تقنيات الطاقة المستدامة
Sustainable Energy Technologies

Nuclear Desalination and Hybrid Energy Systems

Dr. Salah Ud-Din Khan

Assistant Professor

Outlines

- **Energy estimation scenarios in KSA**
- **Nuclear desalination system and SMRs**
- **Coupled nuclear desalination concept**
- **Kingdom of Saudi Arabia as special case**
- **Nuclear hybrid energy concept**

Energy estimation for KSA

- It is calculated that the current reservoirs of KSA are estimated to be 268.35 billion barrels/day (43×10^9 m^3) and the decline of resources is about 3.4M barrel/day* (as calculated in 2009) and will further deteriorate to 8.3M barrel/day up to the year 2028**(*This will remarkably decrease the export of the country*)
- Considerably, the electricity demands is estimated to increase from 75GWe by 2018 to above 120GWe by 2030 and this demand will definitely reduce its crude oil exportation if the local demand needs to be met.
- This demand of energy forced the decision maker of the country to think about other resources that could pave way for better options. In lieu of this, development of nuclear reactors has been considered to be the obvious and workable choice.

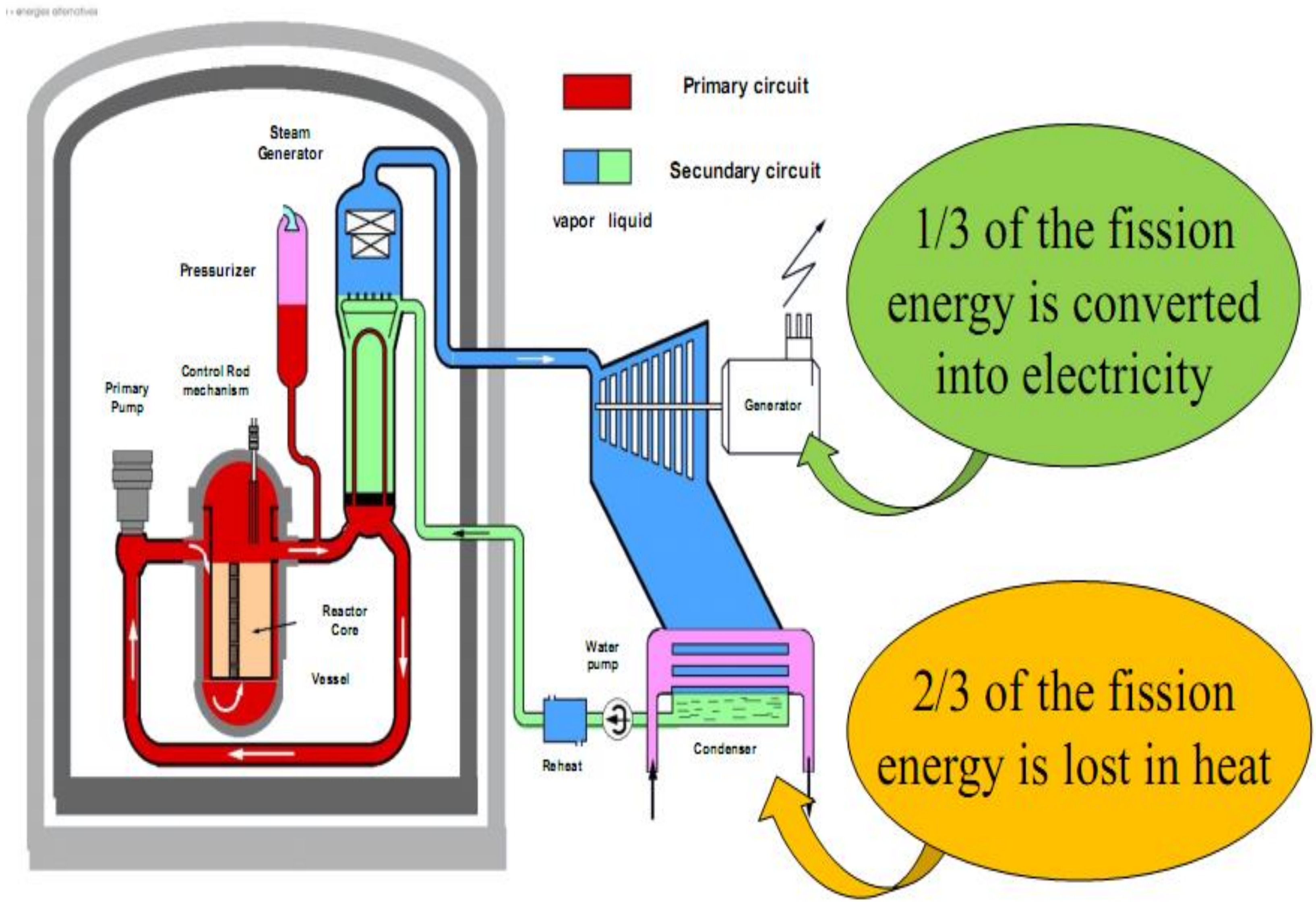
*US EIA, International Energy Statistics, Reserves, 2015.

**Sulaiman AlYahya, Mohammad A. Irfan, The techno-economic potential of Saudi Arabia's solar industry, Renewable and Sustainable Energy Reviews, Volume 55, March 2016, Pages 697-702, ISSN 1364-0321

Nuclear concerns-KSA

- 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.
- 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.

Nuclear Heat Recovery



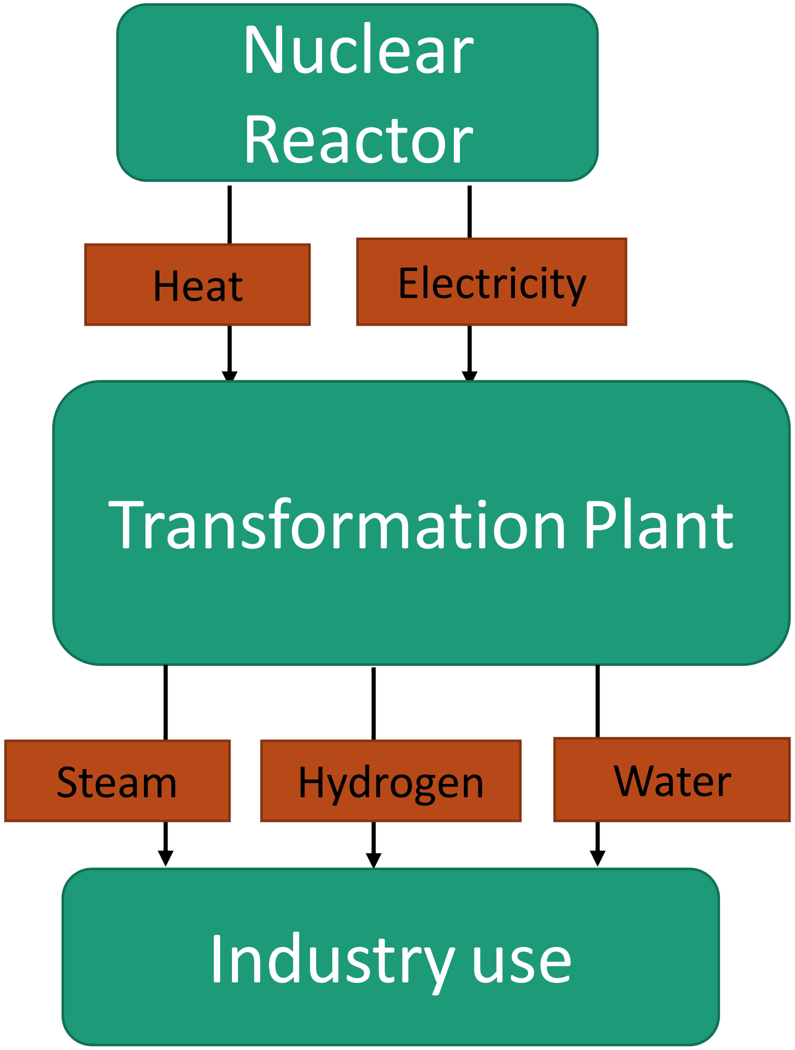
Prospects of Nuclear Power

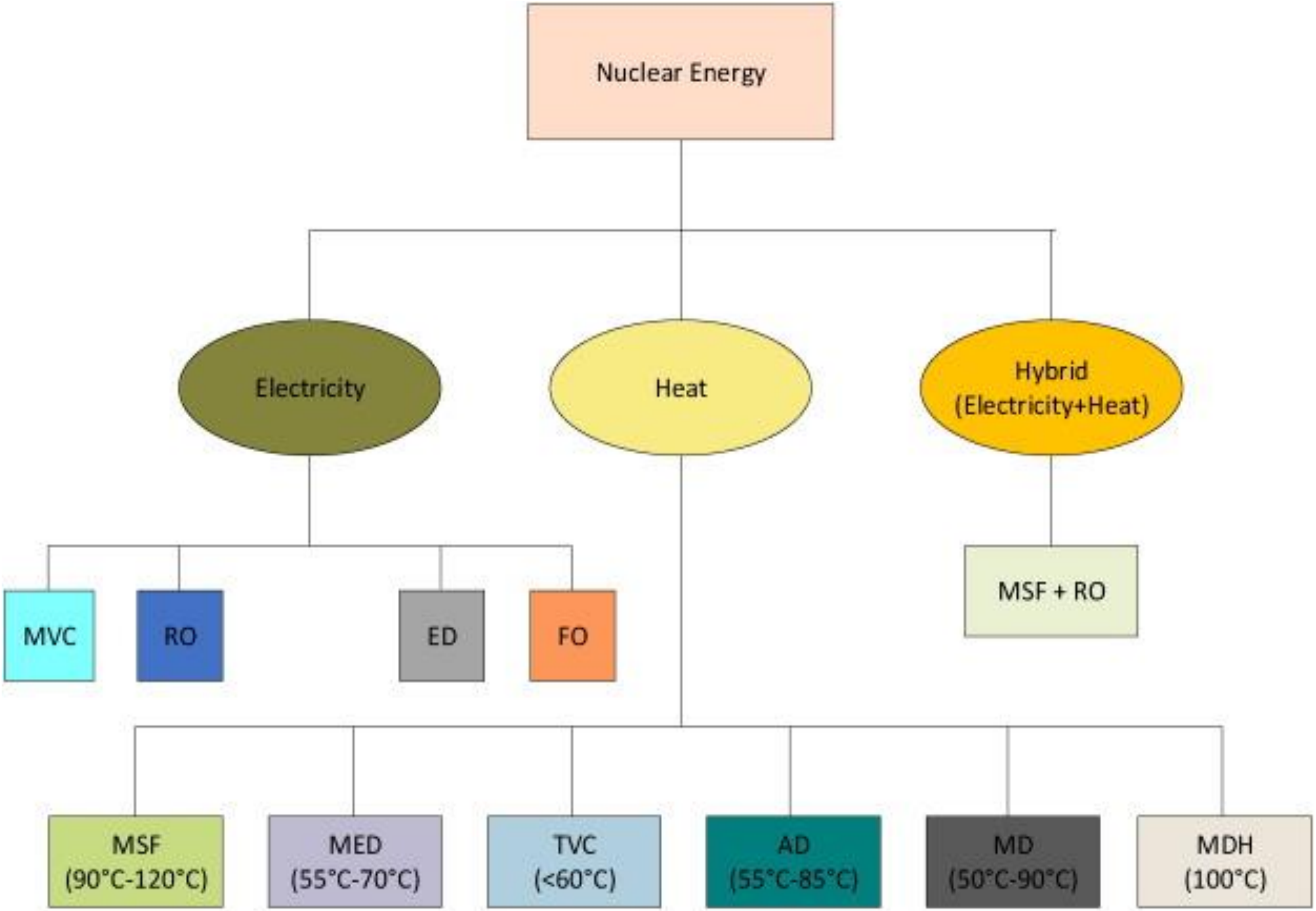
Low Temperatures (40-250)C → **District Heating**, **Water Desalination**

Medium Temperature (250-550)C → **Industrial Steam**, **Coal Liquefaction & Gasification**, **Bio mass & Bio fuels**

High Temperature (550-900)C → **Hydrogen Production**

Industry requires steam at moderate temperature and about 40% of energy consumption is heat;





AD	Adsorption Desalination	MSF	Multi Stage Flashing
ED	Electro Dialysis	MVC	Mechanical Vapor Compression
FD	Forward Osmosis	RO	Reverse Osmosis
MD	Membrane Distillation	TVC	Thermal Vapor Compression
MED	Multi Effect Distillation		

Desalination

- Fresh water is one of the main concerns in Gulf countries for their sustainable development as well as in many arid regions of the world. The actual production of electric power and desalted water in Saudi Arabia is about forty gigawatts and three million meter cube per day which require consumption of about two and half million barrel of petrol per day.
- The future demand for electricity and water is set to grow by 7% per year which may be doubled in 2025, owing to a rapidly-growing population, increasing urbanization and swift industrialization.
- Most of the fresh desalinized water in the world is located in the Middle East and North Africa. The largest plant produces about 0.5 million m^3 of clean water per day. Two thirds of the desalted water produced in the world is processed from seawater, while the remaining third uses brackish artesian water.

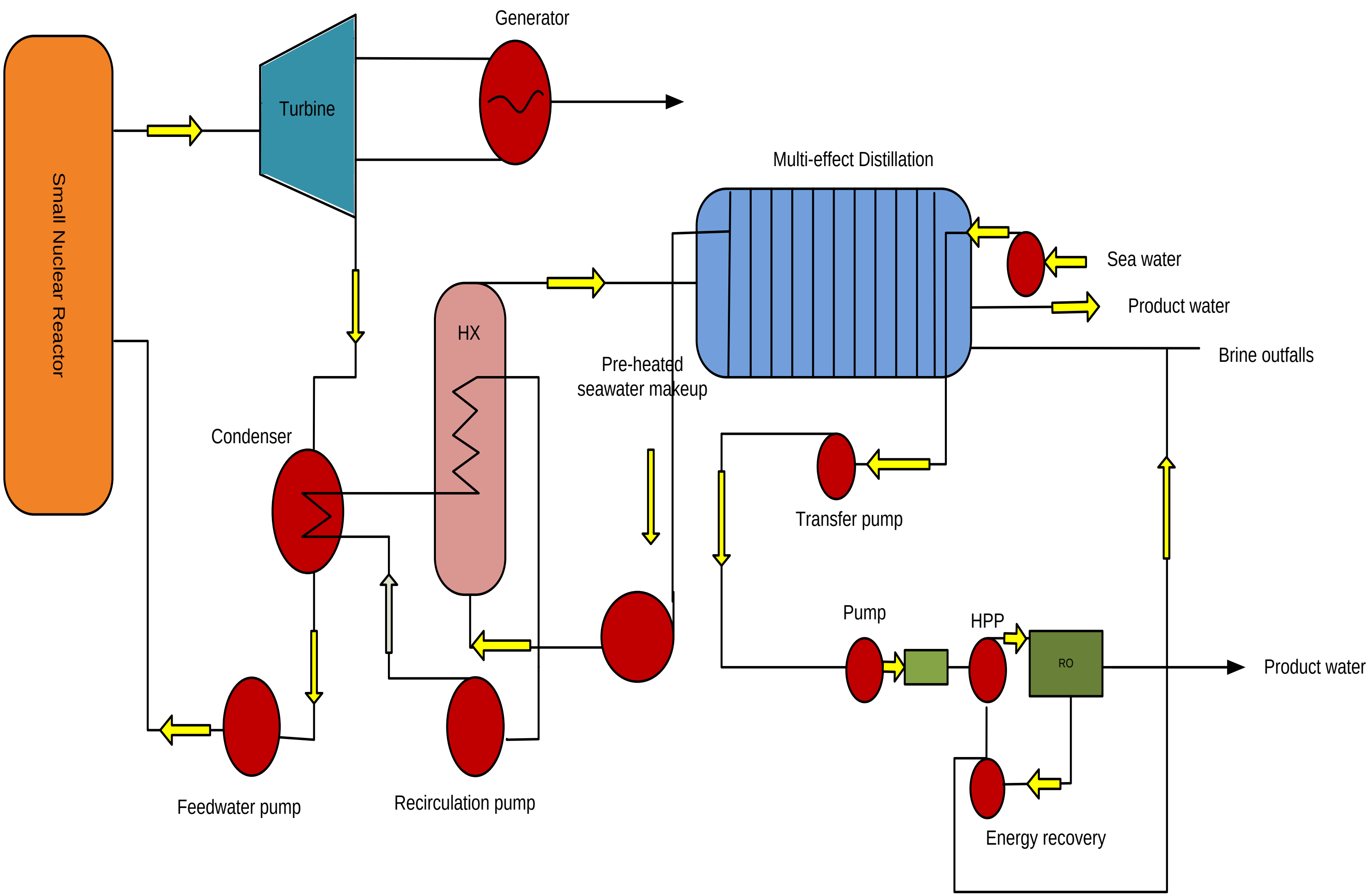
Nuclear Desalination

- Middle East is considered one of the most arid regions on the surface of Earth and is facing a critical water crisis. Majority of desalination plants are located in Middle East and North Africa, having a total capacity of 80 million m^3/day of potable water.
- The largest desalination plant is located in Saudi Arabia (Jubail 2) with a capacity of 948,000 m^3/day operated by Saudi Water Conversion Corporation. About 2/3rd of the plants across the globe are desalinating seawater and 1/3rd desalts brackish water. Presently distilled water is produced mostly by burning fossil fuels which are depleting exponentially with every passing day.
- Nuclear desalination is considered one of the viable and cost effective medium/long term solution to this crisis. Many countries are using nuclear desalination system which includes Kazakhstan, India and Japan. Since there is a vital importance of employing small to medium sized nuclear reactors for desalination purposes. Therefore, it is viably important to study the different aspects of the potential use of nuclear reactors for water desalination and electricity co-generation in the Kingdom of Saudi Arabia (KSA).

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)			

Schematic diagram of Integration of Small modular reactor with desalination system



Nuclear reactor coupled with desalination

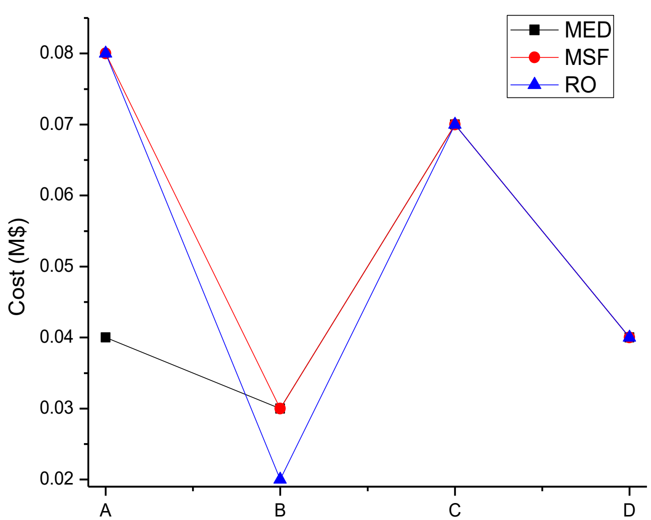
- One of the main advantages of the nuclear reactor interconnected with desalination system is the production of high temperature and pressure steam. The steam generated can be bled off at certain points in the secondary loop of power plant for the desalination purposes. The dual purpose of achieving the low water cost and portable water can be available if connected with any hybrid energy system.
- For the coupling of nuclear reactor with any distillation process it is required for the two plants to be on the same site in order to prevent heat losses. This integration process includes MSF system along with RO plant that will reject the cooling water from the MSF plant to the RO plant. Generally, the purpose of nuclear reactor is to generate electricity but there is some amount of thermal energy that are available in the form of waste heat discharged through the condenser cooling system.

SMRs Technology with ND

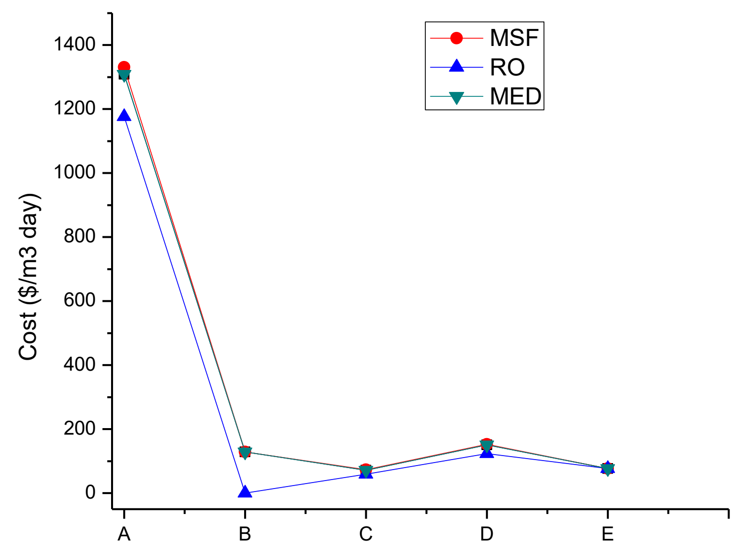
- Small Modular reactors with co-generation of electricity utilize heat from the low pressure steam from the turbine and the hot sea water outlet from the cooling condenser to produce drinkable water. Some studies identify the best outputs from nuclear desalination plants in the range of 80-100,000 m^3/day to 200-500,000 m^3/day .
- The main advantages of nuclear desalination unit over a fossil fuel unit are the water production cost and negligible environmental pollution. The last report of the International Atomic Energy Agency (IAEA) based on country case studies showed that costs would be in the range (US$) 0.5 to 0.94/m3 for RO, US$ 0.6 to 0.96/m3 for MED, and US$ 1.18 to 1.48/m3 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 because the nuclear desalination costs are about half those of the gas plant for MED technology and about one third less for reserve osmosis RO.

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



A= Labor cost, B=Insurance cost, C=Material cost, D=Management cost



A= Construction cost, B=Intermediate loop heat cost, C=Water plant cost, D=Water plant contingency, E= Infall/Outfall

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

Nuclear Hybrid Energy Concept

Integrating nuclear power with other energy conversion processes enables:

- Efficient, stable deployment of renewable energy
- Improved carbon usage during conversion of fossil and biomass into transportation fuels
- Deployment of nuclear energy beyond baseload electricity generation
- System flexibility to accommodate long-term transitions in energy consumption (e.g. from liquid hydrocarbons to electricity from transportation)

Nuclear Hybrid Energy System

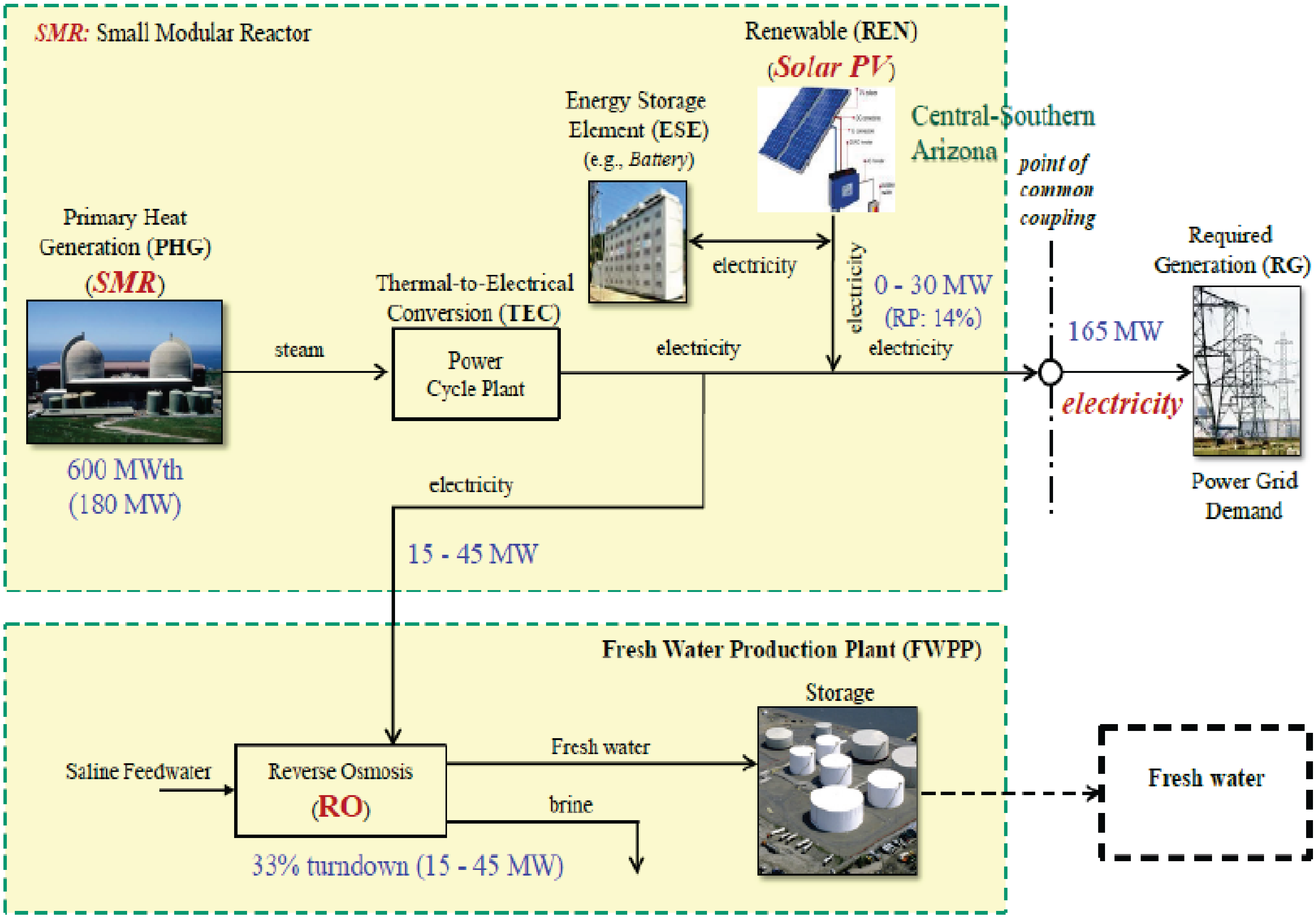
- Design of nuclear hybrid energy system (HES) has been proposed which is the combination of active and passive safety system. The developing process of integration in different electrical as well as non-electrical applications increases the trends for energy production plant like hybrid energy systems.
- Research has already been conducted in terms of renewable energy integration, stability of electric grid, greenhouse gas emission.

Resources	Coupling mode	Storage mode	Products
Nuclear+ biomass	Thermal	Chemical	Electricity+ biofuels
Nuclear+ CSP	Thermal	Thermal	Electricity+ heat
Nuclear+ wind energy	Thermal	Hydrogen	Electricity + hydrogen
Nuclear+ wind+ natural gas	Electrical + thermal	Chemical	Electricity +chemical + diesel fuels

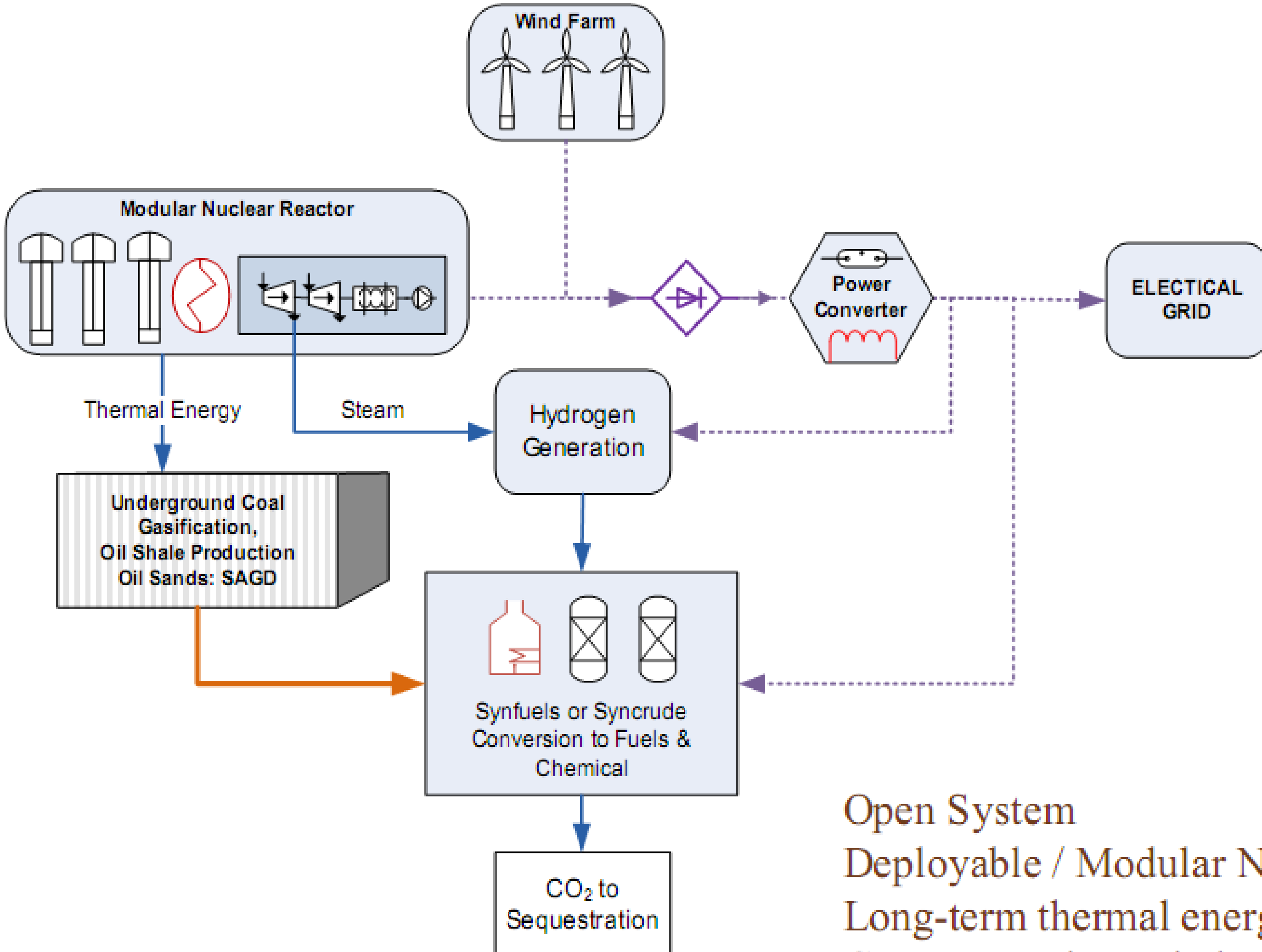
Integration of SMRs with HES

- Considering the integration of HES with nuclear reactor typically of lower power, small nuclear reactors could be an ideal choice.
- The innovation in the design of SMRs expended the markets for nuclear HES by introducing more flexible and affordable option
- Small to medium sized nuclear reactors offer great potential to HES but this concept of using nuclear energy for the variety of non-electrical process applications is not an innovative idea.
- The nuclear HES system may contain numerous problems regarding affordability, operability, feasibility and safety of large scale.

SMRs with Hybrid energy system



Hybrid energy system



Open System
Deployable / Modular Nuclear Reactor
Long-term thermal energy deposition
Constant or dynamic heat maneuvering
Constant Fuels Production

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Thank you