تقنيات الطاقة المستدامة
Sustainable Energy Technologies

Techno-Economic Assessment of Nuclear Power Plants and nuclear desalination option for KSA

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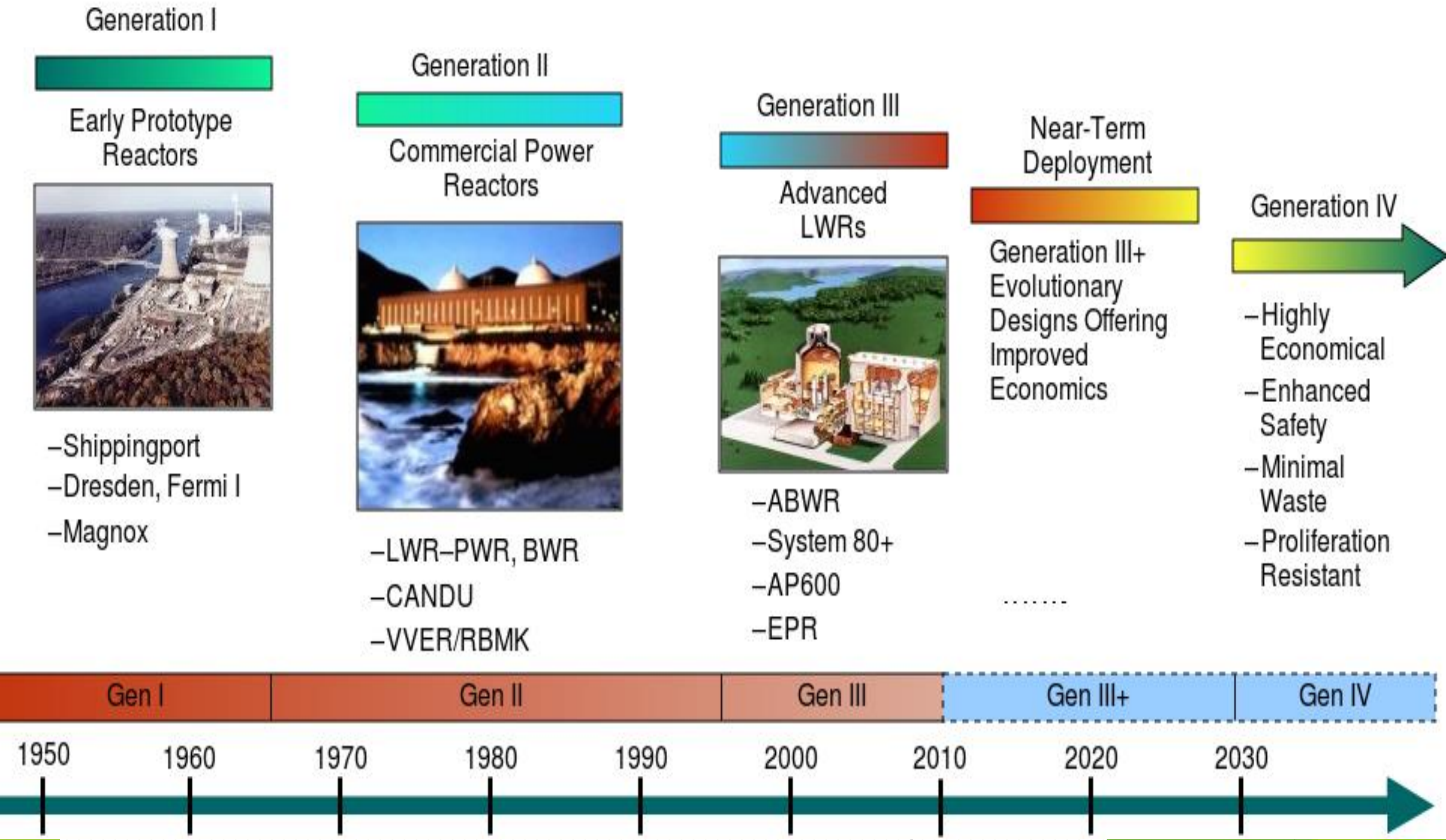
Outlines

- Exploring the status of Nuclear power plants its safety aspects and cost estimation scenario
- To what extent is there momentum to develop nuclear power to limit domestic consumption of oil supplies?
- Reviewing current status of desalination plants across the globe and nuclear desalination system with associated technologies as promising features to KSA region

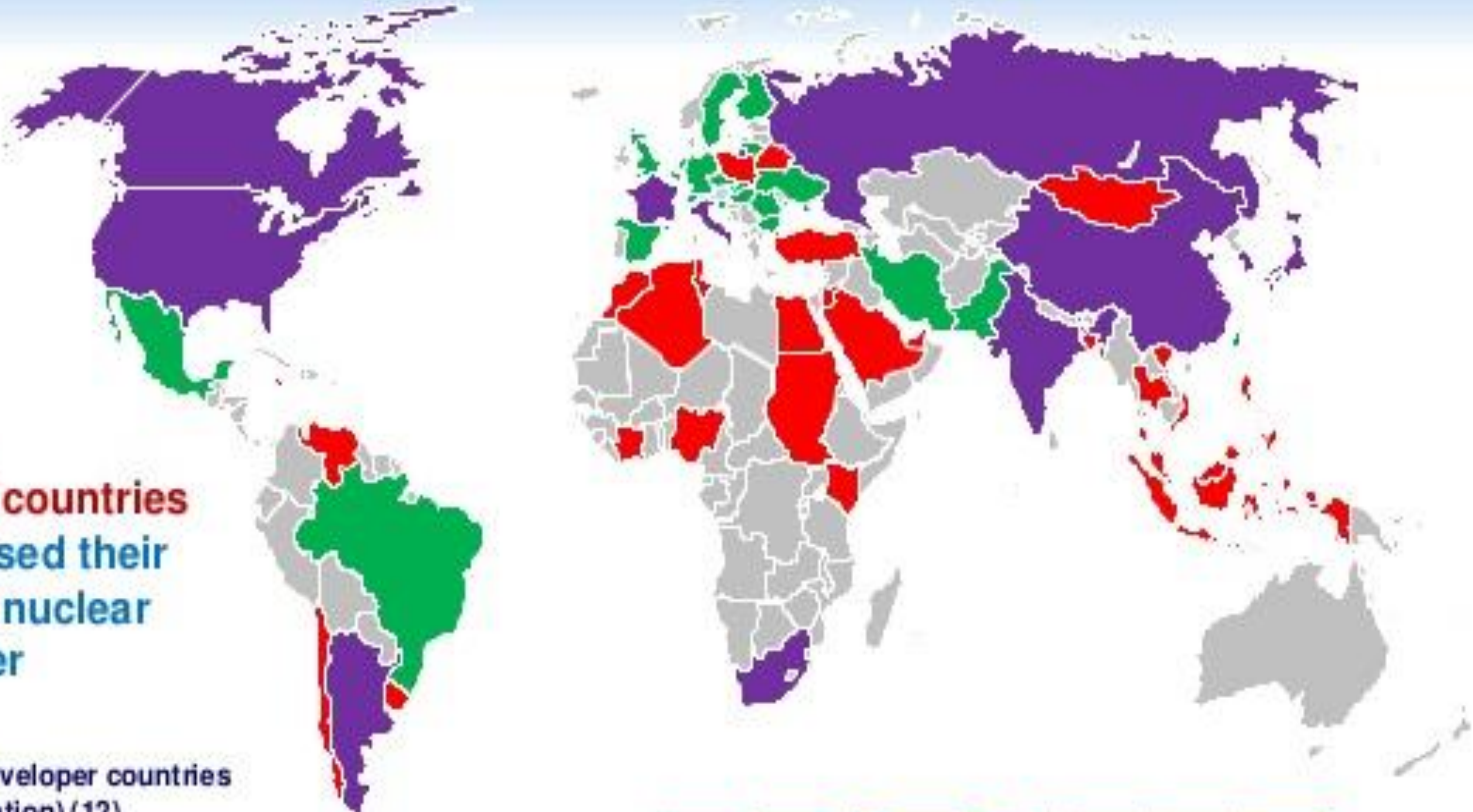
Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics



Web link*4th generation nuclear power 2020 2030 2030s future

Newcomer Countries

IAEA



More than 60 countries have expressed their interest for nuclear power

- Technology developer countries (NPPs in operation) (12)
- Countries with NPPs (18 +12=30)
- Newcomer countries (19)

Asia (7)

Europe (3)

Africa (7)

Latin America (2)

M. A. Zulquarnain, BAEC

Figure 3. **Nuclear Reactors by Country, December 2014**

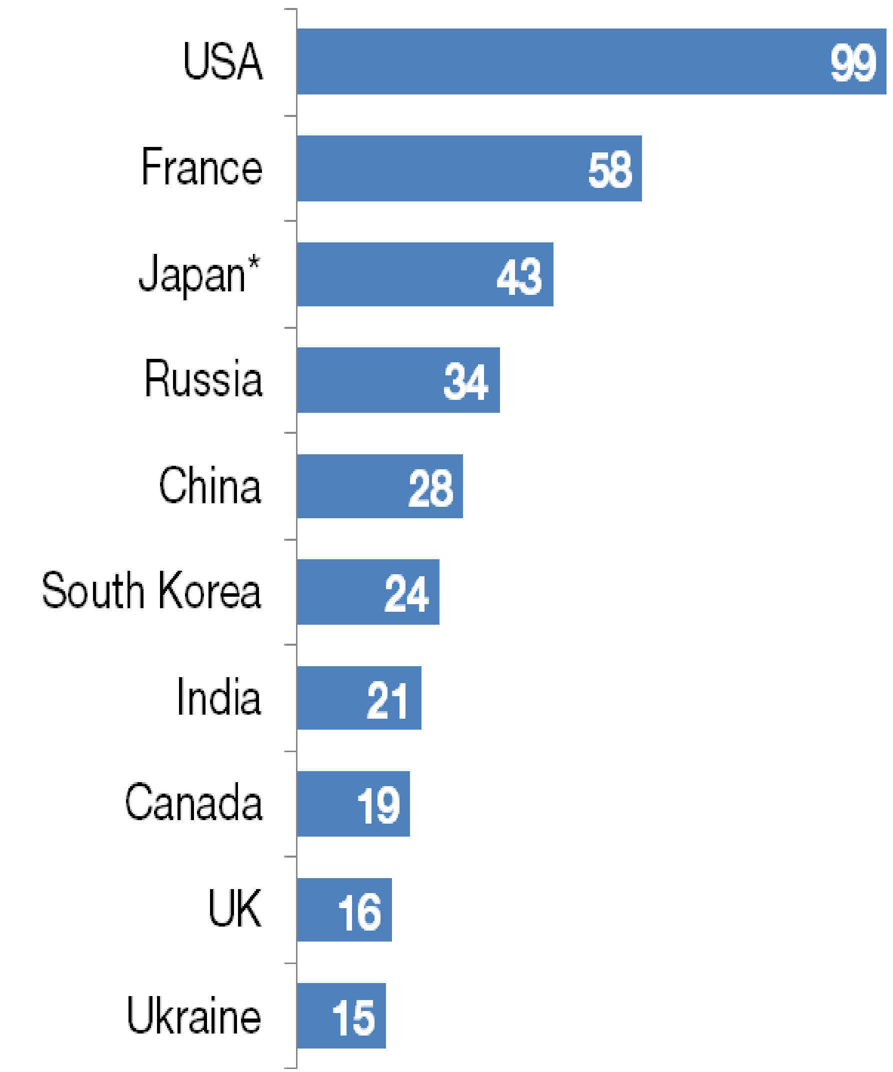
Country	Operating Units	Under Construction	Share of Electricity From Nuclear Energy	Share of Worldwide Nuclear Generation of Electricity	Nuclear as Share of Total Primary Energy
United States	99	5	19.5%	33.1%	8.3%
France	58	1	76.9%	17.2%	41.5%
Russia	34	9	18.6%	7.1%	6.0%
South Korea	23	5	30.4%	6.2%	13.0%
Germany	9	-	15.9%	3.8%	7.1%
China	23	26	2.4%	5.0%	1.0%
Canada	19	-	16.8%	4.2%	7.2%
Ukraine	15	2	49.4%	3.5%	20.0%
United Kingdom	16	-	17.2%	2.5%	7.7%
Sweden	10	-	41.5%	2.6%	28.7%
Spain	7	-	20.4%	2.3%	9.7%
Belgium	7	-	47.5%	1.3%	13.2%
India	21	6	3.5%	1.4%	1.2%
Czech Republic	6	-	35.8%	1.2%	16.8%
Switzerland	5	-	37.9%	1.1%	21.9%
Finland	4	1	34.7%	0.9%	20.6%
Japan*	48	2	-	-	-
Brazil	2	1	2.9%	0.6%	1.2%
Bulgaria	2	-	31.8%	0.6%	20.1%
Hungary	4	-	53.6%	0.6%	17.7%
Slovakia	4	2	56.8%	0.6%	23.4%
South Africa	2	-	6.2%	0.6%	2.9%
Romania	2	-	18.5%	0.5%	7.8%
Mexico	2	-	5.6%	0.4%	1.1%
Argentina	3	1	4.1%	0.2%	1.5%
Iran	1	-	1.5%	0.2%	0.4%
Netherlands	1	-	4.0%	0.2%	1.1%
Pakistan	3	2	4.3%	0.2%	1.5%
Slovenia	1	-	37.3%	-	21.1%
Armenia	1	-	30.7%	-	20.3%
United Arab Emirates	-	3	-	-	-
Belarus	-	2	-	-	-
World	432	68			

Sources: International Atomic Energy Agency, Nuclear Power Reactors in the World, Reference Data Series No. 2 (Vienna: IAEA, 2015), http://www-pub.iaea.org/MTCD/Publications/PDF/rds2-35web-85937611.pdf; and BP Statistical Review of World Energy 2015, http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Notes: *Japan shut down all its nuclear reactors following the Fukushima accident. It has since worked to gradually restore operations, beginning with the restart of one of the nuclear reactors at the Sendai plant in August 2015.

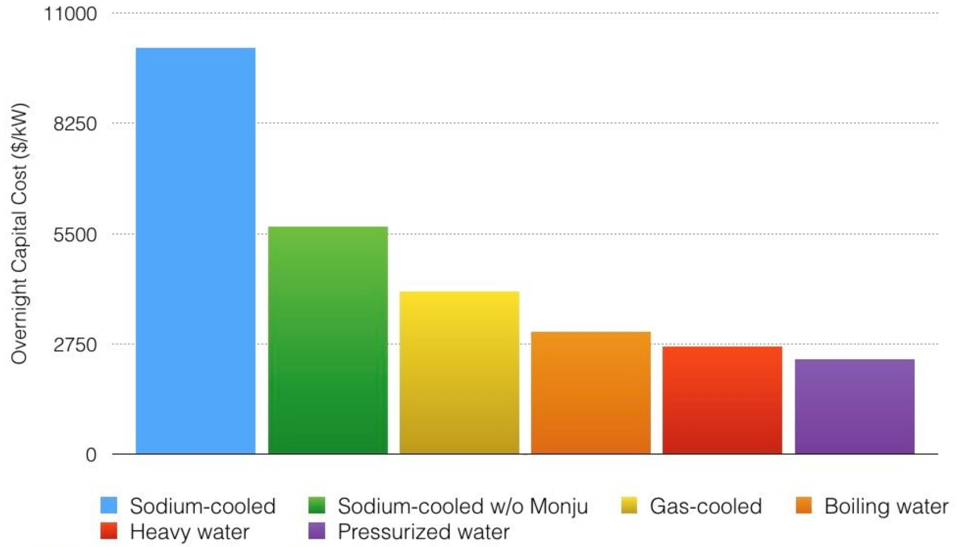
Operational nuclear power reactors around the world

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD



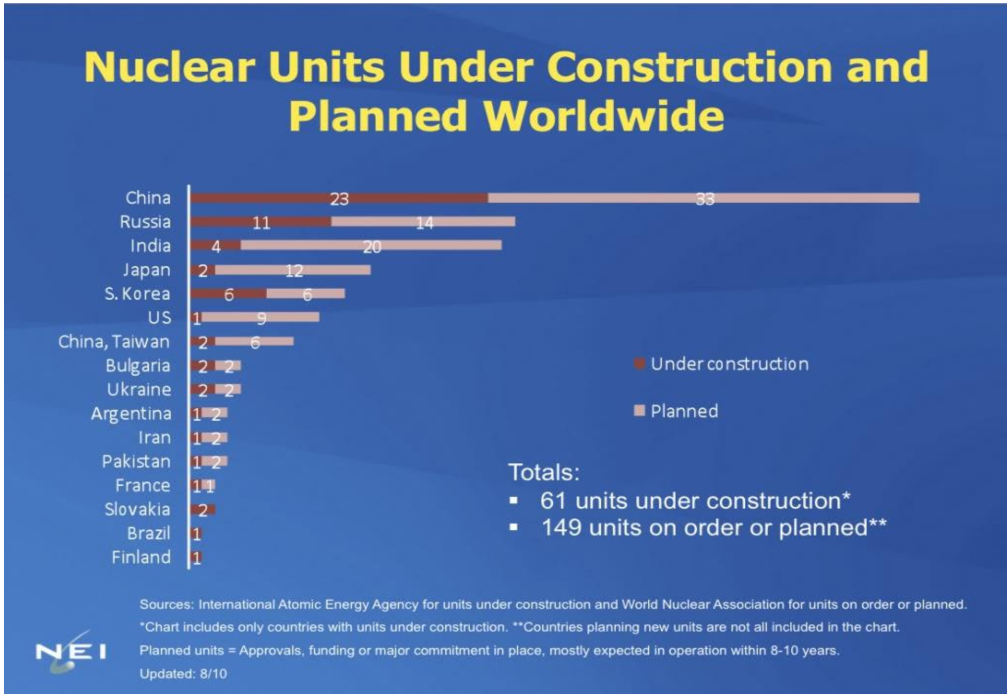
Source: IAEA
* Figure includes reactors which are offline, but potentially operational

Construction cost of reactors by type

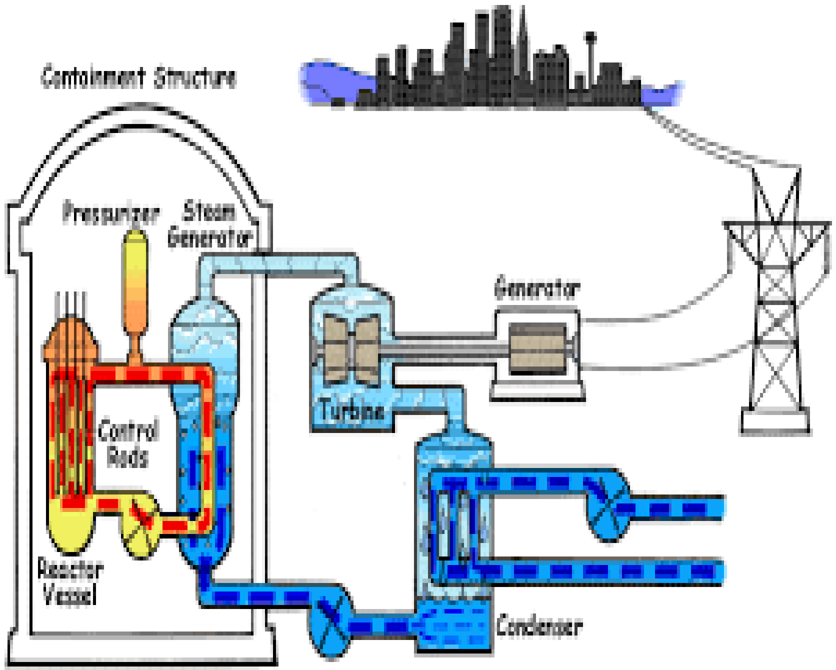


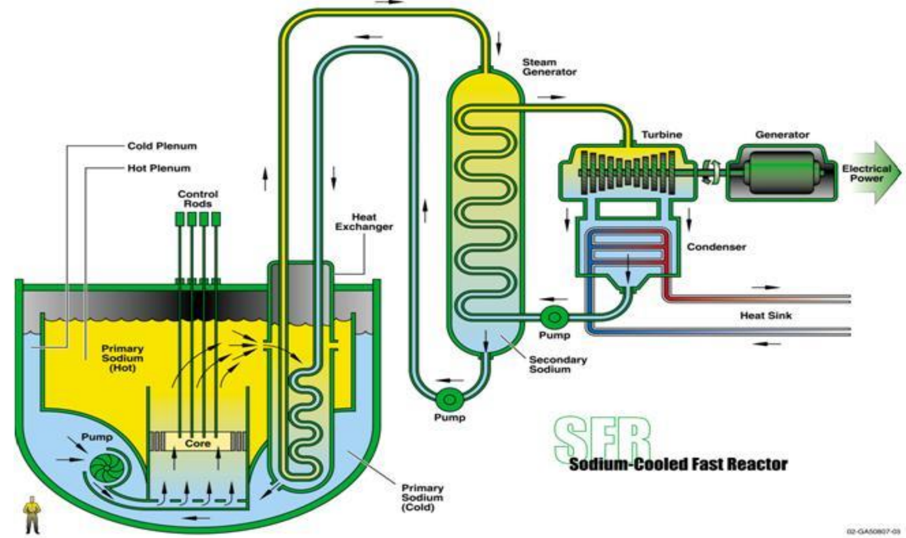
ENVIRONMENTAL PROGRESS

Source: Lovering, J. R., Yip, A., & Nordhaus, T. 2016. Historical construction costs of global nuclear power reactors. *Energy Policy, 91*, 371-382. Accessed March 7, 2017. http://www.sciencedirect.com/science/article/pii/S0301421516300106



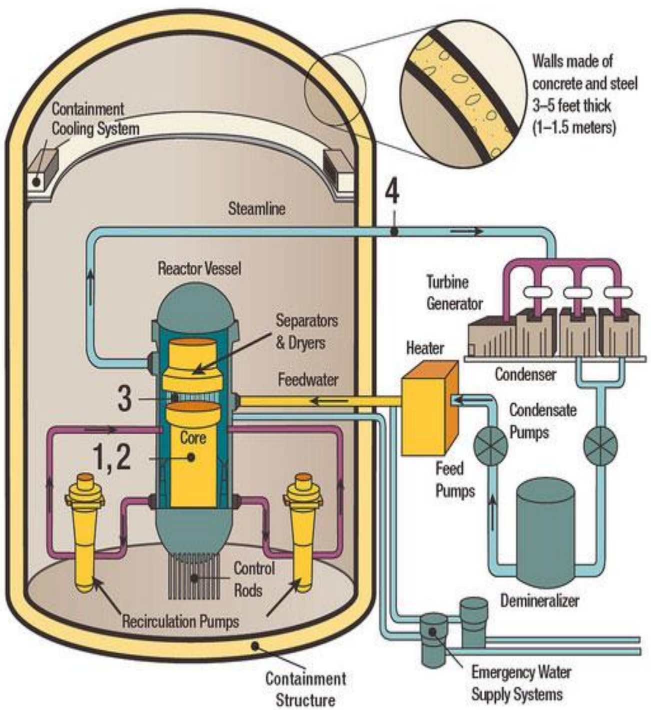
Pressurized Water Reactor(PWR)



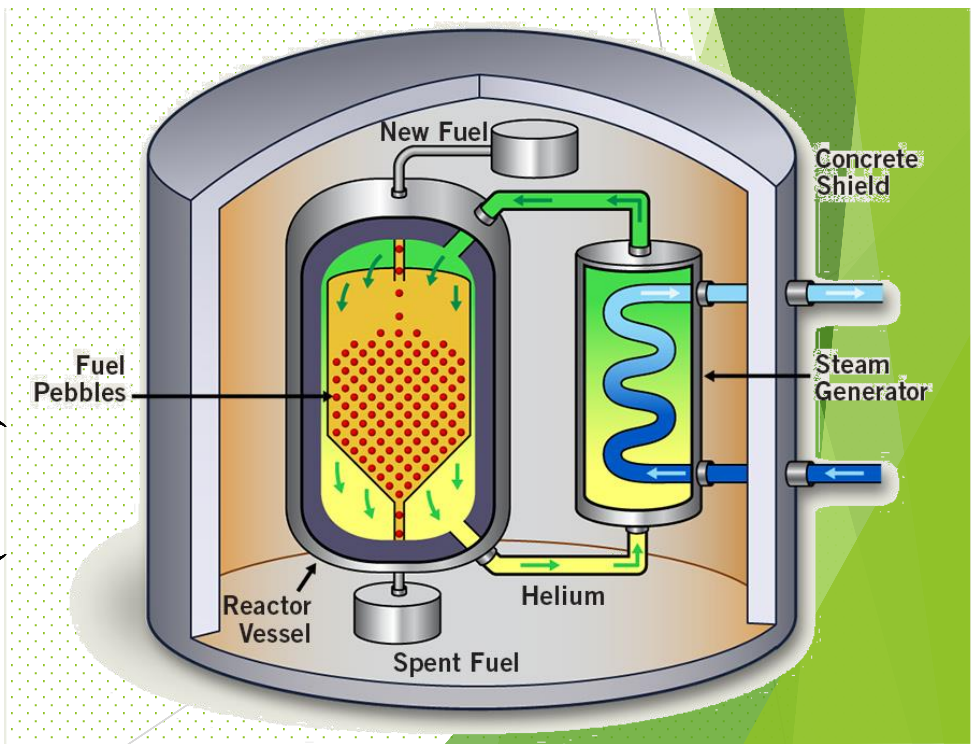


Sodium cooled fast reactor(SFR)

Boiling Water Reactor(BWR)

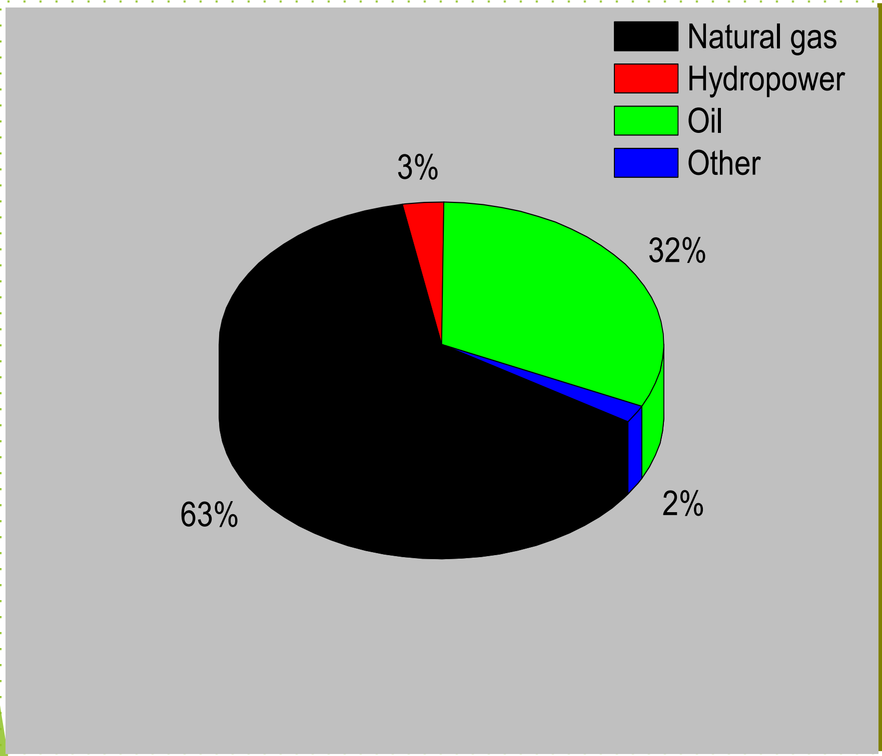


High temperature gas cooled reactor(HTGR)

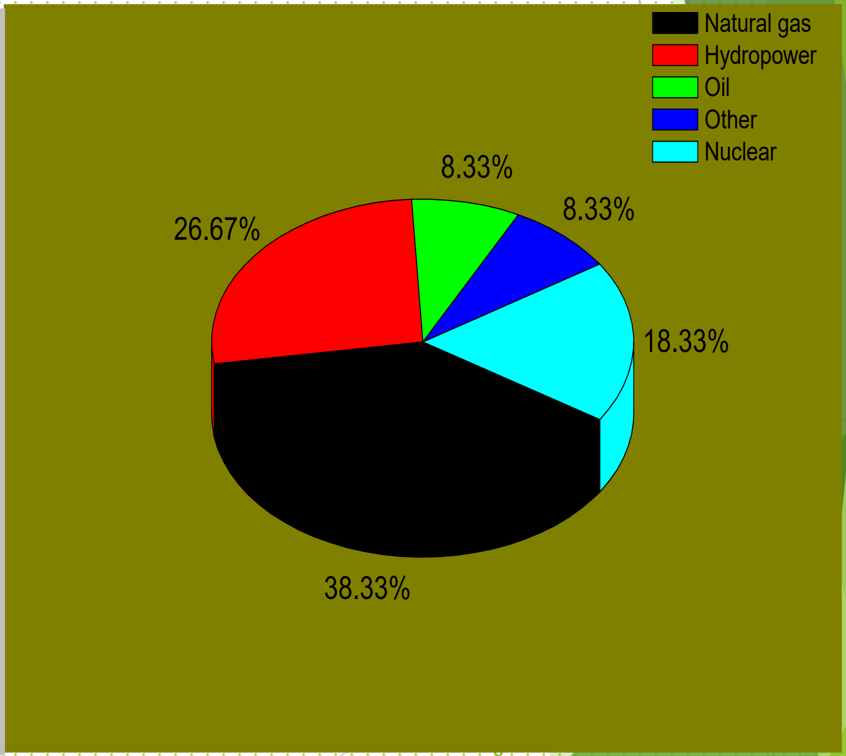


Energy Distribution

Middle East and North Africa Region(MENA)



World



MENA region-Energy issue

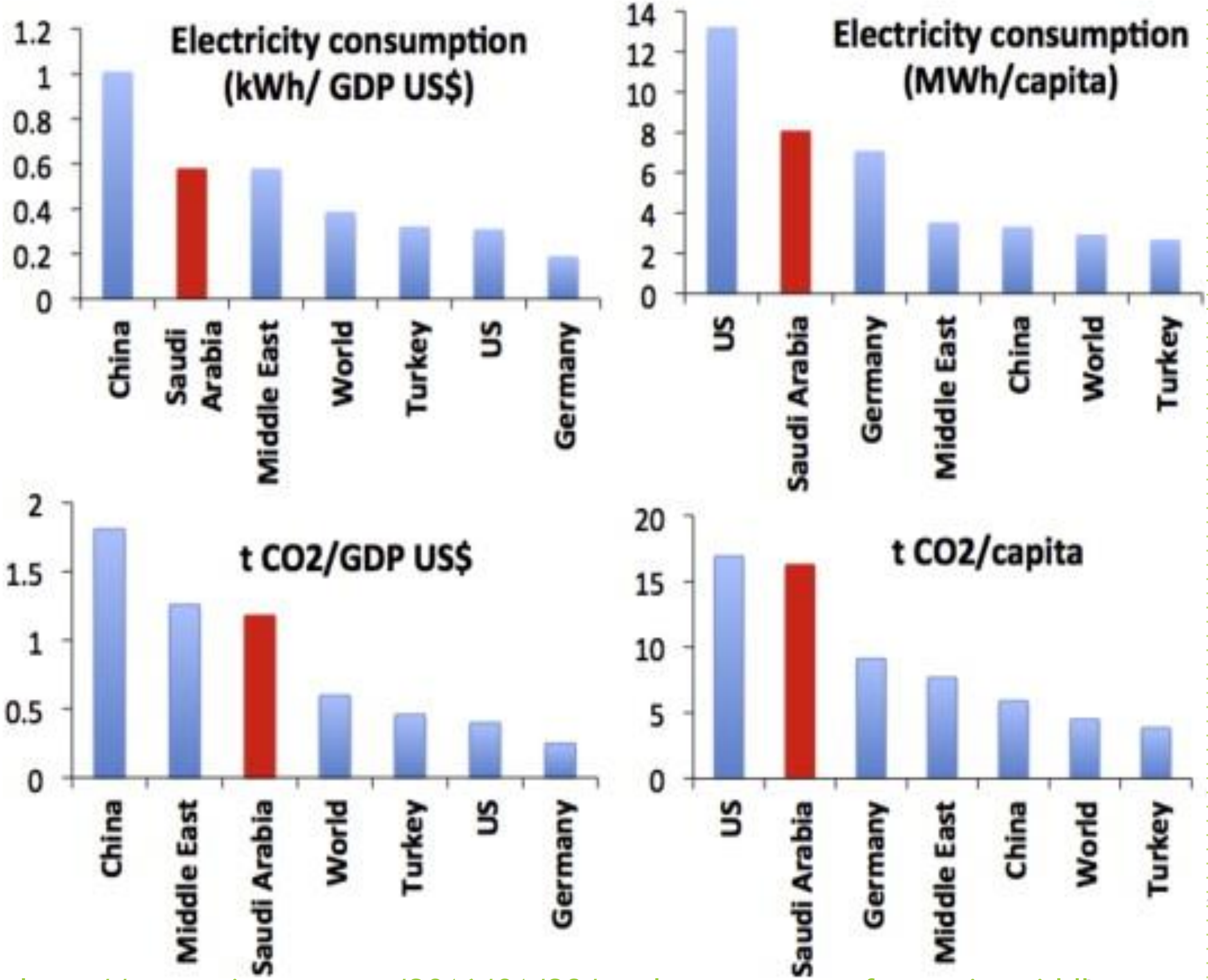
- Demand for electricity and water in MENA region is increasing corresponds to 7% per year, which will double in 2025, due to rapid population growth rate, increase in urbanization and swift to industrialization.
- MENA region offer 48% cheap prices relative to income resulting to fuel wasteful consumption and inefficiencies
- Energy intensity in Middle East in 1970 was less than half of other non-OECD but by 2010 it was exceeded to 50% higher
- Trends moving to renewable energies but cost and rapid expansion hinder
- Natural gas usage increases across the MENA region and are considered to be the largest gas flaring nations and also contributed to carbon emission as well.

http://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa/itac

Nuclear Power Plans among MENA region

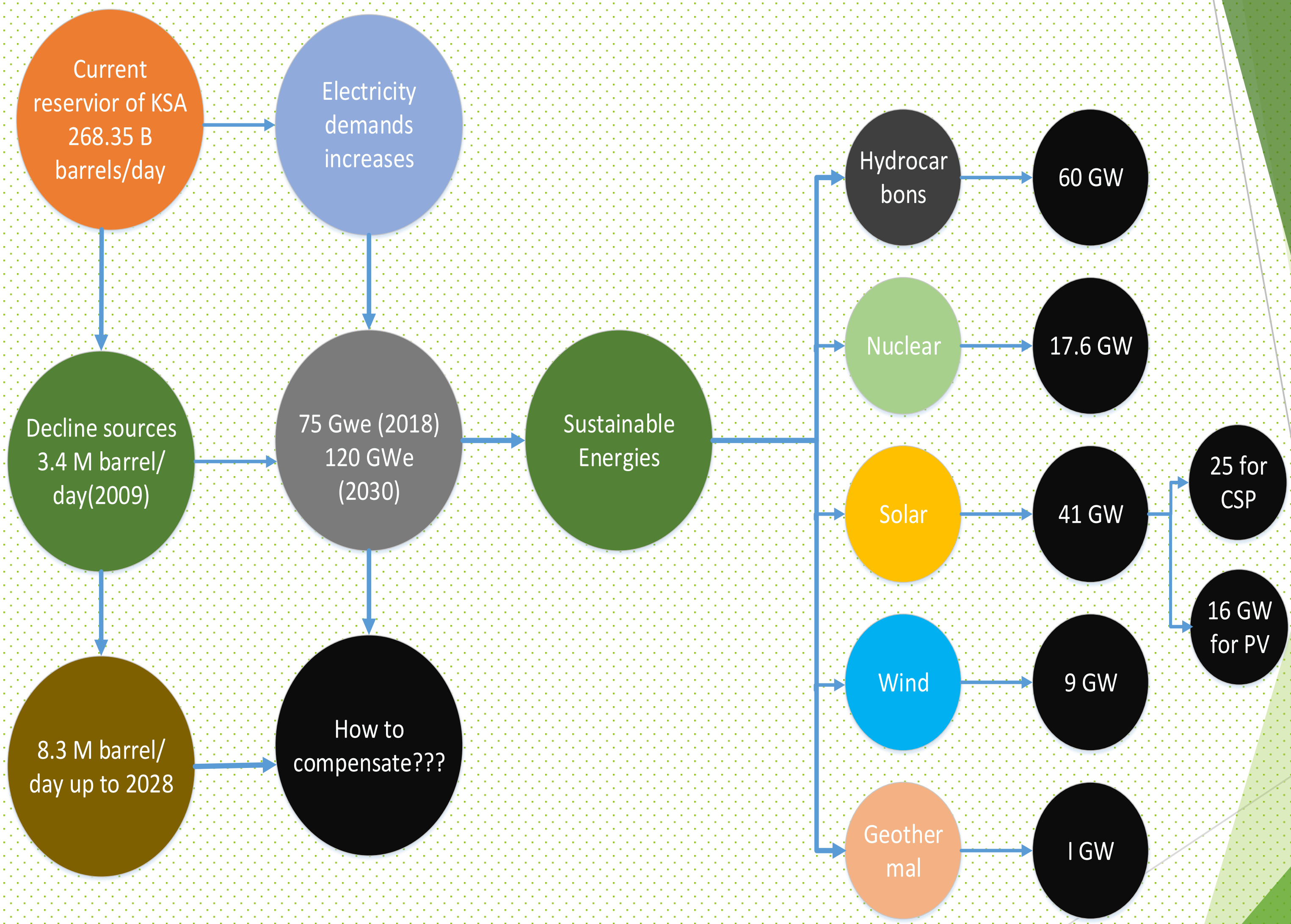
MENA Countries	Expected power
United Arab Emirates First unit online in 2017	5.6 GW
Kingdom of Saudi Arabia Total 16 nuclear reactors First unit to be started in 2022	17 GW
Jordon First unit operational in 2023	2000 MW
Egypt with first operational in 2028	4x1200 MW
Morocoo, Tunisia and Algeria	Two research reactors since early 1990s
Kuwait, Oman and Qatar	Cancelled

KSA Energy Consumption…



http://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa/itac

KSA Energy Plans…

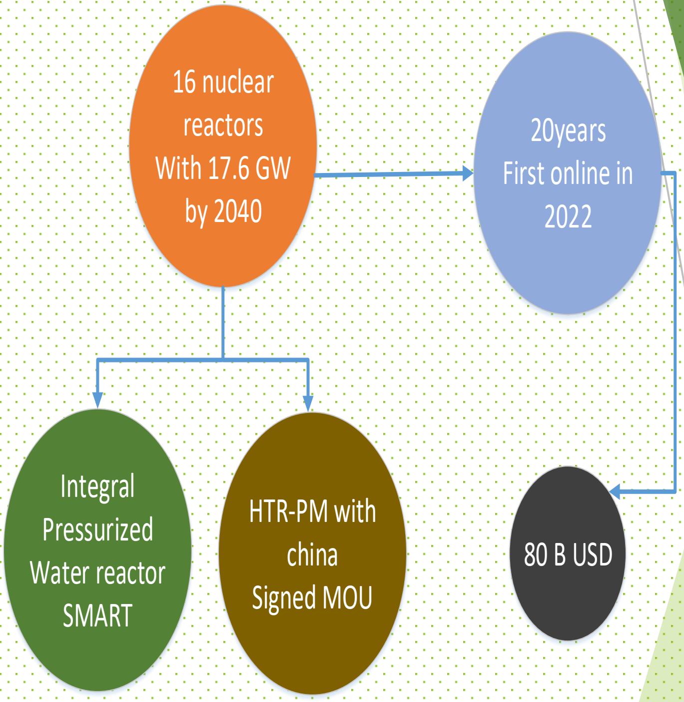


Views from National Energy Institute(NEI) and union of scientists

- "Compared to other energy sources used for electricity production, nuclear power plants use moderate amounts of water and minimal land per amount of electricity produced."
- "nuclear power plants withdrew 8 times as much freshwater as natural gas plants per unit of energy produced, and up to 11 percent more than the average coal plant."

Continue...

- In the light of recent developments, fourth generation high-temperature gas-cooled (helium) nuclear reactors in the USA, Japan, China are possibly the best technical and economical choice for nuclear power plants in the future across many countries in the world, including Kingdom of Saudi Arabia (KSA).
- There is a significant need to conduct a feasibility study to explore the technical aspects of manufacturing this type of reactors in great details parallel to an economic feasibility study.



Nuclear concerns-KSA

- The comparison of fourth generation reactors to the third generation nuclear reactors that are commercially available can be considered for the local economy of KSA
- The high temperature operation allows high efficiency for electricity production (50%) in addition to other high quality heat applications like production of hydrogen for petrochemical industry and desalination of seawater.
- Disadvantages and advantages of these reactors from a local perspective and benefits of related industries in KSA can be examined in the same sense. In the event that the use of these reactors is feasible for KSA, then it can play a leading role in the commercialization of these generation nuclear power.

In march 2016,Kingdom has **signed an agreement with South Korea for building up of SMART nuclear reactor developed by Korean Atomic Energy Research Institute (KAERI).**

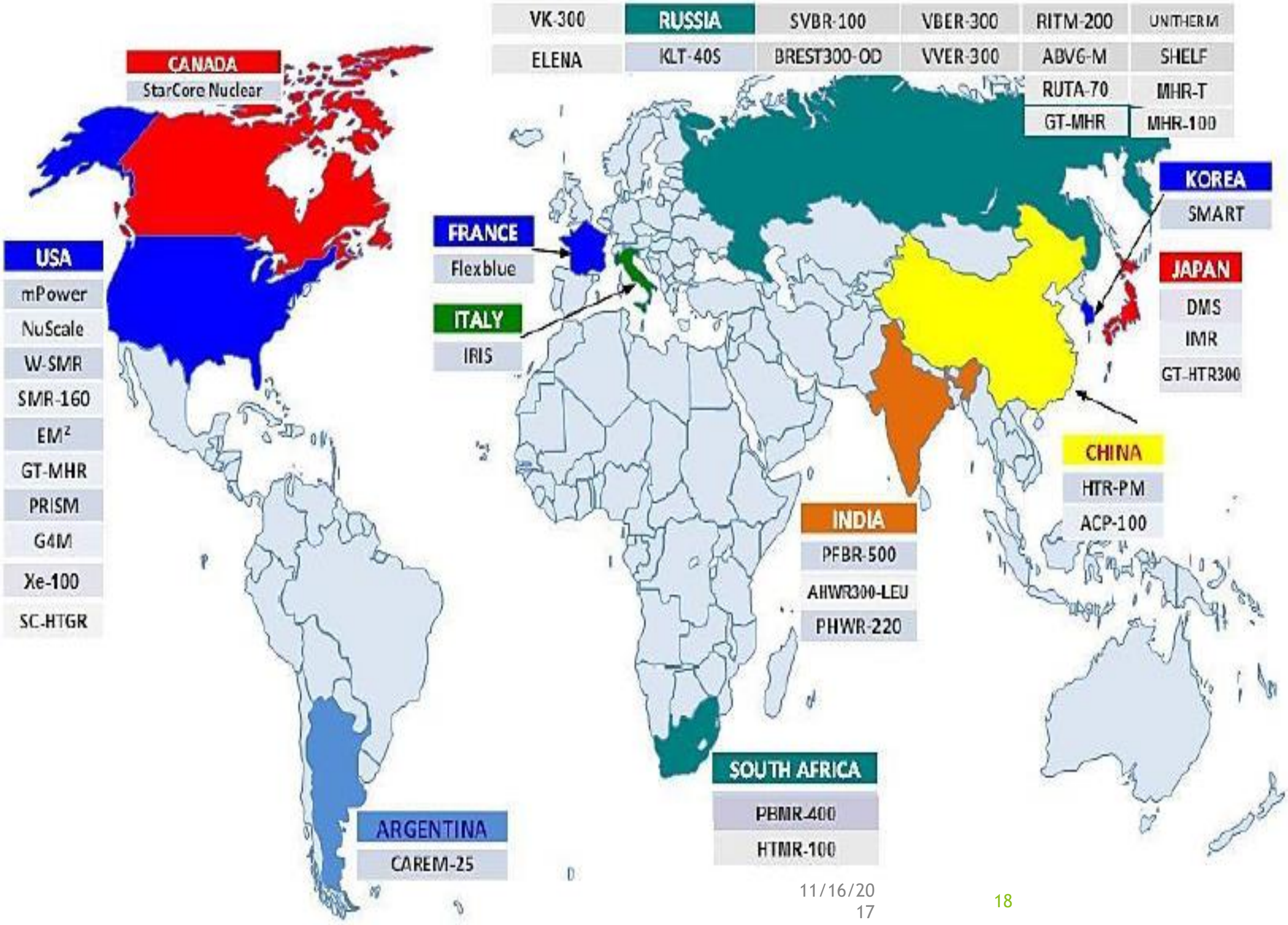
Dr. J. K. Kim and Dr. Waleed Abul Faraj, deputy president of K.A.CARE signed several contracts, which aim at building partnership to establish knowledge infrastructure in SMART technology fields, such as designing and building reactors and maintaining their mechanical and safety features.

These contracts aim at achieving actual partnership to establish an infrastructure knowledge in the scopes of the techniques of small Korean compact reactor SMART, as follows:

1. Cooperation and joint construction in *designing the core of SMART reactor*
2. Cooperation and joint construction in the *fluid system design of SMART technology*
3. Cooperation and joint construction in the *mechanical design of SMART technology*
4. Cooperation and joint construction for the *design of interaction between the machine and the user of Cooperation and joint construction*.
5. Cooperation and joint construction in *Safety Analysis of Cooperation and joint construction*

Exploring the status of Small Modular Reactor(SMR) its safety aspects and cost estimation scenario

MAP OF GLOBAL SMR TECHNOLOGY DEVELOPMENT



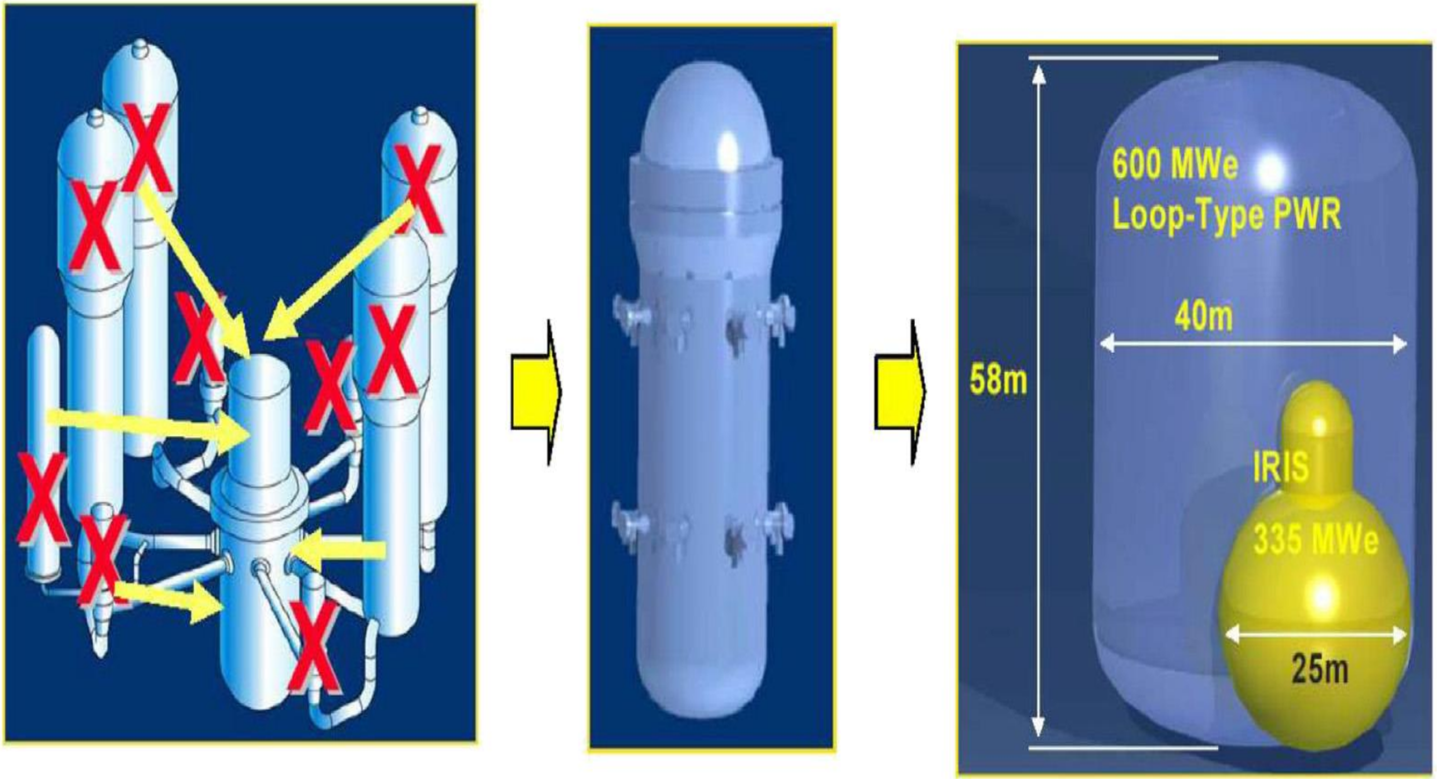
General overview

- There are about 45 small modular reactor (SMR) designs under development around the world, half of them under preparation for deployment over the next 10 years, and the first three expected to become operational over the next four years, an International Atomic Energy Agency meeting said.
- 59th IAEA general conference in Vienna, delegates were told that the first three SMRs with advanced technologies expected to become operational are the KLT-40S in Russia, the HTR-PM in China, and the Carem-25 in Argentina.

Current Small Modular Reactors

Light Water-Cooled SMRs (iPWRs)	Heavy Water-Cooled SMRs	Liquid Metal-Cooled Fast Reactors	High-Temperature Gas-Cooled Reactors
KLT-40(Russia)	PHWR 220(India)	4S(Japan)	CEFR(China)
SMART(Korea)	EC-6/CANDU-6(Canada)	PFBR-500 (India)	HTR-10(China)
CAREM-25 (Argentine)	AHWR300-LEU (India)	Hyperion (USA)	HTR-PM(China)
IRIS(USA)		PRISM (USA)	GTHTR300 (Japan)
NuScale(USA)		SVBR (Russia)	PBMR(South Africa)
MPower(USA)			HTMR 100 (South Africa)
ACP 100(China)			EM2 (USA)
VBER-300 (Russia)			SC-HTGR (USA)
ABV-6M (Russia)			Xe-100 (USA)
Flexblue (France)			GT-MHR (Russia)
DMS (Japan)			MHR-T /100(Russia)
IMR (Japan)			

IRIS As Contradictory Example



(a) (b) (c)

Economy of Scale

- Increased size…increase construction time
- Last two decades only proven designs built(Gen II & Gen III)
- Modularization needs heavy machines to carry and expensive software packages
- Factory manufactured, transportable and re-locatable, suitable for heat and desalination water and other by-products for industrial applications
- Smaller power output of SMRs may have a smaller emergency planning zone and cooling demand which means that it can be sited at a much greater range of sites than a large conventional nuclear reactor

Continue…

- Plug and play concept fits well with SMR as no need for on-site preparation
- Can be attractive for 300-400 MWe PWRs under capital cost of ($/Mwe)*
- According to OECD and NEA, SMRs can cost more than 50% depends upon the no. of units and economies of scale

*Hayns, M.R., Shepherd, J., 1991. Sir-reducing size can reduce cost. Nucl. Energy 30,85e93.

Continue…

- While considering the operation and maintenance(O&M) cost, multiple units of SMRs seems to be more expensive as compared to ONE big unit of LR.
- Decommissioning of SMRs seems to be easier than LRs as factory assembling and transportation is easy compared at on-site.
- SMRs are expected to be located very near to final destination thus to overcome the possible reduction in cost scenarios

Safer SMRs

- SMRs have smaller power output which means that in some designs, passive cooling of the core is being considered, thus allowing for reduced operator intervention in the event of an accident
- In the event of a catastrophic accident because the core is smaller less radioactive material is released to the environment
- Passive safety features reduces cost
- Competitive electricity rates, simple refueling and little waste storage
- Remotely controlled and have long time between refueling (10~30 yrs)

Continue…

- Fuel used is less enriched and cannot be enriched further to weapons grade
- Good for environment due to zero carbon emission
- Does not require large area for construction
- Economical, safe and secure
- Can be placed underground to reduce hazardous effects
- During the planning and construction, more sites can be evaluated

Continue…

- Short construction time resulting less capital cost and less maintenance
- Easier to recycle heat due to small size and core temperature
- Good for "new comers" as no need for having knowledge for building and construction scene.
- Categories in two: LRs with above 1000 MWe and SRs with 300 Mwe but for MRs no appealable concern.(AP 600 upgraded to AP1000)

Licensing issues..

Some of the licensing challenges that a potential SMR(PWR) would face are:

- **Testing and proving of the integral SMR (PWR) design** i.e. core, steam generator, and pumps etc being in a single vessel.
- **Testing and proving of designs with passive cooling**.
- Multiple SMR reactor **maintenance & safety** e.g. **number of reactor desk operators required for multiple SM PWRs at one site**.
- The Licensing Process in the U.S. is **quite lengthy** and Incompatible with SMRs(US-NRC report)
- **Initial Costs: Up to $30 Million** for one unit(hard to achieve for under developed nations)

Licensing issues..

Some SMRs designs are already well advanced and are due to be built or are being built, these are:

- In march 2015,KSA has signed an agreement with South Korea for building up of SMART nuclear reactor developed by Korean Atomic Energy Research Institute (KAERI).
- ACP100: a Chinese designed 100MWe integral SM PWR emplaced below ground which is due to start operation in 2018.
- HTR-PM: a Chinese designed high temperature gas cooled reactor currently under construction. The reactor uses a technology similar to South African Pebble Bed Modular Reactor (PBMR)

Economic Analysis

- Average investment & operating cost per unit of electricity are decreasing with increase in plant size with principle

NOT REALLY FOR SMRS

As other things might be equal

- But Number of benefits are greater than Large reactors

Competitiveness of SMRs

- Difference in design & approach
- Comprehensive quantitative evaluation approach

Design & Approach

- Compactness
- Design related scenario
- Cogeneration
- Planning margin decline
- Supply to demand
- Grid stability
- Economy of application
- Bulk ordering
- Modularization
- Size
- Factory fabrication
- Learning scenario
- Multiple unit on-site
- Construction time required
- Front end investment
- Progressive or operational of multiple units

Investment scenario

- Smaller size and shorter construction time gives more flexibility in sizing, timing and siting than those of LRs
- Change market conditions(Generation cost, revenues and financial cost)

  Construction $\propto$ net investment

- Big potential for investors and quickly adopt varying market conditions

Multiple units of SMRs $\leq$ one LR unit

Power grid & stability issues

- Big power grid needs development of larger units(1000MWe) which requires well developed infrastructure that are capable of accepting larger grids thus limits the probability of acquiring LRs

- This problem can easily be tailored by SMRs while meeting the rising power demand & economic growth and urbanization
- While avoiding grid instability using fossil fuels and related green house gases concerns at the same time.
- In this case multiple SMRs unit can reap profit lost by LRs

New design & Concern Solutions

- Technological design is directly proportional to economies of NPPs
- Integral and modular approach gives possibility to exploit simplification of the plant thus gets more safer design(e.g IRIS design)
- Integration concept increases the compactness of the plant
- Limited occupied area gives lower probability of air strikes
- Life time of the plant increases and radiation damaged on RPV is inherently avoided by large water thickness between RPV and core thus maintaining the Levelized Unit of Electricity Cost(LUEC)

Cogeneration

- Integral approach produces heat for urbanization and for desalination VERY near to the plant.
- Enhanced Safety features and reduced source term can lead to reduction of emergency planning zones and hence to locate the SMRs not far from urban areas
- More importantly, thermal power from SMRs(non-electric) is coherent with thermal loads or water needed for an urban areas
- This feature dramatically increase the possibility of SMRs compared to LRs
- Another important factor ….some SMRs have limited installed power therefore many more SMRs could be possible to achieve heat bulk production of ordering process (e.g. valves and other components) thus stabilizing the economies

Major factors affecting cost

- Plant Size demonstrate the specific capital cost
- Factory fabrication is cheaper than on-site thus less expensive and less time consuming…Allowing greater standardization (Modularization)
- Maintenance and technical concept will be within the plant size thus reducing the cost and investment
- NOAK(Nth Of-A-Kind) plant cost is less than FOAK(First Of-A-Kind) due to lesson learned in the construction and deployment of earlier units….Consequently …NOAK reaches less MeV than SMRs and LRs

Continue ….

- Learning opportunities at on-site is greater in SMRs than in LRs
- Greater the no. of co-sited, lower is the investment cost, best utilization of material and sharing of human resources
- With each additional module, subsequent cost is decreases as well
- Current projected scheduled for SMRs are three years for FOAK and 1-2 yr for NOAK
- The critical cost of ONE unit is smaller than LRs…good market for the utility or country with limited resources

Cost generation cost model

- Production cost of electricity($/MWh) corresponds to plant to be analyzed gives a cash flow expenditure(LEUC)
- This model should be flexible and sufficient to receive data for new reactor solution

$$TC = TC(q,S,T,X)$$

q : MWh

S : Mwe

T : Reactor technology(LR or SMRs)

X : Economies of scale

Cost Function $\propto$ total capital cost/total operating cost

$$CF = CF(TCC:TOC)$$

Challenges..

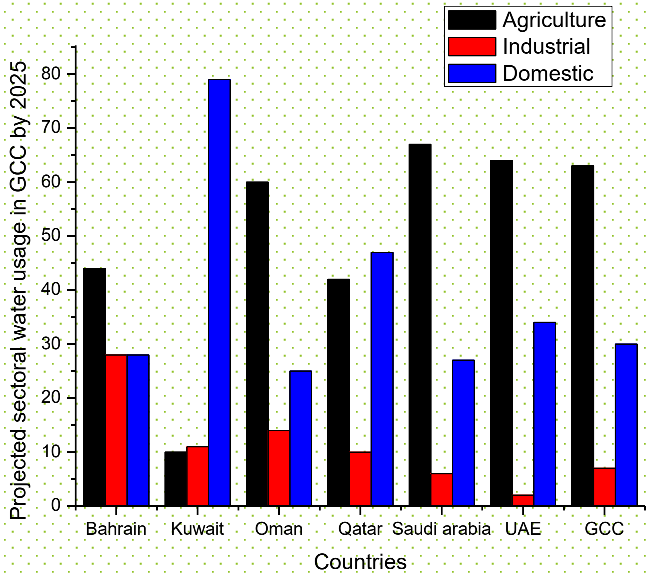
Besides the effective and substantial benefits of SMR's there must be considered some challenges like technical and institutional.

- Concerning with technical issue additional development in instrumentation and control system is required such as lack of external primary coolant loops which means measurement of coolant flow and heat balance are not possible and in-vessel measurement should be adopted.
- Extended fuel cycle length is required which incorporates online monitoring instrumentation for plant safety.

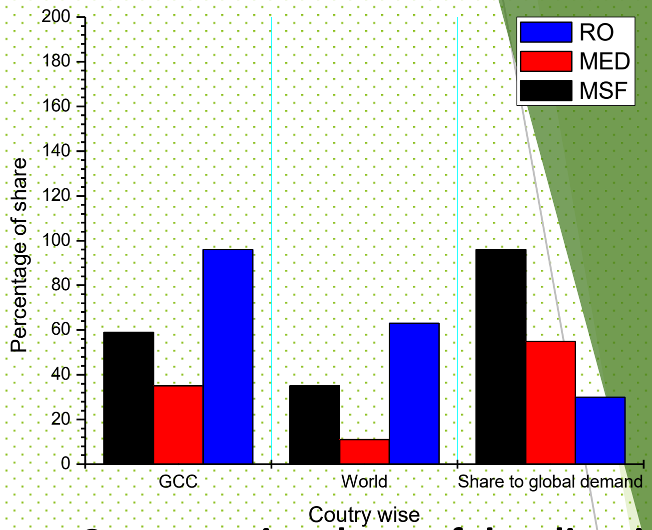
Challenges..

- Second phase is the institutional challenges, since there are too many competing designs which make confusion on the number of choices also the economy consideration and mindset implicates that SMR's are not competitive.
- Moreover it also includes public perception, investor relations and extensive and protracted licensing activities

Current status of desalination plants across the globe and nuclear desalination system with associated technologies as promising features to KSA region



Projected water usage plan up to 2025*



Country wise share of desalination technologies*

Recent figures of online and contracted plant with their capacities in GCC region

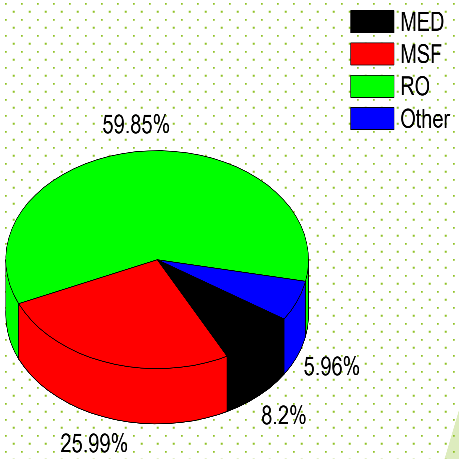
Country	Population	Online capacity(m^3/day)	Online plants	Contracted capacity (m^3/day)	Contracted plants	Desalinated water production(million m^3)
KSA	28290000	13080497	2664	14791660	2688	1690.6
Oman	5517000	1094740	184	1350832	187	114.13
UAE	9205651	9358492	492	10109057	497	1357.1
Kuwait	3250500	3023369	88	3477969	89	749.34
Qatar	2035106	1832762	139	1997218	141	252.61
Bahrain	1318000	113001	165	113001	165	161.96

*DesalData [www Document], 2013. URL http://desaldata.com/ (accessed 6.14.13

Water concerns-MENA region

- Fresh water is one of the main concerns in Gulf countries for their sustainable development, the actual production of electric power and desalted water in Saudi Arabia is about 40 GW and 3.3 Mm^3/day, which require consumption of about 2.5 M barrel/day of petrol.
- Most of the desalinated water in the world is produced in the MENA region. The largest plant produces about 0.5 M m^3 of clean water per day
- Globally, 2/3rd of the desalted water is produced from seawater, while the remaining 1/3rd uses brackish artesian water

Total installed capacity: 66.4 M m3/day



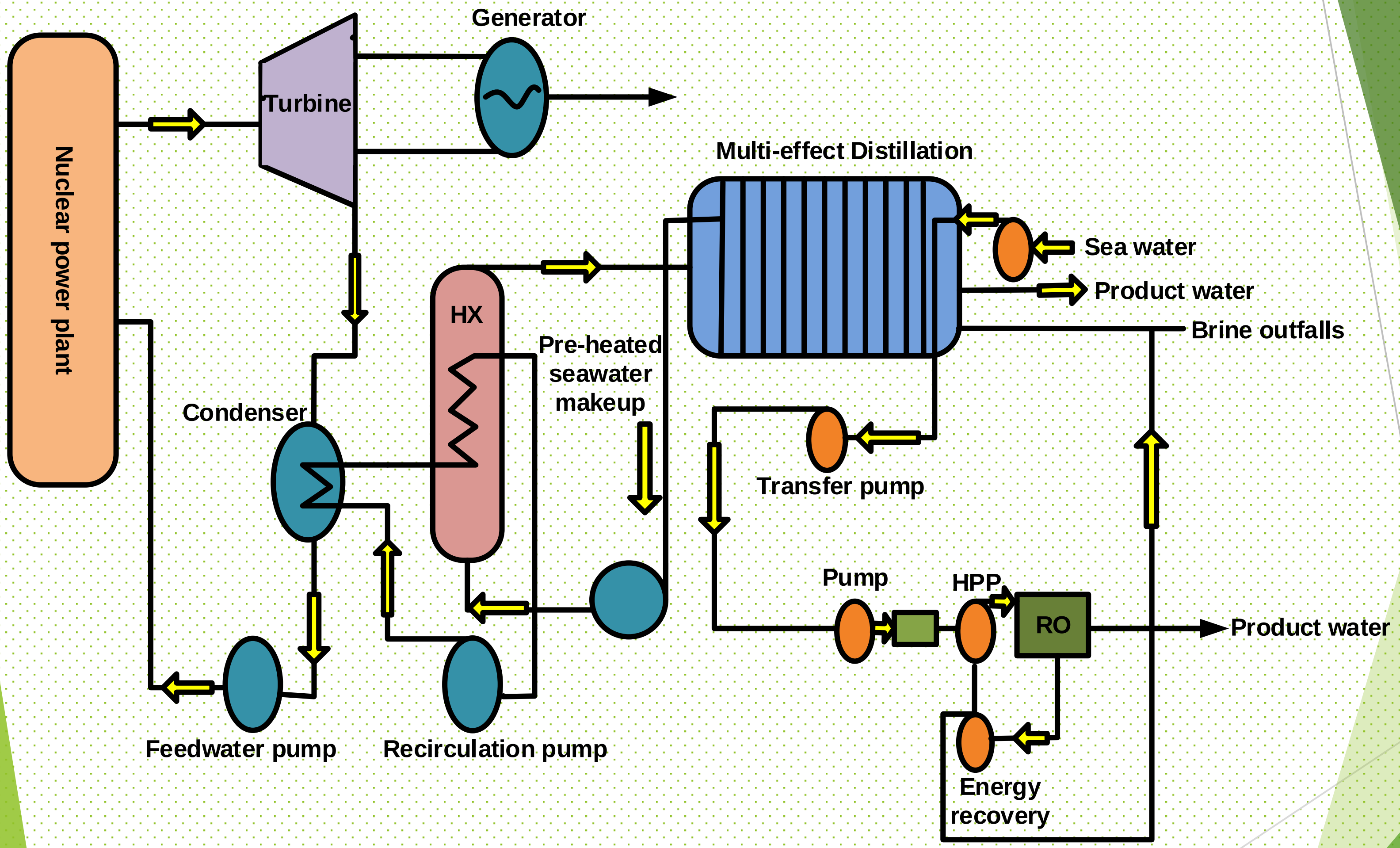
Nuclear concerns-MENA region

- Reverse Osmosis (RO) is one of the major techniques used these days to produce clean water. Cost effective RO process have swapped multistage flash distillation process (MSF) which was very prominent earlier for processing brackish water by using waste heat from power plants, despite the fact that MSF gives cleaner water than RO
- Nuclear energy is being used in desalination processes and has proved to have great potential of producing potable water.
- Small modular reactors with co-generation of electricity utilize heat from low-pressure steam from the turbine and the hot seawater outlet from the cooling condenser to produce drinkable water.
- Some studies identify the best outputs from nuclear desalination plants in the range of 80-100,000 m^3/day to 200-500,000 m^3/day.

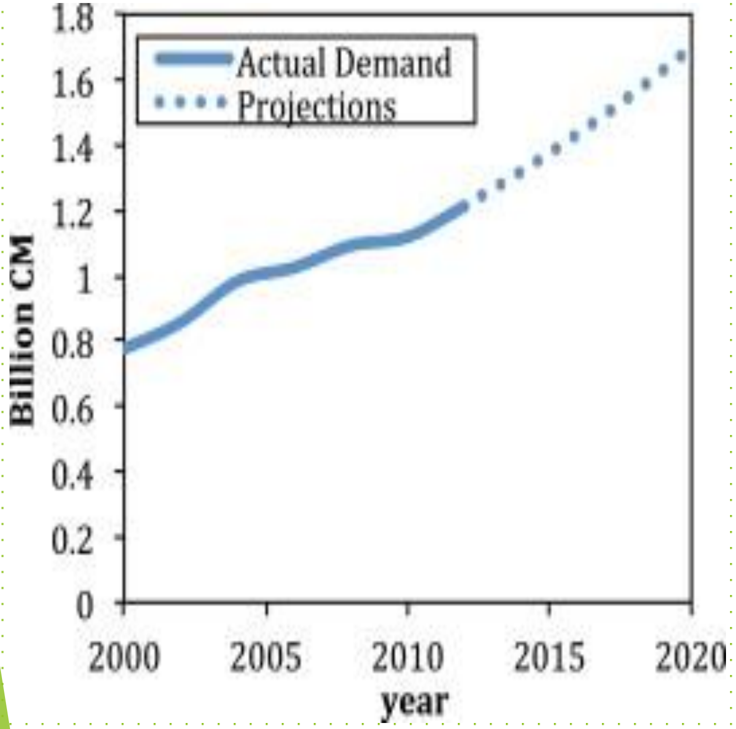
Nuclear concerns-MENA region

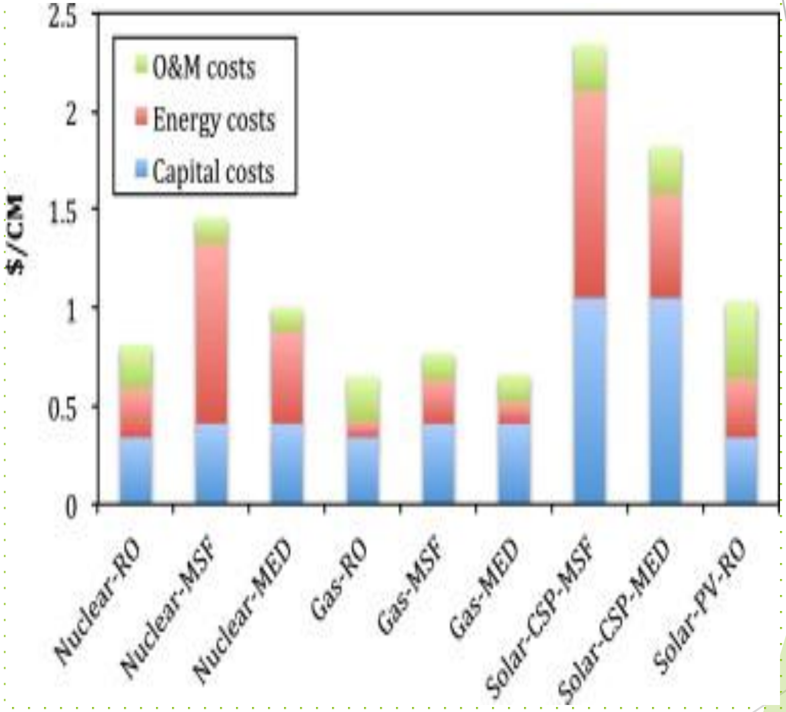
- Based on the country-wise studies from International Atomic Energy Agency (IAEA), it has been showed that costs would be in the range (US$) 0.5 to 0.94/m^3 for RO, US$ 0.6 to 0.96/m^3 for MED, and US$ 1.18 to 1.48/m^3 for MSF processes
- Nuclear desalination appears very interesting not only for countries, which are poor in fossil energy resources but also for countries having gas and petrol resources.
- One of the main advantages of the nuclear reactor to be coupled with desalination system is the production of high temperature and pressure steam.
- The steam generated can be used at certain points in the secondary loop for desalination purposes.
- The dual purpose of achieving the low water cost and potable water can be available if connected with any hybrid energy system

Schematic diagram of coupling of nuclear power plant with desalination system



Actual and projected water demand in Saudi Arabia





Nuclear reactor coupled with desalination

- One of the main advantages of the nuclear reactor interconnected with desalination system is the production of high temperature and pressure steam.
- The steam generated can be bled off at certain points in the secondary loop of power plant for the desalination purposes.
- The dual purpose of achieving the low water cost and portable water can be available if connected with any hybrid energy system.

Country	**Desalination Technology**	**Output water Ratio (m3/day)**	**Region**	**Status**
Australia	RO	450,000	Wonthaggi	Expandable to 200GL/yr using renewable Energy
	RO	100,000	Adelaide's	Expandable to 100GL/yr
China	MED (by 200MWt NHR-200 reactor)	80,000-160,000	Shandong peninsula	Planned
	RO	100,000	Qingdao	Started operation in 2013
	Nuclear+MED	330,000	Daya bay	Expected in 2015
	RO	100,000	Caofeidian	Expanded to double in 2012
Algeria	MSF	150,000	Oran	Study
	MSF	500,000	Magtaa	Started in 2012
	RO	120,000	Fouka	Started in 2011
Egypt	RO	24,000	Marsa Matrouh	Expected to start in 2013
	Cogeneration plant for electricity and potable water		El-Dabaa	Expected to start in 2019-2025
Ghana	RO	60,000	Nungua	
India	MSF+RO	45,000		
	RO	100,000	Nemmeli	In operation, 2013
	RO	200,000	Pattipulam	Planned
Indonesia	MSF(by SMART nuclear reactor)	-	Madura Island	Expanded to large scale PWR cogeneration
Iran	MSF(by Bushehr NPP)	200,000	Bushehr	Construction Delays
Kuwait	Co-generation 1000MWe reactor	140,000	Kuwait	Under consideration
Jordon	-	-	-	Water shortage of 1,400,000. Looking for nuclear power.
Libya	MED+RO(by using SMR)	-	-	Plan for adapting Tajoura research reactor
Mexico	RO	21,000	El Salitral	Expected to start in 2013
Morocco	MED(by 100MWt NPP)	8,000	Sidi Boulbra	NPP to be started in 2016-17
Oman	RO	45,460	Barka	To be started in 2013
	RO	190,000	Al-Ghubrah	Operation in 2014
Qatar	MSF	160,000	Ras Abu Fontas	Expected to start in 2015
Russia	RO	10,000	Vladivostok	Commissioned in 2011-2012
Saudi Arabia	MED	68,000	Yanbu	Expected to complete in 2014(Largest MED)
	MSF	550,000	Yanbu	Completed in 2016
	MSF	880,000	Shoaiba	
	RO+MSF	1,025,000	Ras Al Khair	Expected to complete in 2014
Spain	RO	1,100,000	South East of Spain	Under Construction
Tunisia	-	-	Southeast region	Looking for Cogeneration(desalination + electricity)
UAE	RO	68,130	Ras Al-Kaimah	Under planning
	RO+MSF	591,000	Qidfa in the Emirate of Fujairah	
	Cogeneration MSF	454,000	Al Ruwais	Started in 2011
	MSF	450,000	Hassyan	Deferred bidding
United Kingdom	RO	150,000	Lower Thames estuary	Proposed
USA-	RO	375,000	Baja, California	Working

Status of Nuclear Desalination system

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
China	MED (by 200MWt NHR-200 reactor)	80,000-160,000	Shandong peninsula	
	RO	100,000	Qingdao	Started operation in 2013
	Nuclear+MED	330,000	Daya bay	Expected in 2015
	RO	100,000	Caofeidian	Expanded to double in 2012
Indonesia	MSF(by SMART nuclear reactor)		Madura Island	Expanded to large scale PWR cogeneration

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
Jordon				Water shortage of 1,400,000. Looking for nuclear power.
Libya	MED+RO(by using SMR)			Plan for adapting Tajoura research reactor
Morocco	MED(by 100MWt NPP)	8,000	Sidi Boulbra	NPP to be started in 2016-17
Iran	MSF(by Bushehr NPP)	200,000	Bushehr	Construction Delays

CAREM and SMART desalination units

Nuclear Reactor Name	Technology	Thermal power (MWth)	Water output (m^3/day)	Power cost($/MWh)	Water cost($/$m^3$)
CAREM	RO	100	10,000	68	1.5
	MED				1.81
	RO+MED				1.88
	MSF				2.36
SMART	RO	330	40000	67.4	0.81
	RO+MED				1.07
	RO+MSF				1.53

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Development and techno-economic analysis of small modular nuclear reactor and desalination system across Middle East and North Africa region

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ABSTRACT

In the Middle East region, desalination technology is gaining higher attention as compared to other part of the globe. In this article, we have carried out a study to evaluate the current status of small modular nuclear reactors and the International Atomic Energy Agency (IAEA) assisted desalination projects for the Middle East and North Africa region, developing and developed countries of the world. The potential of the Kingdom of Saudi Arabia (KSA) for adopting nuclear reactors and coupled nuclear reactor desalination is also discussed. Theoretical and computational techniques that could be best suited for adopting nuclear desalination are described in details. Finally, the techno-economics analysis of CAREM and SMART nuclear reactors with cost estimation is discussed. The obtained results will be helpful in estimation of different cost scenarios of desalinated water from nuclear reactor.

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Theoretical calculation simulation studies of ABV nuclear reactor coupled with desalination system

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SUMMARY

In this paper, research has been conducted on the floating type nuclear power plant named as ABV reactor which is designed for district heating, power, and sea water desalination by OKBM facility at Russia. This reactor was tested under different thermal loads during the designing phase, and three modules have been investigated. Theoretical calculations and simulation studies have been performed on these three modules having specifications as ABV-6M with $47MW_{th}$, ABV-6 with $38MW_{th}$, and ABV-3 with $18MW_{th}$. The results obtained from these modules have been calculated mathematically and verified by simulation. We have compared the originally derived data of ABV desalination system with our theoretical and simulation analysis. The results from two desalination techniques including RO and RO + MED have been calculated and are presented in this paper with details. The results obtained from both analysis show that the efficiency of ABV nuclear reactor desalination system increases with the decrease in corresponding water cost ratio. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS
ABV nuclear reactor; desalination; reverse osmosis (RO); multieffect desalination (MED); mathematical calculations; simulation; comparative analysis; water cost

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