सत्यमेव जयते

Water Technology Initiative

Technology Mission Division (Energy, Water & Others)

Department of Science and Technology

Ministry of Science and Technology
Government of India

Technology Bhavan, New Mehrauli Road, Department of Science & Technology, Ministry of Science & Technology
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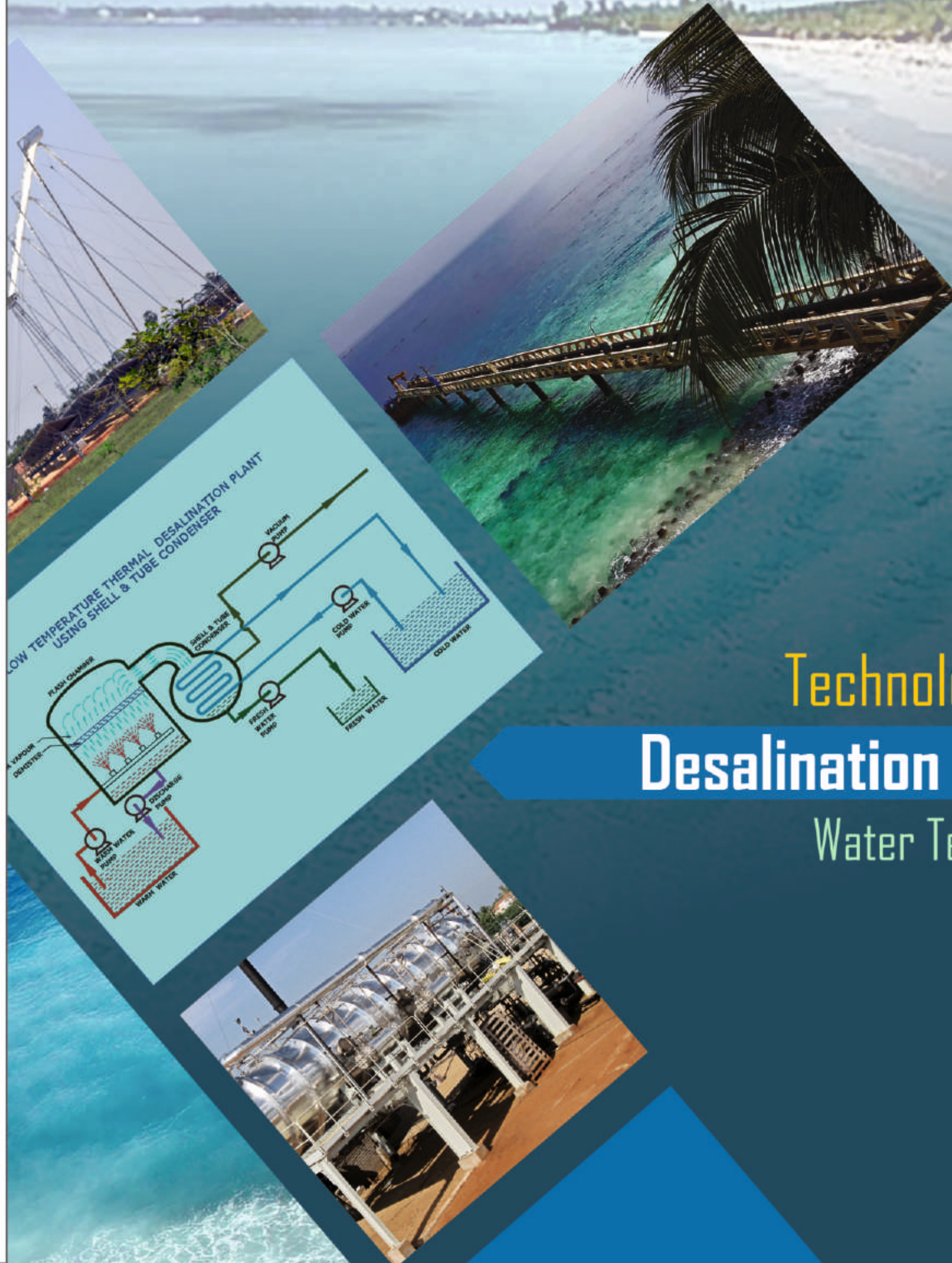
Department of Science & Technology
Govt. of India



Technology Options for Desalination of Sea Water

Water Technology Initiative

March 2019

Edited by
Neelima Alam
Sanjay Bajpai

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Prof. Ashutosh Sharma

एक कदम स्वच्छता की ओर

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विज्ञान और प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

22nd March, 2019

FOREWORD

Water Technology Initiative is a flagship programme of Department of Science and Technology (DST). This programme aims to provide technological solutions to prevalent and emerging water challenges through development research, application research, capacity development and field interventions.

DST has set up 7 Water Innovation Centres to develop knowledge network to tackle the problems of Water. 28 Demand Driven Technological solutions have been mounted in field for addressing the challenges of unavailability of water, water quality, salinity, waste water, flood management, distribution losses, drought management, providing water in distressed areas during disasters etc.

Availability of sufficient amount of water for the household needs, agricultural and industrial needs of India is an important goal of Government of India. In the decades to come expanding population, industrialization, urbanization and expectation of improved standard of living will all create serious demand for water. Future water shortage is an issue. Water is critical for sustainable development, environmental integrity and the eradication of poverty and hunger. Inaccessibility of clean water sources negatively impacts health, ability to work and the economy. Water facilities must be available for use at a price that is affordable to economically challenged people.

As demand for water is going to rise exponentially and water supply will continue to be scarce and even more erratic, desalination of sea water appears to be only mode for ensuring water security of the nation. The challenges to affordability could only be surmounted through research, development and innovation. I hope this compendium which presents technology choices and their current status would be immensely useful to various stakeholders and enable them to take informed decision for enhanced water security.

(Ashutosh Sharma)

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List of Abbreviations

BOO	Build, Own, and Operate
BOT	Build, Own, and Transfer
DST	Department of Science & Technology
ED	Electro Dialysis
EPC	Engineering, Procurement, & Construction
FO	Forward Osmosis
HDH	Humidification-Dehumidification Method
Listserv	Online Mailing List
LTTD	Low-Temperature Thermal Desalination
MD	Membrane Distillation
MED	Multi-Effect Distillation
MED-TVC	Multi Effects Distillation - Thermal Vapor Compression
MLD	Millions of Liters Per Day
MSF	Multi-Stage Flash Distillation
MSF-RO	Multi Stage Flash - Reverse Osmosis
MVC	Mechanical Vapour Compression
PPM	Parts per Million
RO	Reverse Osmosis
TDS	Total Dissolved Solid
TVC	Thermal Vapour Compression

Technology Options for Desalination of Sea Water

1.0 Background

The Desalination Mission, a Water Technology Initiative of the Department of Science and Technology (DST), Ministry of Science and Technology (MoST), Government of India in partnership with concerned ministries and departments at the behest of NITI Aayog, aims to ensure water security of the country and provide clean and safe drinking water to water-scarce areas of the country. The Mission envisages providing viable technological options for making use of desalinated water as a sustainable solution for water supply in the coastal states across India. As a first step in this endeavor, enlistment of all technologies (developed and commercialized, developed and awaiting commercialization, and likely to be developed in next five years) was done to enroll Indian and global desalination technology solution providers. As an initial step in this direction, this document identifies technology solution providers offering diverse technology options both from India and abroad for conversion of seawater/ brackish water into water for of acceptable quality different end use applications (domestic/agriculture/ industrial).

1.1 Desalination Technologies: An Overview

To provide clean and safe drinking water to all our water-scarce areas, the ability to use seawater that most coastal states have access to could be a sustainable solution. Desalination essentially means removing salt and other minerals to make water fit for drinking or other purposes. The filtration of saline water can be done through Thermal Desalination Technology or Membrane Technology like Reverse Osmosis (RO). These technologies are relatively expensive and also require costly infrastructure, so the challenge is to develop cost-effective variants.

Indian scientists have been working for many decades for development of seawater desalination technologies. Many of the successful models are now commissioned to upscale for commercial installations. Figure 1 reflects on available desalination technologies for commercial deployment.

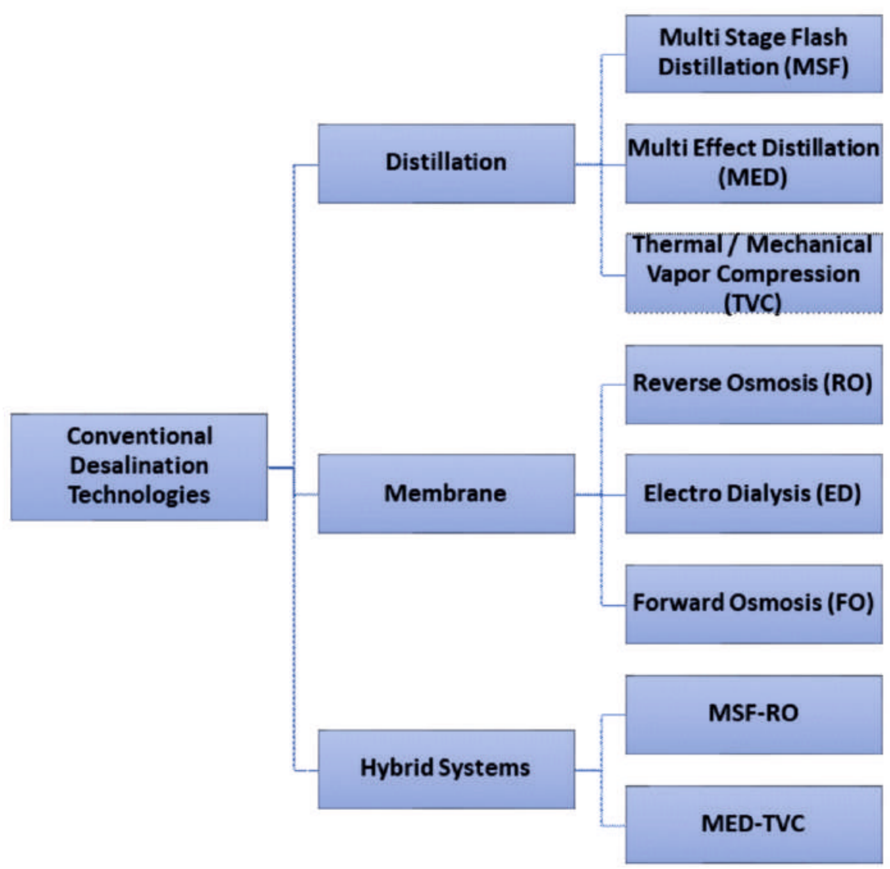


Figure 1: Conventional Desalination Technologies

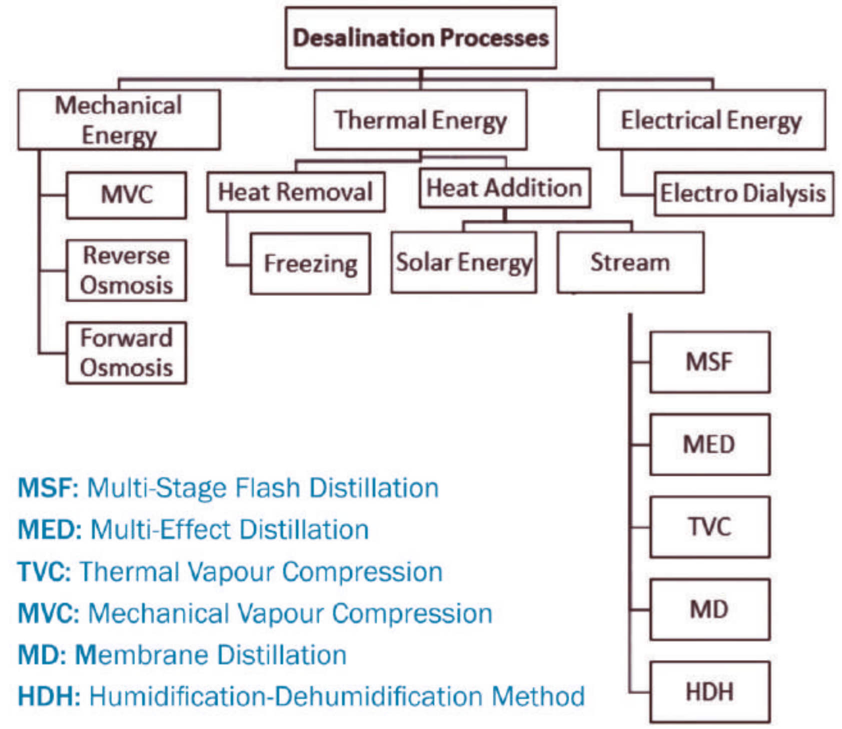


Figure 2: Desalination Processes

Thermal Technologies involve the heating of saline water and collecting condensed vapour to produce useable or potable water. Thermal technologies are usually used in the treatment of seawater and not brackish water due to the high costs involved.

Multi-Stage Flash Distillation (MSF): Invented in 1950 and the first plant built in 1957 in Kuwait, the MSF process makes use of distillation through multi-stage chambers. Each successive stage of the plant reduces salinity progressively. The feed water is heated first under high pressure and channelled into 'flash chamber', where the pressure is released causing the water to boil rapidly resulting in sudden evaporation of flashing. The pressure gets reduced in successive stages, and further evaporation of water takes place. The vapour generated by flashing is converted into fresh water and is collected through a series of channels. MSF distillation plants can receive feed water either a once-through or recycled process.

Multi-Effect Distillation (MED): First built in 1930 in Saudi Arabia, MED involves a series of vessels (effects) and uses the principles of evaporation and condensation at reduced ambient pressures. In MED a series of evaporator effects produce fresh water at progressively lower pressures. A popular scheme of the MED process is HTME scheme, which is used in the Gulf Countries and the US. A number of MED plants are also operational across India.

Fig. 2.1: A MED Plant at Narippaiyur in Tamil Nadu, India

Fig. 2.2: A Solar MED Integration at Narippaiyur in Tamil Nadu

A DST-supported MED plant was commissioned at Narippaiyur in February 2013, in collaboration with the Empereal-KGDS Renewable Energy Private Ltd. and the National Institute of Ocean Technology (NIOT), to meet the potable water requirements of the 7500 people in the Narippaiyur village of Ramanathapuram district in Tamil Nadu.

The direct steam generating Linear Fresnel Reflector (LFR) solar energy collector of 1404 m2 is suitably integrated with a biomass boiler for round the clock operation. The plant is designed to deliver 6 m3 per hour of desalinated water which having Total Dissolved Solid (TDS) less than 5 Parts per Million (ppm). This water can be used for industrial needs and is subjected to anti-microbial treatment and re-mineralized to meet the potable water requirements.

Process Involved: The concentrated solar radiation generates saturated steam water mixture at a pressure of 21 bar. This steam water mixture is passed to the steam drum where saturated steam is separated from saturated liquid. The saturated water in the steam drum is fed back to the LCR by recirculation pump and the saturated steam is taken to the steam accumulator. Saturated steam enters the accumulator at a pressure of 21 bar. Steam from the accumulator is supplied to the MED-TVC system at a pressure of 5-7 bar with the help of pressure reducing valve. The steam from the accumulator act as the motive steam for the TVC which compresses the entrained vapour coming from the sixth effect of MED to a pressure of 0.245 bar. Thus, a steam of mass flow rate 1215 kg/h is discharged by TVC at 0.245 bar pressure and 91 °C temperature. This steam is fed to the 6 effect MED unit after de-superheated to 64.6 °C. The steam entering effect 1 condenses by giving up its heat to the sufficiently preheated sea water sprayed (5432 kg per hour) through the nozzles. Around 20% of the sea water is converted into vapour and is passed to the next effect where it acts as the thermal source for further distillation of the sea water and the process is continued in all the 6 effects. A portion of the steam generated by Effect 2, 3, 4 and 5 is used for preheating the feed water. Nearly 300 kg per hour of steam from the sixth effect is condensed using 40 TPH of incoming sea water using a four-pass shell and tube condenser. The distillate water is siphoned to the successive effects and finally pumped from the final condenser to the distillate water tank with the help of distillate pump. The brine from each effect is also siphoned to the next effect and finally pumped out by the brine pump. 18 TPH of the brine is re-circulated back into the system in order to improve the energy efficiency of the system. About 6000 kg per hour of desalinated water having TDS less than 5 ppm is further UV treated and remineralised to meet the potable water standards. (Fig. 2.1 & 2.2)

Text Box 1: Design, Fabrication Testing and Installation of Solar Multi-Effect Distillation System for Providing Potable Water in Arid Rural Areas.

Department of Science and Technology (DST), Govt. of India provided support for designing, developing and demonstration of a sea water desalination system that will be partly powered by solar energy. KG Design Services in Coimbatore, and the National Institute of Ocean Technology in Chennai were entrusted with the responsibility as principal and co-principal investigators in this developmental project.

Linear Fresnel concentrating solar thermal system is employed to focus solar radiation on to an overhead receiver with a concentration of about 50 suns. The receiver carries water in tubes that

continued ▶

have a surface treatment providing high absorptivity of solar radiation in the visible spectrum and low emissivity in the infra-red spectrum. This concentrator produces direct dry saturated steam at 230° C

The saturated steam enters a multiple-effect distillation system to produce distilled water from sea water through an evaporator that is operating under an absolute pressure of 0.25 bar. The steam produced in the solar thermal system enters hundreds of tubes on which sea water is sprayed. The heat from the steam inside the tubes makes some of the sea water evaporate by a process called falling film evaporation. At the same time the steam inside the tube condenses and produces distilled water.

The steam produced by the partial evaporation of sea water moves into the second effect by means of a favourable pressure gradient. Here some more water is sprayed just like in the first effect and more distillate is produced. The process is repeated to produce a total of six effects. Majority of the uncondensed steam in the final effect is sucked into the initial motive steam through a process called thermo-vapour compression. Thus 1 kg of original motive steam produced by solar energy ends up producing more than 8 kg of desalinated water. The distillate is subjected to ultraviolet rays for ensuring biological purity and then subjected to re-mineralization with calcium bicarbonate and other salts to meet WHO potable water standards.

Thermal Vapour Compression (TVC): TVC method is made simple, reliable and highly efficient process. In an energy efficient manner, it used latent heat present in the vapour and exchanged in the evaporation condensation process. TVC is similar to MED, but the vapour produced evaporation of brine is not condensed in the separate condenser. If compression is performed by a mechanically driven compressor or blower, this evaporation process is usually referred to the mechanical vapour compression (MVC).

Low-Temperature Thermal Desalination (LTTD): This process uses the availability of a temperature gradient between two water bodies or flows to evaporate the warmer seawater at low pressures and condense the resultant vapour with the colder seawater to obtain fresh water. As a newspaper report suggested, India has pioneered in the development of world's first LTTD plants for different islands and coastal cities. (Fig. 2.3)

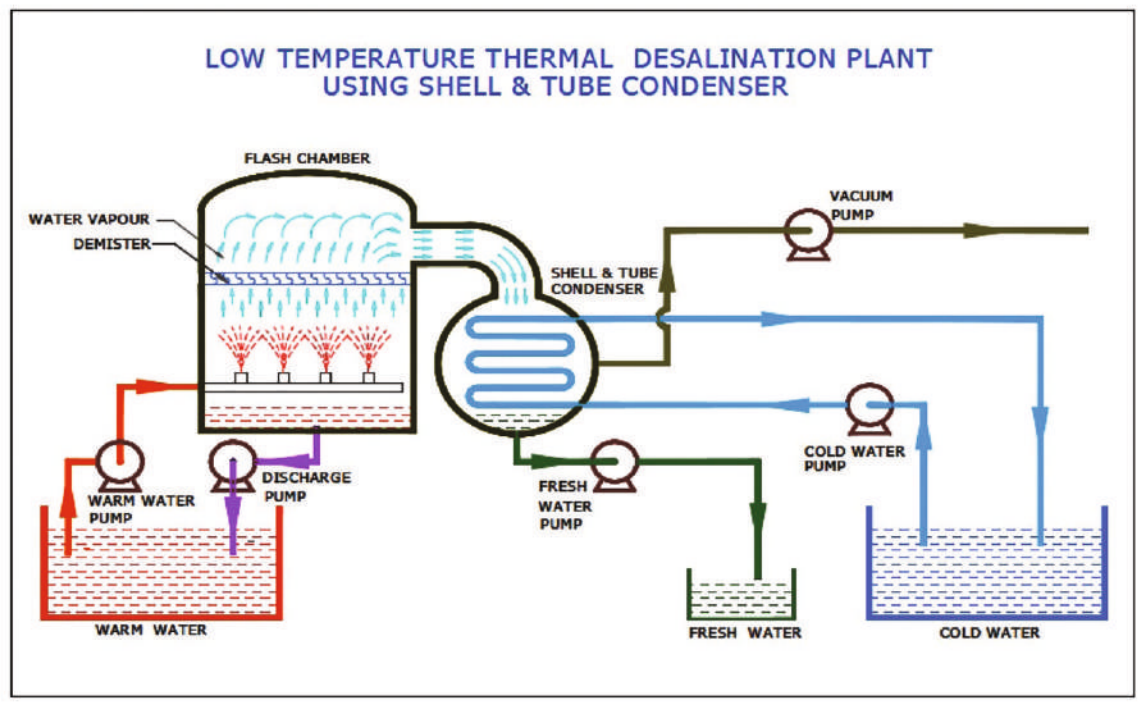


Fig. 2.3: Low Temperature Thermal Desalination (LTTD) Process

Fig. 2.4: Major LTTD Plant Components

The National Institute of Ocean Technology (NIOT) developed a technology for generating fresh water from sea water by using the temperature gradient in the ocean called Low Temperature Thermal Desalination (LTTD) process. A 100 m3/day land-based plant was commissioned at Kavaratti island in Lakshadweep in 2005 using the LTTD technology where there was a severe drinking water scarcity. This plant has been continuously generating fresh water for the past nearly fourteen years to meet the drinking water needs of the island community. The water is of excellent quality. This first ever plant has become the main source of drinking water for the islanders and health of the people has improved considerably due to reduction of water borne diseases. This indigenized technology, was later made operational in two more islands of Lakshadweep namely Agatti and Minicoy in 2011. LTTD plants in 6 more islands (Amini, Androth, Chetlat, Kadamat, Kalpeni and Kiltan) are currently underway.Towards mainland requirements an offshore barge mounted plant was demonstrated using the LTTD process for a capacity of 1 million liters per day. The same process was also demonstrated in the North Chennai Thermal Power station using the temperature difference between the condenser reject waste heat and surface seawater. Currently a scaled-up plant using waste heat is being put up in the Tuticorin thermal power station for a capacity of 2 million liters per day. A design for an offshore plant of capacity 10 million liters per day is also ready. (Fig 2.4-2.6)

Fig. 2.5:
NIOT's One Lakh Liters Per Day LTTD Plant, Kavaratti

Fig. 2.6:
A Close View of LTTD plant at Kavaratti Island

Humidification-Dehumidification (HDH): HDH Desalination makes use of a solar heater while seawater passes through a common heat transfer wall along with a carrier gas, then evaporated water is dehumidified to produce potable water. Sometimes, HDH process combines with thermal vapour compressor and reverse osmosis process that makes a hybrid system.(Fig. 2.7)

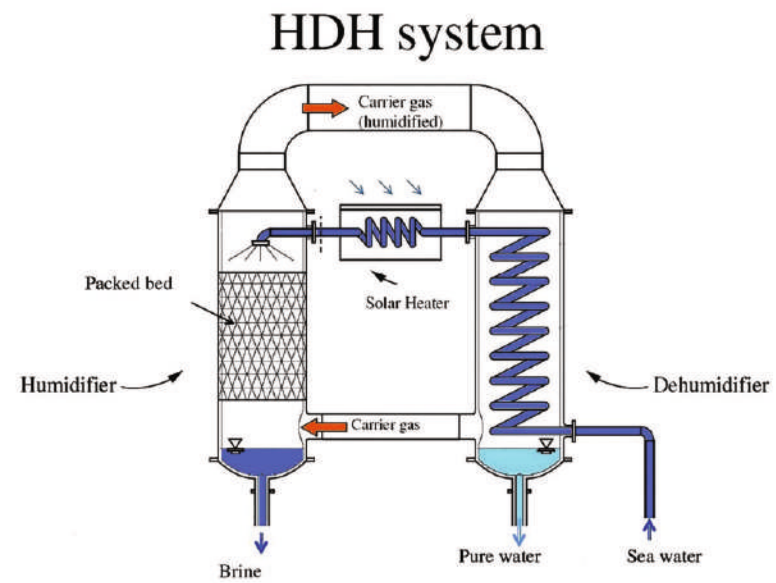


Fig. 2.7: A Diagram of Humidification-Dehumidification Desalination (HDH) Process

Membrane Technologies

Reverse Osmosis (RO): Reverse Osmosis is a water purification technology invented in the 18th Century, but was popularized post-World War-II with the invention of cellulose acetate membranes. A semipermeable cellulose acetate RO membrane is capable of removing salt from water. The process of osmosis involves water molecules in a dilute solution diffusing through a semipermeable membrane to a concentrated solution until equilibrium is achieved. It also requires an efficient pre-treatment purification process to remove the dirt, solid and biological elements. The first large capacity seawater reverse osmosis (SWRO) desalination plant was built in Saudi Arabia in 1978. RO can be used effectively on seawater as well as brackish water.

Text Box 2: Remotely Monitored and Controlled RO Plant for Desalination of Sea Water integrated with energy recovery turbine

DST has established an energy recovery membrane based remotely monitored plant for addressing challenges related to deficit of assurance for drinking water quality, alkaline earth metal salt salinity and hardness and biological contamination covering population of 12500 at Ervadi Panchyat and Mullimunai Panchyat in Ramanathapuram district of Tamil Nadu that has been operationalised for sea water desalination. CSIR-CEERI Pilani and CSIR-CSMCRI Bhavnagar have jointly designed and developed remotely monitored and controlled high capacity RO plant using indigenously developed membrane for desalination of Sea Water. The project aimed at design and development of automation system for high capacity RO plant for desalination of Sea water. The monitoring and controlling of the RO plant is done with two technologies based on Linux and embedded system. A handheld water parameter measurement system and embedded backwash controller have also been developed and tested during the project. The pressure energy recovery system utilizing energy recovery turbine has also been integrated. (Fig. 2.8-2.9)

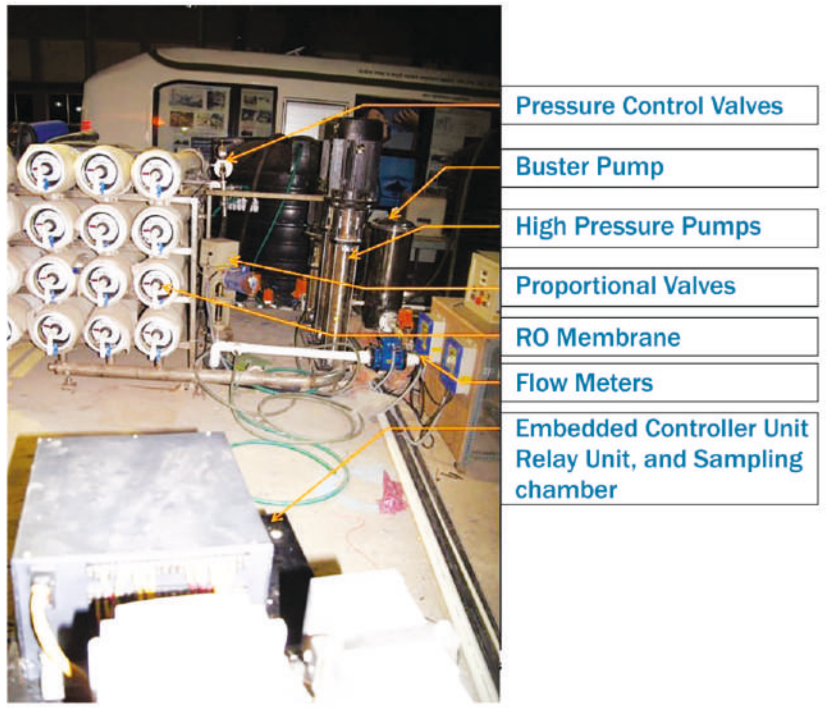


Fig. 2.8: Remotely Monitored and Controlled RO Plant for Desalination of Sea Water

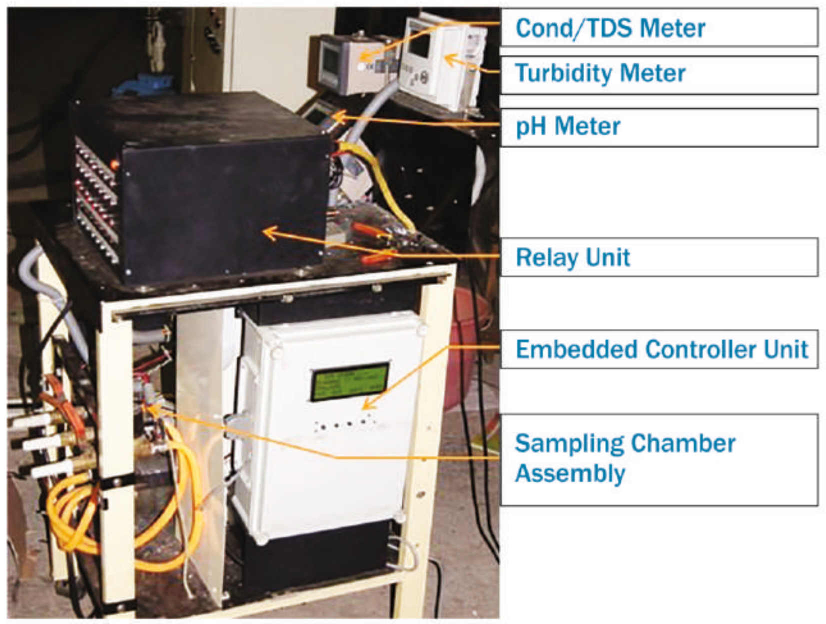


Fig. 2.9: Embedded Controller Unit, Relay Unit & Sampling Chamber Assembly

Nano-filtration (NF): NF is a new water purification technology, which makes use of a pressure driven membrane process between reverse osmosis and ultrafiltration. NF is widely used in the food processing applications such as dairy, for simultaneous concentration and partial (monovalent ion) demineralisation.

Electrodialysis (ED): In this process, salt is removed by transporting ions through membranes using an electric current. Here an electric current migrates dissolved salt ions, including fluorides, nitrates, and sulphates, through an electrodialysis stack consisting of alternating layers of cationic and anionic ion exchange membranes. This is effective for brine water (with lower salt concentration than seawater) but very expensive for obtaining potable water from seawater.

Membrane Distillation (MD): In MD process a hydrophobic membrane makes a barrier for the passing liquid phase, allowing the vapour phase (e.g., water vapour) to pass through the membrane's pores. Later water vapour is condensed through the coolant or condenser to generate potable water. MD process can utilize waste heat generated in an associated industry (e.g., thermal power plant).

Hybrid Technologies

Hybrid technologies make use of the two or more technology processes to achieve better energy efficiency and productivity. Commonly, multi-stage flash distillation (MSF) combines with reverse osmosis (RO), and an MSF-RO process is obtained. Similarly, multi-effect distillation (MED) combines with thermal/mechanical vapor compression (TVC), and MED-TVC process is obtained.

Figure 1 illustrates the conventional desalination technologies. Figure 2 illustrates the desalination processes that are commonly used.

2.0 Study Objectives

This Study aimed at achieving the following broad objectives:

- To enroll the solution providers on the choice of technologies/ solutions.
- To prepared a Compendium of Technological Solutions for use by state governments, urban local bodies and other organizations regarding selection and use of appropriate technologies for processing of seawater/ saline/ brackish water to be made safe for human, agricultural and industrial consumption.
- To create an information bank on desalination technologies, and operational desalination units, which will be used by the central, state and local governments.
- To enable user agencies take an informed decision on appropriate technology choices suited in specific socio-economic context.
- To provide an opportunity to enrolled solution providers to be a part of activities of the Desalination Mission.

3.0 Methodology

For this report, two kinds of surveys were undertaken. One was a Scopus-based Literature Survey, where India's contribution to the global desalination research literature is surveyed using the Scopus citation database. The other one was the Online Survey for the Enrolment of Indian and Global Desalination Solution Providers for the Desalination Mission, based on an extensive questionnaire. Details of the methodology are described in the appropriate Sections.

3.1 Scopus-based Literature Survey

The Scopus is a global citation database of scientific literature, covering major scientific periodicals in all possible subject disciples. For this study the used search query was summarily ((Title(Desalination) OR Keyword(Desalination) OR Source Title(Desalination)) AND (Limit-To (Publication Years 2009 until 2018)). This search query retrieved 26737 records for the world as on 03-12-2018. The retrieved records were further refined and 2078 records were reported for India.

3.2 Online Enrolment of Desalination Solution Providers

An online survey titled "Enrolment of Indian and Global Desalination Solution Providers for the Desalination Mission" was conducted during July-August 2018, while a survey questionnaire was posted online for collecting relevant data from the global desalination solution providers. This Call for Enrolment was also circulated through different online mailing lists (listservs) of the industry associations. Out of the 49 responses received, 46 responses were valid and contained the required information – however, some respondents filled in the questionnaire in duplicate. Table 8 provides the list of Indian & global desalination solution providers responded to this survey. We have codified the respondents to analyze their respective responses further.

4.0 Findings

4.1 Scopus-based Literature Survey

The result of this literature survey is reported in Tables 1 to 7, and Figure 3. As Table 1 indicates, India is one of the top three countries engaged in the desalination research during the 2009-18 period. While India ranks 3rd, People's Republic of China secures 1st Rank, and the United States achieves 2nd rank in the global production of desalination literature. Other top ten countries include Iran, South Korea, Australia, Saudi Arabia, Spain, Turkey, and Egypt. Majority of these countries also have successfully deployed desalination plants for generating potable water for their citizens. Figure 3 indicates year-wise growth of desalination literature in India and the world during 2009-18. Table 3 provides a list of top ten periodicals producing desalination literature from India. These are also top ten preferred publication avenues for Indian researchers during 2009-18. The top two preferred journals for Indian authors are, namely, 'Desalination and Water Treatment' (ISSN: 1944-3986) with 1158 records on Scopus, the 'Desalination: The International Journal on the Science and Technology of Desalting and Water Purification' (ISSN: 0011-9164) with 422 records. Other journals in this Table include periodicals having less than 100 records from Indian contributors. These ten journals cover about 82.09% of India's research outcomes in desalination.

Table 1: Countries Featuring Most in Desalination Literature, 2009-2018

Country Rank	Country	No. of Records
1	China	5591
2	United States	2998
3	**India**	**2078**
4	Iran	1891
5	South Korea	1779
6	Australia	1272
7	Saudi Arabia	1164
8	Spain	1110
9	Turkey	939
10	Egypt	832
Source: Scopus, dated 03-12-2018		

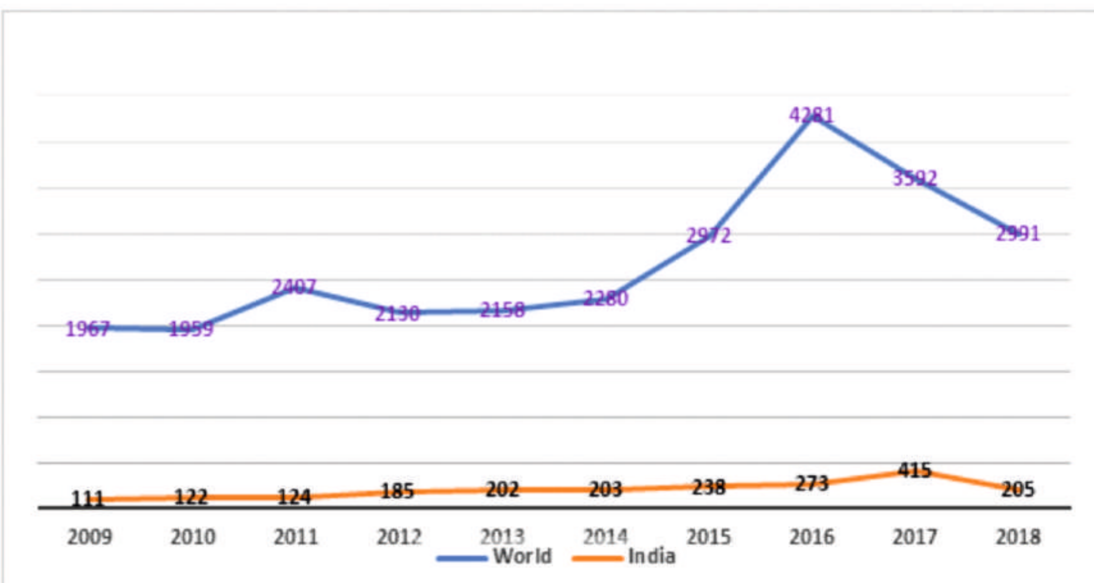


Figure 3: Global Outcome of Desalination Literature, 2009-18

Table 2: Collaborating Countries with India for Research in Desalination, 2009-18*
(based on 2078 Scopus Records)

Collaborating Country	No. of Records	Rank
Malaysia	60	1
Saudi Arabia	60	1
South Korea	59	3
United States	51	4
Australia	29	5
United Kingdom	29	5
Egypt	20	7
Iran	20	7
Canada	14	9
China	13	10
Oman	12	11
Italy	10	12
South Africa	10	12
Japan	9	14
Taiwan	9	14
Source: Scopus, dated 03-12-2018		

Table 3: Preferred Publication Avenues for Indian Researchers, 2009-2018

Source Title	No. of Records	Rank
Desalination and Water Treatment	1158	1
Desalination	422	2
Journal of Water Reuse and Desalination	28	3
International Journal of Nuclear Desalination	27	4
Renewable and Sustainable Energy Reviews	25	5
RSC Advances	12	6
Journal of Membrane Science	10	7
Energy Conversion and Management	8	8
International Journal of Chemtech Research	8	9
IOP Conference Series Materials Science and Engineering	8	10
Total	1706	
Source: Scopus, dated 03-12-2018		

Table 4 provides a list of top twenty Indian researchers, during 2009-2018, contributing desalination literature from India. Here top three researchers are affiliated to the Energy and Resources Institute (TERI), New Delhi; Bag Energy Research Society (BERS), Ghaziabad; and National Institute of Technology Karnataka (NITK), Surathkal. They contributed respectively 30, 29 and 27 papers on the subject. Among the top twenty researchers, three scholars belong to Bhabha Atomic Research Centre (BARC), Mumbai; another three scholars belong to Jadavpur University, Kolkata. Similarly, two researchers in the list represent the Thiagarajar College of Engineering, Madurai; and another two represent Sri Sivasubramaniya Nadar College of Engineering, Chennai.

Table 4: Indian Researchers and Solution Providers, 2009-2018 (based on 2078 Scopus Records)

Author Name	No. of Records	Affiliation
Tewari, P.K.	30	Formerly with Bhabha Atomic Research Centre, Mumbai; & President of Indian Desalination Association (InDA)
Tiwari, G.N.	29	Indian Institute of Technology Delhi
Isloor, A.M.	27	National Institute of Technology, Surathkal, Karnataka
Srithar, K.	25	Thiagarajar College of Engineering, Madurai
Manchanda, V.K.	24	Bhabha Atomic Research Centre, Mumbai
Sathyamurthy, R.	22	Hindustan Institute of Technology and Science, Chennai
Naushad, M.	20	Sri Sivasubramaniya Nadar College of Engineering, Chennai
Bhattacharjee, C.	19	Jadavpur University, Kolkata
Senthil Kumar, P.	19	Sri Sivasubramaniya Nadar College of Engineering, Chennai
Arunkumar, T.	18	Anna University, Chennai
Purkait, M.K.	18	Indian Institute of Technology, Guwahati
Prabhakar, S.	16	Bhabha Atomic Research Centre, Mumbai
Rajaseenivasan, T.	16	Thiagarajar College of Engineering, Madurai
Mohapatra, P.K.	14	Bhabha Atomic Research Centre, Mumbai
Rafiuddin	14	Aligarh Muslim University, Aligarh
Rajesh Banu, J.	14	Anna University, Chennai
Ahsan, A.	13	Uttara University, Dhaka, Bangladesh
Datta, S.	13	Jadavpur University, Kolkata
Padaki, M.	13	Jain University, Centre for Nano and Material Sciences, Bangalore
Saha, P.D.	13	Jadavpur University, Kolkata
Singh, P.S.	13	Central Salt and Marine Chemicals Research Institute, Bhavnagar
Solutions Providers		
Kharul, U.K.	49	Academy of Scientific and Innovative Research, New Delhi
Bindal, R.C.	31	Bhabha Atomic Research Centre, Mumbai
Kar, S.	25	Bhabha Atomic Research Centre, Mumbai
Panicker, L.V.	25	Bhabha Atomic Research Centre, Mumbai
Ghosh, P. K.	9	Institute of Chemical Technology, Mumbai
Mudgal, A.	5	Pandit Deendayal Petroleum University, Gandhinagar
Jalihal, P.	4	National Institute of Ocean Technology, Chennai
Krishnan, N.	1	Water Systems India (P) Ltd, Chennai
Viswanathan, S.P.	1	Empereal KGDS Renewable Energy Private Limited, Coimbatore
Pathak, N.	-	Central Salt and Marine Chemicals Research Institute, Bhavnagar

Table 5 provides a list of major Indian institutions, during 2009-2018, contributing to significant desalination literature. Here top three Indian institutions are Bhabha Atomic Research Centre (BARC), Mumbai; Anna University, Chennai; and Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar with respectively 150, 132, and 73 publications on Scopus database.

Table 5: Institutions doing Research in Desalination in India, 2009-18

Affiliation	No. of Records	Rank
Bhabha Atomic Research Centre (BARC)	150	1
Anna University, Chennai	132	2
Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar	73	3
Indian Institute of Technology Roorkee	71	4
Indian Institute of Technology (IIT) Delhi	66	5
Aligarh Muslim University (AMU)	65	6
Council of Scientific and Industrial Research India (CSIR)	63	7
Indian Institute of Technology (IIT), Guwahati	58	8
National Institute of Technology, Durgapur	58	9
Jadavpur University, Kolkata	57	10
Indian Institute of Technology (IIT) Madras	46	11
National Institute of Technology (NIT) Karnataka	44	12
National Institute of Technology (NIT), Tiruchirappalli	44	13
Sri Sivasubramaniya Nadar College of Engineering, Chennai	39	14
Vellore Institute of Technology (VIT), Vellore	38	15
Sardar Vallabhbhai National Institute of Technology Surat	33	16
Institute of Chemical Technology, Mumbai	31	17
Thiagarajar College of Engineering, Madurai, Tamil Nadu	30	18
SRM Institute of Science and Technology Kattankulathur, Tamil Nadu	26	19
National Chemical Laboratory (NCL), Pune	25	2

Table 6 provides a list of major subject areas for research in desalination in India, during 2009-18. These are namely, environmental science, general engineering, chemical engineering, chemistry, materials science, and energy with respectively 1736, 1728, 555, 511, 503 and 150 publications on Scopus database. This can be noted here that there is a possibility of multiple subject areas for each publication.

Table 6: Major Subject Areas for Research in Desalination in India, 2009-18

Subject Area	No. of Records
Environmental Science	1736
Engineering	1728
Chemical Engineering	555
Chemistry	511
Materials Science	503
Energy	150
Others	170

Table 7 indicates a list of major funding sponsors for research in desalination in India, during 2009-18. As recorded on Scopus, top three funding sponsors were namely, Council of Scientific and Industrial Research (CSIR), Department of Science and Technology, Ministry of Science and Technology (DST), and University Grants Commission (UGC) with respectively with respectively 112, 107, and 91 publications on Scopus database. This can be noted here that there is a possibility of non-mentioning of the names of the funding sponsor in every publication.

Table 7: Major Funding Sponsors for Research in Desalination in India, 2009-18*

Funding Sponsor	No. of Records
Council of Scientific and Industrial Research (CSIR)	112
Department of Science and Technology, Ministry of Science and Technology (DST)	107
University Grants Commission (UGC)	91
Ministry of Coal, Government of India	23
Department of Science and Technology, Government of Kerala	18
Science and Engineering Research Board (SERB)	18
Department of Atomic Energy, Government of India (DAE)	14
National Research Foundation of Korea (NRF)	14
Ministry of Human Resource Development (MHRD)	13
Board of Research in Nuclear Sciences (BRNS)	11
Ministry of Education, Science and Technology (MEST), South Korea	11
King Saud University (KSU), Saudi Arabia	10

*Multiple Sponsor is possible. Only few desalination publications reported their funding sponsors.

4.2 Online Enrolment of Desalination Solution Providers

The findings of this online survey are reported in this Section, while Tables and Figures give us more specific information as obtained from the respondents. Figure 4 indicates that out of 46 respondents, the majority of the respondents belong to India (63.04%), while 36.96% respondents belong to the other countries.

As indicated in Figure 5 in term of the type of organizations, 80.43% respondents belong to companies, 15.22% belong to R&D sector (including the universities), while only 4.35% respondents belong to NGO or civil society organizations.

Figure 4: Country of Origin of the Respondents

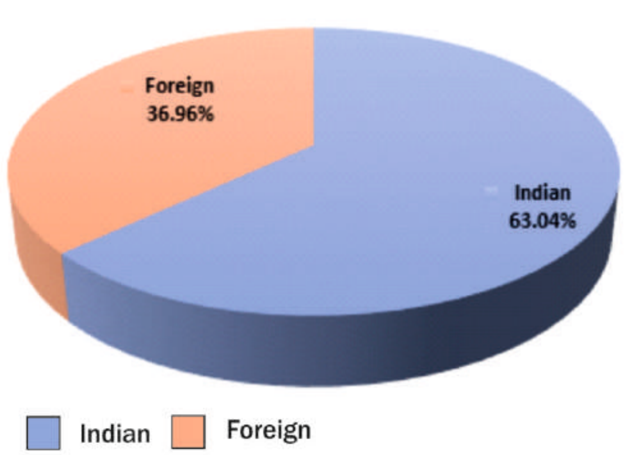
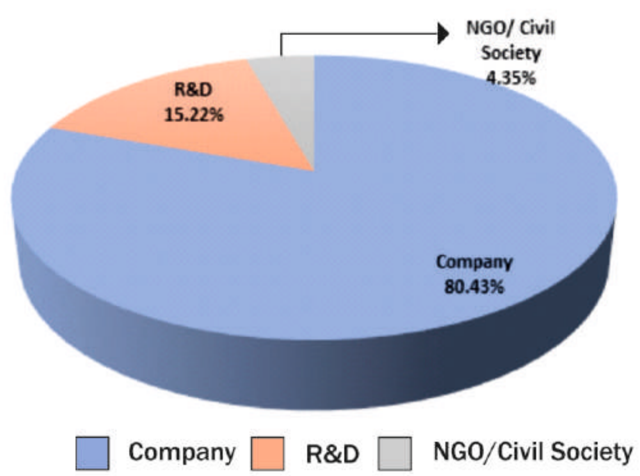


Figure 5: Type of Organizations of the Respondents



As indicated in Figure 6 in term of the Product Status, 65.22% respondents reported to have 'Developed and Commercialized' products or solutions, while 21.74% respondents have 'developed but not yet commercialized' products or solutions, and 13.04% respondents have products 'under development' or laboratory testing stage out of 46 respondents.

Figure 6: Product Status of the Respondents

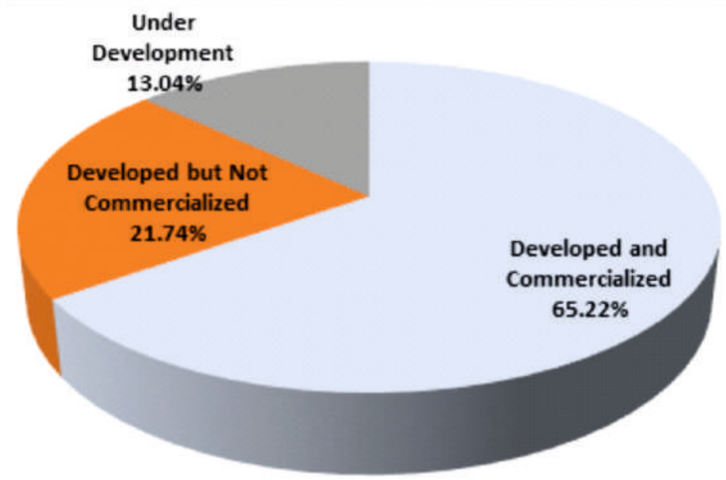


Table 8 indicates the processes of desalination applied by the respondents. A majority of respondents, viz., 54.35% offer solutions with membrane-based Reverse Osmosis (RO) process. Only 8.7% of respondents offer solutions with Thermal-based Multi-Effect Distillation (MED) process. The two respondents offer solutions with Membrane-based Electro Dialysis (ED) process. Another two respondents offer solutions with Hybrid System employing the Multi-Stage Flash Reverse Osmosis (MSF-RO) process.

Table 8: Process of Desalination

Process of Desalination	No. of Respondents	%
Membrane >> Reverse Osmosis (RO)	25	54.35
Thermal >> Multi Effect Distillation (MED)	4	8.70
Membrane >> Electro Dialysis (ED)	2	4.35
Hybrid Systems >> MSF-RO (Multi Stage Flash - Reverse Osmosis)	2	4.35
Membrane >> Osmotically Assisted Reverse Osmosis (OARO)	1	2.17
Other Processes	12	26.0

As indicated in Figure 7, the respondents mentioned the required Stage of Filtration (if applicable, as in the case of membrane or hybrid process) in their offered solutions. 70% respondents, out of 40 respondents, required to have multi-stage filtration, while remaining 30% respondents' solutions required to single stage filtration process.

Figure 7: Stage of Filtration (applicable, in case of membrane or hybrid solution)

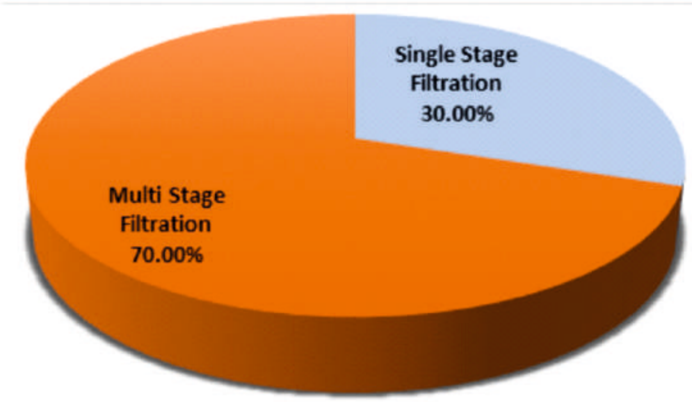
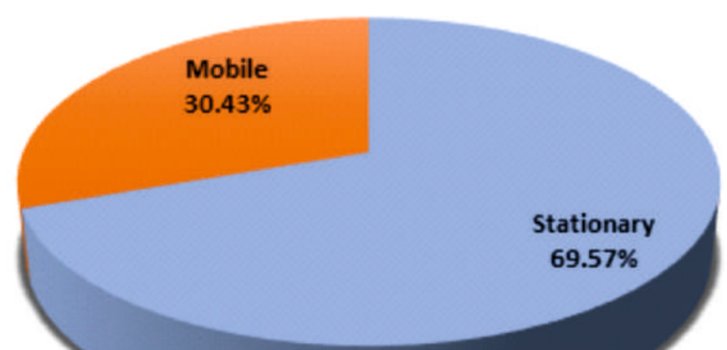


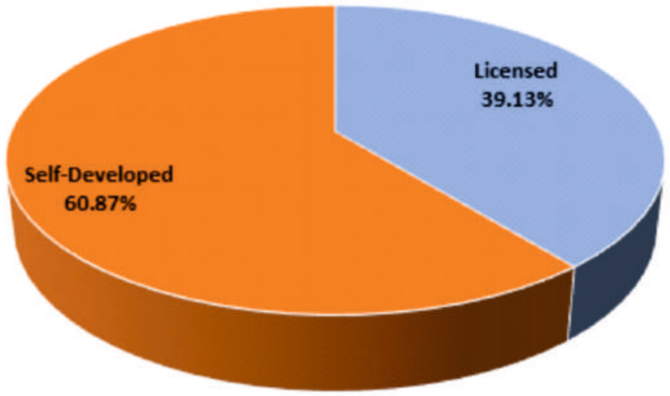
Figure 8: Mobility by Design



Concerning the mobility of the offered desalination solutions out of 46 respondents, 69.57% respondents reported having stationary desalination plants or solutions, while 30.43% of respondents offer mobile desalination plants (Figure 8).

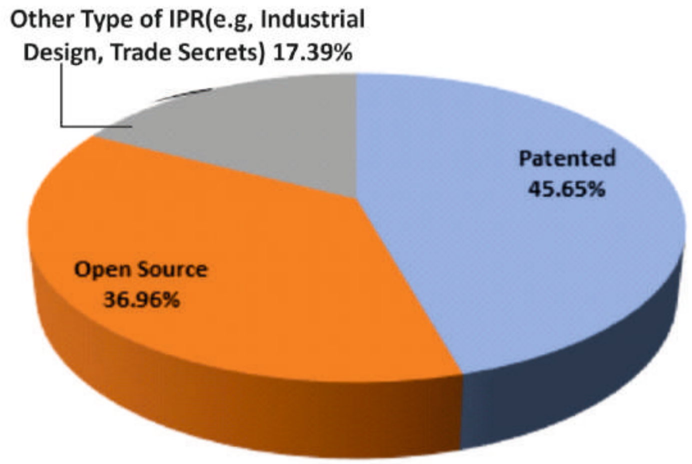
Concerning Source of Technology amongst the 46 respondents, 60.87% respondents reported having the Self-Developed technology, followed by 39.13% respondents reported to have the licensed technology from the third-party (Figure 9).

Figure 9: Source of Technology



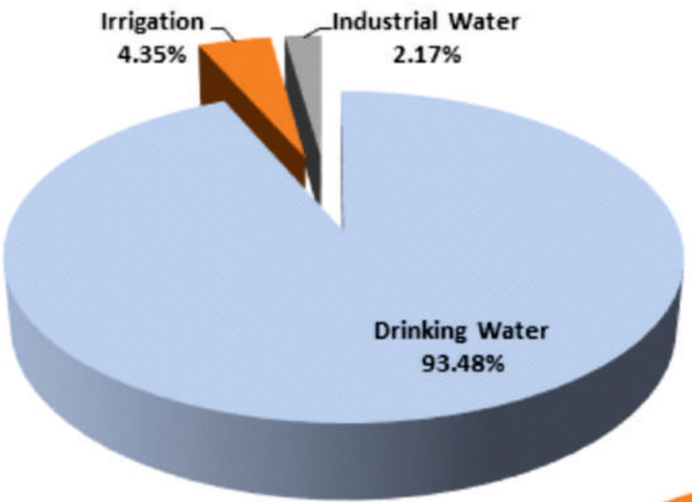
Further iterating the intellectual property rights (IPR) of the offered desalination solutions by the 46 respondents, 45.65% respondents reported to have the patented technology, followed by 36.96% respondents reported to have the open source technology, and remaining 17.39% respondents from reported to have other type of IPR, viz., industrial design or trade secret (Figure 10).

Figure 10: IPR of Desalination Solutions



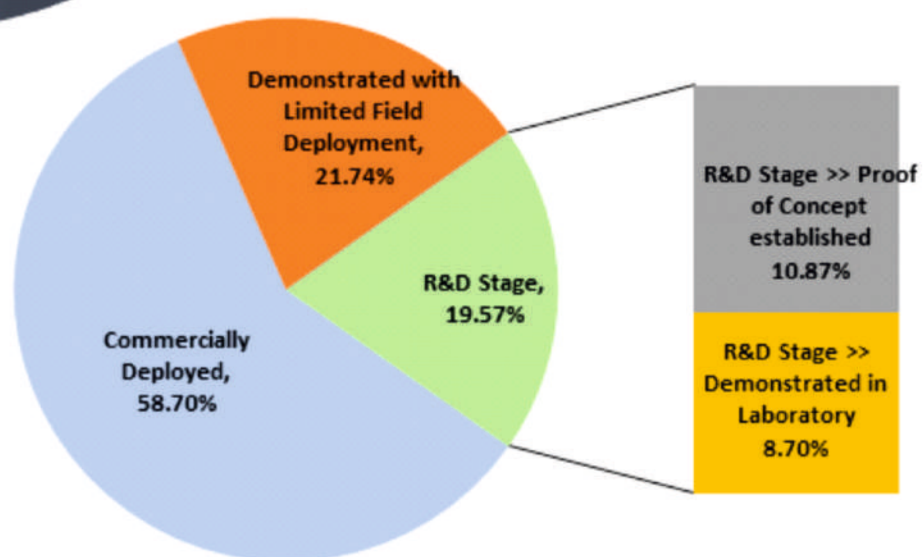
As indicated in Figure 11 concerning meeting the requirements of BIS or ISO water standards, 93.48% of respondents reported meeting drinking water standards after undertaking the desalination process. On the other hand, 4.35% and 2.17% respondents reported meeting irrigation water and industrial water standards respectively.

Figure 11: Filtered water meeting the requirements of BIS Water standards



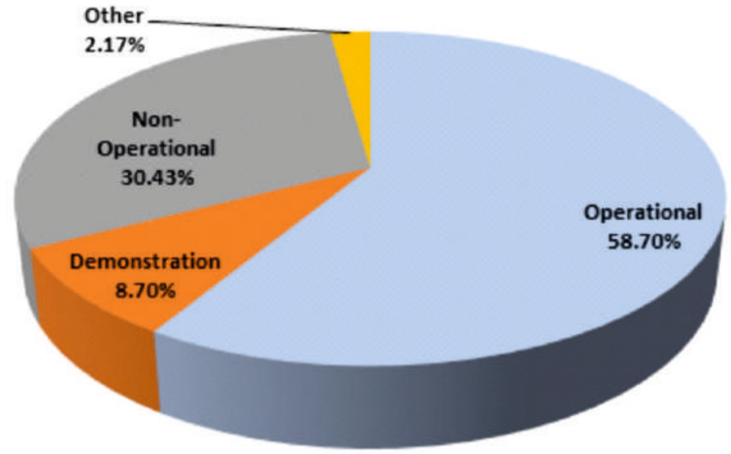
As indicated in Figure 12 concerning the desalination system installation or deployment stage, 58.70% of respondents reported having Commercially Deployed solutions, while 21.74% of respondents reported have demonstrated solutions with limited field deployment, and 19.57% of respondents reported have solution in R&D Stage including the ones with proof of concept established or the demonstrated in laboratory.

Figure 12: Desalination System Technology Readiness Levels



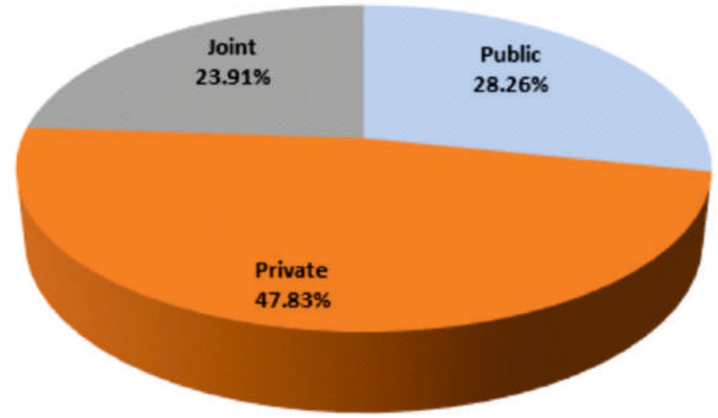
About the question related to the commercial operation of the desalination units in India of the respondents as indicated in Figure 13, 58.70% of respondents reported have operational desalination units, 30.43% of respondents reported have non-operational desalination units, while 8.70% respondents reported have demonstration units.

Figure 13: Commercial Operation of the Desalination Systems



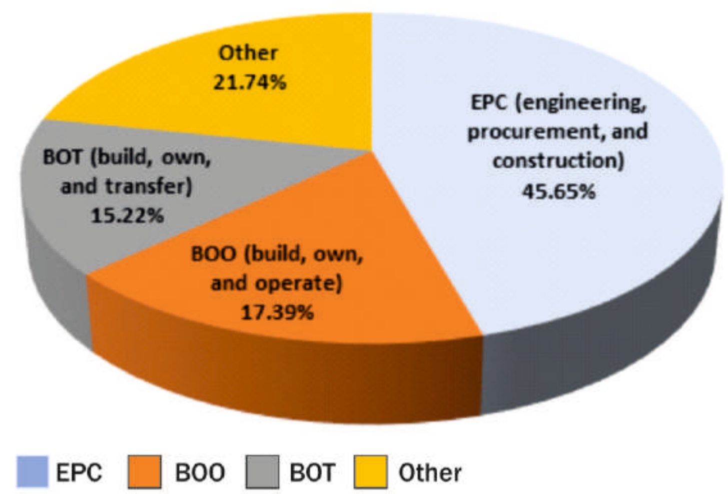
Concerning preferred of practiced ownership of desalination plants, as indicated in Figure 14, 47.83% of respondents preferred to have private ownership, while preferences for public ownership and joint ownership are respectively 28.26% and 23.91%. Here, the respondents indicated either their preference or as practiced in the field.

Figure 14: Ownership of Desalination Plant (Preferred/ Practiced)



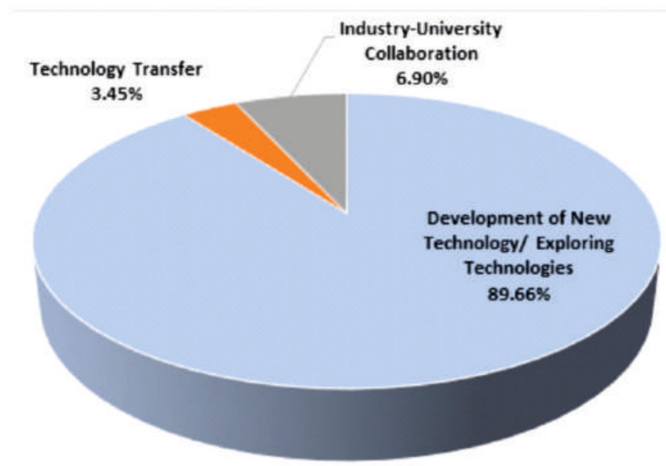
In relation to preferred or practiced terms of operational contract by the respondents as indicated in Figure 15, 45.65% of respondents reported to invoke the EPC (engineering, procurement, and construction), while 17.39% of respondents reported opting the BOO (build, own, and operate), and 15.22% of respondents reported to opt the BOO (build, own, and operate) kinds of operational contract.

Figure 15: Preferred/ Practiced Terms of Operational Contract



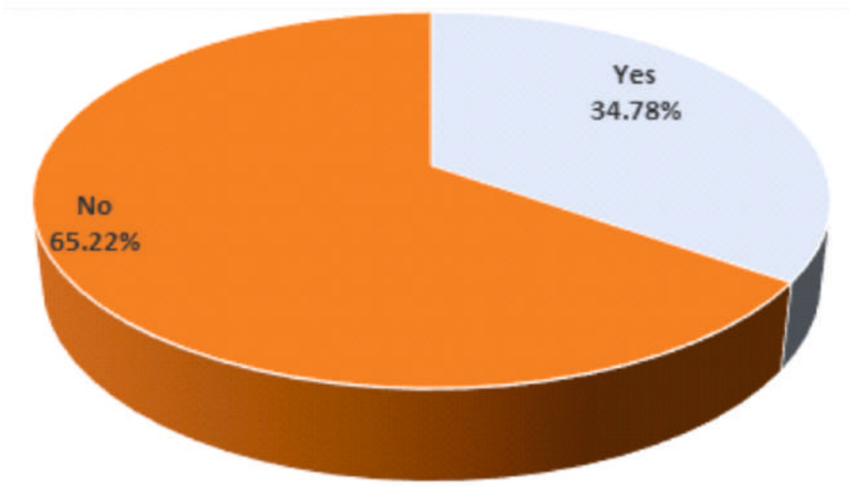
As indicated in Figure 16, the respondents have different levels of research capabilities. 89.66% of respondents reported to have in-house capabilities for development or exploring new technology solutions, while 6.9% of respondents reported having industry-university collaboration and 3.45% of respondents reported to have some kind of arrangement for technology transfer.

Figure 16: Research Capabilities of the Respondents



As indicated in Figure 17, in relation to a question whether the respondents have any linkage with state governments, central line ministry, or any other public body for commissioning any desalination plant, 34.78% of respondents reported to have some kind of linkages with the public body in India, while 65.22% respondents don't have any such linkage.

Figure 17: Linkages with Public Agencies for Desalination Solution or Research



Annexure 1: Questionnaire for Collecting Information from Solution Providers

The Desalination Mission, conceptualized in 2017 by the Department of Science and Technology (DST), Ministry of Science and Technology (MoST), Govt. of India in partnership with concerned ministries and departments at the behest of NITI Aayog, aims to provide research and technology updates for water security of the country and to provide clean and safe drinking water to water-scarce areas of the country. The Mission envisages making use of desalinated water as a sustainable solution for water supply in the coastal states across India. It is proposed to enlist all technologies (developed and commercialized, developed and awaiting commercialization, and likely to be developed in next 5 years) and enroll Indian and Global desalination technology Solution Providers in this Mission. As an initial step in this direction, it is planned to identify technology solution providers offering diverse technology options both from India and abroad for conversion of seawater/ brackish water into water for different end use (domestic/agriculture/ industrial) under the Mission.

Department of Science & Technology (DST) seeks to enroll the solution providers on the choice of technologies/ solutions. Based on the information, this Compendium of Technological Solutions is prepared for use by state governments, urban local bodies and other organizations regarding selection and use of appropriate technologies for processing of seawater/ saline/ brackish water to be made safe for human, agricultural and industrial consumption. The information bank on desalination technologies, and operational desalination units can be used by the central, state and local governments to take an informed decision on appropriate technology choices suited in specific socio-economic context and would provide an opportunity to enrolled solution providers to be a part of activities of National Mission on Desalination.

1. Technology Solution Provider's Details

1.1 Name of the Company/ Organization/ R&D Centre...

....

1.2 Registration Number...

1.3 Complete Postal Address..

1.4 Pincode/ Zip..............................1.5 Telephone No. (with country code)..

1.6 Email ID...1.7 Website Address...

1.8 Type of Organization:

☐ Private Company ☐ Public Company ☐ Public Institution ☐ R&D Centre

2. Technology Details (Key Technology Solutions offered by you):

2.1 Product Status

☐ Developed and Commercialized ☐ Developed but not Commercialized ☐ Under Development

2.2 Process of Desalination

a) Thermal

☐ Multi Stage Flash Distillation (MSF) ☐ Multi Effect Distillation (MED)

b) Membrane

☐ Reverse Osmosis (RO) ☐ Electro Dialysis (ED)

c) Hybrid Systems

☐ MSF-RO (Multi Stage Flash - Reverse Osmosis)
☐ MED-TVC (Multi Effects Distillation - Thermal Vapor Compression)

d) Any Other

2.2.1 Stage of Filtration (if applicable, as in Case of Membrane or Hybrid)

☐ Single stage ☐ Multi Stage

2.3 Mobility

☐ Stationary ☐ Mobile

2.4 Source of Power

☐ Conventional

Renewable

☐ Solar ☐ Wind ☐ Any Other

☐ Hybrid (Pl. specify)

2.5 Capacity Range (in Million Liters per Day, MLD)

☐ Minimum ☐ Maximum

2.6 Source of Technology

☐ Self-Developed ☐ Licensed(If yes, please mention name and address of know-how provider)

....

2.7 IPR of Technology

☐ Patented (If yes, please provide patent details, including country of origin)......................................

....

☐ Open Source ☐ Other type of IPR (e.g., industrial design, trade secrets)

2.8 Unit Cost (*In case of Commercialized Technology, or Developed but yet to be commercialized Technology)

☐ Capital Cost of the system ☐ Annual O&M Cost
☐ Electricity Cost per Million Liters of treated water
☐ Unit cost of treated water taking into consideration of capital cost and other O&M cost of system

2.9 --

Water Quality	Pre-Treatment	Post Treatment
Turbidity		
Total Hardness (mg/liter)		
pH value		
Odour		
Colour (Hazen units)		
Taste		
Total Dissolve Solids (mg/liter)		
Chemical (specify, if present; e.g., iron fluoride, etc.)		
Biological E-coli or Thermo-tolerant bacteria (MPN/ 100ml) Total Coli form bacteria (MPN/ 100ml)		

2.10 Name of the agency/ laboratory who certified the post-treated water quality and indicate if the laboratory is accredited by accreditation agency (e.g NABL in case of India)...

....

2.11 What is the ratio of final treated water to raw water intake?..

2.12 Does filtered water meet the requirements of BIS or ISO standards?

☐ Drinking Water (e.g., IS:10500 of 2004) ☐ Irrigation Water

☐ Industrial Water (e.g., pharma industry)

2.13 Manpower Requirement

☐ Skilled Manpower ☐ Semi-Skilled Manpower ☐ Unskilled Manpower

2.14 Specific Training Requirement, if any..

2.15 Energy Efficiency Measures used, if any...

Energy Reuse Measure

☐ Utilization of Waste Heat ☐ Recirculation of Hot Water ☐ Efficient Pumps/ Valves

Any other

☐ Energy Recovery Measure

2.16 Reject Management method used

☐ Solid Waste ☐ Sludge ☐ Brine Water Residue

2.17 Water Reuse Measures, if any

☐ Backwashing ☐ Water Recovery ☐ Any other

2.18 Life of Unit...

2.18.1 Life of Plant (in case of RO)..

2.18.2 Life of Membrane (in case of RO)..

2.18.3 Life of Equipment (in case of Thermal)..

2.19 Boundary Condition for applicability of technology
(e.g., highest range of salinity that can be dealt, etc.)

3.0 Deployment Experience

3.1 System Installation/ Deployment Details

· ☐ Commercially Deployed ☐ Demonstrated with Limited Field Deployment

· R&D Stage

☐ Proof of Concept established ☐ Demonstrated in Laboratory

3.2 If commercially deployed:

☐ Number of installation ☐ Locations of installation

Stage of installation

☐ Operational ☐ Demonstration ☐ Non-Operational (please give details)....................

....

3.3 If Demonstrated with limited field deployment:

☐ Number of demos ☐ Locations of demos

Stage of installation

☐ Operational ☐ Intermittently Operational ☐ Non-Operational

3.4 Average size of land required in square meters per plant (or for per MLD capacity)

3.5 Capital investment required per plant (or for per MLD capacity)

3.6 Key equipment required/acquired per plant (or for per MLD capacity)

3.7 Ownership of desalination plant (preferred/ practiced)

☐ Public ☐ Private ☐ Joint ☐ Community

3.8 Terms of operational contract (preferred/ practiced)

EPC (engineering, procurement, and construction)

BOO (build, own, and operate)

BOT (build, own, and transfer)

Other:

3.9 Research Capabilities

Development of New Technology/ Exploring Technologies

Technology Transfer

Industry-University Collaboration

Other

3.10 Do you have any linkage with state governments/central line ministry/ or any other public body for commissioning any Desalination Plant?

☐ Yes ☐ No

If yes, please provide details...

....

4. Please provide URL of online profile of your Company/Desalination Plant. You may send some pictures (with good resolution) of your plant/machinery by email to desalinationmission@gmail.com

SUBMIT

Annexure 2: Composition of Technical Expert Committee

1.	Prof. Ashutosh Sharma, Secretary, Department of	Chairman
2.	Nominee of Secretary, Department of Atomic Energy, Mumbai	Member
3.	Nominee of Secretary, Ministry of Earth Sciences, New Delhi	Member
5.	Nominee of Secretary, Ministry of Drinking Water and Sanitation, New Delhi	Member
6.	Nominee of Secretary, Ministry of Water Resources, New Delhi	Member
7.	Nominees of Member, NITI Aayog, New Delhi	Member
8.	Nominee of Secretary, Ministry of Shipping	Member
9.	Nominee of Secretary, Ministry of Power	Member
10.	President, Indian National Academy of Engineering	Member
11.	President, Indian Desalination Association, Mumbai	Member
12.	CMD, NTPC, New Delhi	Member
13.	CMD, BHEL, New Delhi	Member
14.	Prof. V. Ramgopal Rao, Director, IIT Delhi	Special invitee
15.	Dr. T. Sundararajan, Indian Institute of Technology Madras	Member
16.	Dr. Pushpito Ghosh, Distinguished Professor of Chemical Engineering, Institute of Chemical Technology, Mumbai	Member
17.	Dr. S. Prabhakar, Visiting Professor, SRM University. Kattankulathur, Ex. Scientist, Bhabha Atomic Research	Member
18.	Dr. S.P. Viswanathan, KGDS Renewable Energy (P) Ltd, Saravanampatti, Coimbatore	Member
19.	Dr. P. Pradeep, TCS	Member
20.	Shri. J.B. Mohapatra, JS & FA, Department of Science & Technology, New Delhi	Member
21.	Dr. Sanjay Bajpai, Head, TMD-EWO, DST	Member Secretary
22.	Dr. Neelima Alam, Sc. E, DST	Convener

Annexure 3: Participants of First Meeting of Technical Expert Committee

S.No.	Name of Participant	Designation and Organization
1.	Prof. Ashutosh Sharma	Secretary, Department of Science and Technology, New Delhi
2.	Dr. Sanjay Bajpai	Head, TMD-EWO, DST, New Delhi
3.	Dr. R.C. Bindal	Head Membrane Division, BARC Mumbai
4.	Dr. Soumitra Kar	Scientist F, BARC, Mumbai
5.	Dr. Purnima Jalihal	Adviser, NIOT, Chennai
6.	Dr. Milind Wakdikar	Scientist G, Ministry of Earth Sciences, New Delhi
7.	Dr. Sudeep Kumar	Head, CSIR, New Delhi
8.	Dr. Ashok A. Sonkusare	Jt. Adviser (S&T) Niti Aayog
9.	Shri. K. Touthang	JS, Ministry of Shipping, New Delhi
10.	Dr. T. Pradeep	Indian Institute of Technology - Madras, Chennai (FNAE)
11.	Dr. P. K. Tewari	President (Mumbai), Indian Desalination Association
12.	Shri Shaswattam	AGM, NTPC, New Delhi
13.	Shri S. Biswas	Director (Engineering, Research & Development) BHEL, New Delhi
14.	Prof. V. Ramgopal Rao	Director, Indian Institute of Technology Delhi
15.	Dr. T. Sundararajan	Indian Institute of Technology Madras

Annexure 4: Indian & Global Desalination Respondents

Sr. No.	Name of the Respondent and Website Address	Whether Indian or Foreign Entity	Type of Organization	Whether Having any Installation/ Demo in India
1	Advent Envirocare Technology Private Limited Ahmedabad, Gujarat, India E: mohit@adventenvirocare.com www.adventenvirocare.com	Indian	Company	Yes
2	BWA Water Additives UK Ltd Stretford, Manchester, United Kingdom www.wateradditives.com	Foreign	Company	Yes
3	Centre for Applied Research on Problematic Soils (CARPS) Mangalore, Karnataka, India www.cofmanagalore.com	Indian	R&D	Yes
4	Composium Group Ltd Edinburgh, Scotland, United Kingdom www.composium-group.com	Foreign	Company	Yes
5	CSIR-Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI) Bhavnagar, Gujarat, India E: vkshahi@csmcri.res.in www.csmcri.res.in	Indian	R&D	Yes
6	Empereal KGDS Renewable Energy Pvt. Ltd. Coimbatore, Tamil Nadu, India http://solar.kgisl.com/	Indian	Company	Yes
7	GB Saline Water Solutions Private Limited Tiruchirappalli, Tamil Nadu, India www.gbsaline.in	Indian	Company	Yes
8	Hitachi Zosen Corporation Osaka, Tokyo, Japan http://www.hitachizosen.co.jp/english/	Foreign	Company	No
9	Hutchison Water International Holdings Pte. Limited Fuji Xerox Towers, Singapore http://www.hutchisonwater.com/	Foreign	Company	No

Sr. No.	Name of the Respondent and Website Address	Whether Indian or Foreign Entity	Type of Organization	Whether Having any Installation/ Demo in India
10	Hybrid Recovery Concentration and Purification (HYREC) Limited St Helier Jersey, United States E: info@hyrec.co www.hyrec.co	Foreign	Company	No
11	inge GmbH Greifenberg, Germany http://www.inge.basf.com/ev/internet/inge/en/	Foreign	Company	Yes
12	InnoDI Water Technologies Pvt. Ltd. Kanakapura Taluk, Ramanagar, Karnataka, India E: vijay@innodi.in, M: +91-9731174200 sawww.innodi.in	Indian	Company	Yes
13	Intake Works LLC Sacramento, CA, United States www.intakeworks.com	Foreign	Company	No
14	International Centre for Clean Water (To be incubated at IIT Madras Research Park) Chennai, Tamil Nadu, India E: pradeep@iitm.ac.in http://www.dstuns.iitm.ac.in/listpdf/ICCW%20eBrochure%20-%20Our%20new%20initiative.pdf	Indian	Company	Yes
15	JMSI Group [J M Smith International, LLC] West Palm Beach, Florida, United States www.jmsigroup.com	Foreign	Company	Yes
16	Komal Industries Mumbai, Maharashtra, India www.komalwater.com	Indian	Company	Yes
17	Larsen & Toubro L&T Construction Chennai, Tamil Nadu, India www.lntecc.com	Indian	Company	No

Sr. No.	Name of the Respondent and Website Address	Whether Indian or Foreign Entity	Type of Organization	Whether Having any Installation/ Demo in India
18	LG Chem Limited Seoul, South Korea www. lgwatersolutions.com	Foreign	Company	Yes
19	Mera Paryavaran Madgaon, Goa, India In process	Indian	NGO	No
20	MHD Technology Corporation Orlando, Florida, United States E: info@MHDTechCorp.com, allan.sanford@gmail.com www.mhdtechnologycorporation.com	Foreign	Company	No
21	National Institute of Ocean Technology (NIOT) Chennai, Tamil Nadu, India www.niot.res.in	Indian	R&D	Yes
22	NoPo Nanotechnologies India Private Limited Bangalore, Karnataka, India T: +91-8105608995 www.nopo.in	Indian	Company	No
23	Orion Appliances Pvt Ltd Ahmedabad, Gujarat, India T: +91-9825005177 | E: info@powerh2o.net www.powerh2o.net	Indian	Company	Yes
24	Osmoflo Water Management Pty Ltd Burton SA, Australia www.osmoflo.com	Foreign	Company	No
25	Permionics Membranes Pvt Ltd Vadodara, Gujarat, India http://permionics.com	Indian	Company	No
26	RainMaker World Wide Inc Kolkata, West Bengal, India | Ontario, Canada www.rainmakerww.com	Indian	Company	No

Sr. No.	Name of the Respondent and Website Address	Whether Indian or Foreign Entity	Type of Organization	Whether Having any Installation/ Demo in India
27	Salt of the Earth Energy LLC San Antonio, Texas, United States www.saltoftheearthenergy.com	Foreign	Company	No
28	Sasi Institute of Technology & Engineering Tadepalligudem, West Godavari, Andhra Pradesh, India E: sashok@sasi.ac.in, M: +919823503512 www.sasi.ac.in	Indian	R&D	Yes
29	SLCE Watermakers Caudan, Lanester, France www.slce.net	Foreign	Company	No
30	SM Sehgal Foundation Gurgaon, Haryana, India www.smsfoundation.org	Indian	NGO	Yes
31	Sri Krishna College of Technology Kovaipudur, Coimbatore, Tamil Nadu, India www.skct.edu.in	Indian	R&D	No
32	Tamilnadu Water Investment Company Limited Chennai, Tamil Nadu, India www.twic.co.in	Indian	Company	Yes
33	TAS Engineering Co. Pvt. Ltd Thane, Maharashtra, India www.tasengg.in	Indian	Company	Yes
34	Tecton Engineering & Construction (India) Private Limited Chennai, Tamil Nadu, India | Ajman, UAE T: +9144-43403740 | E: info@tectonme.com www.tectonme.com	Indian	Company	Yes
35	The Knew Co San Diego, California, United States www.theknewco.com	Foreign	Company	No

Sr. No.	Name of the Respondent and Website Address	Whether Indian or Foreign Entity	Type of Organization	Whether Having any Installation/ Demo in India
36	Tripura University (A Central University) Suryamaninagar, Tripura(W) E: harjeetnath@tripurauniv.in www.tripurauniv.in	Indian	R&D	No
37	Triveni Engineering & Industries Ltd Noida, Uttar Pradesh, India www.trivenigroup.com	Indian	Company	Yes
38	UCLA NanoMeTeR Lab Los Angeles, California, United States www.nanometer.ucla.edu	Foreign	R&D	No
39	Vanson Engineering Pvt Ltd Mumbai, Maharashtra, India E: info@vansonengineering.com www.vansonengineering.com	Indian	Company	No
40	Vinira Solutions LLP Pune, Maharashtra, India E: saraogipradip@gmail.com www.bak2nature.in	Indian	Company	No
41	Water Systems India Private Limited Chennai, Tamil Nadu, India www.watersystemsindia.com	Indian	Company	Yes
42	WatMan Engineering Ltd Oy Paraatikatu 17, FI-15700 Lahti, Finland E: juha.lintujarvi@watman.fi, siddhomalage@vsnl.net, vkg@siddhomalgroup.com www.watmanengineering.fi, www.siddhomalgroup.com	Foreign	Company	No

Annexure 5: Technology Options for Desalination

Sr. No.	Technology-wise Solution Provider (Process | Tech)	Capacity MLD	Stage of Development/ Commercially Deployed	Power Source (Conventional/ Renewal/ Hybrid)	Patent & IPR	Water Quality (Drinking/ Irrigation/ Industrial = DW, IrW, InW)	Salinity Range	No. of installation / demos in India	Space Requirement/ MLD	Ownership & Terms of Contract	Cost of Water	Reject Management
	a) Thermal											
	a.1) Multi Effect Distillation (MED)											
1	Empereal KGDS Renewable Energy Pvt. Ltd.	0.01- 5.0	Commercially Deployed	Renewable >> Solar	Patented	DW	70000 ppm	2	150 m^2	Private, EPC	INR 59/ KL	Blending & Returning
2	GB Saline Water Solutions Private Limited	0.05- 6.0	Commercially Deployed	Conventional; or Renewable	Patented	DW	50000 ppm	4	240 m^2	Joint; EPC	INR 100/ KL	Brine Water Residue
3	RainMaker WorldWide Inc, India	0.04- 1.5	Commercially Deployed	Conventional; Renewable, or Hybrid	Patented; Other Type IPR	DW	35000 ppm	5	1000 m^2	Private, EPC	INR 30/ KL	Brine Water Residue
4	Rainmaker Worldwide Inc., Canada	0.0375- 1.0	Demonstrated with Limited Field Deployment	Hybrid	Patented	DW	No limit	0; 5 (demos)	200 sq meters per 0.15 MLD	Private, BOO	INR 150/ KL	Brine Water Residue
	b) Membrane											
	b.1) Electro Dialysis (ED) | Single Stage											
5	CSIR-Central Salt and Marine Chemicals Research Institute	0.01-0.5	Demonstrated with Limited Field Deployment	Conventional; Renewable, or Hybrid	Patented	DW	10000 ppm or less	0; 5 (demos)	200 m^2	Joint, BOO	INR 25/KL	Reject can be used for energy generation by reverse electrodialysis

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	b.2) Reverse Osmosis (RO) | Single Stage											
6	Composium Group Ltd	5.0-75.0	R&D Stage >> Proof of Concept...	Renewable	Other Type IPR	DW	45000 ppm	1	1800 m^2	Private, BOO	INR 35/KL	Brine Water Residue
7	CSIR-Central Salt and Marine Chemicals Research Institute	0.006-1.0	Commercially Deployed	Conventional; Renewable	Patented; Other Type IPR	DW	10000 ppm	150	2000 m^2	Public, BOT	INR 25/KL	Brine Water Residue
8	inge GmbH	1-500	Commercially Deployed	Conventional	Other Type IPR	DW	50000	500	10 m^2	Private, EPC	INR 40/KL	Brine Water Residue
9	Tamilnadu Water Investment Company Limited	4.0-60.0	Demonstrated with Limited Field Deployment	Conventional	Open Source	DW	45000 ppm	0; 1 (demo)	1000 m^2	Public, BOT (build, own, and transfer)	INR 90/KL	Brine Water Residue
10	UCLA NanoMeTeR Lab	0.034-100	R&D Stage >> Demonstrated in Laboratory	Conventional; Renewable	Patented	DW	45000 ppm	0	Same as standard RO	Private, EPC	INR 3500/KL	Brine Water Residue
	b.3) Reverse Osmosis (RO) | Multi Stage											
11	Advent Envirocare Technology Pvt. Ltd.	0.1 - unspecified	Commercially Deployed	Conventional; Renewable	Patented	DW	175000 ppm	1; (4 demos)	500-1000 m^2	Joint, EPC	INR 40-100/KL	Sludge; Brine Water Residue
12	Hitachi Zosen Corporation	1.0-400	Commercially Deployed	Conventional	Patented	DW	High Turbidity Seawater	N.A.	200 m^2	Private, EPC, BOO, BOT	INR 70/ KL	Depends on regulation
13	Hutchison Water International Holdings Pte. Limited	50 - unspecified	Commercially Deployed	Conventional; Renewable	Open Source	DW	upto 10 mg/l; turbidity < 30 mg/l	1	Depends	Joint, BOT	Unspecified	Brine disposal to the sea

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14	Intake Works LLC	10-94	Commercially Deployed	Conventional	Patented; Other Type IPR	IrW	45000 ppm	6	100 m^2	Joint, BOO	INR 700/KL	N.A.
15	JMSI Group	5.0-450	Commercially Deployed	Hybrid	Patented	DW	45000 ppm	10	100	Private, BOT	INR 210/KL	Solid Waste; Sludge; Brine Water Residue
16	Komal Industries	0.006-0.24	Commercially Deployed	Conventional; Renewable	Open Source	DW	6000 ppm, Turbidity level < 150 NTU	3	21 m^2	Private, EPC	INR 375/ KL	Brine Water Residue
17	Larsen & Toubro	5.0-400	R&D Stage >> Demonstrated in Laboratory	Conventional	Open Source	DW	50000 ppm	N.A.	Depends	Public, EPC	Unspecified	Sludge; Brine Water Residue
18	LG Chem Limited	1.0-300	Commercially Deployed	Hybrid	Patented	DW	45000 ppm	20; 10 (demos)	500 m^2	Private, Membrane supplier	Unspecified	NA
19	Osmoflo Water Management Pty Ltd	0.2-60	Commercially Deployed	Conventional	Patented; Open Source	DW	120,000 ppm	450	Depends	Private, EPC, BOO, BOT	Unspecified	Solid Waste; Sludge; Brine Water Residue
20	Permionics Membranes Pvt Ltd	0.05-100	Commercially Deployed	Conventional	Open Source	DW	50000 ppm	N.A.	NA	Private, EPC & others	Unspecified	Brine Water Residue
21	Sasi Institute of Technology & Engineering	0.01-0.02	Demonstrated with Limited Field Deployment	Hybrid	Open Source	DW	5000 ppm	0; 1 (demo)	24 m^2	Private, EPC	INR 250/KL	Solid Waste
22	SLCE Watermakers	1.0-15	Commercially Deployed	Conventional	Open Source	DW	50000		Depends	Public, EPC	Unspecified	Brine Water Residue

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23	Tecton Engineering & Construction (India) Private Limited	9.0-91	Commercially Deployed	Conventional	Open Source	DW	55000	9	300 m^2	Public, EPC	INR 45/ KL	Outfall
24	Tecton Engineering & Construction LLC	9.0-91	Commercially Deployed	Conventional	Open Source	DW	55000	8	500 m^2	Public, EPC	INR 45/ KL	Sea water outfall
25	Tripura University	01- 284 liters per day	R&D Stage >> Demonstrated in Laboratory	Renewable	Other Type IPR	DW	2500 ppm	0	4.9 m^2	Joint, BOT	INR 360/KL	Brine Water Residue
26	Triveni Engineering & Industries Ltd	3.0-16	Commercially Deployed	Conventional	Open Source	DW	55000 ppm	2	Depends	Private, EPC	INR 30/KL	Brine Water Residue
27	Vanson Engineering Pvt Ltd	1.0-100	Demonstrated with Limited Field Deployment	Conventional	Open Source	DW	NA	0	NA	Joint, EPC	Unspecified	NA
28	Water Systems India Private Limited	0.1-5.0	Commercially Deployed	Conventional	Open Source	DW	50000 ppm	10	2500 m^2	Public, EPC	INR 60/KL	Disposal Back to Sea
29	Water Systems India Private Limited	0.1-2.83	Commercially Deployed	Conventional; Renewable	Open Source	DW	40000 MG/L	10	3600 m^2	Public,	INR 90/KL	Brine Water Residue
30	WatMan Engineering Ltd Oy	0-3	Commercially Deployed	Hybrid	Open Source	DW	45000 ppm	0	8 m^2	Private, EPC	Unspecified	Brine Water Residue
	c) Hybrid											
	c.1) MSF-RO (Multi Stage Flash - Reverse Osmosis)											
31	TAS Engineering Co. Pvt. Ltd	0.01-5.0	Commercially Deployed	Conventional	Open Source	DW	40000 mg /Liter Salinity	120	1200 m^2	Private, EPC	Rs 235/ KL	Brine Water Residue

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	d.1) Any Other: Single Stage:											
	Membrane Distillation											
32	Vinira Solutions LLP	0.1-0.3	Demonstrated with Limited Field Deployment	Renewable, Hybrid	Patented	DW	45000 ppm	0	2000 m^2	Private, Other	INR 40/KL	Brine Water Residue
	Capacitive Deionization (CDI)											
33	International Centre for Clean Water	0.03-10.0	Commercially Deployed	Conventional; Renewable	Patented	DW	2500 mg/L	1000	1500 f^2	Public, BOT, Incubation	INR 1000/KL	Self contained or safely disposed
	Vertically aligned Single walled carbon nanotube reinforced polymer membrane											
34	NoPo Nanotechnologies India Private Limited	0.003-0.01	R&D Stage >> Demonstrated in Laboratory	Conventional	Other Type IPR	DW	N.A.	N.A.	N.A.	Private, BOT	Unspecified	Sludge
	Solar Distillation											
35	Orion Appliances Pvt Ltd	0.01-1.0	Commercially Deployed	Renewable	Other Type IPR	DW	100000 ppm	40; 2 (demos)	270000 m^2	Public, EPC	INR 620/KL	Solid Waste
	2D Graphene Filter Membrane											
36	MHD Technology Corporation	1.0-2.0	R&D Stage >> Proof of Concept established	Need no fuel	Patented	DW	No limit	2	Minimal	Private, Other	Unspecified	Virtually no brine created

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	d.2) Any Other: Multi Stage:											
	Creating fresh water source within saline aquifer											
37	SM Sehgal Foundation	0.001-0.01	Demonstrated with Limited Field Deployment	No power source	Open Source	DW	Any range	0; 15 (demos)	60 m^2	Public, BOT	Rs 42.25/KL	NA
	Ex-Situ Method of Managing Salts in Soils											
38	Centre for Applied Research on Problematic Soils (CARPS)	0-0	Demonstrated with Limited Field Deployment	Conventional	Open Source	IrW	All command areas of agriculture	0; 3 (demos)	NA	Public, Participatory mode with farmers	Unspecified	Natural Resources
	Ion Exchange											
39	The Knew Co	2.0-100.00	Demonstrated with Limited Field Deployment	Conventional; Renewable	Patented	DW	35,000 ppm	0	5000 m^2	Private, EPC	Unspecified	Reject as Fertilizers
	Specialty Products											
40	BWA Water Additives UK Ltd	0.5-5.0	Commercially Deployed	NA	Other Type IPR	DW	100000 ppm	1000	NA	Private, Supply & Service	Unspecified	NA

Sr. No.	Technology-wise Solution Provider (Process | Tech)	Capacity MLD	Stage of Development/ Commercially Deployed	Power Source (Conventional/ Renewal/ Hybrid)	Patent & IPR	Water Quality	Salinity Range	No. of installation / demos in India	Space Requirement/ MLD	Ownership & Terms of Contract	Cost of Water	Reject Management
	Patented process											
41	Salt of the Earth Energy LLC	0.5-40	R&D Stage >> Proof of Concept established	Conventional; Renewable	Other Type IPR	DW	Any range	0	4000 m^2	Private, BOO	INR 77/KL	Precipitated Solids
	Solar cum Thermal Assisted Distillation											
42	Sri Krishna College of Technology	0.1-2.5	Commercially Deployed	Renewable	Other Type IPR	InW	Brackish water	0	1500 m^2	Joint, BOO	INR 520/KL	Brine Water Residue
	Carbon Coated Electrodes											
43	InnoDI Water Technologies Pvt. Ltd.	4 to 24 KLD/ plant	Commercially Deployed	Conventional; Renewable	Patented	DW	upto 2000 ppm of TDS	150	2 M^2 for a 4 KLD plant. 20 M^2 for a 24 KLD plant	Joint, Purchase	INR 300/KL	Brine Water Residue
	FO and Membrane based Hybrid											
44	Mera Paryavaran	0.1-2.0	R&D Stage >> Proof of Concept established	Renewable; Hybrid	Open Source	DW	35,000 ppm	0	2 Acres	Joint, BOO	Unspecified	Brine Water Residue
	Low Temperature Thermal											
45	National Institute of Ocean Technology	0.1-10	R&D Stage >> Proof of Concept established	Conventional; Renewable	Patented; Other Type IPR	DW	35,000 ppm	4; 3 (demos)	750 m^2	Public, EPC	Unspecified	None

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	Membrane>>Osmotically Assisted Reverse Osmosis (OARO)											
46	Hybrid Recovery Concentration and Purification (HYREC) Limited	0.03-100	Demonstrated with Limited Field Deployment	Conventional	Patented	DW	35,000 ppm	0	40 f^2	Private, BOO	INR 67700/KL	Selective Salt Recovery & Concentration