Integrating Activities for Advanced Communities

D8.1 - Catalogue listing local and transboundary emerging pollutants

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Publishable Executive Summary

Over the past three decades, and based on increasing research and monitoring effort, bodies such as the Arctic Monitoring and Assessment Programme (AMAP) have documented the presence and effects of (chemical) environmental contaminants in the Arctic. This information has been used to inform policy- and decision-making at the national and international level aimed at reducing and where possible eliminating the sources of such contaminants. Persistent, bio-accumulative and toxic organic chemicals that are transported over long distances are addressed under the Stockholm Convention on Persistent Organic Pollutants (POPs), which entered into force in 2004 (http://chm.pops.int/TheConvention/Overview/tabid/3351/Default.aspx). Since most synthetic chemicals have historically not been used in the Arctic (AMAP 1998; 2004; 2010), their presence there is recognized as evidence of long-range transport in the criteria applied for listing chemicals under the Stockholm Convention. This has contributed to global regulation under the Stockholm Convention, initially of 12 main chemicals including polychlorinated biphenyls (PCBs) and DDT, and subsequently an additional 18 POPs (http://chm.pops.int/TheConvention/ThePOPs/AllPOPs/tabid/2509/Default.aspx).

In 2017, AMAP released a report addressing Chemicals of Emerging Arctic Concern (CEACs) (AMAP 2017a; 2017b), documenting the presence in Arctic environmental media of a number of 'new' chemicals/groups of chemicals. Some of these CEACs have been introduced to replace banned substances, many lack information concerning their properties and possible toxic effects, and many are challenging to analyze without sophisticated instrumentation. Some CEACs will reach the Arctic due to long-range transport, others are associated with consumer products that may be used in Arctic communities and therefore enter waste streams in the Arctic. CEACs may also have sources associated with industrial development in the Arctic, or even research activities themselves.

The Arctic is undergoing unprecedented change, primarily associated with climate warming from emissions of greenhouse gasses and short-lived climate forcers (AMAP 2021a; 2021b). Surface air temperatures in the Arctic have increased at three times the global average over the past 50 years, resulting in cryosphere change (loss of sea- and land ice, permafrost thaw, etc.) and changes to Arctic ecosystems. Related to these environmental changes are improved access, in particular marine access, to areas that are potentially rich in natural resources. Human development of the Arctic has increased, and this trend is expected to continue. With increasing human presence in the Arctic comes increasing use of chemicals within the region. Climate change is also altering pathways and fate of environmental contaminants, potentially remobilizing contaminants that have accumulated in Arctic snow, ice, water, and sediments as well as altering their uptake and transfer through Arctic ecosystems and food webs (AMAP, 2021c).

The INTERACT station network, and its connectivity to local communities, provides an opportunity for enhancing research to better understand the occurrence and sources of POPs and CEACs, at the same time increasing engagement of INTERACT stations in routine monitoring programmes. Based on AMAP and other work to prioritise CEACs for further investigation, this deliverable identifies a number of chemicals that could be considered for a coordinated research/monitoring effort involving the Arctic research station network, their scientific research community, and associated local communities.

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1. Persistent Organic Pollutants and Chemicals of Emerging Arctic Concern – What are they?

Persistent organic pollutants (POPs) are organic chemicals that are environmentally persistent, bioaccumulate and are toxic; many biomagnify in food chains. POPs include industrial chemicals and by-products, well known examples being polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB); some, such as dioxins and furans are associated with combustion processes. Another major category of POPs are organochlorine pesticides, such as DDT and hexachlorocyclohexane (HCH, lindane), used in agriculture for pest and disease control. Conventionally, the term POPs is now used to refer to persistent organic chemicals that are regulated under the Stockholm Convention. In this context POPs constitute only a relatively small number of the chemicals that are, or have been widely used in society.

Many chemicals currently registered for use have characteristics similar to POPs, including a potential to reach the Arctic; however, most are not subject to international (global) regulation. Improved analytical techniques, research and screening programmes continue to reveal the presence of chemicals that have previously gone unnoticed, or were not expected to be present in the Arctic, as well as newly introduced chemicals. Although only recently detected in the Arctic, some of these so-called 'chemicals of emerging Arctic concern' (CEACs) have been in use and present in the environment for years, even decades (AMAP, 2017). Others are being introduced as replacements for banned POPs. Chemicals found in the Arctic may originate from local sources within the region or come from distant sources, or both. The detection of a new substance in the Arctic that has no local sources is particularly important, as it provides evidence of the chemical's potential to disperse globally.

Chemical groups considered CEACs by AMAP (2017) include[1]: current-use brominated flame retardants (BFRs); chlorinated flame retardants (CFRs); chlorinated paraffins (CPs); current-use pesticides (CUPs); unregulated per- and polyfluroalkyl substances (PFASs); organophosphate-based flame retardants (PFRs); pharmaceuticals and personal care products (PPCPs); organotins; phthalates; plastics and microplastics; polycyclic aromatic hydrocarbons (PAHs); siloxanes; and halogenated natural products (HNPs, some of which may have anthropogenic sources in addition to natural biogenic sources).

Some chemicals considered CEACs only a few years ago, such as hexachlorobutadiene; pentachlorophenol (PCP); polychlorinated naphthalenes (PCNs) and some PFASs (e.g. PFOS) are now listed under the Stockholm Convention (i.e., are now considered POPs).

[1] The Stockholm Convention's POPs review committee (POPRC) is currently evaluating or considering some CEACs for possible listing. POPRC has also established a process to consider chemicals associated with plastics. PAHs are addressed under the POPs Protocol to the UN ECE Convention on Long-range transboundary Air Pollution but not the Stockholm Convention.

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2. Screening Approaches and Identification of Candidates for Initial Attention

Tens of thousands of chemicals are presently on the market and new substances continue to enter commerce each year (AMAP, 2017). A relatively small number of hazardous substances, mainly POPs, are routinely **monitored** in relevant abiotic and biotic media under national and internationally-coordinated programmes such as AMAP, OSPAR and EMEP (www.amap.no; www.ospar.org; www.helcom.fi). These tend to be substances that have established protocols for monitoring, including reliable methods for analysis in environmental samples, with involved laboratories operating appropriate QA/QC systems in order to produce comparable quantitative results. For the large number of potential CEACs without such established analytical capability, investigations are conducted more in a research setting using 'screening' approaches (Figure 1). These include **targeted screening** where laboratories with the required capability analyse samples for specific CEACs, and **non-targeted screening** where samples are analysed and the occurrence of 'unidentified peaks' documented for comparison with databases with information from other samples. A sub-category of non-target screening is **suspect screening,** trying to identify pre-selected 'suspect' chemicals in a sample (Schlabach, 2013; González-Gaya, et al., 2021; Zhang et al, 2020). A third approach – ***in silico* screening** – makes use of chemical properties to predict their possible characteristics in relation to long-range transport, persistence, bioaccumulation and toxicity (Muir et al., 2019). This, together with similarities to POPs and known CEACs, provides a way to identify chemicals that may be a priority for screening in environmental samples.

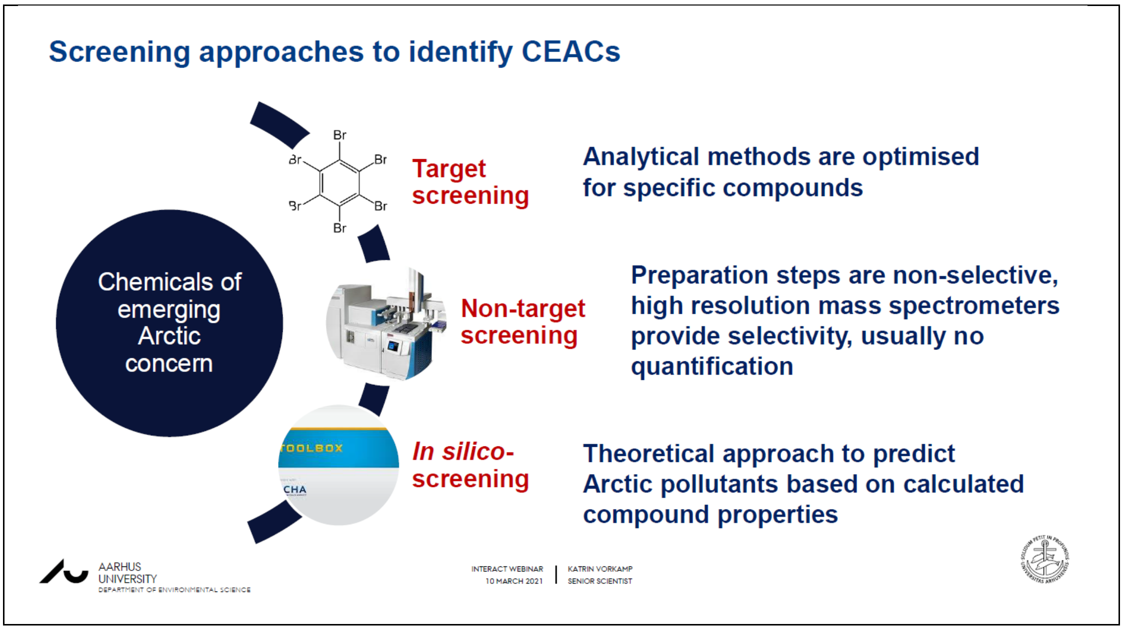

Figure 1: Screening for CEACs. Source: K. Vorkamp (Aarhus University, Denmark)

3. Challenges for Stations, Researchers and Communities wishing to Investigate CEACs, and how these could be addressed

Monitoring and screening studies targeting CEACs and a number of the more recently listed POPs face a number of challenges; not least among these are:

- Availability of protocols for collection, storage and transport of samples that take account of (significant) potential for contamination;
- Availability of appropriate detection and quantification methods, and capability to perform routine analysis with the required level of comparability and quality control/assurance (QA/QC)

A particular problem for a number of CEACs concerns their presence in consumer products ranging from clothing to packaging, and from electrical components to personal care products and pharmaceuticals. These products are ubiquitous, used by people living in the Arctic, as well as in infrastructure, including at research stations. Environmental contamination occurs when these products are used and disposed of, in particular through (often untreated) waste water and uncontrolled burning of waste, which occurs in some Arctic communities.

Potential for contamination during sample collection and handling is therefore considerable. This becomes apparent when measurements are made of indoor and outdoor air at the same location, where indoor air levels of substances such as phthalates, CPs and PFRs can be a factor of 100 times higher than levels in (ambient) outdoor air. Studies have identified sources in a range of laboratory equipment (in particular plastic components) and construction materials (paints, sealing compounds, etc.), but also from personnel involved in sample handling (from use of personal care products).

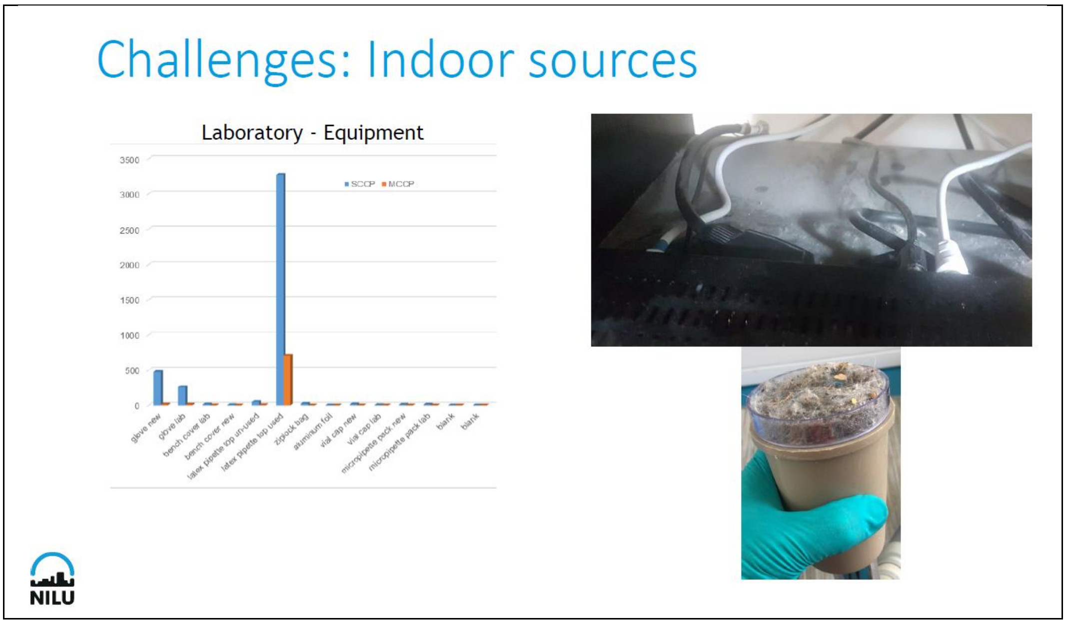

Figure 2: Challenges in analysing CEACs. Source: Pernilla Bohlin Nizzetto (NILU, Norway)

Analytical work therefore requires extreme care to avoid contamination during field sampling, storage and transport, as well as practises to routinely include blanks in field and laboratory work.

A number of these challenges and requirements were presented during the INTERACT webinar arranged as part of WP8 (recording available on https://youtu.be/ps1bwioW72M). Together with results of a survey of current facilities, practises and involvement of INTERACT stations in relevant chemical monitoring and screening activities, these issues will be followed-up in further planned WP8 deliverables.

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4. Listing of Local and Transboundary Emerging Pollutants - Preliminary Priorities for Contaminants that could be addressed under work connected to INTERACT Stations

Objectives of WP8 include increasing engagement of INTERACT stations in research concerning environmental contaminants and through this, if possible, extend capacity for related monitoring and screening activities. As a first stage, a number of CEACs as well as selected POPs (listed under the Stockholm Convention since 2009) have been identified for possible consideration in further work under INTERACT WP8 (Table 1). This table is based primarily on information compiled in AMAP assessments of CEACs (AMAP 2017a, Tables 5.1 and 5.2; AMAP 2021c, Tables 1.1 and Table 2.2.2 - reproduced in Appendix). CEACs with long-range air transport potential (LRATP) are discussed by Röhler et al., 2020 (Table 4 reproduced in Appendix).

	POP / CEAC group	Monitoring/ screening media	Potential local contamination sources	Sources (LRT vs possible local)
Selected POPs (added to Stockholm Convention since 2009)				
Polybrominated diphenyl ethers (PBDEs) (BDE-209)	BFRs (additive)	Air; soil/vegetation; biota	Consumer uses / products (globally regulated in 2017); high impact plastics in electrical and electronic equipment; textiles; waste dumps	LRT + Local
Hexabromocyclododecane (HBCDD)	BFRs (additive)	Air; biota	Consumer uses / products (globally regulated in 2013) ; construction insulation materials, expanded and extruded polystyrene foams (EPS/XPS); textiles; plastics used in electronics	LRT + Local
Perfluorooctane sulfonic acid (PFOS)	PFASs	Air; surface water/groundwater; (biota?)	Consumer products; airports (fire fighting foams); globally phased out in 2009	LRT + Local
Perfluorooctanoic acid (PFOA)	PFASs	Air; surface water/groundwater; (biota?)	Consumer uses / products; globally phased out in 2019	LRT + Local
Short-chain chlorinated paraffins (SCCPs)	CPs	Air; biota	Consumer uses (now regulated)/ products; laboratory equipment; personal care products	LRT + Local

Pentachlorophenol (PCP)	PCP	Often determined as pentachloroanisole (PCA) in air; biota	Wood-preservative; paints; legacy POPs (degradation);	LRT + Local
Endosulfan	CUP	Air; water; biota		
CEACs				
Other perfluorocarboxylates (PFCAs)	PFASs	Air; soil; surface water/groundwater; biota for long-chain PFCAs	Consumer uses / products; airports (fire fighting foams)	LRT + Local
Perfluorohexane sulfonic acid (PFHxS)	PFASs	Surface water/groundwater; biota	Consumer uses / products	LRT + Local
Fluorotelomer alcohols (FTOHs)	PFASs	Air	Consumer uses / products	LRT + Local
Organophosphate-based flame retardants (PFRs) / Organophosphate esters (OPEs)	PFRs	Air; soil; surface water/groundwater	Consumer uses / products; airports (fire fighting foams)	LRT + Local
Dacthal	CUP	Air; water		LRT
Chlorpyrifos	CUP	Air; water		LRT
Trifluralin	CUP	Air		LRT
Pentachloronitrobenzene (PCNB)	CUP	Air; water		
(selected) Polycyclic aromatic hydrocarbons (PAHs)	PAHs	Air (incl. passive samplers); sediments; fish (freshwater); invertebrates	Open burning (wildfires, open waste burning)	LRT + Local
Pentachloroanisole (PCA)	PCP/PCA	Air; biota	Wood-preservative; paints; PCP transformation product	LRT + Local
Pharmaceuticals and personal care products (see Appendix Tables)	PCPPs	Wastewater	Consumer uses / products	Local (wastewater)
Medium-chain chlorinated paraffins (MCCPs)	CPs	Air?; soil; sediments; biota	Consumer uses / products; laboratory equipment; secondary plasticizers in polyvinyl chloride	LRT + Local
Long-chain chlorinated paraffins (LCCPs)	CPs	Air?; soil; sediments; biota	Consumer uses / products; paints, cutting fluids, textiles, plastics	LRT + Local
Microplastics (and associated chemicals)	Plastics;	Air; water; sediment; biota (ref. AMAP monitoring guidelines; AMAP 2021d)	Consumer uses / products; clothing / fleece jacket micro-fibres; packaging	LRT + Local

Chemicals identified by AMAP for targeted screening on the basis of in silico screening				
Bis (4-chlorophenyl) sulfone (BCPS)	OC	Biota	Consumer uses / plastics products	LRT + Local
3,5-Bis(trifluoromethyl) bromobenzene (BTFMBB)	BFR	Air	Chemical intermediate; possible residual in consumer products	LRT + Local
Tris(perfluorobutyl)amine (PFTBA)	PFAS	Air, biota	electrical and electronic equipment	LRT + Local
Undecafluoro(nonafluorobutyl)cyclohexane (PFBCH)	PFAS	Air	Possible personal care product residual/ consumer uses	LRT + Local
1,2,3,4-Tetrachlorohexafluorobutane (TCHFB)	PFAS	Air	Chemical intermediate; possible volatile residual in consumer products	LRT + Local
1,1,1,2,2,3,4,5,5,6,6,6-Dodecafluoro-3,4--bis(trifluoromethyl)hexane (PFDMH)	PFAS	Air	Chemical intermediate; possible volatile residual in consumer products	LRT + Local
Pyridine, 3,5-dichloro-2,4,6-trifluoro- (DCTFP)	OC	Air	Chemical intermediate; possible residual in pharmaceuticals	Local – waste water
Cyclotrisiloxane, 2,4,6-trimethyl-2,4,6-tris(3,3,3-trifluoropropyl)- (TFTMCS)	Siloxane	Air, water	Plastics and rubber additive; possible personal care products	LRT + Local
Cyclotetrasiloxane, 2,4,6,8-tetraethenyl-2,4,6,8-tetramethyl- (TM-TVCS)	Siloxane	Air, water	Insulating materials; food packaging	LRT + Local
2,2,3,5,6-Pentafluoro-5-(pentafluoroethoxy)-3,6-bis(trifluoromethyl)-1,4-dioxane (PFEPFD)	PFAS	Air	Chemical intermediate; possible volatile residual in consumer products	LRT + Local
Heptamethylphenylcyclotetrasiloxane (HMPCTS)	Siloxane	Air, water	Plastics and rubber additive; possible personal care products	LRT + Local
1H-Isoindole-1,3(2H)-dione, 2,2'-(1,2-ethanediyl)bis[4,5,6,7-tetrabromo- (BTBPE)	BFR	Water, biota	Replacement for phased out flame retardants	Local – waste wate

Note – abbreviations and use information is from PubChem and Wikipedia; Other substances that could be considered: dechlorane-plus and methoxychlor (nominated for listing under the Stockholm Convention); polychlorinated naphthalene (PCN), hexabromocyclododecane (HBCD), chlorinated flame retardants.

5. Next Steps

The information contained in this deliverable will be evaluated against information on current activities and capacity at INTERACT stations for research addressing environmental contaminants obtained through a survey. On the basis of this evaluation, practicalities, protocols and proposals for possible implementation of new contaminants monitoring/screening activities will be discussed with INTERACT station managers. This work will also be coordinated with relevant activities under AMAP and the *Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances* (NORMAN network, https://www.norman-network.net/).

6. References

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7. Appendix: Information sources - Extracts

from AMAP assessment reports (Tables 5.1, 5.2 and 2.51: AMAP, 2017a; Tables 1.1 and 2.2.2: AMAP 2021c) and Röhler et al., 2020 (Table 4)

Table 5.1 Status of CECs with respect to requirements for their inclusion in routine monitoring programs in the Arctic.

	Analytical methods and quality assurance measures in place or feasible	Are concentrations detectable and quantifiable? (optimal media for study)
PFASs	Limitations on methods for short-chain (C_4–C_6) and 'new' PFASs such as PFECHS and 6:2-Cl-PFAES	Yes. Large datasets available for C_8-C_{14}-PFCAs in biota and for volatile PFASs in air
BDE-209	Intercomparison studies/proficiency testing schemes available	Yes (abiotic media)
HBCDD	Intercomparison studies/proficiency testing schemes available. Lack of certified values in reference materials	Yes (air, snow, biota)
'novel' BFRs	Diverse group of compounds. Lack of certified values in reference materials and lack of intercomparison studies	Yes (air, snow, biota), but analytical detection limits will be challenging for some compounds
CFRs	Lack of certified values in reference materials, lack of intercomparison studies	Yes (air, biota), but analytical detection limits will be challenging
PFRs	Limited number of mass labelled standards. Lack of certified values in reference materials; few intercomparison studies	Yes (water, air and abiotic archives - ice cores, sediment may be best media for temporal trends). Very limited data for biota
Phthalates	Limited number of mass labelled standards. Lack of certified values in reference materials. Not addressed in current intercomparison studies	Yes, but sporadic detection (very limited data for biota)
SCCPs	Methods available but many challenges due to complex mixture of chlorinated n-alkanes in environmental samples, with the consequence of limited comparability. Intercomparison studies available. Lack of certified reference materials	Yes (air, biota)
Siloxanes	Lack of certified reference materials; not addressed in any current intercomparison studies	Yes (air, biota). Biota sampling near communities. Background levels poorly defined
PPCPs	Diverse group of compounds. Validated methods available for ~150 PPCPs using LC-MS/MS. Mainly wastewater focused. Lack of reference materials; not addressed in any current laboratory performance studies	Yes (local: community wastewater and harbors). Very limited data for Arctic biota
PCNs	Validated methods available. Lack of certified values in reference materials. Not addressed in current inter-laboratory studies	Yes (biota), but concentrations are low compared with legacy POPs
HCBD	Validated methods available. Lack of certified values in reference materials. Intercomparison studies/proficiency testing schemes available	Yes (biota), but concentrations are low compared with legacy POPs
CUPs	Validated methods available for multi-pesticide analysis	Yes (air, snow, biota). Very limited number studied in Arctic compared to >1000 in commerce
PCP/PCA	Validated methods available. Lack of certified values in reference materials. Not addressed in current inter-laboratory studies	Yes for PCA (air, biota), but concentrations are low compared with legacy POPs. Very limited data for PCP (air, biota)
Organotins	Validated methods available for tributyl tin. Intercomparison studies/proficiency testing schemes available. Less established for other organotins	Yes (biota). Large dataset for TBT in marine gastropods. Limited Arctic data for other butyl and phenyl tins
PAHs	Validated methods available for unsubstituted PAHs but more limited validation for alkylated PAHs. Certified reference materials and intercomparison studies/proficiency testing schemes available	Yes (air, sediment, low trophic level biota). Overlap with oil-gas industry monitoring
'New' unintentionally generated PCBs	Validated methods available, but usually not addressed in intercomparison studies	Yes (air), unknown for biota because of limited data due to focus on bioaccumulative congeners found in commercial PCBs
Microplastics	Guidelines needed, taking into consideration guidelines recently published by other organizations (e.g. OSPAR, 2010; EC JRC, 2013; ICES, 2015)	Yes (water, fish, seabirds) but low occurrence relative to non-Arctic regions

Table 4.2 Chemicals in commerce (>1 t/y Europe or 4.5 t/y USA) identified with P, B and LRTP characteristics that have not been determined in Arctic environmental media as of January 2016.

Based on listing in the European (REACH registered as of 2015) and US (TSCA) chemical inventory update (IUR). Cells with 'PR' indicate the chemical was pre-registered under REACH (>1 t/y) in 2008 but may not be in commercial use in Europe or North America as of 2015. Quantity in use in metric tonnes per year (range in t/y) based on values reported in the REACH registered chemical list, REACH pre-registration (>1 t/y), and TSCA IUR (>4.5 t/y in 2002 and 2006).

	CAS number	REACH, t/y	IUR 2006, t/y	IUR2002, t/y	REACH Pre-reg 2008	Reference
Bis (4-chlorophenyl) sulfone	80079	10 000–100 000	4500–23 000	4500–23 000	PR	Howard and Muir (2010)
1,2,3,4,5-Pentabromo-6-chlorocyclohexane	87843	>1	<4.5	4.5–227	PR	Muir and Howard (2006)
Pyrene, 1,3,6,8-tetrabromo-	128632	>1	4.5–227	227–454	PR	Scheringer et al. (2012)
3,5-Bis(trifluoromethyl) bromobenzene	328701	>1			PR	Öberg and Iqbal (2012)
Perfluorotripropylamine	338830	100–1000			PR	Scheringer et al. (2012)
Perfluoroperhydrophenanthrene	306912	>1	<4.5	<4.5	PR	Howard and Muir (2010); Scheringer et al. (2012)
Tris(perfluorobutyl)amine	311897	>1	<10	<10	PR	Scheringer et al. (2012)
Bromopentafluorobenzene	344047	>1	<10	<10	PR	Howard and Muir (2010)
Undecafluoro(nonafluorobutyl) cyclohexane	374607	>1			PR	Rorije et al. (2011)
1,2,3,4-Tetrachlorohexafluorobutane	375451	>1			PR	Scheringer et al. (2012)
1,1,1,2,2,3,4,5,5,6,6,6-Dodecafluoro-3,4--bis(trifluoromethyl)hexane	1735484	>1			PR	Rorije et al. (2011)
Pyridine, 3,5-dichloro-2,4,6-trifluoro-	1737935	>1	<4.5	454–4550	PR	Howard and Muir (2010)
Bicyclo[2.2.1]hept-5-ene-2,3-dicarboxylic acid, 1,4,5,6,7,7-hexachloro, dibutyl ester	1770805	>1	<4.5	4.5–227	PR	Howard and Muir (2010)
Cyclotrisiloxane, 2,4,6-trimethyl-2,4,6-tris(3,3,3-trifluoropropyl)-	2374143	100–1000	4.5–227	454–4550	PR	Howard and Muir (2010)
Cyclotetrasiloxane, 2,4,6,8-tetraethenyl-2,4,6,8-tetramethyl-	2554065	100–1000	<4.5	4.5–227		Howard and Muir (2010)
Propanoyl fluoride, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy]-	2641341	>1	4.5–227	<4.5	PR	Öberg and Iqbal (2012)
1,1,1,2,2,3,4,5,5,5-Decafluoro-3-(1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl)-4-	5028518	>1			PR	Rorije et al. (2011)
N,N'-Bis(4-(tert-butyl)phenyl)benzene-1,4-diamine	5432995	>1			PR	Rorije et al. (2011)
Heptamethylphenylcyclotetrasiloxane	10448096	>1	<4.5	<4.5	PR	Howard and Muir (2010)
Octadecafluoro-9--(trifluoromethyl) decanoylfluoride	15720986	>1			PR	Rorije et al. (2011)
1H-Isoindole-1,3(2H)-dione, 2,2'-(1,2-ethanediyl)bis[4,5,6,7-tetrabromo-	32588764	100–1000	454–4550	454–4550	PR	Howard and Muir (2010)
3-[2-Chloro-4-(trifluoromethyl)phenoxy] phenyl acetate	50594779	>1	<4.5	454–4550	PR	Howard and Muir (2010)
6-[(2-Nitrophenyl)azo]-2,4-di-tert-pentylphenol	52184197	>1	454–4550	<4.5	PR	Scheringer et al. (2012)
2,2,3,5,6-Pentafluoro-5-(pentafluoroethoxy)-3,6-bis(trifluoromethyl)-1,4-dioxane	84041667	>1			PR	Öberg and Iqbal (2012)
1,2-Dichloro-3-(trichloromethyl)benzene	84613978	>1			PR	Öberg and Iqbal (2012)

Table 2.51 Selected classes of pharmaceuticals and personal care products identified in Arctic environments (for a complete list of compounds, including CAS registry numbers and IUPAC nomenclature, see Annex Table A2.8/1).

Compound group	Effect/Application area	Relevant examples
NSAID	Painkillers and anti-inflammatory effect	Ibuprofen, diclofenac, acetylsalicylic acid, naproxen, paracetamol and others
Antimicrobials/Antiseptics	Additives to personal care products	Triclosan, Bronopol, Resorcinol, m-Cresol
Antibiotics and antiseptics	Antimicrobial agents	Benzyl penicillin, Sulfomethizole and others
Antidepressants	Neuro-regulatory agents	Paroxetine, Sertraline, Citalopram and others
Antidiabetics	Insulin regulators	Metformin, Gliclazide
Anti-cancer drugs	Cancer therapy and treatment	Ifosfamide, Cyclophosphamide
Antiulcer drugs	Gastric system controlling drugs	Omeprazole and others
Cardiovascular drugs	Blood circulation controlling agents	Anti-arrhythmic drugs
Anticoagulants	Blood clotting control	Coumarin derivatives, Amlodipin, Warfarin, Dipyridamole
Steroids/Hormones	Endocrine functions	Ethinylestradiol, Mestrone, Estrone and others
Hypnotics	Consciousness control	Zopiclone, Lidocaine
Complexing agents	Additives to cosmetic products	Ethylene diamine tetraacetic acid (EDTA)
Detergents	Sebum removal	Sodium dodecyl sulfate (SDS) and others
Surfactants	Reducing surface tension pressure	Cetrimonium salts and others
Synthetic fragrances	Additives to perfumes, soap etc.	Polycyclic musks, nitro musks
Angiotensin II receptor antagonists	Blood pressure regulation	Losartan, Candesartan and others
Additives/stabilizers	Added to personal care products	Butylparaben, Siloxanes, Bisphenol A
Lipid regulators	Regulating cholesterol levels	Fenofibrate, Clofibric acid
Illicit drugs	Illegal drugs	Cocaine, metamphetamine and others
Stimulants	Added to drinks and pharmaceutical products	Caffeine, 1,7 dimethylxanthine
Diuretics	Liquid regulation	Furosemide, Hydrochlorothiazide and others
UV-filters	Sun screen	Benzophenone, Octocrylene and others
Bisphenol monomers	Monomer for polymers (packing materials and additives)	Bisphenol A, methylenebisphenols and others
Artificial sweeteners	Food additives	Sucralose, Cyclamate

Table 1.1 The predominant persistent organic pollutants (POPs) and chemicals of emerging Arctic concern (CEACs) discussed or referenced in this assessment.

Chemical / Chemical Group	Primary Sources			
	Industrial and consumer uses	Agricultural and disease control uses	Unintentional byproducts	Natural products
Legacy POPs				
Polychlorinated biphenyls (PCBs)	X			
Hexachlorobenzene (HCB)	X		X	
Polychlorinated dibenzo-*p*-dioxins (PCDDs)	X		X	
Polychlorinated dibenzofurans (PCDFs)	X		X	
Dichlorodiphenyltrichloroethanes (DDTs)		X		
Chlordanes		X		
Heptachlor		X		
Toxaphene		X		
Mirex		X		
New POPs				
Polybrominated diphenyl ethers (PBDEs)	X			
Hexabromocyclododecane (HBCDD)	X			
Perfluorooctane sulfonic acid (PFOS)	X			
Perfluorooctanoic acid (PFOA)	X			
Short-chain chlorinated paraffins (SCCPs)	X			
Pentachlorophenol (PCP)	X	X		
α-, β- and γ-hexachlorocyclohexanes (HCHs)		X		
Endosulfan		X		
Polychlorinated naphthalenes (PCNs)			X	
Other Chemicals & Substances				
Other perfluorocarboxylates (PFCAs)	X			
Perfluorohexane sulfonic acid (PFHxS)	X			
Fluorotelomer alcohols (FTOHs)	X			
Organophosphate esters (OPEs)	X			
Dacthal		X		
Chlorpyrifos		X		
Trifluralin		X		
Pentachloronitrobenzene (PCNB)		X		
Polycyclic aromatic hydrocarbons (PAHs)			X	
Pentachloroanisole (PCA)			X	
Microplastics	X			
Halogenated Natural Products (HNPs)				
Bromoanisoles (BAs)				X
Hydroxylated PBDEs (OH-PBDEs)				X
Methoxylated PBDEs (MeO-PBDEs)				X

Legacy POPs: Chemicals included in the original 'dirty dozen' listed under the 2004 Stockholm Convention. New POPs: Chemicals listed under the Stockholm Convention between 2005–2019. PBDEs include tetra-, penta-, hexa-, hepta- and deca- congeners. See Chapter 2.2 for a more detailed list of CEACs (Table 2.2.2) and HNPs (Box 2.2.1).

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Table 2.2.2 Relevant groups of chemicals of emerging Arctic concern (CEACs) identified in AMAP (2017), many of which have little information on their occurrence or transport pathways within and outside the Arctic. Some chemicals originally identified as CEACs have since been listed as POPs under the Stockholm Convention. Refer to Table 1.1 for updated designations.

CEAC group	Abbreviation	Characteristic compounds	Main pathways to the Arctic		
			Long-range transport	Local sources	Notes
Per- and polyfluoroalkyl substances	PFAS	perfluoroalkyl acids (PFAA) including perfluorooctanesulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonate (PFHxS) volatile neutral PFAA precursors including fluorotelomer alcohol (FTOH) and perfluoroalkylsulfonamide-based substances	X	X	Local communities and airports may act as local sources
Brominated flame retardants	BFR	decabromodiphenylether (PBDE-209)	X	X	Dump sites may act as a local source
Chlorinated flame retardants	CFR	dechlorane plus	X	X	Dump sites may act as a local source
Organophosphate ester-based flame retardants and plasticizers	OPE	chlorinated OPE such as tris(2-chloroethyl) phosphate (TCEP) alkylated OPE such as tri-*n*-butyl phosphate (TnBP), tris meta-(cresyl) phosphate (TmCP) aryl-OPE such as 2-ethylhexyl diphenyl phosphate (EHDPP)	X	X	Airports may act as local sources
Phthalates		diethylphthalate	X	X	
Short-chain chlorinated paraffins	SCCP	$C_{10}H_{17}Cl_5$	X	X	
Siloxanes		hexamethyldisiloxane (HMDS) decamethylcyclopentasiloxane (D_5)	X	X	Atmospheric transport is a major source to the Arctic, however, local sources (e.g. personal care product use) also exist
Pharmaceuticals and personal care products	PPCP	ibuprofen, caffeine		X	Sewage outflows are primary local sources
Polychlorinated naphthalenes	PCN	halowax	X	X	
Hexachlorobutadiene	HCBD	HCBD	X		
Current-use pesticides	CUP	chlorpyrifos, chlorothalonil, dacthal	X	X	Agricultural applications are primary sources
Pentachlorophenol and pentachloroanisol	PCP & PCA	PCP & PCA	X	X	
Organotins		R_nSnX_{4-n}, where R represents an alkyl or aryl group and X is represented by an anion such as chloride, oxide, hydroxide, acetate, or other functional group, e.g. tributyltin (TBT).		X	Use associated with population and shipping densities. Harbors are major local sources
Polycyclic aromatic hydrocarbons	PAH	napthalene, anthracene	X	X	Summer wildfires in sub-Arctic regions act as episodic sources
Unintentionally produced PCBs	uPCB	PCB-11	X	X	
Halogenated natural products	HNP	brominated phenols, mixed halogenated compounds	X	X	Algae blooms are primary sources
Marine plastics and microplastics	μPlastic	polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), including monomers and additives	X	X	

Table 4 Overview of L2 compounds classified as new potential CEACs with LRATP.

Name	Sample	Molecular formula
3,4-Dichloropropiophenone-related positional isomer[a]	GFF (particle phase)	$C_9H_8Cl_2O$
Diphenyl sulfone	GFF (particle phase)	$C_{12}H_{10}O_2S$
Dibenzothiophene sulfone	GFF (particle phase)	$C_{12}H_8O_2S$
N-(2-Cyanoethyl)-*N*-methyl-benzenesulfonamide	GFF (particle phase)	$C_{10}H_{12}N_2O_2S$
Two chloroneb-related positional isomers[b]	PUF (gas phase)	$C_8H_8Cl_2O_2$
One chlorothalonil-related positional isomer[c]	PUF (gas phase)	$C_8Cl_4N_2$
Two trichloro-dimethoxybenzen isomers	PUF (gas phase)	$C_8H_7Cl_3O_2$
Two dichloro-methylanisole isomers	PUF (gas phase)	$C_8H_8Cl_2O$
One dibromo-dimethoxybenzene isomer	PUF (gas phase)	$C_8H_8Br_2O_2$
1-Naphthalenecarbonitrile	PUF (gas phase)	$C_{11}H_7N$
One pentachloro-methylbenzene positional isomer[d]	PUF (gas phase)	$C_7H_3Cl_5$

[a] Retention times close, but not identical, to those of a 3,4-dichloropropiophenone standard. [b] Retention times close, but not identical, to those of a chloroneb standard. [c] Retention times close, but not identical, to those of a chlorothalonil standard. [d] Retention times close, but not identical, to those of a pentachlorotoluene standard.

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