WETT Research Centre's Contributions to Water Research at RMIT

Veeriah Jegatheesan (Jega)

Director, Water: Effective Technologies and Tools (WETT) Research Centre

RMIT University, 30 November, 2018 (Revised Version)

RMIT UNIVERSITY

Contents

RMIT UNIVERSITY

1. Research Focus – Enabling Capability Platforms

Advanced manufacturing and fabrication

Biomedical and health innovation

Global business innovation

Social change

Urban futures

Design and creative practice

Information and systems (engineering)

Advanced materials

RMIT UNIVERSITY

The Millennium Development Goals (MDGs)

- UN Millennium Summit in 2000 – United Nations Millennium Declaration
- 8 International Development Goals
- 189 UN member states and 22 international organisation committed to achieve the goals by 2015
    - To eradicate extreme poverty and hunger
    - To achieve universal primary education
    - To promote gender equality and empower women
    - To reduce child mortality
    - To improve maternal health
    - To combat HIV/AIDS, malaria and other diseases
    - To ensure environmental sustainability
    - To develop a global partnership for development

Sustainable Development Goals (SDGs)

"there can be no Plan B, because there is no Planet B" – Ban Ki-Moon

- A set of 17 aspirational "Global Goals" with 169 targets among them
- 304 proposed indicators to show compliance
- 193 Member States as well as Global Civil Society

RMIT UNIVERSITY

How can *research* contribute to achieving UN Sustainable Development Goals and address local/global challenges?

If one single man suffers from starvation, we will destroy the entire world – Subramania Bharati, 1882-1921

Let the sky fall, when it crumbles, we will stand tall and face it all together
-Theme song of the 23rd James Bond movie "Sky Fall"

RMIT UNIVERSITY

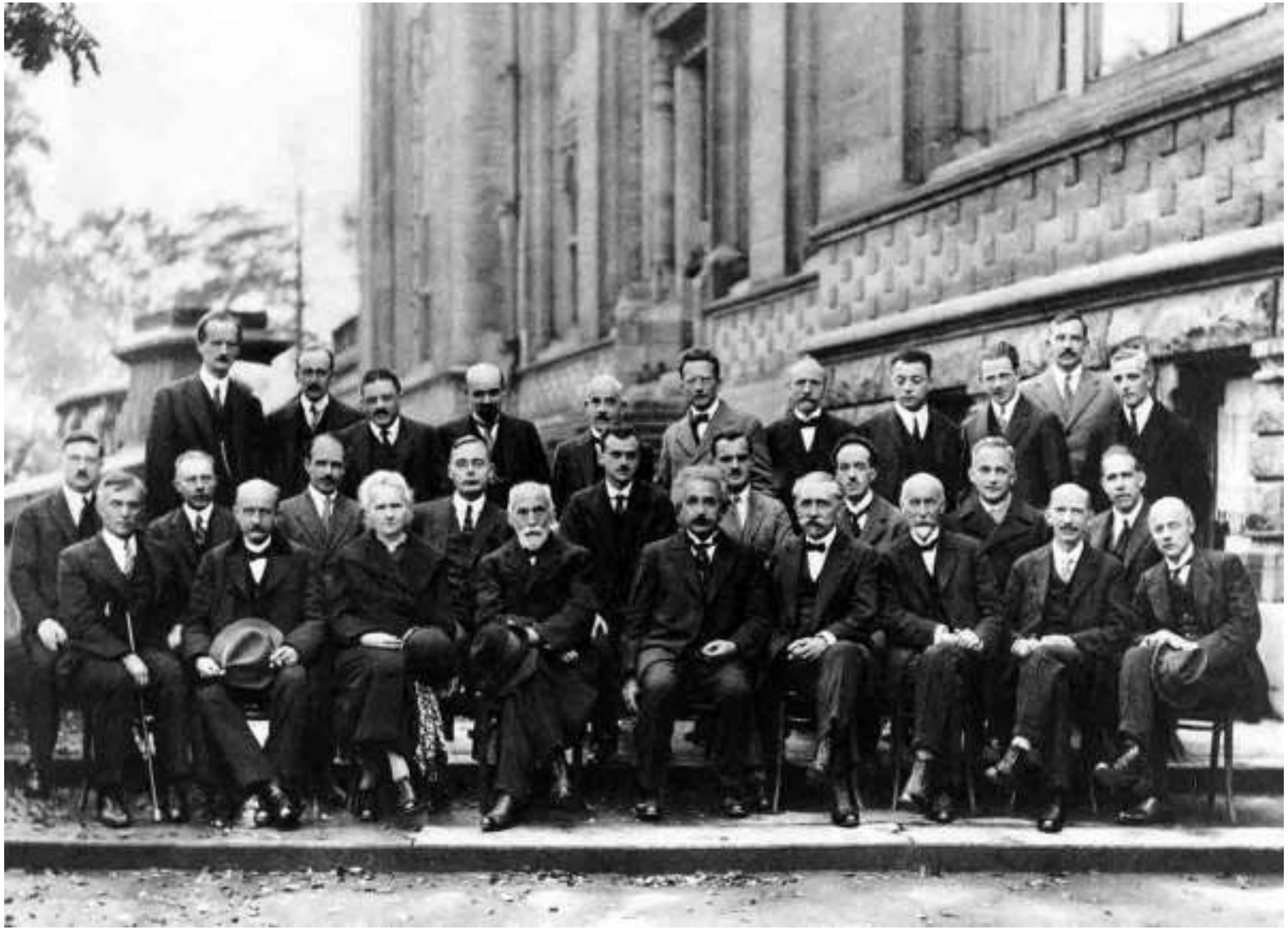
Something to note.....

WaSH (Water, Sanitation and Hygiene) experts have stated that without progress on Goal 6, the other goals and targets will not be able to be achieved

A bit of a distraction

The School of Athens
(Italian: *Scuola di Atene*) is one of the most famous frescoes by the Italian Renaissance artist Raphael
1510-1511

Giants of Our Time 1927 Solvay Conference on Quantum Mechanics



1927 Solvay Conference on Quantum Mechanics. Photograph by Benjamin Couprie, Institut International de Physique Solvay, Brussels, Belgium.
From back to front and from left to right :

Auguste Piccard, Émile Henriot, Paul Ehrenfest, Édouard Herzen, Théophile de Donder, Erwin Schrödinger, Jules-Émile Verschaffelt, Wolfgang Pauli, Werner Heisenberg, Ralph Howard Fowler, Léon Brillouin,

Peter Debye, Martin Knudsen, William Lawrence Bragg, Hendrik Anthony Kramers, Paul Dirac,Arthur Compton, Louis de Broglie, Max Born, Niels Bohr,

Irving Langmuir,Max Planck, Marie Skłodowska Curie, Hendrik Lorentz, Albert Einstein,Paul Langevin, Charles-Eugène Guye, Charles Thomson Rees Wilson,Owen Willans Richardson This picture is also available with names at the bottom.

RMIT UNIVERSITY

There are a lot of interesting communications, dialogues and quotes ……..

When Niels Bohr complained that Paul Dirac did not know how to finish a sentence in a scientific article he was writing, Dirac replied, "I was taught at school never to start a sentence without knowing the end of it". When asked about his views on poetry, Dirac responded, "In science one tries to tell people, in such a way as to be understood by everyone, something that no one ever knew before. But in poetry, it's the exact opposite".

"One should allow oneself to be led in the direction which the mathematics suggests…..one must follow up a mathematical idea and see what its consequences are, even though one gets led to a domain which is completely foreign to what one started with……Mathematics can lead us in a direction we would not take if we only followed up physical ideas by themselves" - Paul Dirac.

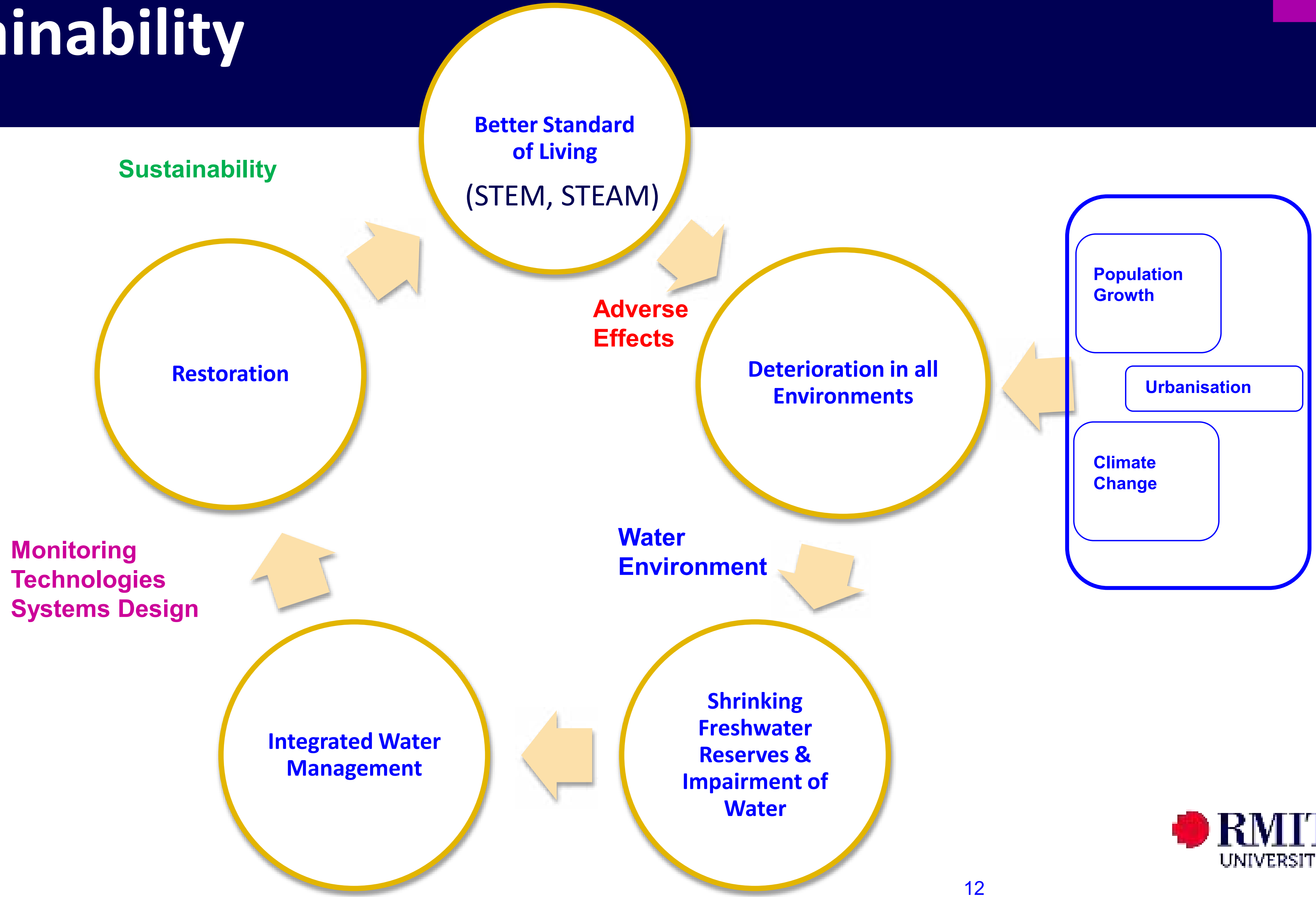
"It will be impossible to answer any one question completely without at the same time answering them all" - Paul Dirac

Water: Effective Technologies and Tools (WETT) Research Centre

2

RMIT UNIVERSITY

Sustainability



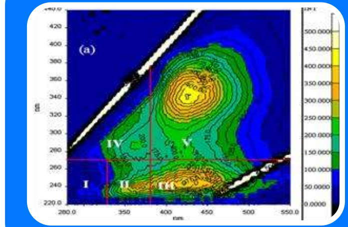
Profile

- Members : 28
- Strength: Engineering, environmental chemistry and microbiology, ecotoxicology, biology, modelling and renewable energy

Director
Professor Veeriah Jegatheesan

Deputy Director
Assoc. Professor Oliver Jones

Strategic Advisor
Emeritus Professor Felicity Roddick



Assist practitioners to provide secure, sustainable supply of safe clean water with minimal impact on the environment and so build resilient communities

in 2017:

>100 Projects

150 journal publications (94 in top quartile)

21 HDR completions

ERA 2015: ranked

5 for 0502 environmental science and management and 0912 materials engineering

Some of WETT's Research partners

Melbourne Water

South East Water

City West Water™

Goulburn Valley Water

Barwon Water

Smart Water Fund

City of Casey

Australian Water Recycling Centre of Excellence

Cranfield University

Water Research Australia

seqwater WATER FOR LIFE

VICTORIA State Government — Environment, Land, Water and Planning

RMIT UNIVERSITY

WETT Focus

Quality and Quantity of Water

Research covers the entire water cycle, 3 major themes

Water Resources and Management

Water sensitive urban design, systems for management of quality and quantity of all water types (potable, storm, waste, ground)

Water and Wastewater Treatment, Reclamation

Treatment of potable, industrial, wastewater and water reclamation, desalination, generation and utilisation of renewable energy

Biosolids and Bioenergy

Health, safety and utilisation of biosolids from water treatment processes, sustainable production of energy via bioenergy systems

Value to Industry

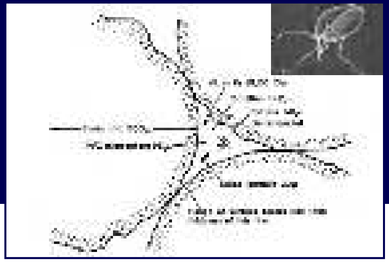
- Improving the efficiency of water and wastewater treatment processes
- Developing methods for monitoring water quality
- Investigating alternative water sources and resource reclamation
- Sustainable management of solids generated by water treatment processes

Immobilised algae
for wastewater treatment
- A project in collaboration with
Cranfield University

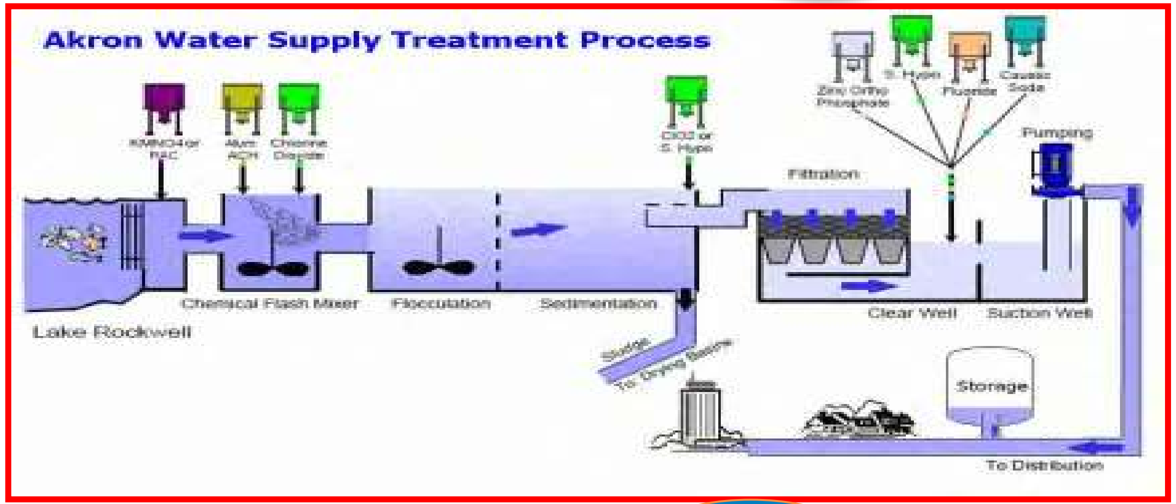
RMIT UNIVERSITY

Water Treatment

- ✓ Process Selection
- ✓ Process Optimisation
- ✓ Chemical Selections
- ✓ Performance Evaluation



- ✓ Water Quality Monitoring
- ✓ Organic Characterisation
- ✓ Overall Treatment Process Development

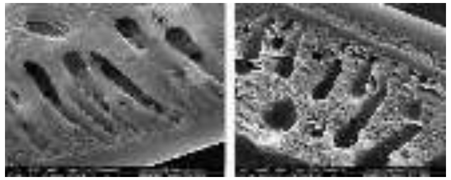


- ✓ Modelling Disinfectant Decay
- ✓ Modelling the Formation of DBPs
- ✓ Modelling the Performance of Processes

- ✓ Distribution Network Modelling
- ✓ Biofilm Growth & Disinfectant Decay
- ✓ Corrosion Hotspots

RMIT UNIVERSITY

Wastewater Treatment



Membrane
- ✓ Preparation
- ✓ Characterisation
- ✓ Application
- ✓ Modelling the Fouling & Performance

Application of Advanced Treatment Technologies
- ✓ Membrane Bioreactors
- ✓ Advanced Oxidation Processes

- ✓ Waste to Energy through Anaerobic Digestion
- ✓ Dissolved Methane Recovery
- ✓ Rheology of Sludge
- ✓ Modelling the Mixing in Digesters

- ✓ Wastewater Quality Analysis
- ✓ Characterisation
- ✓ Overall Treatment Process Development

Water Reuse
- ✓ Process Development
- ✓ Option Studies
- ✓ Lab Trials

Bio-solids Management
- ✓ Production of Biochar

Challenges faced

- Designing smart and efficient water systems – robust and resilient systems
- Shrinking green spaces
- Increased urban heat islands
- Damages to natural waterways due to flooding caused by increased stormwater flow

Challenges faced

- Offsetting carbon emissions to counteract damage to the environment
- Creating new technologies for mining and drilling of resources that have far less impact on the environment
- Ecosystem management for expanding cities and suburban zones
- Interdisciplinary teams to manage the conditions brought about by climate change

An answer to Q#1.2

Skill sets needed to face those challenges

- Ability to forecast such challenges
- Capability to develop incremental and sometimes drastic solutions to provide response to such challenges
- Skills to incorporate sustainability in all their solutions
- Effective and intelligent use of IT, AI etc.

Climate Change

Clear Air Turbulence (CAT)


CLIMATE CHANGE SET TO ROCK AIRLINES

Rising levels of global warming could spell trouble for passengers, as Honey Tsang reports.

THE CAUSE OF CAT

- Pre-industrial CO_2 concentration ~ 280 ppm
- Current ~ 400 ppm
- According to current projections it will reach 500-1000 ppm by the end of the century
- Climate model simulations predict when CO_2 concentration doubles to 560 ppm,
  - Light CAT events will rise by 59%
  - Moderate CAT events by 94%
  - Severe CAT events 149%
  - Severe CAT events have risen from just one, to now, two days per year
  - Severe CAT can throw an aircraft out of control
- The planes that will be in the air at the end of this century are probably being designed now
- Aircraft manufacturers should put climate change above their fleet design horizons
- Equip their aircraft for the long term effects of global warming

Operating Cost of Different Membrane Desalination Systems for a 25,188 m^3/d Feed Flow Rate

Process	Water recovery factor (%)	Amount of salt recovered (kg per m^3 of feed)	Total annual cost ($)	Total annual profit of salts sale ($)	Unit cost* ($/m^3)	Unit cost*,b ($/m^3)
MF-NF-RO	49.2		1,871,000		0.46/0.39[a]	0.46/0.39[a]
NF-RO	52		2,005,000		0.47/0.40[a]	0.47/0.40[a]
RO	45		2,040,000		0.61/0.40[a]	0.61/0.40[a]
MF-NF(/MCr)-RO	71.9	5.4	4,024,000	6,398,000	0.68/0.63[a]	0.55/0.51[a]
MF-NF-RO(/MCr)	70.6	14.2	3,440,000	2,991,000	0.59/0.54[a]	0.47/0.43[a]
MF-NF(/MCr)-RO(/MD)	88.4	5.4	5,445,000	6,398,000	0.74/0.71[a]	0.55/0.51[a]
MF-NF(/MCr)-RO(/MCr)	92.4	19.5	5,593,000	9,389,000	0.73/0.69[a]	0.54/0.51[a]

* - desalted water unit cost without considering the gain from the sales of salts

a - if Pelton turbine is used as energy recovery device

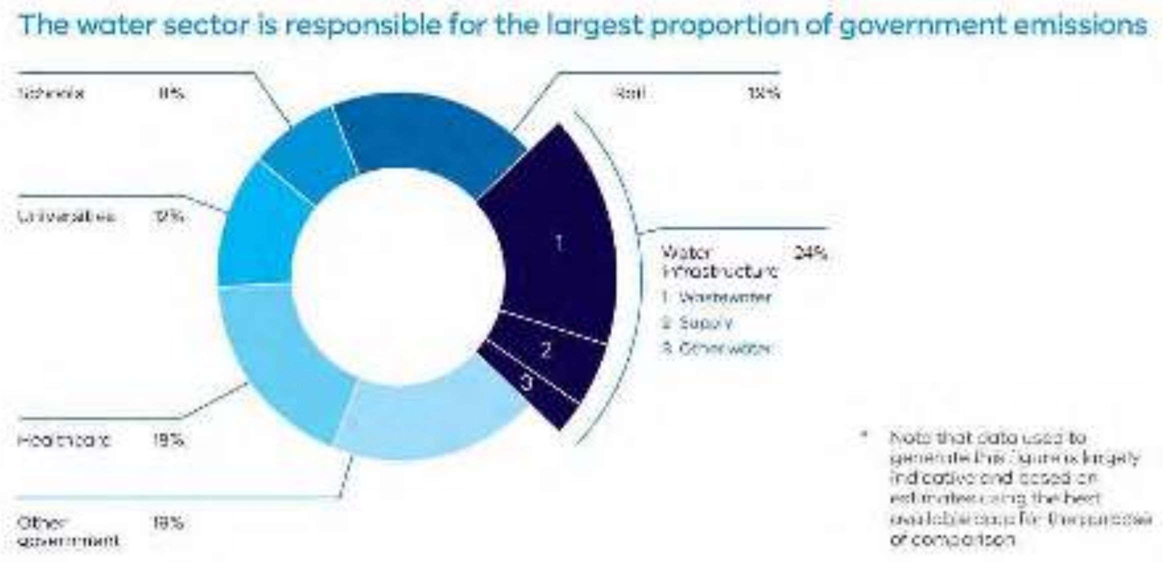
b - if thermal energy is available in the plant or the stream is already at the operating temperature of the MCr

With annual sales of salts, the annual cost per m^3 of fresh water produced = $ **-0.49/-0.68**[a]

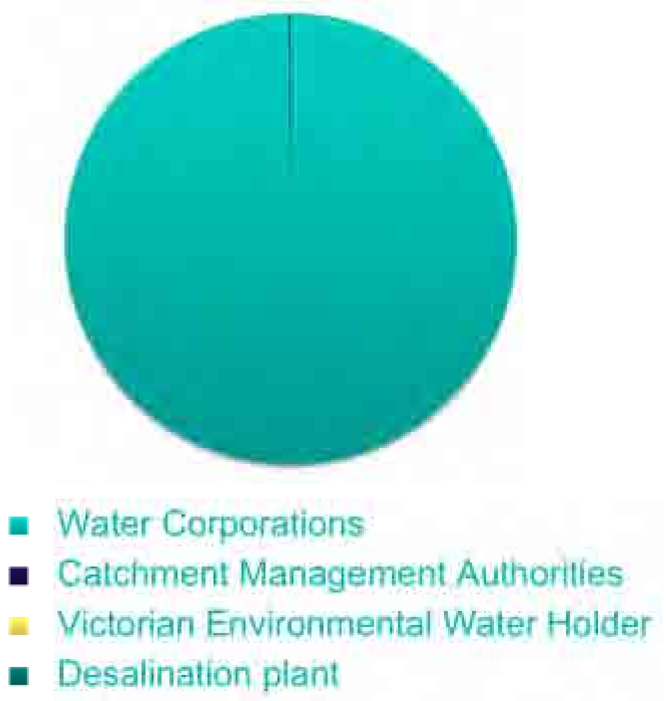
Macedonio, F., Curcio, E. and Drioli, E. (2007).*Desalination* (203) 260-276.

RMIT UNIVERSITY

3. Water & Energy



Who are the big emitters



Water for Victoria (WfV)

Achieve net zero-emissions
In the water sector

Statement of obligation
Issued by Hon Lisa Neville MP

Minister for Environment, Climate Change and Water

- Reduce emissions by 42% by 1 July 2025
- Achieve emissions reduction efficiently
- Pursue at the lowest possible cost
- Seek to minimise impacts on customer bills and vulnerable customers

Large-scale renewable projects

- Water corps forming Joint Venture under section 127 of Water Act
- Renewable Energy Certificates can be used to offset cost of Capex, sold or surrendered to reduce your carbon footprint

Water Corporation Emissions Reduction

Yackandandah Energy Storage Project
https://www.water.vic.gov.au/media-releases/2018/creating-a-renewable-future-for-yackandandah

Biogas cover to deliver more renewable power
https://vicwater.org.au/newsletters/winter-2017#Upgraded-biogas-covers-deliver-more-renewable-power-at-WTP

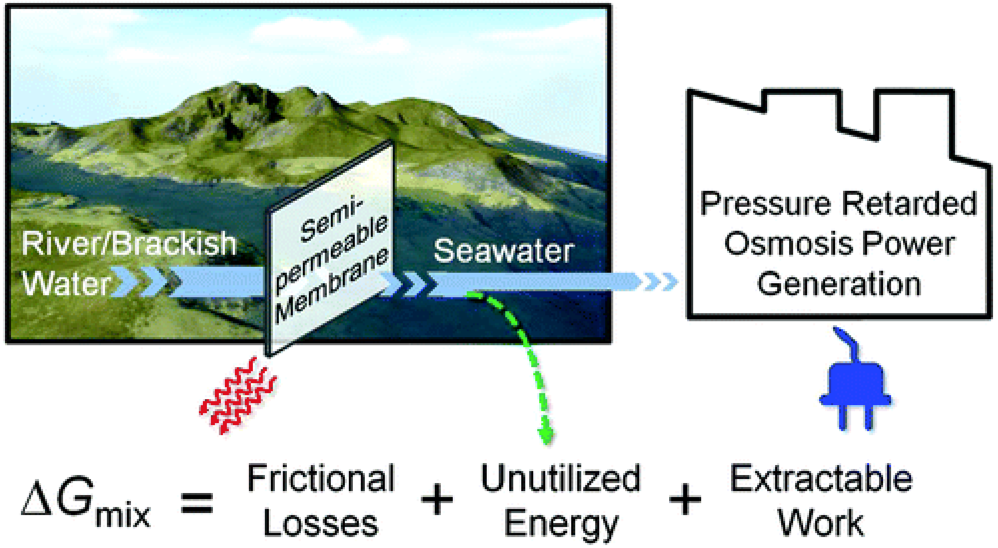
YVW's waste to energy facility
https://www.yvw.com.au/help-advice/waste-energy

RMIT UNIVERSITY

Dr. Jill Fagan, DELWP, 14 Nov.2018

How could we tap the energy that is trapped in the environment

- Green Energy - wind, solar, geothermal, biomass, ocean thermal, wave & tidal
- Blue Energy - Salinity Gradient Energy
  - Mixing of two aqueous solutions of different salinities

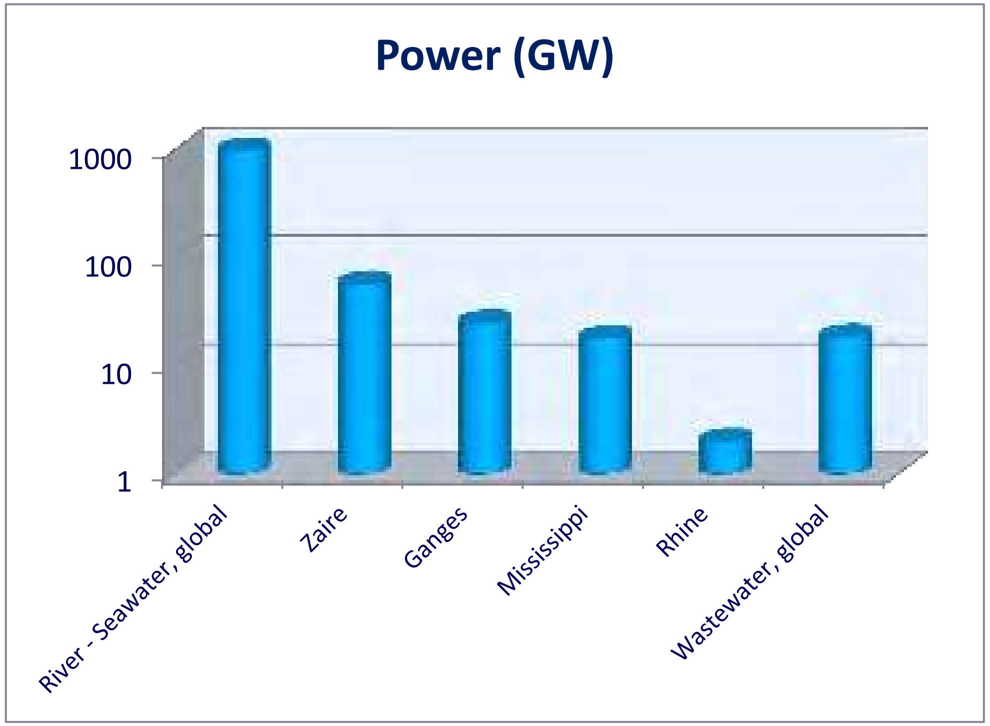


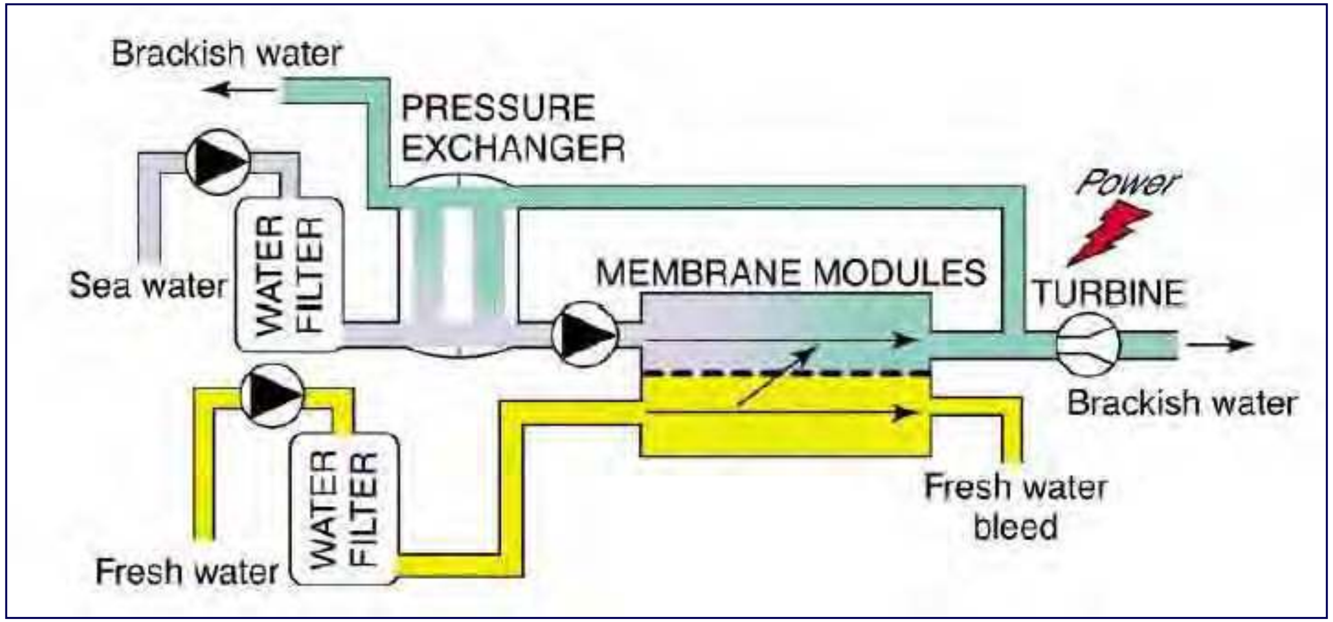
Water Utility Journal 5:3-13, 2013

Energy & Environmental Science, DOI: 10.1039/c1ee01913e

How could we tap the energy that is trapped in the environment

- Mixing 1 m^3 of seawater (~0.5 M – energy source) and 1m^3 of fresh river water (~5 mM) releases 0.5kWh energy (1m^3 water falling 175 m waterfall)
- The more the concentrated solution is diluted, the more energy is extracted

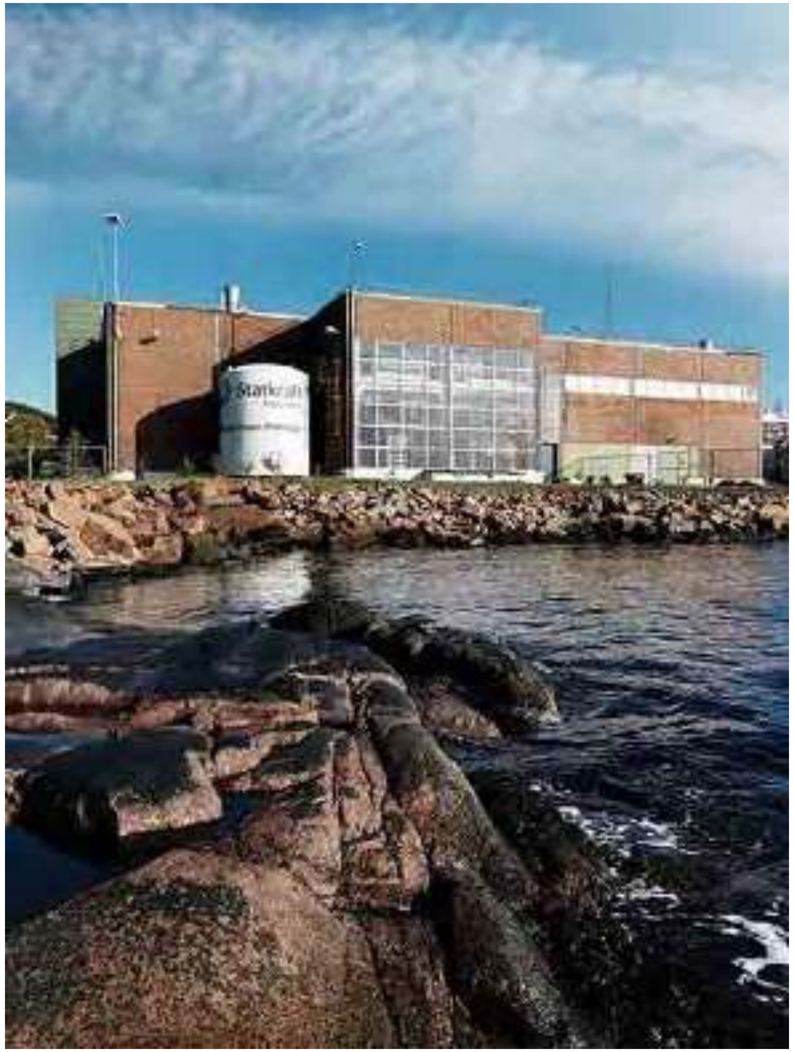




Water Utility Journal 5:3-13, 2013

Energy & Environmental Science, DOI: 10.1039/c1ee01913e

Statkraft Osmotic Power Plant

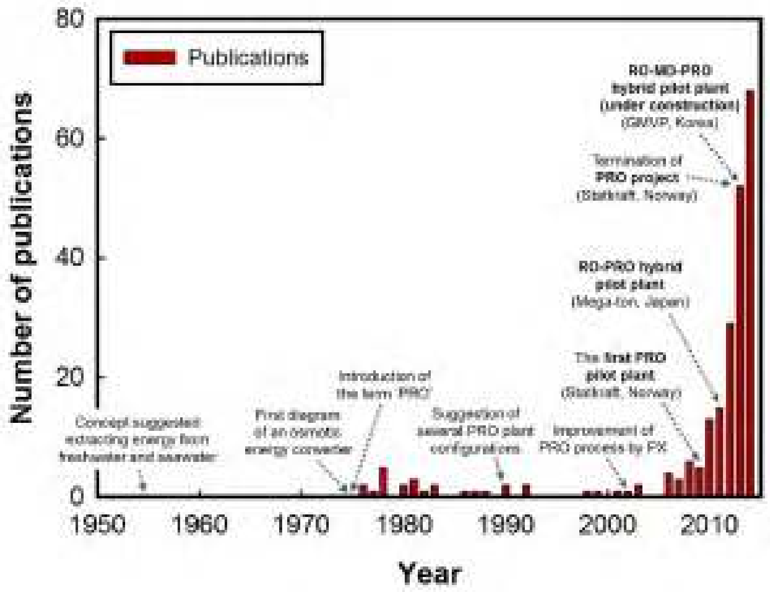


- Statkrat had a collaborative research and development program with the Norwegian University of Science and Technology
- In 2009 one of the world's first osmotic power plants
- Tofte on the Oslo Fjord in Norway
- Facility that produced 2 kW to 4 kW

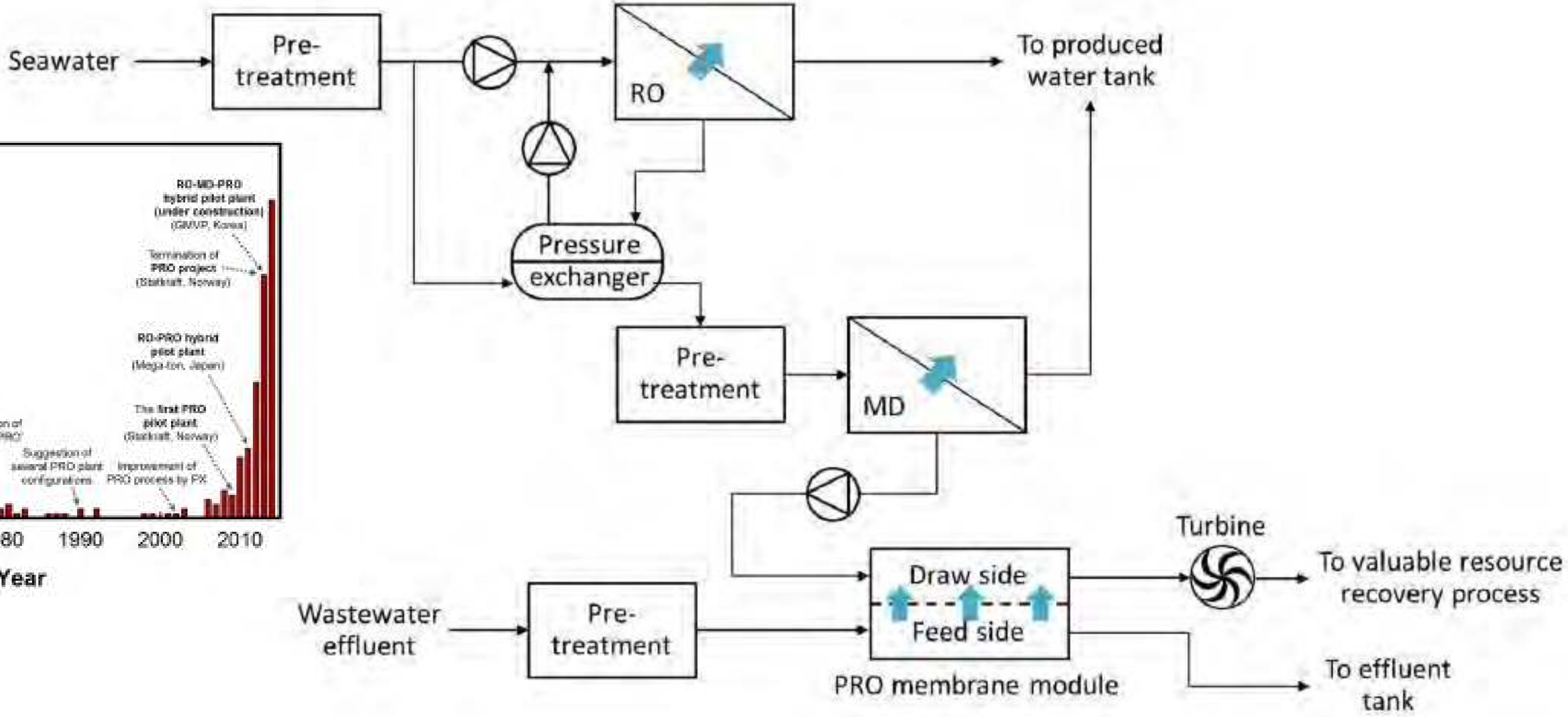
RMIT UNIVERSITY

https://www.powermag.com/statkraft-shelves-osmotic-power-project/

RO-MD-PRO



Publications
RO-MD-PRO
hybrid pilot plant
(under construction)
Termination of
PRO project
RO-PRO hybrid
pilot plant
(Mega-ton, Japan)
The first PRO
pilot plant
Introduction of
the term 'PRO'
First diagram
of an osmotic
energy converter
Suggestion of
several PRO plant
configurations
Improvement of
PRO process by FX
Number of publications
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
Year

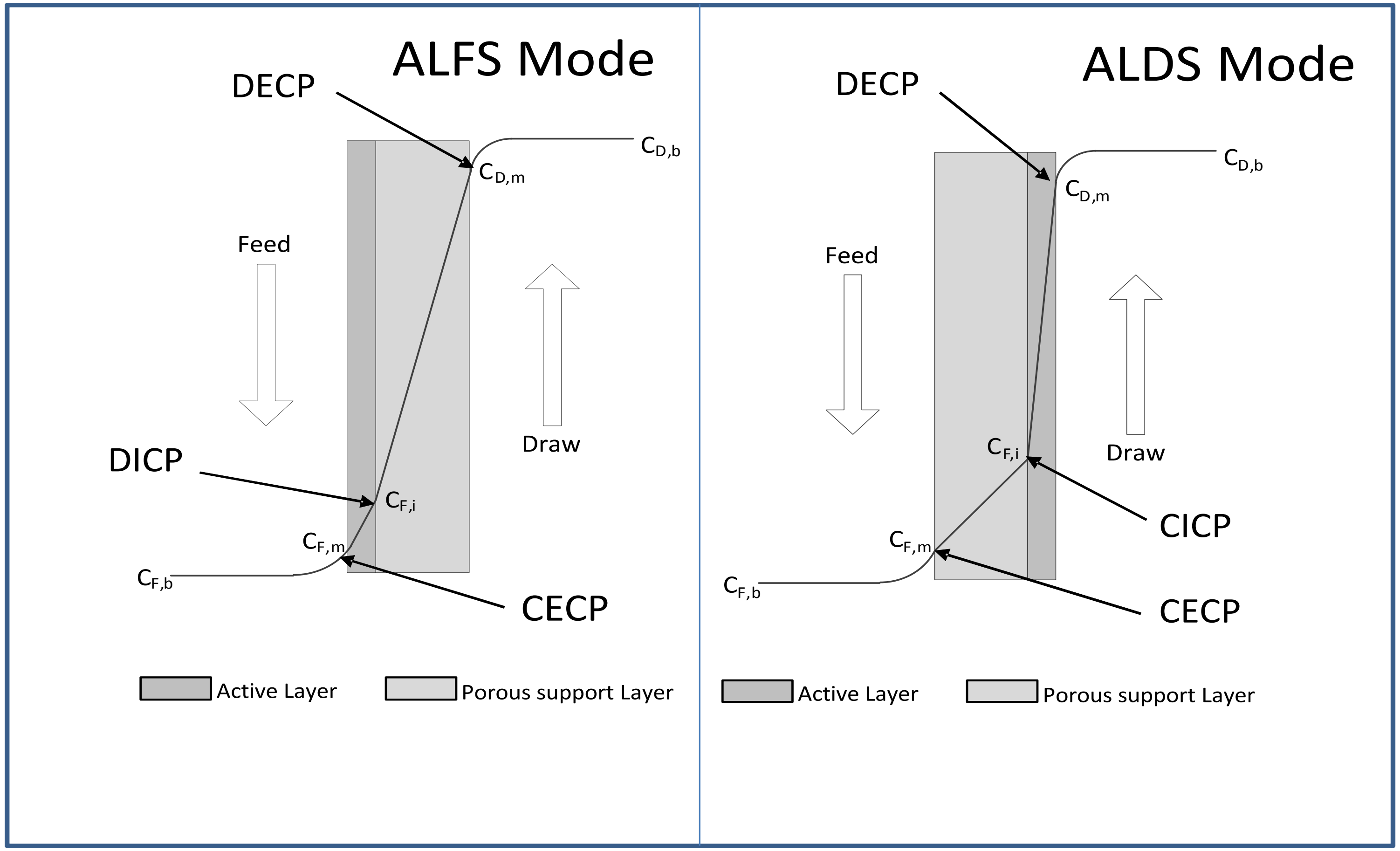


Seawater
Pre-
treatment
RO
To produced
water tank
Pressure
exchanger
Pre-
treatment
MD
Turbine
Draw side
Feed side
To valuable resource
recovery process
Wastewater
effluent
Pre-
treatment
PRO membrane module
To effluent
tank

Pressure-Retarded Osmosis (PRO) for Power Generation

- **Maximum power density generated, $W_{max} = (A/4)(\Delta\pi)^2$**
- **Hydraulic pressure drop across the membrane $\Delta P = \Delta\pi/2$**
- **Membrane permeability is key for power generation**
- **Concentration polarisation will affect effective $\Delta\pi$**
- **Mass transfer coefficient, Diffusion coefficient, structural constant of the porous support of the membrane, S ($= \tau\delta/\varepsilon$), Salt permeability coefficient**

FO Theory



ALFS: $J_w = A\sigma(\pi_{F,i} - \pi_{F,m})$

$$\pi_{F,m} = \pi_{F,b}\exp(-\frac{J_w}{k_F})$$

$$\pi_{F,i} = \pi_{D,b}\exp(-J_w K_D)$$

$$J_w = A\sigma[\pi_{D,b}\exp(-J_w K_D) - \pi_{F,b}\exp(-\frac{J_w}{k_F})]$$

ALDS:

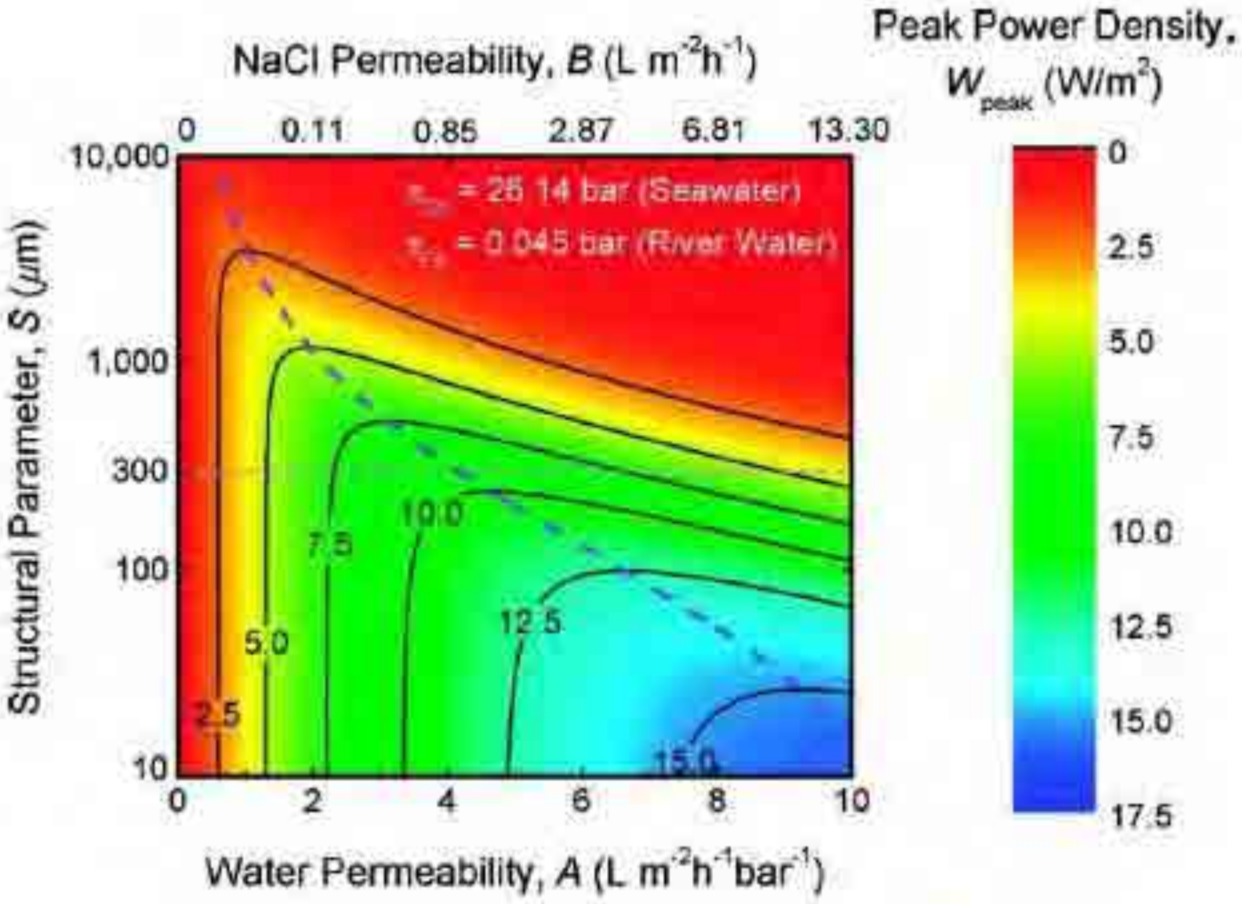
$$J_w = A\sigma[\pi_{D,b}\exp(-\frac{J_w}{k_D}) - \pi_{F,b}\exp(-J_w K_F)]$$

$$K_D = \left(\frac{1}{J_w}\right) ln\left[\frac{B + A\pi_{D,b}}{B + J_w + A\pi_{F,m}}\right]$$

$$K_F = \left(\frac{1}{J_w}\right) ln\left[\frac{B + A\pi_{D,b} - J_w}{B + J_w + A\pi_{F,m}}\right]$$

RMIT UNIVERSITY

Factors affecting the power density



Demonstrated Power Density

- 0.5 W/m^2, spiral wound module
- 2.7 W/m^2, same commercial membrane
- 3.5 W/m^2, lab-cast TFC membrane

RMIT UNIVERSITY

Commercial & Prototype Membranes (target ~ 5W/m²)

Membranes	Water Permeability	Salt Permeability	Structural Constant	Power Density	
	$\times 10^{-12}$ m/Pa.s	$\times 10^{-7}$ m/s	μm	W/m^2	W/m^2
				Sea Water	RO Brine
Lab Cellulose acetate –FO	0.41	0.22	52	0.7	2.7
Lab TFC-FO (PA/Polysulfone)	**5.27**	**0.91**	**312**	**6.1**	**15.3**
Lab TFC-FO	3.22	1.30	492	3.8	10.1
Lab TFC-FO (hollow fiber)	6.20	0.56	595	5.5	8.7
Commerical FO (CTA)	2.20	1.20	625	2.8	7.8
Lab TFC-FO	7.10	1.10	670	4.7	6.5
Commercial RO (CA)	2.00	0.60	1000	2.4	5.9
Commercial TFC (RO)	1.60	0.80	2200	1.2	2.1

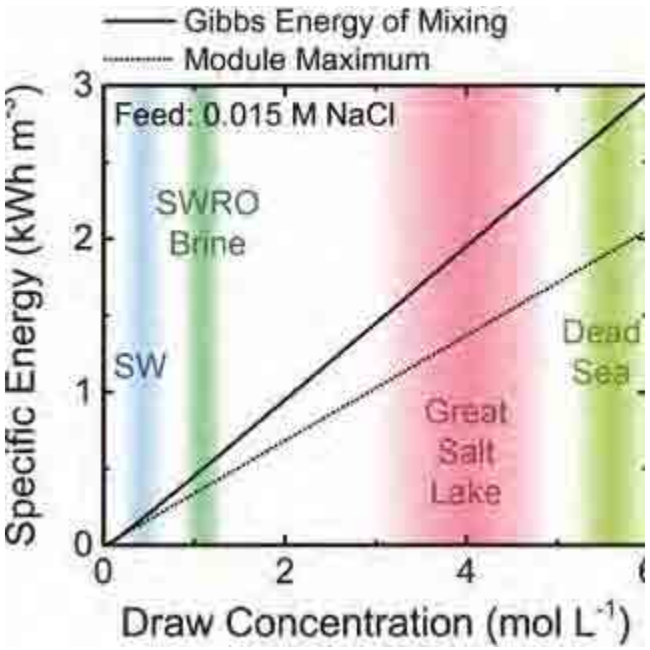
Flat Sheet Membranes

Name	Material Active/Support	Draw Solution	Feed Solution	Pressure (Bar)	Power Density (W/m^2)
PA-PSf TFC	PA/PSf flat-sheet	0.5 M NaCl	40 mM NaCl	12	10.0
PA-PI TFC	PA/PI flat-sheet	1.0 M NaCl	DI water	15	12
PAN-TFC	PA/PDA coated PAN flat-sheet	3.5 wt % NaCl	DI water	10	2.6
TFC-PRO	Modified PA with SDS/PI flat sheet	1.0 M NaCl	DI water	22.0	18.09
TNC-PRO	PA/modified PAN nanofiber	1.06 M NaCl (Seawater brine)	80 mM NaCl (Synthetic brackish)	15.2	15.2
TNC-PRO	PA/modified PAN nanofiber	1.06 M NaCl (Seawater brine)	0.9 mM NaCl (Synthetic river)	15.2	21.3
PAN-mTFC (RO-like)	PA/PAN nanofiber	0.5 M NaCl	DI water	10.3	8
PAN-pTFC (NF-like)	PA/PAN nanofiber	0.5 M NaCl	DI water	8.6	6.2
TFC-PRO	PA/CNTs-PEI composite nanofiber	1.0 M NaCl	DI water	16.9	17.3
TFN-PRO	PA/CNTs-PES	0.5 M NaCl	DI water	6	1.65

PSf: polysulfone, CNTs: Carbone nanotubes, PI: P84 copolyimide (Matrimid®5218), PDA: Polydopamine, SDS: Sodium dodecyl sulphate.

RMIT UNIVERSITY

Hollow Fibre Membranes



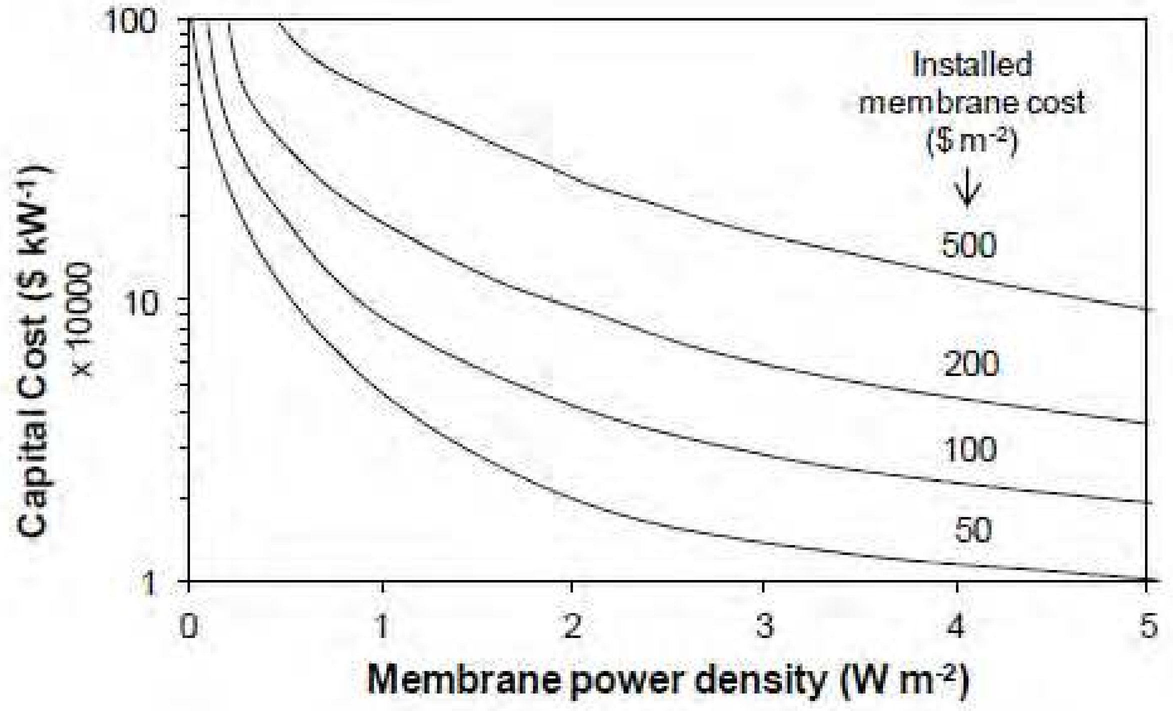
Name	Material Active/Support	Selective Layer	Draw Solution	Feed Solution	Pressure (Bar)	Power Density (W/m^2)
PES-TFC	PA/PES	Lumen side	1.0 M NaCl	10 mM NaCl	8.4	11.0
PES-TFC	PA/PES	Lumen side	1.0 M NaCl	40 mM NaCl (Waste water brine)	9.0	10.6
TFC-PEI	PA/PEI	Lumen side	1.0 M NaCl	10 mM NaCl	15.1	20.9
TFC-PEI	PA/PEI	Lumen side	1.0 M NaCl	10 mM NaCl	15.1	18.7
PBI-PAN	PBI-POSS/ PAN	Outer layer	1.0 M NaCl	10 mM NaCl	7.0	2.5
TFC-PI	PA/PI	Outer layer	1.0 M NaCl	DI water	20.0	7.6 (=13.7 [1])
TFC-PI	PA/PI	Lumen side	1.0 M NaCl	10 mM NaCl	15.0	14.4
TFC-PI	PA/PI	Lumen side	1.0 M NaCl	40 mM NaCl	15.0	10.6
TFC-PI	PA/PI	Lumen side	1.0 M Na-Fe-Ca	DI water	12.0	16.2
TFC-P84	PA/P84	Lumen side	1.0 M NaCl	DI water	21.0	12.0
PDA-TFC	PA/PDA-PES	Outer layer	0.6 M NaCl	DI water	7.0	3.0
PDA-TFC	PA-TBP/ PDA-PES	Outer layer	0.6 M NaCl	DI water	8.0	3.9
PES-TFC	PA/PES	Lumen side	1.0 M NaCl	DI water	20.0	24.3
PES-TFC	PA/PES	Outer layer	0.6 M NaCl	DI water	6.0	1.6

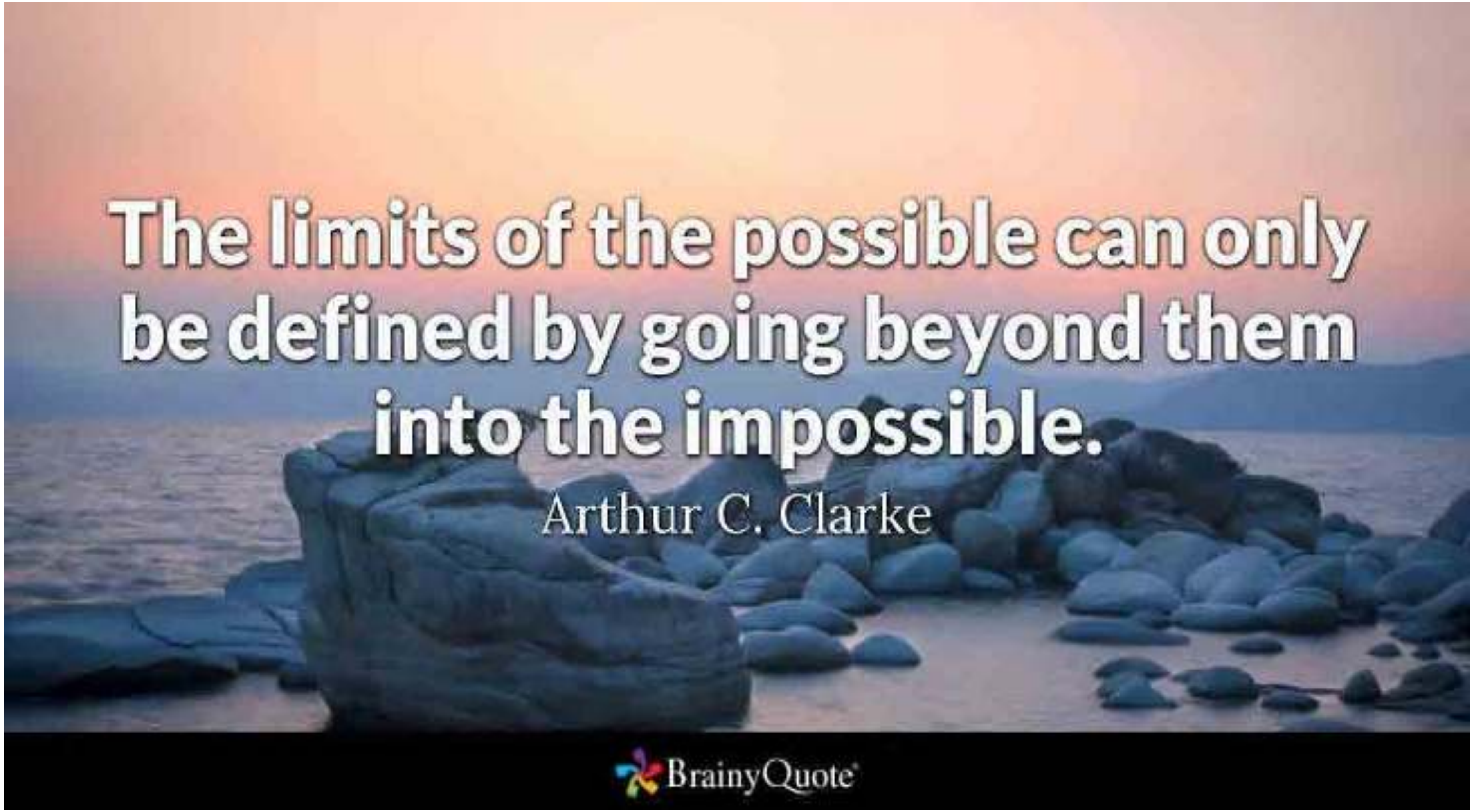
PSf: polysulfone, CNTs: Carbone nanotubes, PI: P84 copolyimide (Matrimid®5218); PDA: Polydopamine, SDS: Sodium dodecyl sulphate; [1] The power density is equivalent to its inner-selective (lumen side) hollow-fiber counterpart (*i.e.*, membrane area calculated on the basis of the inner diameter) having the same module size, packing density, and fiber dimensions.

Cost

- Power density 3.2 W/m^2; 11.2 GW, the Mississippi River
  - $20,000/kW installed; $0.2/kWh

- Power density 7.7 W/m^2
  - $12,000/kW installed; $0.06/kWh




The limits of the possible can only be defined by going beyond them into the impossible.
Arthur C. Clarke
BrainyQuote

4.1 Australia – China Strategic Research Collaboration

ECP Supported Activities

Oct. 2016
Workshop on Australia -China
strategic research collaboration in Water and Waste Management

Made possible by
Enabling Capability Platforms Funding Initiative

Tsinghua University
QIBEBT

RMIT UNIVERSITY

4.2 Capability Building in Appropriate Technology

ECP Supported Activities

RMIT UNIVERSITY

China | India | South Korea | Taiwan

Capability Building in Appropriate Technologies for Water/Sanitation to Combat Climate Change

Supported by ECP Capability Development Fund 2017-18

Project Team

RMIT

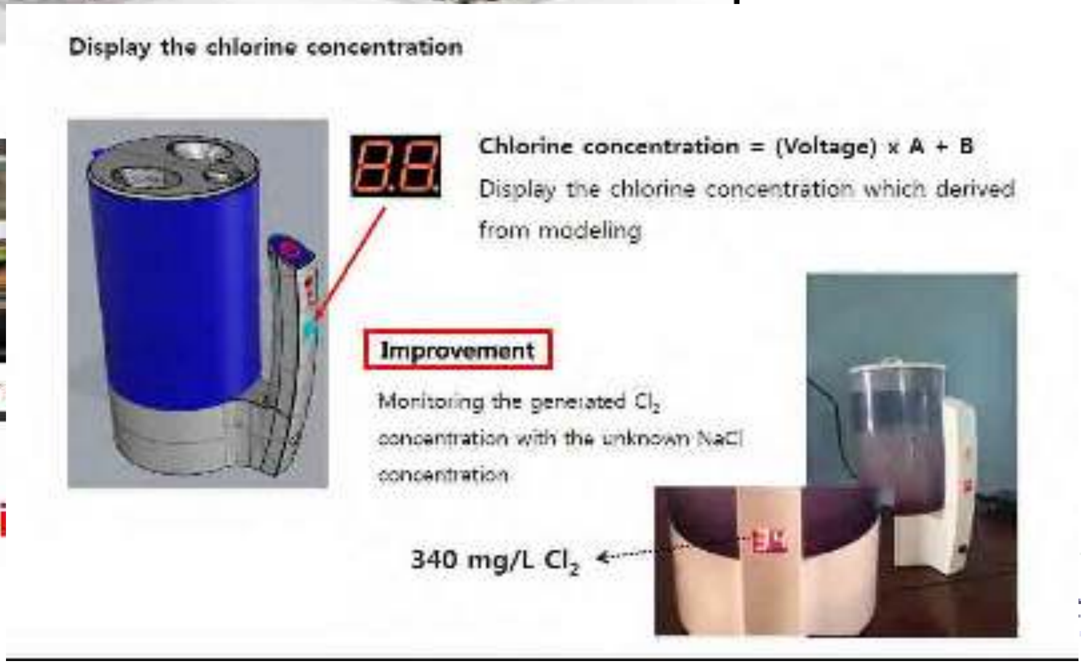
Professor Veeriah Jegatheesan
Emeritus Professor Felicity Roddick
Dr. Linhua Fan
Assoc. Professor Rajaratnam Parthasarathy
Dr. Karyn Bosomworth
Dr. Brian Coffey
Dr. Muthu Pannirselvam

International

Professor Ashok Pandey, CSIR-IITR
Professor Jeyong Yoon, SNU
Professor Tsair-Fuh Lin, NCKU
Professor Yang Zhang, QIBEBT

Forward Osmosis to Produce Drinks In Water Scarce Areas

Portable Chlorine Disinfection Unit



- Designed to disinfect the 500 L of drinki

Outcomes of the workshop

		RMIT	NCKU	QIBEBT	CSIR - IITR	SNU	SGW	CSIRO	Cranfield
1	**Reservoir Management**								
	Detection (algal)	✓	✓		✓	✓	✓		
	Chemical application	✓	✓		✓		✓		
2	**Mn Removal**								
	Mechanisms	✓	✓		✓		✓		
	Processes	✓	✓	✓	✓		✓		
3	**Public perception, planning & co-design**								
	community engagement	✓	✓	✓	✓	✓	✓	✓	✓
	strategic planning	✓	✓	✓	✓	✓	✓	✓	✓
	translation	✓	✓	✓	✓	✓	✓	✓	✓
	question of scale (1 to 10)	✓	✓	✓	✓	✓	✓	✓	✓
4	**Energy from Waste Water**								
	Electrochemical process (membrane)	✓	✓	✓					
	Biological process	✓			✓				
5	**resource recovery**								
	nutrients (phosphorus) from wastewater	✓	✓	✓	✓	✓	✓	✓	✓
	biochar	✓			✓				
	dissolved methane recovery	✓		✓					
	ammonia	✓		✓	✓				
6	**International activities**								
	Mekong region	✓	✓	✓	✓	✓	✓	✓	✓

RMIT - RMIT University; NCKU - National Cheng Kung University; QIBEBT - Qingdao Institute Of Bioenergy & Bioprocess Technology; CSIR - Council of Scientific & Industrial Research; SNU - Seoul National University; SGW - South Gippsland Water; CSIRO - Commonwealth Scientific and Industrial Research Organisation

RMIT UNIVERSITY

Capability Building in Appropriate Technology

Workshop on Appropriate Technologies for Water
July 4-5, 2018, NCKU, Tainan, Taiwan

July 5, 2018

Time	Speaker
08:30 - 09:00	Biological pre-treatment of river water slightly contaminated by ammonia for using as a drinking water source. Dr. Yi-Ju Wu — *National Cheng Kung University*
09:00 – 09:30	A study on the effects of feed water quality and pretreatment on membrane fouling control. Dr. Chun-Hsi Lai — *National Cheng Kung University*
09:30 – 10:00	Monitoring of cyanotoxin and odorant-producing cyanobacteria in drinking water reservoirs using real-time PCR. Dr. Yi-Ting Chiu — *National Cheng Kung University*
10:00 – 10:20	Tea break
10:20 – 10:50	Oxidation treatment of a novel cyanotoxin BMAA in water Dr. Yi-Ting Chen — *National Cheng Kung University*
10:50 – 11:20	The application of remote sensing in landslide and turbidity management Mr. John F. Harrison — *National Cheng Kung University*
11:20 – 11:50	Managing risk associated metabolites of Cyanobacteria by modified alert level framework. Mr. Kang-Yu Lu — *National Cheng Kung University*
11:50 – 13:00	Lunch
13:00 – 17:00	Technical Tour

RMIT UNIVERSITY

Capability Building in Appropriate Technology

International Conference on Energy and Sustainability

RMIT UNIVERSITY

Consortium Appropriate Technologies in Water and Sanitation to Combat Climate Change

6 November 2018

RMIT – Australia (WETT)
SNU – Korea (Cost effective water/sanitation tools)
NCKU – Taiwan (Water quality)
QIBEBT – China (Resource recovery)
CSIR-IITR – India (Bioenergy)
KU – Japan (Energy reduction)
LUT – China (controls)
IHE-Delft Institute for Water Education – The Netherlands (waste to energy)

RMIT UNIVERSITY

Consortium Appropriate Technologies in Water and Sanitation to Combat Climate Change

- **Vision:** Resilient water and sanitation systems for all
- **Mission:** Responding to climate change through the development and implementation of appropriate technologies for water and sanitation aided by international collaboration
- **Terms of reference**
- **Possible collaborative actions and plans for regular meetings**
- Skype meetings once in three months; meet during CESE conference
- Pre-conference at Yixing; details are being discussed
- **A book based on past and future collaboration (to AESE Series by Springer)**

RMIT UNIVERSITY

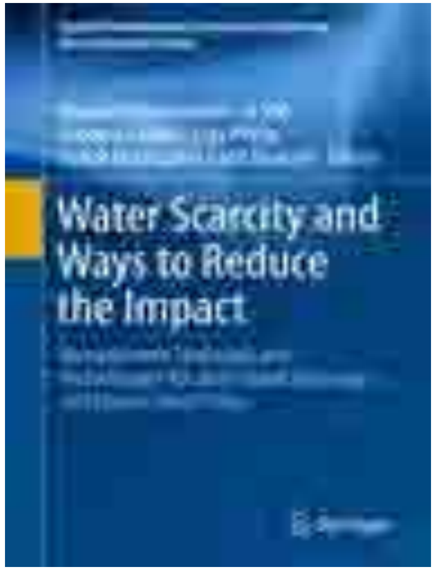
4.3. Advancing Research Corporation through Joint Workshops between Australia and India

RMIT UNIVERSITY

twic

Australian Government | Australia-India Council

Water Scarcity and Ways to Reduce the Impact 2016



AUSTRALIAN TECHNOLOGY NETWORK OF UNIVERSITIES

& University Alliance, UK (2017)

Storm Water & Flood Management

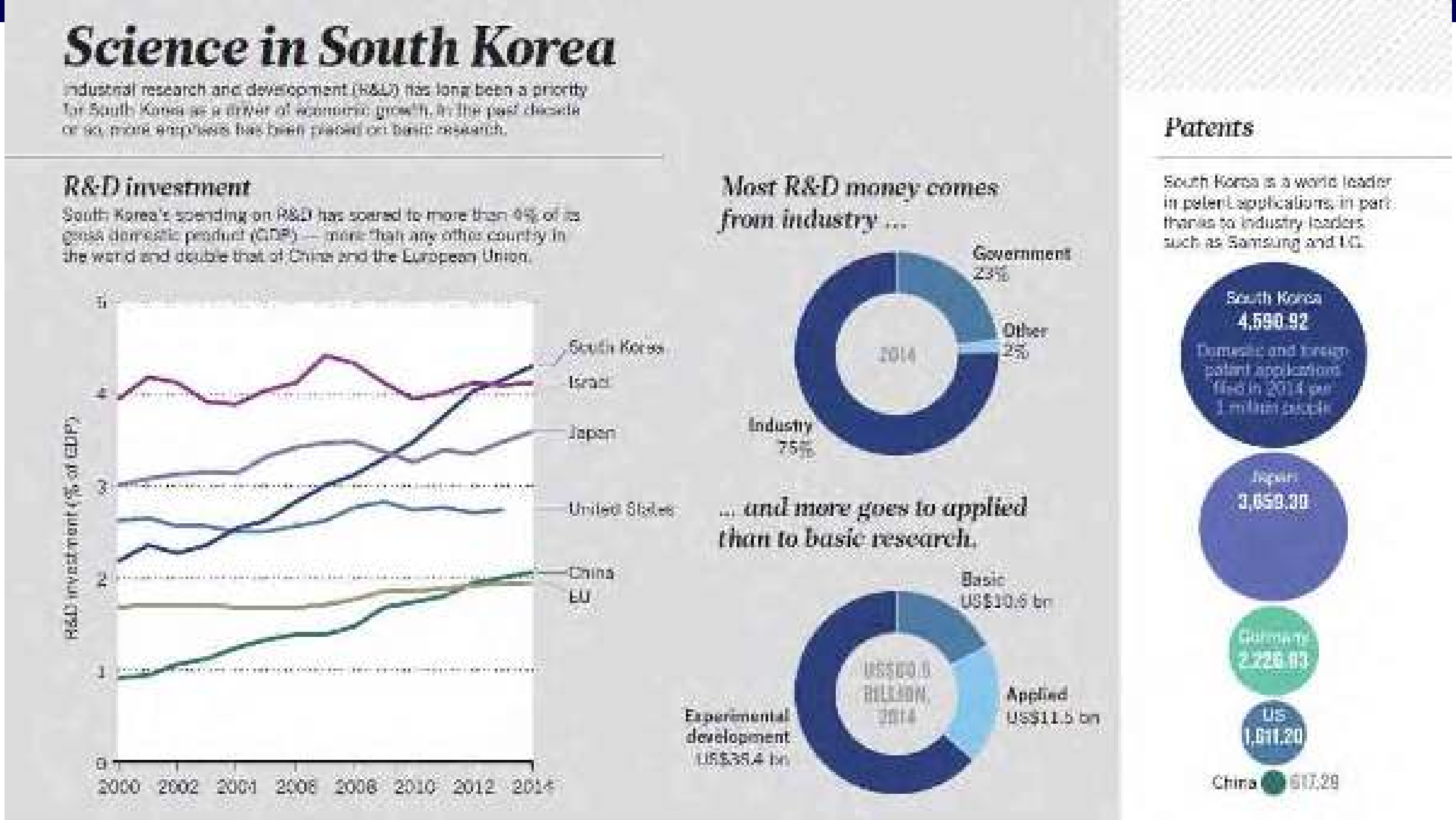
RMIT UNIVERSITY

5. Research Support – Bench Marking
How Research Dominates in Some Places?

Behind the doors of a drab brick building in Daejeon, South Korea, a major experiment is slowly taking shape. Much of the first-floor lab space is under construction, and one glass door, taped shut, leads directly to a pit in the ground. But at the end of the hall, in a pristine lab, sits a gleaming cylindrical apparatus of copper and gold. It's a prototype of a device that might one day answer a major mystery about the Universe by detecting a particle called the axion — a possible component of dark matter.

SHIN WOONG-JAE

20 | NATURE | VOL 534 | 2 JUNE 2016



24	Israel	37,206
—	European Union	36,448
25	Japan	36,194

9	United States	54,630
77	China	7,590

28	South Korea	27,971

RMIT UNIVERSITY

Quick Calculation!

Country	Population	GDP	Total Worth	Research
South Korea	50,801,405	$ 27,971.00	$ 1,420,966,099,255.00	$ 60,391,059,218.34
Israel	8,515,100	$ 37,206.00	$ 316,812,810,600.00	$ 12,989,325,234.60
Japan	126,960,000	$ 36,194.00	$ 4,595,190,240,000.00	$165,426,848,640.00
United States	323,704,000	$ 54,630.00	$ 17,683,949,520,000.00	$495,150,586,560.00
China	1,376,889,522	$ 7,590.00	$ 10,450,591,471,980.00	$209,011,829,439.60

Top ten Countries based on GDP

2015 IMF

Rank	Country	US$
1	Luxembourg	101,994
2	Switzerland	80,675
3	Qatar	76,576
4	Norway	74,822
—	*Macau*	69,309
5	United States	55,805
6	Singapore	52,888
7	Denmark	52,114
8	Ireland	51,351
9	Australia	50,962
10	Iceland	50,855

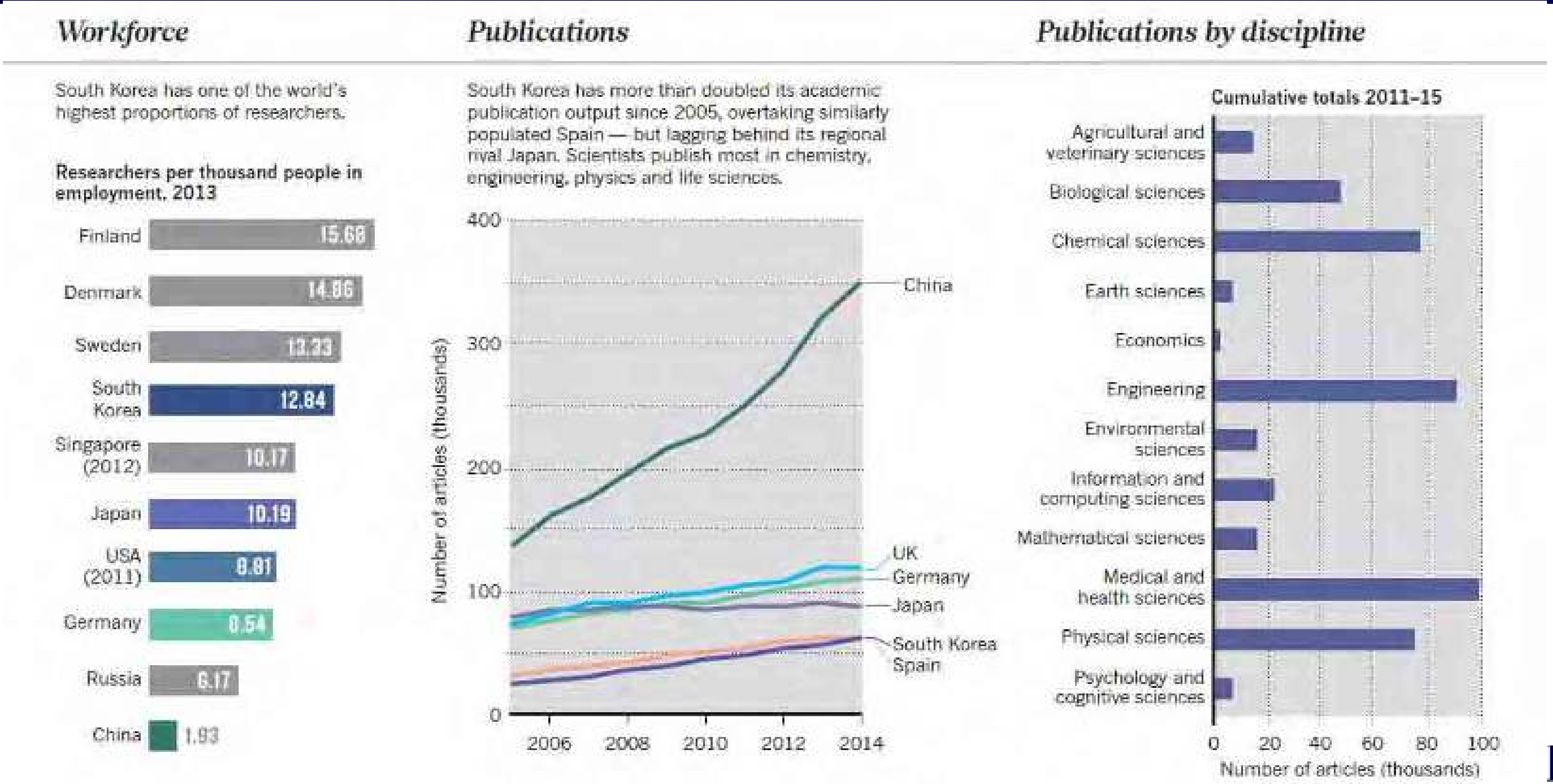
332,529

2014 World Bank

Rank	Country	US$	Population
1	Luxembourg	116,613	576,200
2	Norway	97,300	5,223,256
3	Qatar	96,732	2,587,564
—	*Macau*	96,038	649,100
4	Switzerland	85,617	8,325,194
5	Australia	61,980	24,089,650
6	Denmark	60,718	5,717,014
7	Sweden	58,899	9,875,378
8	Singapore	56,284	5,535,000
9	United States	54,630	323,704,000
10	Ireland	54,339	4,635,400

RMIT UNIVERSITY

How Research Dominates in Some Places?



16 Japanese have received Noble Prize within 18 years and there are more than 52 Japanese companies in the world top Fortune Global 500 companies

Fortune Global 500 (2018)

Rank	Company	Country	Industry	Revenue in USD
1	Walmart	United States	Retail	$500 billion
2	State Grid	China	Power	$349 billion
3	Sinopec Group	China	Petroleum	$327 billion
4	China National Petroleum	China	Petroleum	$326 billion
5	Royal Dutch Shell	Netherlands United Kingdom	Petroleum	$312 billion
6	Toyota Motor	Japan	Automobiles	$265 billion
7	Volkswagen	Germany	Automobiles	$260 billion
8	BP	United Kingdom	Petroleum	$245 billion
9	Exxon Mobil	United States	Petroleum	$244 billion
10	Berkshire Hathaway	United States	Holding	$242 billion

RMIT UNIVERSITY

6. SOME PHILOSOPHICAL THOUGHTS…..

Nothing in this world is ever really new, yet everything is in some way different from all that has gone before.

At least once in his life even the dullest of us has found himself contemplating with amazement and perhaps with fear, some thought so original and so startling that it seems the creation of an exterior, infinitely more subtle mind.

Such thoughts pass through the consciousness so swiftly that they are gone before they can be more than glimpsed, but sometimes like comets trapped at last by a giant sun, they cannot escape and from their stubborn material the mind forges a masterpiece of literature, of philosophy or music.

From such fleeting, fragmentary themes are the symphonies of Sibelius built – perhaps, with the Theory of Relativity and the conquest of space, the greatest achievements of the century before the year 2000.

Sir Arthur C Clarke in Reverie, First published in *New Worlds*, Autumn 1939

RMIT UNIVERSITY

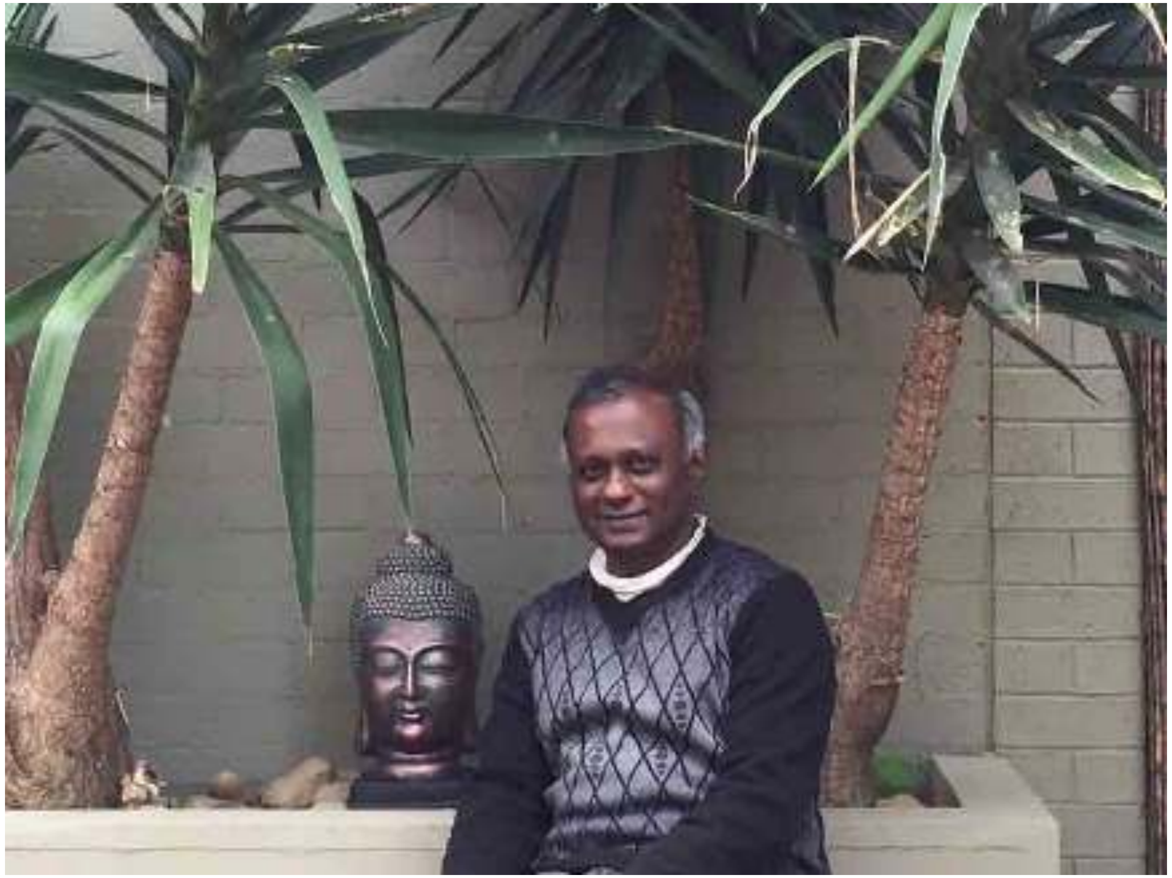
Some philosophical thoughts…..

- Research should not be carried out for one's survival …..

- One ….. Individual researcher, research institution, ….

- It should be for the betterment and sustenance of the humankind

- In that sense a true global(/local) coordination is essential



RMIT UNIVERSITY

Teach thy tongue to say, "I do not know," and thous shalt progress.
- Maimonides

THANK YOU

RMIT UNIVERSITY