



# Provision of water in arid environments – Lessons in water use and reuse from Australia

Never Stand Still

Faculty of Engineering

Civil & Environmental Engineering

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# Overview

- Water availability in Australia
- Water recycling
- New technologies for water/wastewater treatment
- Conclusions



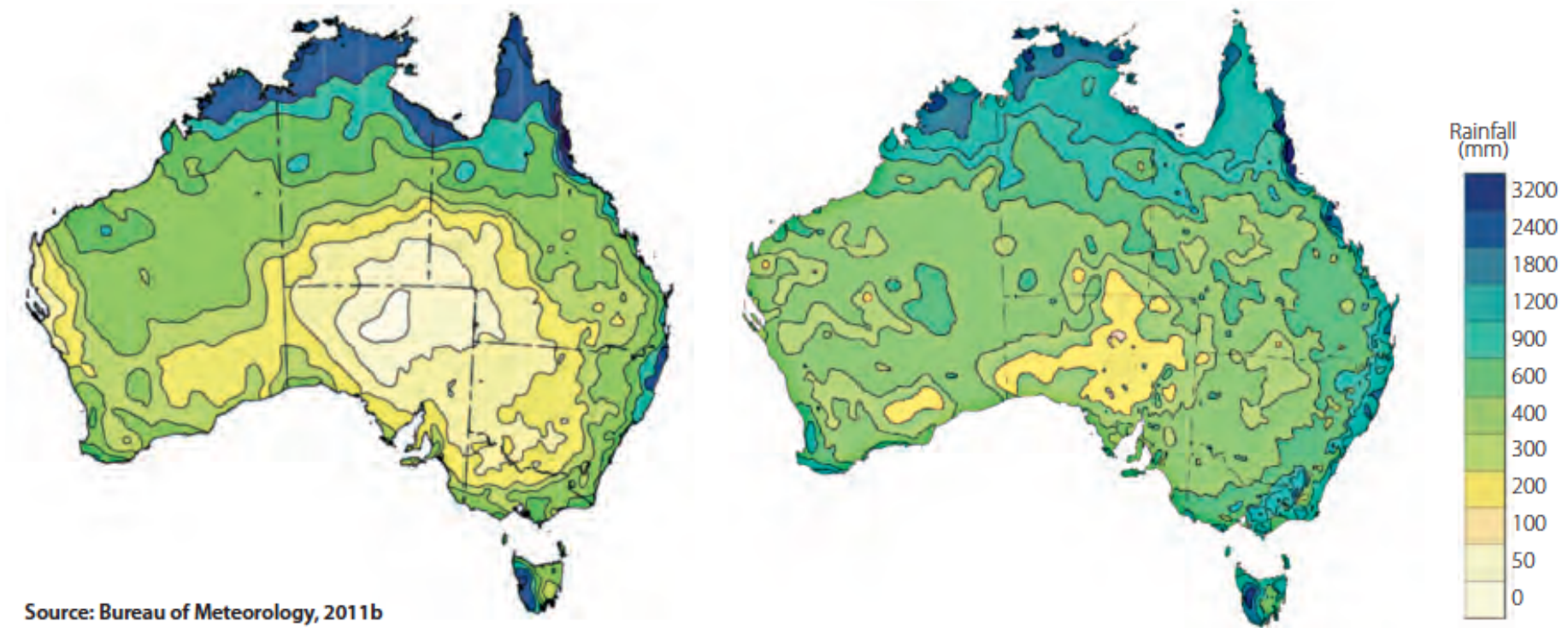
Australia's average total annual rainfall	3,700,000 GL
Total annual renewable water resource	400,000 GL
Annual water extracted	70,000 GL
Annual water consumption	24,000 GL
Agriculture	50–70% (irrigation water on 1% of agricultural land)
Urban	10–15% (50 – 100 kL per person per year)
Manufacturing	2–5%
Mining	1–4%
Other	15–30%

Cost (\$/kL) of water from:

Reservoirs	\$0.50 – \$1.30
Desalination	\$1.20 – \$2.20 (or up to \$7.00 if underutilised)
Recycled wastewater	\$0.80 – \$6.00
Harvested stormwater	\$0.40 – \$3.00
Rainwater tanks	\$1.40 – \$12.00
Bottled water	\$500 – \$3,000

**From “Sustainable Water Management: Securing Australia’s Future in a Green Economy”. Australian Academy of Technological Sciences and Engineering, April 2012 (hereafter referred to as ATSE (2012)).**

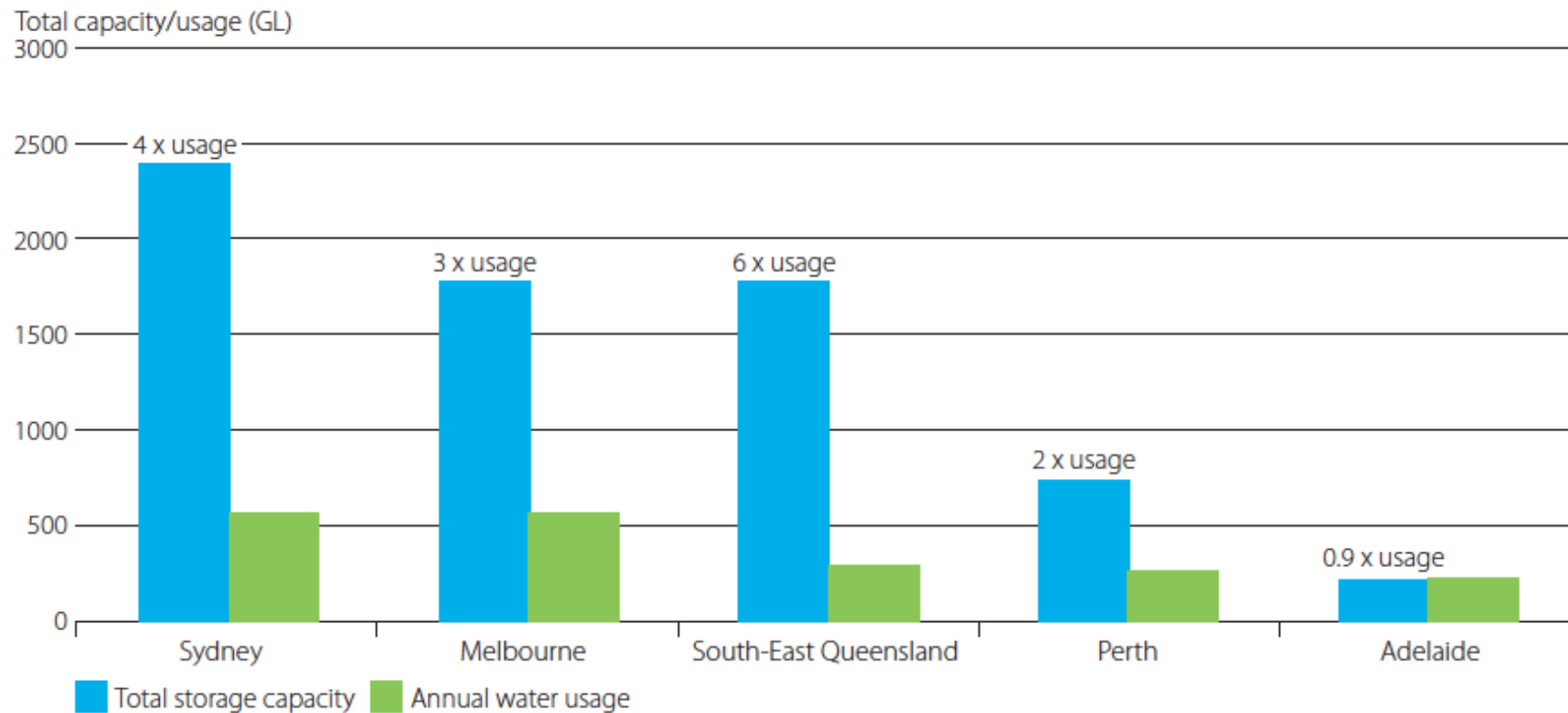
# Comparisons of annual rainfall for a dry year, 2006 (left) and wet year, 2011 (right)



Source: Bureau of Meteorology, 2011b

From ATSE (2012)

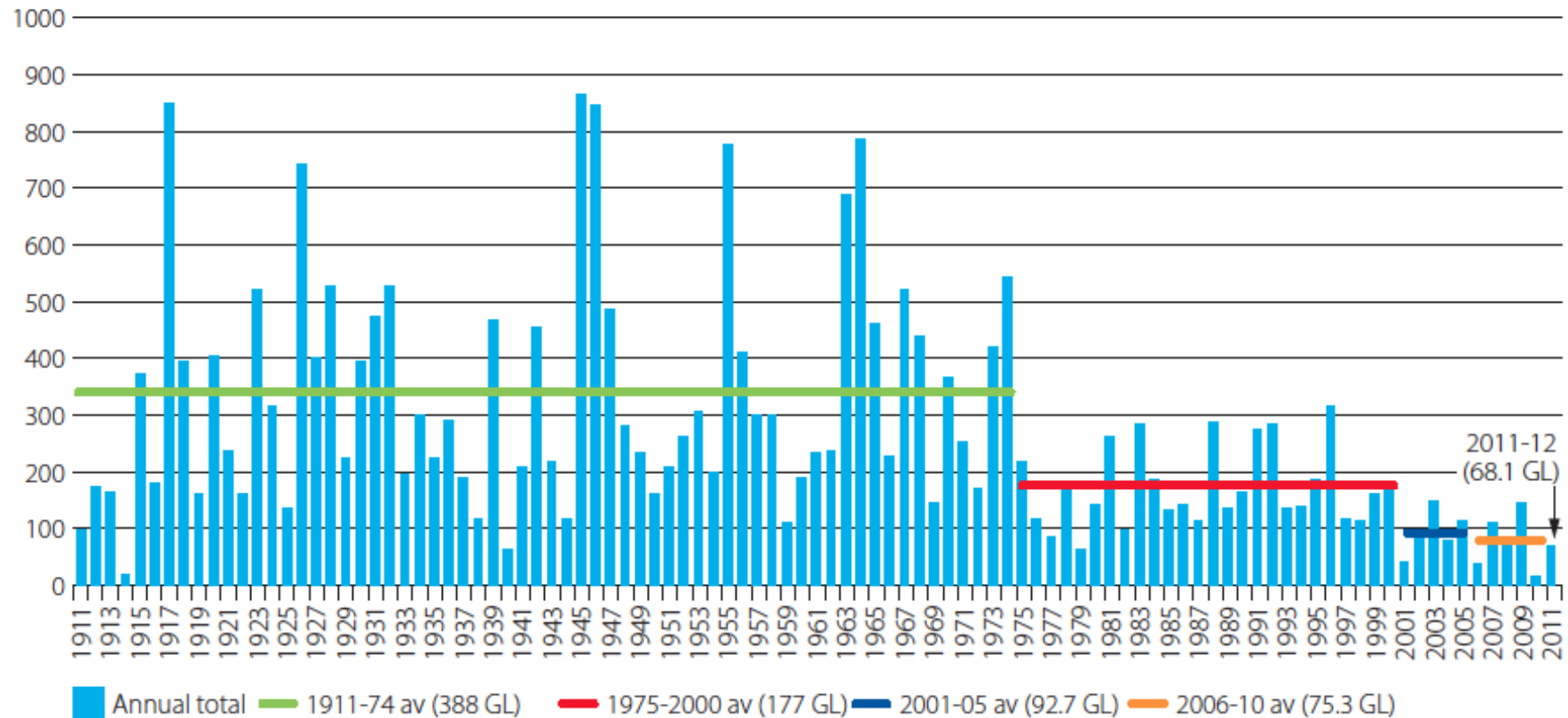
# Total storage capacity and annual usage for mainland State capitals



From ATSE (2012)

# Inflows into Perth dams since 1911

Total annual inflow to Perth dams (GL)



From ATSE (2012)

# Annual consumption and sources of urban water by jurisdiction for utilities with greater than 10,000 connections (2009-10)

Area	Total water sourced (GL)	Surface water %	Groundwater %	Desalination %	Recycled water %
NSW-metro	692	92.3	1.0	2.8	3.9
NSW-regional urban	311	78.2	15.7	–	6.1
Victoria	616	72.6	3.3	–	24.1
Queensland	435	69.6	2.4	4.3	23.7
South Australia	177	70.2	1.7	–	28.1
Western Australia	310	39.8	38.5	9.7	12.0
Tasmania-metro	43	93.8	–	–	6.2
Northern Territory	53	65.5	28.5	–	6.0
ACT	50	86.7	–	–	13.3
TOTAL	2686	78.2	8.7	2.7	10.4

From ATSE (2012)



# Large desalination plants in Australia

Location	Initial capacity (GL/yr)	Maximum expandable capacity (GL/yr)	Initial (and expandable) capacity as % of annual consumption in 2009-10	Initial capital cost		Year of completion
				(\$M)	(\$M/ML/day)	
Sydney (Kurnell)	90	180	18 (36)	1890	7.7	2010
Melbourne (Wonthaggi)	150	200	43 (57)	3500	8.5	2012
SE Queensland (Tugun)	49	N/A	25	1200	8.9	2009
Perth (Kwinana)	45	N/A	18	387	3.1	2006
Perth (Binninyup)	100	N/A	40	1400	5.1	2012
Adelaide (Port Stanvac)	100	N/A	70	1830	6.7	2012
Point Lowly (BHP)*	24	69	N/A	N/A	N/A	2017-21

From ATSE (2012)

# Operating cost, energy consumption and greenhouse gas emissions for various water supply options for Adelaide

Source	Operating cost (\$/kL)	Energy consumption (MWh/ML)	Greenhouse-gas emissions (tonnes CO <sub>2</sub> -e/ML)
Mt Lofty Ranges	0.20	0.3	0.24
River Murray	0.44*	1.9*	1.54*
Desalination	1.00	5.0	4.10
Stormwater harvesting	0.55	0.8	0.65
Wastewater reuse	0.70	1.3	1.05

From ATSE (2012)

# Water recycling

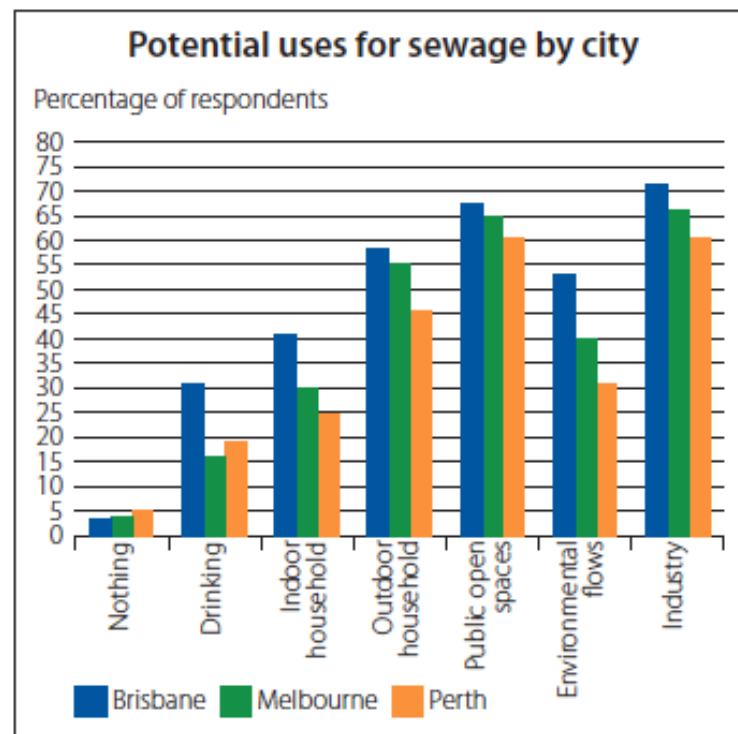
- Australia recycled 17 per cent of its wastewater effluent and stormwater in 2009–10, and is expected to reach 19 per cent to 20 per cent by 2015.
  - South Australia reuses the highest proportion of wastewater at 28 per cent followed by Victoria and Queensland (both 24 per cent).
  - Western Australia's recycling to 2015 is dependent upon a plan to supply between 25 and 35 GL/year to Perth's potable supplies, using recharge to aquifers. This would increase recycled water use in WA from 12 per cent to 30 per cent, and the national proportion to 20.3 per cent.
- Recycled water is mainly used for industry, watering parks and sporting fields, and agriculture. Several new urban developments incorporate third pipe systems to supply recycled water for non-potable uses such as gardens and toilets.
- In 2009–10, 245 GL of water was recycled by urban utilities with over 10,000 connections, up from 160 GL in 2005–06.

# Major recycling projects

- Wastewater recycling using advanced (tertiary) treatment
  - St Marys scheme in western Sydney for replacement environmental flows (27 GL/yr)
  - Kwinana and Alkimos schemes in Perth (13 GL/yr)
  - Glenelg/Adelaide Parklands (5.5 GL/yr)
  - Southeast Queensland Western Corridor sewage treatment (47 GL/yr)
- Stormwater harvesting using of wetlands or partial biological treatment
  - In Adelaide, 3 projects near completion (supplying 12.6 GL/yr)
  - In Orange (NSW), 2.1 GL replenishment of potable supply
- Aquifer storage of both stormwater and tertiary treated sewage
  - Botany aquifer being used to store and reuse Sydney stormwater runoff
  - IN WA, injection of treated wastewater from Beenyup WTP to groundwater aquifers has commenced (could supply up to 20% of WA water supply (115 GL/yr) by 2060).

# Community concerns

- The public appears deeply sceptical about drinking recycled water, due to fears about health risk, despite scientific evidence of the safety of modern treatment processes.
- Targeted social research in communities with proposed drinking water recycling schemes to better understand the factors related to perception of risk, motivations, attitudes, beliefs and behaviour may assist.
- Public participation in decision-making in improving confidence and trust in recycling is of key importance



From ATSE (2012)

# Keys to uptake and acceptance of greater recycling in Australia

In a recent analysis of approaches to sustainable water management in Australia , the Australian Academy of Technological Science and Engineering recommended that the following areas be seen as priorities:

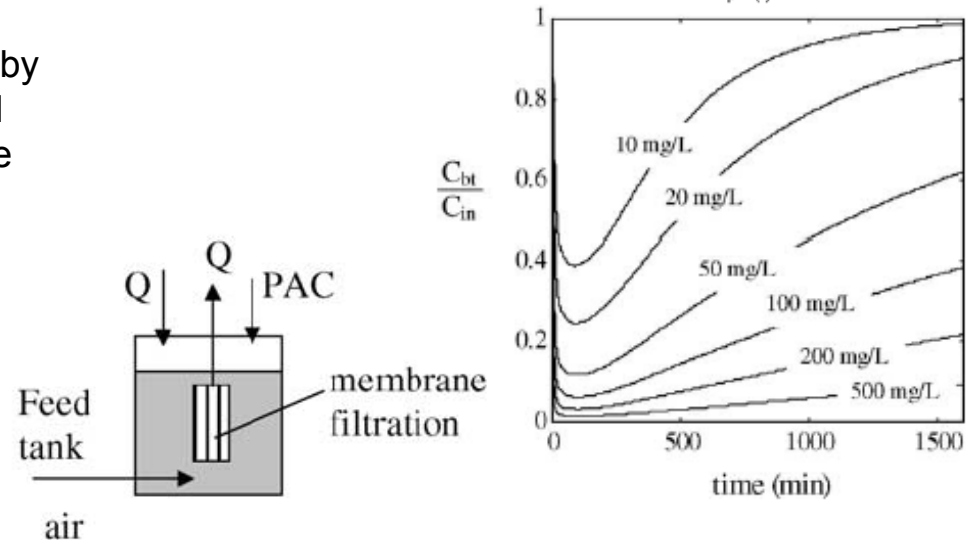
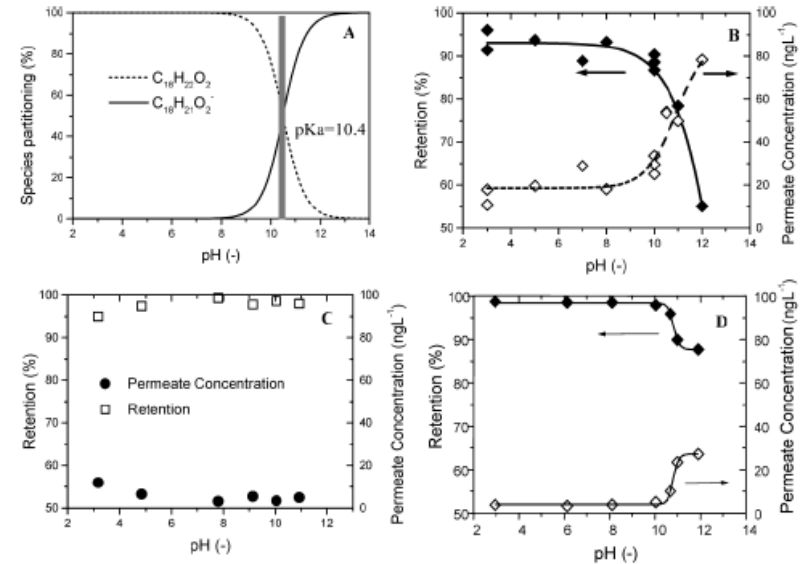
- science and technology – strategic and targeted R&D in advanced treatment technologies, realtime performance testing of multi-barrier controls, pathogen and chemical testing, risk assessment, technology transfer and sharing of best practice;
- economic – full cost/benefit analysis that takes account of social and environmental externalities and avoided costs; and
- socio-political – public education and awareness programs to improve public confidence in water supply options and technologies, sharing regulation and frameworks for validation of recycling schemes and accreditation of operators and certifiers.

# S&T Investigations at UNSW

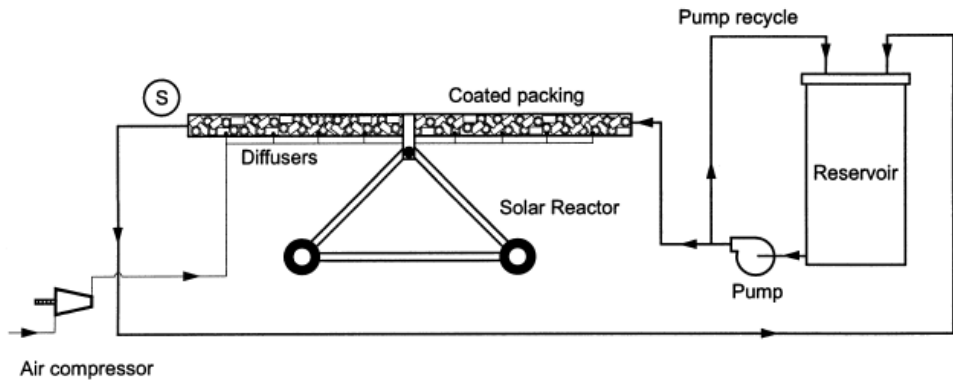
Schaefer, A.I., Nghiem, L.D. and Waite, T.D. (2003). Removal of the natural hormone estrone from aqueous solutions using nanofiltration and reverse osmosis. *Environ. Sci. Technol.* 37, 182-188.

Chang, S., Waite, T.D. and Fane, A.G. (2005). A simplified model for trace organics removal by continuous flow PAC adsorption/submerged membrane processes. *Journal of Membrane Science* 253/1-2, 81-87.

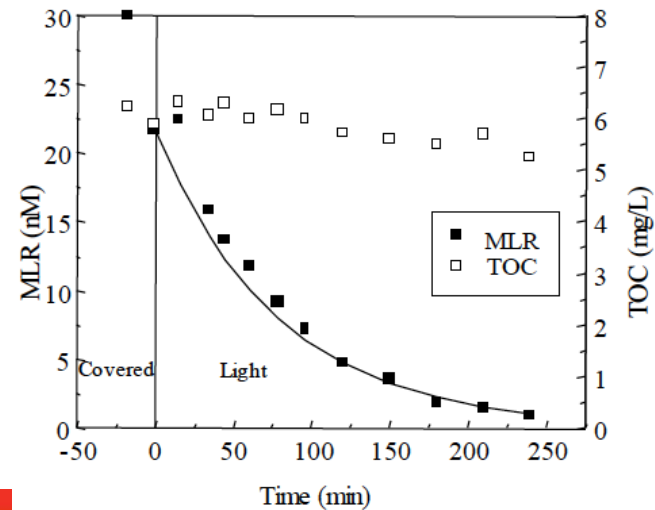
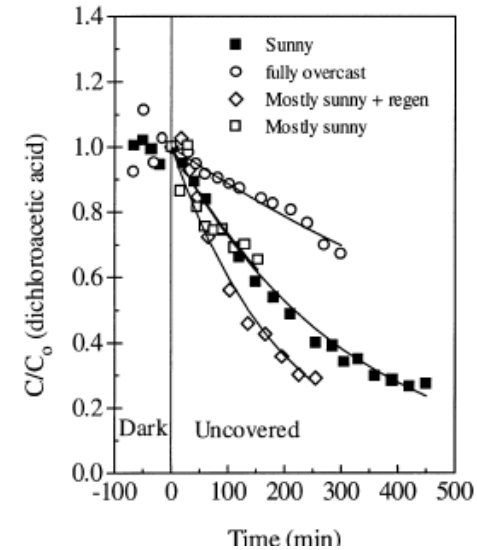
**See papers by Stuart J Khan et al  
UNSW Water Research Centre**



# Advanced oxidation processes for degradation of trace organic contaminants – initial studies using $\text{TiO}_2$ + light



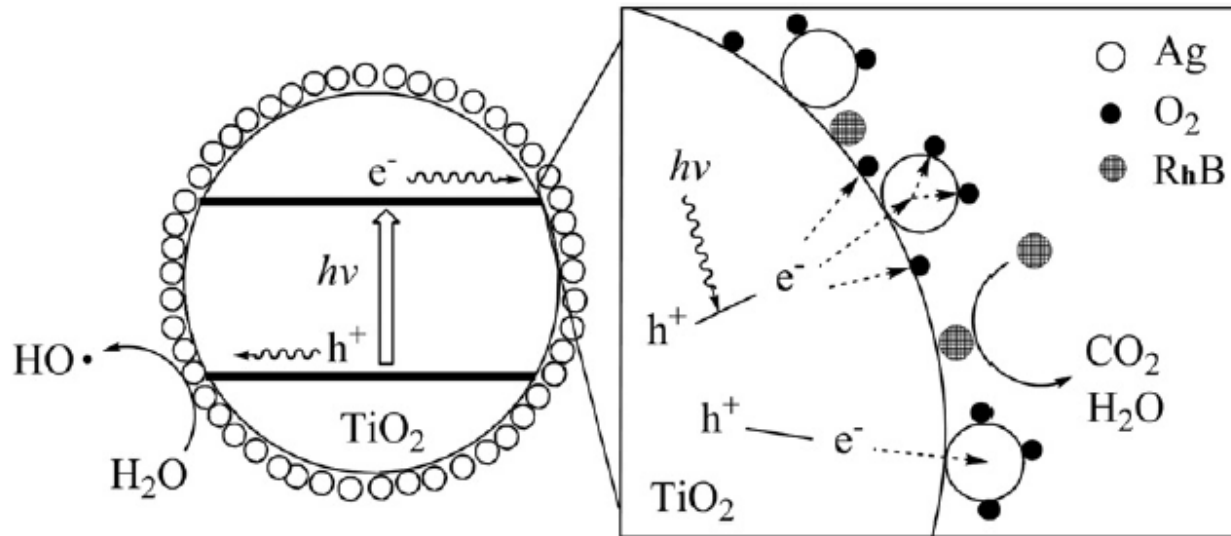
Feitz, A.J., Boyden, B.H. and Waite, T.D. (2000). Evaluation of two solar pilot scale fixed-bed photocatalytic reactors. *Water Research* 34, 3927-3932.



Feitz, A.J., Waite, T.D., Boyden, B.H and Jones, G.J. (2002). Solar pilot-scale photocatalytic degradation of microcystin-LR, *Journal of Advanced Oxidation Technologies* 5(1), 22-26.



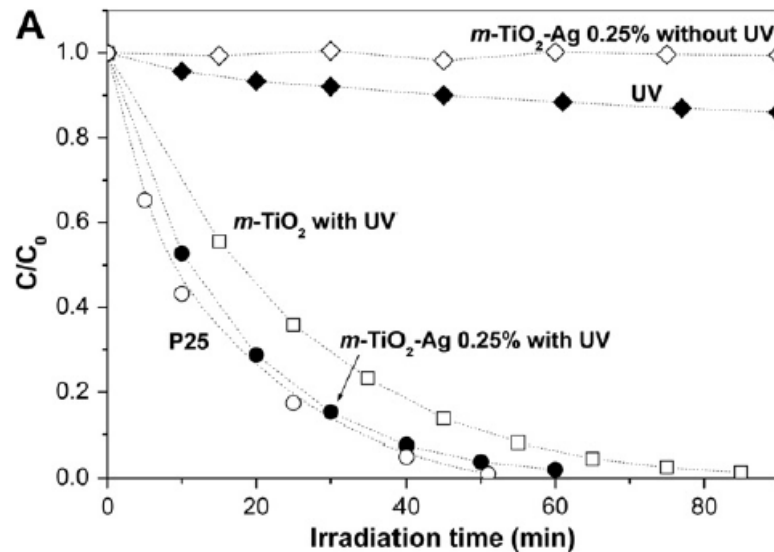
# Interest in increasing efficiency of $\text{TiO}_2$ by reducing band-gap or using other “enhancers”



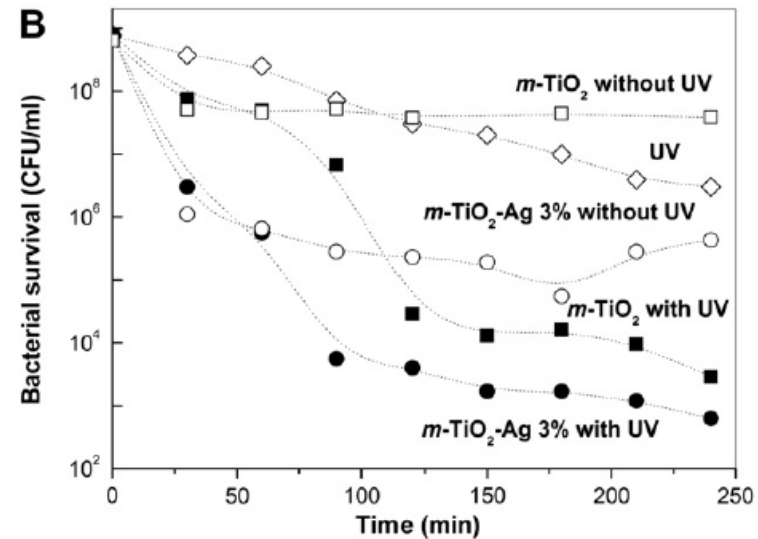
Xiong, Ma, Ng, Waite & Zhao (2011). Silver-modified mesoporous  $\text{TiO}_2$  photocatalyst for water purification. *Water Research* 45, 2095-2103.

# Presence of AgNPs enhances degradation/ inactivation performance of TiO<sub>2</sub>

RhB degradation

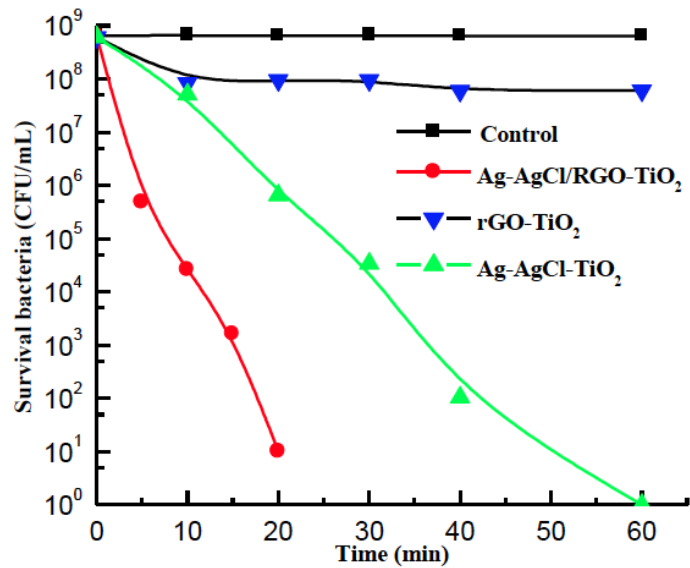


*E. coli* inactivation

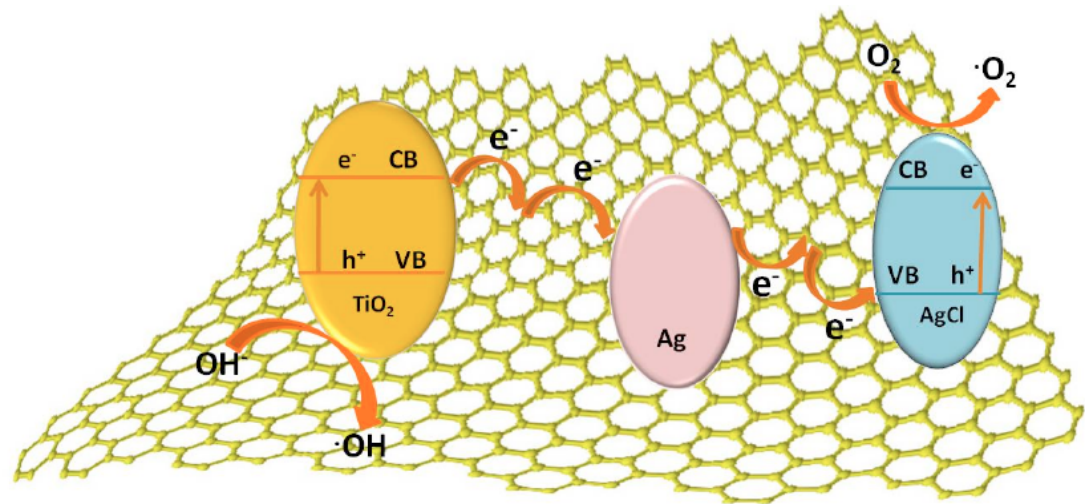


Xiong, Ma, Ng, Waite & Zhao (2011). Silver-modified mesoporous TiO<sub>2</sub> photocatalyst for water purification. *Water Research* 45, 2095-2103.

More effective assemblages can be constructed where  $e^-$ - $h^+$  recombination is further reduced by placing semiconductor(s) on highly conducting graphene sheets



AgCl(s) is a semiconductor with band gap of 3.2 eV



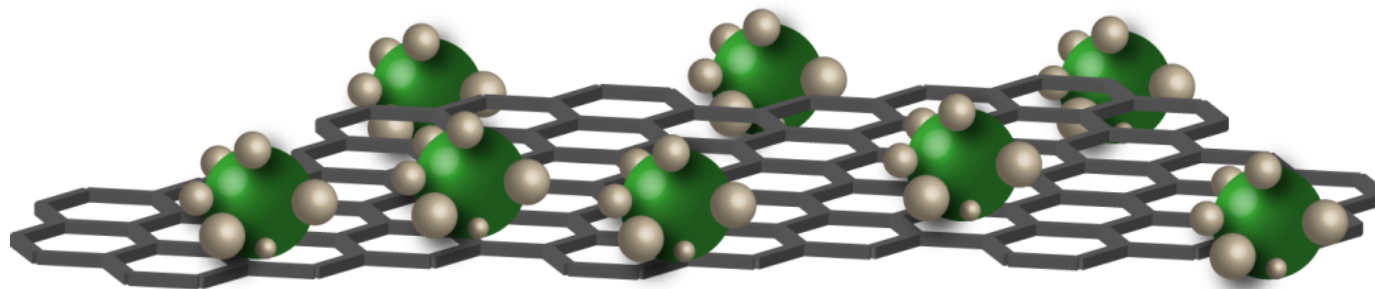
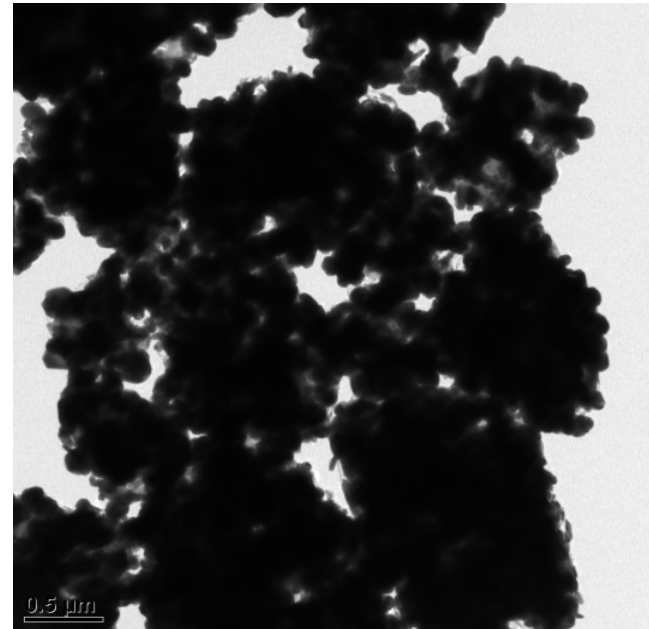
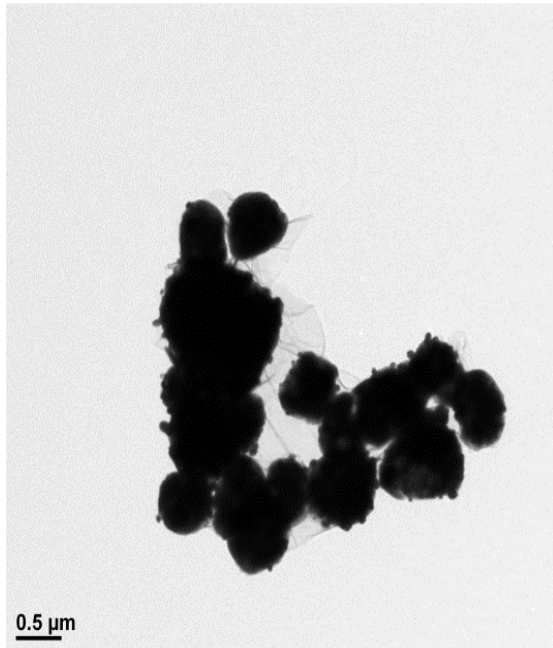
Ma, J., Xiong, Z., Ng, W.J., Shi, F., Waite, T.D. and Zhao, X.S. Ag-AgCl/RGO-TiO<sub>2</sub> nanocomposite as a novel and efficient photocatalyst for water disinfection. Water Research (under review)

# May be possible to simplify the system with use of only Ag@AgCl and light

Wang, P.; Huang, B.; Qin, X.; Zhang, X.; Dai, Y.; Wei, J.; Whangbo, M.-H. Ag@AgCl: A Highly Efficient and Stable Photocatalyst Active under Visible Light. *Angew. Chem. Int. Ed.* **2008**, 47 (41), 7931-7933

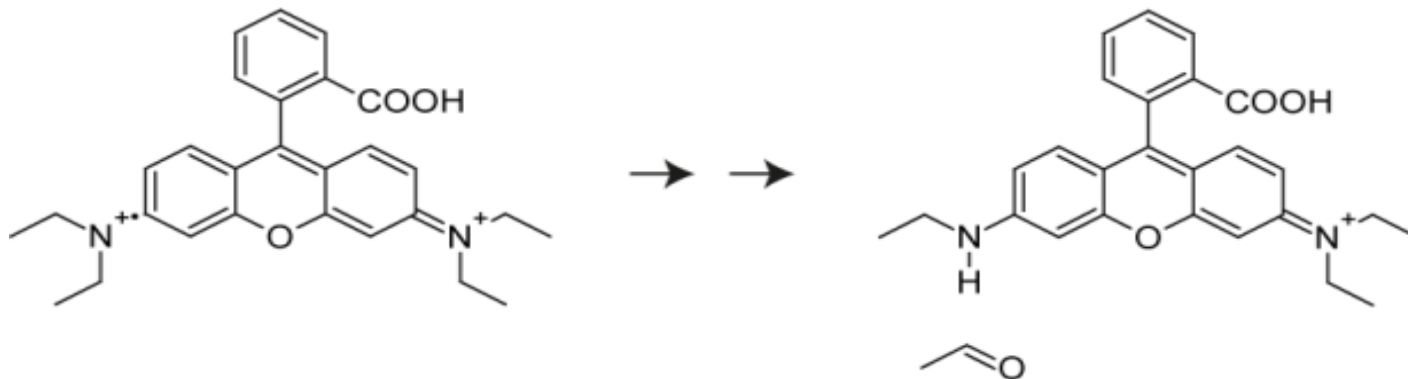
Zhang, H.; Fan, X.; Quan, X.; Chen, S.; Yu, H. Graphene sheets grafted Ag@AgCl hybrid with enhanced plasmonic photocatalytic activity under visible light. *Environ. Sci. Technol.* **2011**, 45 (13), 5731-5736

# TEM and schematic of Ag@AgCl/rGO



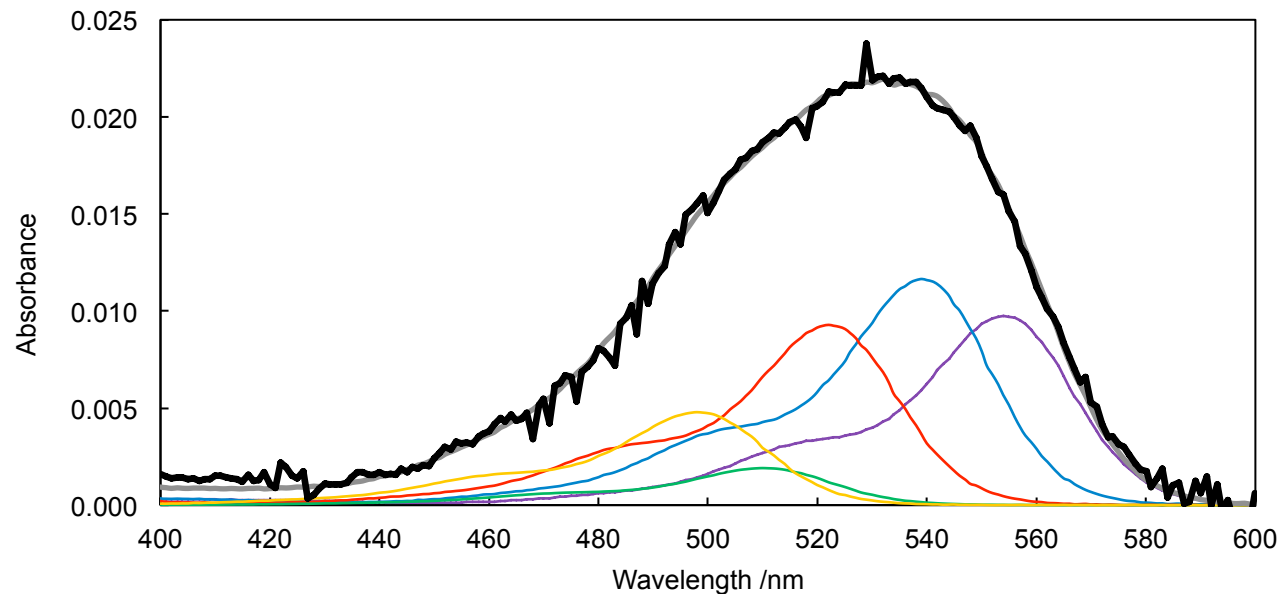
# Degradation of Rhodamine B

- In the dark, rhodamine B rapidly adsorbs to the particles (but is not degraded)
- Upon illumination, absorbance decreases rapidly and also shifts in peak wavelength, wavelength shift due to de-ethylation

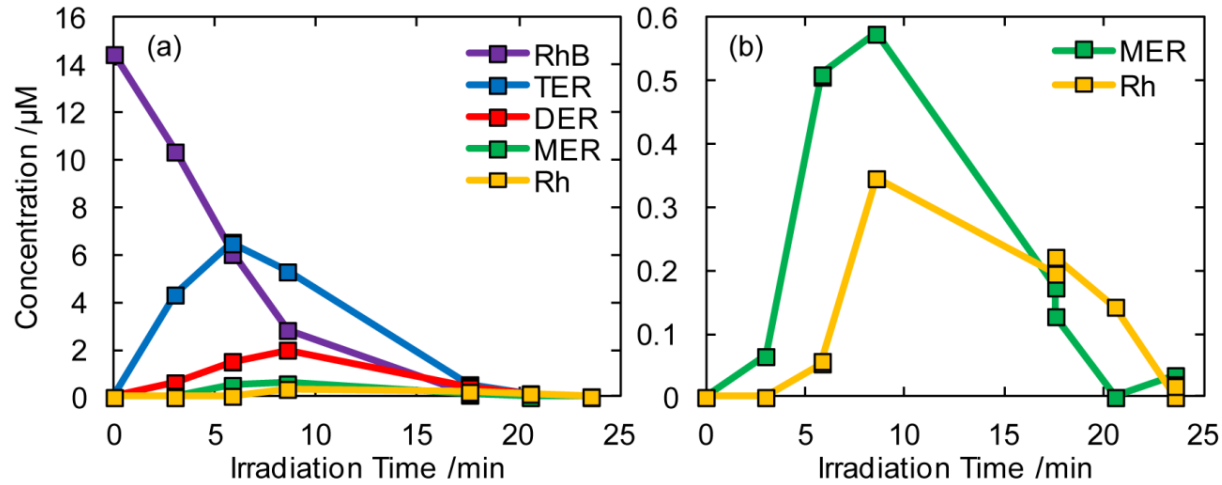


# Degradation of Rhodamine B

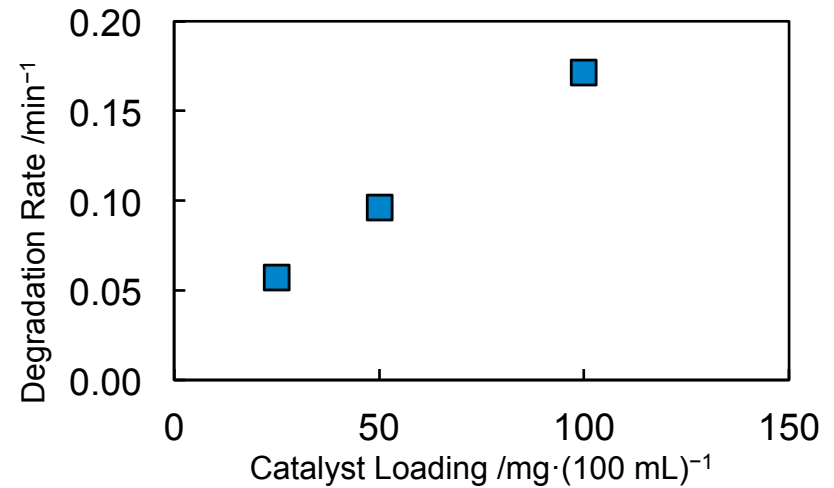
- The absorbance of de-ethylated rhodamine products (TER, DER, MER and Rh) are known (Watanabe et al. 1977), as such, the concentration of these species can be determined by de-convoluting the spectra obtained



# Degradation of Rhodamine B



- Degradation rate is linear function of catalyst loading => degradation driven by availability of surface sites on catalyst



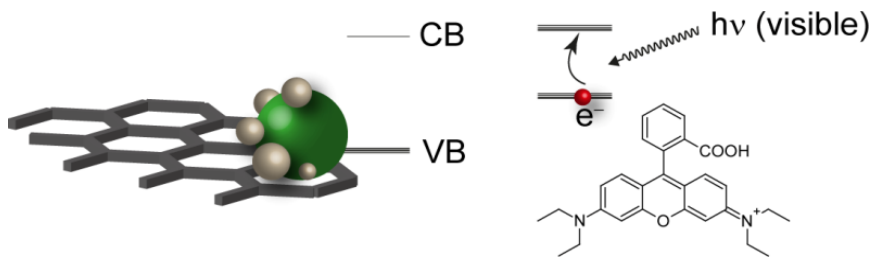


# Influence of *tert*-butanol

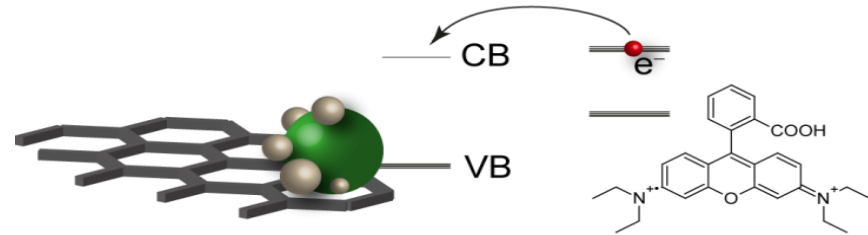
- Degradation rate is not impacted by *tert*-butanol even at concentrations up to 50 mM, where 99.3% of HO• would be scavenged by *tert*-butanol
- This implies that HO• is highly unlikely to be important
- Adsorbed rhodamine B is critical

# Degradation mechanism

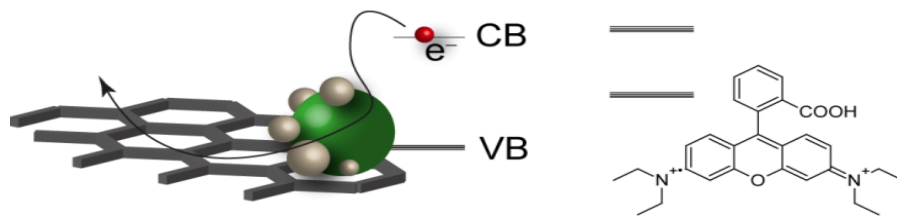
**Step 1** Excitation of adsorbed rhodamine B



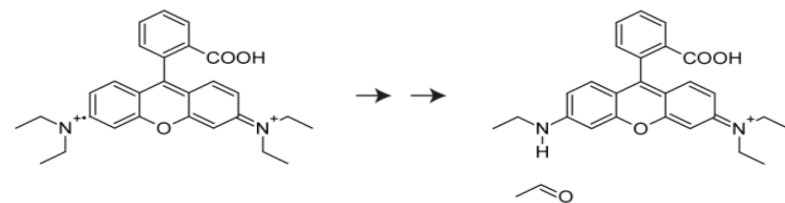
**Step 2** Electron transfer to conduction band



**Step 3** Efficient transfer of electron



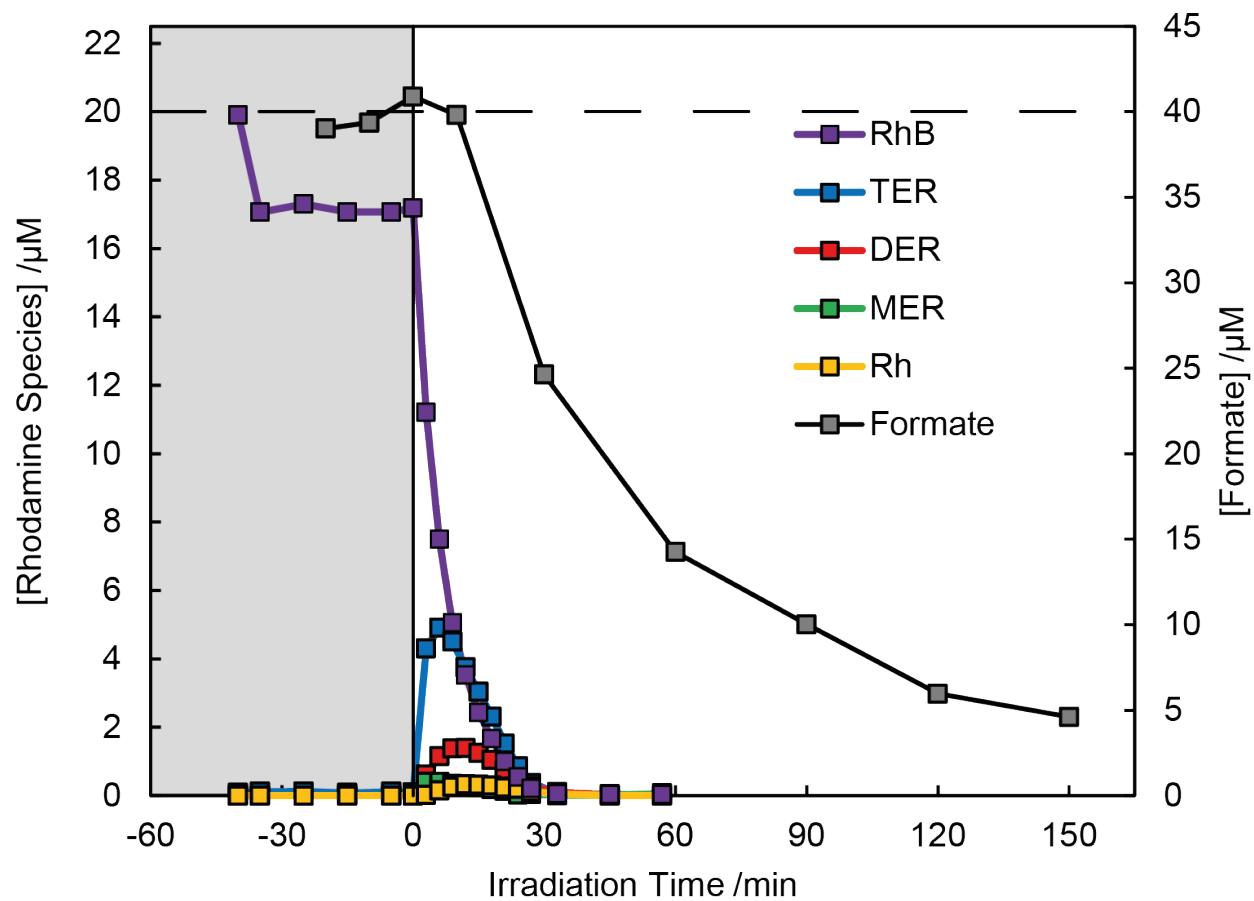
**Step 4** Subsequent reactions



# Degradation of formic acid

- Radiolabelled formic acid ( $\text{H}^{14}\text{COOH}$ ) employed as substrate (since degradation much simpler than RhB)
- $\text{H}^{14}\text{COO}^- + \text{Ox} \rightarrow {}^{14}\text{CO}_2^{\cdot-} + \text{Red}$
- ${}^{14}\text{CO}_2^{\cdot-} + \text{O}_2 \rightarrow {}^{14}\text{CO}_2 + \text{O}_2^{\cdot-}$
- No visible light absorption

# Degradation of formic acid

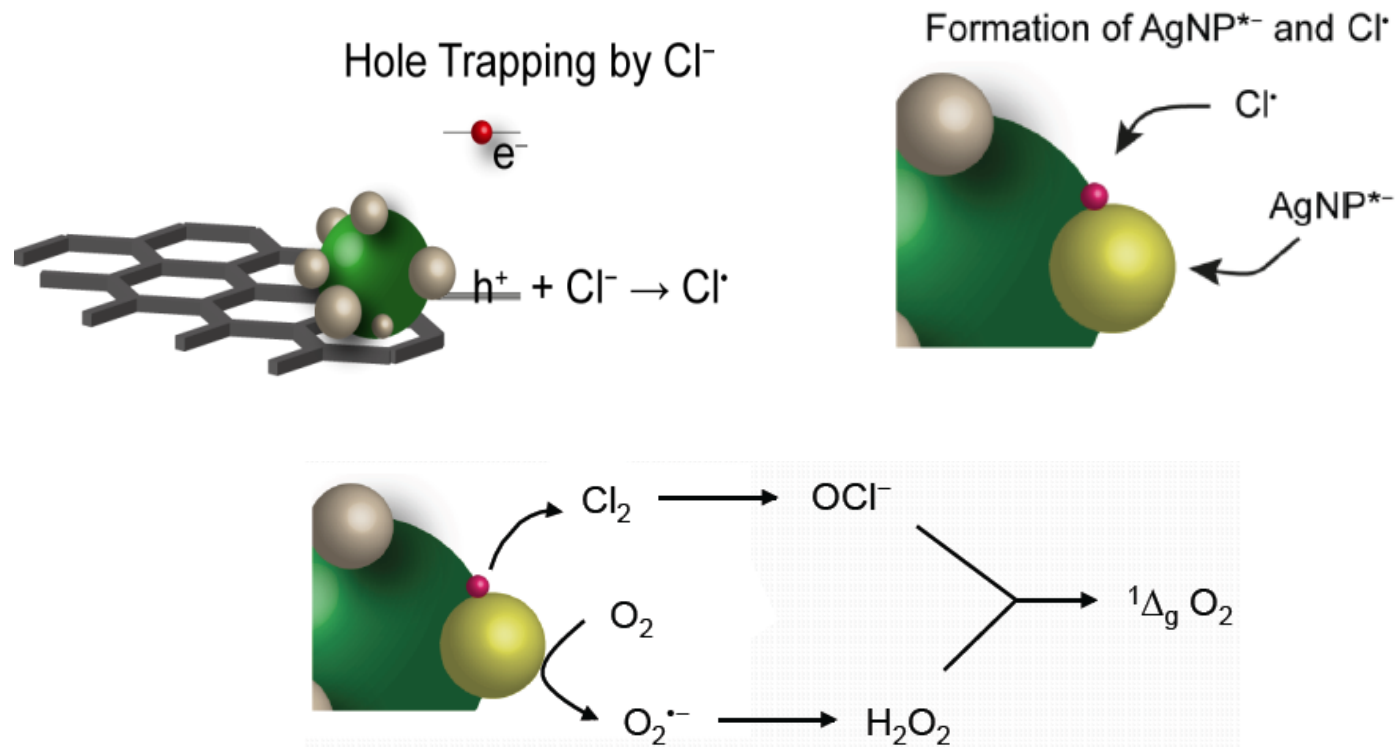


# Key observations

- Formate does not partition significantly to particles
- Formate degrades much more slowly than rhodamine B
- Bulk phase oxidant generation may also be important for formate → multiple potential degradation pathways, the importance of each being substrate-dependent

# Potential mechanisms

- Wang et al. (2008) studied Ag@AgCl and proposed that plasmon absorption may lead to:



# Summary

- Ag@AgCl/rGO is highly effective for visible-light mediated degradation
- Although effective, There is a range of mechanisms that may be involved, with further work needed to elucidate the dominant processes operating. Only when this has been achieved, will optimisation of the process be possible.