NON-ELECTRICAL APPLICATIONS AND SYNERGIES WITH NON-NUCLEAR ENERGY SOURCES

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INTRODUCTION

For a number of years in NRC “Kurchatov Institute” researches of global structure of nuclear power are carried out simultaneosly under two umbrellas:

NRCKI was an active participant of the INPRO collaborative projects GlOBAL VISION, SYNERGIES, GAINS, ROADMAPS, KINDS – participating in mentioned projects were the very informative part of the whole work.

Another part of work in parallel has begun as a part of Direction 3 of U.S.-Russia Civil Nuclear Energy Cooperation Action Plan - **Global Civil Nuclear Energy Framework Development** (principal from Russian side – N.N. Ponomarev-Stepnoi) and continued in frame of activity devoted to Maintenance of Rosatom participation in work of the International forum Generation – IV.

The main tasks of Direction 3 were:

Concept Development for the International Fuel Cycle Center

Cradle-to-Grave Fuel Cycle Services Concept Development

Analysis to Elucidate Nonproliferation & Benefits CTG and other services

INTRODUCTION (2)

During researches for each of considered reactor technologies we pursued the following problems :

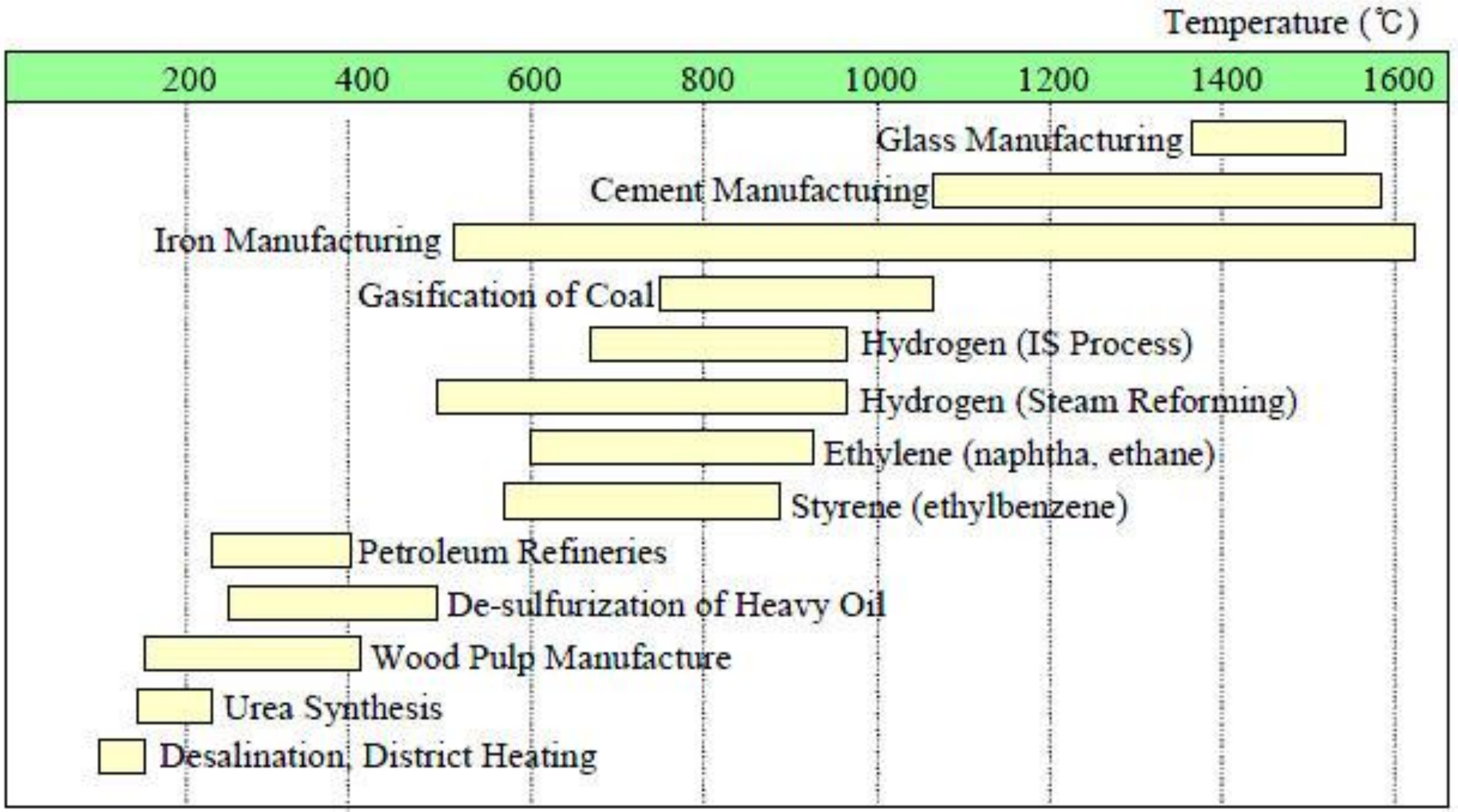
- the assessments of the potential each reactor technologies in a covering of global and regional energy demands;
- the analysis of features reactor technologies from the point of view of granting services of a fuel cycle « from a cradle up to grave»;
- the assessments reactor technologies in multicomponent nuclear power from the point of view of a problem of non-proliferation and radiating threats.

The special attention addressed on an opportunity of use reactor technologies in newcomers countries , i.e. in the countries, in which else there is no nuclear power but which have already made the decision on its development.

RESEARCHES

- On the basis of the forecast of dynamics of demand for power resources, scale and dynamics of a backlog demand for them, the potential of nuclear-power technologies was estimated from the point of view of electro-generation (LWR, FR, HTGR, reactors of small and average capacity - SMR), and also their potential from the point of view non-electrical applications and synergy with non-nuclear energy technologies.
- *It was shown that synergic interaction of nuclear power and organic power should prevent SO_2, CO_2, NO_x, radioactivity emission from organic fuel.*

NON-ELECTRICAL APPLICATIONS



NON-ELECTRICITY PRODUCTS OF NUCLEAR ENERGY, OECD/NEA, 2004

REACTOR TECHNOLOGIES UNDER CONSIDERATION

Reactor	Electro-Generation	Cogeneration: Heavy oil reprocessing, /coal, hydrogen production, desalination	CTG	Nonproliferation
LWR (VVER)	+			+
VVER—S	+			+
FR (sodium, lead, lead-bismuth)	+		+	+
FGR	+			+
HTGR	+	+/+	+	+
SMR	+	+	+	+
VVER-SCP (LWR-SCP)	+	+		

PROBLEMS TO BE SOLVED

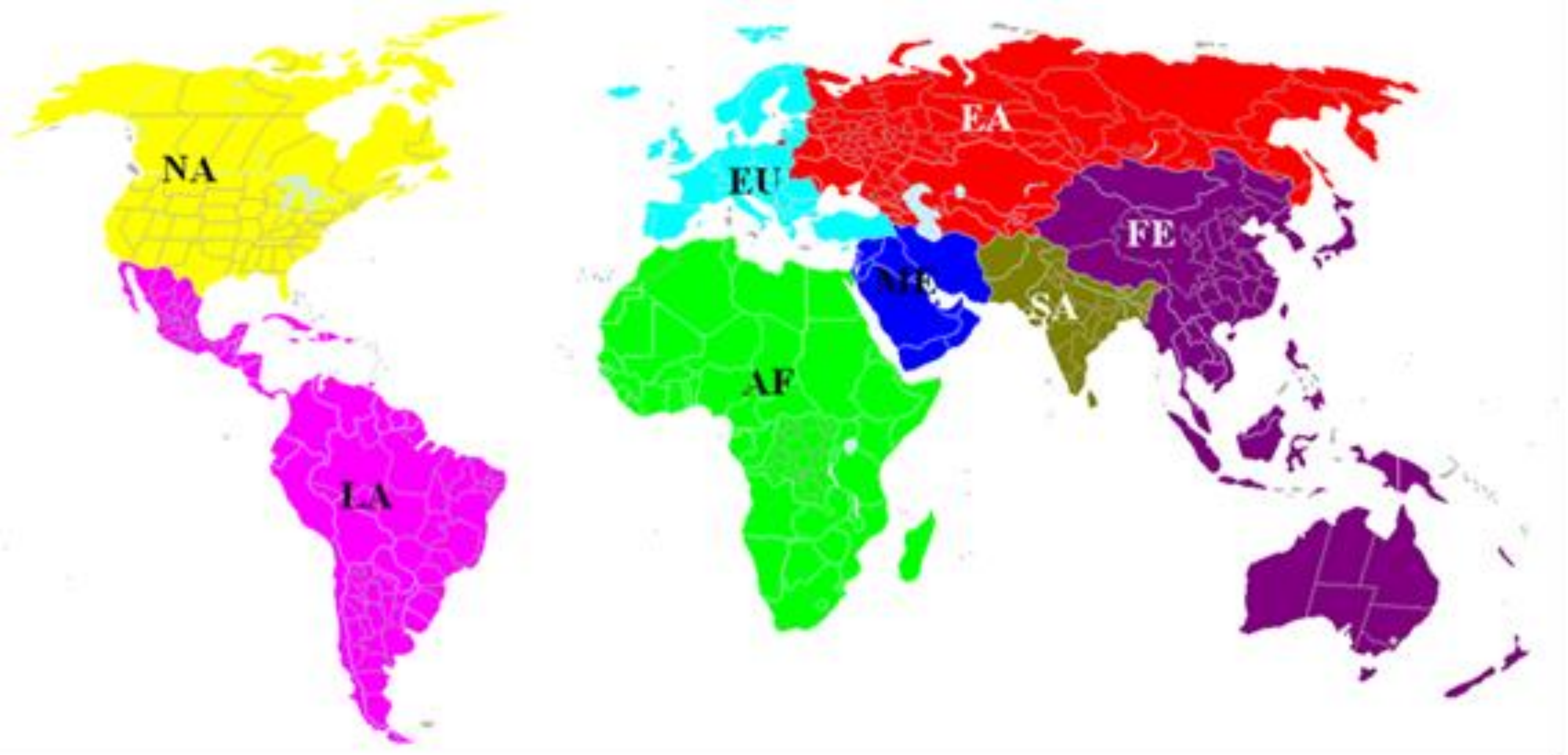
In present paper we will consider possibility of nuclear power to decrease environmental impact of the coal power industry, heavy oil production and petroleum refining, coal gasification and motor fuel production. For this purpose high scenario of nuclear power development (including HTGR or FGR) was considered. Total annual power production achieves 5000 Gw/year to 2100.

Another field of non-electrical application of nuclear power (SMR) to be considered in this paper is desalination of water. This option was investigated in moderate development scenario, where total annual power production achieves 2500 Gw/year to 2100.

REGIONAL ASPECTS – HETEROGENEOUS APPROACH

The features of HTGR defined regional aspects of their placement in the considered scenario. For that reason the geographical arrangement of heavy oil or coal reserves was considered. Already at a stage of global consideration the reactors working in the cogeneration mode were located in proportion to reserves of heavy oil or coal, i.e. the applied approach was "heterogeneous".

REGIONAL DISTRIBUTION



NUCLEAR POWER IN SYNERGIC INTERACTION WITH COAL POWER INDUSTRY

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

The factors of influence of coal power industry on environment are:

- CO_2 Emission
- SO_2 Emission
- NO_x Emission
- Ashes
- Radiotoxity.

(Average world activity of isotopes of ^{238}U, ^{232}Th and ^{40}K in coal is rated by values 20 Bk/kg and 40 Bk/kg respectively).

Now in Russia coal is classified by three categories with specific activity:

1) **123** Bk/kg;
2) 123–1230 Bk/kg;
3) 1230 Bk/kg (forbidden for implementation).

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

Concentrations of radionuclides in coal, slim and flying ashes, Bk/kg

Isotope	Coal	Slim	Flying ashes
^{238}U	9–31	56–185	**70–370**
^{226}Ra	7–25	20–166	**85–281**
^{232}Th	9–19	59	**81–174**
^{40}K	26–130	230–962	**233–740**

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

Radiation control of dump trucks with coal

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

Impurities	Coal	Ashes
Be	2.7	10.5
Cd	1.8	9.0
V	24.7	120.4
Cu	11.8	60.0
Zn	28	140.1
Hg	0.15	0.9
Pb	12.8	63.3
As	18.8	94.0
Ni	10.4	50.5

The average contents of impurities, g/t

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

Heavy metal	Emission in an atmosphere of heavy metals, t/year
Zn	11100
Ni	4860
Cu	3040
Pb	1930
Cr	1170
Hg	245
Cd	203

Emission in an atmosphere of heavy metals in Europe

IMPACT OF COAL POWER INDUSTRY ON ENVIRONMENT

Technical or ecological parameters	Modern Power Plant	Brown coal Power Plant	Coal Power Plant
Power Plant Efficiency, %	47.5	35	36
Efficiency of purification on SO_2, %	90	0	0
Efficiency of purification on NO_x , %	80	0	0
Efficiency of ashes catching, %	99.5	96	96
Emission and wastes:			
(SO_2), g/ KWt·h;	0.65	2.6	3.5
(NO_x), g/ KWt·h;	0.61	1.5	3.7
– ashes,), g/ KWt·h.	0.14	1.2	3.3

NUCLEAR POWER IN SYNERGIC INTERACTION WITH COAL POWER INDUSTRY

Scenario under consideration

- LWR;
- LWR-M are started from 2020 and new starts canceled after 2050 (advanced);
- FBR-S are started from 2030 (BR=1,4);
- HTGRs are started from 2030, work both in electro-generation mode, and in mode of production of technological heat to process coal into motor fuel (Cogeneration mode)
- As a reference scenario for comparison of natural uranium consumption a similar scenario with HTGR without cogeneration mode was considered.

DEVELOPMENT OF POWER AND ATOMIC ENGINEERING IN REGIONS OF THE WORLD

Year	Northern America	Latin America	Europ e	Former USSR	Africa	Near East	Southern Asia	Southeast Asia	Total
The established capacities of NPP on regions, GWn(e)									
2030	128	24	144	61	44	11	57	130	**600**
2050	240	77	280	115	152	40	273	322	**1500**
2100	538	331	595	341	683	184	1231	1097	**5000**
Specific manufacture of NPP electric power in regions, KWt H/man/ year									
2100	**6315**	**3009**	**6880**	**7318**	**1754**	**2642**	**2942**	**3415**	**3270**

It is considered to be general opinion that restriction on reserves of natural uranium equally 20 million tonnes. Taking into account this fact the cogeneration scenario of nuclear power development is acceptable.

BROWN COAL ENERGY NEEDS AND OPPORTUNITY TO REPLACEMENT IT WITH HTGR POWER FOR PRODUCTION 1 TON OF SYNTHETIC LIQUID FUEL

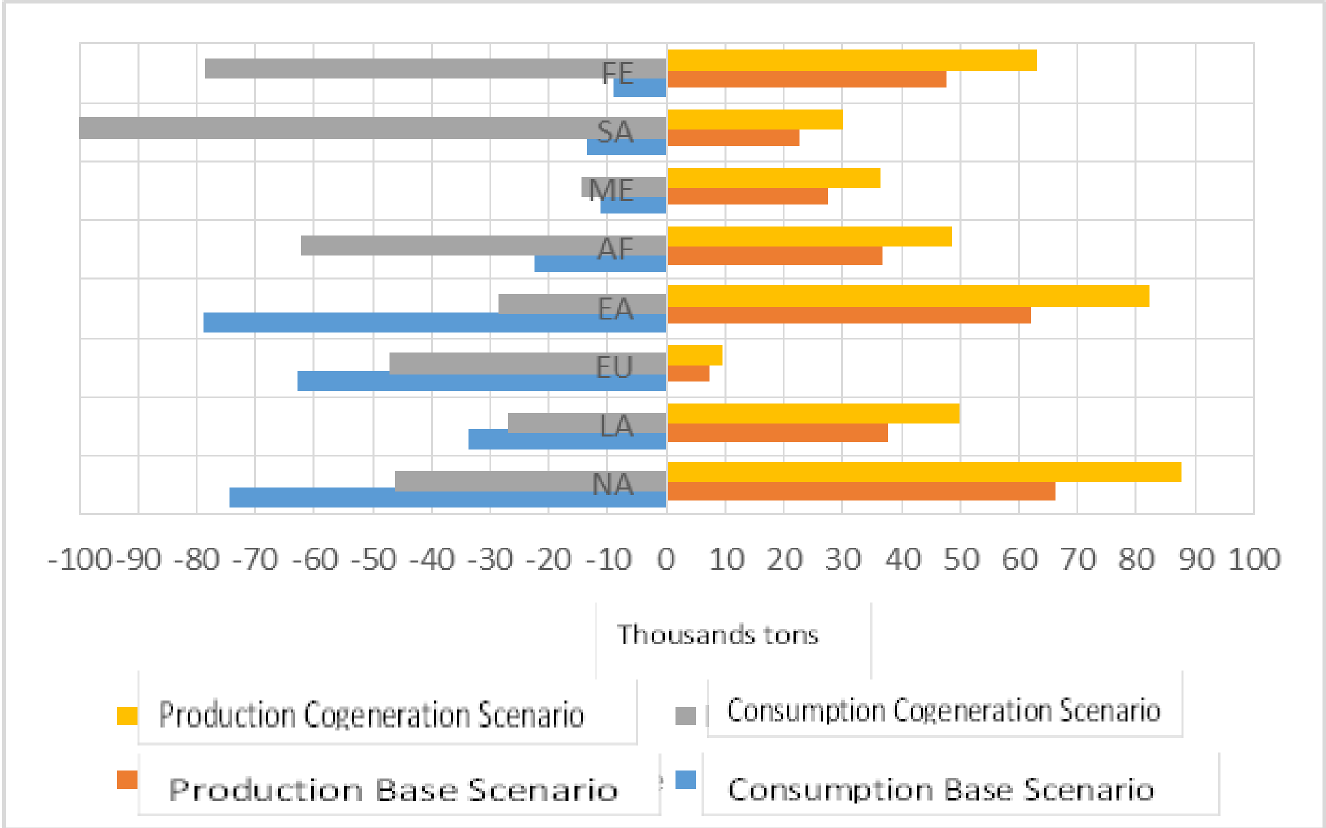
Application	Needs of coal energy, G calories	Conversion efficiency, %	Useful energy, G calories	Replacement with HTGR power, %
Technological fuel	10.15	74.2	7.53	–
Hydrogen Production	7.37	47.6	3.51	40
Secondary resources:				
– gases *	2.8	60	1.68	–
– slim*	3.22	40	1.29	–
– coal	1.35	40	0.54	–
Heating of installations	3.33	46	1.52	100
Electricity Production	0.88	40	0.35	100
Steam Production	4.07	80	3.26	100
Total	19.75	51.4	10.15	56.9

* – inherent implementation, not included into total.

QUANTITY OF PROCESSED COAL,

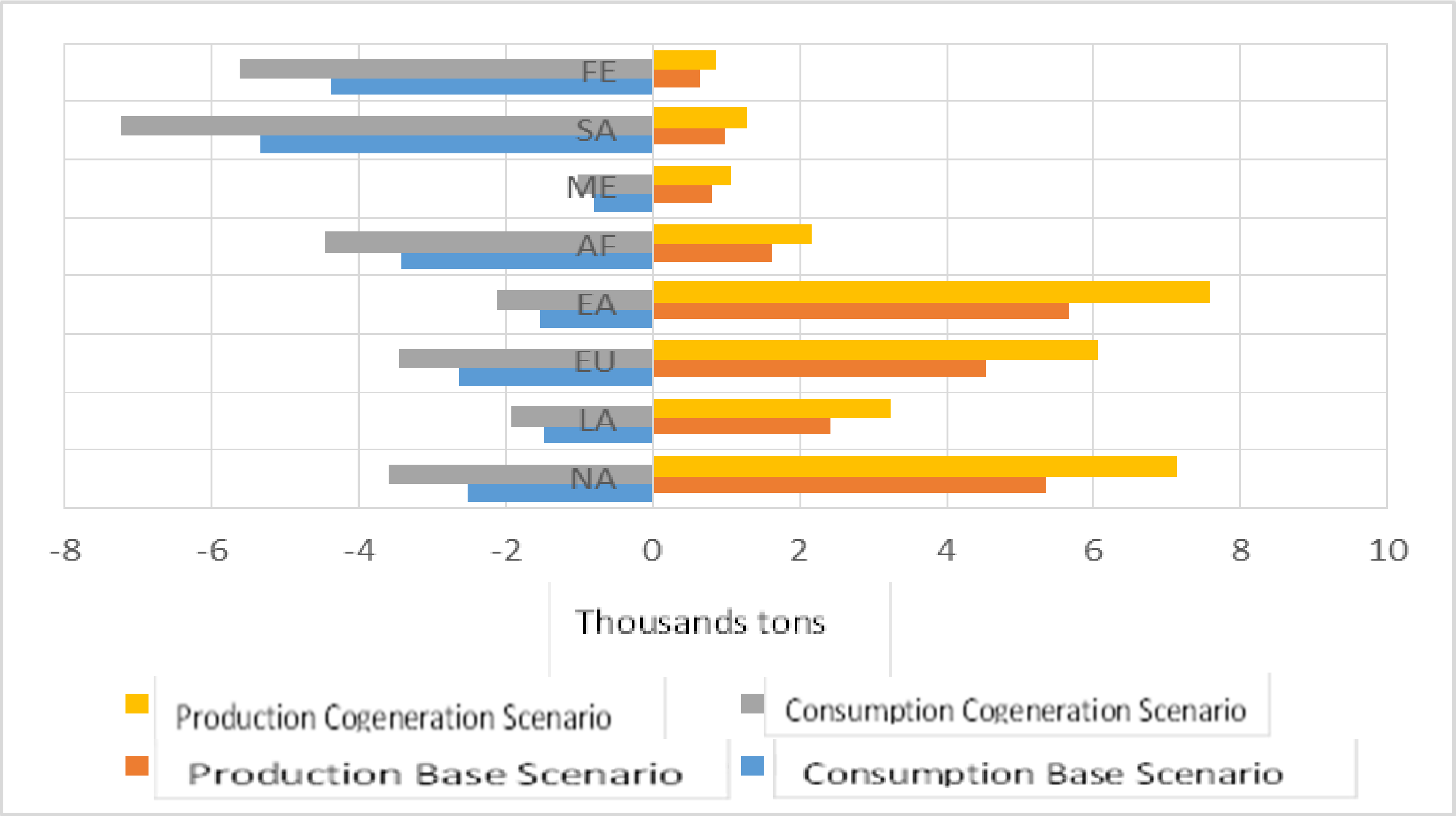
Region	Brown coal reprocessing (50% of mining), 2050 y., bln. tons	Processing of coal (% of mining), 2050 y., bln.tons	Partial processing of total coal 2100 y., bln tons
EU	280	36 (20)	810.4
EA	40	24 (6)	147.2
FE	85	506 (17)	1103.2
SA	15	12 (3)	38.8
ME	0	0	0
NA	45	180 (17)	424.3
LA	0.2	0	0.4
AF	0	24 (10)	40.8
Total	465.2	783 (15)	2 565

BALANCES OF NATURAL URANIUM ON REGIONS FOR 2100



In some regions the balance of consumed and made resources has exchanged to opposite: the Far East (FE), Southern Asia (SA), Africa (AF) where consumption of uranium began to exceed its mining, but not in East Asia (EA). It is caused not only by significant stocks of coal available, but also by the growth of capacities of HTGRs.

BALANCE OF NUCLEAR FUEL ON REGIONS FOR 2100.



Apparently, the basic fuel manufacturing is concentrated in regions Northern America (NA), Europe (EU), Eurasia (EA).

FINAL ASSESSMENTS

Year	2030	2050	2100
Capacities, GWt (thermal)	788.7	1035.1	2137.3
Liquid fuel production, bln ton/year	544	714	1475
Coal consumption for reprocessing with NP, bln ton/year	946.4	465.2 brown coal and 783 coal. Summary 1248	2565
Alternative coal consumption without NP, bln ton/year	1893	2496	5130
Prevented emission:			
— CO_2 bln ton	1325	1747	3591
— SO_2 bln ton	7.0	9.2	19.0
— NOx bln ton	4.0	5.3	11.0
— Flying ashes bln ton	3.2	4.2	8.7
— Radioactivity, MBk	132510	174720	359100

NUCLEAR POWER IN SYNERGIC INTERACTION WITH HEAVY OIL, HYDROGEN AND MOTOR FUEL PRODUCTION

HEAVY OIL PRODUCTION

Scenario under consideration

- LWR;
- LWR-M are started from 2020 and new starts canceled after 2050 (advanced);
- FBR-S are started from 2030 (BR=1,4);
- HTGRs are started from 2030, work both in electro-generation mode, and in mode of production of technological heat to process heavy petroleum into motor fuel (Cogeneration mode).
- As mentioned above a reference scenario for comparison of natural uranium consumption a similar scenario with HTGR without cogeneration mode was considered.

HEAVY OIL PRODUCTION

According to U.S. Geological Survey data there are 3400 billion barrels of heavy oil. As shown in next slide main oil reserves are in South America and the Middle East.

Technologies with steam pumping are applied for heavy oil production. Besides oil extraction it is required to improve it up to light oil. For this purpose it is necessary to add hydrogen. In average 1 ton of heavy oil needs 70-90 kg of hydrogen for this process.

It should be noted, that oil, produced by this way, could not be transported through pipeline, so its primary processing is necessary. Taking into account that for oil processing steam with temperature 700-850 ^{o}C is required, only HTR reactors could provide specified parameters.

RESERVES OF HEAVY OIL PER REGIONS

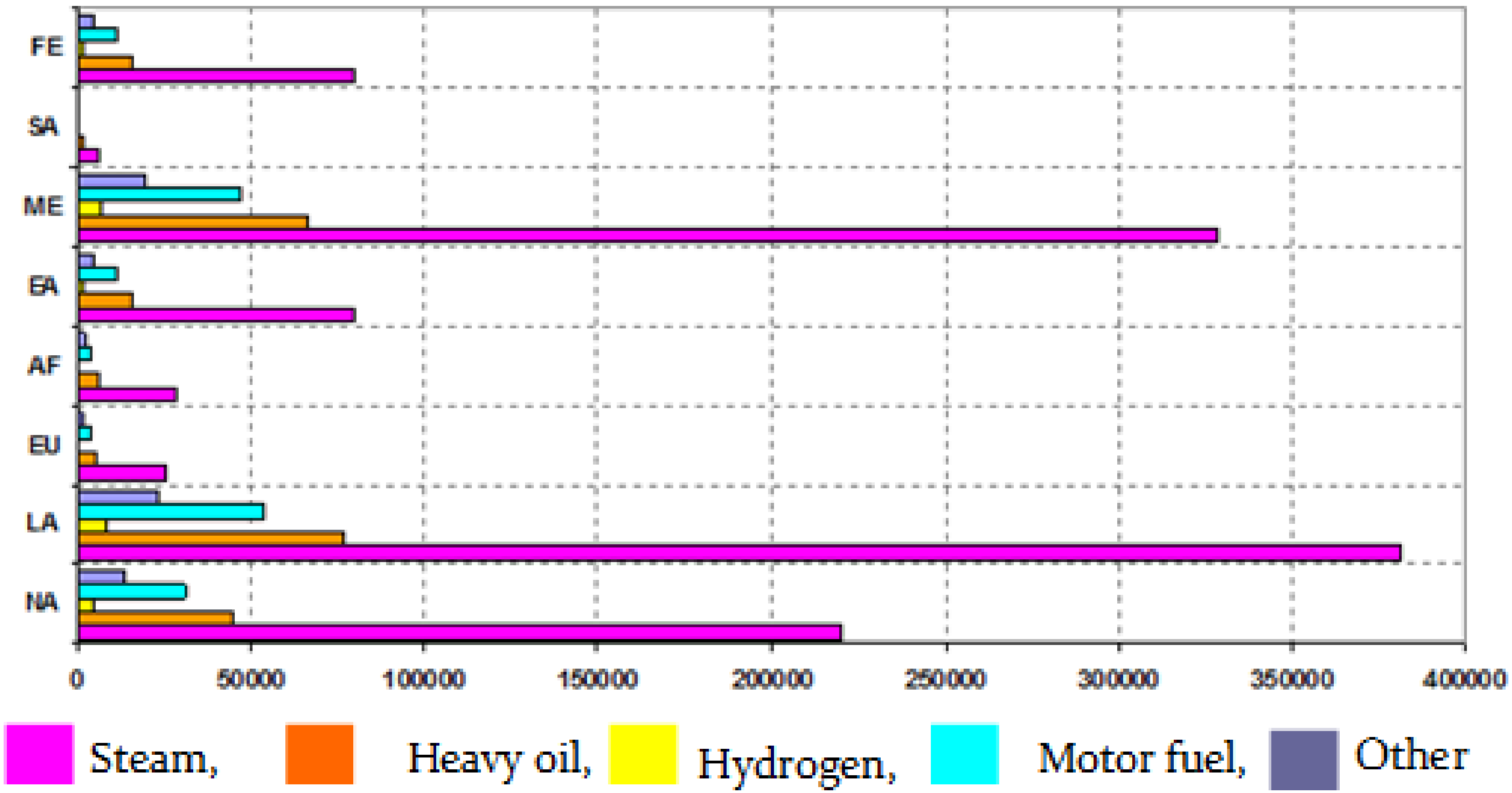
Region	bill.barrels	bill.tonnes	Share
NA	651	94,40	0,19
LA	1127	163,42	0,33
EU	75	10,88	0,02
AF	83	12,04	0,02
EA	234	33,93	0,07
ME	971	140,80	0,29
SA	18	2,61	0,01
FE	236	34,22	0,07
Whole world	3395	492,28	1

STRUCTURE OF USE OF HTGR REACTORS HEAT

For the NPP consisting of 5 blocks of the HTGR with a power of 600 MW

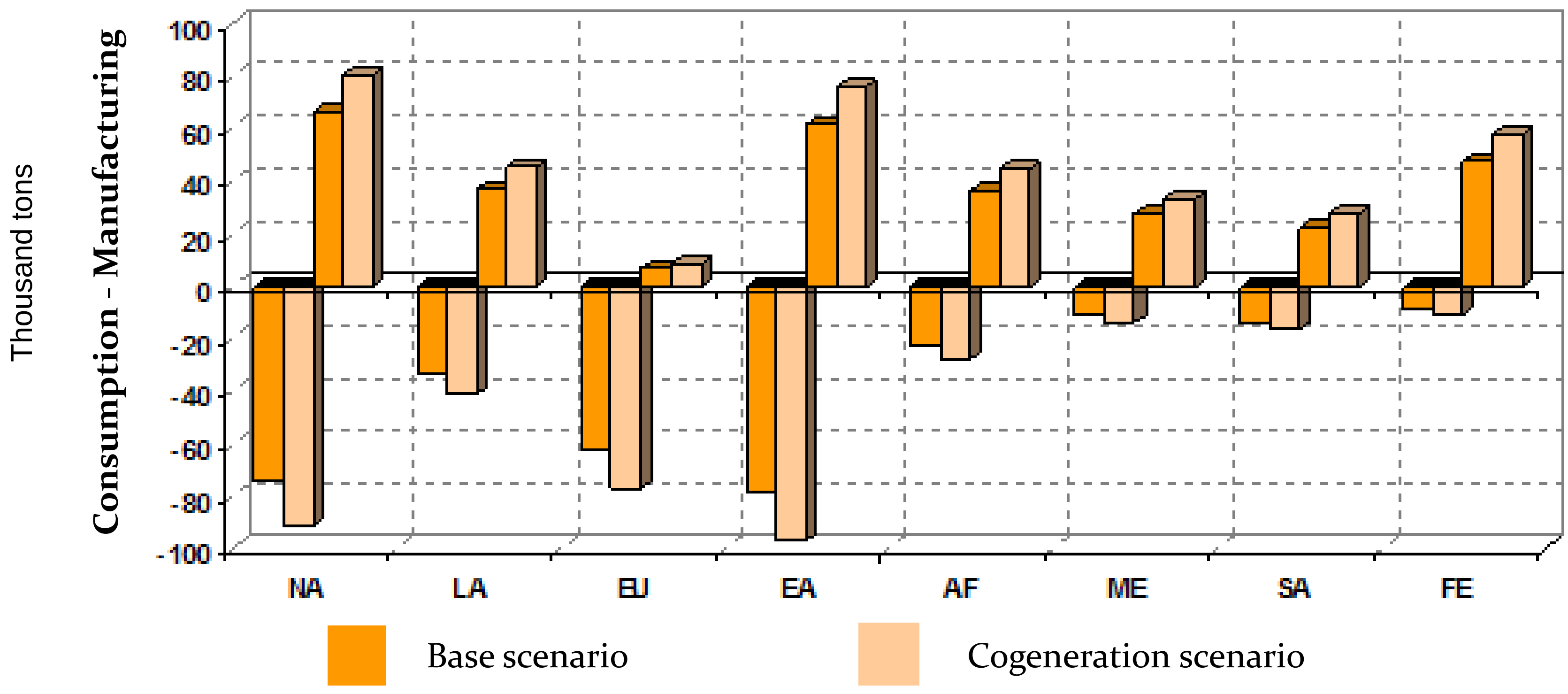
Area of Steam Application	Value	Measurement Unit
Technological steam	2650	t/h
Heavy Petroleum	535	t/h
Hydrogen	53,5	t/h
Elictricity	230	MWt
Motor Fuel	375	t/h
Other hydrocarbons	160	t/h

THE VOLUMES OF PRODUCTIONS AT MINING OF HEAVY OIL WHICH ARE CARRIED OUT DUE TO HEAT OF HTGR REACTORS ON REGIONS

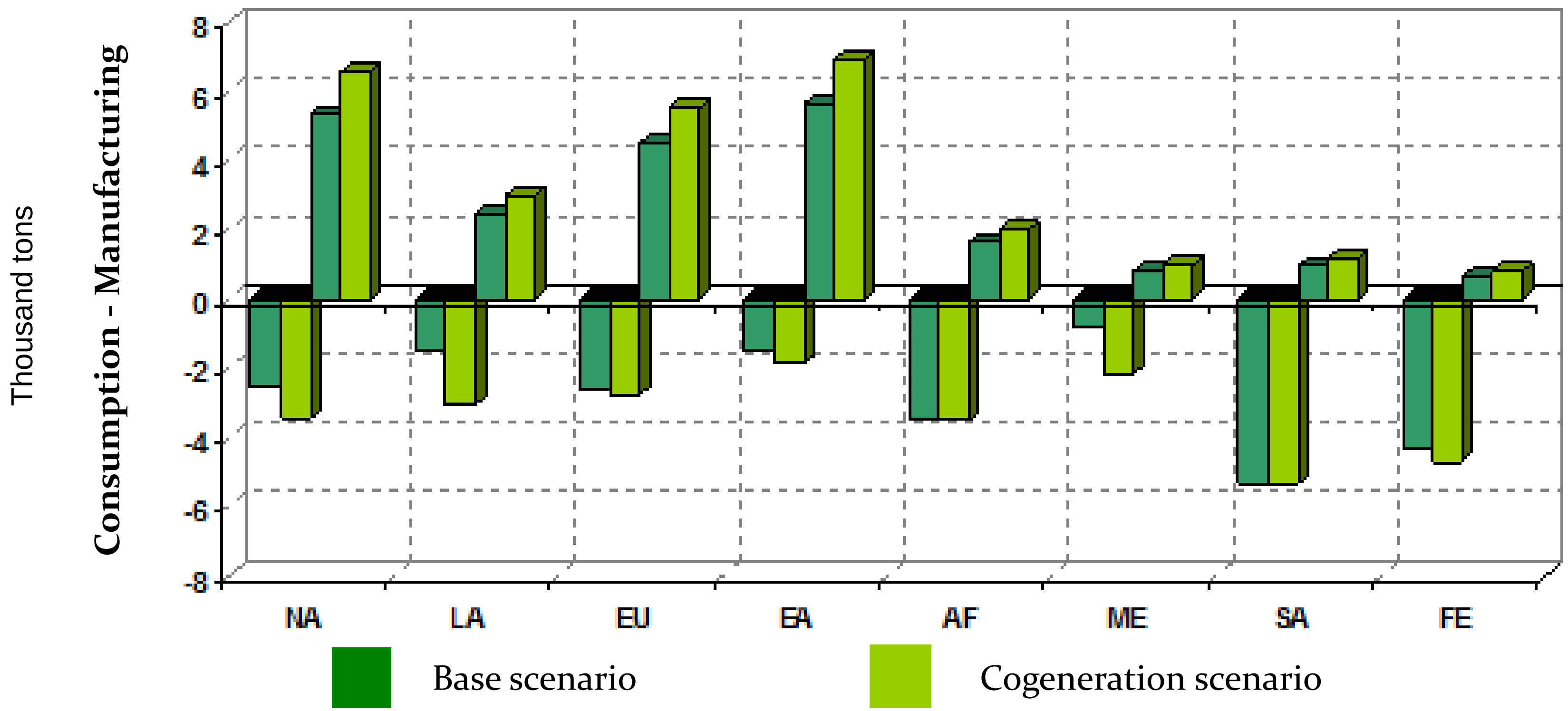


The main oil production is the share of regions the Middle East(ME) and Latin America (LA). In the same regions the main reserves of heavy oil are concentrated.

BALANCES OF NATURAL URANIUM ON REGIONS



BALANCE OF NATURAL FUEL ON REGIONS FOR 2100.



The balance of manufacturing and consumption of fuel changes according to reserves of heavy oil. In such countries as India, Africa, Europe needs for non-electric use of HTGR for oil production are insignificant therefore volumes of consumption of fuel in the NPP in the respective regions didn't change.

APPLICATION OF SMALL REACTORS FOR DESALINATION SEA WATER

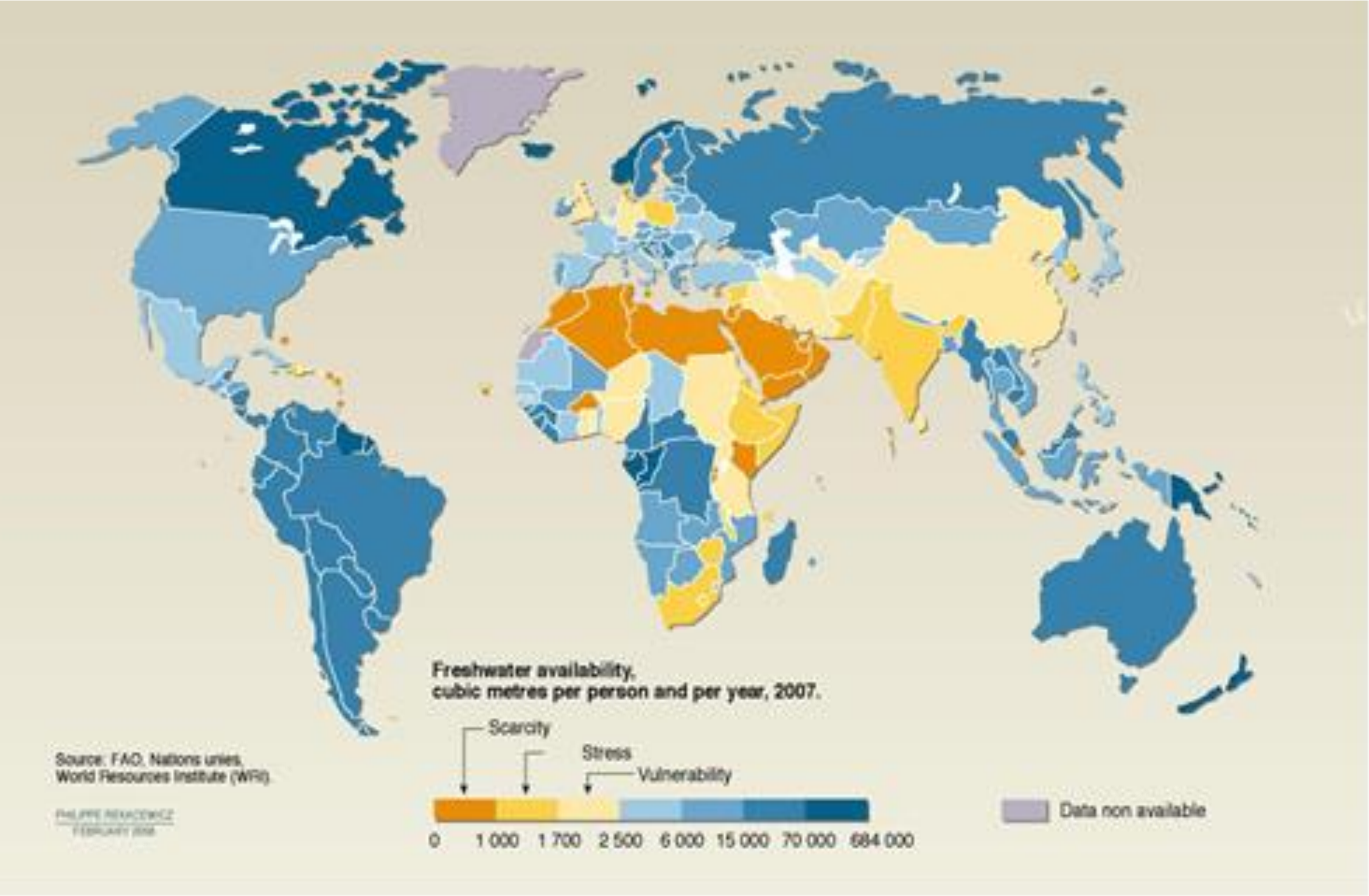
NEEDS OF WATER DESALINATION

Some countries achieved extreme level of water use and current climate change just exacerbates the situation. It may result in fight between countries, cities for water resources. In the end this problem may pass from water resources area to political level. According to UN assessment 5 billion people will not have water with satisfactory quality to 2030 at saving of current situation; it is about 67 % of whole world population. The maximum shortage of fresh water is in Africa's, the middle East's countries.

It is assumed that part of NPPs is aimed for water desalination. It is planned to use SMRs for these purposes. According to IAEA scale, SMR is reactor with power capacity less than 300 MW(e). Main advantages of these reactors are:

- longer fuel residence time
- short building period
- low specific power density and higher reliability
- work in flexible mode
- compactness
- absence of water resources (water consumption is negligible)

NEEDS OF WATER DESALINATION



Fresh wate availability m^3/man/year

THE BIGGEST DESALINATION PLANTS

Country	Capacity, m^3/day
Saudi Arabia	880000
Saudi Arabia	800000
Saudi Arabia	730000
UAE	600000
Kuwait	567000
UAE	450000
UAE	454600
USA	454200
UAE	454000
UAE	454000

There are more than 15000 desalination plants with installed capacity 60 millions m^3/day. Additional desalination capacities (almost 10 millions m^3/day) are building.

LOCATION OF DESALINATION PLANTS

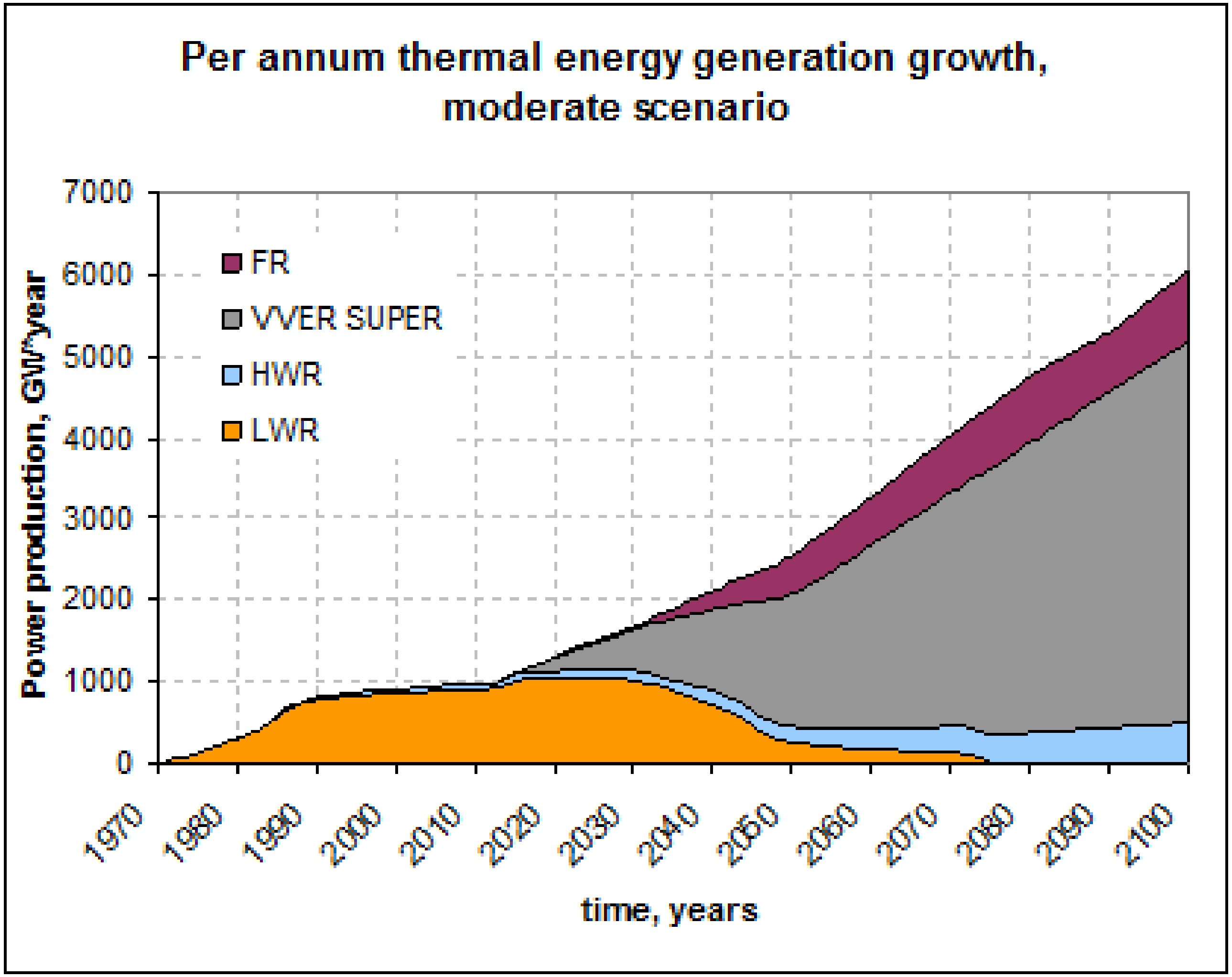
WATER DESALINATION

Production of 1 kg fresh water requires 300-400 kJ heat, i.e. two reactor units KLT-40 may produce 8000-10000 m^3/day. In study share of SMRs is one fifth of all desalination plants capacities because of world nuclear electricity production share is 15-20 %. It means that power production by SMR is about 7 % power production of all thermal capacities for moderate scenario. For high case it is possible to increase fresh water production twice so SMRs share will be also 7 % in nuclear energy structure.

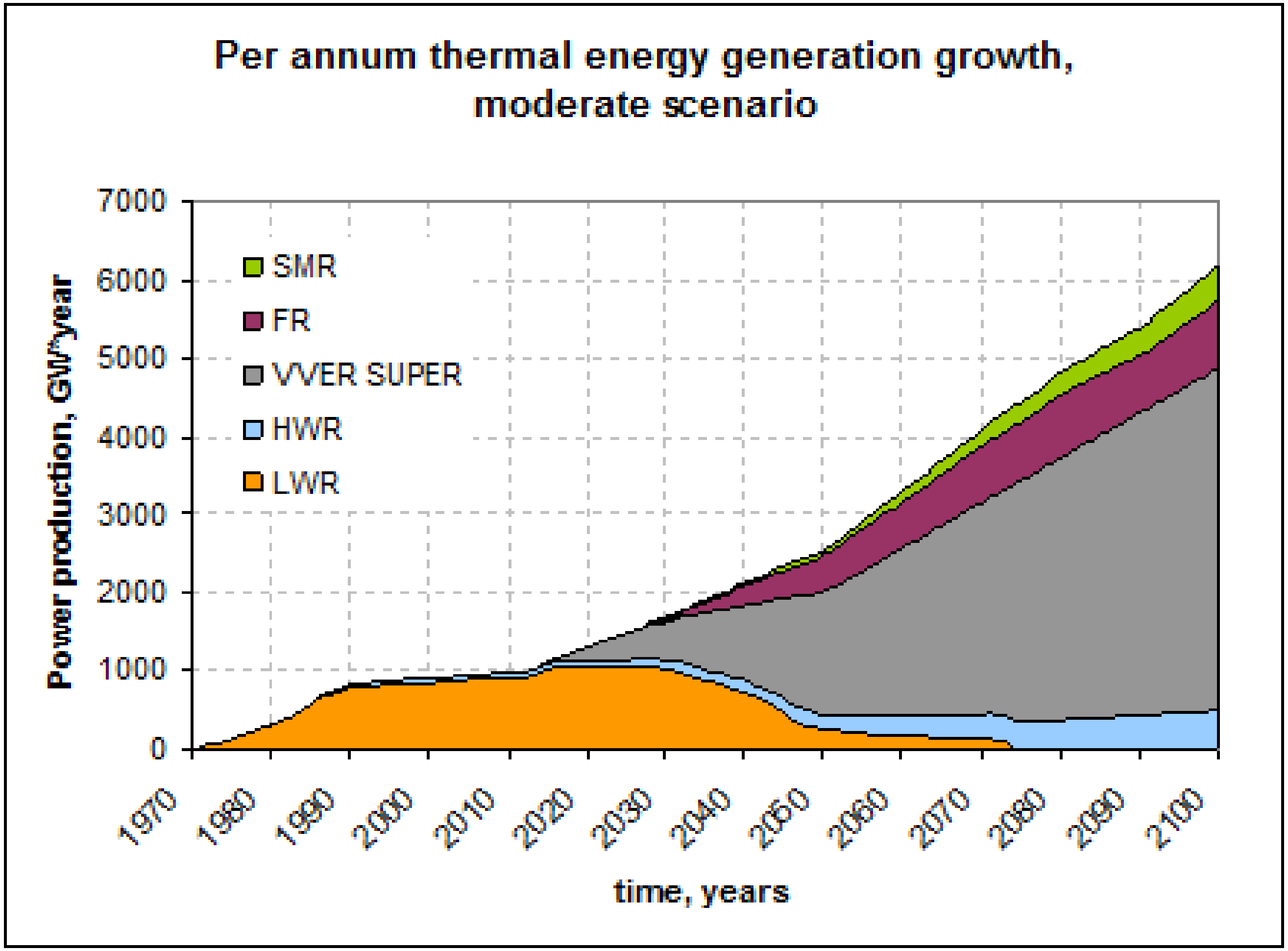
REACTOR PARAMETERS

Reactor specifications	Value
Reactor net electric output, MW	38.5
Reactor thermal output, MW	150
Thermal efficiency, %	25.7
Average load factor, %	70
Operation cycle length, EFPD	583
Enrichment, %	14.1
Specific power density, MW/t	115
Initial core inventory, tHM	1.2728
Share of heat (option):	
electricity, %	56
desalination, %	44

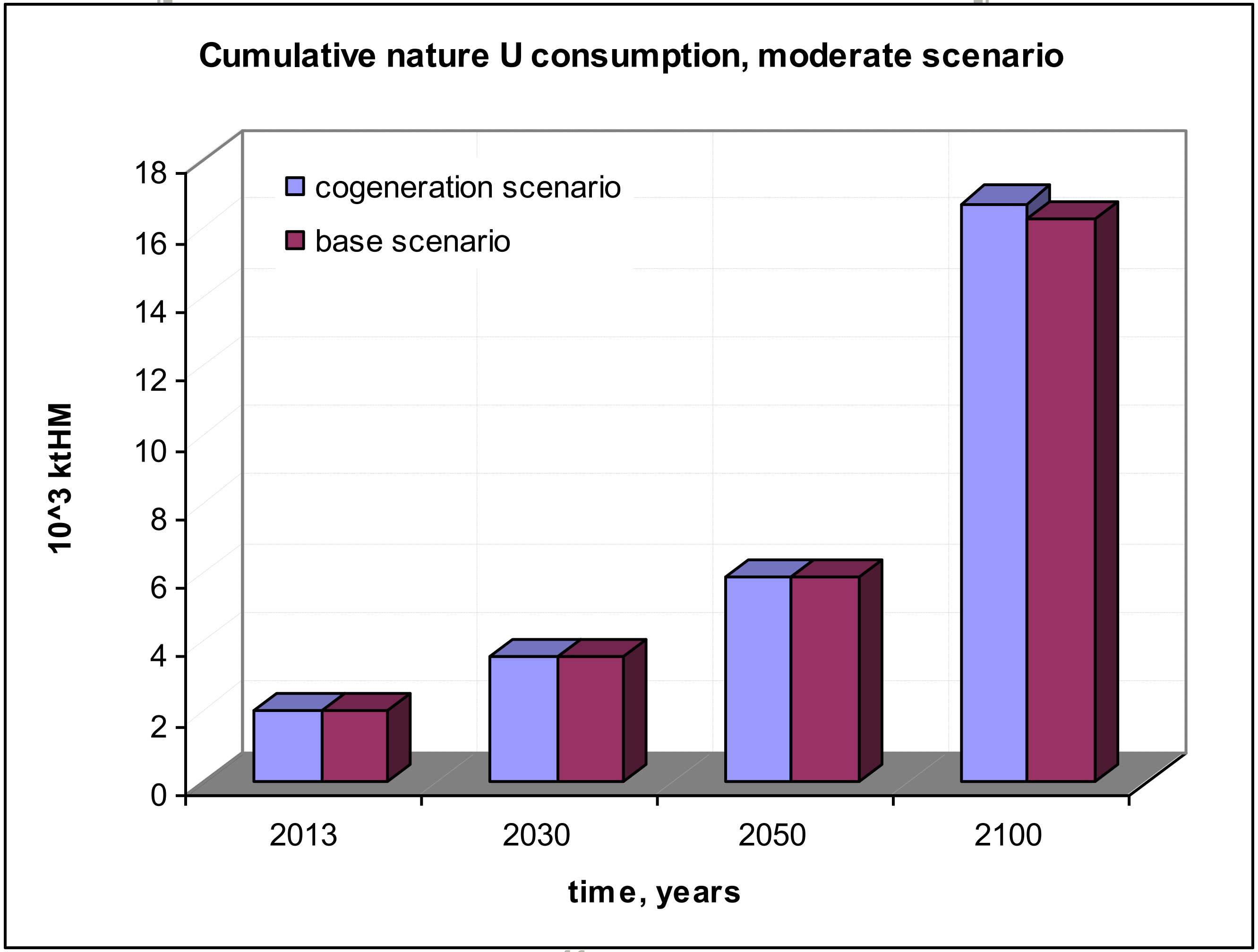
BASE SCENARIO NUCLEAR POWER DEVELOPMENT



COGENERATION SCENARIO



WATER DESALINATION



WATER DESALINATION

Thermal power production is higher for cogeneration scenario of nuclear energy. It follows from the case that for saving of electricity production it is necessary to increase thermal production at cogeneration application.

SMRs have lower value of fuel use characteristics because of their features but their application is necessary for expansion of nuclear energy application especially in developing countries. Without SMRs sustainable development and widening of resource base is almost impossible. As it is shown non-electrical application of nuclear energy in chosen scale insignificantly influence on recourses consumption. Besides, it should be noted that this difference may be less at reprocessing of SMR spent fuel.

CONCLUSION

1. The provided data allows us to approve that on technological capabilities high-temperature reactors (FGR and HTGR) with the helium coolant can have the niche in structure of large-scale nuclear power that is essential to perspective development of economy.
2. FGR and HTGR - the reactors which is organically fitting into nuclear power of the next century of development of economy.
3. The results of calculations allow to draw a conclusion, that the complex combining a high-temperature gas reactor and processing of coal in synthetic fuel is the powerful factor of reduction of environmental contamination

This niche can't be filled with other known types of reactors !!!

CONCLUSION (2)

Outside the consideration there were scenarios which allow to provide needs of the countries (including newcomers) needing energy carriers not due to production of nuclear energy and, the related deliveries of nuclear fuel, and due to delivery received by use of high-temperature heat of synthetic energy carriers and hydrogen, supply of the additional oil products received from fields of heavy oil, etc. The approach used for such researches can rely in strong degree on SYNERGIES project philosophy, on the one hand, generalizing its approach on a combination of nuclear and non-nuclear power technological options, and on the other hand, the model of nuclear power will receive twice heterogeneous structure: in relation to nuclear technologies and a fuel cycle, and in relation to non-nuclear power technological applications and consumption of their production.

CONCLUSION (3)

Without SMRs sustainable development and widening of resource base is almost impossible. As it is shown non-electrical application of nuclear energy in chosen scale insignificantly influence on recourses consumption.

THANK YOU FOR ATTENTION

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