1991	2019[A]	OAO TVEL	2020
China	Tianwan 1	VVER-1000/V-428	2006	2046	OAO TVEL	2023[C]
	Tianwan 2	VVER-1000/V-428	2007	2047	China Jianzhong Nuclear Fuel Company, Ltd. (CNNC)	2047[C]
Czech Republic	Dukovany 1	VVER-440/V-213	1985	Indefinite	OAO TVEL	2028
	Dukovany 2	VVER-440/V-213	1986	2016[A]	OAO TVEL	2028
	Dukovany 3	VVER-440/V-213	1986	2016[A]	OAO TVEL	2028
	Dukovany 4	VVER-440/V-213	1987	2017[A]	OAO TVEL	2028
	Temelín 1	VVER-1000/V-320	2000	2020	OAO TVEL	2020
	Temelín 2	VVER-1000/V-320	2002	2022	OAO TVEL	2020
Finland	Loviisa 1	VVER-440/V-213	1977	2027	OAO TVEL	2027[D]
	Loviisa 2	VVER-440/V-213	1980	2030	OAO TVEL	2030[D]
Hungary	Paks 1	VVER-440/V-213	1982	2032	OAO TVEL	2032
	Paks 2	VVER-440/V-213	1984	2034	OAO TVEL	2034
	Paks 3	VVER-440/V-213	1986	2016[A]	OAO TVEL	2016[E]
	Paks 4	VVER-440/V-213	1987	2017[A]	OAO TVEL	2017[E]
India	Kudankulam 1	VVER-1000/V-412	2013	2073	OAO TVEL	2073[F]
	Kudankulam 2	VVER-1000/V-412	2016	2076	OAO TVEL	2073[F]
Iran	Bushehr 1	VVER-1000/V-446	2011	2071	OAO TVEL	2021
Slovak Republic	Jaslovské Bohunice V2 1	VVER-440/V-213	1984	2024[A]	OAO TVEL	2021
	Jaslovské Bohunice V2 2	VVER-440/V-213	1985	2025[A]	OAO TVEL	2021
	Mochovce 1	VVER-440/V-213	1998	2028	OAO TVEL	2021
	Mochovce 2	VVER-440/V-213	2000	2030	OAO TVEL	2021
Ukraine	Rivne 1	VVER-440/V-213	1980	2030	OAO TVEL	2030[G]
	Rivne 2	VVER-440/V-213	1981	2031	OAO TVEL	2030[G]
	Rivne 3	VVER-1000/V-320	1986	2016[A]	OAO TVEL	2030[G]
	Rivne 4	VVER-1000/V-320	2004	2034	OAO TVEL	2030[G]
	Khmelnitsky 1	VVER-1000/V-320	1987	2017[A]	OAO TVEL	2030[G]
	Khmelnitsky 2	VVER-1000/V-320	2004	2034[A]	OAO TVEL	2030[G]
	South Ukraine 1	VVER-1000/V-302	1982	2023	Westinghouse EC LLC	2020[G]
	South Ukraine 2	VVER-1000/V-338	1985	2025	Westinghouse EC LLC	2020[G]
	South Ukraine 3	VVER-1000/V-320	1989	2019	Westinghouse EC LLC	2020[G]
	Zaporizhzhya 1	VVER-1000/V-320	1984	2015[A]	OAO TVEL	2030[G]
	Zaporizhzhya 2	VVER-1000/V-320	1985	2016[A]	OAO TVEL	2030[G]
	Zaporizhzhya 3	VVER-1000/V-320	1986	2016[A]	OAO TVEL	2030[G]
	Zaporizhzhya 4	VVER-1000/V-320	1987	2017	OAO TVEL	2030[G]
	Zaporizhzhya 5	VVER-1000/V-320	1989	2019	OAO TVEL	2030[G]
	Zaporizhzhya 6	VVER-1000/V-320	1995	2025	OAO TVEL	2030[G]

Alternative Fabricators of VVER Design Nuclear Units Fuel				
Reactor Type	**Company**	**Previous Experience**	**Current Contracts**	**Operational experience and Limitations**
VVER-440	Westinghouse Electric Company LLC*	Nova E-3 fuel type for Loviisa NPP Unit 1 (Finland) in 1998-2007	-	The fuel performed in accordance with expectations during operation. BNFL signed a contract with Finnish NPP operator IVO and Hungarian Paks NPP in 1996 for the design, development, licensing and supply of test fuel assemblies for the VVER-440 reactor at Loviisa NPP. At the same time, Hungarian Paks NPP was considering using an alternative supplier for at least one reactor. But no BNFL fuel was ever loaded into Hungarian reactors (likely because of the Hungarian-Russian contract for fuel supply until the end of plant´s life-cycle) and BNFL´s fuel was licensed in Hungary only until 2008.
VVER-1000	Westinghouse Electric Company LLC	VVANTAGE-6 fuel type for Temelín NPP (Czech Republic) in 2000-2009; VVANTAGE-6 (TVS-W) fuel type for South Ukraine NPP (Ukraine) in 2009-2014; TVS-RW fuel type for South Ukraine NPP since 2015	South Ukraine NPP (Ukraine) until 2020	Temelín NPP experienced massive malfunctions related to the geometric stability of the fuel that eventually led to premature unloading of all of Westinghouse's fuel assemblies despite financial losses, and replacement with TVEL fuel. Problems with fuel recurred in Ukraine to a lesser extent, but still enough to cause a lengthy unscheduled outage at two of the units, which eventually led to technological adjustments to the fuel and consequent relabeling to Robust (TVS-RW).
	China National Nuclear Corporation (CNNC)	-	Tianwan NPP (China) until the end of plant´s life-cycle	As part of the 2008 contract with TVEL and CNNC, TVEL sold production technology for TVS-2M fuel for VVER-1000 units. China's Yibin fabrication plant will thus produce the fuel for Tianwan Units 1 and 2 and future Units 3 and 4 (currently under construction) from fourth refuel onwards. The contract is for Tianwan NPP only.
VVER-1200	-	-	-	-

* This contract was operated by British Nuclear Fuels Limited (BNFL), owner of Westinghouse Electric Company LLC between 1999 and 2006. All Westinghouse’s nuclear power business was restructured by BNFL, including ABB Group's nuclear power business, bought and merged into Westinghouse in 2000. In 2007, BNFL sold Westinghouse Electric Company LLC to Toshiba Corporation and Toshiba sold shares of the company to minorities (20% to The Shaw Group and 3% to Ishikawajima-Harima Heavy Industries Co. Ltd.; later in 2007 10% to Kazatomprom) leaving the Japanese company with 67% share. When BNFL bought Westinghouse, it was decided that the reload fuel for Loviisa NPP Unit 1 would be assembled via a manufacturing license by Enusa Industrias Avanzadas, S.A. in Spain instead of at Westinghouse´s Springfields plant in UK.

Source: public sources; company information; compiled by T. Vlček.

What is it for?

- Potentially the biggest single obstacle to fuel market diversification is the license.
- It is here that Euratom makes its entrance. The Euratom funding noted earlier is targeted directly at diversifying the VVER-440 fuel market by qualifying a second supplier for the EU's VVER-440 reactor fleet. The program will chiefly focus on establishing the methods and methodology required to license a VVER-440 fuel design.

- To support the business of a Western nuclear company by removing market barriers to allow entry to the relatively small EU market for VVER-440 reactors—fourteen in operation, two in construction—seems nonsensical from at least two vantage points.

Euratom Grant as a Direct Market Support I

- The Euratom funding is targeted directly at diversifying the VVER-440 fuel market by qualifying a second supplier for the EU's VVER-440 reactor fleet.
- The Dukovany NPP in the Czech Republic, the Loviisa NPP in Finland, and the Paks NPP in Hungary all have lifetime fuel contracts with OAO TVEL for all their VVER-440 units.
- Only at the Jaslovské Bohunice and Mochovce NPPs in Slovakia do the contracts expire in 2021.
- There are thus no contractual obstacles to changing suppliers in subsequent years, and the plants will continue in operation well beyond that point: up to 30 years for Mochovce NPP Units 1 and 2; up to 10 years for Jaslovské Bohunice V2 Units 1 and 2; and up to 60 years for Mochovce NPP Units 3 and 4.

Euratom Grant as a Direct Market Support II

- Since Westinghouse Electric Company LLC truly is the sole alternative provider of fuel for VVER-440 reactors, the evidence also backs the argument that financial support for the diversification of fuel to VVER reactors in fact constitutes direct support of one private company on the market.
- But this is not the key reason for Euratom's grant scheme, nor for the European Commission's diversification efforts. It is a mere corollary outcome; Westinghouse is indeed the only alternative supplier of nuclear fuel for this region.
- Finally, we may expect the instalment of Lead Test Assemblies in a VVER-440 reactor in the near future. It may occur either at Ukraine's Rivne NPP, since Westinghouse already has a commercial presence in Ukraine, or at Slovakia's Jaslovské Bohunice and Mochovce NPPs.

What is it for?

- The Slovak Government has discussed the possibility of cutting dependency on Russian nuclear fuel, and in November 2014, information emerged about a contract for uranium fuel supply being signed with a non-Russian company
- Additionally, in 2014 Slovakia began a diversification effort targeting not only uranium enrichment, but also nuclear fuel manufacture, crude oil and natural gas infrastructure, and military equipment based on Resolution 146 of the Committee of the Slovak Republic National Council for Defence and Security

However:

- *"Our business with TVEL has always been very smooth. Slovenské Elektrárne has never experienced any technical problems with the fuel, not even small leakages, which may occur in one out of a thousand fuel assemblies. The quality has been outstanding, and even during this period of tension we have not experienced any delivery disruptions. When the situation was especially tense, we used aerial transport to avoid passing through Ukraine by train."* Nicola Cotugno, general-director of Slovenské Elektrárne