Nuclear Hybrid Energy Concept and Nuclear Desalination System

Dr.Salah Ud-Din Khan
Assistant Professor
Sustainable Energy Technologies Center
King Saud University, Riyadh,
Kingdom of Saudi Arabia

Goals

- Analysis of the growing energy demands interconnected with oil assets consumption and increasing population as challenge for the Kingdom of Saudi Arabia (KSA) to make a strategic plan for energy.
- With development of a nuclear energy program underway in the KSA, gain insight into the many possible options for the development of nuclear reactors including (small modular reactors) which are considered to be the best choice
- Hear about the feasibility studies for nuclear desalination systems in terms of integrating nuclear technology with desalination systems

Introduction(1)

- The growing energy demands interconnected with oil assets consumption and growing population warn the Kingdom of Saudi Arabia (KSA) to make a strategic plan for energy.
- The total reserves of the KSA have been calculated as 267 billion barrels while the current situation leads to the increase of 3.4 million barrels in 2009 to 8.3 million barrels by the year 2028.
- Keeping in mind the entire current situation, the KSA government has increased its subsidies of energy to 100 billion dollar in 2011 only for the domestic consumptions.

Introduction(2)

- Considerably, the electricity demand is estimated to increase from 75GWe by 2018 to more than 120GWe by 2030. This demand cannot be compensated by only fossil fuel and the decline recourses of oil.
- In these criteria, the development of nuclear reactors is considered to be an obvious choice and the KSA government is agreed to work on the nuclear energy.

Hybrid Energy System

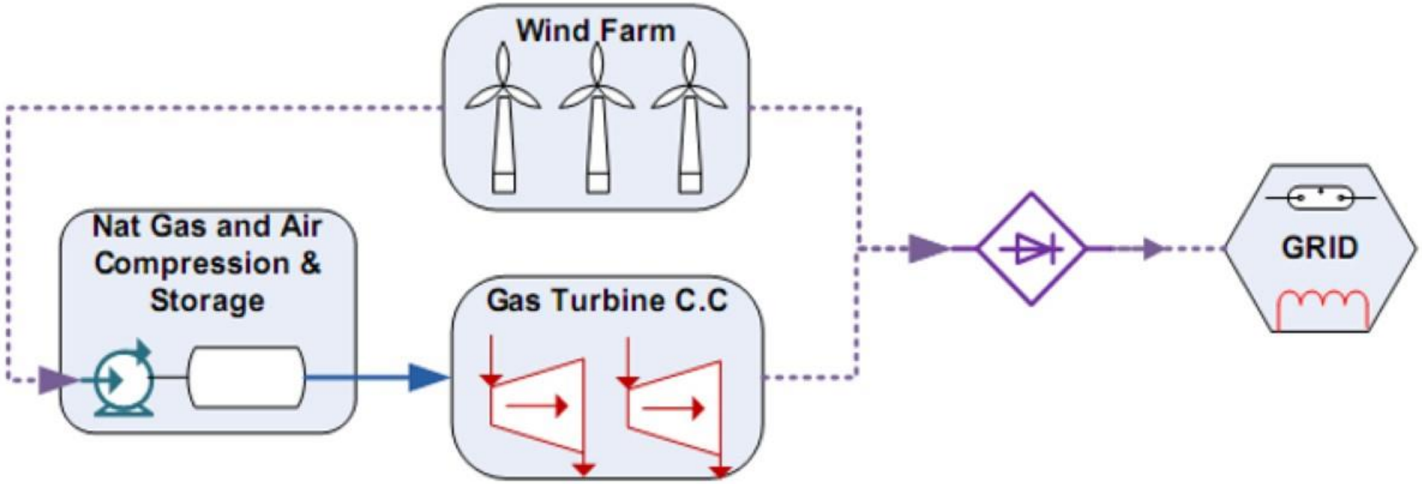
Definition:

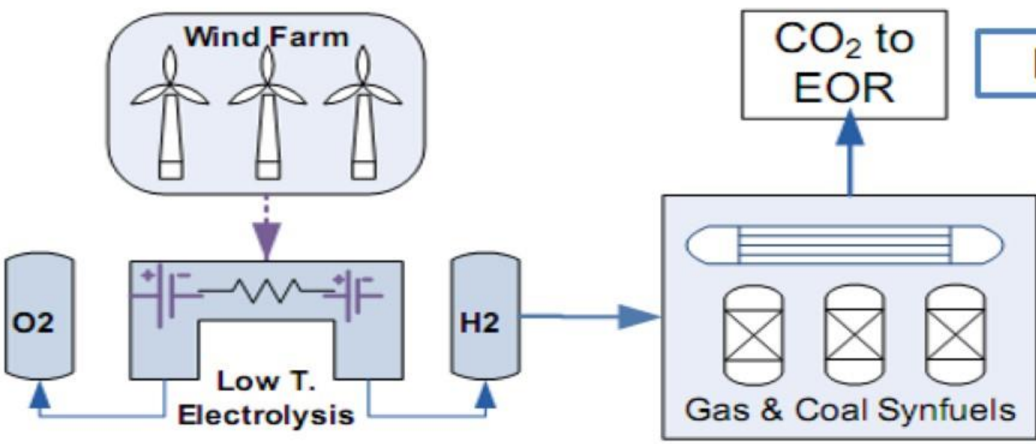
System which uses a combination of energy-producing components that provide a constant flow of uninterrupted power.

OR

Hybrid energy is the combined use of two or more forms of energy resulting in a more efficient system overall.

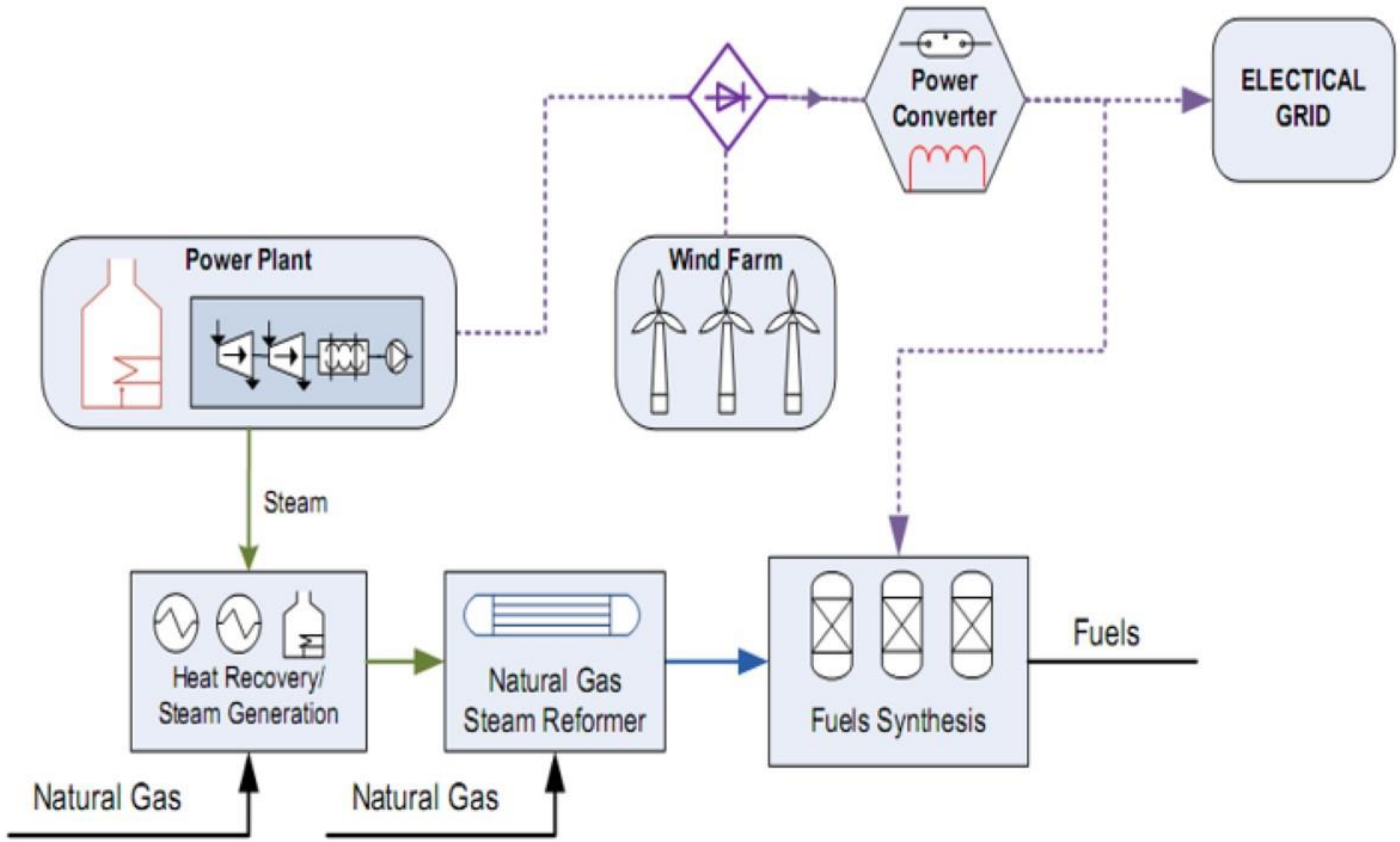
Hybrid energy system



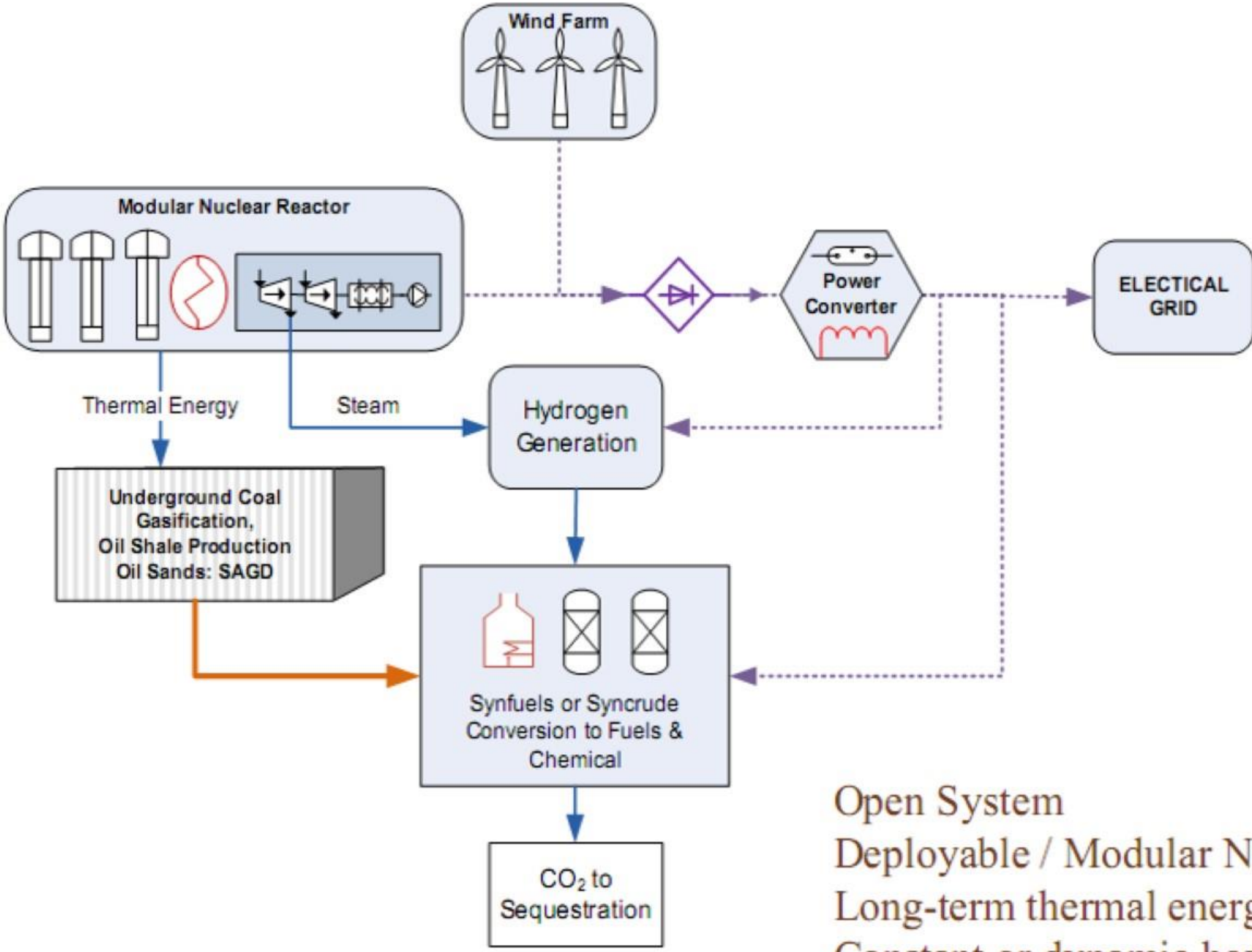


Enhanced oil recovery

Hybrid energy system



Hybrid energy system



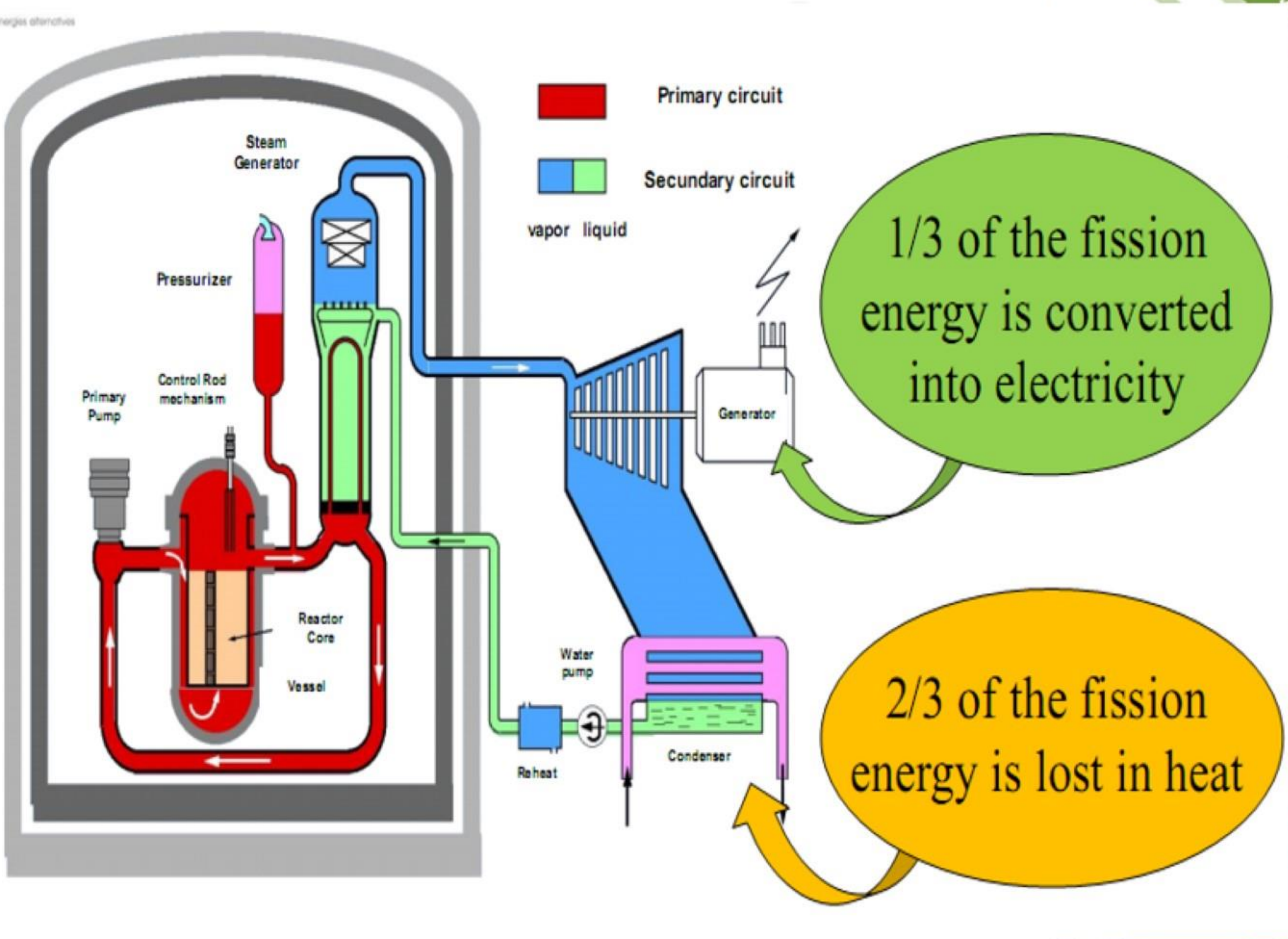
- Open System
- Deployable / Modular Nuclear Reactor
- Long-term thermal energy deposition
- Constant or dynamic heat maneuvering
- Constant Fuels Production

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 heat recovery



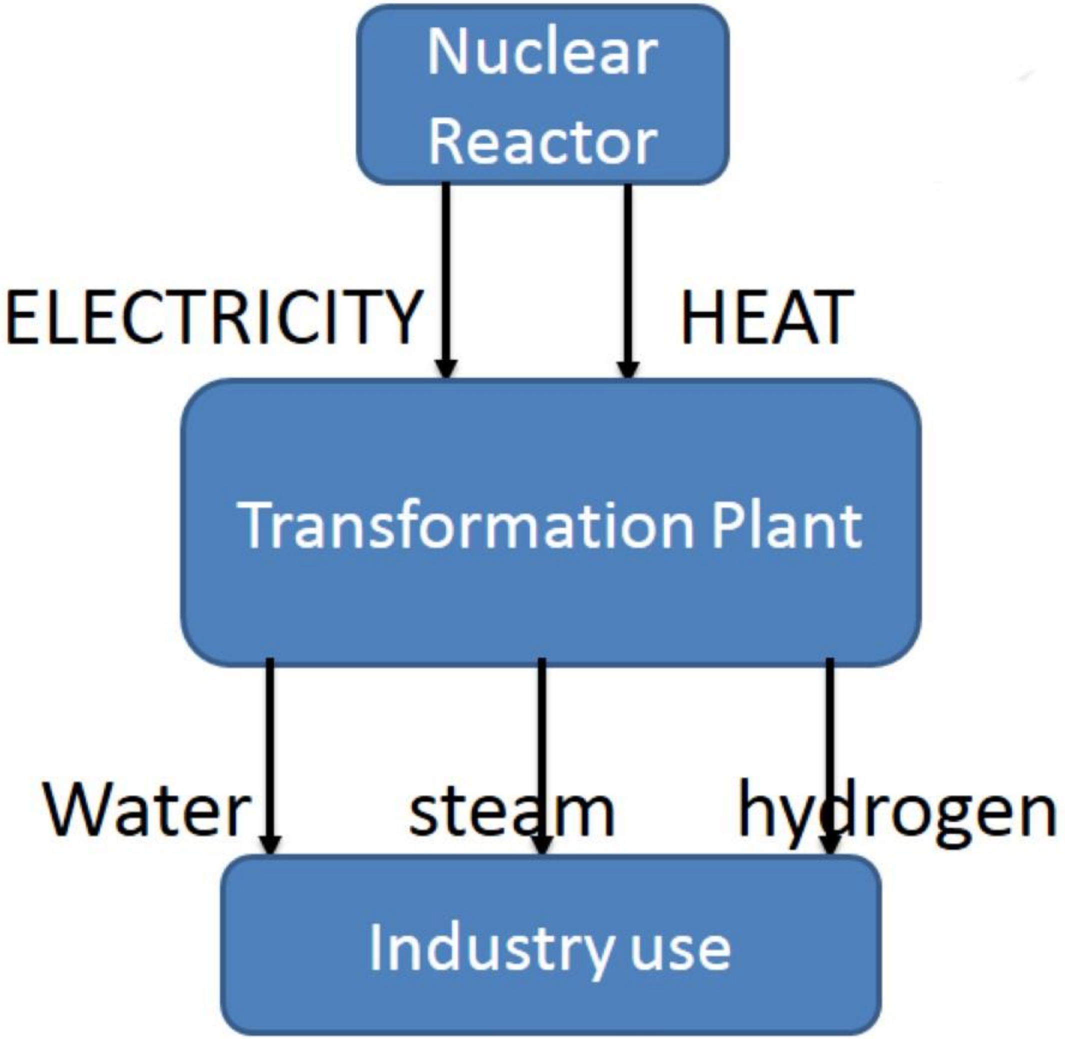
Prospects of Nuclear Power

Low Temperatures
$(40\text{-}250)^0C$ → District Heating
Water Desalination

Medium Temperature
$(250\text{-}550)^0C$ → Industrial Steam
Coal Liquefaction
& Gasification
Bio mass & Bio fuels

High Temperature
$(550\text{-}900)^0C$ → Hydrogen Production

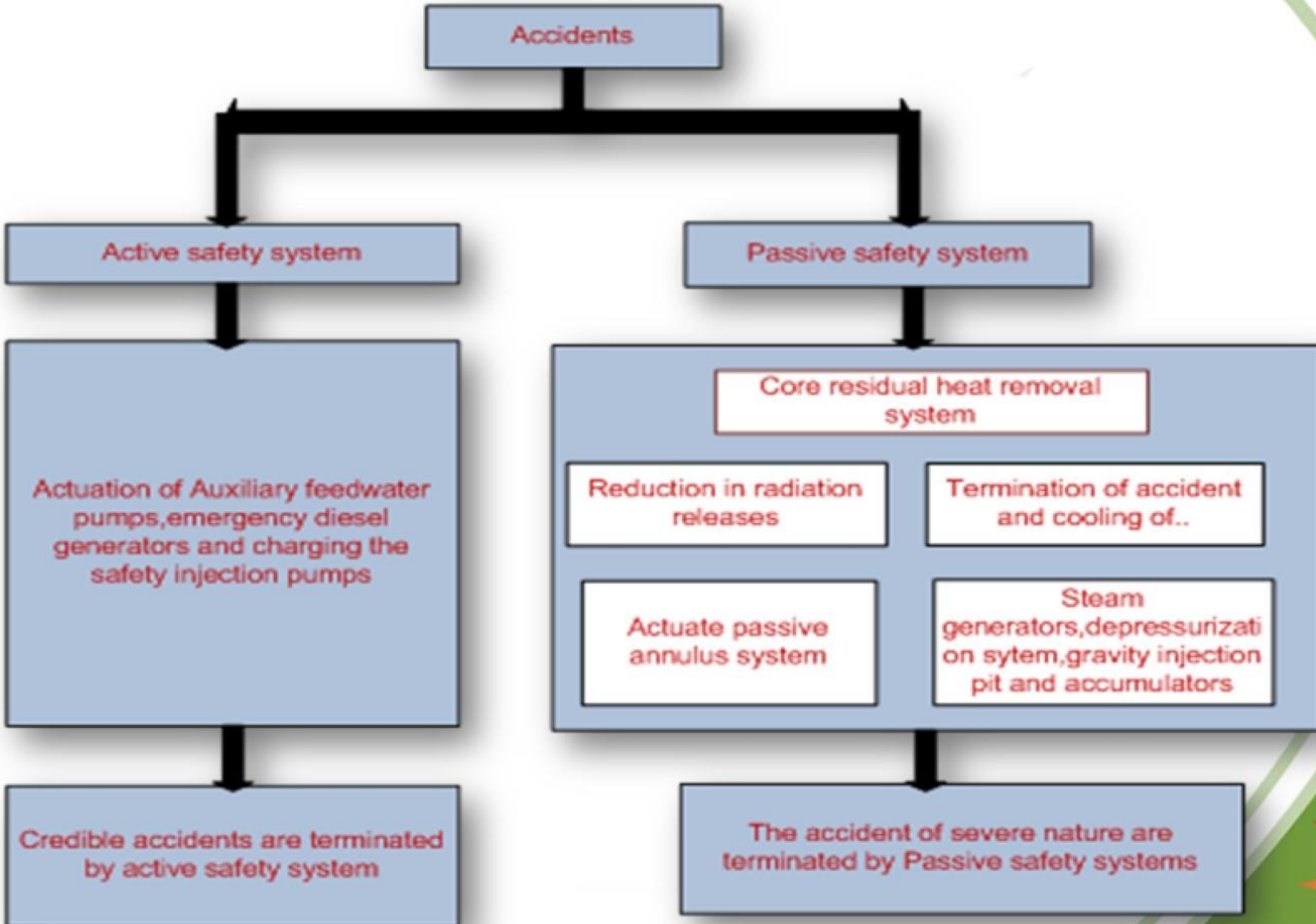
Industry requires steam at moderate temperature and about 40% of energy consumption is heat;



Nuclear Hybrid Energy System(1)

- Design of nuclear hybrid energy system (HES) is being 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.

Safety Studies for Nuclear hybrid system



Nuclear Hybrid Energy System(2)

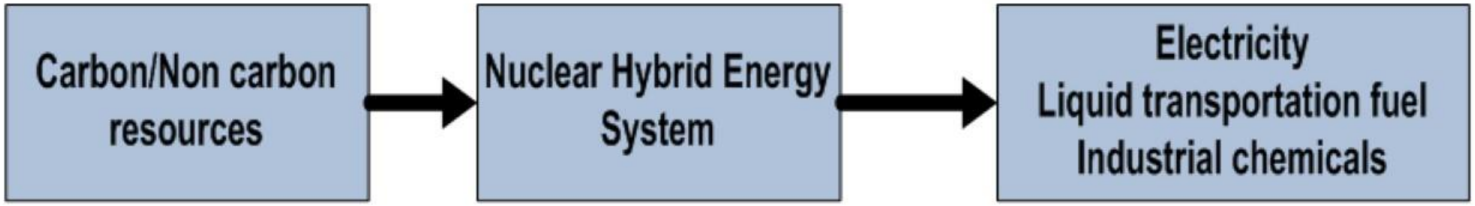
Resources	Coupling mode	Storage mode	Products
Nuclear+ biomass	Thermal	Chemical	Electricity+ biofuels
Nuclear+ CSP	Thermal	Thermal	Electricity+ heat
Nuclear+ wind energy	Thermal	Hydrogen	Electricity + hydrogen
Nuclear+ wind+ natural gas	Electrical + thermal	Chemical	Electricity +chemical + diesel fuels

Nuclear HES(3)

- Let us consider a case of nuclear hybrid energy system which is based on less than 3GWe high temperature reactor island integrated with coal gasification plant which is accepting 8,000 metric tons/day coal.
- The rough calculation shows that this plant can produce more than 300MWe in excess of carbon dioxide emission which is again then be utilized by coupling with biomass plant.
- This kind of system can be very useful to provide greater grid stability with electricity production. In this case, very high temperature reactor system could be considered more suitable than the light water reactor system with less outlet temperature (more suitably applicable to fossil or renewable energy).

Nuclear HES(4)

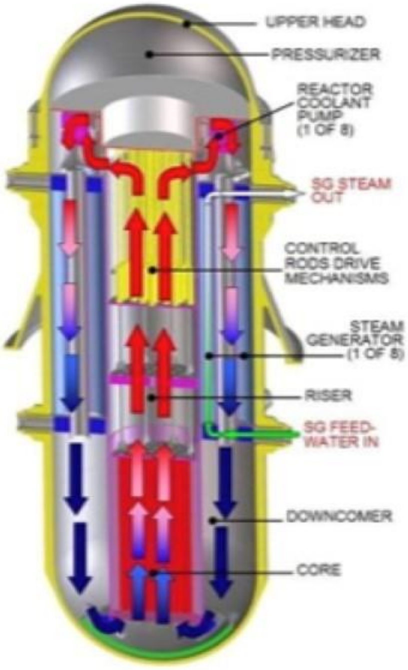
- The nuclear hybrid energy system of this type could be a paradigm for advancement in energy security systems, environmental friendly, grid stability by employing renewable energy and overcoming the energy crises.



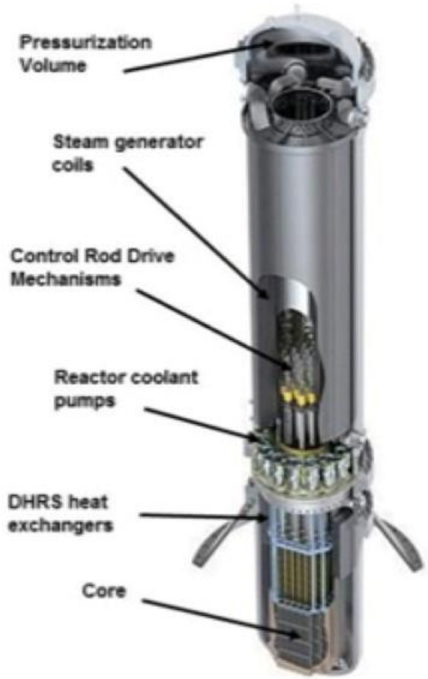
Nuclear HES(5)

- The nuclear hybrid system may possibly lessen the carbon emission and are able to extract the positive aspects of various energy systems.
- This system is more efficient as compared to individual system thus making a possibility of flexibility and resiliency.
- The suggested hybrid system may increase the sustainable nuclear energy for potential market and provide an attractive route to manage the lifecycle of carbon resources across the global energy market besides the application of electricity production.

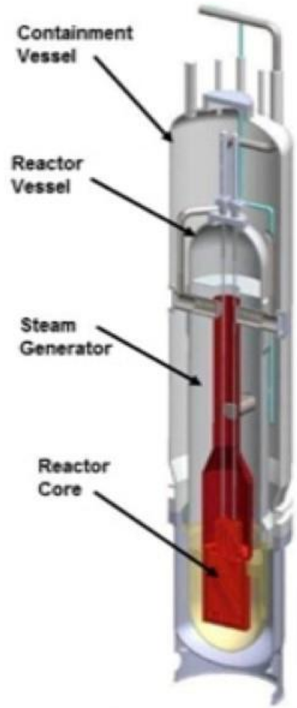
Small Modular Reactors



IRIS (Westinghouse)
335 MWe



mPower (Babcock & Wilcox)
125 MWe



NuScale (NuScale)
45 MWe

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.

Integration of SMRs with HES

- Active safety systems are meant for quickly terminated credible accident and to secure its prevention and expansion.
- This system also provides operational flexibility under different situations with respect to operator but uncertainty lies upon the misunderstanding or of the complexity of system.
- While the passive safety system are used to eliminate the human errors which can make accident situations even worst. The advantage of the passive system is that it uses natural forces and do not requires operator's action.

Nuclear Desalination(1)

- 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.

Nuclear Desalination(2)

- 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.
- 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.

Nuclear Desalination(3)

- The largest desalination plant is located in Saudi Arabia (Jubail 2) with a capacity of 948,000 m3/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.

Nuclear Desalination(4)

- 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).

Status of Desalination system

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
UAE		68,000	Ras Al-Kaimah	Under planning
	RO+MSF	591,000	Qidfa in the Emirate of Fujairah	
	Cogeneration MSF	454,000	Al Ruwais	Started in 2011
		450,000	Hassyan	Deferred bidding
United Kingdom	RO	150,000	Lower Thames estuary	Proposed
USA-Mexico		375,000	Baja, California	Working

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
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

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
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)

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
Ghana	RO	60,000	Nungua	
India	MSF+RO	45,000		
		100,000	Nemmeli	Started in 2011
		200,000	Pattipulam	Planned
USA		95,000	San Antonio, Texas	Under construction
		189,000	Carlsbad, NM	Under planning

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
Mexico	RO	21,000	El Salitral	Expected to start in 2013
Morocc o	MED(by 100MWt NPP)	8,000	Sidi Boulbra	NPP to be started in 2016-17

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
Indonesia	MSF(by SMART nuclear reactor)		Madura Island	Expanded to large scale PWR cogeneration
Iran	MSF(by Bushehr NPP)	200,000	Bushehr	Construction Delays
Israel	RO	510,000	Soreq	Expected to start in second half of 2013
Kuwait	Co-generation 1000MWe reactor	140,000	Kuwait	Under consideration

Country	Desalination Technology	Output water Ratio(m^3/day)	Region	Status
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

SMRs Technology with ND

- Small and medium sized nuclear power 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$) 0.5 to 0.94/$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.

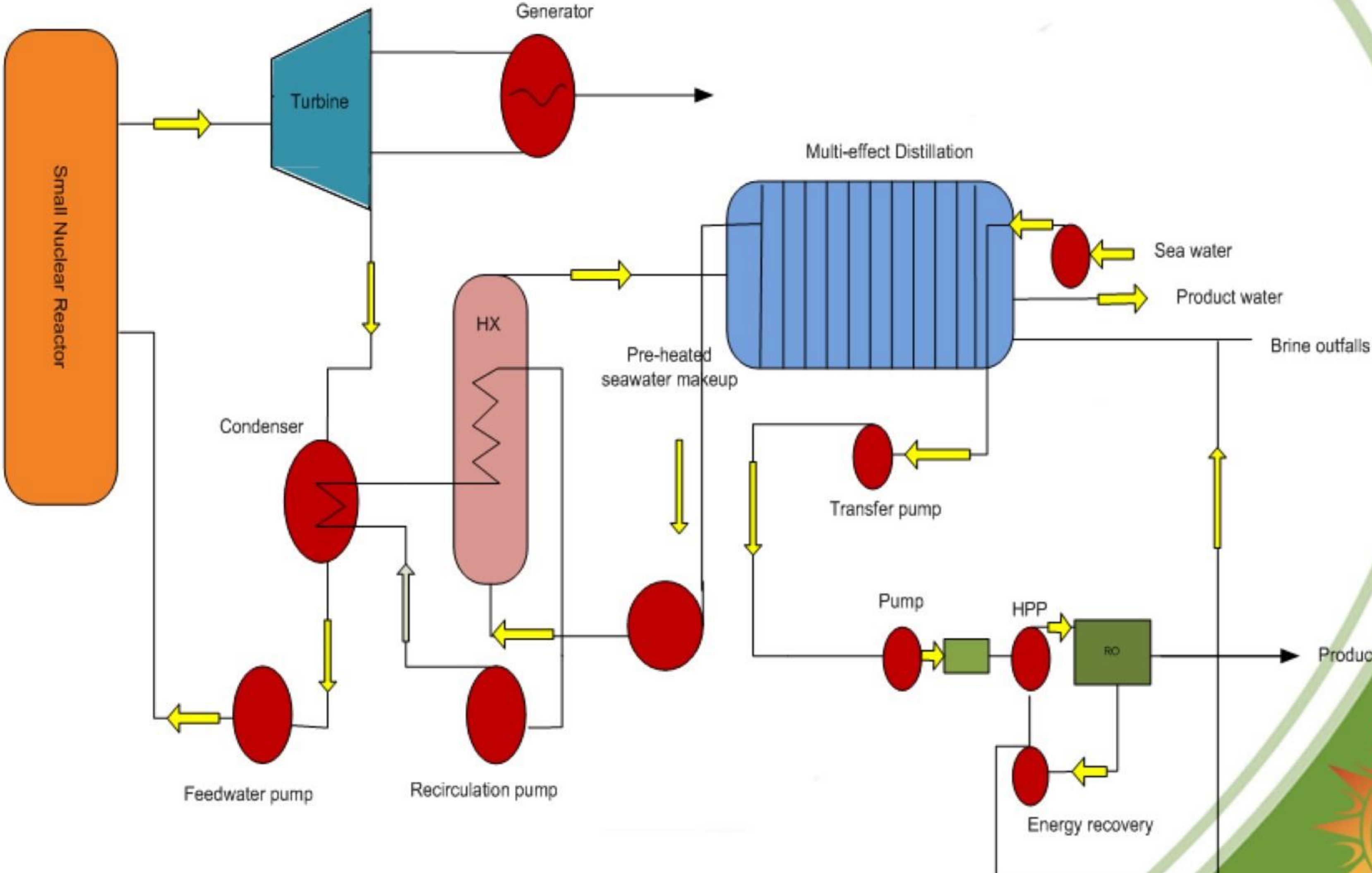
SMRs Technology with ND

- 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
- Nuclear desalination costs are about half those of the gas plant for MED technology and about one third less for reserve osmosis RO.
- One of the main advantages of the nuclear reactor to be 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.

SMRs Technology with ND-Cont...

- 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.

Schematic diagram of Integration of Small nuclear reactor with desalination system



Nuclear Desalination Integration

- According to IAEA standards for the designing of nuclear desalination system design approach including siting, safety, design life of plant, operational flexibilities, design integration and limitation, construction schedule etc. should be considered.
- The nuclear desalination process can be setup on these three basic steps i.e.:

a. Modeling of nuclear reactor components with integrated system.

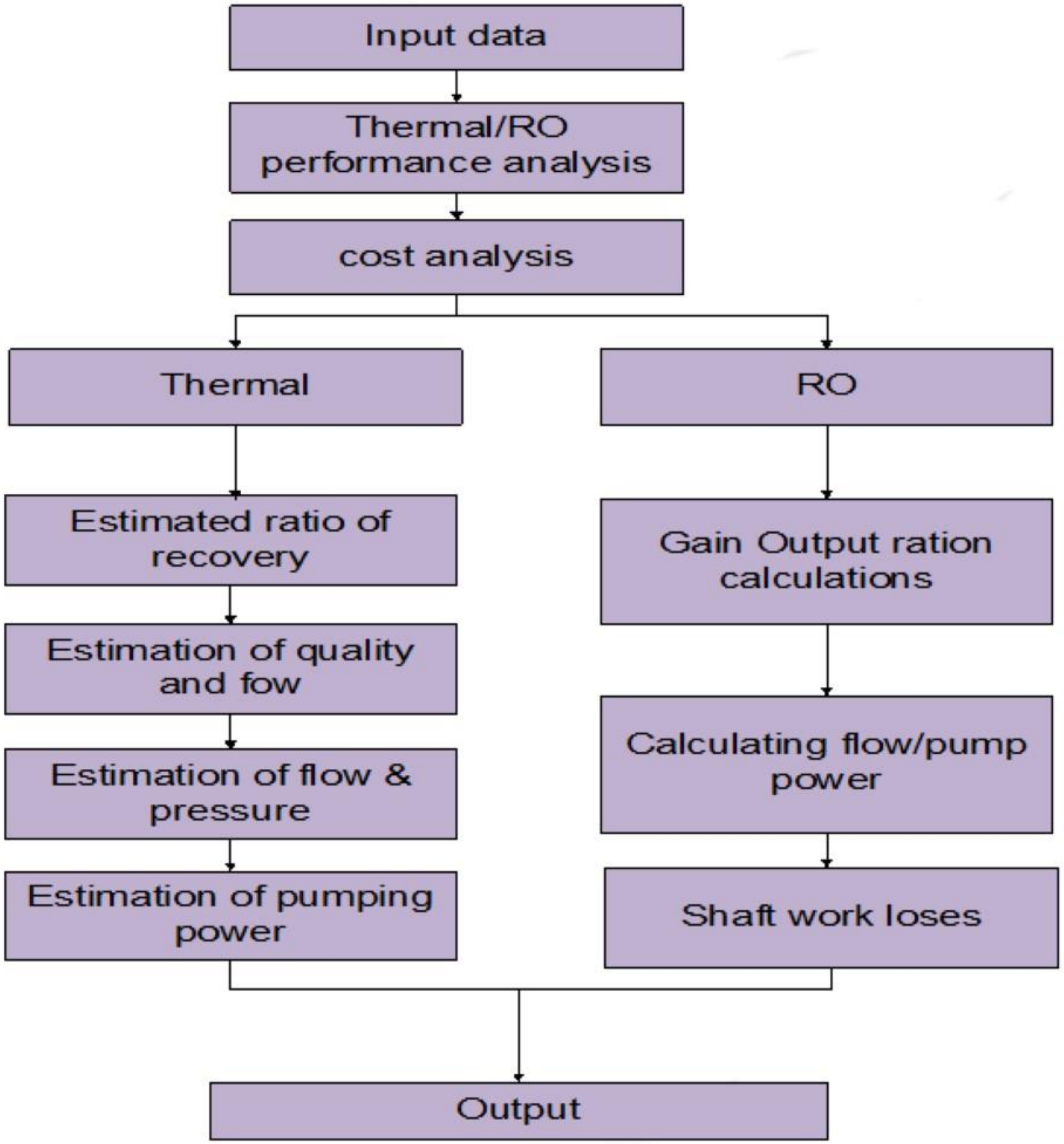
b. Evaluate the characteristics of intermediate circuits for the safety of the reactor that links to desalination process.

c. Technical findings of the desalinations process.

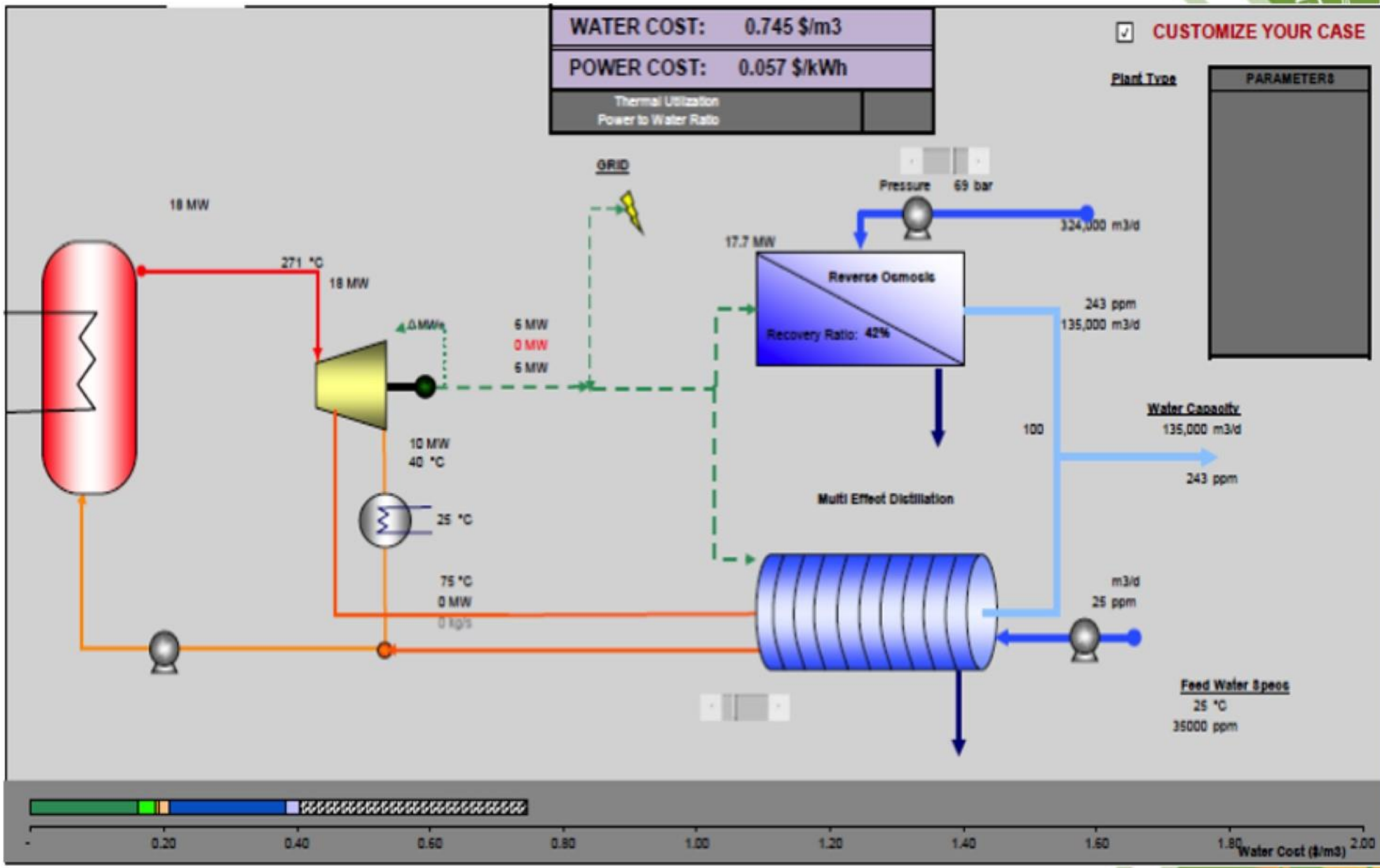
Desalination Economic Evaluation Program(DEEP)

- For the evaluation of nuclear desalination system, IAEA has developed a nuclear desalination system program named as DEEP (Desalination Economic Evaluation Program).
- This software can be used for desalination strategies by calculating the estimates of **technical performance and costs** for various alternative of energy and desalination system.
- The desalination technology includes multi-stage flashing (MSF), multi-effect distillation (MED), reverse osmosis (RO) and hybrid system (RO-MSF, RO-MED).
- This code was originally developed by General Atomics and then expended by IAEA. This code has been modified from DEEP 2.0 to DEEP 4.0.

DEEP- Flow diagram



ABV Nuclear Reactor of 18MW



Objectives for desalination technology

- Computationally evaluate the existing and proposed new nuclear reactors for nuclear desalination technology and electricity cogeneration as appropriate for KSA working conditions.
- Benchmark studies of existing nuclear desalination system in order to facilitate and to compare the proposed integrated desalination system for KSA.
- Selection of the adequate nuclear reactors types and desalination technologies according to different fixed criteria such as economic, security and socio-cultural aspects of the country.
- Testing and validation of the site for nuclear desalination system by using available data from literature.
- Based on the computational/theoretical data, select the most promising site for desalination system and implement to the nuclear reactor for future promises

Thank you