Supplementary Material

Toxicity and biodegradability of dicationic ionic liquids

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Synthesis of dicationic ionic liquids

1-methylimidazole and 1-methylpyrrolidinium were distilled over calcium hydride prior to use. Copper(I)bromide was purified by stirring in acetic acid for 2 days, washed with dry diethyl ether several times and dried in vacuum under an argon atmosphere. All other substances were used without further purification.

^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian Gemini 2000 FT-NMR spectrometer (400 MHz) and a Varian unity Inova 500 (500 MHz). MestRec-C software (version 4.9.9.6) was used for data interpretation. Deuterated chloroform ($CDCl_3$) and dimethylsulfoxide (DMSO-d_6) were used as solvents. All chemical shifts (δ) are relative to tetramethylsilane (TMS) and referenced to the significant solvent signals. Mass spectrometry measurements were performed on ESI-TOF BrukerDaltonics spectrometer. Melting points were observed with a Büchi B-540 apparatus (BÜCHI Labortechnik GmbH, Essen, Germany) at a 2 °C min^{-1} heating rate.

1. General procedure A for the synthesis of **1**-**6**

The synthesis was described in [1–3]. A mixture of dihaloalkane and 3 mol equivalent of 1-methylimidazole (for **1**-**4**), 1-butylimidazole (for **5**) or 1-hexylimidazole (**19**) (for **6**) in acetonitrile (toluene was used for **1**) was refluxed for 24-72 h. After cooling to room temperature the solids were collected by filtration, washed with THF (toluene was used for **1**) and ethyl acetate and dried under vacuum.

1.1. Synthesis of 1,1-bis(3-methylimidazolium-1-yl)methane diiodide (**1**)

3.3 g (12.4 mmol, 1.0 mL) diiodomethane and 3.1 g (38.2 mmol, 1.1 mL) 1-methylimidazole in 8 mL toluene were reacted according to the general procedure A (see 1.) to yield 1.8 g (47 % of the theoretical value) of **1** as a yellowish solid (melting point >260 °C, decomposition, as reported in [1]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.37 (s, 2H), 7.97 (t, J=1.7 Hz, 2H), 7.80 (t, J=1.6 Hz, 2H), 6.65 (s, 2H), 3.90 (s, 6H); as reported in [1]. ^{13}C (DMSO-d_6), δ (ppm): 137.9, 124.3, 121.8, 58.0, 36.3.

1.2. Synthesis of 1,2-bis(3-methylimidazolium-1-yl)ethane dibromide (**2**)

2.0 g (10.4 mmol, 0.9 mL) dibromoethane and 2.9 g (34.7 mmol, 1.0 mL) 1-methylimidazole in 12 mL acetonitrile were reacted according to the general procedure A (see 1.) to yield 2.4 g (64 % of the theoretical value) of **2** as a white solid (melting point 230 °C, similar as reported in [2]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.26 (s, 2H), 7.76 (t, J=1.6 Hz, 2H), 7.74 (t, J=1.7 Hz, 2H), 4.77 (s, 4H), 3.86 (s, 6H); similar as reported in [2]. ^{13}C (DMSO-d_6), δ (ppm): 137.0, 123.6, 122.1, 48.1, 35.8; as reported in [2].

1.3. Synthesis of 1,3-bis(3-methylimidazolium-1-yl)propane dibromide (**3**)

1.6 g (7.9 mmol, 0.8 mL) dibromopropane and 2.0 g (24.3 mmol, 0.7 mL) 1-methylimidazole in 10 mL acetonitrile were reacted according to the general procedure A (see 1.) to yield 1.8 g (61 % of the theoretical value) of **3** as a white solid (melting point 161 °C, similar as reported in [3]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.34 (s, 2H), 7.87 (t, J=1.8 Hz, 2H), 7.77 (t, J=1.7 Hz, 2H), 4.27 (t, J=6.9 Hz, 4H), 3.87 (s, 6H), 2.41 (quin, J=6.9 Hz, 2H); similar as reported in [3]. ^{13}C (DMSO-d_6), δ (ppm): 136.8, 123.6, 122.1, 45.5, 35.8, 29.4.

1.4. Synthesis of 1,6-bis(3-methylimidazolium-1-yl)hexane dibromide (**4**)

1.6 g (6.5 mmol, 1.0 mL) dibromohexane and 1.7 g (20.8 mmol, 0.6 mL) 1-methylimidazole in 10 mL acetonitrile were reacted according to the general procedure A (see 1.) to yield 1.3 g (47 % of the theoretical value) of **4** as a white solid (melting point 157 °C, similar as reported in [3]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.27 (s, 2H), 7.83 (t, J=1.7 Hz, 2H), 7.74 (t, J=1.7 Hz, 2H), 4.18 (t, J=7.2 Hz, 4H), 3.86 (s, 6H), 1.78 (m, 4H), 1.26 (m, 4H); similar as reported in [1,3]. ^{13}C (DMSO-d_6), δ (ppm): 136.4, 123.5, 122.2, 48.5, 35.7, 29.0, 24.7.

1.5. Synthesis of 1,2-bis(3-butylimidazolium-1-yl)ethane dibromide (**5**)

2.6 g (13.9 mmol, 1.2 mL) dibromoethane and 4.7 g (38.1 mmol, 5.0 mL) 1-butylimidazole in 15 mL acetonitrile were reacted according to the general procedure A (see 1.) to yield 3.7 g (65 % of the theoretical value) of **5** as a white solid (melting point 167 °C, as reported in [2]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.36 (s, 2H), 7.86 (t, J=1.7 Hz, 2H), 7.77 (t, J=1.7 Hz, 2H), 4.78 (s, 4H), 4.17 (t, J=7.2 Hz, 4H), 1.74 (m, 4H), 1.19 (m, 4H), 0.88 (t, J=7.4 Hz, 6H); similar as reported in [2]. ^{13}C (DMSO-d_6), δ (ppm): 136.5, 122.7, 122.4, 48.6, 48.2, 31.1, 18.6, 13.2.

1.6. Synthesis of 1,2-bis(3-hexylimidazolium-1-yl)ethane dibromide (**6**)

1-hexylimidazole (**19**) was prepared as follows: 1.5 g (22.2 mmol) imidazole was dissolved in 1.1 g 50 % NaOH solution (26.7 mmol). 3.7 g (22.1 mmol, 3.1 mL) 1-bromohexane and 15 mL THF were added and the mixture refluxed for 3 days. After cooling to room temperature, THF was removed by rotary evaporation and the residue extracted 3 times with CH_2Cl_2/H_2O. The combined organic phases were washed with water and dried over anhydrous Na_2SO_4. After filtration the organic solvent was removed by rotary evaporation and the product dried under vacuum. 1H-NMR indicated the presence of starting material. The crude product was therefore purified by column chromatography through a silica-gel column with CH_2Cl_2:CH_3OH (10:1) to yield 2.2 g (66 % of the theoretical value) of **19** as a yellowish oil.

NMR: ^{1}H ($CDCl_3$), δ (ppm): 7.46 (s, 1H), 7.05 (s, 1H), 6.90 (s, 1H), 3.92 (t, J=7.2 Hz, 2H), 1.77 (m, 2H), 1.29 (m, 6H), 0.88 (t, J=6.8 Hz, 3H); exactly as reported in [2]. ^{13}C (DMSO-d_6), δ (ppm): 137.0, 129.3, 118.7, 47.0, 31.2, 31.0, 26.2, 22.4, 13.9.

1.1 g (5.8 mmol, 0.5 mL) dibromoethane and 2.1 g (14.1 mmol) **19** in 10 mL acetonitrile were reacted according to the general procedure A (see 1.) to yield 1.9 g (67 % of the theoretical value) of **6** as a white solid (melting point 231 °C, similar as reported in [2]).

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.27 (s, 2H), 7.84 (t, J=1.7 Hz, 2H), 7.73 (t, J=1.7 Hz, 2H), 4.75 (s, 4H), 4.15 (t, J=7.3 Hz, 4H), 1.75 (m, 4H), 1.26 (m, 12H), 0.86 (t, J=6.9 Hz, 6H); similar as reported in [2]. ^{13}C (DMSO-d_6), δ (ppm): 136.5, 122.7, 122.4, 48.9, 48.3, 30.5, 29.1, 25.0, 21.8, 13.8 corresponding to the values reported in [2].

2. General procedure B for the synthesis of **7** and **8**

The synthesis was described in [4]. TEG was functionalized to α,ω-dichloro-3,6,9-trioxaundecane (**20**) as described in [5].

NMR: ^{1}H ($CDCl_3$), δ (ppm): 3.74 (t, J=5.79 Hz, 4H), 3.69-3.63 (m, 8H), 3.61 (t, J=5.93 Hz, 4H), ^{13}C ($CDCl_3$), δ (ppm): 70.7, 71.4, 42.8.

About 1 mmol of **20** was added to 3 mmol of the corresponding amine in 5 mL of toluene. The reaction mixture was heated under reflux at 110 °C for 20 h. After cooling to room temperature the lower phase was separated and washed three times with 5 mL of toluene. The viscous liquid obtained was dissolved in a small amount of methanol and precipitated in ethyl acetate. After decantation of the ethyl acetate the yellowish product was dried under high vacuum.

2.1. Synthesis of bis-1,11-[(3-methyl-1H-imidazolium-1-yl)]-(3,6,9-trioxaundecane) dichloride (**7**)

20 (0.23 g, 1 mmol) and 1-methylimidazole (0.24 g, 3 mmol) were reacted according to the general Procedure B (see 2.) to yield 0.32 g (85 % of the theoretical value) of **7**.

NMR: ^{1}H (DMSO-d_6), δ (ppm): 9.3 (s, 2H), 7.78 (s, 2H), 7.75 (s, 2H), 4.37 (t, J=4.9 Hz, 4H), 3.88 (s, 6H), 3.77 (t, J=3.4 Hz, 4H), 3.55–3.52 (m, 4H), 3.48–3.46 (m, 4H). ^{13}C (DMSO-d_6), δ (ppm): 136.7, 123.1, 122.4, 69.4, 68.0, 48.5, 35.6.

MS: ESI-TOF, m/z (%), negative mode: found: 429.11 (100) $[C_{16}H_{28}Cl_2N_4O_3Cl_3]^-$, calculated: 429.12.

2.2. Synthesis of bis-1,11-[(1-methyl-pyrrolidinium-1-yl)]-(3,6,9-trioxaundecane) dichloride (**8**)

20 (0.23 g, 1 mmol) and 1-methylpyrrolidine (0.26 g, 3 mmol) were reacted according to the general Procedure B (see 2.) to yield 0.328 g (82 % of the theoretical value) of **8**.

NMR: ^{1}H (DMSO-d_6), δ (ppm): 4.39 (t, J=4.4 Hz, 4H), 3.64 (t, J=4.4 Hz, 4H), 3.60–3.51 (m, 16H), 3.08 (s, 6H), 2.15 (b, 8H). ^{13}C (DMSO-d_6), δ (ppm): 69.3, 64.4, 63.9, 61.7, 47.9, 20.8.

MS: ESI-TOF, m/z (%), negative mode: found: 435.18 (100) $[C_{18}H_{38}Cl_3N_2O_3]^-$, calculated: 435.19.

3. General procedure C for the synthesis of **9** and **10**

The synthesis was described in [4]. HEG was functionalized to α,ω-dibromo-3,6,9,12,15-pentaoxaheptadecane (**21**) as described in [5] and further modified to α,ω-diazido-3,6,9,12,15-

pentaoxaheptadecane (**22**): **21** (5.19 g, 16.26 mmol) was dissolved in N,N-dimethylformamide followed by the slow addition of sodium azide (5.29 g, 81.30 mmol). The reaction mixture was then stirred for 72 h at 70 °C, filtered, after which the solvent was removed under reduced pressure. The product was purified by column chromatography through a silica-gel column with $CHCl_3$:CH_3OH (10:1) to yield 5.0 g (93 % of the theoretical value) of **22** as a yellow liquid.

NMR: ^1H ($CDCl_3$), δ (ppm): 3.58 (m, 20H), 3.30 (t, J=5.0 Hz,4H). ^{13}C ($CDCl_3$), δ (ppm): 70.5, 69.9, 50.5.

22 (1.0 mol equivalent), alkyne ligands (**23** and **24**) (2 mol equivalents), DIPEA (6 mol equivalents) and copper(I)bromide (CuBr) (0.2 mol equivalents with respect to **22**) were dissolved in a mixture of the solvents H_2O/DMF (1:1) under an atmosphere of nitrogen and then heated in an oil bath (70 °C). On completion of the reaction the solvent was removed under reduced pressure. The crude product was dissolved in methanol and filtered through Al_2O_3 to remove excess CuBr. Subsequently, the solvent was evaporated and the product was purified by precipitation with CH_3OH:ethyl acetate (0.5:5). The desired product was dried under high vacuum for 24 h.

3.1. Synthesis of bis-1,17-[4-(3-methyl-1H-imidazolium-1-yl)methylene-1H-1,2,3-triazole-1-yl]-(3,6,9,12,15-pentaoxaheptadecane) di(methanesulfonate) (**9**)

3-Methylimidazolium-1-propargyl methanesulfonate (**23**) was prepared as follows: 1-Methylimidazole (1.02 g, 12.43 mmol) and propargyl methanesulfonate (1.39 g, 10.36 mmol) were reacted for 20 h in dry toluene (25 mL) to yield 2.20 g (98 % of the theoretical value) of **23** as a yellow solid.

NMR: ^1H (DMSO-d_6), δ (ppm): 9.22 (s, 1H), 7.78 (t, J=1.8 Hz, 1H), 7.74 (t, J=1.8 Hz, 1H), 5.18 (d, J=2.6 Hz, 2H), 3.86 (s, 3H), 3.81 (t, J=2.6 Hz, 1H), 2.30 (s, 3H). ^{13}C (DMSO-d_6), δ (ppm): 137.2, 124.6, 122.6, 79.4, 76.6, 40.3, 38.9, 36.4.

Compound **9** was prepared according to the general Procedure C: a mixture of **22** (0.15 g, 0.45 mmol), **23** (0.19 g, 0.90 mmol), DIPEA (0.35 g, 2.70 mmol), and CuBr (0.013 g, 0.09 mmol) in H_2O/DMF (4 mL) was reacted to yield 0.34 g (98 % of the theoretical value) of **9** as a viscous brown liquid.

NMR: ^1H (DMSO-d_6), δ (ppm): 9.23 (s, 2H), 8.25 (s, 2H), 7.75 (t, J=1.8 Hz, 2H), 7.70 (t, J=1.8 Hz, 2H), 5.53 (s, 4H), 4.53 (t, J=5.3 Hz, 4H), 3.85 (s, 6H), 3.79 (t, J=5.3 Hz, 4H), 3.47 (m, 16H), 2.31 (s, 6H). ^{13}C (DMSO-d_6), δ (ppm): 140.8, 137.2, 125.4, 124.3, 122.8, 109.9, 70.0, 69.1, 50.0, 44.0, 36.3, 15.6.

MS: ESI-TOF, m/z (%), negative mode: found: 859.26 (100) $[C_{29}H_{51}N_{10}O_{14}S_3]^-$, 94.97 $[CH_3O_3S]^-$, calculated: 859.27, 94.98.

3.2. Synthesis of bis-1,17-[(methyl-pyrrolidinium-1-yl)methylene-1H-1,2,3-triazole-1-yl]-(3,6,9,12,15-pentaoxaheptadecane) di(methanesulfonate) (**10**)

3-Methylimidazolium-1-propargyl methanesulfonate (**24**) was prepared as follows: 1-Methylpyrrolidinium (1.74 g, 20.46 mmol) and propargyl methanesulfonate (1.83 g, 13.64 mmol) were reacted for 24 h in dry toluene (40 mL) to yield 2.74 g (92 % of the theoretical value) of **24** as a yellowish solid.

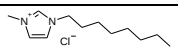
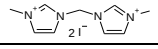
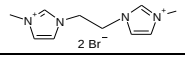
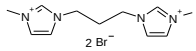
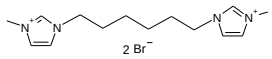
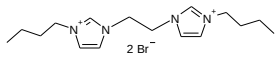
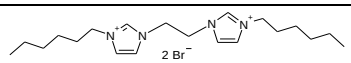
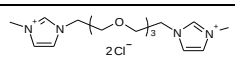
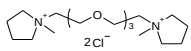
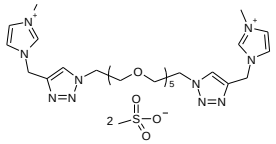
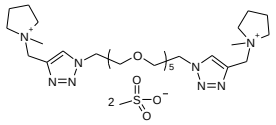
NMR: ^1H (DMSO-d_6), δ (ppm): 4.39 (d, J=2.5 Hz, 2H), 3.99 (t, J=2.5 Hz, 1H), 3.51 (m, 4H), 3.10 (s, 3H), 2.29 (s, 3H), 2.10 (m, 4H). ^{13}C (DMSO-d_6), δ (ppm): 82.4, 73.8, 63.7, 52.8, 49.4, 22.0.

Compound **10** was prepared according to the general Procedure C: a mixture of **22** (0.15 g, 0.45 mmol), **24** (0.20 g, 0.90 mmol), DIPEA (0.35 g, 2.70 mmol), and CuBr (0.013 g, 0.09 mmol) in H_2O/DMF (4 mL) was reacted to yield 0.35 g (100 % of the theoretical value) of **10** as a yellow viscous liquid.

NMR: ^{1}H (DMSO-d_6), δ (ppm): 8.40 (s, 2H), 4.67 (s, 4H), 4.58 (t, J=5.2 Hz, 4H), 3.82 (t, J=5.2 Hz, 4H), 3.49 (m, 24H), 2.96 (s, 6H), 2.30 (s, 6H), 2.09 (m, 8H). ^{13}C (DMSO-d_6), δ (ppm): 136.4, 128.7, 70.2, 69.0, 63.3, 56.7, 50.2, 48.6, 21.7.

MS: ESI-TOF, m/z (%), negative mode: found: 865.34 (100) $[C_{31}H_{61}N_8O_{14}S_3]^-$, 94.97 $[CH_3O_3S]^-$, calculated: 865.35, 94.98.

Tab. S1 Results for biodegradation and sludge respiration inhibition of DILs and reference compounds

		biodegradation [%]		
#	structure	primary degradation test	O_2 consumption test (OECD 301F)	IC_{50} [µM] sludge inhibition test (OECD 209)
Ref 1		100	n.d.[a]	n.d.[a]
Ref 2		100	n.d.[a]	1380 (1047-1819)[b]
Ref 3		n.d.[a]	84 ± 0.3	n.d.[a]
1		< 5	n.d.[a]	> 1000
2		< 5	n.d.[a]	> 1000
3		< 5	n.d.[a]	> 1000
4		< 5	0 ± 0.5	> 1000
5		< 5	n.d.[a]	> 1000
6		< 5	2 ± 2.5	380 (279-507)
7		< 5	n.d.[a]	> 1000
8		< 5	n.d.[a]	> 1000
9		< 5	n.d.[a]	> 1000
10		< 5	14 ± 2	> 1000

[a] not determined

[b] data taken from [6]

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