Electronic Supplementary Material (ESI) for Chemical Science.

Supporting information for

Potassium Ion-selective Fluorescent and pH Independent Nanosensors Based on Functionalized Polyether Macrocycles

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General Remarks

NMR spectra were recorded on 300, 400 or 500 MHz spectrometer at 20 °C unless otherwise stated. ^{1}H-NMR chemical shifts are given in ppm relative to Me_4Si with the solvent resonance used as the internal standard ($CDCl_3$ $\delta = 7.26$ ppm). ^{13}C-NMR (125 or 101 MHz) chemical shifts were given in ppm relative to Me_4Si with the solvent resonance used as the internal standard ($CDCl_3 = 77.16$ ppm). IR spectra were recorded using an ATR sampler and are reported in wave numbers (cm^{-1}). Melting points (Mp) were measured in open capillary tubes and were uncorrected. Optical rotations were measured in a thermostated (20 °C) 10.0 cm long microcell at 589 nm (Na) or 435 nm (Hg) and are reported as follows: $[\alpha]_D$ (c (g/mL), solvent). Electrospray mass spectra (ESI +) were obtained by the department of Mass Spectrometry of the University of Geneva. All reactions involving air sensitive compounds were carried out under dry N_2 or argon by means of an inert gas/vacuum double manifold line and standard Schlenk techniques. Flash column chromatography was performed with silica gel 40-63 or alumina (neutral Brockmann I, 50-200 μm).

General procedure for the synthesis of macrocycles.

t-BuOK (44.8 mg, 0.4 mmol) was added into the suspension of starting macrocycles (0.1 mmol) and 1-aminopyrene (0.4 mmol) in 1.0 mL of dry THF at -100 °C (see Figure S1). After 2 minutes, the cooling bath (EtOH, N_2 liquid) was removed and the reaction was allowed to reach room temperature on its own. It was stirred for additional 2 hours. Without further treatment or work-up, the reaction mixture was purified by column chromatography (SiO_2) or preparative TLC.[1]

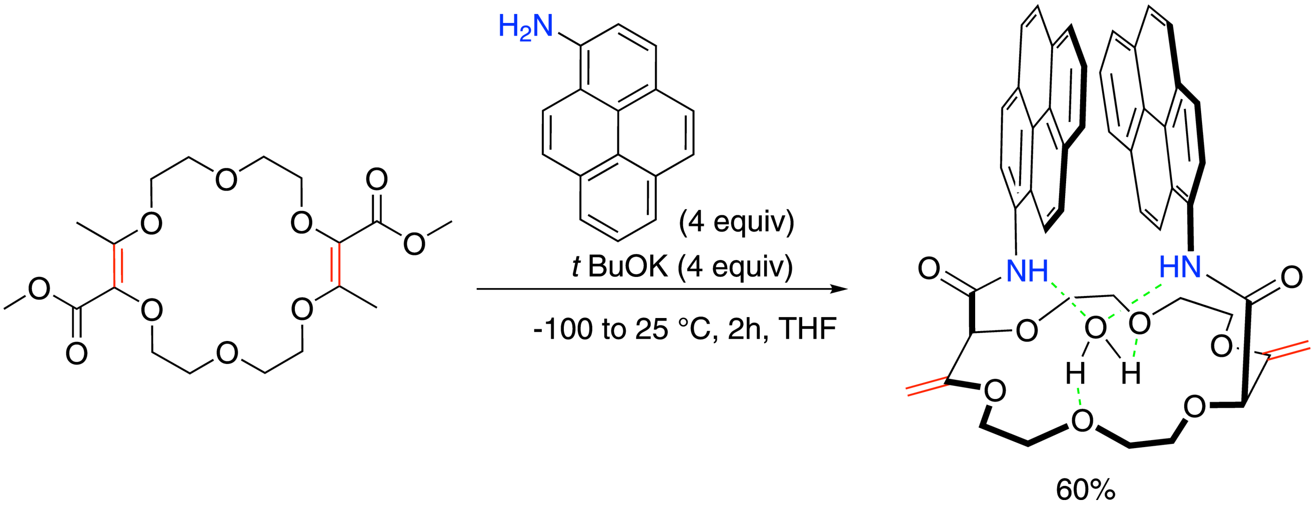

Figure S1. Synthetic routes to macrocyclic compounds functionalized with pyreneamide derivatives.

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[1] Vishe, M.; Hrdina, R.; Poblador-Bahamonde, A. I.; Besnard, C.; Guenee, L.; Buergi, T.; Lacour, J. *Chem. Sci.* **2015**.

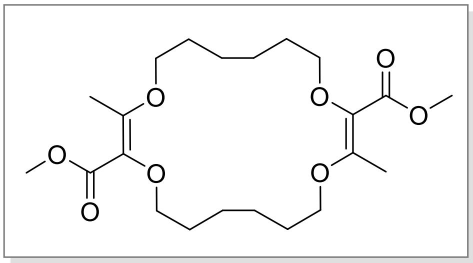

Figure S2. Starting material used for the synthesis of reported macrocyclic compounds.[2]

Yield: 30 %

M.p. 106 °C - 107 °C (crystallized from heptane/CH_2Cl_2)

R*f* : 0.24 (silica gel, mobile phase Pentane : Ether 5/5)

m.p. : 106 °C – 107 °C (recrystallized from Heptane and CH_2Cl_2 mixture).

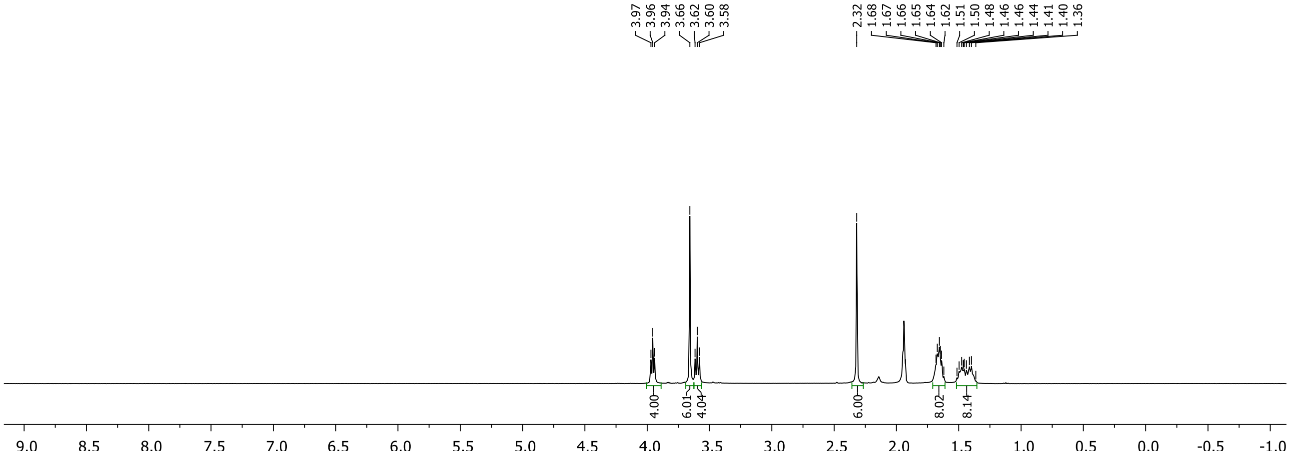

Figure S3. ^{1}H NMR (400 MHz, CD_3CN)**:** δ/ppm = 1.53-1.31 (m, 8H), 1.74-1.59 (m, 8H), 2.32 (s, 6H), 3.60 (t, *J* = 7.2 Hz, 4H), 3.66[3] (s, 6H), 3.96 (t, *J* = 5.9 Hz, 4H).

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[2] Zeghida, W.; Besnard, C.; Lacour, J. *Angew. Chem. Int. Ed.* **2010**, *49*, 7253-7256.

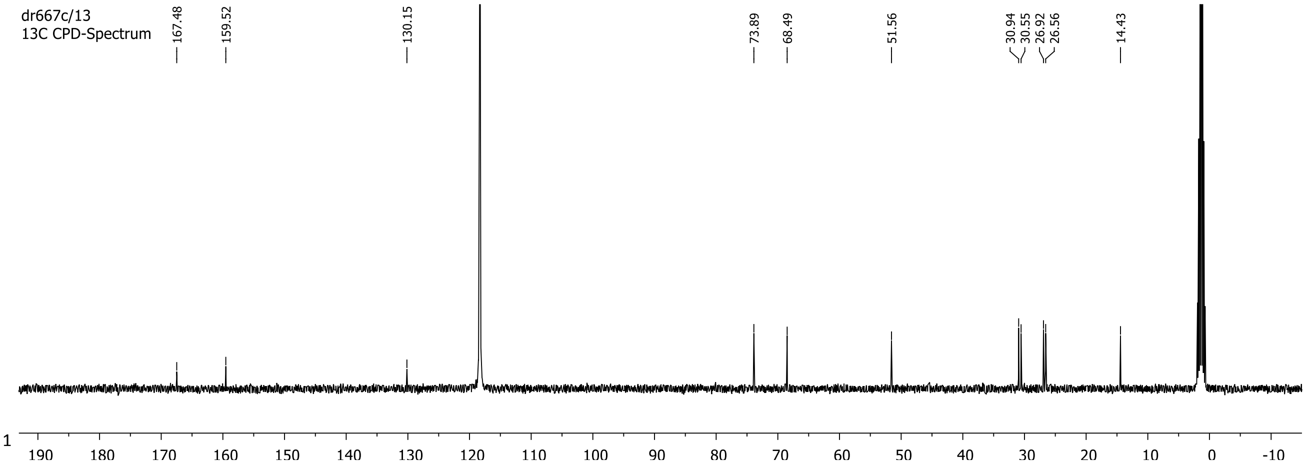

Figure S4. ^{13}**C NMR** (101 MHz, CD_3CN): δ/ppm : 14.4 ($2CH_3$), 26.5 ($2CH_2$), 26.9 ($2CH_2$), 30.5 ($2CH_2$), 30.9 ($2CH_2$), 51.5 ($2CH_3$), 68.4 ($2CH_2$), 73.8 ($2CH_2$), 130.1 (2C), 159.5 (2C), 167.4 (2C).

IR (neat): $\tilde{\nu}$ /cm^{-1} 2936, 2860, 1703, 1609, 1439, 1384, 1271, 1192, 1151, 1086, 997, 774 cm^{-}

HR-ESI: m/z = 429.2487 $[M+H]^+$ (calculated for $C_{22}H_{36}O_8$ m/z = 429.2483).

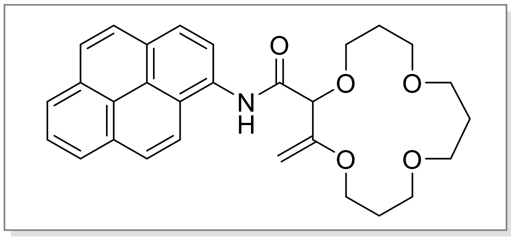

Figure S5. 15C4.

Yield: 85% of red crystalline solid (140 mg)

M. p. 119 °C - 120 °C (crystallized from CH_2Cl_2 / Heptane)

$\mathbf{R}_f$: 0.48 (silica gel, mobile phase EtOAc)

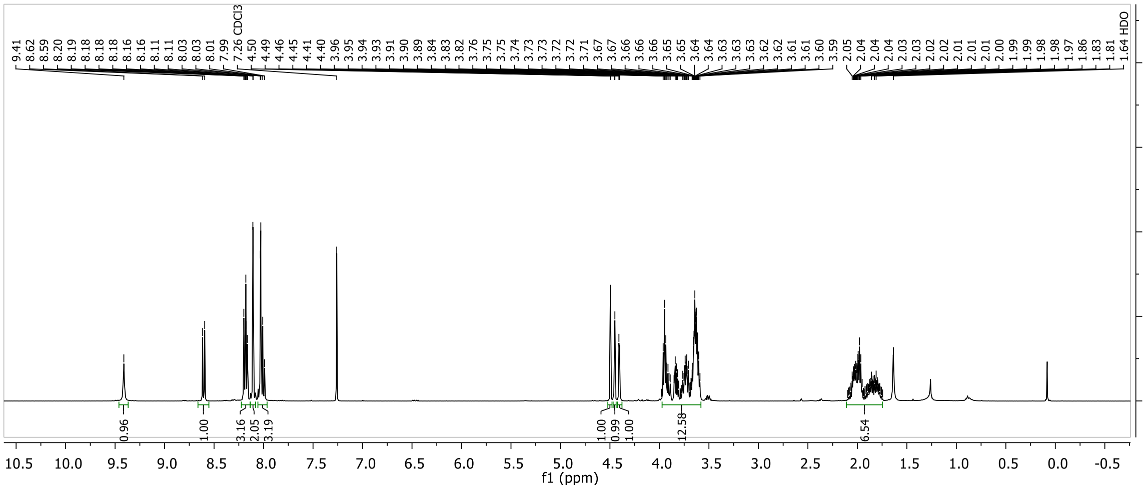

Figure S6. ^{1}**H NMR** (400 MHz, $CDCl_3$): δ/ppm = 1.75 – 2.10 (m, 6H), 3.59 – 3.98 (m, 12H), 4.41 (d, *J* = 2.6 Hz, 1H), 4.45 (d, *J* = 2.6 Hz, 1H), 4.50 (s, 1H), 7.99 – 8.03 (m, 3H), 8. 1 (s, 2H),8.16 – 8.20 (m, 3H), 8.60 (d, *J* = 8.3 Hz, 1H) 9.41 (s, 1H).

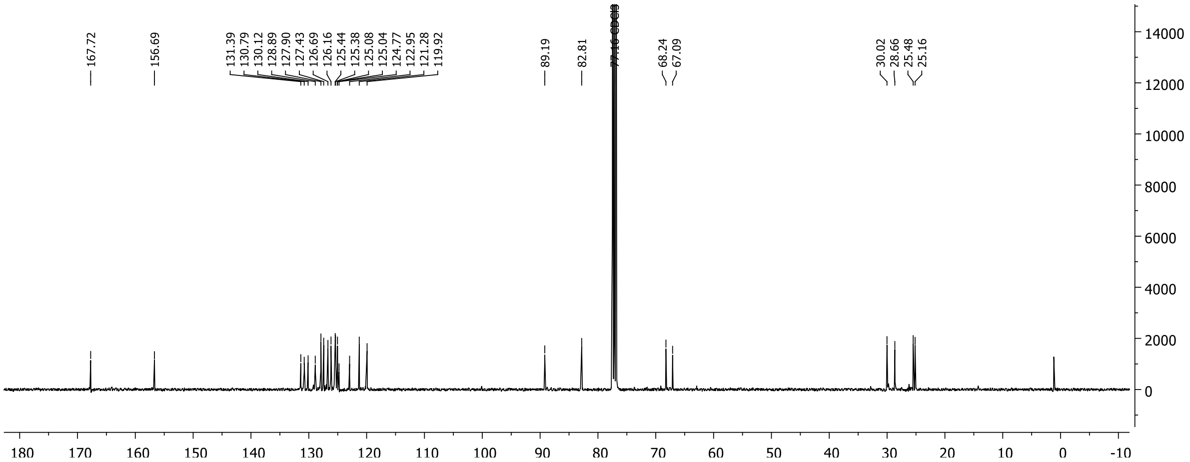

Figure S7. ^{13}**C NMR** (101 MHz, $CDCl_3$): δ/ppm = 29.45 (1CH_2), 30.58 (1CH_2), 30.97 (1CH_2), 63.82 (1CH_2), 66.55 (1CH_2), 66.90 (1CH_2), 67. 00 (2CH_2), 67. 53 (1CH_2), 83. 10 (1CH), 88. 36 (1CH_2),120.10 (1CH), 121.29 (1CH), 123.03 (1C), 124.94 (1CH), 125.08 (1C), 125.30 (1C), 125.52 (1CH), 125.57 (1CH), 126.28 (1CH), 126.82 (1CH), 127.53 (1CH), 128.01 (1CH), 129.04 (1C), 130.22 (1C), 130.93 (1C), 131.52 (1C), 157.93 (1C), 167.89 (1C).

IR (neat): $\tilde{\nu}$ /cm^{-1} = 3382, 2867, 1695, 1624, 1555, 1512, 1484, 1325, 1207, 1121, 1086, 1031, 1014, 850, 815, 756, 709, 613.

HR-ESI: m/z = 474.2281 [M+H]$^+$ (calculated for $C_{29}H_{31}NO_5$ m/z = 474.2275)

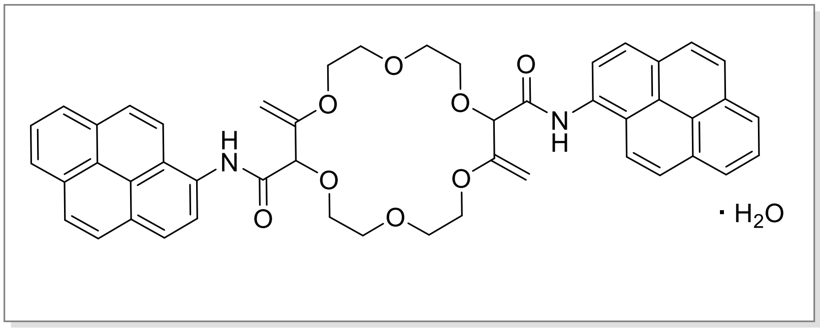

Figure S8. 18C6.

Yield: 60 % of off white solid (115 mg)

X-ray crystallized from CH_2Cl_2/ heptane (see crystallographic section)

R$_f$: 0.28 (silica gel, mobile phase MeOH/ CH_2Cl_2 5/95)

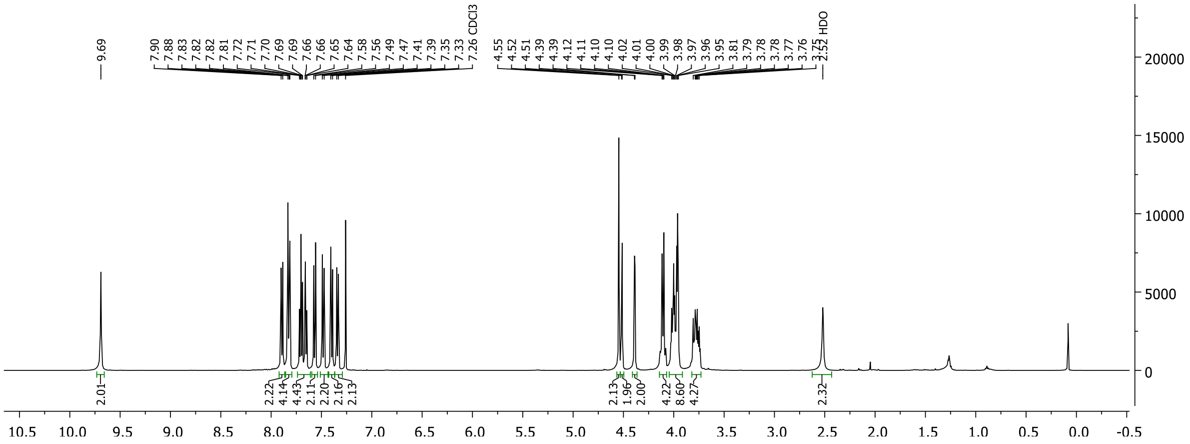

Figure S9. ^{1}H NMR (500 MHz, $CDCl_3$): δ/ppm = 2.52 (bs, H_2O), 3.74 – 3.81 (m, 4H), 3.95 – 4.03 (m, 8H), 4.08 – 4.13 (m, 4H), 3.98 – 4.01 (m, 2H), 4.39 (d, *J* = 2.7 Hz, 2H), 4.52 (d, *J* = 2.7 Hz, 2H), 4.55 (s, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 7.40 (d, *J* = 8.8 Hz, 2H), 7.48 (d, *J* = 9.1 Hz, 2H), 7.57 (d, *J* = 8.8 Hz, 2H), 7.64 – 7.66 (m, 2H), 7.70 (t, *J* = 7.5 Hz, 2H), 7.81 – 7.83 (m, 4H), 7.89 (d, *J* = 8.1 Hz, 2H), 9.69 (s, 2H).

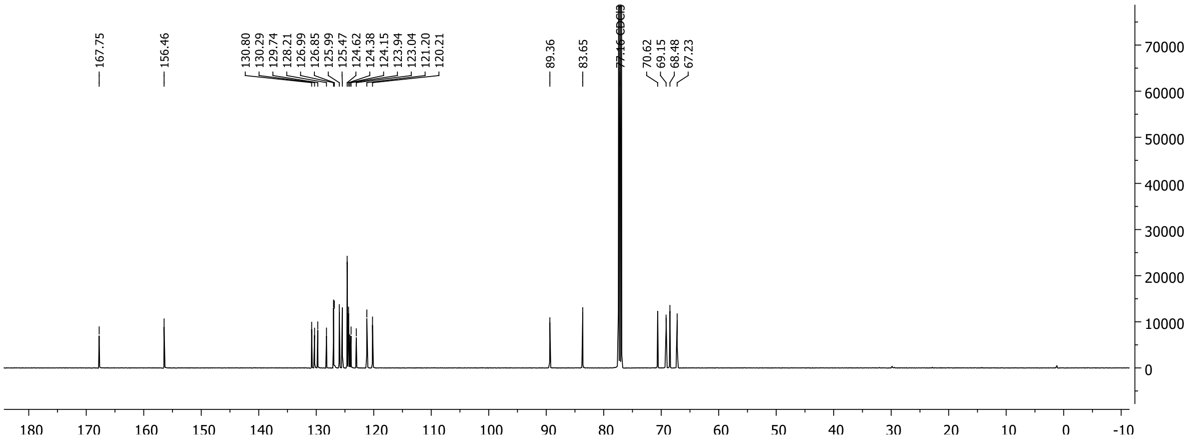

Figure S10. ^{13}**C NMR** (126 MHz, $CDCl_3$): δ/ppm = 67.23 ($2CH_2$), 68.48 ($2CH_2$), 69.15 ($2CH_2$), 70.62 ($2CH_2$), 83.65 (2CH), 89.36 ($2CH_2$), 120.21 (2CH), 121.20 (2CH), 123.04 (2C), 123.94 (2C), 124.15 (2C), 124.38 (2CH), 124.62 (4CH), 125.47 (2CH), 125.99 (2CH), 126.85 (2CH), 126.99 (2CH), 128.21 (2C), 129.74 (2C), 130.29 (2C), 130.80 (2C), 156.46 (2C), 167.75 (2C).

IR (neat): $\tilde{\nu}$ /cm^{-1} = 3371, 2923, 2874, 2240, 1684, 1637, 1599, 1557, 1520, 1487, 1415, 1368, 1287, 1187, 1135, 1096, 1074, 990, 908, 838, 759, 712, 645.

HR-ESI: m/z = 775.3034 $[M+H]^+$ (calculated for $C_{48}H_{42}N_2O_8$ m/z = 775.3014)

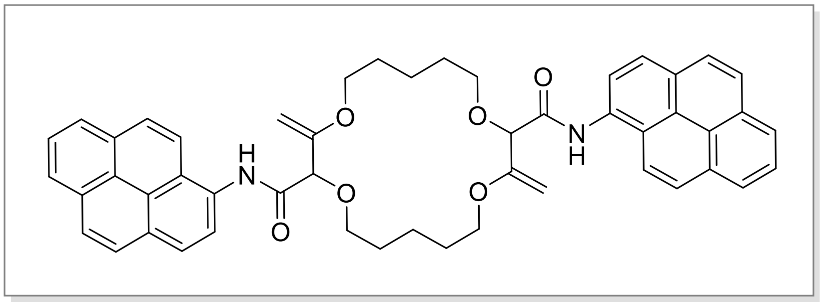

Figure S11. 18C4.

Yield: 70% of pink non crystalline solid (135 mg)

R$_f$: 0.6 (silica gel, mobile phase EtOAc)

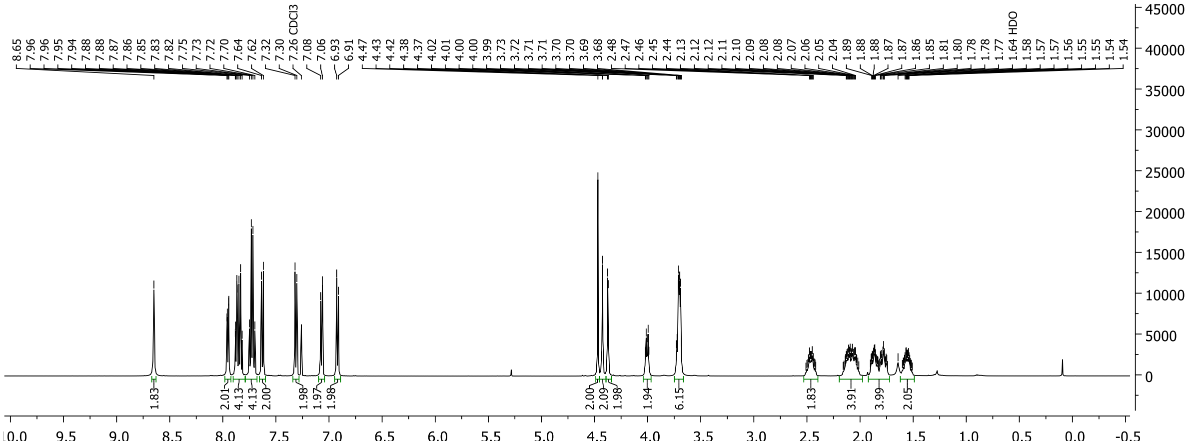

Figure S12. ^{1}H NMR (500 MHz, CDCl$_3$): δ/ppm = 1.51 – 1.60 (m, 2H), 1.75 – 1.90 (m, 4H), 2.01 – 2.16 (m, 4H), 2.42 – 2.51 (m, 2H), 3.68 – 3.73 (m, 6H), 3.99 – 4.02 (m, 2H), 4.37 (d, *J* = 2.5 Hz, 2H), 4.43 (d, *J* = 2.5 Hz, 2H), 4.47 (s, 2H), 6.92 (d, *J* = 8.1 Hz, 2H), 7.07 (d, *J* = 8.0 Hz, 2H), 7.31 (d, *J* = 8.8 Hz, 2H), 7.63 (d, *J* = 8.8 Hz, 2H), 7.72 (q, *J* = 9.1 Hz, 4H), 7.82 – 7.88 (m, 4H), 7.95 (dd, *J* = 7.3, 1.3 Hz, 2H), 8.65 (s, 2H).

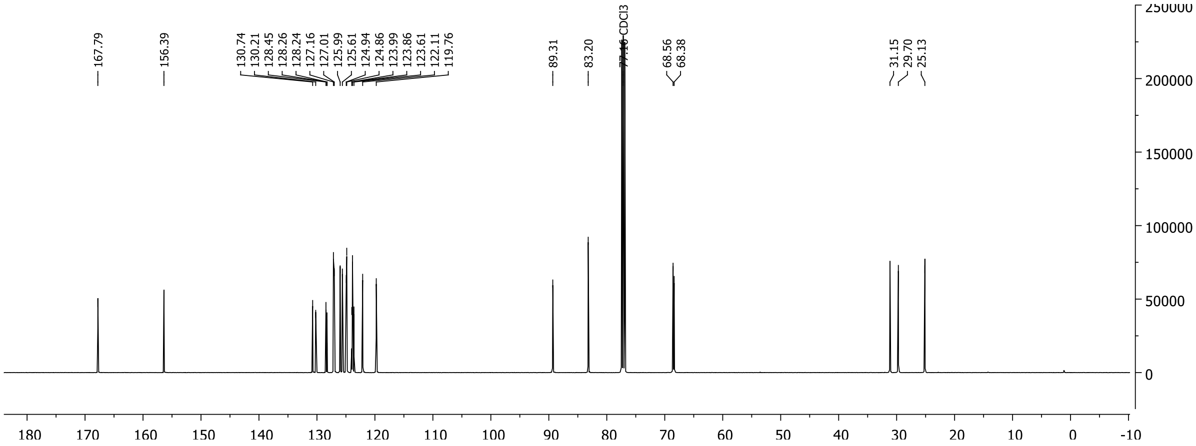

Figure S13. ^{13}**C NMR** (126 MHz, CDCl$_3$): δ/ppm = 25.13 (2CH$_2$), 29.70 (2CH$_2$), 31.15 (2CH$_2$), 68.38 (2CH$_2$), 68.56 (2CH$_2$), 83.20 (2CH), 89.31 (2CH$_2$), 119.76 (2CH), 122.11 (2CH), 123.61 (2C), 123.86 (2CH), 123.86 (2C), 123.99 (2C), 124.86 (2CH), 124.94 (2CH), 125.61 (2CH), 125.99 (2CH), 127.01 (2CH), 127.16 (2CH), 128.26 (2C), 128.45 (2C), 130.21 (2C), 130.74 (2C), 156.39 (2C), 167.79 (2C).

IR (neat): $\tilde{\nu}$ /cm^{-1} = 3386, 2923, 2875, 1692, 1628, 1556, 1516, 1487, 1368, 1281, 1187, 1086, 837, 751, 710, 562.

HR-ESI: m/z = 771.3429 [M+H]$^+$ (calculated for C$_{50}$H$_{46}$N$_2$O$_6$ m/z = 771.3429)

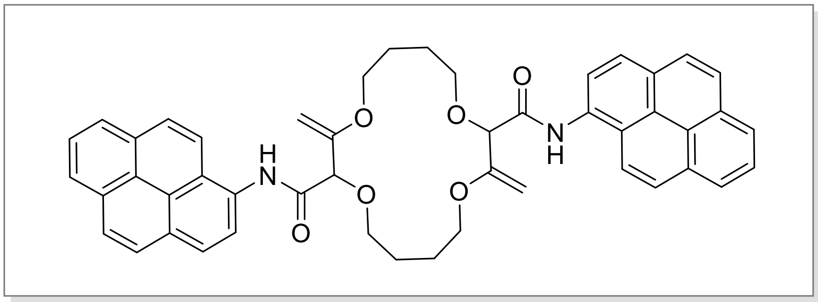

Figure S14. 16C4.

Yield: 80% of maroon solid (160 mg)

M.p. 238 °C - 240 °C (crystallized from CH_2Cl_2 / Heptane)

R$_f$: 0.47 (silica gel, mobile phase EtOAc)

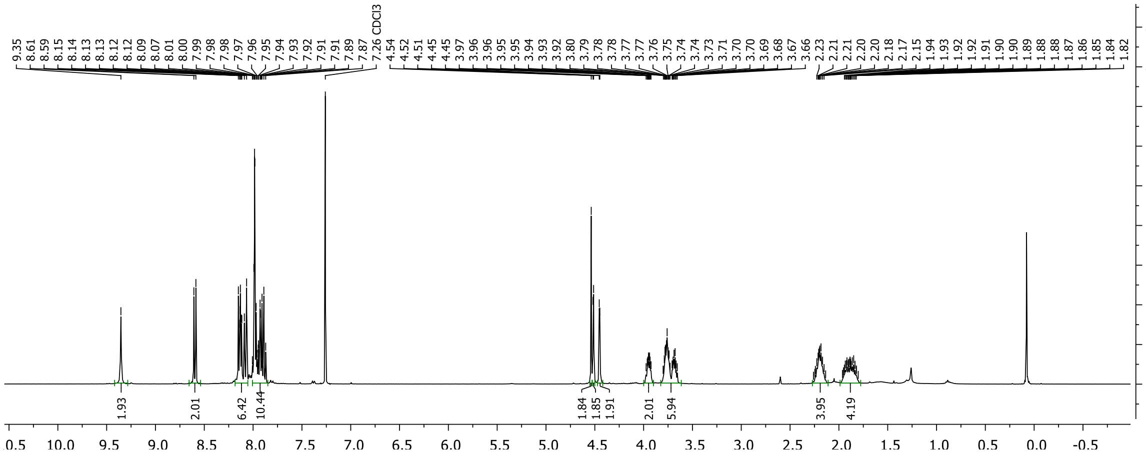

Figure S15. ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 1.80 – 1.96 (m, 4H), 2.14 – 2.26 (m, 4H), 3.66 – 3.80 (m, 6H), 3.92 – 3.97 (m, 2H), 4.45 (d, *J* = 2.5 Hz, 2H), 4.52 (d, *J* = 2.4 Hz, 2H), 4.54 (s, 2H), 7.87 – 8.01 (m, 10H), 8.07 – 8.15 (m, 6H), 8.60 (d, *J* = 8.3 Hz, 2H), 9.35 (s, 2H).

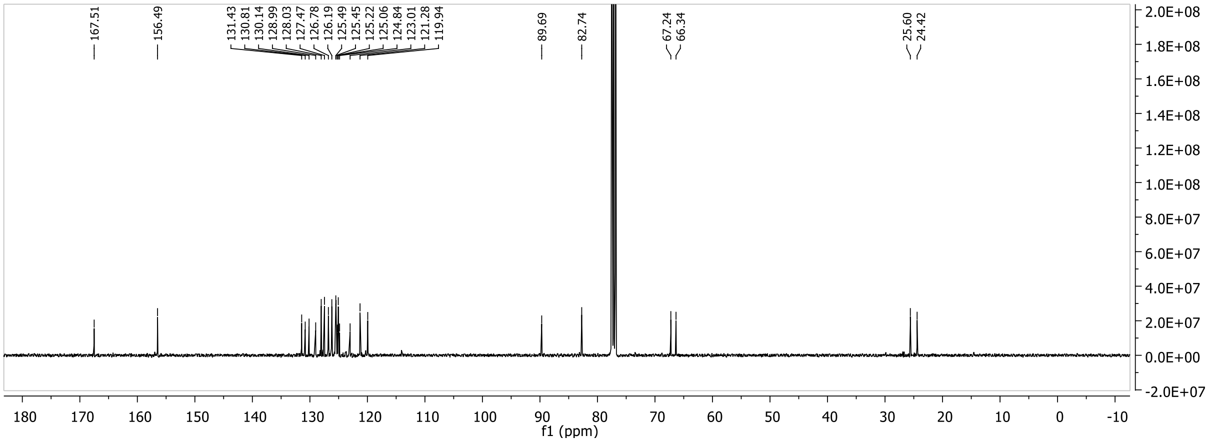

Figure S16. ^{13}**C NMR** (101 MHz, $CDCl_3$): δ/ppm = 24.42 ($2CH_2$), 25.60 ($2CH_2$), 66.34 ($2CH_2$), 67.24 ($2CH_2$), 82.74 (2CH), 89.69 ($2CH_2$), 119.94 (2CH), 121.28 (2CH), 123.01 (2C), 124.84 (2C), 125.06 (2CH), 125.22 (2C), 125.45 (2CH), 125.49 (2CH), 126.19 (2CH), 126.78 (2CH), 127.47 (2CH), 128.03 (2CH), 128.99 (2C), 130.14 (2C), 130.81 (2C), 131.43 (2C), 156.49 (2C), 167.51 (2C).

IR (neat): $\tilde{\nu}$ /cm^{-1} = 3399, 2940, 2869, 1692, 1628, 1597, 1519, 1485, 1366, 1274, 1093, 1030, 955, 839, 819,758, 711, 684, 588.

HR-ESI: m/z = 743.3128 $[M+H]^+$ (calculated for $C_{48}H_{42}N_2O_6$ m/z = 743.3116)

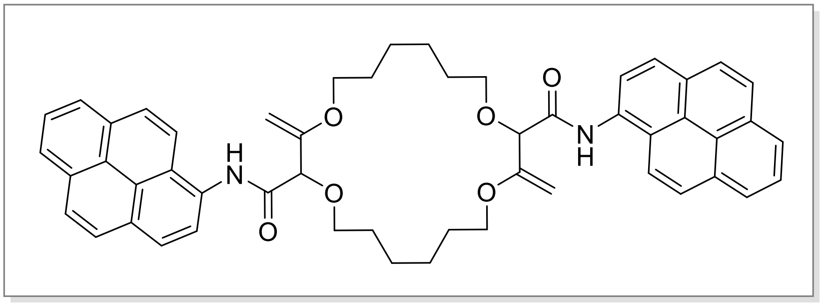

Figure S17. 20C4.

Yield: 35% of brown non crystalline solid (68 mg)

R$_f$: 0.53 (silica gel, mobile phase EtOAc)

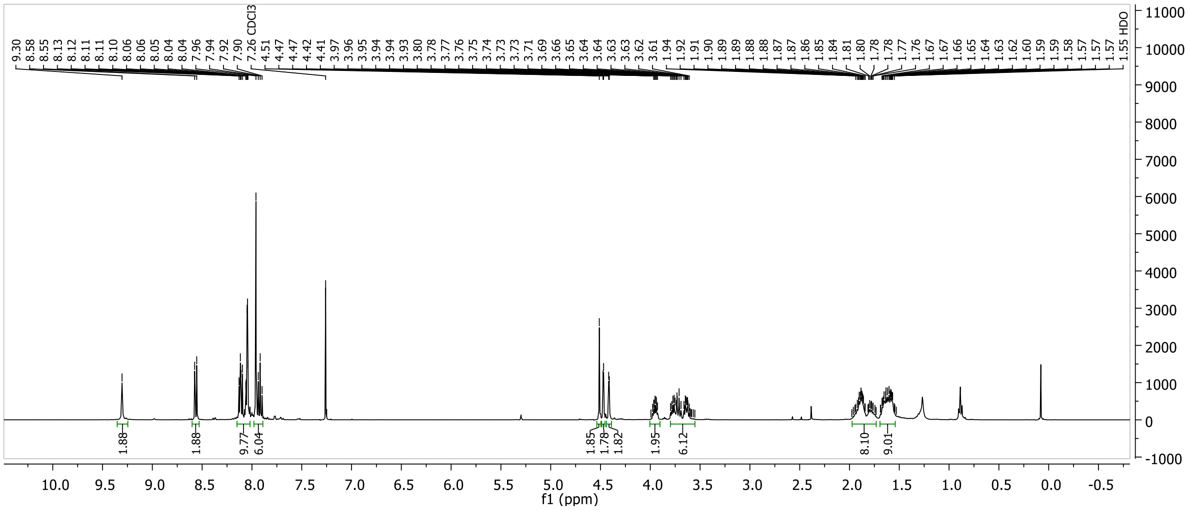

Figure S18. ^{1}H NMR (400 MHz, CDCl$_3$): δ/ppm = 1.53 – 1.69 (m, 8H), 1.73 – 1.98 (m, 8H), 3.55 – 3.80 (m, 6H), 3.93 – 3.99 (m, 2H), 4.41 (d, *J* = 2.4 Hz, 2H), 4.47 (d, *J* = 2.4 Hz, 2H), 4.51 (s, 2H), 7.90 – 7.96 (m, 6H), 8.04 – 8.13 (m, 10H), 8.56 (d, *J* = 8.3 Hz, 2H) 9.30 (s, 2H).

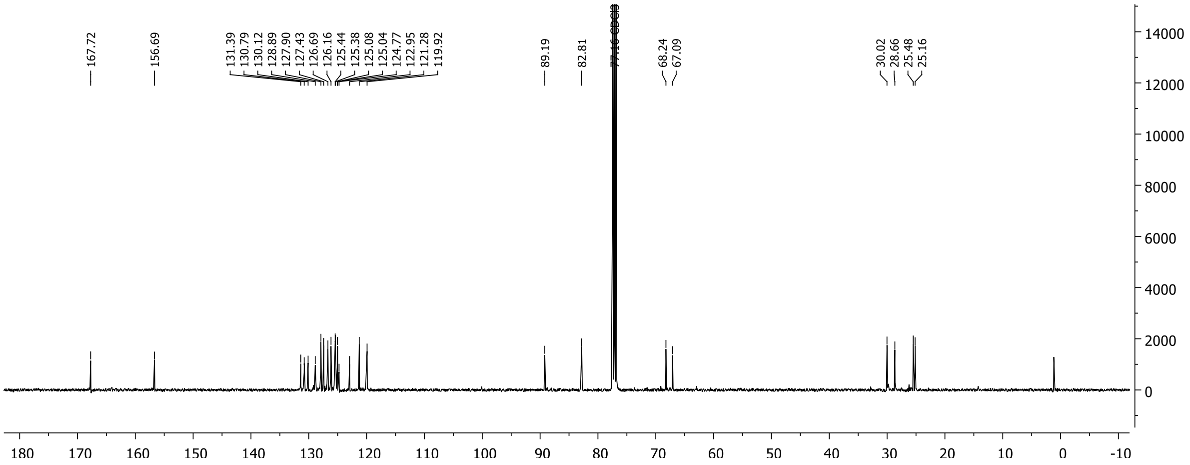

Figure S19. **^{13}C NMR** (101 MHz, $CDCl_3$): δ/ppm = 25.16 ($2CH_2$), 25.48 ($2CH_2$), 28.66 ($2CH_2$), 30.02 ($2CH_2$), 67.09 ($2CH_2$), 68.24 ($2CH_2$), 82.81 (2CH), 89. 19 ($2CH_2$), 119.92 (2CH), 121.28 (2CH), 122.95 (2C), 124.77 (2C), 125.04 (2CH), 125.12 (2C), 125.38 (2CH), 125.44 (2CH), 126.16 (2CH), 126.69 (2CH), 127.43 (2CH), 127.90 (2CH), 128.89 (2C), 130.12 (2C), 130.79 (2C), 131.39 (2C), 156.69 (2C), 167.72 (2C).

IR (neat): $\tilde{\nu}$ /cm^{-1} = 3383, 2928, 1686, 1600, 1557, 1517, 1486, 1261, 1186, 1082, 1015, 816, 758, 710.

HR-ESI: m/z = 799.3758 $[M+H]^+$ (calculated for $C_{52}H_{50}N_2O_6$ m/z = 799.3742)

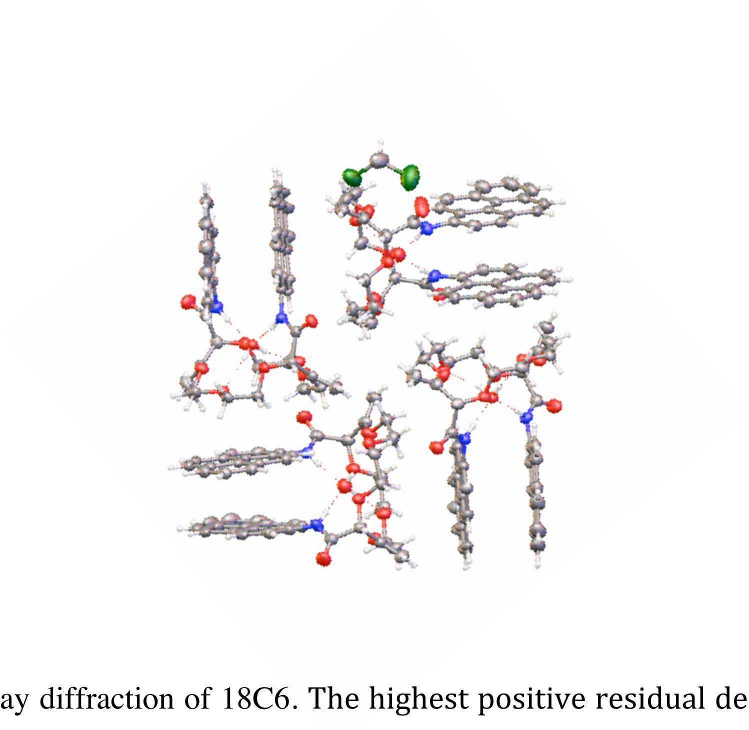

Figure S20. X – ray diffraction of 18C6. The highest positive residual density (2 eÅ^{-3}) is located near the chlorine atom of the solvent molecule, probably due to partial disorder. Hydrogen atoms of water molecules were found in the difference Fourier map and the water molecule was then refined as a rigid group.

Table S1. Detailed parameters of X – ray diffraction of 18C6.

CCDC number	**1045592**
Formula	$C_{193}H_{178}Cl_2N_8O_{36}$
$D_{calc.}$/ g cm^{-3}	1.342
μ/mm^{-1}	1.049
Formula Weight	3256.33
Colour	colorless
Shape	plate
Max Size/mm	0.23
Mid Size/mm	0.14
Min Size/mm	0.05
T/K	180(2)
Crystal System	triclinic
Space Group	P-1
a/Å	14.0049(2)
b/Å	23.6564(3)
c/Å	26.0431(4)
α/°	71.0350(10)
β/°	82.9750(10)
γ/°	82.2710(10)
V/Å^3	8057.2(2)
Z	2
Z'	1
Θ_{min}/°	3.07
Θ_{max}/°	73.39
Measured Refl.	137062
Independent Refl.	31950
Reflections Used	25045
R_{int}	0.0316
Parameters	2164
Restraints	0
Largest Peak	2.102
Deepest Hole	-1.243
GooF	0.996
wR_2 (all data)	0.1677
wR_2	0.1522
R_1 (all data)	0.0691
R_1	0.0533

Table S2. List of the membrane cocktail composition for the selectivity screening and the determination of the stability constant [mg].

	M1	M2	M3	M4	M5	M6	M7
NaTFPB	0.44	0.44	0.44	0.44	0.44	0.44	0.89
15C4	0.71	-	-	-	-	-	-
16C4	-	1.11	-	-	-	-	-
18C4	-	-	1.16	-	-	-	-
20C4	-	-	-	1.19	-	-	-
18C6	-	-	-	-	1.19	-	2.38
PVC	-	-	-	-	-	-	65.58
d-NPOE	98.89	98.85	98.40	98.85	98.79	98.79	131.16

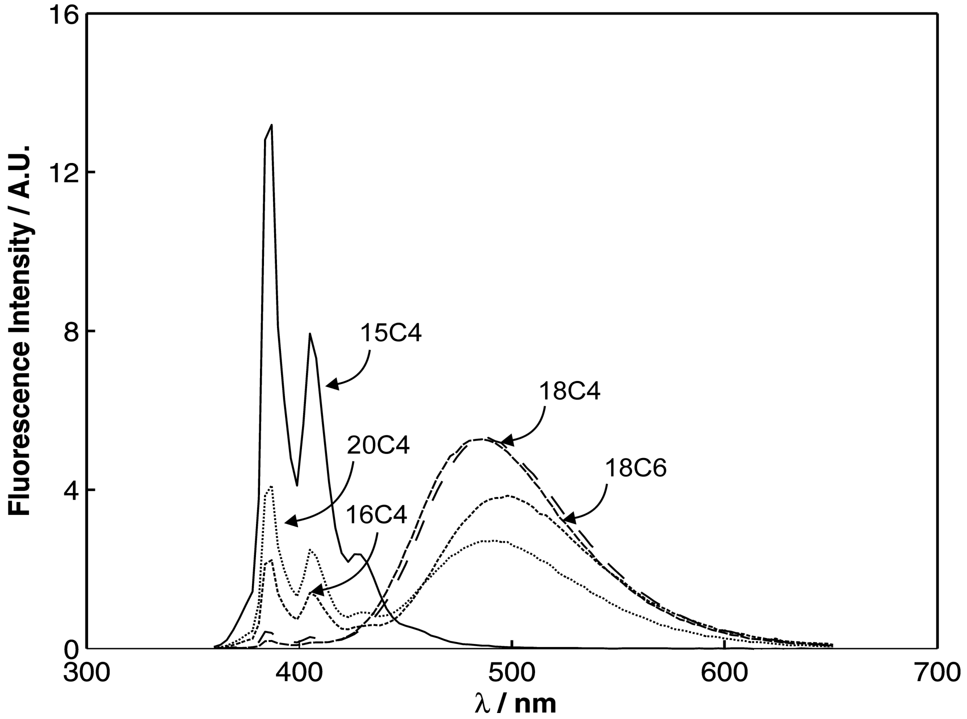

Figure S21. Emission spectra of synthesized compounds.

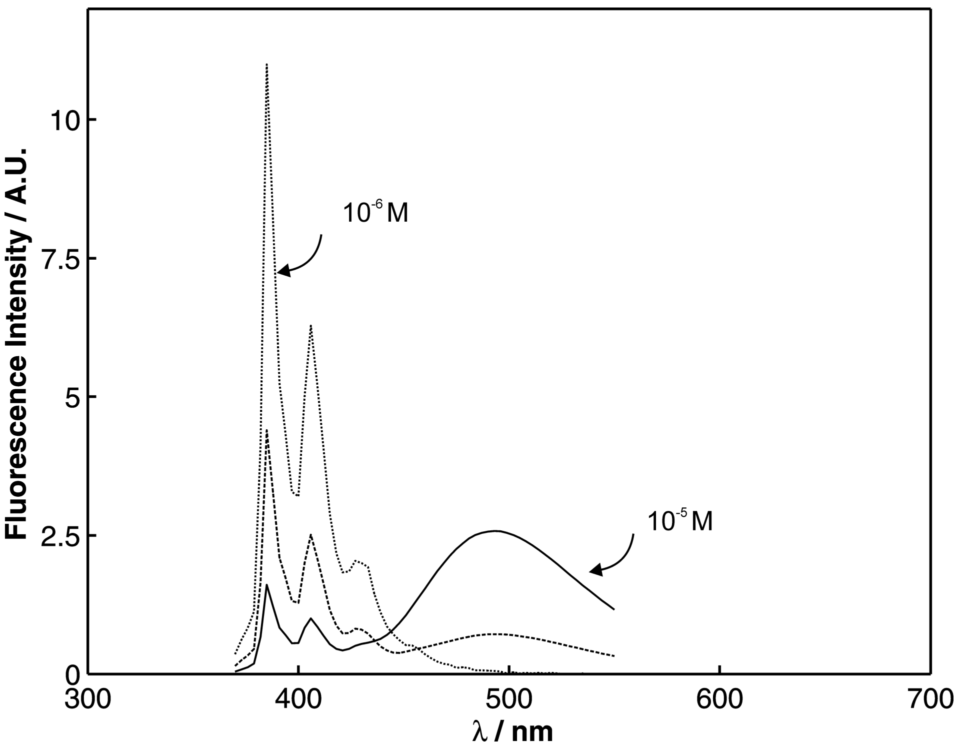

Figure S22. Normalized fluorescence intensities of emission of 15C4 and the excimer formation due to π-π stacking interaction between two pyreneamide arms.

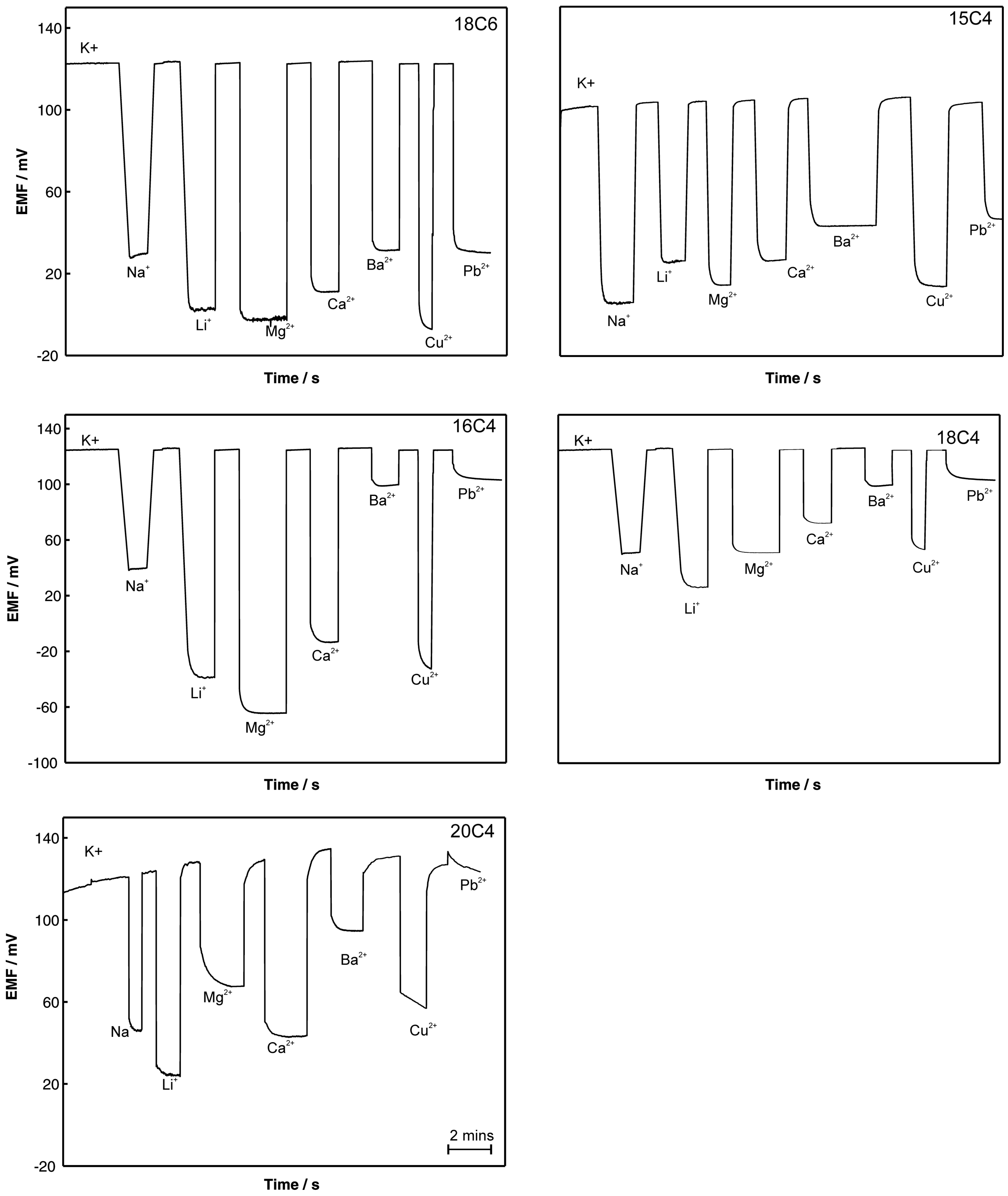

Figure S23. Selectivity screening of studied macrocyclic compounds.

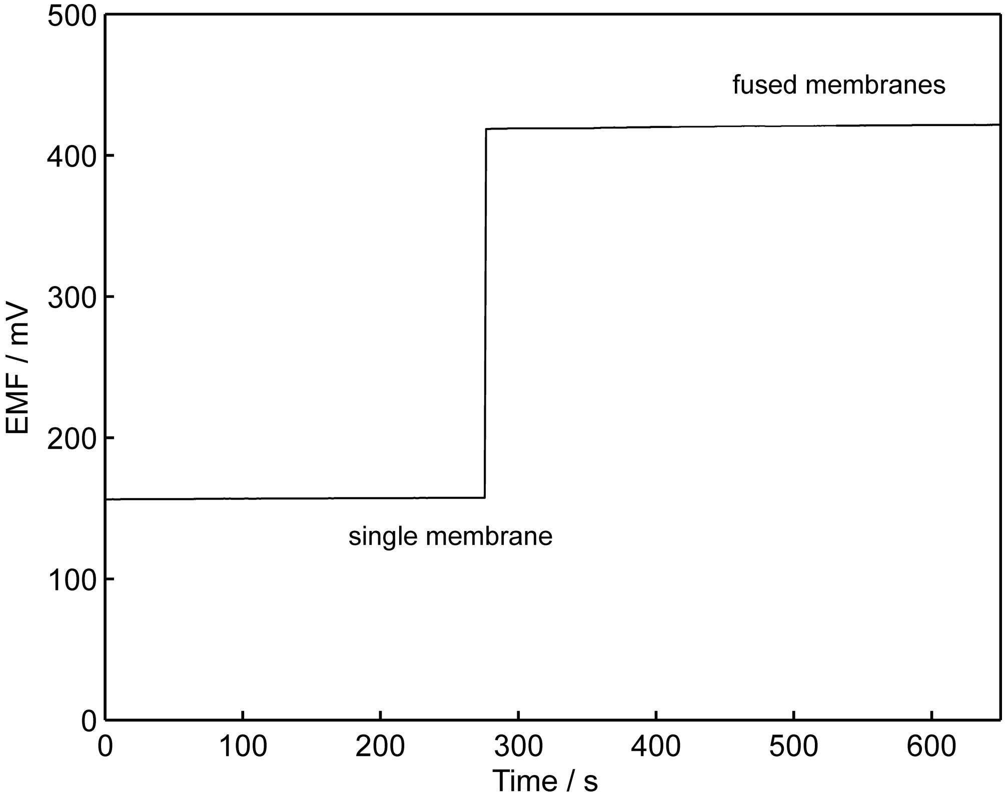

Figure S24. The observed potential changes of single membranes and fused membrane for determination of the complex formation constant using the segmented sandwich membrane method. This method is based on a direct measurement of potential arising from ligand-ion complexation. Two single membranes, one containing only the ion-exchanger salt and another one contains the same composition as the first with an additional ionophore, are well conditioned and examined under identical conditions in symmetrical setup (inner and outer filling solution are the same as one used for conditioning). Under symmetrical conditions (no concentration polarization on the phase boundaries) the membrane potential is zero and the observed potential of ISE corresponds to the sum of the constant potential contribution. The fusion of two single membranes results two different phase boundaries. On one side, the potential is dictated by ion-exchange process, while on the other side by ion-ionophore complexation and the potential difference is observed.

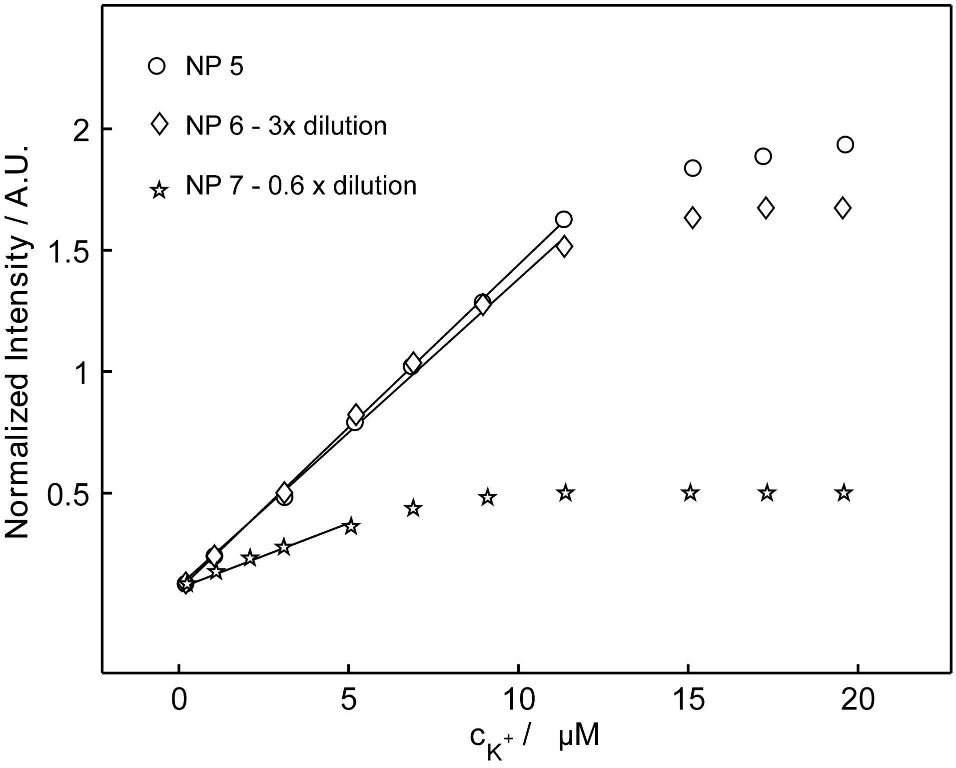

Figure S25. Optimization of the cocktail composition.