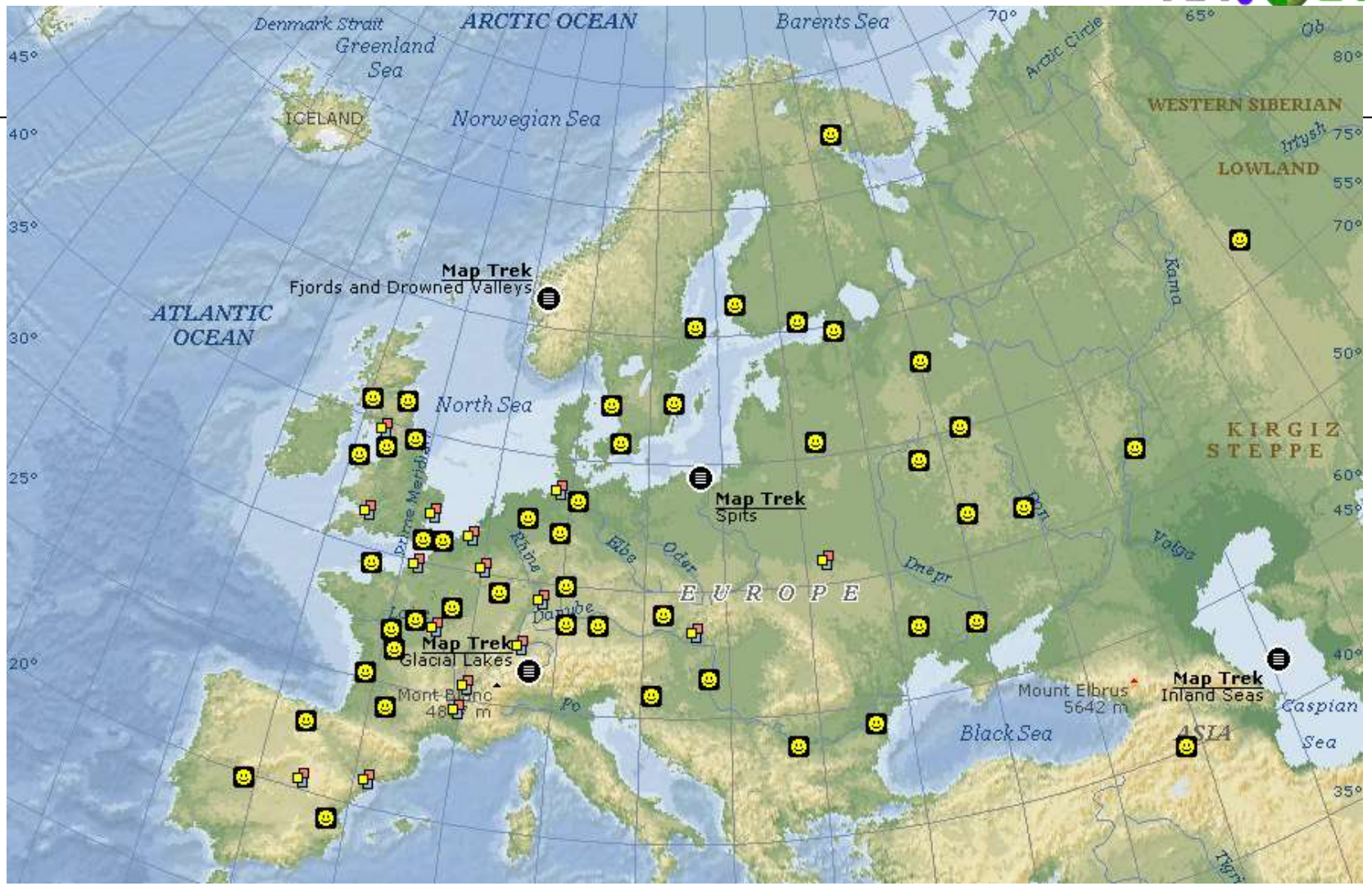
Nuklearna energija u RH i EU

Prof.dr.sc. Nenad Debrecin
Prof.dr.sc. Nikola Čavlina
Fakultet elektrotehnike i računarstva
Sveučilište u Zagrebu

Noć nad Europom

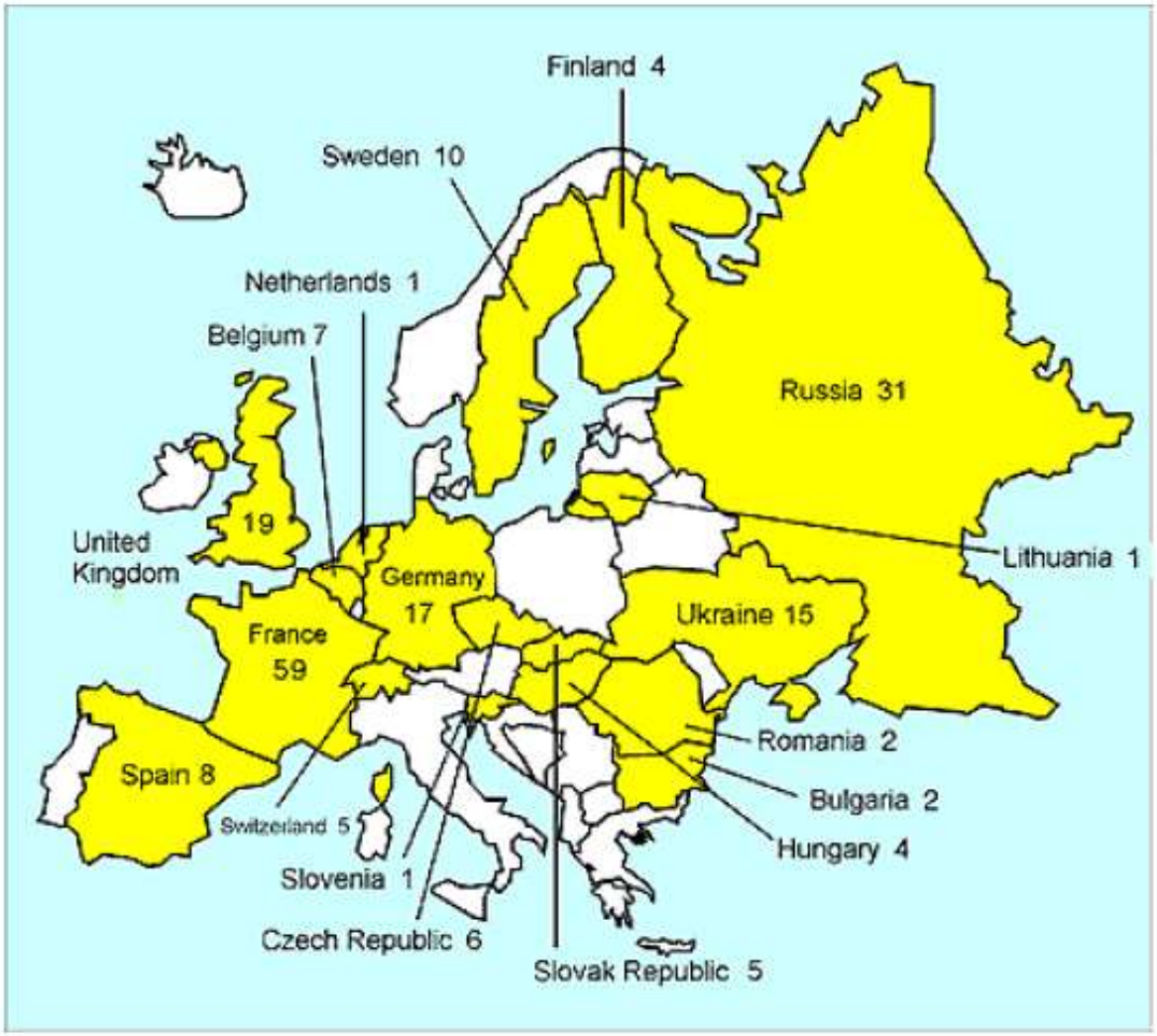
Noć nad Europom

Nuklearne elektrane u Europi



- 216 reactors
- 89 sites, 17 countries
- 168.846 MWe installed power
- 35.3% share of annual production

Nuklearne elektrane u Europi



Nuclear Power Plants in Operation in Europe, April 2008

- u 15 država članica Europske unije, u pogonu je 146 nuklearnih elektrana
- proizvode trećinu od ukupno proizvedene električne energije
- u EU u gradnji je nuklearna elektrane u Finskoj (Olkiluoto-3, 1600 MW) i u Francuskoj (Flamanville-3, 1600 MW)

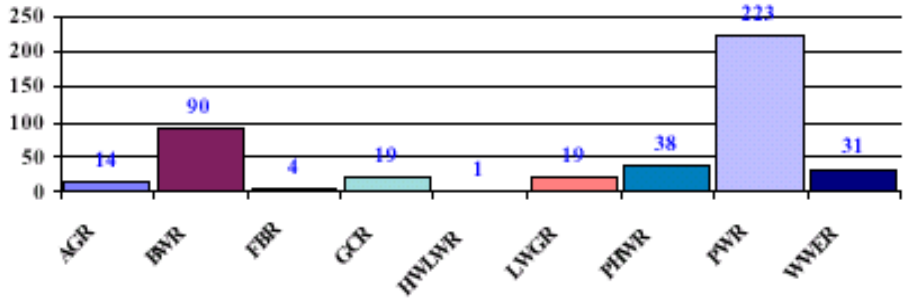
In total (world):

- **436 units**
- **production of ~ 2500 billion kWh**
- **= all Hydropower**
- **> Saudi Oil production**
- **~17% world power**
- **~6% primary energy**

Pregled tipova nuklearnih reaktora

Number and power (in MW) of operating reactors by types and continents

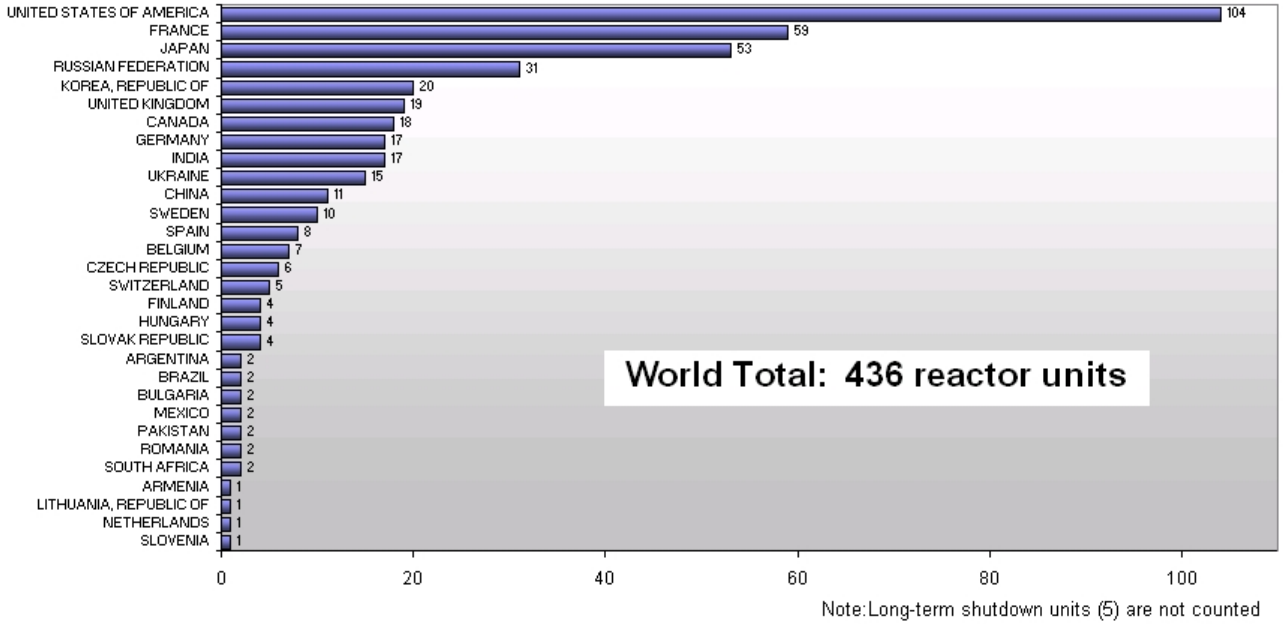
Code	Type	Europe		Africa		America		Asia		Total	
AGR	Advanced Gas Cooled Reactor	14	8.360							**14**	**8.360**
BWR	Boiling Water Reactor	20	17.261			36	31.639	34	28.120	**90**	**77.020**
FBR	Fast Breeder Reactor	2	793					2	261	**4**	**1.054**
GCR	Gas Cooled Reactor	19	3.125							**19**	**3.125**
HWLWR	Heavy-Water-Moderated, Light-Water Cooled							1	148	**1**	**148**
LWGR	Light Water Cooled Graphite Reactor	19	13.544							**19**	**13.544**
PHWR	Pressurized Heavy Water Reactor	1	650			23	15.305	14	4.411	**38**	**20.366**
PWR	Pressurized Water Reactor	111	107.330	2	1.842	71	65.917	39	31.748	**223**	**206.837**
WWER	Water Cooled Water Moderated Power Reactor	30	17.783					1	376	**31**	**18.159**
		216	**168.846**	**2**	**1.842**	**130**	**112.861**	**91**	**65.064**	**439**	**348.613**



POWER REACTOR INFORMATION SYSTEM

NUCLEAR POWER PLANTS INFORMATION

Number of Reactors in Operation Worldwide



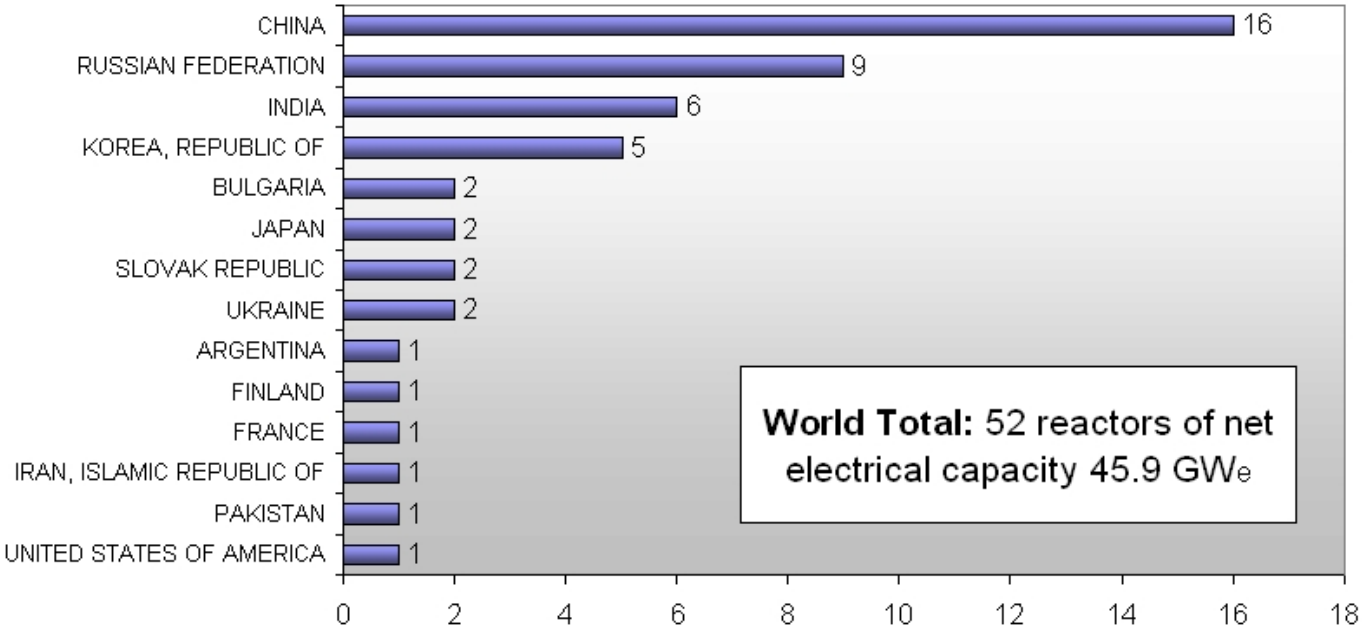
Note: In the World Total there are also 6 reactors in operation in Taiwan, China.

Go Back to Nuclear Power Plant Information

This page was automatically created on 07 Sep 2009, 11:33:19 .

NUCLEAR POWER PLANTS INFORMATION

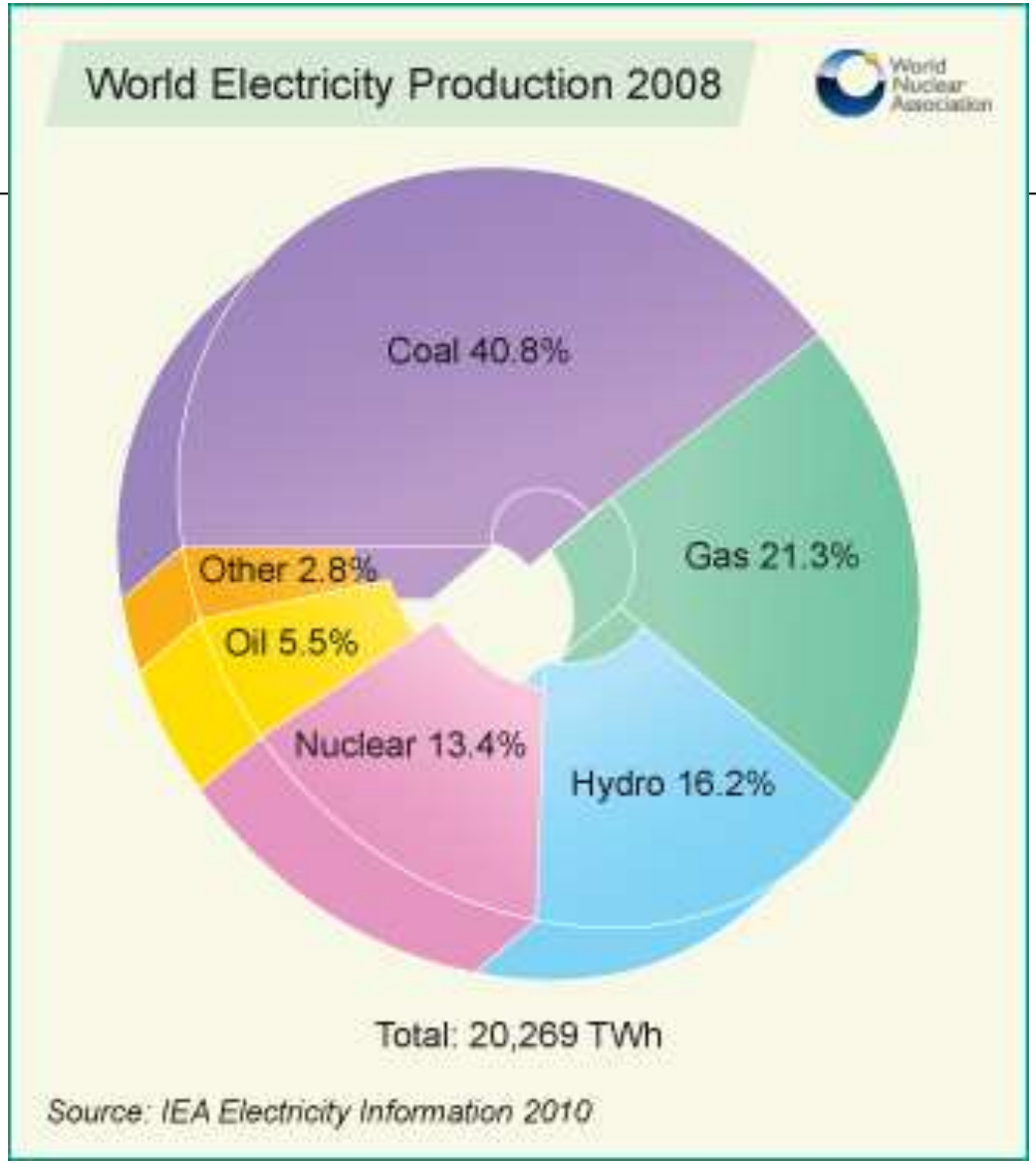
Number of Reactors under Construction Worldwide



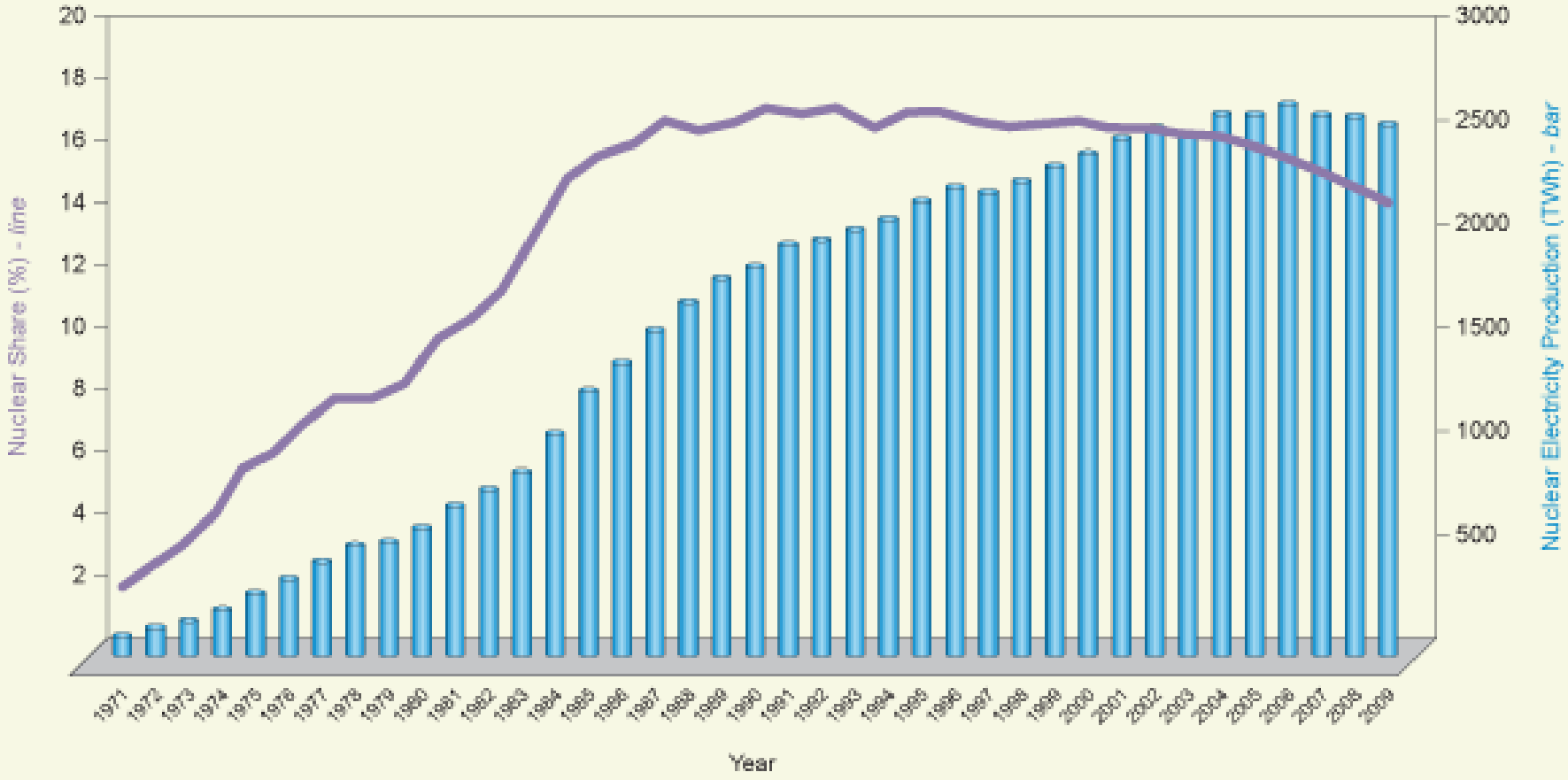
Note: The World Total includes also 2 reactors under construction in Taiwan, China.

Go Back to Nuclear Power Plant Information

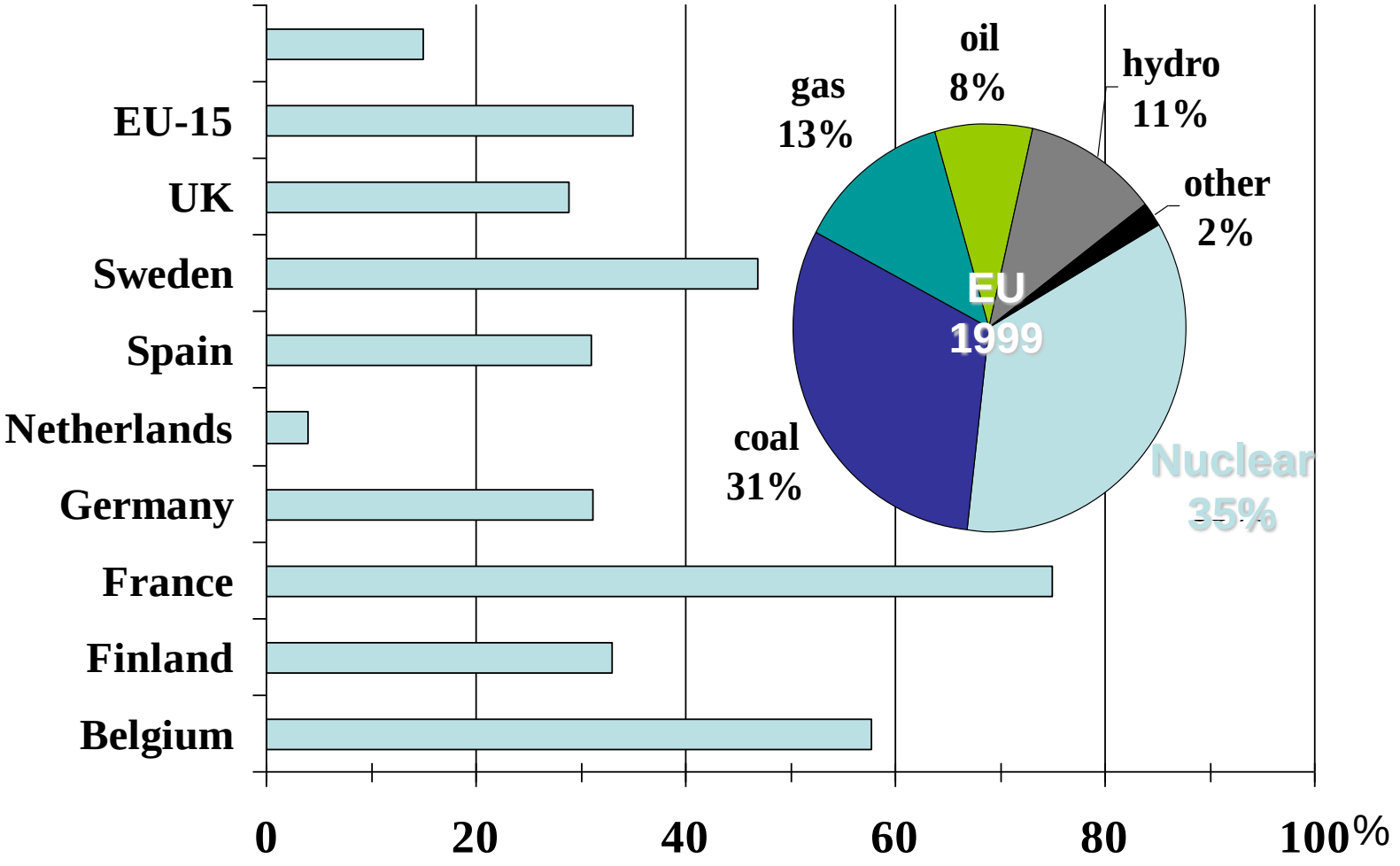
This page was automatically created on 07 Sep 2009, 11:31:01 .


World Electricity Production 2008
World Nuclear Association
Coal 40.8%
Gas 21.3%
Other 2.8%
Oil 5.5%
Nuclear 13.4%
Hydro 16.2%
Total: 20,269 TWh
Source: IEA Electricity Information 2010

Nuclear Electricity Production and Share of Total Electricity Production

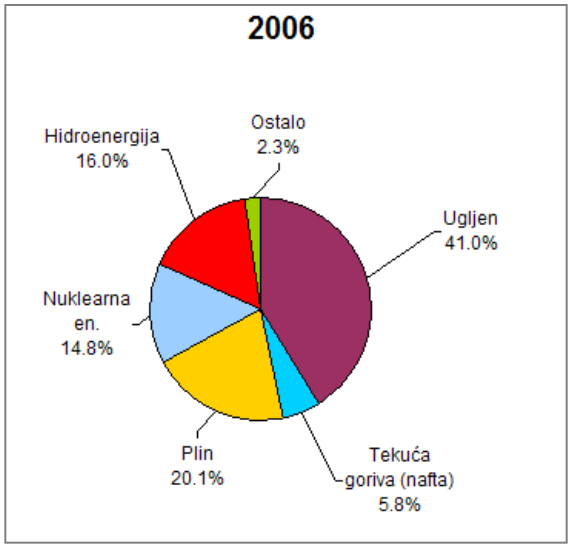


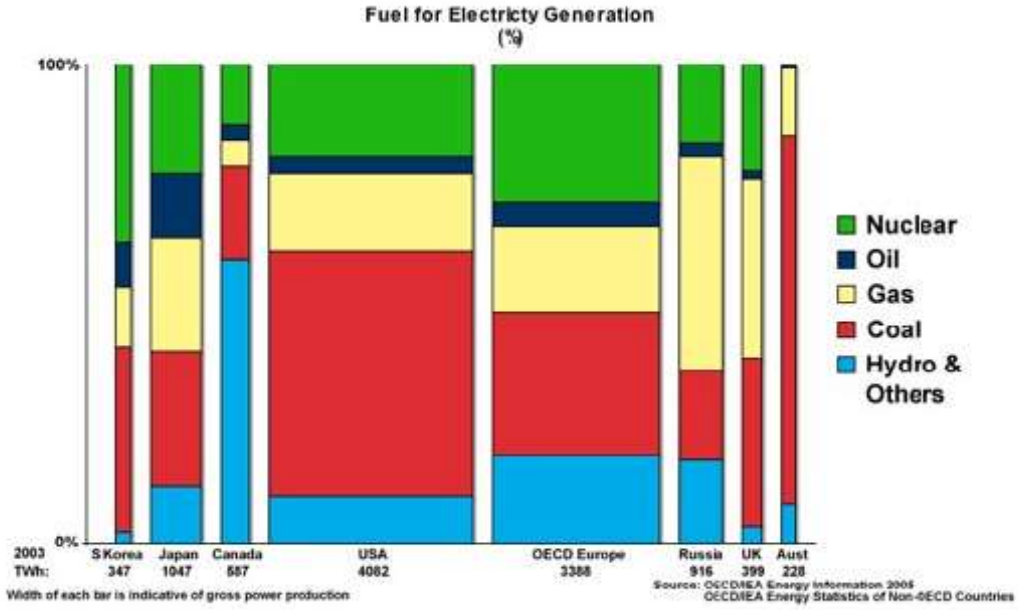
European Union



Nuklearne elektrane
pouzdan i ekonomičan izvor električne energije

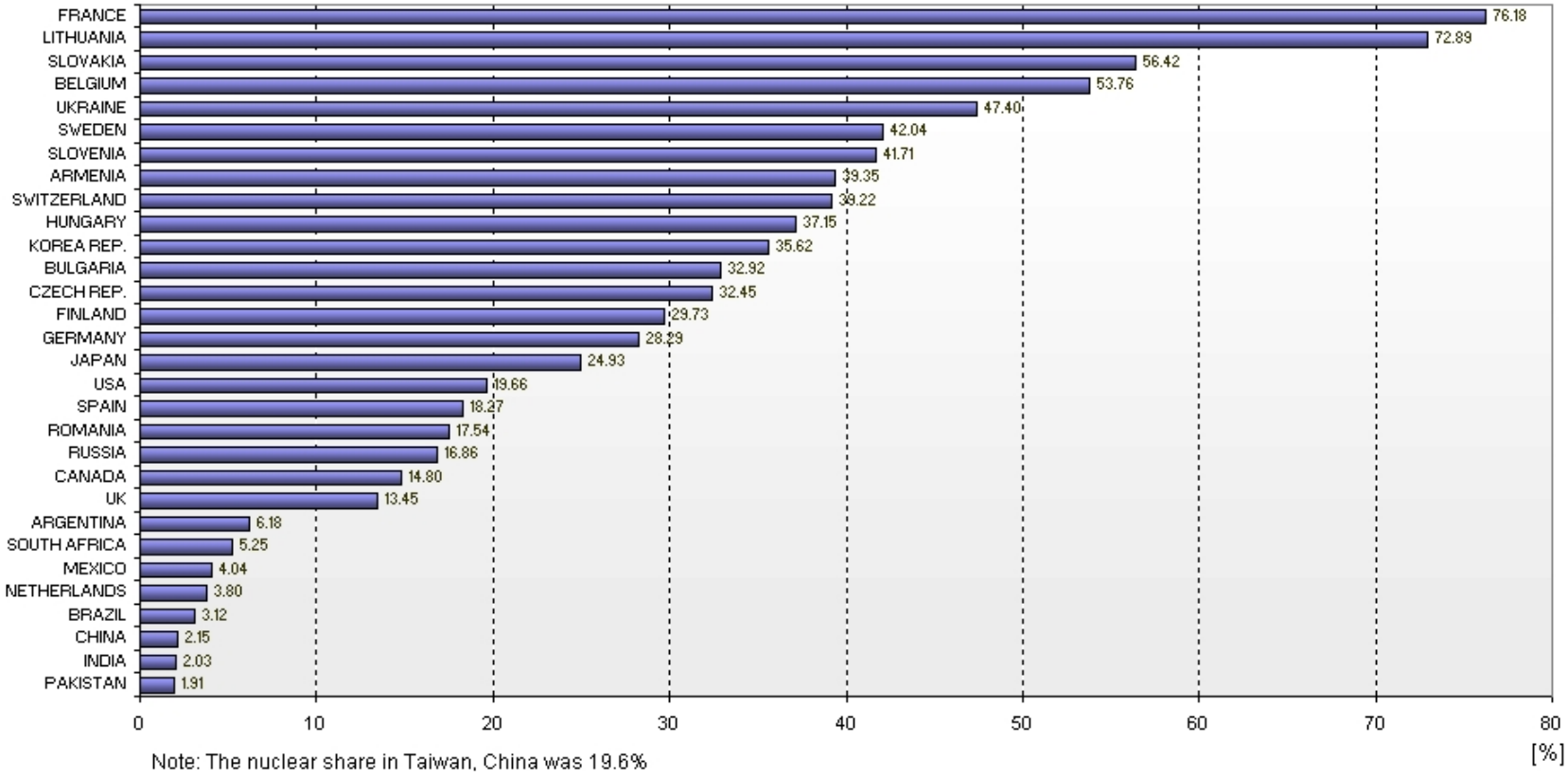
- prema podacima IAEA, u svijetu u pogonu 436 nuklearnih elektrana (instalirana snaga 370.202 MW) radile su s prosječnim faktorom opterećenja većim od 80%
- u izgradnji 34 nuklearne elektrane
- akumulirano iskustvo je veće od 12.700 reaktor godina





NUCLEAR POWER PLANTS INFORMATION

Nuclear Share in Electricity Generation in 2008

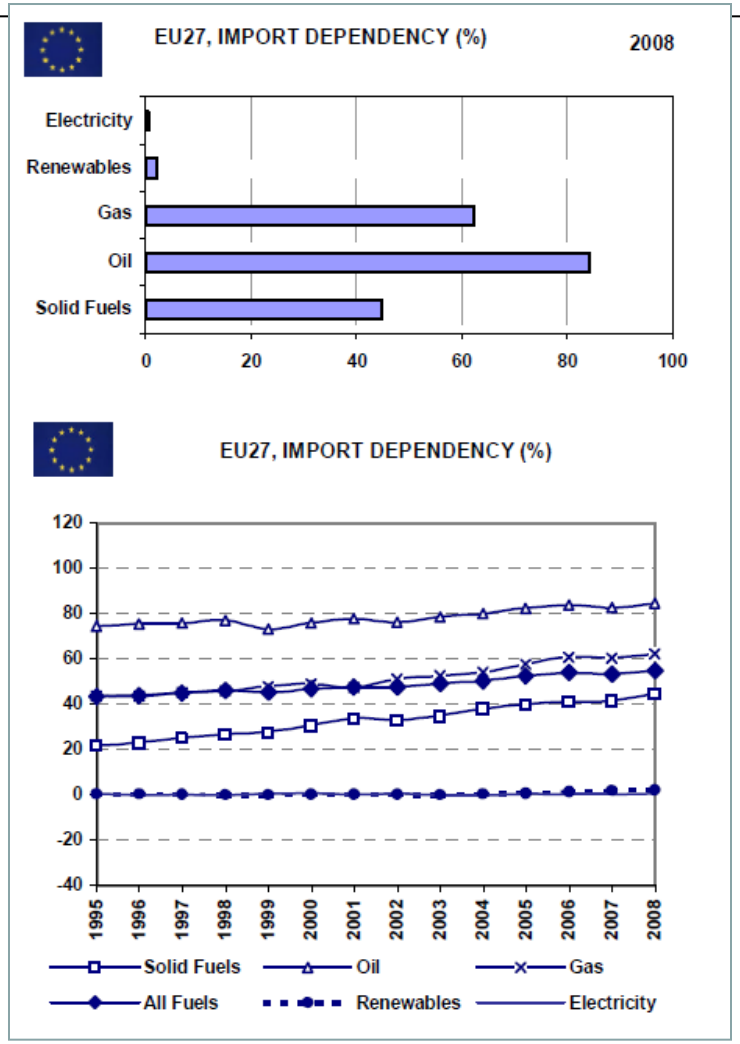


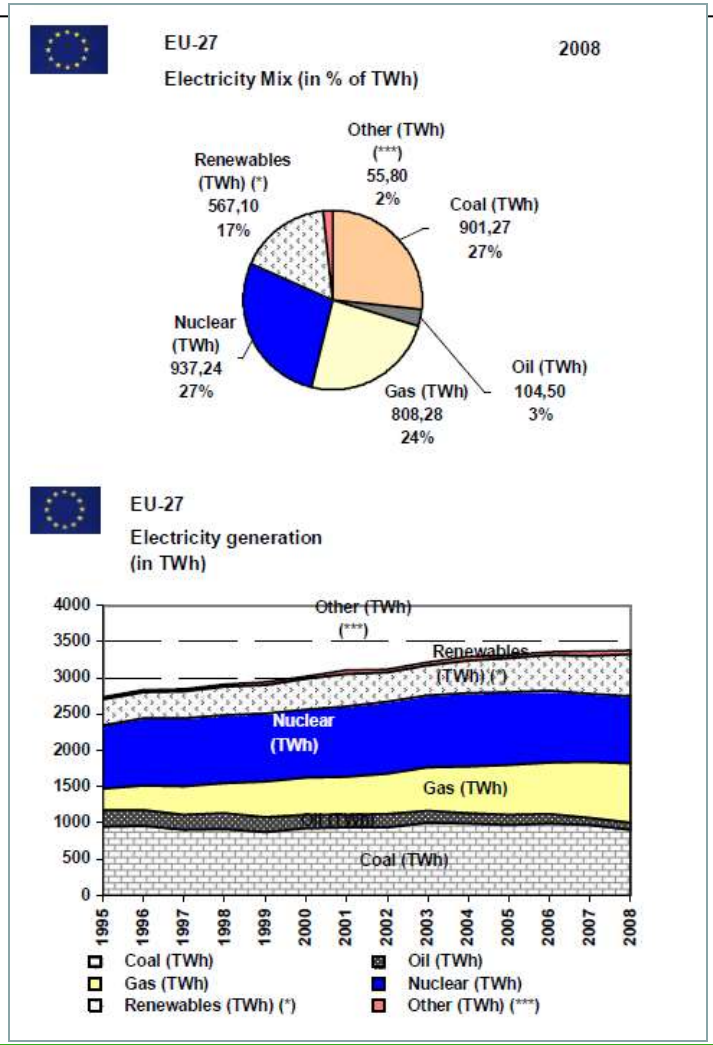
Note: The nuclear share in Taiwan, China was 19.6%

Go Back to Nuclear Power Plant Information

This page was automatically created on 07 Sep 2009, 12:10:34 .

EU-27 Ovisnost o uvozu energenata i diverzifikacija

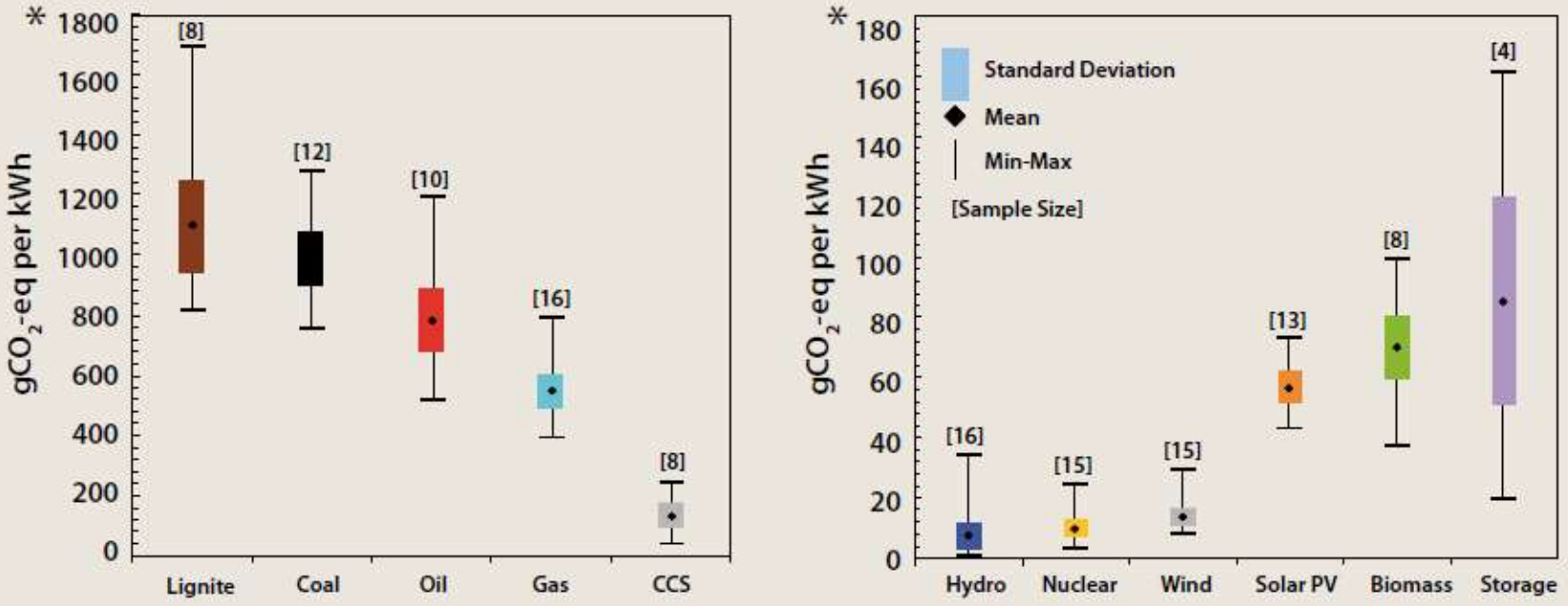




Emisije stakleničkih plinova tijekom cijelog životnog ciklusa elektrane

Fosilne tehnologije

Ne-fosilne tehnologije



*NB: The vertical scales in the two figures differ by a factor of ten.

Note: [WEISSER, D., A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies, Energy 32 (2007) 1543–1559]. Left panel: fossil technologies. Right panel: non-fossil technologies.

Development of Commercial Nuclear Power

"Atoms for Peace" :

- Title of a speech by Dwight D. Eisenhower to the UN General Assembly in 1953.
- The United States then launched an "Atoms for Peace" program that supplied equipment and information to schools, hospitals, and research institutions within the U.S. and throughout the world.

The Atomic Energy Act signed on August 1, 1946, transfers the control of atomic energy from military to civilian hands.

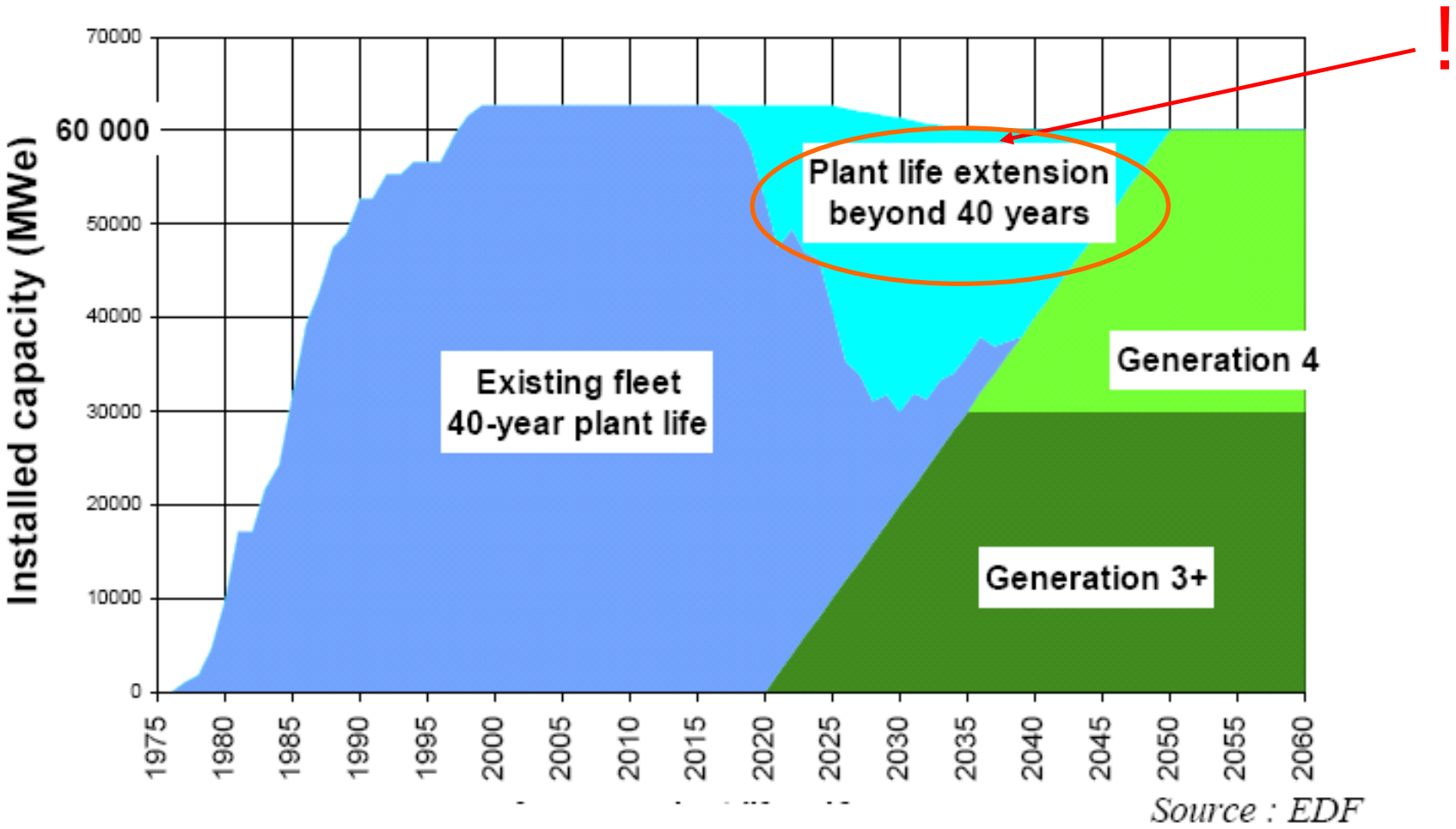
United Nations' "First Geneva Conference" in 1955.

EURATOM In 1957 was launched alongside the European Economic Community (ECC).

In 1957 the International Atomic Energy Agency (IAEA) is established.

IAEA Headquarters in Vienna, Austria

Nuklearne elektrane u Francuskoj



Finland as example: why new NPPs?

Key indicators

Population (millions), 2008	5.3
GDP (US$ billions), 2008	274.0
GDP per capita (US$), 2008	51,989.4

Global Competitiveness Index

	Rank (out of 133)
GCI 2009–2010	6

OL3 construction site in May 2010

Why OL3 ?

- ✓OL3 meets growing demand for electricity
- ✓ reduce carbon dioxide emissions in Finland
- ✓support the competitiveness of Finnish industry by offering a reliable electricity supply at a reasonable price
- ✓reduce dependence on electricity imports

Source: TVO

Primjer: Finska

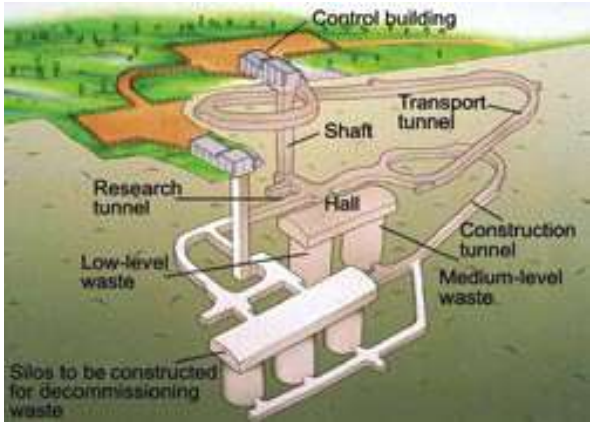
Olkiluoto 3

Primjer: Finska

Odlaganje radioaktivnog otpada i istrošenog goriva

Olkiluoto NPP

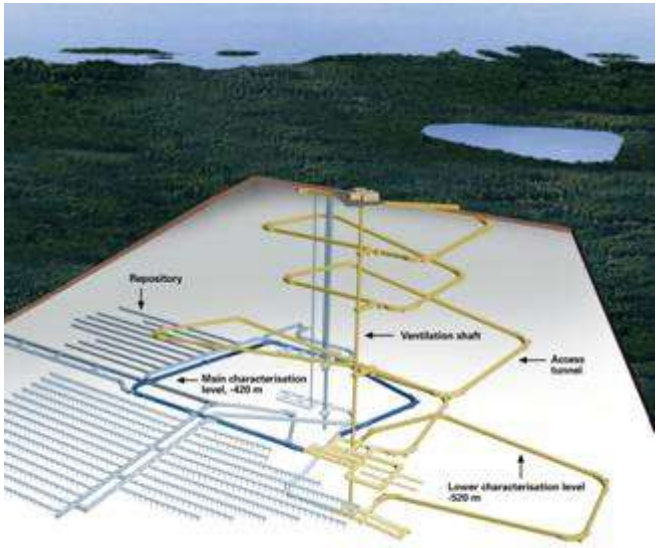
TVO



The final disposal repository for operating waste in Olkiluoto, in operation from 1992

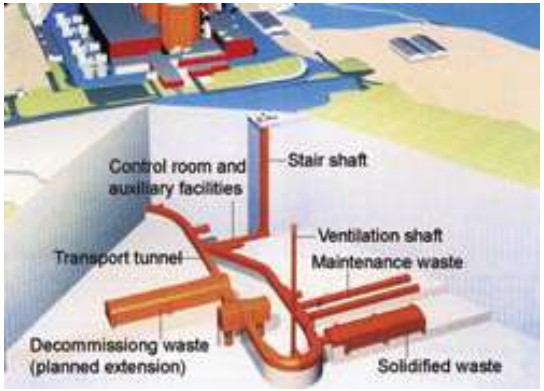
POSIVA

spent nuclear fuel



Loviisa NPP

Fortum



In Loviisa, final disposal of operating wast started in 1998.

German government pledges nuclear phaseout by 2022

Nuclear energy has long been unpopular in Germany

Japan's recent nuclear troubles triggered a rethink of a plan to keep Germany's nuclear power plants on line longer. The governing coalition has now established a new timeline for Germany's nuclear shutdown by 2022.

DW-WORLD.DE
DEUTSCHE WELLE
YOUR LINK TO GERMANY

German nuclear power units

Plant	Type	MWe (net)	Commercial operation	Operator	Provisionally scheduled shut-down 2001	2010 agreed shut-down	March 2011shutdown & May closure plan
Biblis-A	PWR	1167	2/1975	RWE	2008	2016	yes
Neckarwestheim-1	PWR	785	12/1976	EnBW	2009	2017	yes
Brunsbüttel	BWR	771	2/1977	Vattenfall	2009	2018	yes
Biblis-B	PWR	1240	1/1977	RWE	2011	2018	yes
Isar-1	BWR	878	3/1979	E.ON	2011	2019	yes
Unterweser	PWR	1345	9/1979	E.ON	2012	2020	yes
Phillipsburg-1	BWR	890	3/1980	EnBW	2012	2026	yes
Krummel	BWR	1260	3/1984	Vattenfall	2016	2030	yes
Total shut down (8)		**8336**					
Grafenrheinfeld	PWR	1275	6/1982	E.ON	2014	2028	2015
Gundremmingen-B	BWR	1284	4/1984	RWE	2016	2030	2017
Gundremmingen-C	BWR	1288	1/1985	RWE	2016	2030	2021
Gröhnde	PWR	1360	2/1985	E.ON	2017	2031	2021
Phillipsburg-2	PWR	1392	4/1985	EnBW	2018	2032	2019
Brokdorf	PWR	1370	12/1986	E.ON	2019	2033	2021
Isar-2	PWR	1400	4/1988	E.ON	2020	2034	2022
Emsland	PWR	1329	6/1988	RWE	2021	2035	2022
Neckarwestheim-2	PWR	1305	4/1989	EnBW	2022	2036	2022
Total operating (9)		**12,003**					
Total (17)		20,339 MWe					

nuclear power plant	type	gross capacity MWe	net capacity MWe	gross electricity generation 2010 MWh
in operation				
GKN-2 Neckar	PWR	1,400	1,310	10,874,050
KBR Brokdorf	PWR	1,480	1,410	11,945,182
KKE Emsland	PWR	1,400	1,329	11,560,347
KKG Grafenrheinfeld	PWR	1,345	1,275	7,938,413
KKI-2 Isar	PWR	1,485	1,410	12,006,506
KKP-2 Philippsburg	PWR	1,468	1,402	11,797,122
KRB B Gundremmingen	BWR	1,344	1,284	9,953,737
KRB C Gundremmingen	BWR	1,344	1,288	10,935,801
KWG Grohnde	PWR	1,430	1,360	11,416,876
subtotal 1		12,696	12,068	98,428,034
end of licence 7th August 2011				
Biblis A	*PWR*	*1,225*	*1,167*	5,042,097
Biblis B	*PWR*	*1,300*	*1,240*	10,306,260
GKN-1 Neckar	*PWR*	*840*	*785*	2,207,634
KKB Brunsbüttel	*BWR*	*806*	*771*	0
KKI-1 Isar	*BWR*	*912*	*878*	6,543,273
KKK Krümmel	*BWR*	*1,402*	*1,346*	0
KKP-1 Philippsburg	*BWR*	*926*	*890*	6,790,514
KKU Unterweser	*PWR*	*1,410*	*1,345*	11,238,640
subtotal 2		8,821	8,422	42,128,418
total		21,517	20,490	140.556.452

German Energy Sector Open For Russian Grabs After Merkel Medvedev Meeting (Part Two)

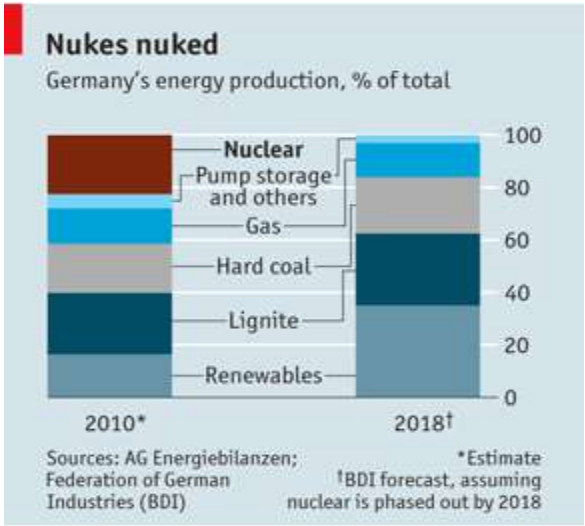
Jamestown Foundation Eurasia Daily Monitor ^ | 7/22/2011 | Vladimir Socor

Posted on **26. srpnja 2011. 7:27:08** by **bruinbirdman**

President Dmitry Medvedev and Chancellor Angela Merkel led the Russian-German Interstate Consultations on July 19-20 in Hannover. This annual event, with the collective participation of Russian and German government ministers and industry leaders, punctuates the gradual integration in key economic sectors of the two countries.

Nord Stream pipeline

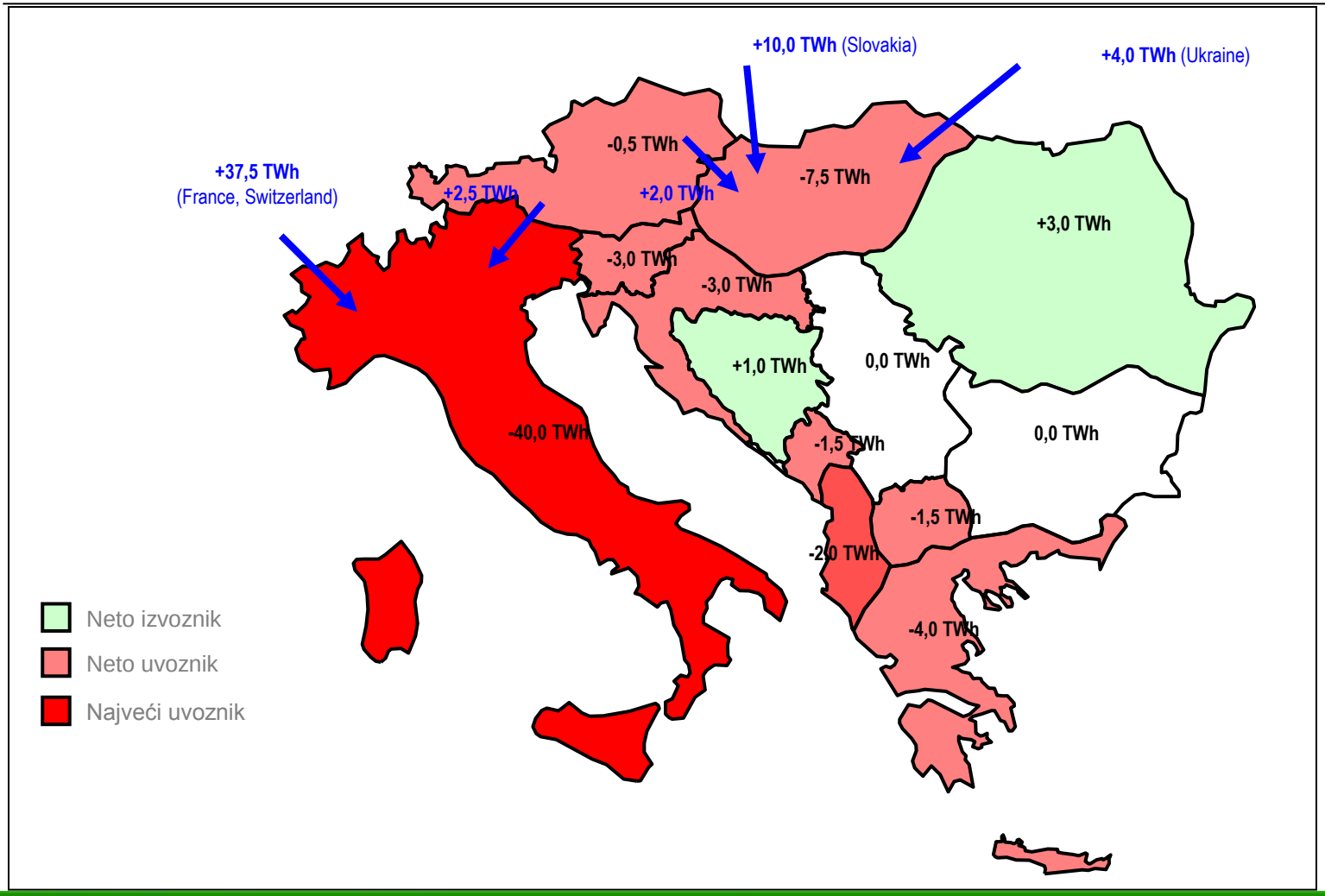
Germany's recent political decision to phase out nuclear energy delighted the Russian side at this summit. Medvedev's delegation offered to supplement gas deliveries massively within the next decade and beyond, so as to replace the lost nuclear power at least in part with Russian gas in Germany's energy mix.



EES Hrvatske

	Total Power Product. (including Nuclear)	Nuclear Power
Hungary	**35.377 GWh(e)**	**12.787 GWh(e)**
Slovakia	32.805 GWh(e)	17.953 GWh(e)
Czech Republic	76.348 GWh(e)	18.738 GWh(e)

Regionalna elektroenergetska bilanca



Slovakia , in 2007, 28.1 billion kWh gross was produced, 55% of this from nuclear power

Operating Slovak power reactors

Reactor	Model	Net MWe	First power	Expected closure
Bohunice V2-1	V-213	436	1984	2025
Bohunice V2-2	V-213	452	1985	2025
Mochovce 1	V-213	436	1998	
Mochovce 2	V-213	436	1999	
Total (4)		1760 MWe		

Slovak power reactors under construction, planned and proposed

Reactor	Model	Net MWe	Construction start	First power	Operator
Mochovce 3	V-213	405	6/09	2012	SE
Mochovce 4	V-213	405	6/09	2013	SE
Bohunice V3	?	1000-1600		Before 2025	Jess[k]
Kecerovce	?	1200		After 2025	?
Total under construction (2)		810			

SLOVENSKÉ ELEKTRÁRNE

Enel

66%

Czech Republic, in 2007, electricity generation was 88.2 billion kWh, of which 62% (54.9 billion kWh) was from coal, 30% (26.2 billion kWh) from nuclear, with net export of 16.2 billion kWh

Operating Czech power reactors

Reactor	Model	Net MWe	First power
Dukovany 1	VVER-440 V-213	428	1985
Dukovany 2	VVER-440 V-213	428	1986
Dukovany 3	VVER-440 V-213	470	1986
Dukovany 4	VVER-440 V-213	434	1987
Temelin 1	VVER-1000 V-320	963	2000
Temelin 2	VVER-1000 V-320	963	2003
Total (6)		3686	

Planned and Proposed Czech power reactors

Reactor	Model	MWe	First power
Temelin 3	?	1200 approx	2018?
Temelin 4	?	1200 approx	2020?
Dukovany 5	?	1200 assumed	
Total planned (2)		2400 approx	

Hungary , in 2008, electricity generation was 40.0 billion kWh, of which nuclear 14.8 billion kWh

the price of a kilowatt-hour of electricity from Paks was 3.58 Euro cents/kWh

Operating Hungarian power reactors

Reactor	Model	Net MWe	First power	Scheduled close
Paks 1	VVER-440/V-213	470	1982	2012
Paks 2	VVER-440/V-213	470	1984	2014
Paks 3	VVER-440/V-213	470	1986	2016
Paks 4	VVER-440/V-213	470	1987	2017
Total (4)	1880 MWe (2000 MWe nominal gross)			

Proposed Hungarian power reactors

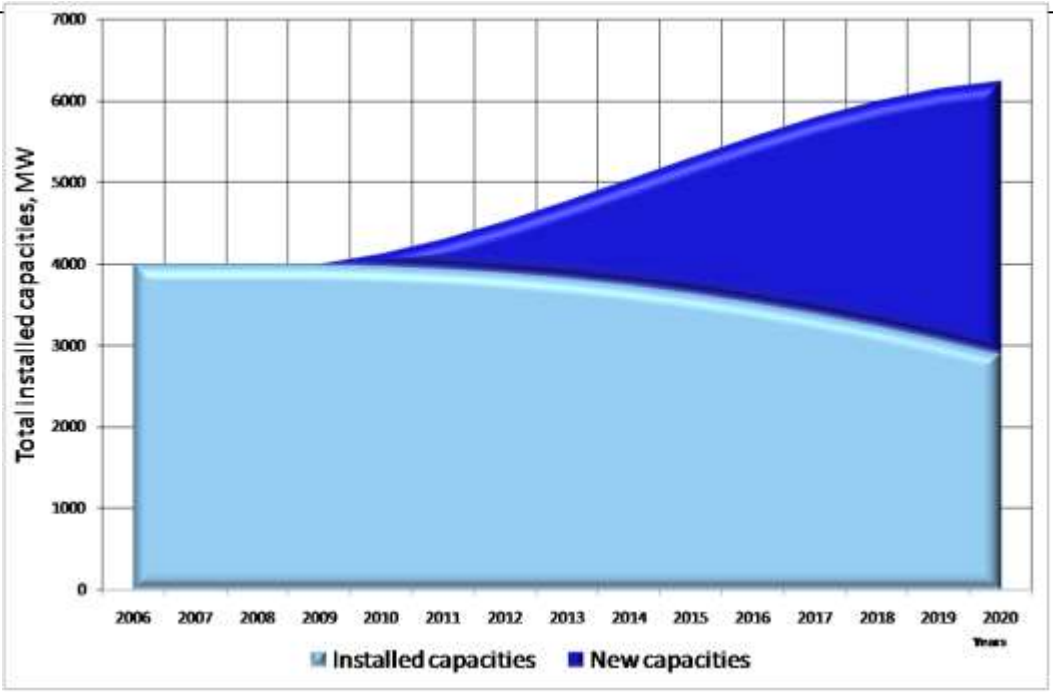
Reactor	Model	MWe gross	First power
Paks 5	?	1250-1700	2020
Paks 6	?	1250-1700	2025
Total (2)	2500-3400 MWe		

Fakultet elektrotehnike i računarstva - Zavod za visoki napon i energetiku

Unska 3, HR-10000 Zagreb Tel: 01/ 6129 907, Fax: 01/ 6129 890 E-mail: zvne@fer.hr URL: http://www.zvne.fer.hr/

Strategy of Energy Development in Croatia

Power plants: Installed capacities and new capacities



- coal-fired power plants and gas-fired power plants, with installed capacity of 1200 MW each, are expected to be built before the year 2020
- decision to build nuclear power plant will be made by the end of the year 2012
- ….


Hrvatski sabor
Sjednice Sabora
Aktualno
Najave
Pristup informacijama
O Saboru
Ustrojstvo Sabora
Važniji propisi
Naslovna / Sjednice Sabora / Akti 6. saziva / 14. sjednica Hrvatskoga sabora
PRIJEDLOG STRATEGIJE ENERGETSKOG RAZVOJA REPUBLIKE HRVATSKE
Rasprava je zaključena 15. listopada 2009.
Strategija je donesena na 14. sjednici 16. listopada 2009. (73 glasova "za", 30 "protiv", 1 "suzdržan").

HRVATSKI SABOR

3192

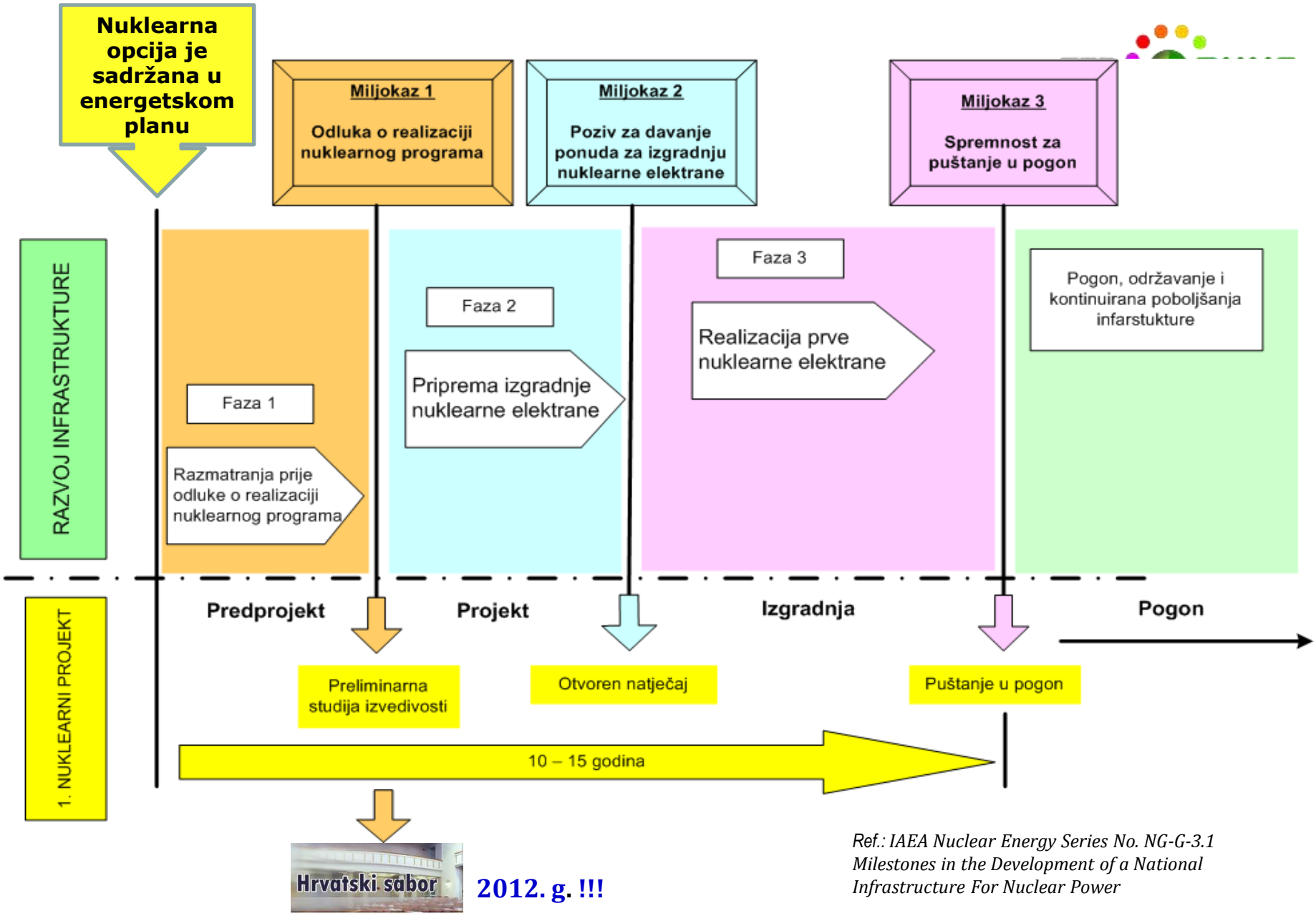
Na temelju članka 80. Ustava Republike Hrvatske i članka 5. stavka 3. Zakona o energiji (»Narodne novine«, br. 68/01., 177/04., 76/07. i 152/08.) Hrvatski sabor na sjednici 16. listopada 2009. donio je

STRATEGIJU

ENERGETSKOG RAZVOJA REPUBLIKE HRVATSKE

. . .

- ✓ Republika Hrvatska pokreće hrvatski nuklearni energetski program
- ✓ U Programu provedbe Strategije Vlada Republike Hrvatske razradit će program pripremnih aktivnosti kako bi se do kraja 2012. godine moglo pristupiti donošenju odluke o izgradnji nuklearne elektrane
- ✓ Donošenje odluke o izgradnji nuklearne elektrana očekuje se najkasnije 2012.godine



Ref.: IAEA Nuclear Energy Series No. NG-G-3.1 Milestones in the Development of a National Infrastructure For Nuclear Power

1970

Listopad: predsjednik IS Skupštine SR Slovenije Stane Kavčič i predsjednik IS Sabora Hrvatske Dragutin Haramija potpisuju sporazum o gradnji nuklearne elektrane

1974.

- investitori **Savske elektrane Ljubljana** i **Elektroprivreda Zagreb** u sklopili ugovor o nabavi opreme i gradnji s **Westinghouse**om
- položen je kamen temeljac za nuklearnu elektranu Krško

1982

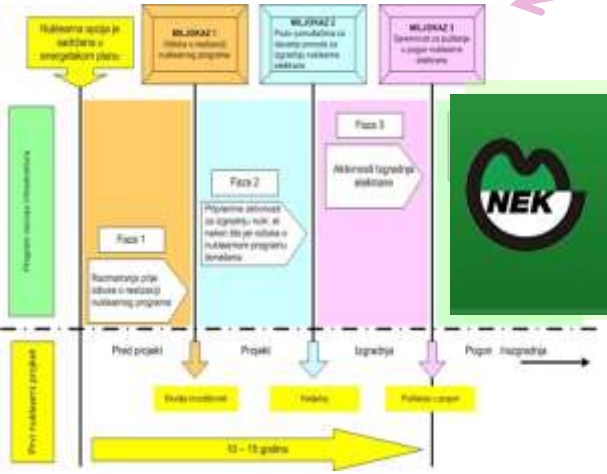
Veljača: prvi je put postignuta 100-postotna snaga elektrane

Srpanj: obavljena je modifikacija sustava za napajanje parogeneratora

Kolovoz: početak rada punom snagom

1983

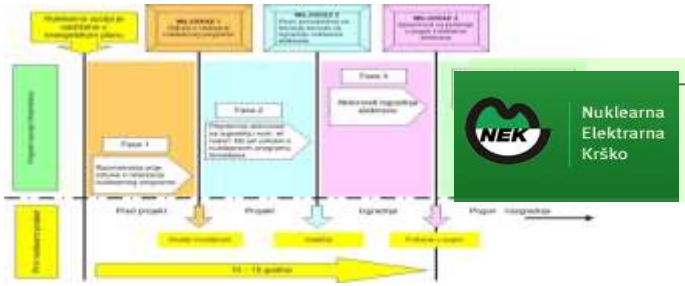
Siječanj: početak komercijalnoga poslovanja



NEK Nuklearna Elektrarna Krško

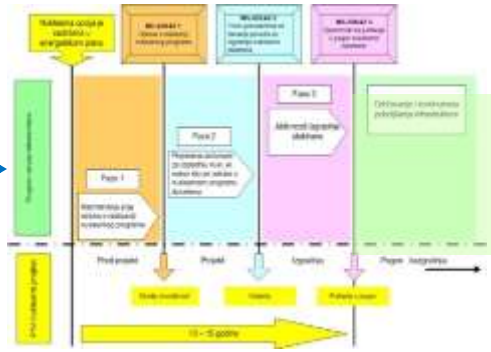
1970 1980 1990 2000 2010 2020 2030 2040

Kadrovi za novi nuklearni program



Projekt NE
Prevlaka

~ 40 godina



Smjer **Nuklearna energ.** | Smjer Energetske teh. | Smjer Energetika

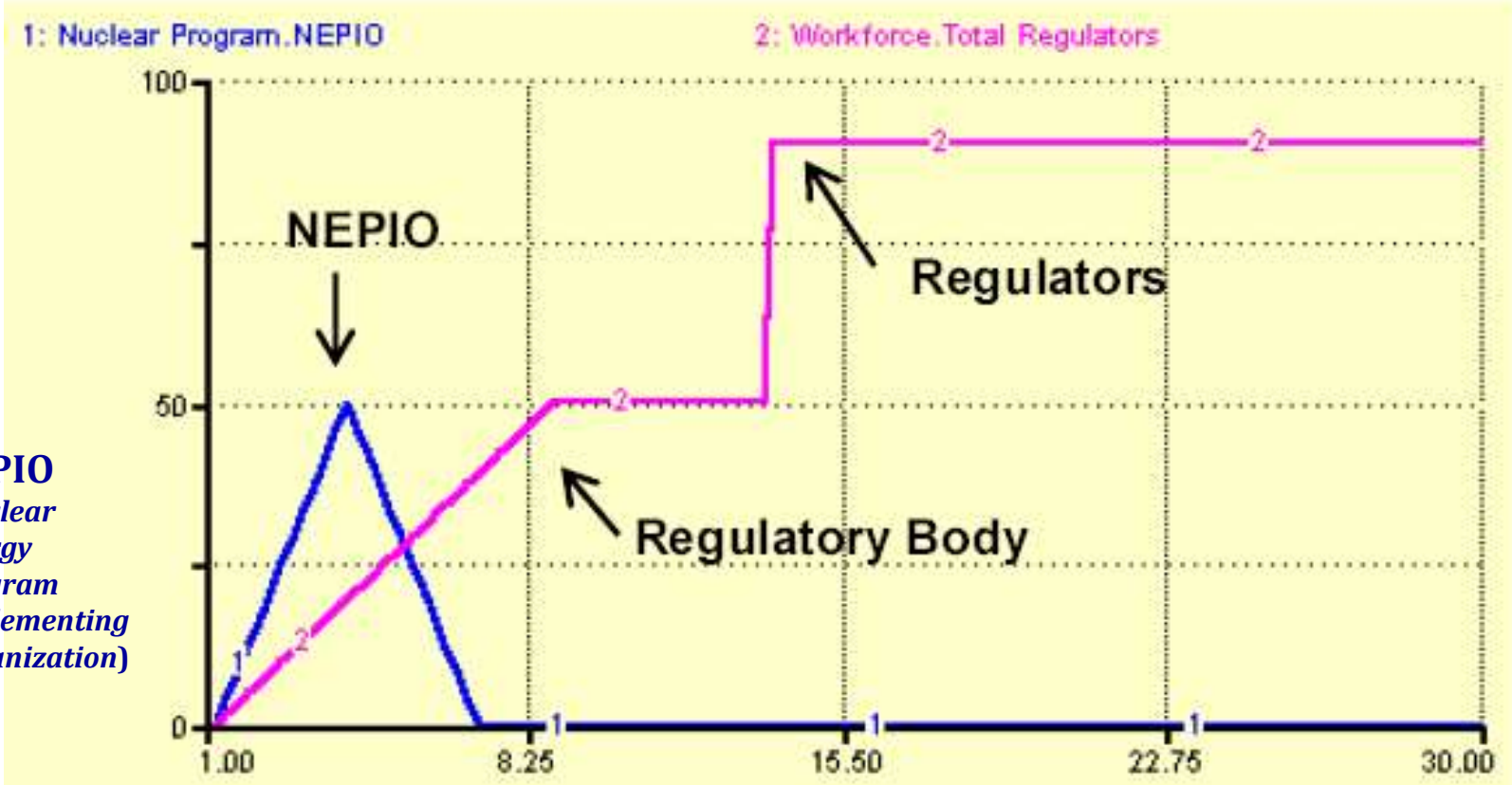
1970 1980 1990 2000 2010 2020 2030 2040

FSB, PMF

dipl.inž. (mag. struke) građevine, strojarstva, elektrotehnike, fizike, računarstva, kemije, …

- specijalistički kursevi (IAEA,..)
- jednogodišnji specijalistički studij

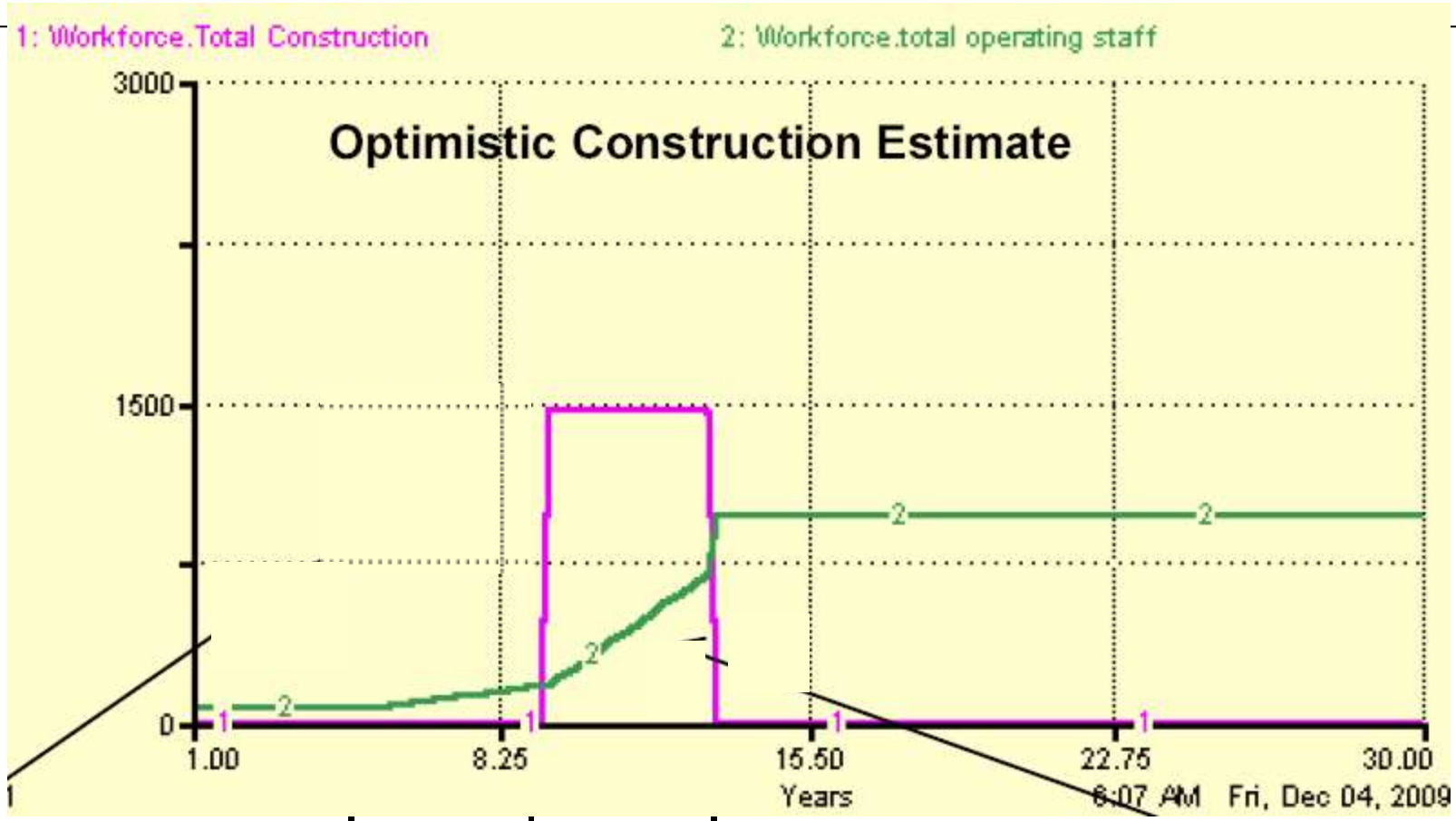
Procjena potrebnog broja kadrova za prvi nuklearni program



NEPIO ***(Nuclear Energy Program Implementing Organization)***

Ref.: Sara Scott, Los Alamos National Laboratory: **Modeling Human Resource Development for New Nuclear Power Programs**, International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programs, Abu Dhabi, United Arab Emirates, March 14 to 18, 2010

Procjena potrebnog broja kadrova za prvi nuklearni program (nast.)



Ref.: Sara Scott, Los Alamos National Laboratory: **Modeling Human Resource Development for New Nuclear Power Programs**, International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programs, Abu Dhabi, United Arab Emirates, March 14 to 18, 2010

Razmatranja i podloge za odluku o realizaciji nuklearnog programa:

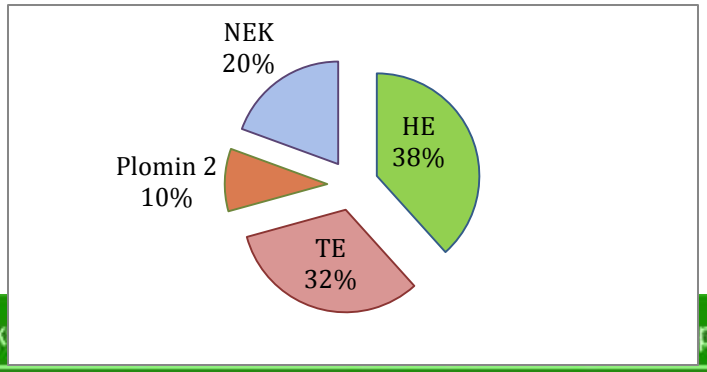
1. Nacionalno stajalište
2. Nuklearna sigurnost
3. Upravljanje nuklearnim programom
4. Financiranje programa
5. Zakonski okvir
6. Pitanje proliferacije
7. Regulatorni okvir
8. Zaštita od zračenja
9. Elektroenergetska mreža
10. Kadrovi za nuklearni program
11. Zaštita okoliša
12. Komunikacija s javnošću
13. Lokacija i infrastruktura
14. Krizno planiranje
15. Sigurnost i fizička zaštita
16. Nuklearni gorivni ciklus
17. Zbrinjavanje radioaktivnog otpada
18. Uključivanje lokalne industrije
19. Politika nabave opreme i usluga

Odluka o realizaciji nuklearnog programa

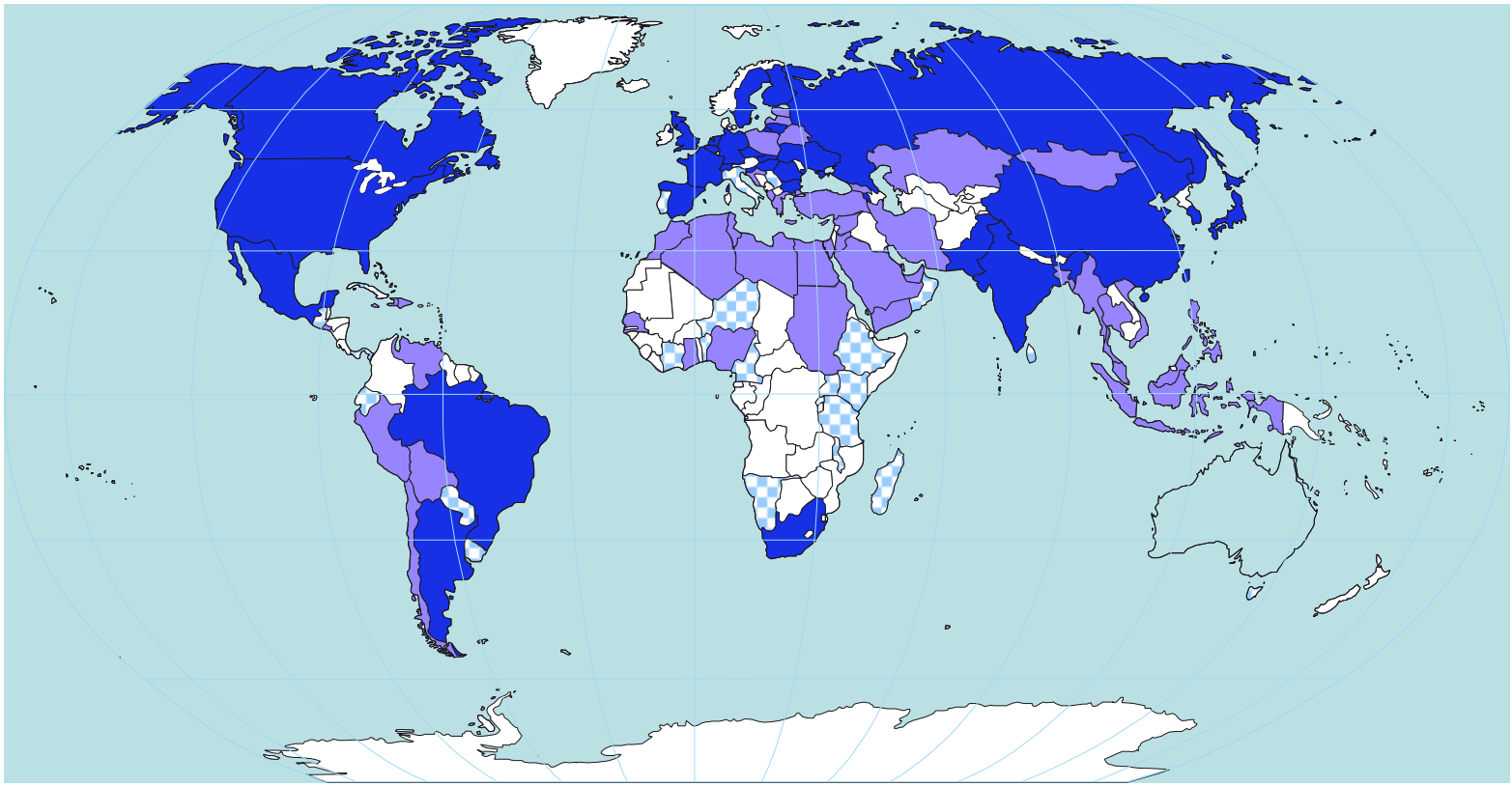
do 2012.g. !!!

U 2008. godini:

hidroelektrane	**5890** GWh
termoelektrane	**4978** GWh
TE Plomin 2	**1514** GWh
Nukl.el. Krško (1/2)	**2985** GWh

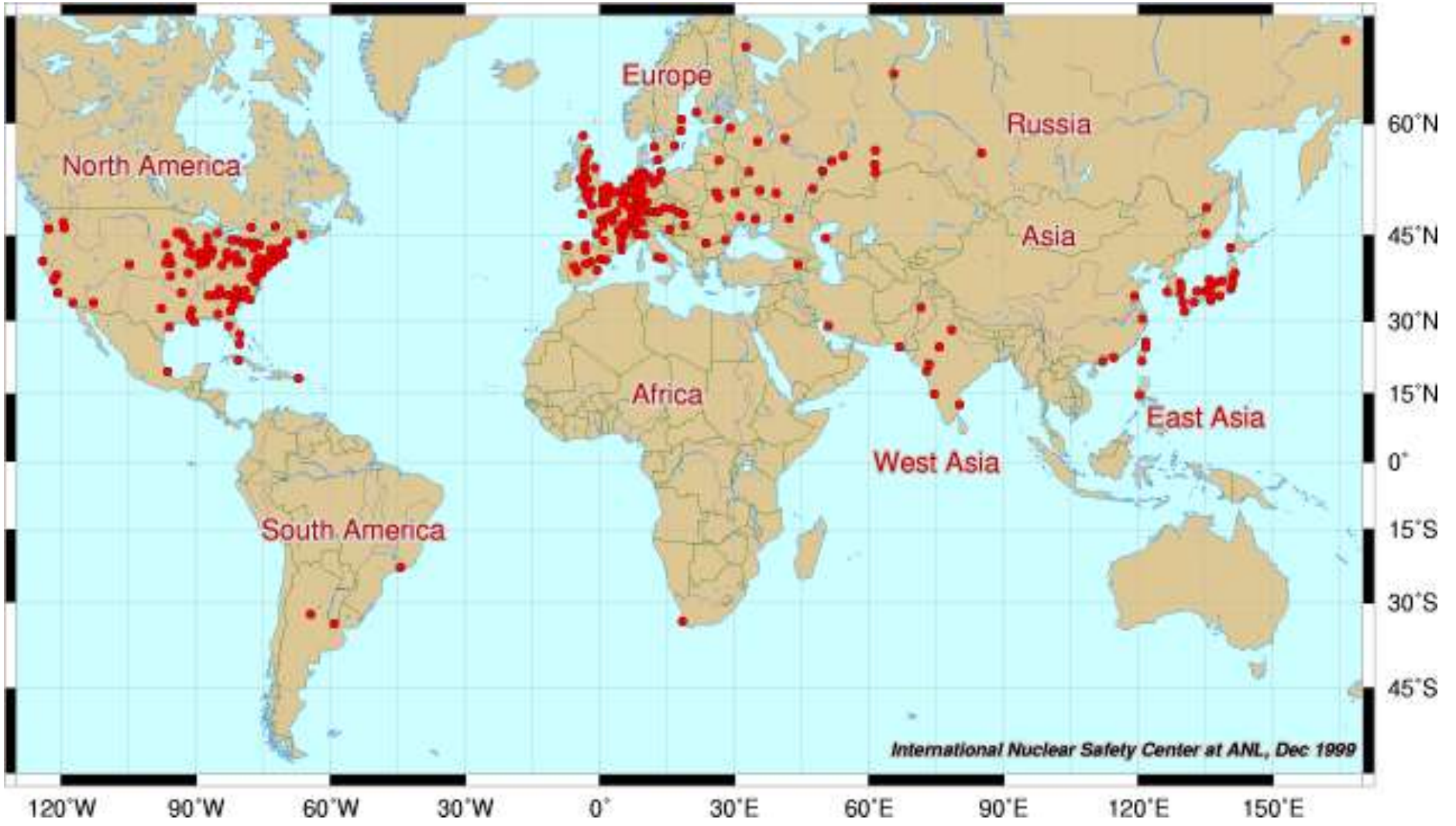


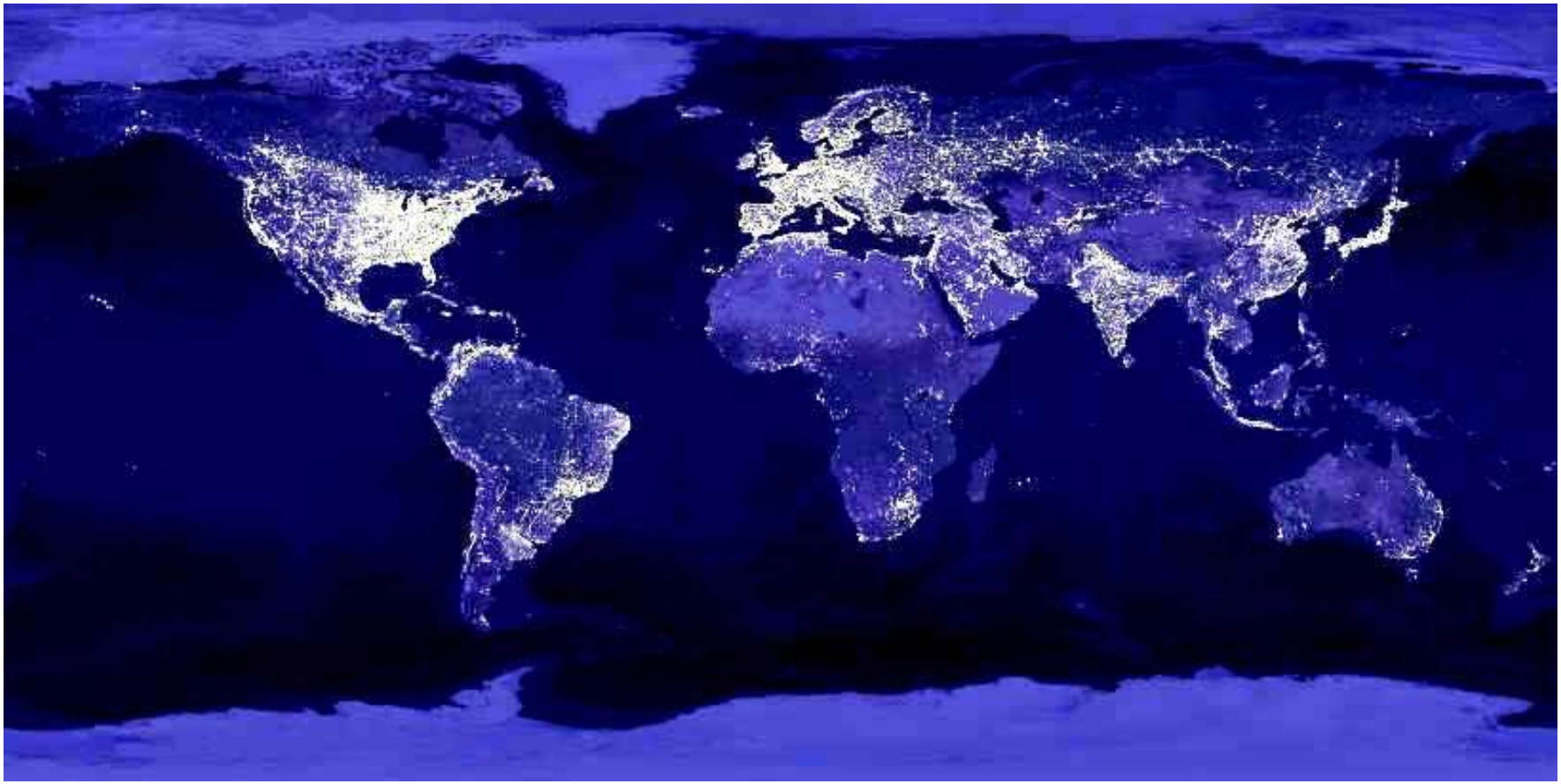
Countries Considering Nuclear Power



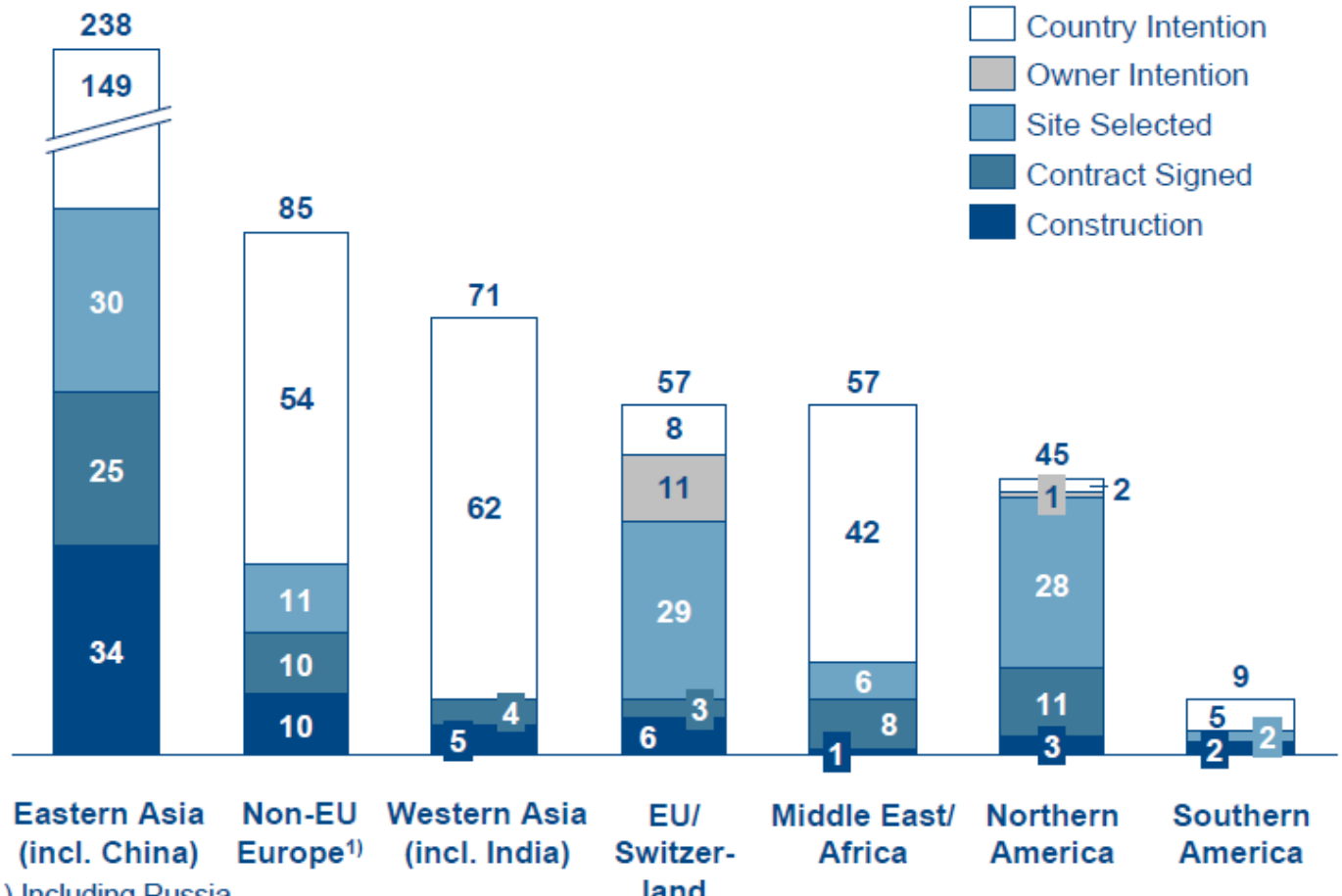
Operating (30) Considering (43) Expressing interest (25)

Source: IAEA, B.Tyobeka: Global Status of Nuclear Power, Int. Conf. HND, 2010


Europe
Russia
North America
Asia
Africa
East Asia
West Asia
South America
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
International Nuclear Safety Center at ANL, Dec 1999



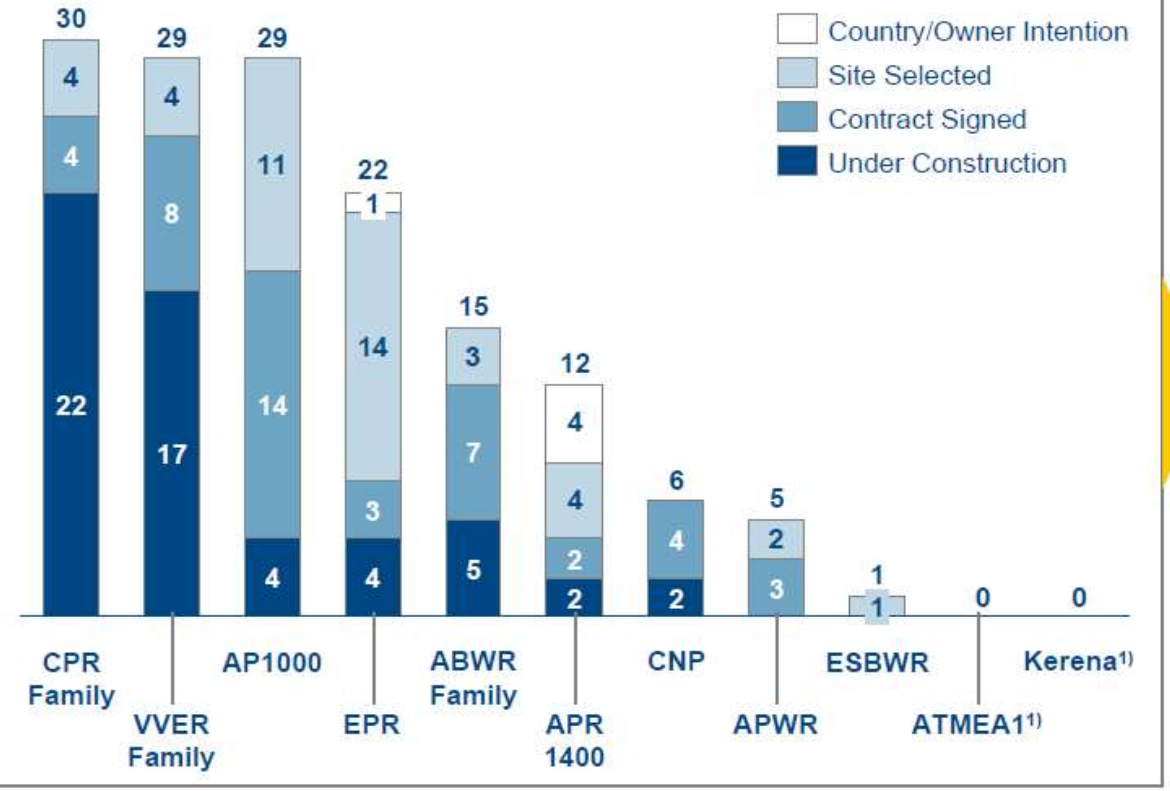
Status Nuclear New Build Intentions in Regions and Units (Σ=562)



1) Including Russia

Source: World Nuclear Association; Arthur D. Little Analysis (Status June 2010)

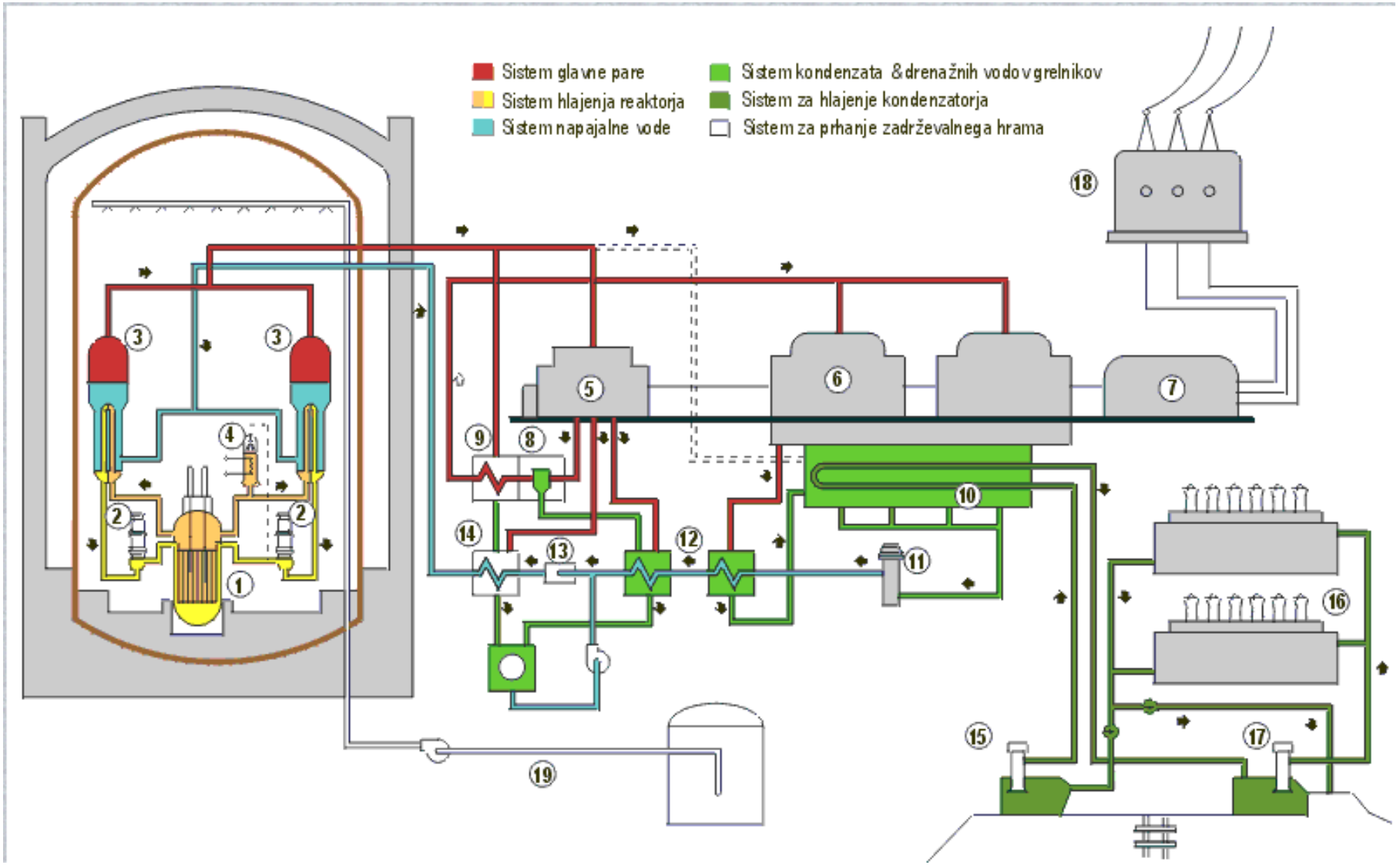
Status of formally selected Light Water Reactors (Σ=149)



Country of Origin	Reactor Types
CGN	▪ CPR Family
ACB-ASE	▪ VVER Family
Westinghouse	▪ AP-1000
AREVA	▪ EPR ▪ ATEMA-1 ▪ Kerena
TOSHIBA	▪ ABWR ▪ AB-1600[1)]
HITACHI	▪ ABWR
GE	▪ ESBWR ▪ ABWR
kepco	▪ APR-1400
MITSUBISHI	▪ APWR ▪ ATMEA-1
CNNC	▪ CNP Family

1) ATMEA1 and Kerena considered by several owner but not formally selected. Toshiba's AB-1600 not included due to unclear design status, Chinese CAP-1400 (Demonstration-) Reactor not included; Source: Arthur D. Little Analysis (Status June 2010)

Nuklearna elektrana Krško - Funkcionalna shema



Usporedba elektrana Krško i Angra-1
(31.12.2009.)

KRSKO

Historical Summary

Date of Construction Start:	30 Mar 1975	Lifetime Generation:	127838.395 GW(e).h
Date of First Criticality:	11 Sep 1981	Cumulative Energy Avail. Factor:	83.78%
Date of Grid Connection:	02 Oct 1981	Cumulative Load Factor:	82.81%
Date of Commercial Operation:	01 Jan 1983	Cumulative Operating Factor:	82.25%
		Cumulative Energy Unavail. Factor:	16.22%

Δ= 67.038.000 MWh

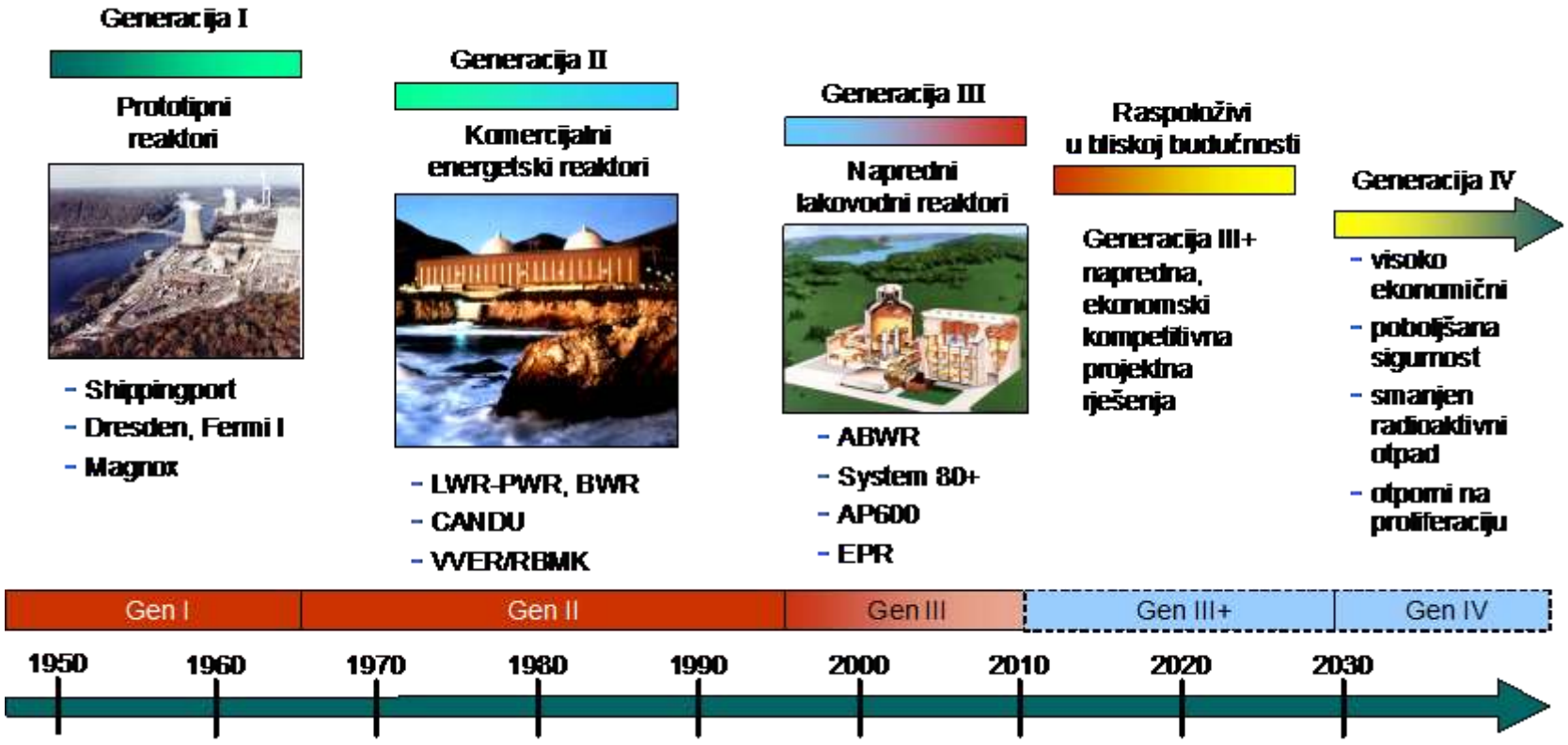
$\Delta \sim$ 3 milijarde €

ANGRA-1

Historical Summary

Date of Construction Start:	01 May 1971	Lifetime Generation:	60800.391 GW(e).h
Date of First Criticality:	13 Mar 1982	Cumulative Energy Avail. Factor:	53.46%
Date of Grid Connection:	01 Apr 1982	Cumulative Load Factor:	43.71%
Date of Commercial Operation:	01 Jan 1985	Cumulative Operating Factor:	58.06%
		Cumulative Energy Unavail. Factor:	46.54%

Četiri generacije nuklearnih elektrana



IRIS Partners

Westinghouse Electric Company

Berkeley

ANSALDO NUCLEARE

BECHTEL

BNFL

ENSA

ININ

日本原子力発電株式会社

MITSUBISHI HEAVY INDUSTRIES, LTD.

OAK RIDGE NATIONAL LABORATORY

FER

Hvala na pozornosti!

Prof.dr.sc. Nenad Debrecin

Prof.dr.sc. Nikola Čavlina

Fakultet elektrotehnike i računarstva

Sveučilište u Zagrebu