



PFAS and Contaminants of Emerging Concern (CEC) – Landfill Liner Performance and Regulation

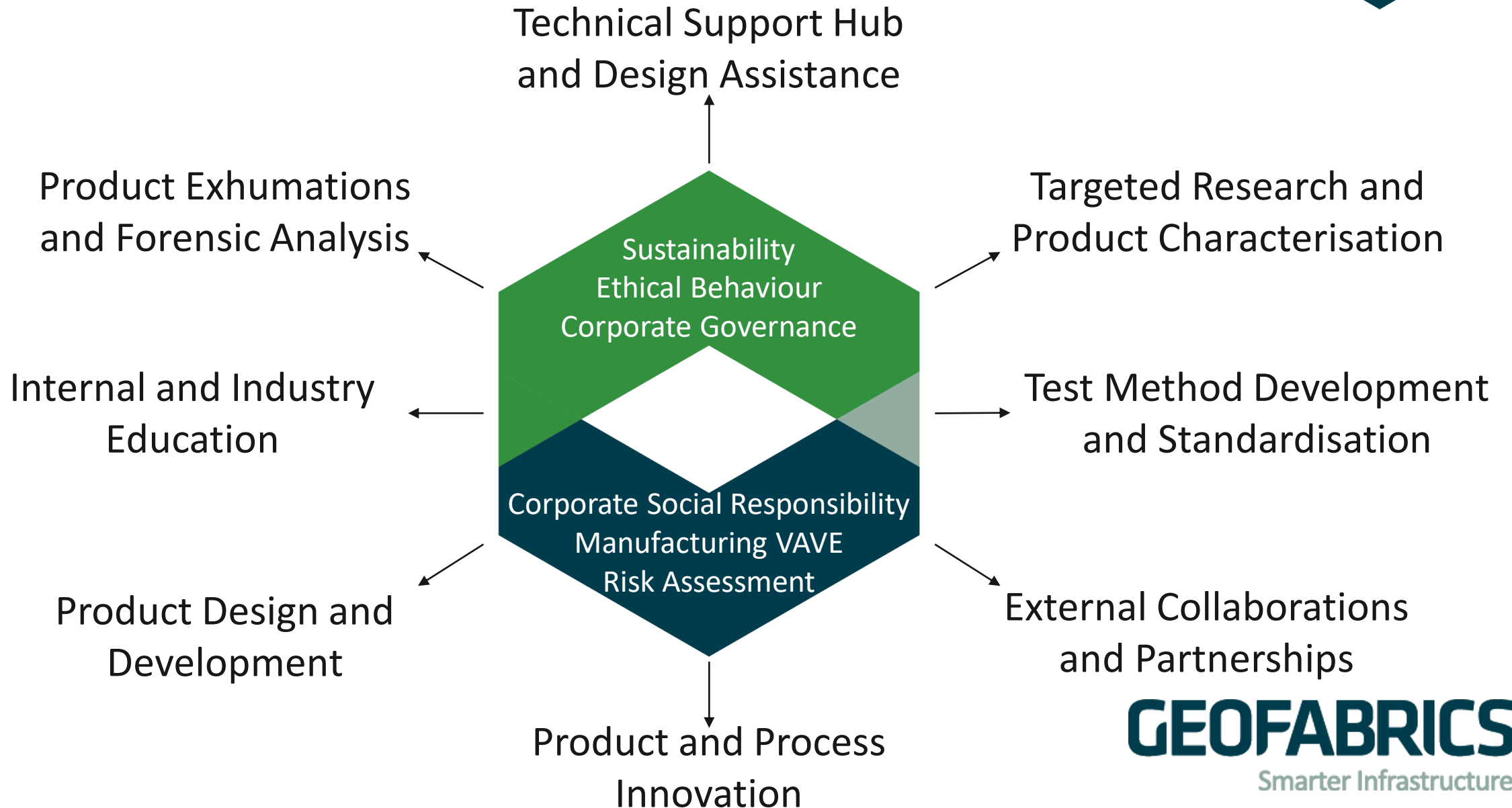
By Daniel Gibbs




Geofabrics Centre for
**GEOSYNTHETIC
RESEARCH,
INNOVATION &
DEVELOPMENT**

GEOFABRICS[®]
Smarter Infrastructure

A Multidisciplinary Approach





During the last 10 years, the GRID has undertaken over 700 research and innovation projects, across a broad range of geosynthetic products used in a wide variety of infrastructure projects

How many chemicals?

According to a study published in 2020, over **350,000** chemicals and mixtures of chemicals have been registered for production and used globally


C H E M I S T R Y

A colourful history of chemical use

**“STANDARD”
RADIUM
PREPARATIONS**




“Standard” Radium Solution for Drinking
—
Each bottle contains two micrograms radium element in 60 cc. aqua dist.
—
Maximum-equilibrium constant of radium emanation, 5400 mache units.



“Standard” Radium Solution for Intravenous Use.
—
In Ampules of 2 cc. N. P. S. S. containing 5, 10, 25, 50, or 100 micrograms radium element.
PERMANENT

PERMANENT

“Standard” Radium Compress
—
A means of applying radium locally for the relief of pain.
—
A flexible pad of standardized, guaranteed radium element content.



PERMANENT RADIO-ACTIVITY

INDICATIONS
Subacute and Chronic Joint and Muscular Conditions.
High Blood Pressure. Nephritis.
The Simple and Pernicious Anemias.

“The value of radium is unquestionably established in chronic and subacute arthritis of all kinds (luetic and tuberculous excepted), acute, subacute and chronic joint and muscular rheumatism (so called), in gout, sciatica, neuralgia, polyneuritis, lumbago and the lancinating pain of tabes.”—Rowntree and Baetjer, Journal A. M. A. Oct. 18, 1913.

For Descriptive and Clinical Literature Address

| | | |
|--|---|--|
| <p>New York C. Everett Field, M. D., 50 E. 41st St.</p> | <p>RADIUM CHEMICAL COMPANY</p> | <p>Chicago C. W. Hanford, M. D., 749 1st Nat'l Bank Bldg.</p> |
| <p>Boston Samuel Delano, M. D., 39 Newbury St.</p> | <p>PITTSBURGH</p> | <p>San Francisco Fred I. Lackenbach Biologic Depot 908 Butler Bldg.</p> |

**NICO TIME
CIGARETTES**



**THE
SMOOTH
TASTE
EXPECTANT
MOTHERS
CRAVE!**

NO FLIES ON ME



THANKS TO DDT




500 20370
Compressed Tablets
containing
1/4 grain each
Meron Hydrochloride
Directions:
Two to three, to be taken only
by order of a physician.
THE BAYER CO. LTD.

*Let this magic mineral,
ASBESTOS,
protect the buildings
on your farm!*



STEEDMAN'S



**IN USE
OVER FIFTY YEARS**

**SOOTHING
POWDERS**

RELIEVE
FEVERISH HEAT.
Prevent
Fits, Convulsions, etc.
Preserve
a Healthy State of the
Constitution during the
period of TEETHING.

For Children
cutting TEETH.

WALWORTH, Surrey.

Dichlorodiphenyltrichloroethane

“We have discovered many preventives against tropical diseases, and often against the onslaught of insects of all kinds, from lice to mosquitoes and back again. The excellent DDT powder which had been fully experimented with and found to yield astonishing results will henceforth be used on a great scale by the British forces in Burma and by the American and Australian forces in the Pacific and India in all theatres.”
– Winston Churchill, September 24, 1944



Dichlorodiphenyltrichloroethane



"DDT is good for me-e-e!"

The great expectations held for DDT have been realized. During 1946, exhaustive scientific tests have shown that, when properly used, DDT kills a host of destructive insect pests, and is a benefactor of all humanity.

Pennsalt produces DDT and its products in all standard forms and is now one of the country's largest producers of this amazing insecticide. Today, everyone can enjoy added comfort, health and safety through the insect-killing powers of Pennsalt DDT products . . . and DDT is only one of Pennsalt's many chemical products which benefit industry, farm and home.

GOOD FOR STEERS—Beef grows meatier nowadays . . . for it's a scientific fact that—compared to untreated cattle—beef-steers gain up to 50 pounds extra when protected from horn flies and many other pests with DDT insecticides.

KNOX FOR THE HOME—helps to make healthier, more comfortable homes . . . protects your family from dangerous insect pests. Use Knox-Out DDT Powders and Sprays as directed . . . then watch the bugs "bite the dust"!

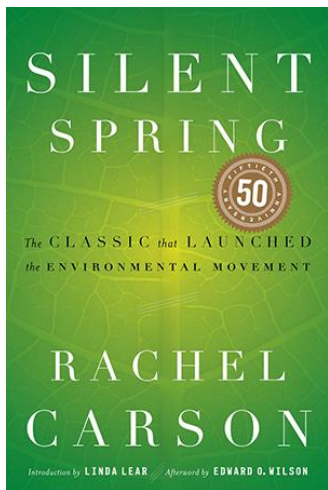
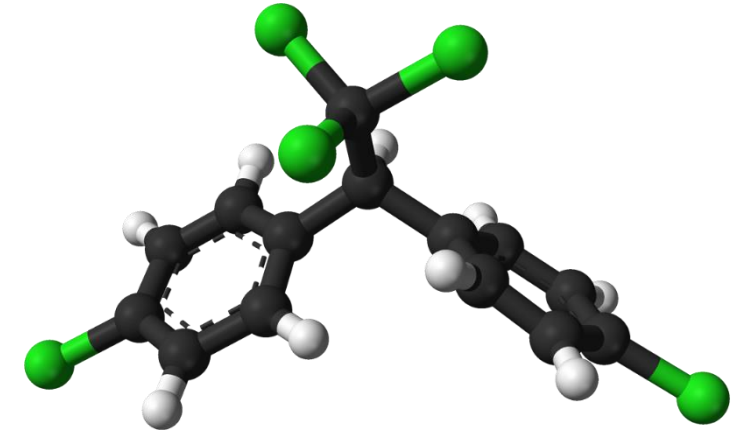
GOOD FOR DAIRIES—Up to 20% more milk . . . more butter . . . more cheese . . . tests prove greater milk production when dairy cows are protected from the annoyance of many insects with DDT insecticides like Knox-Out Stuck and Barn Spray.

GOOD FOR FRUITS—Bigger apples, juicier fruits that are free from unsightly worms . . . all benefits resulting from DDT dusts and sprays.

GOOD FOR ROW CROPS—25 more barrels of potatoes per acre . . . actual DDT tests have shown crop increases like this! DDT dusts and sprays help truck farmers pass these gains along to you.

KNOX FOR INDUSTRY—Food processing plants, laundries, dry cleaning plants, hotels . . . dozens of industries gain effective bug control, more pleasant work conditions with Pennsalt DDT products.

PENNSALT CHEMICALS
97 Years' Service to Industry • Farm • Home
PENNSYLVANIA SALT MANUFACTURING COMPANY
WIDENER BUILDING, PHILADELPHIA 7, PA.



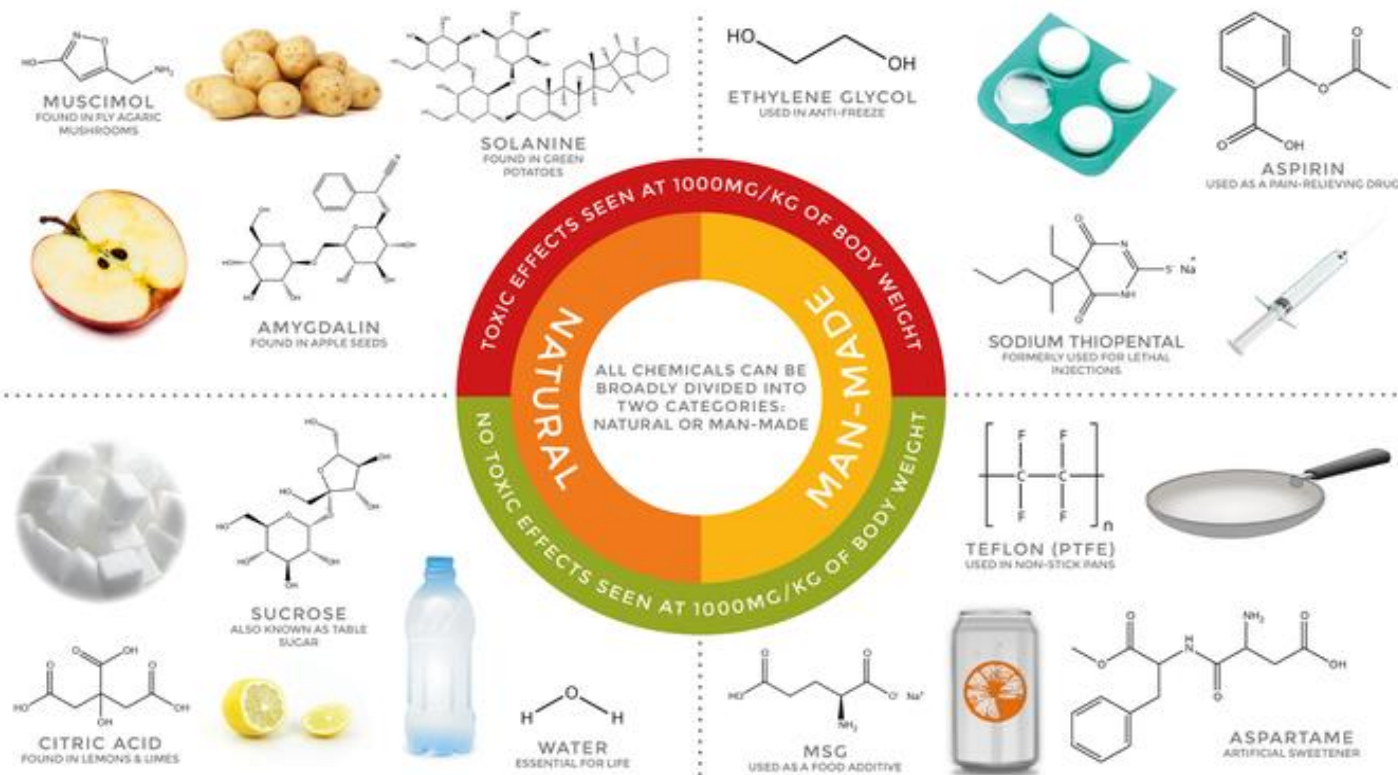
**What
determines
whether a
chemical is
helpful...**



**..or
harmful?**

NATURAL & MAN-MADE CHEMICALS

A COMMON MISCONCEPTION IS THAT ALL MAN-MADE CHEMICALS ARE HARMFUL, AND ALL NATURAL CHEMICALS ARE GOOD FOR US. HOWEVER, MANY NATURAL CHEMICALS ARE JUST AS HARMFUL TO HUMAN HEALTH, IF NOT MORE SO, THAN MAN-MADE CHEMICALS.



"EVERYTHING IS POISON, THERE IS POISON IN EVERYTHING. ONLY THE DOSE MAKES A THING NOT A POISON."

PARACELSUS, 1493-1541, 'THE FATHER OF TOXICOLOGY'

ANY SUBSTANCE, IF GIVEN IN LARGE ENOUGH AMOUNTS, CAN CAUSE DEATH. SOME ARE LETHAL AFTER ONLY A FEW NANOGRAMS, WHILST OTHERS REQUIRE KILOGRAMS TO ACHIEVE A LETHAL DOSE.

CHEMICAL TOXICITY IS A SLIDING SCALE, NOT BLACK AND WHITE - AND WHETHER A CHEMICAL IS NATURALLY OCCURRING OR MAN-MADE TELLS US NOTHING ABOUT ITS TOXICITY.



FAMOSO DOCTOR

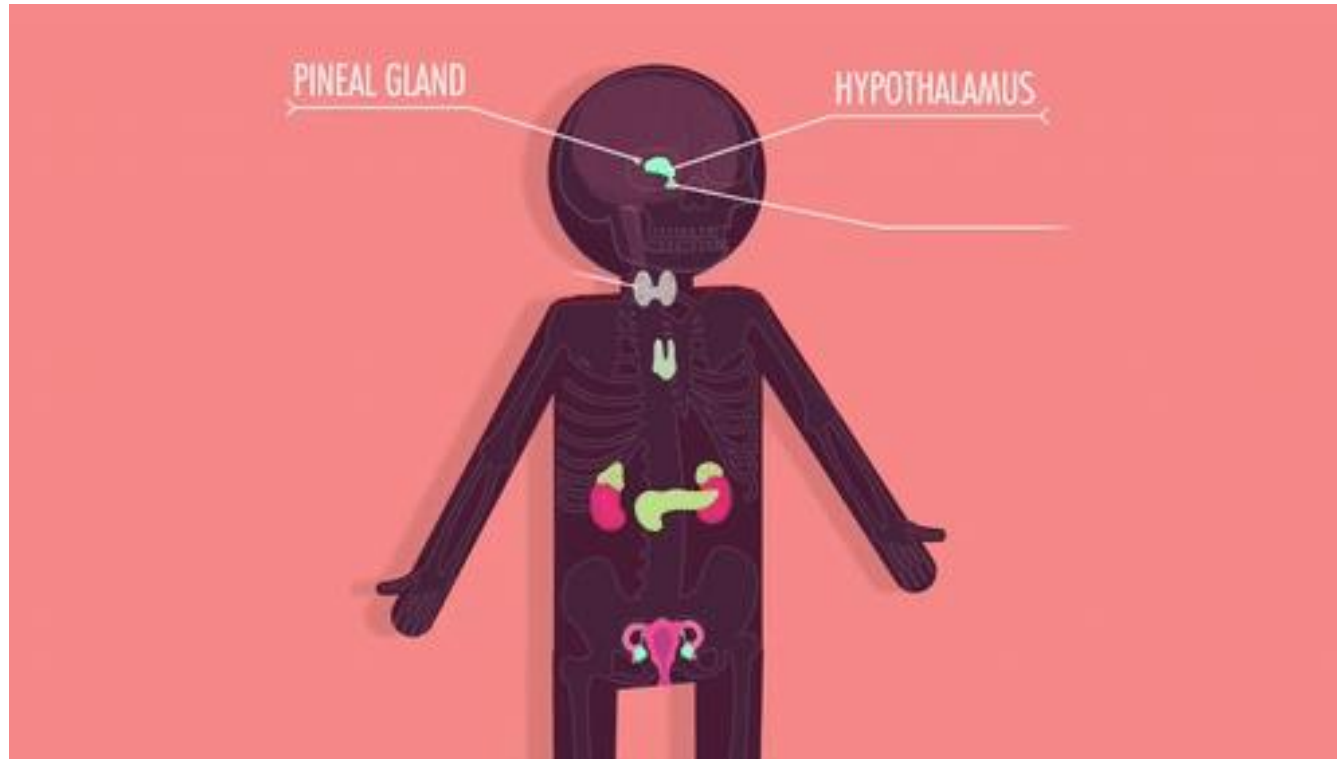
PARACELSUS.



© COMPOUND INTEREST 2014 - WWW.COMPOUNDCHEM.COM
MADE ON BEHALF OF SENSE ABOUT SCIENCE (@SENSEABOUTSCI) WWW.SENSEABOUTSCIENCE.ORG
MISCONCEPTIONS ABOUT CHEMICALS ARE ADDRESSED FURTHER IN THE PUBLIC GUIDE, 'MAKING SENSE OF CHEMICAL STORIES', AVAILABLE HERE:
www.senseaboutscience.org/pages/making-sense-of-chemical-stories.html



Endocrine Disrupting Chemicals

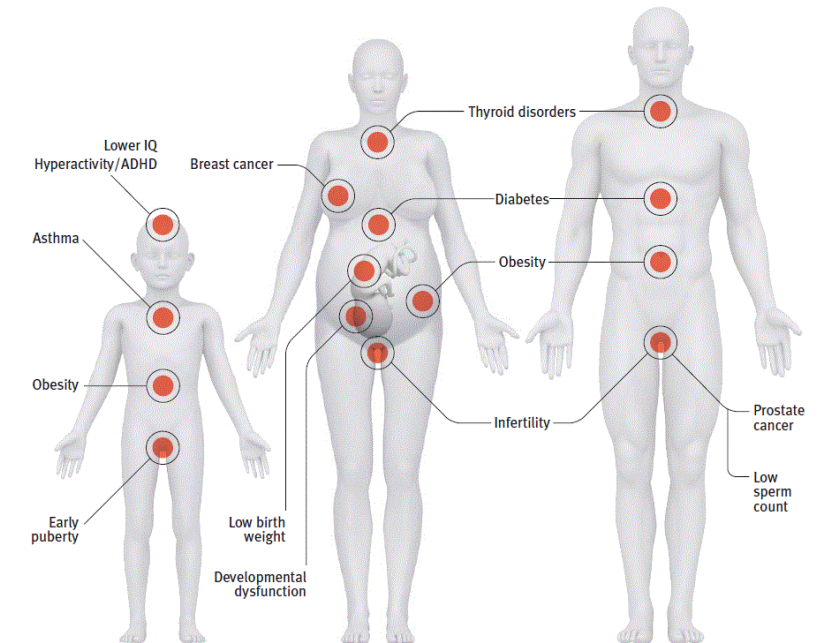


The endocrine system is a complex collection of glands and organs that helps to regulate various bodily functions. This is accomplished through the production and release of hormones and steroids which act as chemical messengers.

Endocrine
Disrupting
Chemicals

Low Doses Matter

Everyday exposures to EDCs contribute to modern health epidemics.



How are people exposed?

| | |
|---|--|
| Children's toys (phthalates) | Fragrances (phthalates) |
| Plastic drinking bottles (BPA, BPS, BPF) | Food (pesticides like chlorpyrifos) |
| Cleaning products (phthalates, triclosan) | Food packaging (BPA, PFAS, phthalates) |
| House dust (flame retardants, pesticides) | Thermal cash register receipts (BPA, BPS) |
| Home furniture/electronics (flame retardants, PFAS) | Drinking water (arsenic, lead, perchlorate) |
| Building materials (flame retardants, phthalates, PFAS) | Personal care products (parabens, phthalates, triclosan) |





Contaminants of Emerging Concern (CEC)





Definition of ECs

We have defined ECs as chemical or nonchemical materials that have a reasonably possible pathway to enter the environment; present a potential unacceptable human health or environmental risk; and either do not have federal regulatory standards based on peer-reviewed science (Type 1 EC), or the regulatory standards are evolving due to new science, detection capabilities, or pathways (Type 2 EC).



Contaminants of Emerging Concern (CEC)

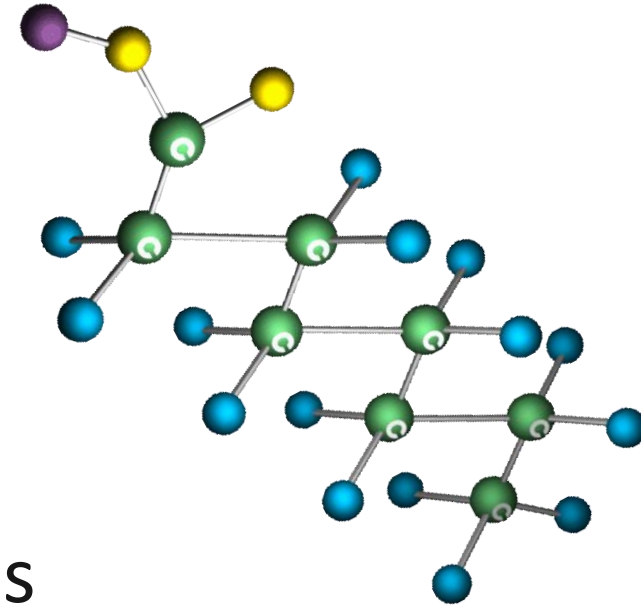
| EC Category | Description and Examples |
|---|--|
|  <p>Industrial Chemicals</p> | Plasticizers, surfactants, and solvents; examples include 1,4-dioxane, bisphenol-A, alkylphenols, and various phthalates |
|  <p>Microbes and Viruses</p> | Biological contaminants; examples include cyanobacteria, microcystins, and <i>Legionella pneumophila</i> |
|  <p>Flame Retardants</p> | Brominated flame retardants and poly- and perfluoroalkyl substances |
|  <p>Metals</p> | Mostly Type 2 ECs such as arsenic, lead, and hexavalent chromium |

| EC Category | Description and Examples |
|---|--|
|  <p>Pharmaceuticals</p> | Prescription and nonprescription over-the-counter drugs, synthetic hormones |
|  <p>Pesticides</p> | Herbicides and insecticides and their metabolic and environmental degradation products; examples include 2,4- dichlorophenoxyacetic acid, atrazine, alpha- and beta-hexachlorocyclohexane, chlorpyrifos, glyphosate, and metolachlor |
|  <p>Nanomaterials</p> | Chemicals or materials that range from approximately 1 to 100 nm in size and can be naturally occurring or engineered; examples include nanometal oxides, carbon nanotubes, and carbon buckyballs |
|  <p>Personal Care Products</p> | Chemicals in soaps, cosmetics, sunscreens, fragrances, lotions, preservatives, microbeads, and microplastics |

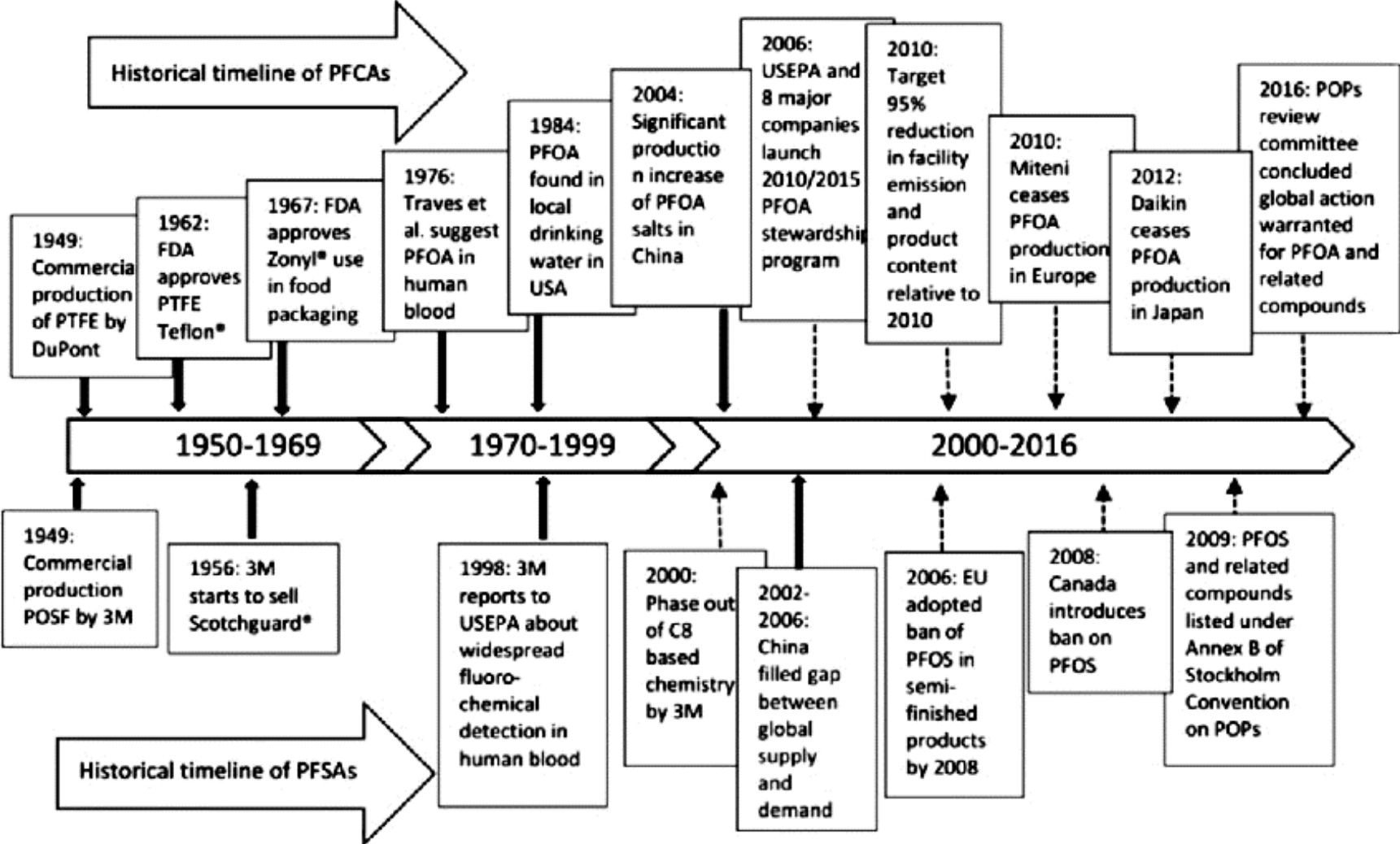
Contaminants of Emerging Concern (CEC)

Per- and Polyfluoroalkyl Substances (PFAS)

- Used in everyday products
- Persistent in the environment
- Ubiquitous in landfill leachates
- A large range of chemicals (<4,700)
- Bioaccumulates in the human body
- Biomagnifies through the food chain
- Some PFAS are readily absorbed by plants
- Exposure may result in adverse health effects



PFAS Timeline





Major Sources of PFAS in Waste

| Waste stream | Industry Application | Selected examples | Waste stream quantity destined for Australian landfill (approx.) ¹ |
|-----------------------------------|------------------------------------|---|---|
| Municipal solid waste | Cosmetics & personal care products | Cosmetics, shampoos | 13.8 MT |
| | Food processing | PTFE liners (trays, ovens), food packaging | |
| | Household products | Non-stick coatings, surface treatments for textiles, upholstery, carpet and leather, floor polishes, cleaning agents, car waxes | |
| | Biocides (herbicides & pesticides) | EtFOSA in ant/termite baits, PFPAs and PFPiAs as anti-foaming agents | |
| Construction & demolition | Building & construction | Waste concrete and brick (contamination from AFFFs) Sealants, PTFE, PVDF coatings, adhesives, surface treatments | 20.4 MT |
| Contaminated wastes & wastewaters | Metal plating | Wetting agent, mist suppressant, surfactants | 1.8 MT |
| | Mining | Surfactants in ore mining | |
| | Firefighting & safety | AFFFs | |

Source: Gates WP, MacLeod AJ, Fehervari A, Bouazza A, Gibbs D, Hackney R, Callahan DL, Watts M. Interactions of Per- and Polyfluoroalkyl Substances (PFAS) with Landfill Liners. Adv Environ Eng Res 2020;1(4):40; doi:10.21926/aer.2004007.



Major Sources of PFAS in Waste

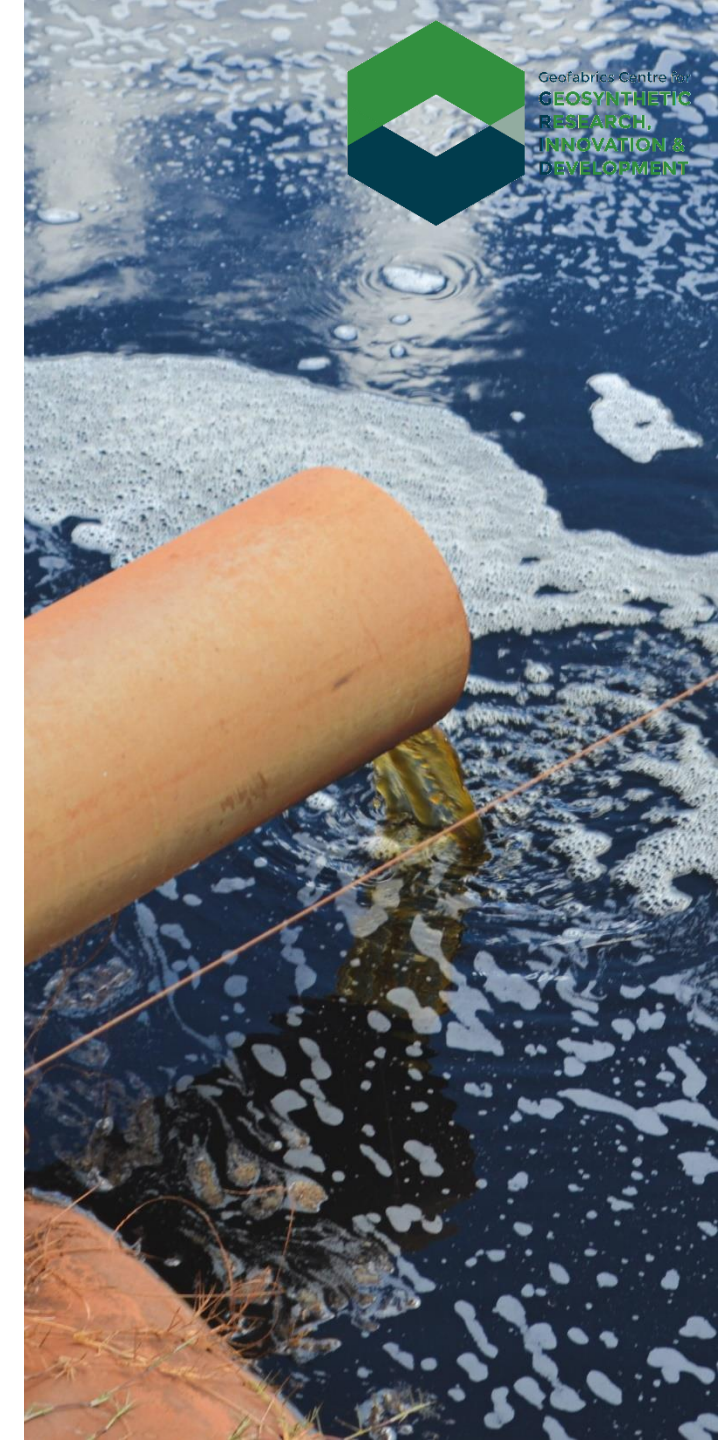
| Waste stream | Industry Application | Selected examples | Waste stream quantity destined for Australian landfill (approx.) ¹ |
|-------------------------|---|---|---|
| Commercial & industrial | Aviation & aerospace | PTFE and PFA tubing, gaskets, cables | 20.4 MT |
| | Automotive | Wiring and cabling, seals, gaskets, lubricants | |
| | Electronics | PVDF and PTFE as insulators | |
| | Energy | FEP, PVDF films covering photovoltaic panels | |
| | Medical products | Biocompatible implants and surgical patches | |
| | Paper & packaging | Oil, grease and water repellent (including food packaging), LDPE bags | |
| | Textiles (upholstery, carpets), leather & apparel | PTFE in consumer products (outdoor equipment and clothing, housewares), oil- and water-repellent coatings, PFOA-based chromium treatment for paper and leather. | |
| | Photo-lithography & semi-conductors | PFOS used in chip manufacture | |
| | Cable & wiring | PTFE, PVDF coatings and jackets | |
| | PFAS production | Processing aids | |

Source: Gates WP, MacLeod AJ, Fehervari A, Bouazza A, Gibbs D, Hackney R, Callahan DL, Watts M. Interactions of Per- and Polyfluoralkyl Substances (PFAS) with Landfill Liners. Adv Environ Eng Res 2020;1(4):40; doi:10.21926/aer.2004007.

PFAS in Landfill Leachate



| PFAS compound detected | Mean Concentration (ng/L) | | |
|------------------------|--|---|--|
| | Operating landfills (> 50% MSW) n = 12 | Operating landfills (> 50% C&D) n = 7 | Closed landfills (> 50% MSW) n = 7 |
| PFHxA | 1300 (1700) | 5000 (8100) | 660 (300) |
| PFHxS | 940 (1000) | 3700 (5100) | 740 (490) |
| PFOA | 510 (410) | 1400 (1200) | 390 (170) |
| PFHpA | 360 (360) | 760 (760) | 220 (110) |
| PFOS | 300 (330) | 1100 (910) | 180 (250) |
| PFNA | 29 (24) | 98 (110) | 13 (6.8) |
| PFDA | 22 (36) | 46 (83) | 11 (14) |
| PFUdA | 3.0 (4.7) | 4.6 (3.4) | 2.2 (1.9) |
| PFDoDa | 1.8 (3.5) | 1.1 (1.6) | 2.7 (3.3) |

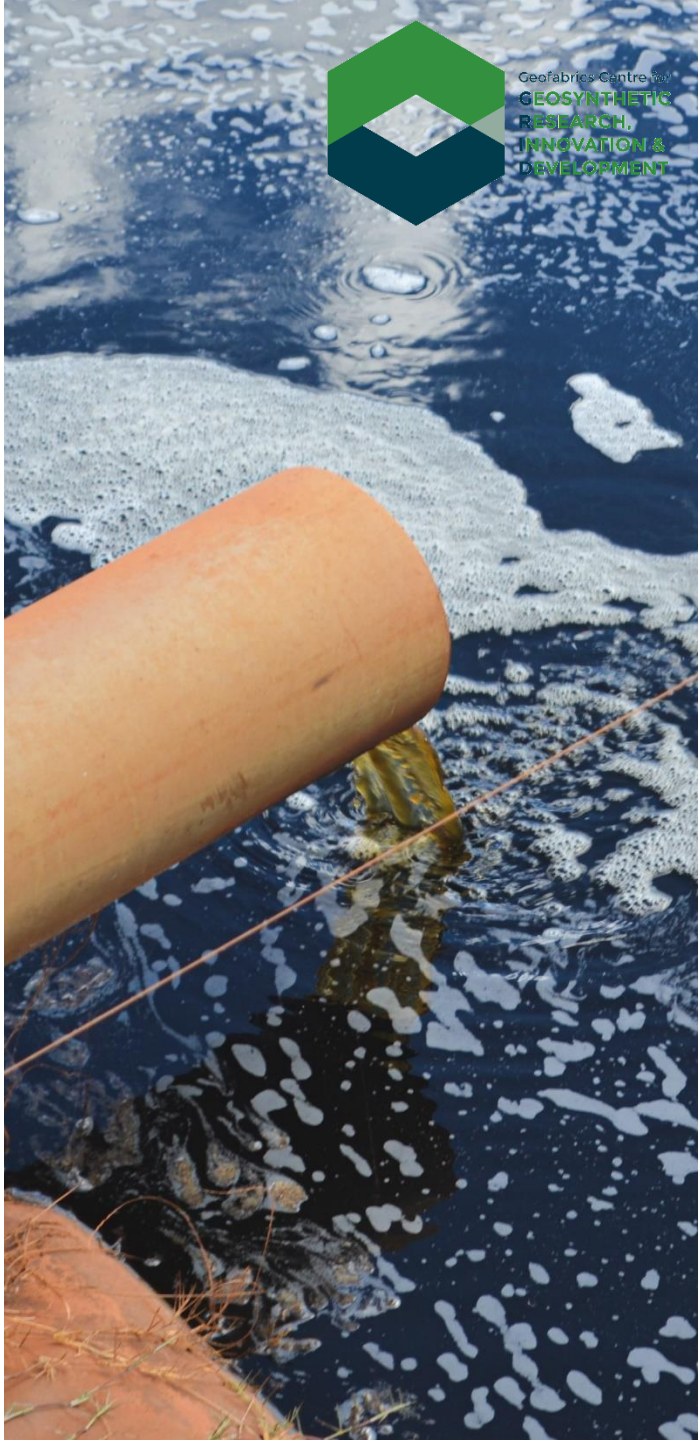
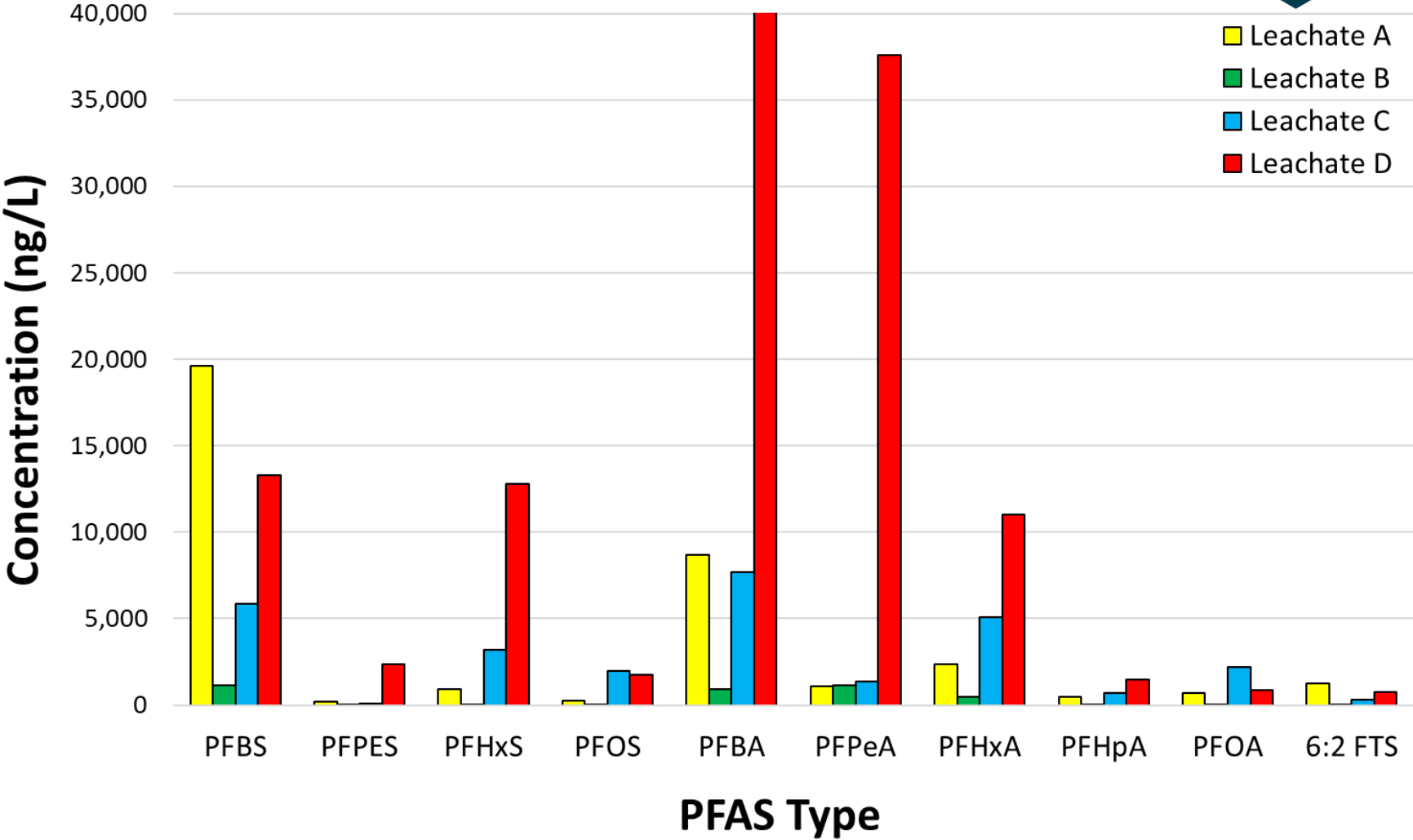


Source: Gates WP, MacLeod AJ, Fehervari A, Bouazza A, Gibbs D, Hackney R, Callahan DL, Watts M. Interactions of Per- and Polyfluoralkyl Substances (PFAS) with Landfill Liners. Adv Environ Eng Res 2020;1(4):40; doi:10.21926/aeer.2004007.

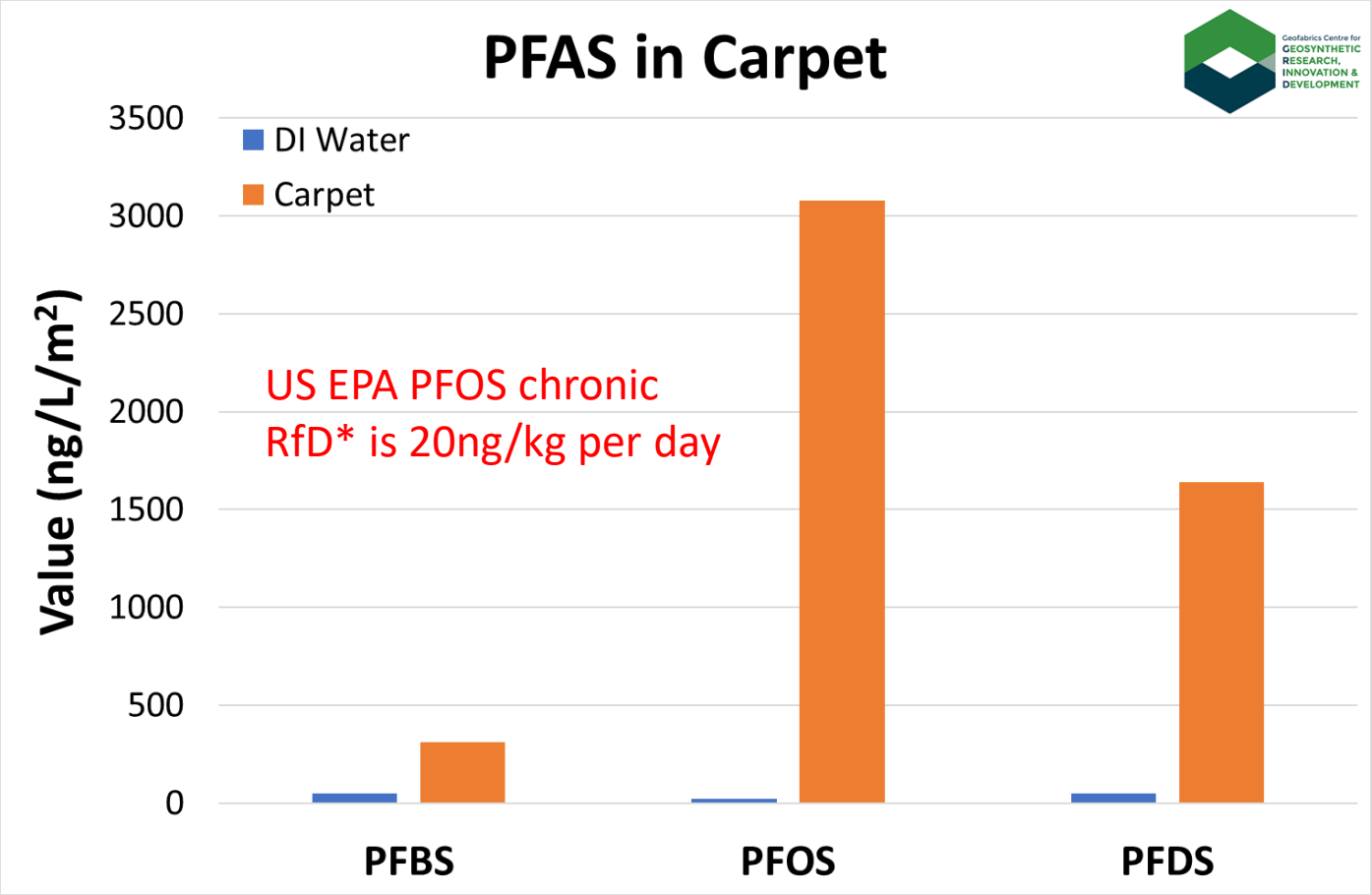
PFAS in Landfill Leachate



PFAS in Australian Landfill Leachate

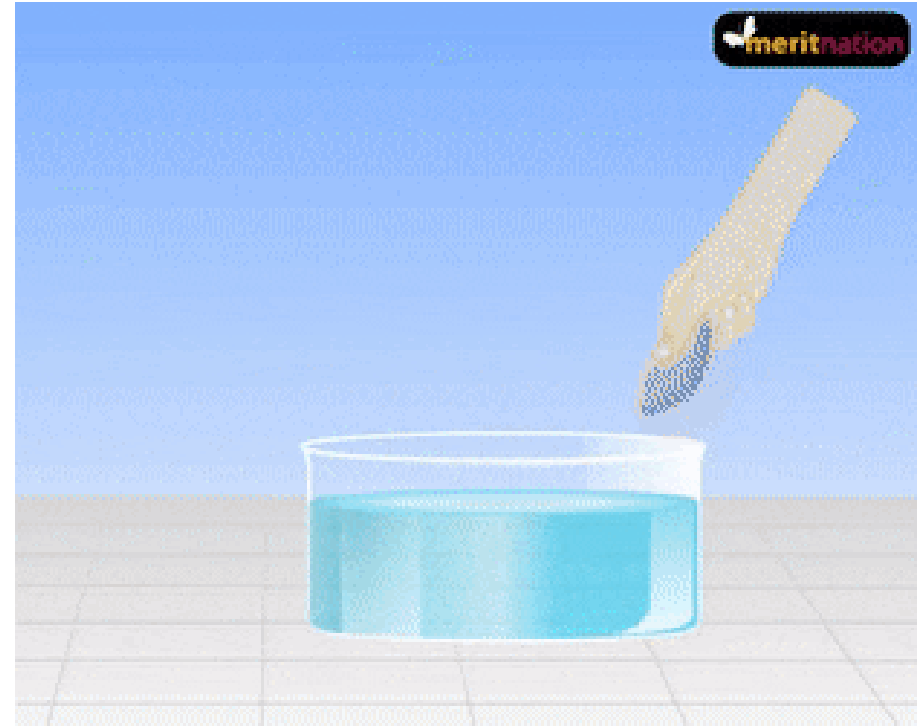
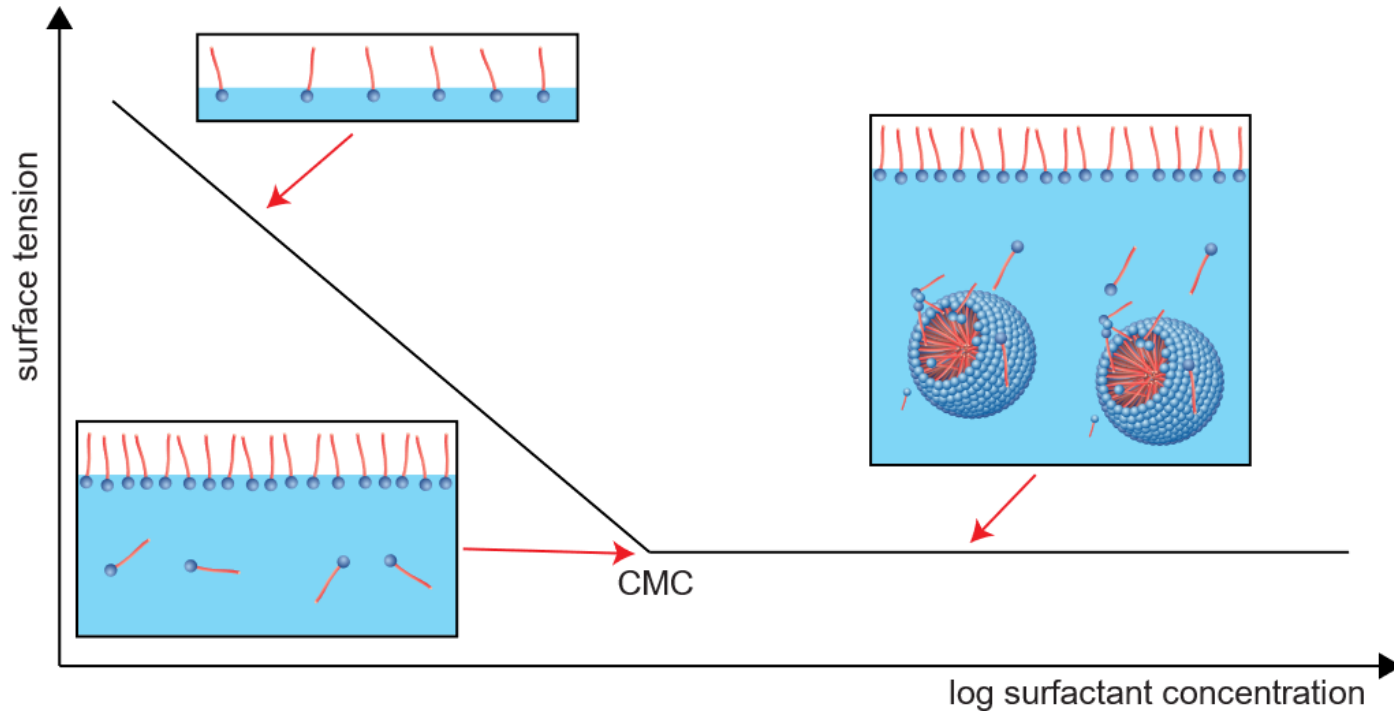


PFAS in Carpet

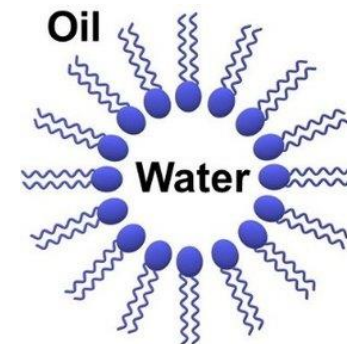


** A chronic reference dose (RfD) is an estimate of the amount of a chemical a person can ingest daily over a lifetime that is unlikely to lead to adverse health effects.*

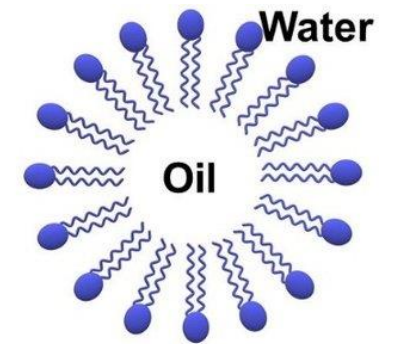
Concentration drives liner performance



When the PFAS reaches its Critical Micelle Concentration (CMC) it forms micelles with either the polar head group facing out in polar liquids such as water, or inverted micelles in non-polar liquids such as oil.



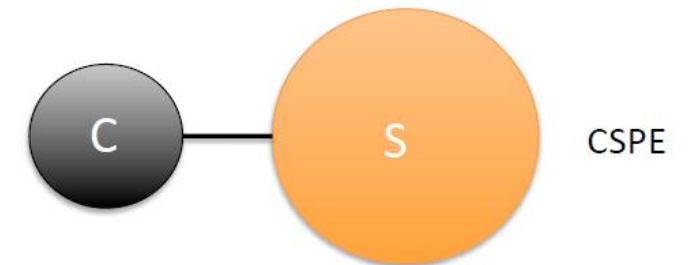
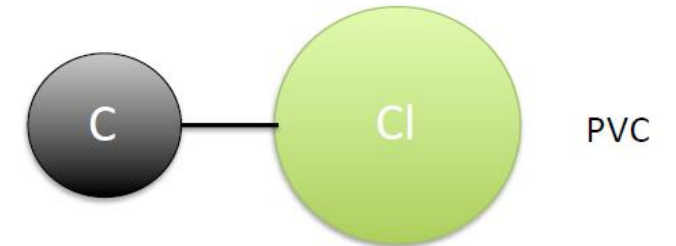
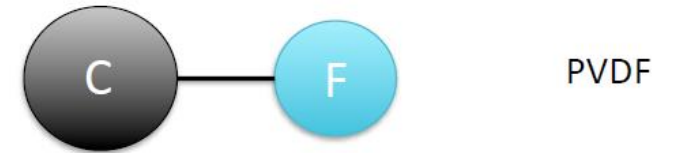
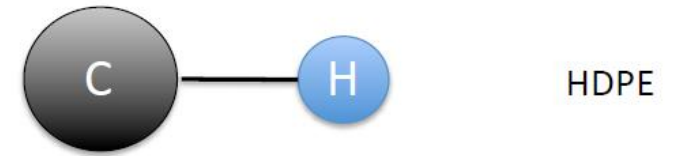
Reverse Micelle (W/O)



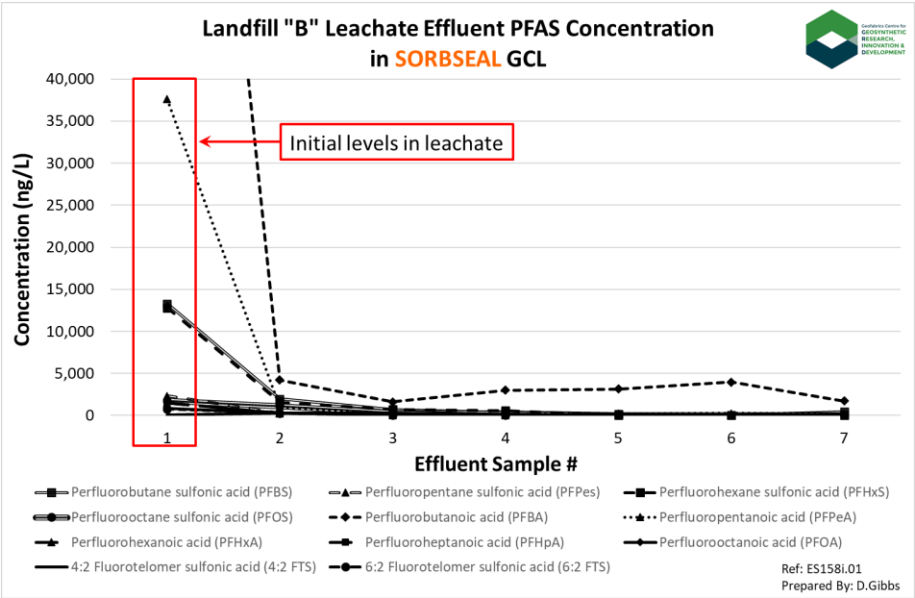
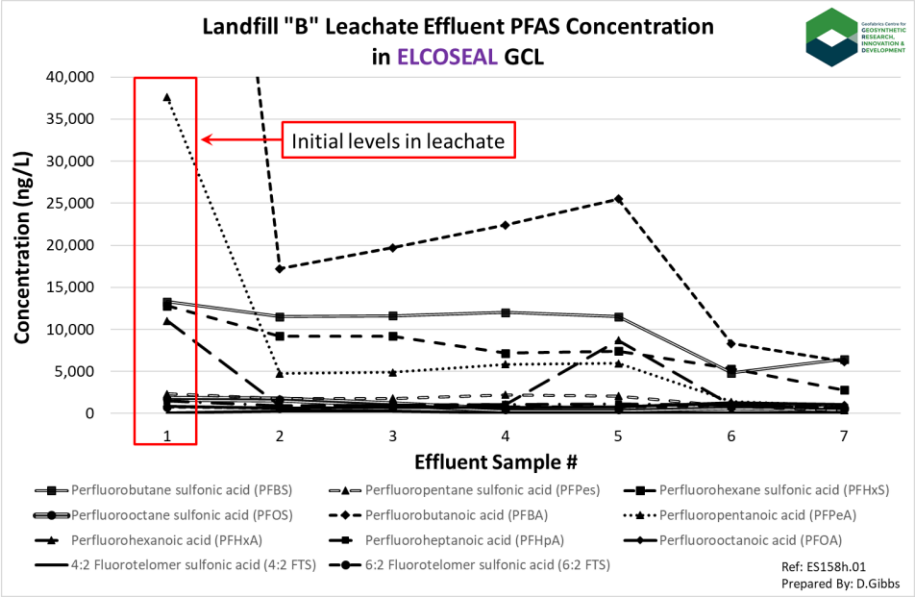
Normal Micelle (O/W)

PFAS migration through Geomembranes

- Thickness of the liner (thicker is better to reduce migration)
- Atomic radius of atoms in liner backbone (larger AR is better to reduce migration)
- Polarity of the polymer liner (high polarity is better to reduce migration)
- Size of PFAS molecules (shorter migrate faster)
- Temperature (diffusion increases with temp.)



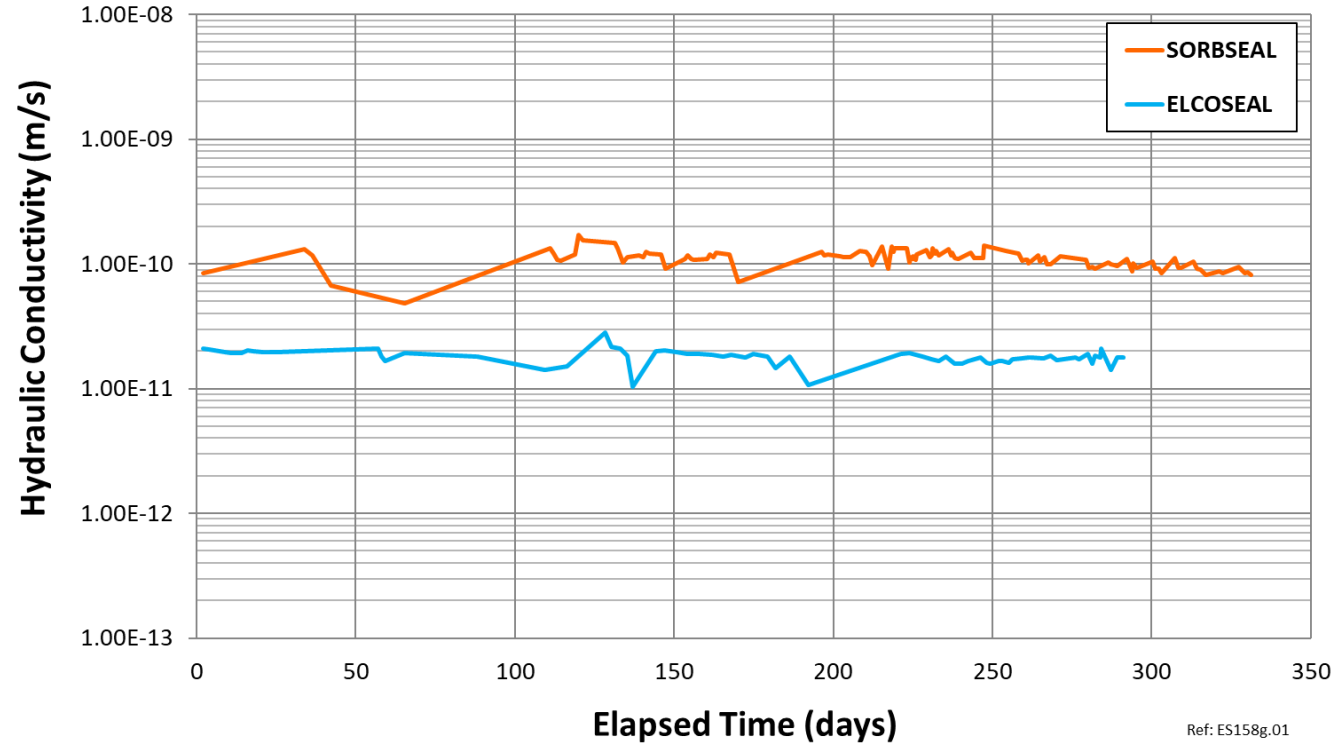
PFAS migration through GCLs



PFAS migration through GCLs

Landfill "B" Leachate Hydraulic Conductivity

ASTM D6766-Evaluation of Hydraulic Properties of Geosynthetic Clay Liners
Permeated with Potentially Incompatible Liquids



Removal Efficiency of Activated Carbon

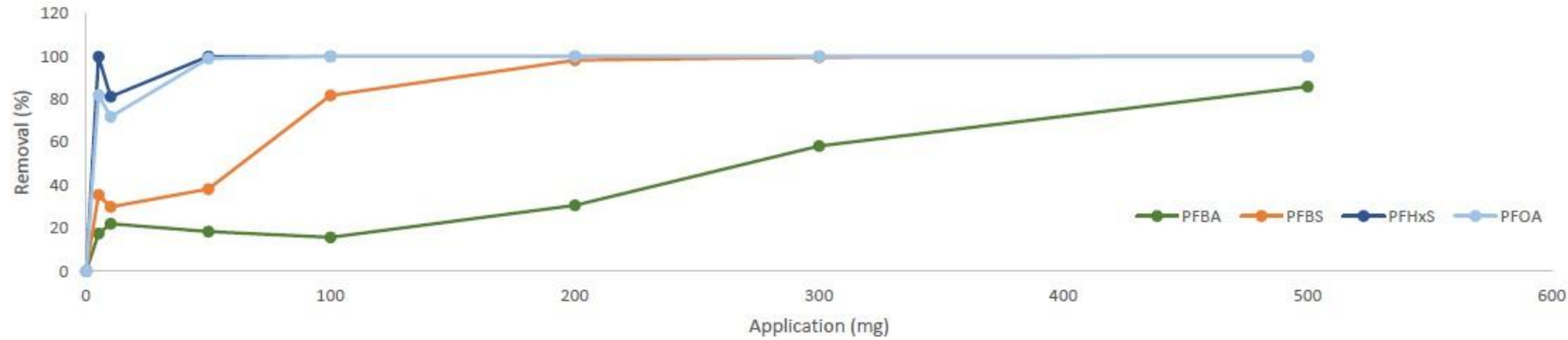
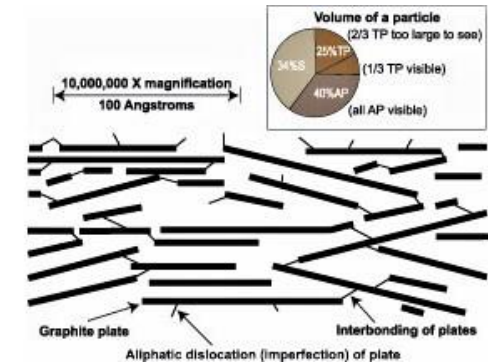
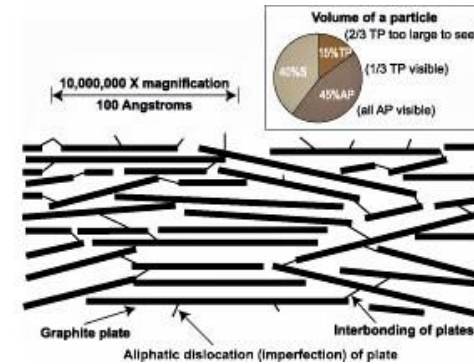
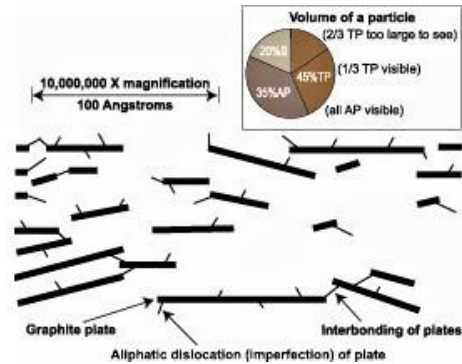


Figure 7 - Percent removal of target PFAS congeners from solution for PS-1300 ver sorbent application rate 0 – 500 mg



Source: Henry Nowicki, Wayne Schuliger, George Nowicki and Barbara Sherman. 2014. "Evaluation of Activated Carbon Performance". <http://wcpnline.com/2014/06/17/evaluation-activated-carbon-performance/>

International Regulation and Initiatives

Geofabrics Centre for
GEOSYNTHETIC
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INNOVATION &
DEVELOPMENT



AGENCY FOR TOXIC SUBSTANCES
AND DISEASE REGISTRY

MINAMATA
CONVENTION
ON MERCURY



BASEL CONVENTION



GEOFABRICS®
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US Regulation



- USEPA Safe Drinking Water Act (SDWA).
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) — “Superfund”
- Toxic Substances Control Act (TSCA). (<https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas>).
- Toxics Release Inventory (TRI) Program. (<https://www.epa.gov/toxics-release-inventory-tri-program/implementing-statutory-addition-certain-and-polyfluoroalkyl>).
- Resource Conservation and Recovery Act (RCRA).

US PFAS Regulations



- EPA's drinking water Lifetime Health Advisory (LHA) limit (70ppt for PFOS and/or PFOA) are not enforceable standards
- Not yet identified as hazardous substances under CERCLA (1980)
- Investigations/risk managements actions driven by other forces
 - ❖ Action due to pressure from the public or regulatory agencies
 - ❖ Litigation
 - ❖ Clean Water Act (TMDL)
 - ❖ State-driven regulatory action

Australian PFAS Regulation



Australian Government
**National Health and
Medical Research Council**



PFAS Per- And
Polyfluoroalkyl
Substances



Australian Government
Department of Health
National Industrial Chemicals
Notification and Assessment Scheme

nicnas.gov.au

Australian Government



Australian Government
Department of Defence

NEPC
National Environment Protection Council



AELERT
AUSTRALASIAN
ENVIRONMENTAL LAW ENFORCEMENT
AND REGULATORS NETWORK

HEPA
National Chemicals Working Group

GEOFABRICS
Smarter Infrastructure

Australian PFAS Regulation

Table 7. Landfill acceptance criteria

| Landfill type | | Interim landfill acceptance criteria ^{60, 61} | | Comments |
|-----------------------------|-------------------------------------|--|-----------|--|
| | | Sum of PFOS + PFHxS | PFOA | |
| Unlined | ASLP leachable concentration (µg/L) | 0.07 µg/L | 0.56 µg/L | Drinking water x 1 (Department of Health 2017) |
| | Total concentration (mg/kg) | 20 mg/kg | 50 mg/kg | Soil - Human health industrial/commercial x 1 Total concentration for PFOA of 50 mg/kg based on the low content limit |
| Clay/single composite lined | ASLP leachable concentration (µg/L) | 0.7 µg/L | 5.6 µg/L | Drinking water x 10 (Department of Health 2017) |
| | Total concentration (mg/kg) | 50 mg/kg | 50 mg/kg | Soil - Human health industrial/commercial x 10 Total concentration for PFOS + PFHxS and PFOA of 50 mg/kg based on the low content limit |
| Double composite lined | ASLP leachable concentration (µg/L) | 7 µg/L | 56 µg/L | Drinking water x 100 (Department of Health 2017) |
| | Total concentration (mg/kg) | 50 mg/kg | 50 mg/kg | Soil - Human health industrial/commercial x100 |



Table 1. Human health guideline values developed by health regulators

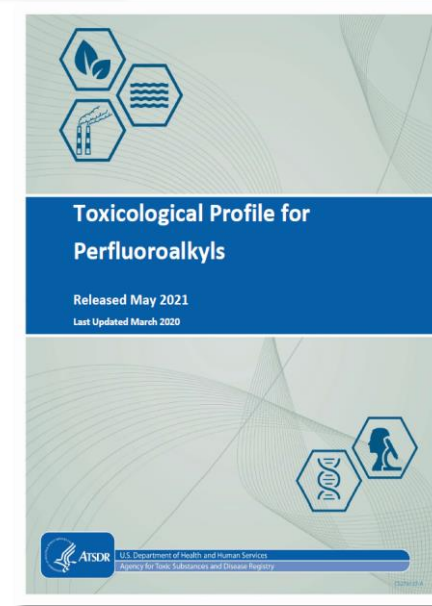
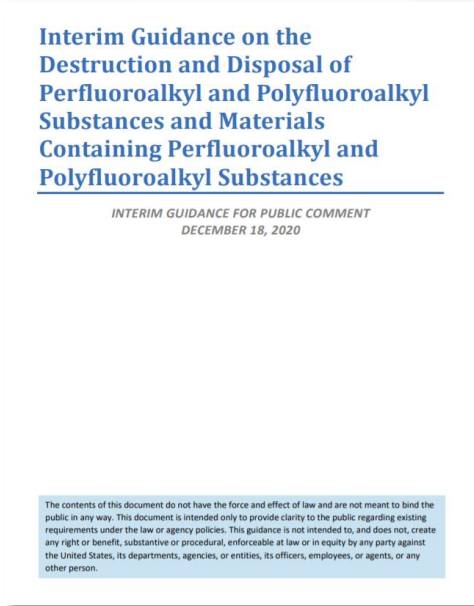
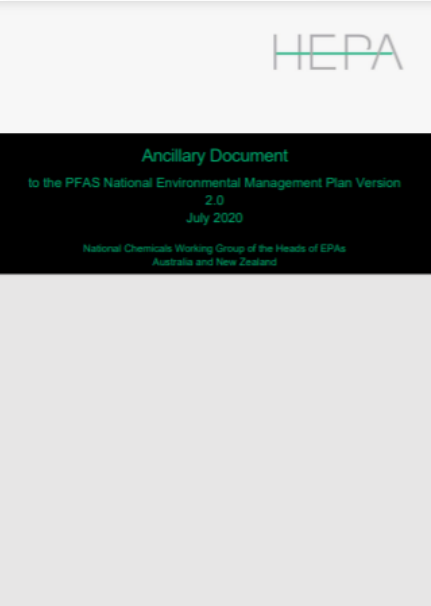
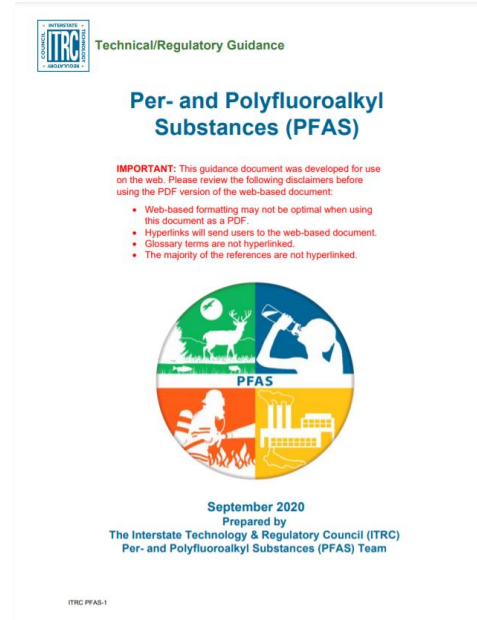
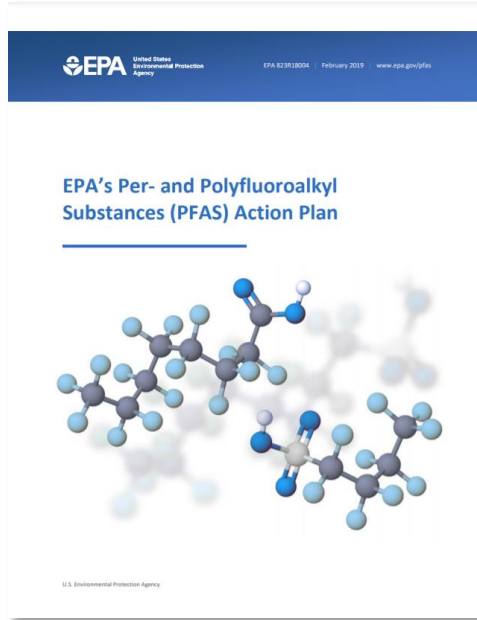
| Sum of PFOS and PFHxS | PFOA | Description | Comments and source |
|-------------------------------|-------------------------------|---|---|
| 0.02 µg/kg _{bw} /day | 0.16 µg/kg _{bw} /day | Tolerable daily intake (TDI) | FSANZ 2017 |
| 0.07 µg/L | 0.56 µg/L | Drinking water quality guideline value | Australian Government Department of Health 2019 |
| 2 µg/L | 10 µg/L | Recreational water quality guideline value* | NHMRC 2019 |

Notes: bw = body weight, µg = micrograms.

Where the guideline values refer to the sum of PFOS and PFHxS, this includes PFOS only, PFHxS only, and the sum of the two.

*NHMRC (2019) notes that people's use of recreational water is not the same, given Australia's climate and geography. Some recreational water resources may be used less frequently than the assumed guidelines (150 days/year), and (in rare cases) some may be used more frequently. In such cases more locally-appropriate event frequency based recreational guidelines can be considered in consultation with the state and regulatory health regulator.

Further Reading



Final thoughts

- Our understanding of CEC's in landfill will continue to grow and with it, a likelihood of increasing regulation around containment.
- Given the large variety of PFAS chemicals, we may see guidance move towards a single maximum total value assigned to a nominated group of PFAS.
- If this occurs, and as we learn more about the performance of different geosynthetic lining materials, lining design may change depending on site-specific contaminant concentrations, and may include one or more higher performing materials than those used currently and/or more double composite liners.
- Monash University's "Fate and migration of PFAS through containment liner systems" currently underway to understand fate and transport and to assist designers and regulators with the next generation of lining system design.

Thank you
for your attention

