MEEF2021002A Completion Report (01 Jul 2022 - 31 Dec 2023)

Executive Summary

The proposed Phase 2 Project aims to determine the occurrences and distributions of a novel group of emerging organic contaminants related to electronic devices and waste (e-waste), namely liquid crystal monomers (LCMs), within the western Hong Kong and Pearl River Estuary (PRE) environment, particularly in the Chinese White Dolphins (CWDs), and reveal the potential origins of these contaminants. LCMs are key components in the manufacture of liquid crystal display panels. It is predicted that these e-device and e-waste related chemicals can be released into the marine environment during the lifecycle of many LCD devices. It is reported that these substances present persistent, bioaccumulative, and toxic properties in ecosystems. The CWDs living in the PRE region have been threatened by the pollution of a variety of pollutants discharged by human activity. However, the contamination status of emerging LCMs and their associated adverse impact were not well understood.

To evaluate the current levels of LCMs contamination in the CWDs and predict their potential sources, this study has successfully established a robust analytical method to determine 39 target LCMs in environmental sample (i.e., estuarian sediment collected in the PRE region) and biota sample (i.e., CWD blubber samples collected from Hong Kong water).

In total 23 LCMs were detected in the leachate sample collected from a Hong Kong local landfill site, (ΣLCMs=1120 ng/L), providing the first evidence suggesting that landfill leachate might be a potential sink of LCMs emitted from e-waste (Jin et al., 2022). Using the established method, another 10 LCMs were detected in the sediment samples collected from the Pearl River Estuary (PRE) region, with ΣLCMs ranged from 0.9 to 31.1 ng/g dry weight, demonstrating a widespread occurrence of LCMs in the sediments of the PRE, and a gradient of their contamination from inshore to offshore regions, indicating land-based origins (Tao et al., 2022).

For the source of LCM contamination, a total of 47, 43, and 33 out of 64 target LCMs were detected in three disassembled parts of smartphone screens, including the LCM layer (LL), light guide plate (LGP), and screen protector (SP), respectively, and a mechanism model was developed to describe the release behaviors (Jin et al., 2023a). In addition, a total of 31 LCMs with concentrations (ΣLCMs) ranging from 43.7 ng/g to 448 ng/g were detected in the collected ventilation and air conditioning filter (VACF) dust. Four main indoor sources of LCMs (i.e., computer (37.1%), television (28.3%), Brand A smartphone (21.2%) and Brand S smartphone (13.4%)) were identified (Jin et al., 2023b).

Furthermore, we also investigated the occurrence of LCMs in wastewater treatment plant (WWTP). In total 14 LCMs were detected in WWTP samples, with Σ_{14}LCMs concentrations of 16.8 ± 0.3 ng/L, 2.71 ± 0.05 ng/L, and 19.2 ± 1.0 ng/g dry weight in crude influent, final effluent, and final sludge, respectively, providing the first evidence of migration of LCMs contaminants from municipal wastewater to aquatic receiving ecosystem (Zhan et al., 2023). Additionally, a total of 30 LCMs were detected in dolphin tissues. The dominant LCMs accumulated in dolphin body were Pe3bcH, 5MeB, tFMeO-3bcHP, MePVbcH, MeP3bcH, and 3cH5cHB, with a similar distribution pattern compared to those in the PRE sediment samples (in press).

Overall, the results of this study, combining with the results to be obtained in the Phase 2 Project, can provide critical information for preliminary assessment on the potential threat of LCMs towards the CWDs, as well as for the recycling, disposal, and management of e-wastes in Hong Kong, contributing to the conservation and enhancement of marine lives particularly the CWDs living in the PRE and Hong Kong waters.

i) Project Title & Brief Description

Tracing a Novel Group of E-Waste Contaminants - Liquid Crystal Monomers - in the Chinese White Dolphins

The proposed project aims to determine the occurrences and distributions of a novel group of emerging organic contaminants related to electronic device and waste (e-device/e-waste), namely liquid crystal monomers (LCMs), in the Chinese White Dolphins (CWDs) within the western Hong Kong and Pearl River Estuary (PRE) waters, and reveal the occurrence, source, distribution and fate of these contaminants in aquatic and indoor environments. LCMs are key components in the manufacture of liquid crystal display panel. It is predicted that these e-device/e-waste related chemicals can be released into the marine environment during manufacture, usage, recycling, and disposal of electronic devices. They are also predicted to be persistent, bioaccumulative, and toxic in ecosystems. To evaluate the current levels of LCMs contamination in the CWDs and predict their potential sources, this study will assess the composition profiles of target LCMs in the CWDs, in comparison with the real LCMs mixtures extracted from different electronic devices obtained from the local market. This study will provide critical information for preliminary assessment on the potential threat of LCMs towards the CWDs, as well as for the recycling, disposal, and management of e-wastes in Hong Kong, contributing to the conservation and enhancement of marine lives particularly the CWDs living in the PRE and Hong Kong waters.

ii) Progress against the Proposed Work Schedule

Table 1. The 2nd funding cycle (2022.07-2023.12)

Activity	Date	Content	Anticipated no. of participants	Progress
LCD/e-device collection & extract preparation	1 Jul 2022 – 31 Oct 2022	1. Collection of various sizes and types of LCD panels from the shops, recycling centers and disposal sites. 2. Collection of LCD panels from CityU Go Green Program. 3. Optimization of the pre-treatment and cleaning procedure for LCD panel extracts.	All key members (3); Senior research assistant (1); PhD student (1)	1. The screen samples have been collected. 2. The pre-treatment and cleaning procedure for screen extract has been developed. ***We confirm that all tasks in this session have been completed following the original schedule.**

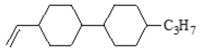
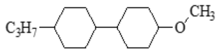
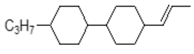
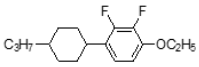
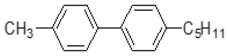
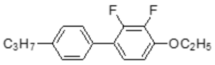
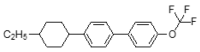
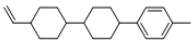
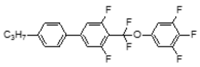
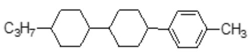
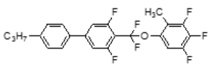
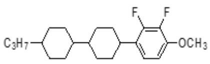
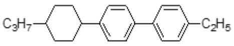
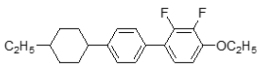
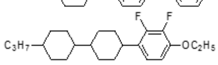
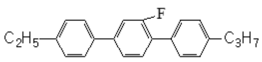
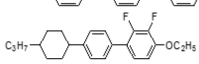
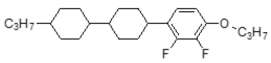
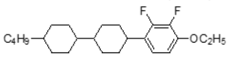
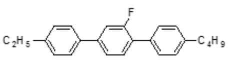
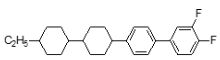
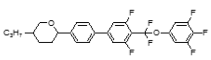
Method development for LCMs in e-devices	1 Sep 2022 – 31 Dec 2022	1. Establishment of the analytical method for LCMs in LCD samples. 2. Optimization of the qualitative and quantitative methods for LCMs in LCD panel extracts. 3. Finish the progress report	All key members (3); Senior research assistant (1); PhD student (1)	1. The instrumental method for LCMs has been established. 2. The qualitative and quantitative methods for LCMs in waste screen extract has been developed. ***We confirm that all tasks in this session have been completed following the original schedule.**
Quantification of LCMs in LCD panels from various e-devices	1 Nov 2022 – 30 Sep 2023	1. Determination of the target LCMs in collected LCD panel extract and generate the composition profiles of various LCMs in different LCD panels. 2. QA/QC.	All key members (3); Senior research assistant (1); PhD student (1)	1. The target LCMs in collected waste screens has been preliminarily determined. ***We confirm that all the tasks in this session following the original/extended schedule.**
Data analysis, preliminary assessment, preparation for seminar and video materials, and report writing	1 Oct 2023 – 31 Dec 2023	1. Finalize the data analysis. 2. Compare the composition profiles of LCMs between CWD and LCD panel extracts for determining whether LCD panel is the major source of LCMs accumulated in CWD. 3. Conduct a preliminary assessment on the potential threat of LCMs towards the CWDs. 4. Finish the manuscript writing for journal publication. 5. Prepare materials for seminar and promotional video. 6. Finish the completion report.	All key members (3); Senior research assistant (1); PhD student (1)	1. All the data analysis work has been completed and materials have been prepared for publication and seminar presentation. ***We confirm that all the tasks in this session following the original/extended schedule.**

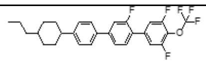
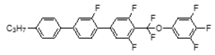
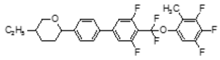
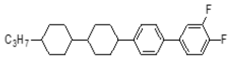
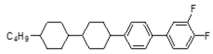
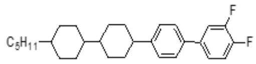
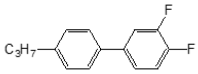
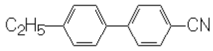
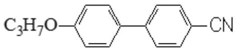
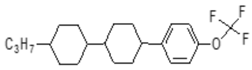
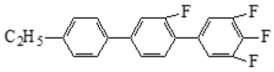
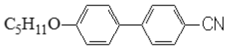
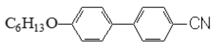
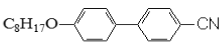
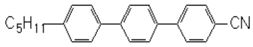
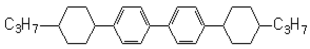
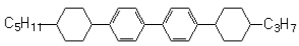
iii) Brief Results

LCMs Standards

Standard chemicals of the 39 target LCMs were purchased from Tokyo Chemical Industry (TCI) Co., Ltd. (Hong Kong, China), J&K Chemical Ltd. (Shanghai, China), and LCM manufacturers, respectively (Table 2). Because stable isotope of LCM was currently not commercially available, isotope-labelled PCB-118 ($^{13}C_{12}$-2,3′,4,4′,5-pentachlorobiphenyl) (Wellington Lab, Guelph, Canada) was selected as the surrogate standard of LCMs. High-performance liquid chromatography (HPLC) dichloromethane (DCM) was obtained from Duksan Pure Chemical (Seoul, Korea) and Merck KGaA (Darmstadt, Germany), respectively.

Table 2. Detailed information on the LCM standards.

Abbr.	CASRN	Mol. Structure	MW (g/mol)	Purity	Suppliers
3VbcH	116020-44-1		234.4	98%	TCI
MeO3bcH	97398-80-6		238.4	98%	TCI
Pe3bcH	279246-65-0		248.5	98%	TCI
2O3cHdFP	174350-05-1		282.4	98%	TCI
5MeB	64835-63-8		238.4	98%	TCI
2OdF3B	157248-24-3		276.3	>99.8%	LCM factories
tFMeO-2cHB	650634-92-7		348.4	>99.8%	LCM factories
MePVbcH	155041-85-3		282.5	98%	TCI
tFPO-CF$_2$-dF3B	303186-20-1		428.4	98%	TCI
MeP3bcH	84656-75-7		298.5	98%	TCI
tFMePO-CF$_2$-dF3B	NA		442.4	>99.8%	LCM factories
MeOdFP3bcH	431947-34-1		350.5	>99.8%	LCM factories
3cH2B	84540-37-4		306.5	98%	J&K
2O2cHdFB	323178-01-4		344.5	>99.8%	LCM factories
2OdFP3bcH	123560-48-5		364.5	>99.8%	LCM factories
2F3T	95759-44-7		318.4	>99.9%	LCM factories
2O3cHdFB	189750-98-9		358.5	>99.8%	LCM factories
3OdFP3bcH	473257-14-6		378.6	>99.8%	LCM factories
2OdFP4bcH	473257-15-7		378.6	>99.8%	LCM factories
2F4T	825633-75-8		332.5	>99.8%	LCM factories
2bcHdFB	139195-63-4		382.5	>99.8%	LCM factories
tFPO-CF$_2$-dF3PyB	NA		512.5	>99.8%	LCM factories

Abbr.	CASRN	Mol. Structure	MW (g/mol)	Purity	Suppliers
tFMeO-3cHtFT	NA		492.5	>99.8%	LCM factories
tFPO-CF_2-tF3T	303186-36-9		522.4	>99.8%	LCM factories
tFMePO-CF_2-dF3PyB	NA		512.5	>99.8%	LCM factories
3bcHdFB	119990-81-7		396.6	>99.8%	LCM factories
4bcHdFB	NA		410.6	>99.8%	LCM factories
5bcHdFB	136609-96-6		424.6	>99.8%	LCM factories
3dFB	118164-49-1		232.3	>99.8%	LCM factories
2CB	58743-75-2		207.3	99.92%	LCM factories
3OCB	52709-86-1		237.3	99.67%	LCM factories
tFMeO-3bcHP	133937-72-1		368.5	98%	TCI
2teFT	326894-55-7		330.3	>99.9%	LCM factories
5OCB	52364-71-3		265.4	99.89%	LCM factories
6OCB	41424-11-7		279.4	99.94%	LCM factories
8OCB	52364-73-5		307.4	99.95%	LCM factories
5CT	54211-46-0		325.5	99.86%	LCM factories
b3cHB	85600-56-2		402.7	99.97%	LCM factories
3cH5cHB	80955-71-1		430.7	99.81%	LCM factories

Instrumental Analysis

A Thermo Fisher Scientific 220 Trace 1300 GC coupled with a Q Exactive Orbitrap hybrid quadrupole (MS/MS) (Thermo Fisher Scientific) was used to quantify the target LCMs. The MS was operated in electron impact (EI) mode, and the analysis was performed in the full-mass scan mode. The GC column used for separation was DB-5HT (30 m × 0.25 mm × 0.1 μm; Agilent). One μL of the sample was injected in the splitless mode with an injector temperature of 285 °C. The flow rate of the carrier gas (helium) was 1.2 mL/min. The temperature program for oven was set as follows: started at 40 °C for 1 min, increased to 180 °C by 40 °C/min, further increased to 250 °C by 30 °C/min, held 2 min, ramped to 300 °C at 10 °C/min, and then held for 5 min. The ion source temperature and transfer line temperature were 290 and 260 °C, respectively, and the ion source filament voltage was 70 eV. The quantification and confirmation ions and retention times of the LCMs are listed in Table 3.

Table 3. Results of the retention time, quantification ion, specific fragment ions, and standard working curve for the LCMs.

Abbr.	Standard Working Curve

No.		Retention time (min)	Quantification Ion [M+H]+	Specific Fragment Ion 1	Specific Fragment Ion 2	R^2	Linearity (ng/mL)
1	3VbcH	6.21	205.195	234.2343	109.1012	0.9995	0.5-100
2	MeO3bcH	6.45	206.2029	163.1481	81.0699	0.9996	0.1-100
3	Pe3bcH	6.76	248.2499	123.1168	81.0699	0.9995	0.5-100
4	2O3cHdFP	7.06	282.1791	156.0382	169.046	0.9993	0.05-100
5	5MeB	7.35	238.1716	181.101	165.0698	0.9993	0.05-100
6	2OdF3B	7.37	276.132	219.0614	247.0928	0.999	0.05-100
7	tFMeO-2cHB	8.3	348.1693	277.0834	264.0757	0.9992	0.05-100
8	MePVbcH	8.48	282.2342	171.1169	118.0777	1.0000	0.5-100
9	tFPO-CF_2-dF3B	8.72	281.0948	252.0557	232.0495	0.9991	0.05-100
10	MeP3bcH	8.99	298.2654	118.0777	131.0856	0.9994	0.1-100
11	tFMePO-CF_2-dF3B	9.35	281.0948	252.0557	232.0495	0.9992	0.05-100
12	MeOdFP3bcH	9.95	350.2414	170.0538	127.0354	0.9993	0.1-100
13	3cH2B	10.07	306.2341	221.1324	193.1012	0.9994	0.05-100
14	2O2cHdFB	10.08	344.1945	316.1631	232.0693	0.9998	0.1-100
15	2OdFP3bcH	10.35	364.2571	156.0381	184.0694	0.9995	0.5-100
16	2F3T	10.48	318.1777	289.1385	274.1151	0.9993	0.05-100
17	2O3cHdFB	10.76	358.2101	330.1789	245.0772	0.9992	0.1-100
18	3OdFP3bcH	11.03	336.2258	378.2728	156.0382	0.9993	0.5-100
19	2OdFP4bcH	11.09	378.2727	184.0694	156.0381	0.9991	0.1-100
20	2F4T	11.22	332.1934	289.1386	274.1152	0.9991	0.1-100
21	2bcHdFB	12.9	382.2464	229.0824	216.0745	0.9992	0.1-100
22	tFPO-CF_2-dF3PyB	13.28	365.1522	219.0416	239.0479	0.9992	0.1-100
23	tFMeO-3cHtFT	13.3	394.0784	407.0865	365.1521	0.9992	0.5-100
24	tFPO-CF_2-tF3T	13.47	375.1164	346.0772	275.0668	0.9993	0.1-100
25	tFMePO-CF_2-dF3PyB	13.52	351.1366	170.0527	239.0479	0.9991	0.1-100
26	3bcHdFB	13.63	396.2622	203.0667	216.0745	0.9993	0.5-100
27	4bcHdFB	14.39	410.2779	203.0667	216.0745	0.9998	0.5-100
28	5bcHdFB	15.14	424.2938	216.0745	229.0824	0.9993	0.5-100
29	3dFB	5.9	203.0666	232.1058	183.0604	0.9996	0.05-100
30	2CB	7.05	192.0807	165.0701	207.1043	0.999	0.01-100
31	3OCB	7.97	195.0678	166.0652	237.1149	0.9992	0.5-100
32	tFMeO-3bcHP	8.46	368.2318	188.0443	175.0365	0.9993	0.05-100
33	2teFT	8.43	330.1025	315.079	275.0668	0.9993	0.05-100
34	5OCB	8.84	195.0678	166.0652	265.1462	0.9993	0.5-100
35	6OCB	9.36	195.0678	166.0652	279.1618	0.9991	0.5-100
36	8OCB	10.69	307.1931	195.0679	166.0652	0.9992	1-100
37	5CT	13.22	268.1122	325.1825	253.0168	0.9993	0.5-100
38	b3cHB	15.98	402.328	304.2186	317.2264	0.9995	0.5-100
39	3cH5cHB	18.13	430.3593	304.2186	332.25	0.9994	0.5-100

LCMs in municipal landfill leachate

Liquid crystal monomers (LCMs) have been proposed as a class of emerging organic pollutants, which were recently detected in indoor dust and sediment samples collected near electronic devices recycling facilities. However, there is a knowledge gap for analytical method, occurrence, and distribution of LCMs in aqueous sample. Herein, a robust method was developed to determine 38 target LCMs in landfill leachate. A combined ultrasonic enhanced liquid-liquid extraction, saponification and silica/florisil packed column purification method achieved recoveries of 76.9~127.1%, 84.5~114.6% and 81.3~104.6% at spiking levels of 2 ng, 10 ng and 50 ng in leachate, respectively. The developed method was validated through determination of target LCMs in leachate samples collected from municipal landfills in Hong Kong (HK) and Shenzhen (SZ), China. There were 23 and 20 LCMs detected in the HK (ΣLCMs=1120 ng/L) and SZ (ΣLCMs=409 ng/L) sample, respectively, with 6 LCMs newly detected in the environment. This study provided the first evidence suggesting that landfill leachate might be a potential sink of LCMs emitted from e-waste. Future study is urged to investigate the potential migration of LCMs from landfill leachate as a point source, and their occurrence, distribution, fate, and ecotoxicological risk in aquatic environments on regional and global scales. Details of the results have been published in Jin et al. (2022) J Hazard Mater 423, 127146.

LCMs in Pearl River Estuary sediment

Liquid crystal monomers (LCMs), commonly used in screens of electronic devices, have recently been identified as a group of emerging chemicals of concern associated with e-waste. They are potentially persistent, bioaccumulative, and toxic substances, and may pose a threat to the marine ecosystem. The Pearl River Estuary (PRE) receives organic contaminants discharged from the Pearl River Delta region, where primitive handling of e-waste is widespread. However, information on the pollution status of LCMs in the PRE is absent. Herein, a rapid and robust analytical method was established using ultrasonic extraction, solid phase extraction cleanup, and GC-Orbitrap-MS analysis. The spatial distribution of 39 target LCMs was investigated in 45 surface sediment samples from the PRE. Ten LCMs were detected, with ΣLCMs ranged from 0.9 to 31.1 ng/g dry weight. Our results demonstrated a widespread occurrence of LCMs in the sediments of the PRE, and a gradient of their contamination from inshore to offshore regions, indicating land-based origins. Our reported ΣLCMs concentrations were relatively higher compared to many other legacy and emerging pollutants found in the same investigated area. Preliminary risk assessment showed 3VbcH, Pe3bcH and tFMeO-3bcHP might be the top 3 risk contributors in the PRE. Further investigation on the ecological impact of LCMs on marine benthic ecosystems, as well as identification of their sources and control measures are warranted. Details of the results have been published in Tao et al. (2022) J Hazard Mater 437, 129377.

Release behavior of LCMs from smartphone screens

Liquid crystal display (LCD) screens can release many organic pollutants into the indoor environment, including liquid crystal monomers (LCMs), which have been proposed as a novel class of emerging pollutants. Knowing the release pathways and mechanisms of LCMs from various components of LCD screens is important to accurately assess the LCM release and reveal their environmental transport behavior and fate in the ambient environment. A total of 47, 43, and 33 out of 64 target LCMs were detected in three disassembled parts of waste smartphone screens, including the LCM layer (LL), light guide plate (LGP), and screen protector (SP), respectively. Correlation analysis confirmed LL was the source of LCMs detected in LGP and SP. The emission factors of LCMs from waste screen, SP, and LGP parts were estimated as 2.38×10^{-3}, 1.36×10^{-3}, and 1.02×10^{-3}, respectively. A mechanism model was developed to describe the release behaviors of LCMs from waste screens, where three characteristics parameters of released LCMs, including average mass proportion (AP), predicted subcooled vapor pressures (P_L), and octanol-air partitioning coefficients (K_{oa}), involving coexistence of absorption and adsorption mechanisms, could control the diffusion-partitioning. The released LCMs in LGP could reach diffusion-partition equilibrium more quickly than those in SP, indicating that LCM release could be mainly governed through SP diffusions. Details of the results have been published in Jin et al. (2023a) Environ Sci Technol 57, 10319-10330.

LCMs in indoor ventilation system and associated health risk

Indoor dust contaminated with liquid crystal monomers (LCMs) released from various commercial liquid crystal display (LCD) screens may pose environmental health risks to humans. This study aimed to investigate the occurrence of 64 LCMs in ventilation and air conditioning filters (VACF) dust, characterize their composition profiles, potential sources, and associations with indoor characteristics, and assess their in vitro toxicity using the human lung bronchial epithelial cells (BEAS-2B). A total of 31 LCMs with concentrations (ΣLCMs) ranging from 43.7 ng/g to 448 ng/g were detected in the collected VACF dust. Additional analysis revealed the potential interactions between indoor environmental conditions and human exposure risks associated with the detected LCMs in VACF dust. The service area and working time of the ventilation and air conditioning system, and the number of indoor LCD screens were positively correlated with the fluorinated ΣLCMs in VACF dust ($r = 0.355 \sim 0.511$, $p < 0.05$), while the associations with the non-fluorinated ΣLCMs were not found ($p > 0.05$), suggesting different environmental behavior and fates of fluorinated and non-fluorinated LCMs in the indoor environment. Four main indoor sources of LCMs (i.e., computer (37.1%), television (28.3%), Brand A smartphone (21.2%) and Brand S smartphone (13.4%)) were identified by positive matrix factorization-multiple linear regression (PMF-MLR). Exposure to 14 relatively frequently detected LCMs, individually and in the mixture, induced significant oxidative stress in BEAS-2B cells. Among them, non-fluorinated LCMs, specifically 3cH2B and MeP3bcH, caused dominant decreased cell viability. This study provides new insights into the indoor LCMs pollution and the associated potential health risks due to the daily use of electronic devices. Details of the results have been published in Jin et al. (2023b) Environ Int 180, 108212.

LCMs in municipal wastewater

Liquid crystal monomers (LCMs), the essential substances used in the display screen of electronic devices, have been proposed as a class of emerging chemicals of concern. Despite their detection in various environmental matrices, little is known about the presence of LCMs in municipal sewage systems. This study aimed to investigate the occurrence, distribution, and fate of 64 LCMs released into the aqueous environment from a municipal wastewater treatment plant (WWTP) in Hong Kong, China. In total 14 LCMs were detected in WWTP samples. Specifically, the Σ_{14}LCMs concentrations in crude influent, final effluent, and final sludge were found to be 16.8 ± 0.3 ng/L, 2.71 ± 0.05 ng/L, and 19.2 ± 1.0 ng/g dry weight, respectively. Among them, 10 fluorinated LCMs (F-LCMs) were determined to be present at concentrations of 8.90 ± 0.10 ng/L, 1.69 ± 0.05 ng/L, and 9.94 ± 1.00 ng/g dry weight, respectively. The predominant non-fluorinated LCMs (NF-LCMs) detected in all samples were 3OCB and EPhEMOB, while 2OdF3B was the dominant F-LCM. The overall removal rate of total LCMs was 83.8 ± 0.3 %, with 25.4 ± 4.8 % being removed by biodegradation and UV treatment. Compared to NF-LCMs, F-LCMs were more resistant to biodegradation. Despite the significant removal of LCMs through WWTP, the remaining LCMs in final effluent could result in an annual emission of 3.04 kg of total LCMs from the population of Hong Kong. This study provides the first evidence of LCMs contamination in municipal wastewater, possibly arising from routine electronic devices usage. Further investigation is needed to elucidate the potential impact of LCMs emission via WWTP effluent on the aquatic receiving ecosystem. Details of the results have been published in Zhan et al. (2023) Water Res 247, 120784.

LCMs in Chinese White Dolphin

In total 30 LCMs were detected in dolphin tissues (Table 4). The results indicated that the dominant LCMs accumulated in dolphin body were Pe3bcH, 5MeB, tFMeO-3bcHP, MePVbcH, MeP3bcH, and 3cH5cHB. The distribution of LCMs in dolphin were similar to the profile detected in PRE sediment samples. Overall, male dolphins accumulated more LCMs compared to female dolphins (Table 5). This is probably because male dolphins were more active and tended to hunt larger prey which might contain higher level of organic contaminants. This study is currently under review for publication.

Table 4. The distribution of 30 detected LCMs in different tissues in dolphin (ng/g)

No.	Abbr.	DF(%)	Kidney	Liver	Brain	Blubber	Muscle
1	Pe3bcH	54.84%	N.D.	N.D.-5.50	N.D.-0.02	N.D.-92.50	N.D.-99.10
2	5MeB	29.03%	N.D.	N.D.-0.01	N.D.-0.90	N.D.-4.80	N.D.-2.30
3	tFMeO-2cHB	1.61%	N.D.	N.D.	N.D.	N.D.	N.D.-0.20
5	MePVbcH	33.87%	N.D.	N.D.-1.50	N.D.-2.00	N.D.-23.90	N.D.-14.90
6	tFPO-CF2-dF3B	1.61%	N.D.	N.D.	N.D.	N.D.-0.40	N.D.
8	MeP3bcH	56.45%	N.D.-0.30	N.D.-0.80	N.D.-8.40	N.D.-10.80	N.D.-30.40
10	tFMePO-CF2-dF3B	1.61%	N.D.	N.D.	N.D.	N.D.	N.D.-0.30
11	MeOdFP3bcH	9.68%	N.D.-0.10	N.D.	N.D.-0.10	N.D.-1.70	N.D.-0.30
12	3cH2B	25.81%	N.D.	N.D.	N.D.	N.D.-0.40	N.D.-2.10
13	2O2cHdFB	3.23%	N.D.	N.D.	N.D.	N.D.-0.80	N.D.
14	2OdFP3bcH	4.84%	N.D.-0.20	N.D.	N.D.	N.D.-0.60	N.D.
15	2F3T	8.06%	N.D.	N.D.-0.20	N.D.-0.20	N.D.-0.80	N.D.-0.30
17	2O3cHdFB	6.45%	N.D.-0.10	N.D.	N.D.-0.10	N.D.-2.10	N.D.-0.10
18	3OdFP3bcH	8.06%	N.D.	N.D.	N.D.-0.40	N.D.-0.40	N.D.-0.60
19	2OdFP4bcH	1.61%	N.D.	N.D.	N.D.	N.D.-0.40	N.D.
20	2F4T	0.00%	N.D.	N.D.	N.D.-0.10	N.D.	N.D.
21	2bcHdFB	1.61%	N.D.	N.D.	N.D.-0.50	N.D.	N.D.-0.50
23	tFPO-CF2-dF3PyB	8.06%	N.D.	N.D.	N.D.	N.D.-1.50	N.D.-0.10
24	tFPO-CF2-tF3T	1.61%	N.D.	N.D.	N.D.	N.D.	N.D.-0.60
25	3bcHdFB	9.68%	N.D.	N.D.	N.D.	N.D.-1.30	N.D.-0.80
26	tFMePO-CF2-dF3PyB	6.45%	N.D.	N.D.	N.D.	N.D.-0.30	N.D.-0.10
27	4bcHdFB	4.84%	N.D.	N.D.	N.D.	N.D.-0.90	N.D.-0.80
28	5bcHdFB	6.45%	N.D.-2.90	N.D.	N.D.	N.D.-3.60	N.D.-2.90
4	tFMeO-3bcHP	19.35%	N.D.	N.D.	N.D.-3.10	N.D.-3.10	N.D.-4.50
7	5OCB	8.06%	N.D.	N.D.	N.D.-0.10	N.D.-0.70	N.D.-0.10
9	6OCB	3.23%	N.D.	N.D.	N.D.-0.10	N.D.-0.90	N.D.
16	8OCB	14.52%	N.D.-0.30	N.D.	N.D.	N.D.-3.70	N.D.-16.50
22	5CT	4.84%	N.D.	N.D.	N.D.-0.10	N.D.-2.20	N.D.-0.30
29	b3cHB	1.61%	N.D.	N.D.	N.D.	N.D.-0.60	N.D.
30	3cH5cHB	20.97%	N.D.	N.D.-2.30	N.D.	N.D.-8.00	N.D.-4.00

Table 5. The concentration distribution of LCMs in different sex in dolphin sample (ng/g).

	*total (n=71)		male (n=30)		female (n=13)	
	mean	range	mean	range	mean	range
total LCMs concentrations	11.69	0-263.53	69.89	0-263.53	8.66	1.13-202.84
Blubber	66.21	0-245.45	73.97	0-243.45	8.66	2-202.84
muscle	28.39	0.07-263.53	72.57	0.07-263.53	25.8	2.04-202.84

liver	5.49	0-14.71	/	/	6.7	1.78-14.71
brain	61.42	0.64-105.96	/	/	/	/
kidney	0.61	0.25-1.7	/	/	/	/
melon	0	0-1.13	/	/	/	/

*n means the number of the sample

Some dolphin is difficult to determine their sex

iv) Deliverables

a) Develop the pre-treatment and cleanup method for target LCMs in complex matrices;
b) Develop the instrumental method of target LCMs;
c) Develop the qualitative and quantitative methods for determining LCMs in landfill leachate;
d) Develop the qualitative and quantitative methods for determining LCMs in marine/estuary sediment;
e) Develop the qualitative and quantitative methods for determining LCMs in indoor dust;
f) Develop the qualitative and quantitative methods for determining LCMs in smartphone screens
g) Develop the qualitative and quantitative methods for determining LCMs in municipal wastewater
h) Develop the qualitative and quantitative methods for determining LCMs in dolphin tissues
i) Preliminarily assess the origin, migration, distribution, and fate of LCMs contaminant in aquatic environments

v) Evaluation of the project effectiveness

The project has been proceeded following the proposed work schedule. The proposed project objectives include:

1. Determine the occurrences and composition profiles of a novel group of e-waste contaminants, liquid crystal monomers (LCMs), in the Chinese White Dolphins (CWDs) living in the Pearl River Estuary (PRE) and the estuarine western waters of Hong Kong.
2. Determine the composition profiles of LCMs in the extracts from various sizes and types of liquid crystal display (LCD) panels obtained from the local market.
3. Characterize the transport behavior of LCMs contaminants from various types of electronic devices to the CWDs.
4. Conduct a preliminary assessment on the threat of LCMs towards the CWDs in the PRE and Hong Kong waters.

All the objectives have been achieved. Specifically, the profiles of a novel group of emerging e-waste pollutants, LCMs, in the CWDs living in the PRE and western water of Hong Kong as well as in the extracts from various sizes and types of LCD panel have been determined. The (see Section iii Brief Results). The transport of LCMs from e-waste to the marine environment through wastewater effluent has been characterized (see Section iii Brief Results). The preliminary assessment on the threat of LCMs in the marine environment has been performed in the sediment and in the CWDs (see Section iii Brief Results). Besides the deliverables listed in Section iv, additionally, we have published 5 research papers on highly reputable peer-review journals, delivered 5 invited seminars in local, reginal and international conferences. We also reached out media to produce newspaper coverage. Moreover, 1 PhD student and 1 Postdoctoral fellow are well trained by this project.

The followings are publications/manuscripts related to this project:

Jin Q, Tao D, Lu Y, Sun J, Lam CH, Su G, He Y. New insight on occurrence of liquid crystal monomers: A class of emerging e-waste pollutants in municipal landfill leachate. J Hazard Mater. 2022 Feb 5;423(Pt B):127146. doi: 10.1016/j.jhazmat.2021.127146.

Tao D, Jin Q, Ruan Y, Zhang K, Jin L, Zhan Y, Su G, Wu J, Leung KMY, Lam PKS, He Y. Widespread occurrence of emerging E-waste contaminants - Liquid crystal monomers in sediments of the Pearl River Estuary, China. J Hazard Mater. 2022 Sep 5;437:129377. doi: 10.1016/j.jhazmat.2022.129377.

Jin Q, Yu J, Fan Y, Zhan Y, Tao D, Tang J, He Y. Release Behavior of liquid crystal monomers from waste smartphone screens: Occurrence, distribution, and mechanistic modeling. Environ Sci Technol. 2023a Jul 18;57(28):10319-10330. doi: 10.1021/acs.est.2c09602.

Jin Q, Fan Y, Lu Y, Zhan Y, Sun J, Tao D, He Y. Liquid crystal monomers in ventilation and air conditioning dust: Indoor characteristics, sources analysis and toxicity assessment. Environ Int. 2023b Oct;180:108212. doi: 10.1016/j.envint.2023.108212.

Zhan Y, Jin Q, Lin H, Tao D, Law LY, Sun J, He Y. Occurrence, behavior and fate of liquid crystal monomers in municipal wastewater. Water Res. 2023 Dec 1;247:120784. doi: 10.1016/j.watres.2023.120784.

Tao D, Ruan Y, Sun J, Jin Q, Lu Y, Kot BCW, Leung KMY, Lam PKS, He Y. Target and suspect screening and temporal trends of Liquid Crystal Monomers in marine mammals from the South China Sea. In press.

The followings are public seminars related to this project:

ICMPE, 10th International Conference on Marine Pollution and Ecotoxicology. City University of Hong Kong, Hong Kong SAR, China, 2024/01/03-06. Invited Presentation: Liquid crystal monomers: from indoor to marine environments. **He Y**.

第四届中国环境与健康大会, 中国疾控中心, 福州. The 4th China Conference on Environment and Health (CCEH 2023), Chinese Center for Disease Control and Prevention, Fuzhou, 2023/08/17-19. Invited Presentation: Liquid crystal monomers: emerging contaminants from e-waste to marine environment. **He Y**.

SETAC, Asia Pacific Conference, Virtual Event, 2022/09/05-08. Presentation: Liquid Crystal Monomers: an emerging class of e-waste pollutants. **He Y**.

The 2nd International Symposium on Marine Science and Technology for Young Scientists and Postgraduates, Hong Kong Branch of the Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Hong Kong, 2022/07/13-15. Invited Presentation: Liquid crystal monomers: a novel class of emerging e-waste pollutants. **He Y**.

2022 年土木工程院士知名專家系列講座暨第十三屆全國研究生暑期學校，東南大學，南京. 2022/07/05. Invited Seminar: Liquid crystal monomers: a concerning group of emerging e-waste pollutants. **He Y**.

The followings are examples of media coverage related to this project:

https://std.stheadline.com/sc/realtime/article/1852340/%E5%8D%B3%E6%99%82-%E6%B8%AF%E8%81%9E-%E6%AF%8F%E6%97%A5%E9%9B%9C%E8%AA%8C-%E6%89%8B%E6%A9%9F%E9%87%8B%E5%87%BA%E9%9A%A8%E6%B1%A1%E6%B0%B4%E6%8E%92%E5%87%BA-%E6%B8%AF%E6%B5%B7%E5%9F%9F%E7%99%BC%E7%8F%BELCMs%E6%AF%92%E7%89%A9

https://www.bastillepost.com/hongkong/article/10980967-%ef%bb%bf%ef%bb%bf%e9%9b%bb%e5%ad%90%e5%b1%8f%e5%b9%95%e6%9c%89%e6%af%92%e6%b1%a1%e6%9f%93%e7%89%a9%ef%bb%bf-%ef%bb%bf%e9%9a%a8%e5%ae%b6%e5%b1%85%e5%bb%a2%e6%96%99%e6%bb%b2%e5%85%a5%e6%b8%af%e6%b0%b4

vi) Summary and Way Forward

For a short summary, this project has established the analytical method for detecting LCMs, a novel group of e-waste contaminants, in biota samples and real electronic products. Quantitative analysis and composition profiles comparison have been performed for LCMs in the CWDs in the PRE/Hong Kong waters and LCD panels from various local sites. Preliminary assessment has also be performed to evaluate the potential hazards of LCMs in the CWDs.

The results of the proposed study shed light on the transportation of LCMs from consumption/disposal ends to its environmental receptor. It provides essential information for preliminary assessment on the potential health impact of LCMs on the CWDs. It also provides guidance information on future recycling, disposal, and management program of e-wastes in Hong Kong. The research outcomes will also raise the public awareness of the potential hazards of e-waste and the pertinent threats to the CWDs. Overall, it will contribute significant value to the conservation and enhancement of marine life particularly the CWDs living in PRE/Hong Kong waters.

vii) Project Assets Photos

No project assets. Photos are not applicable.

viii) Financial statement

Financial statement are not disclosed due to confidentiality reasons.

ix) Supporting Receipts

CityU is Specified Recipient Organisation and we have opted for alternative financial reporting arrangement.

x) Staff Recruitment and Attendance Record

Staff recruitment and attendance record are not disclosed due to confidentiality reasons.

Disclamation

I hereby irrevocably declare to the MEEF Management Committee and the Steering Committee of the relevant Funds including the Top-up Fund, that all the dataset and information included in the completion report has been properly referenced, and necessary authorisation has been obtained in respect of information owned by third parties.

Any opinions, findings, conclusions or recommendations expressed in this report do not necessarily reflect the views of the Marine Ecology Enhancement Fund or the Trustee.

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2024.02.10