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Membrane Science and Membrane Engineering in the past years and tomorrow

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The worldwide recognized role of Membrane Science and Membrane Engineering is today well documented by the significant growth in the Scientific organizations and Scientific Networks created in the years in all the Continents and in most of the Industrialized Countries. In the late 70[ies] and early 80[ties] the Membrane Society of Japan and the European Membrane Society were the only existing organizations. Today we have more than 10 Membrane Societies and new ones are under construction. The Journal of Membrane Science created by Harry Lonsdale in the 70[ies], is today still the most representative but in a field where 9–10 new other Journals are already present. It is impressive the number of events organized yearly worldwide devoted to our field. Efforts for more high education in membrane science and engineering in the traditional curricula for Masters and PhD has to be promoted as multinational large scale research projects in areas of strategic importance as water stress, global warming, energy production, raw materials depletion, artificial hybrid organs, neurosciences, technical textile, etc. The central role of Membrane Science and Engineering for the industrial sustainable growth has to be recognized.

Keywords : membrane society history／international membrane conference

Membrane Science and Membrane Engineering today represent one of the most visible research area together with innovative operations, in a large variety of industrial, medical and biotechnological sectors.

The story of Membrane Engineering is relatively recent. The first never organized international scientific meeting on Membranes with emphasis on industrial application and potentialities and not just on biological membranes, was organized at Villa Cimbrone in Ravello (Italy) in 1966 as a NATO Advanced Study Institute (ASI) on Membrane Transport Phenomena by Prof. Harry Gregor (from NY) and Prof. Alfonso M. Liquori (from Naples). At that time Reverse Osmosis (RO) membranes, invented by Sidney Loeb and Srinivasa Sourirajan, were just starting their successful applications, and their transport properties and potentialities in desalination was, in fact, one of the major topic discussed at the 1966 NATO ASI. All the most respected Scientists active on transport phenomena in artificial and biological membranes were present, probably for the first time, with Professors of Chemical Engineering, with Researchers in molecular separations, with Experts in polymer chemistry, etc., in an exciting multidisciplinary meeting having already all the characteristic of the future Membrane Science and Membrane Engineering.

No organized Scientific Society were existing at National and International level at that time. However,

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Fig. 1 Editorial Committee of Membrane.

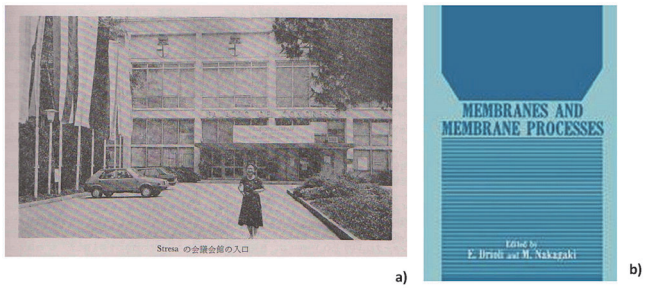


Fig. 2 a) Picture of the Stresa Conference in 1984 and b) Proceedings of the Conference.

a fast growing interest for membrane operation was already attracting scientific and industrial attention in various Countries and specifically in Japan, where Electro Dialysis (ED), in particular, and RO were utilized for the production of NaCl from the sea for the chlorosoda process, and for ultrapure water for electronic industry.

In 1978 the first Membrane Society was created in Japan as The Membrane Society of Japan (MSJ). The President of MSJ at that time was Prof. Masayuki Nakagaki and the Vice Presidents were Prof. Terukatsu Miyauchi and Prof. Toshitsugu Oda.

It is interesting to emphasize the multidisciplinarity character of MSJ from the very early stage, as still today confirmed by the members of the Editorial Board of MAKU, the official journal of The Membrane Society of Japan, in which representatives from industrial groups, such as Mitsubishi Rayon, Toyobo, Toray, etc., from Chemical Engineering Academic Departments, from Medical and Pharmaceutical Faculties, etc., are all working together.

Also in Europe, a growing attention to Membrane Science and Technology was evident. Following the 1966 first Conference, a second Ravello Conference on Membranes was organized in 1977, in the same beautiful Villa Cimbrone environment.

My self (Enrico Drioli) with Prof. Harold Hoffenberg from North Carolina State University in Raleigh, were serving as Chairmen. In 1988 and in 1999 similar events took place in Ravello attracting a selected invited group of scientists from all over the world, creating the first core group of a Membrane International Family.

The success and growing interest for Membrane Science and for all events related to this new scientific topic suggested trying to better organize at European level, the scientific efforts of researchers interested in this field.

In collaboration with few colleagues, F. Aptel from Univ. Sabatier – France, H. Strathmann from Tubingen – Germany, G. Tragardh from Lund Institute of Technology–Food Engineering – Sweden, the possibility to organize an European Membrane Society (at the time EMST) received a strong positive reply.

In 1982, the European Membrane Society (EMS) was created with the following status, "the overall goal of the Society is to:

1) promote co–operation between European Scientists and Engineers involved in research and development in the field of synthetic and artificial membranes and membrane processes;
2) organize periodic workshops and study groups on various aspect of membrane science;
3) publicate a quarterly newsletter describing developments and activities of different membrane groups;
4) stimulate exchange visits of membrane scientists and technologists in different countries;
5) delivery guidelines to national and international agencies to promote the most efficient use of

Table 1 Major Membrane Societies today

#	Name	President	Link
1	Membrane Society of Japan	Mikihisa Takano	www.maku-jp.org/index.html
2	European Membrane Society	Bart van der Bruggen	www.emsoc.eu/ems/site/home/index.php
3	North American Membrane Society	Dibakar Bhattacharyya	www.membranes.org
4	Korean Membrane Society	Kim Sung Soo	www.membrane.or.kr
5	Membrane Industry Association of China	Liu Xianqin	www.membranes.com.cn
6	Chinese Membrane Society	It was proposed in 2015, and is waiting to be approved by Chinese Government	
7	Aseanian Membrane Society	Hideto Matsuyama	www.ams10.org
8	Russian Membrane Society	Andrei Yaroslavtsev	www.memtech.ru/index.php/en
9	Membrane Society of Australasia	Aaron Thornton	www.membrane-australasia.org
10	Indian Membrane Society	B. Chakravorty	indianmembranesociety.com
11	South Central Membrane Association	Alain Richard (board of directors)	www.scmembrane.org
12	American Membrane Technology Association	Scott Freeman	www.amtaorg.com
13	African Membrane Society	Abdoulaye Doucouré (board of directors)	www.sam-ptf.com/
14	Membrane Society in Singapore	Rong WANG	www.memsis.org/
15	Sociedad Mexicana de Ciencia y Tecnología de Membranas	Miguel Torres Rodríguez	www.smcytm.org.mx

resources."

Having internationalization as one of the high priority actions of the Society, Prof. Drioli, President of EMS and Prof. Nakagaki, President of The Membrane Society of Japan had meetings in Tokyo for discussing the collaboration between the two Societies and the decision of organizing the first Euro – Japan Conference in Italy was taken. In 1984 the Europe – Japan Congress on Membranes and Membrane Processes was held in Stresa, on June 18–22.

Following the success of this event, due to a large number of participants, of about 400, from 26 Countries including USA, Australia, China and Brazil and considering the quality of the Plenary Lectures and Scientific Communications, the outcome was the decision to organize the Japan – Europe Congress on Membranes and Membrane Processes in Tokyo, in 1987.

In the meantime, Prof. Elias Klein, a USA participant at the Stresa Conference, going back to USA organized a meeting where the most representative scientists active in Membrane Science in USA and Prof. E. Drioli were invited.

Prof. E. Klein described the activities of the MSJ of Japan and of EMS in Europe.

The proposal of Prof. Klein of founding the North American Membrane Society, NAMS, was very well and unanimously accepted. After this event, the Presidents of MSJ and EMS were in agreement to

Table 2 ICOM Conferences

Year	Location	Organizer	Chair	Statistics
Europe -Japan Congress on Membranes and Membrane Processes -Stresa '84 *June 18-22 1984*	Stresa, *Italy*	The Membrane Society of Japan, EMS	Masayuki Nakagaki Enrico Drioli	400 Particip. 26 Countries
ICOM '87 *June 8-12 1987*	Tokio, *Japan*	The Membrane Society of Japan, EMS	Masayuki Nakagaki Enrico Drioli	700 Particip. 400 Papers 28 Countries
ICOM '90 *August 20-24 1990*	Chicago, *USA*	NAMS	Norman N. Li	500 Presentat.
ICOM '93 *August 30 - September 3, 1993*	Heidelberg, *Germany*	EMS,The Membrane Society of Japan, NAMS, University of Heidelberg	R. Rautenbach J.J. Vier R.N. Lichtenthaler	509 Presentat.
ICOM '96 *August 18-23 1996*	Yokohama, *Japan*	The Membrane Society of Japan, EMS, NAMS	Shoji Kimura Takeo Shimizu	500 Papers. 600 Particip.
ICOM '99 *June 12-18 1999*	Toronto, *Canada*	NAMS	Doug Lloyd Jim Davis	562 Presentat. 629 Papers
ICOM 2002 *July 7-12, 2002*	Toulouse, *France*	Université Paul Sabatier	John Howell, Roger Ben Aïm Pierre Aimar Corinne Cabassud	365 Presentat. 302 Particip.
ICOM 2005 *August 21-26, 2005*	Seoul, *Korea*	The Aseanian Membrane Society, The Membrane Society of Korea, NAMS, EMS	Tae Moon Tak Un Young Kim	793 Presentat. >700 Particip. 40 Countries
ICOM 2008 *July 12-18, 2008*	Honolulu, *Hawaii, USA*	NAMS	Ingo Pinnau, Benny Freeman, Yoram Cohen	827 Presentat.
ICOM 2011 *July 23-29, 2011*	Amsterdam, The *Netherlands*	Membrane Technology Group of University of Twente	Kitty Nijmeijer Antoine Kemperman Matthias Wessling	1064 Presentat. 1051 Particip.
ICOM 2014 *July 20-25, 2014*	Suzhou, *China*	The Aseanian Membrane Society, EMS, NAMS	Congjie Gao Juin-Yih Lai Wanqin Jin Xiaolin Wang	1300 Particip. 514 Oral 662 Posters
ICOM 2017 *29 July – 4 August 2017*	San Francisco, *CA, USA*	NAMS		
ICOM 2020	Pending			

redesign the Japan – Europe Congress, scheduled in Tokyo in 1987, as an International Congress (ICOM) having also the NAMS as member of organizing committee. The successful story of the International

Table 3 Major Conferences in Membrane Science and Technology

Aseanian Membrane Society Conference (AMS)
Euromembrane
World Filtration Congress
International Membrane Science and Technology Conference (IMSTEC)
North American Membrane Society (NAMS) Meeting
International Conference on Inorganic Membranes (ICIM)
International Water Association Events
International Conference on Catalysis in Membrane Reactors (ICCMR13)
Gordon Conferences USA
Engineering Conferences International
European Congress of Chemical Engineering (ECCE)
World Congress of Chemical Engineering (WECCE)
Aachener Membrane Colloquium
Ravello Conferences (from 1966 every 11 years)

Congress on Membranes and Membrane Processes, the ICOM Conferences (still today the most representative of scientific membrane conferences) started at that time.

In parallel, another important action that was realized promoted by EMS, was the creation of Summer Schools all around Europe. Due to the difficulties of students from East Countries to travel to the West, in various occasions, Summer Schools were also organized in Poland, Russia (Soviet Union at that time), Hungary, etc.

The situation of the organized Membrane Societies today is very different from 80[ties]. In the Table 1 a list of major existing Membrane Societies, from the Australasia, to the coming Chinese and the youngest African, is presented.

All of them are quite active, promoting International Conferences and trying to create strong links between their members.

In parallel to the growth of the Societies, a significant number of Scientific Conferences and Exhibitions, has been established annually, biannually, triannually.

In Table 2, the list of different ICOM conferences, following the one in Tokyo in 1987, is reported.

In Table 3, a list of the other major Membrane Conferences and Workshops is shown.

In the early 70[ies], scientific magazines devoted to membrane science were not existing. Dr. Harry Lonsdale in 1976 created the first journal in the field, Journal of Membrane Science (JMS) published by Elsevier. H. Lonsdale made an excellent creative action in promoting the growth of this journal, today the most representative scientific Journal in the Membrane World. The JMS, publishing initially 10 – 15 manuscripts per volume, it is characterized, today, by an IF: 5.557 and receives thousands of submissions per years. NAMS, EMS, Aseanian Membrane Societies are today formally sponsoring this Journal. However, various other International Journals have been created in the years. The majors are in Table 4 together with a large number of newsletters and reports with updates all around the world in Membrane Science and Membrane Engineering.

The necessity to promote more high educational activities at Academia level in Membrane Science and Membrane Engineering has been well recognized in the past years.

The European Union in 2010 approved the project of an Erasmus Mundus Doctorate in Membrane Engineering (EUDIME). The program provided the excellent opportunity to motivated, talented and competent scholars across the Europe and developing countries to pursue their research in some leading European Institutes working in Membrane field (eudime.unical.it)

The success of this project, coordinated by Prof. E. Drioli – University of Calabria and involving seven other European Universities, University of Twente (The Netherlands), Institute of Chemical Technology Prague (Czech Republic), University of Leuven (Belgium), University of Montpellier 2 and University Paul Sabatier–Toulouse (France), and ten associate partners from Academia and Industry, is well documented by the numbers of applicants in the various annual calls (see Table 5).

A similar relevant initiative was realized for an Erasmus Master Program in Membrane Engineering coordinated by Prof. A. Ayral, at the University of Montpellier (www.em3e-4sw.eu/em3e/em3e-home). In parallel to these activities, significant successes were reached in the production at industrial level on Membrane modules and Membrane Operations.

In particular, pressure driven membrane operations (RO, UF, NF, MF) became dominant technologies in desalination, in waste water treatments and water reuse and also in a large variety of industrial sectors.

Membrane systems are largely present in the food and beverage, dairy, textile industries and in electronics, automobile, petrochemical productions etc.

Table 4 Major Journals, Newsletters and Reports published on Membrane Science and Membrane Engineering

Journal	Editor(s)	Publisher
Journal of Membrane Science	Ed.- in - Chief: A.L. Zydney Founded by Harry Lonsdale in 1976	Elsevier
Membrane (MAKU)	Ed.- in - Chief: Mikihisa Takano (Hiroshima University)	Membrane Society of Japan
Membrane Journal	Ed.- in - Chief: Sang Yong Nam	Membrane Society of Korea.
Membrane Technology	Ed.- in - Chief: S. Atkinson	Elsevier
Journal of Membrane and Separation Technology	Ed.- in - Chief: Masakazu Yoshikawa	Lifescience Glob
Journal of Membrane Science & Technology	Hao Fong, Abdul Latif Ahmad, Subrata Mondal, George Perry	OMICS Publishing Group
The Journal of Membrane Biology	Ed.- in - Chief: Wolfgang E. Trommer (TU Kaiserslautern)	Springer
Membranes	Ed.-in-Chief: Spas D. Kolev	MDPI AG, Basel, Switzerland
Biochimica et Biophysica Acta (BBA) – Biomembranes	Editors -in-Chief: Yechiel Shai, Hans Vogel	Elsevier
Biochemistry (Moscow) Supplement Series A: Membrane and Cell Biology	Ed.- in - Chief: Stanislav S. Kolesnikov	Springer
Journal of Membrane Science and Technology (China) (Bimonthly publication of the Membrane Industry Association of China)	Ed: Liu Xianqiu	Editorial Department of Membrane Science and Technology
Journal of Membrane Science and Research (JMSR) (Iran)	Ed.- in - Chief: Ali Kargari	Membrane Processes Research Center (MPRC)
Molecular Membrane Biology	Ed.- in - Chief: Anthony I Magee	Taylor & Francis
Membrane Water Treatment	Editors -in-Chief: Enrico Drioli, Youngchul Choi, Ruey-Shin Juang	Techno-Press

Table 5 Total number of applicants, their nationalities and number of selected candidates for each EUDIME edition

Edition	# of applicants	# of nationalities	Fellowships awarded
I	110	35	9
II	99	24	9
III	90	28	9
IV	67	23	7
V	103	26	5

It is interesting to mention the progresses in desalination, where the so–called third generation desalination systems are involved in fresh water production integrated, however, with energy production and row material extraction and reuse from the brine of RO and NF operations.

The strategy of integrated membrane systems is becoming largely and successfully accepted today in a variety of industrial productions.

The MEDINA research project in Europe (cordis.europa.eu/project/rcn/81392_en.html and E. Drioli, A. Criscuoli, and F. Macedonio, eds. Membrane–based

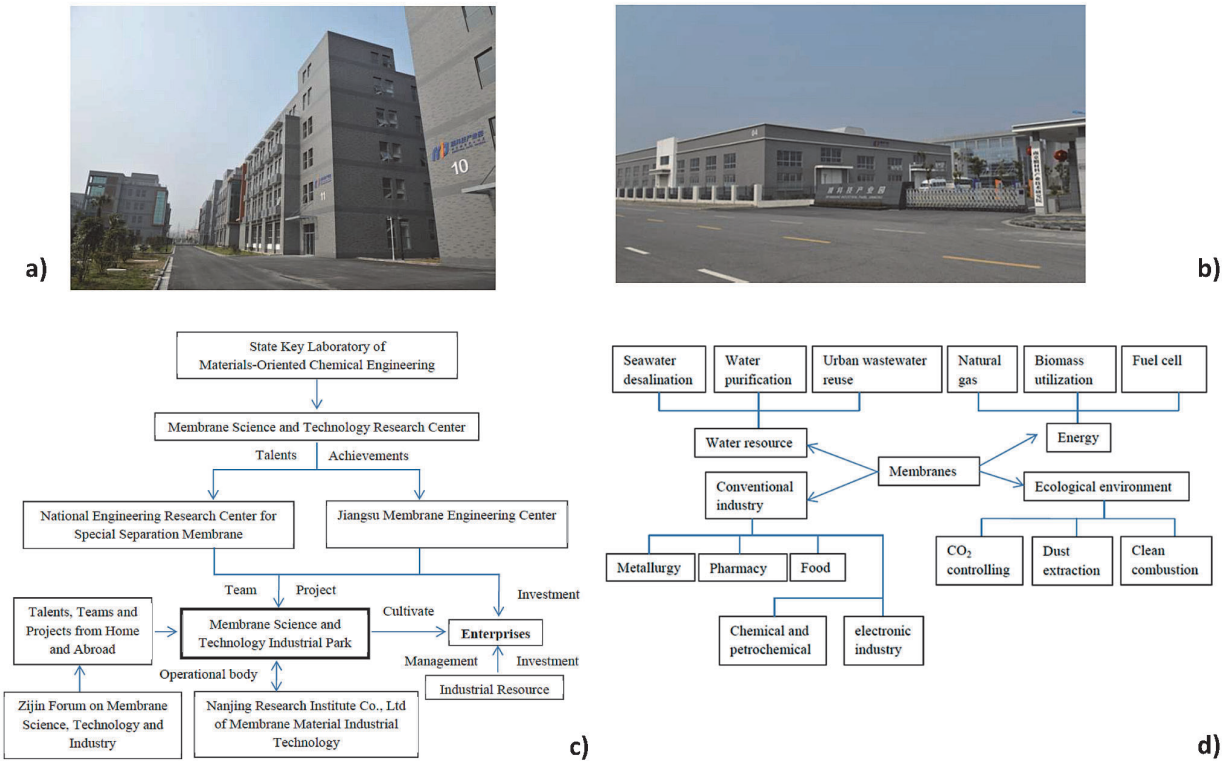


Fig. 3 The Jiangsu Membrane Industrial Park, in Nanjing. a) – b) Pictures, c) Operational framework of the Membrane Science and Technology Industrial Park, d) Technologies developed in the Membrane Industrial Park.

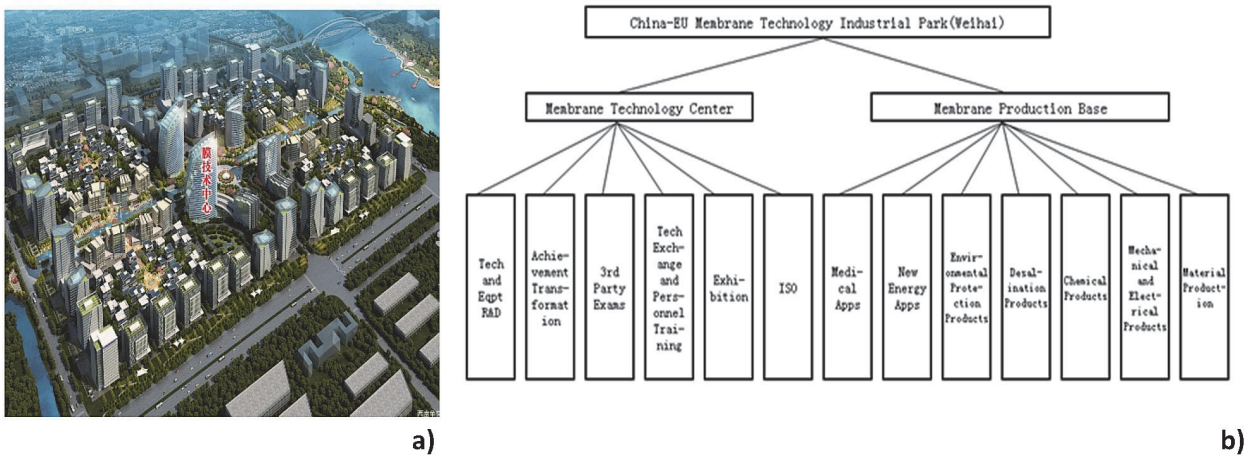


Fig. 4 The Weihai Membrane Technology Center. a) Picture, b) Activities related to the membrane technology center and membrane production base.

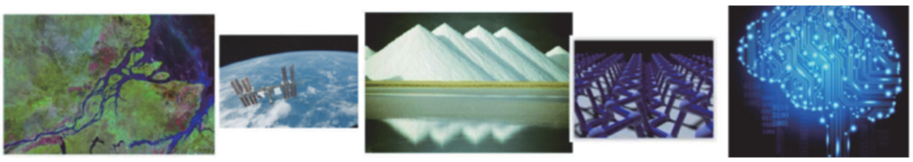
Desalination: An Integrated Approach (MEDINA). Iwa Publishing, 2011), MEGATON in Japan (www.megatonwater.com/en/research.html) and SEAHERO in Korea (www.seahero.org/), are the best examples of these innovative strategies, today present also in the Middle East as evidenced by the Masdar program for desalination (www.masdar.ae/en/energy/detail/renewable-energy-water-desalination-in-uae).

A novel and significant approach to promote the development of Membrane Science and Technology is the recent creation of Membrane Science and Technology Industrial Parks, sponsored by the Chinese Government. In Fig. 3 a) – d) are summarized the activities of the already existing Jiangsu Membrane Science and Technology Industrial Park.

In Fig. 4 are shown the activities of the Membrane Technology Center supported by the Weihai Municipal Government in Shandong Province, and today in real-

Table 6 Strategic topics to be promoted

○ Blue energy from salinity gradients
○ Membrane systems in the Space
○ Hybrid organs as artificial brains
○ A new Mining Industry: mineral recovery from the sea
○ New 2D materials (Graphene, Graphene derivatives, and other 2D materials like phosphorenes, borenes,…) for new Membranes



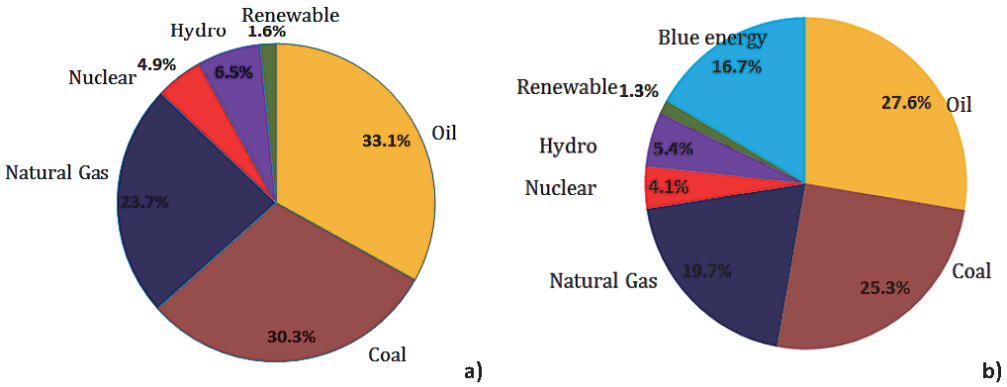


Fig. 5 Blue energy and energy resources distribution. a) BP: Statistical review 2011, b) Recalculated considering blue energy (J.W. Post, PhD thesis, Wageningen University, Wageningen The Netherlands (2009)).

ization.

A strong International character and a multidisciplinary approach are present and recognized necessary for the success of these initiatives.

The central role of Membrane Science and Engineering for an Industrial Sustainable Growth is more and more well recognized and promoted worldwide.

Following the Process Intensification strategy, the basic properties of modern Process Engineering related to Membrane Engineering, are:

a) a strong fundamental multidisciplinary character from Chemical Engineering and Material Science Engineering to Biotechnology, Biology, Tissue Engineering, etc.
b) the largest spectrum of realized and potential application in practically all Industrial Sectors and in Agriculture, Medicine, Space Technologies, etc.

Some of the actions to be promoted for realizing a continuously successful future growth of Membrane Science and Engineering, will be the creation of:

1. A Global Membrane Network,
2. Large scale multinational projects on strategic matters,
3. International Doctorates in Membrane Engineering (following the Erasmus Mundus Doctorate in Membrane Engineering, EUDIME).

Example of ambitious strategic topics to be developed by the Membrane Researchers might be the ones listed in Table 6.

The creation of a Global Membrane Network will facilitate to obtain further positive follow out in the vari-

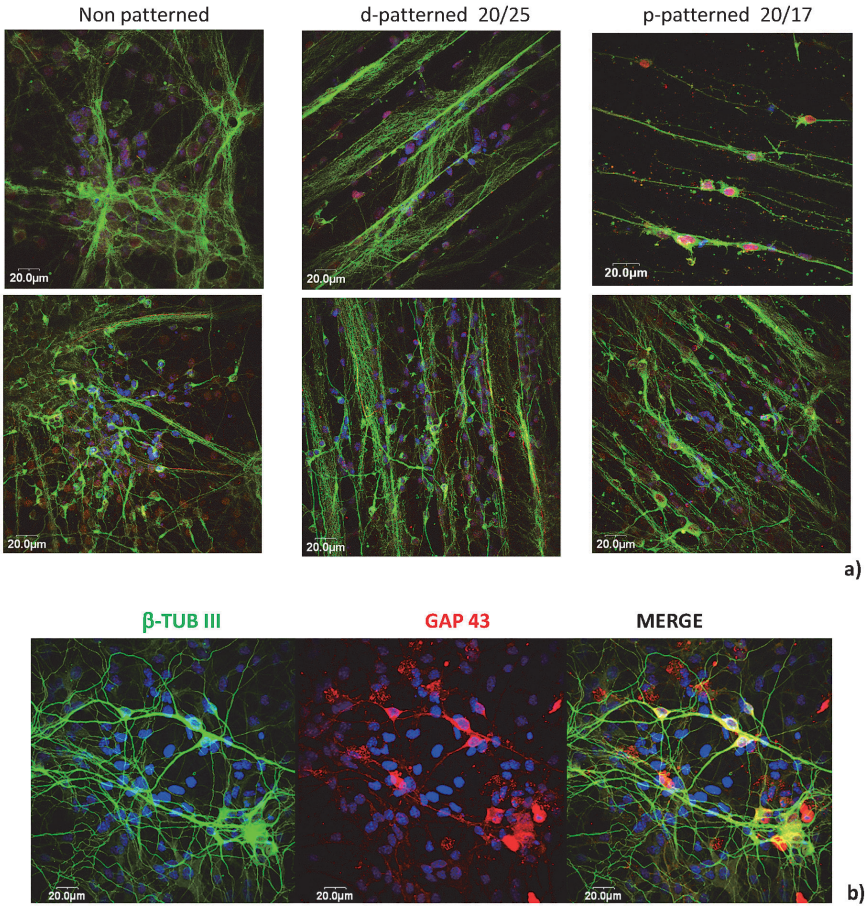


Fig. 6 Neuronal network construct in a membrane system. a) Micropatterned PLLA membranes for guidance of neuronal cells (S. Morelli, S. Salerno, A. Piscioneri, B.J. Papenburg, A. Di Vito, G. Giusi, M. Canonaco, D. Stamatialis, E. Drioli, L. De Bartolo Biomaterials 2010, 31: 7000–7011, Adapted with permission from Elsevier), b) Human mesenchymal stem cells in a compartmentalized neuronal membrane system (A. Piscioneri, S. Morelli, M. Mele, M. Canonaco, E. Bilotta, P. Pantano, E. Drioli, L. De Bartolo Acta Biomaterialia 2015; 24: 297-308, Adapted with permission from Elsevier).

Fig. 7 Membrane systems in the space.ESA astronaut Andreas Mogensen's 10–day 'iriss' mission to the International Space Station includes the scientific experiment to purify some of the Station's waste water and test a 'biomimetic' membrane from Denmark. The membrane mimics nature to create clean drinking water using a nano–technology that requires no energy.
ESA is gratefully acknowledged: www.esa.int/Our_Activities/ Human_Spaceflight/ iriss/Highlights/ Andreas_in_space.

ous topics indicated. It will not be easy, however. In the blue energy area the visibility of the membrane operations (Pressure retarded osmosis (PRO) and Reverse electrodialysis (RED)) in the recent years has been very modest, as evidenced in the Fig. 5 a) in front of a potential contribution of blue energy of about 17 % as shown in Fig. 5 b).

In regenerative medicine and in the study of hybrid artificial organs as artificial brain (Fig. 6), in the space

Table 7 Thermal conductivity [1]

Material	Thermal conductivity @ T=300 K [W m^{-1} K^{-1}]	Reference
MONOLAYER graphene	**~5000**	A. A. Balandin et al. Superior Thermal Conductivity of Single-Layer Graphene, *Nano Lett.* **2008,**8, 902.
MONOLAYER SnSe	0.46-0.68 (anisotropic)	L.D. Zhao et al. Ultralow thermal conductivity and high thermoelectric figure of merit in SnSe crystals. *Nature* **2014,** *508*, 373-377.
Sb_2Te_3 (similar to Bi2Se3)	0.23-0.5	J. Chen et al. Sb_2Te_3 Nanoparticles with Enhanced Seebeck Coefficient and Low Thermal Conductivity. *Chem. Mater*. **2010**, 22, 3086-3092.
Bi_2Se_3	0.4 (few layers)	M.K. Jana et al. Ionothermal Synthesis of Few-Layer Nanostructures of Bi2Se3 and Related Materials. *Chem. Eur. J.* **2013,** *19*, 9110-9113.
MoS_2	108 (monolayer)	W. Li, et al. Thermal conductivity and phonon linewidths of monolayer MoS2 from first principles. *Appl. Phys. Lett.* **2013**, 103, 253103.
WSe_2	0.05 (monolayer) 1.5 (bulk)	C. Chiritescu at al. Ultralow Thermal Conductivity in Disordered, Layered WSe_2 Crystals. *Science* **2007,** *315*, 351-353.
Phosphorene	zigzag direction: 110 armchair direction: 36	A.Jain and A.J.H. McGaughey Strongly anisotropic in-plane thermal transport in single-layer black phosphorene. *Sci. Rep.* **2015,** *5*, 8501.
_____Polymers_____		
PVDF	0.19	http://www.quadrantplastics.com/fileadmin/quadrant/documents/QEPP/EU/Product_Data_Sheets_PDF/Product_Data_Sheet_Symalit_PVDF_1020.pdf
Polytetrafluoroethylene	0.24-0.35	http://www.bearingworks.com/content_files/pdf/retainers/PTFE%20datasheet.pdf
Polypropylene	0.10-0.22	http://www.professionalplastics.com/professionalplastics/ThermalPropertiesofPlasticMaterials.pdf
Cellulose acetate	0.16-0.36	http://www.professionalplastics.com/professionalplastics/ThermalPropertiesofPlasticMaterials.pdf

[1]E. Drioli, A. Gugliuzza, A. Politano Composite graphene and beyond graphene membranes, Korea–Italy Bilateral Symposium on Beyond Graphene, Hanyang University, Korea, May 27th 2016

research activities (Fig. 7) as in a new Mining Industry, having the sea as an open-sky mine, important results might be reached by a strong International Team promoted by Membrane Associations.

The interest today for 2D material as graphene and beyond graphene, with their quite interesting characteristics, as the thermal conductivity (Table 7), might offer the opportunity of production of new class of membranes for various operations able to overcome the limits of the membrane and modules realized until now.

Very impressive and positive progresses have been done in the last thirty – forty years, but the impact of Membrane Science and Membrane Engineering in our modern society is just at its beginning.

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Elena Tocci is currently a researcher at the Institute on Membrane Technology of the National Research Council (ITM–CNR), Rende, Italy. She earned her Ph.D. in Chemical and new materials technologies at the University of Calabria, Italy, in 2000. She is expert in computational chemistry applied to membrane and membrane processes: molecular dynamics and Monte Carlo simulations of transport properties of gases and vapors in dense amorphous glassy membranes, modelling of morphological properties of amorphous glassy membranes and in high free volume polymers, mesoscale modeling of nanostructured polymeric materials.