



Ammonium Salts Catalyzed Acetalization Reactions in Green Ethereal Solvents

Ugo Azzena ^{1,*}, Massimo Carraro ^{1,2}, Martina Corrias ¹, Rosella Crisafulli ¹, Lidia De Luca ¹, Silvia Gaspa ¹, Luca Nuvoli ¹, Salvatore Pintus ¹, Luisa Pisano ¹, Riccardo Polese ¹, Michela Sanna ¹, Giuseppe Satta ¹, Nina Senes ¹, Luigi Urtis ¹ and Sebastiano Garroni ^{1,*}

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1. Experimental Part

1.1 General Remarks

Starting materials were of the highest commercial quality and were employed as received, including silica gel (60 Å, 230-400 mesh). ¹H-NMR (400 MHz) and ¹³C-NMR (100 MHz spectra were recorded with a Bruker Ascend 400 spectrometer in CDCl₃ (99.8% D content) solution with the residual peak of CHCl₃ as internal standard. FTIR spectra of reaction products were recorded from KBr pellets on a Fourier Transform Infrared Spectrophotometer S2 on a Jasco FT/IR-480 Plus. Gas chromatographic analyses were recorded on a Agilent 6890N Network GC System on an Alltech Econo-Cap EC-WAX column 30 m x 0.32 mm I.D. x 0.25 µm under a constant flow (2 mL/min) of He in split mode (split ratio 50:1); injection volume 1 µL; injector temperature 280 °C, detector (FID) temperature 280 °C, oven temperature 40 °C × 4 min – 15 °C/min to 220 °C × 4 min. The HRMS spectra were acquired on a Thermo Finnigan Q Exactive instrument with API-HESI source. Samples were introduced as 0.1 mg/L solutions in MS grade methanol with a 5 μ L/min flow and the following source parameters: positive polarity; Sheath gas flow rate: 5 a.u.; Aux gas flow rate: 3 a.u.; Sweep gas flow rate: 0 a.u.; Spray voltage: 3.50 kV; Capillary temperature: 250 °C; S-lens RF level: 60,0 V; Aux gas heater temperature: 0 °C. The peroxide content of the solvents was tested employing semiquantitative test-strips Quantofix[®], measuring range 0.5 - 25 mg/L H₂O₂, in agreement with the general indications furnished by the producer.

1.2 General procedure for the acetalization reaction

In a 50 mL flask fitted with a Dean-Stark distiller and bubble condenser provided with a CaCl² valve(for reactions run in CPME or toluene) or under an Ar atmosphere (for reactions run in 2-MeTHF), the starting material (**1**, 80 mmol) was dissolved in the appropriate solvent (20 mL) together with the amount of the required diol (**2**, 88 to 160 mmol, 1.1 to 2.0 equiv), as reported in Tables 2 and 3 and Schemes 1 and 2 and equations 1-5. After addition of the appropriate catalyst (2.4 mmol, 3 mol % of the starting material), the reaction mixture was heated in an oil bath under vigorous stirring and allowed to reflux for 6 h, then cooled to rt and the reaction mixture was filtered. Reaction run in the presence of 1.5 to 2.0 equivalents of diol were then washed with H₂O (3 × 5 mL) and dried over anhydrous Na₂SO₄. The resulting solution was evaporated under reduced pressure and the crude product analysed by ¹H-NMR spectroscopy. No other product, besides starting material, was detected, unless otherwise indicated (Table 2 and Equation 1).

Recovery of the catalyst (washed twice with the reaction solvent and dried in vacuo) usually exceeded 90%.

1.3. Characterization of reaction products

Reaction products were identified by comparison with literature data and/or with authentic samples synthesized according to the literature, and characterized as follows:

2-Methyl-2-phenyl-1,3-dioxolane, **3a**:^{1,2} white crystals, mp 61-62 °C (CPME); ¹H-NMR (400 MHz, CDCl₃) δ (ppm) 1.66 (3H, s, CH₃), 3.73-3.83 (2H, m, CH₂O), 3.99-4.09 (2H, m, CH₂O), 7.29 (1H, t, *J* = 7.6 Hz, ArH), 7.35 (2H, t, *J* = 7.6 Hz, 2 × ArH), 7.48 (2H, d, *J* = 7.6 Hz, 2 × ArH); ¹³C-NMR (100 MHz, CDCl₃): δ (ppm) 27.6, 64.4, 108.8, 125.2, 127.8, 128.1, 143.2.

2-Phenyl-1,3-dioxolane, 3b:^{1,2} colourless oil which solidifies upon standing, bp 136-138 °C/30 mmHg; ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.90-7.88 (m, ArH-4), 7.50-7.48 (m, 2 H, ArH-3/5), 7.39-7.37 (m, 2 H, ArH-2/6), 5.82 (s, 1 H, OCHO), 4.16-3.99 (m, 4 H, OCH₂CH₂O); ¹³C NMR (CDCl₃; 100 MHz) δ =137.9, 129.1,128.3, 126.4, 103.7, 65.3.

2-(4-Nitrophenyl)-1,3-dioxolane, 3c:³ White powder, mp 89-90 °C (MeOH); ¹H NMR (400 MHz, CDCl₃) @ (ppm) 8.28-8.21 (m, 2 H, 2 × ArH), 7.69-7.67 (m, 2 H, 2 × ArH), 5.90 (s, 1 H, OCHO), 4.14-4.06 (m, 4 H, OCH₂CH₂O); ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 148.6, 145.1, 127.6, 123.7, 102.4, 65.6.

Spiro[1,3-dioxolane-2,3'-indolin]-2'-one, 3d:⁴ Light brown powder, mp 131-132 °C (CPME); ¹H NMR (400 MHz, DMSO-*d*₆) δ (ppm) 10.43 (br s, 1 H, NH), 7.35-7.31 (m, 2 H, ArH), 7.03-6.99 (m, 1 H,

ArH), 6.84-6.82 (m, 1 H, ArH), 4.36-4.21 (m, 4 H, OCH₂CH₂O); ¹³C NMR (100 MHz, DMSO-*d*₆) [∞] (ppm) 174.4, 142.8, 131.6, 124.9, 124.6, 122.4, 110.4, 101.6, 65.4.

2-(3,4,5-Trimethoxyphenyl)-1,3-dioxolane, **3ea**:⁵ light yellow oil, which solidifies upon standing; ¹H-NMR (400 MHz, CDCl₃) δ (ppm) 3.84 (3 H, s, CH₃O), 3.86 (6 H, s, 2 × CH₃O), 4.00-4.19 (4 H, m, 2 × CH₂), 5.75 (1 H, s, CHO₂), (2 H, s, 2 × ArH); ¹³C-NMR (CDCl₃; 100 MHz) δ (ppm) 153.3, 138.6, 132.2, 103.6, 103.2, 62.2, 60.8, 56.1.

Synthesis of 3,4,5-trimethoxybenzaldehyde dimethyl acetal, 3eb:^{5,6} In a 25 mL flask fitted with a bubble condenser provided with a CaCl₂ valve, 3.0 g of **1e** (15 mmol) was dissolved in CPME (10 mL) together with 1.4 mL of CH₃OH (0.034 mmol), 1,80mL of HC(OCH₃)₃ (16 mmol) and 0,053 g (0.45 mmol, 3 mol %) NH₄HSO₄-SiO₂ (25% w/w). The mixture was stirred at 65 °C during 6 h, then chilled to rt and filtered. The solvent was evaporated, and the crude product was analysed by ¹H-NMR spectroscopy to evaluate the conversion (92%), and characterized as following:

colourless viscous oil which solidifies upon standing: ¹H-NMR (400 MHz, CDCl₃) δ (ppm) 6,69 (2 H, s, 2 × ArH), 5,30 (1 H, s, CH), 3,88 (6 H, 2 × OCH₃), 3,85 (3 H, OCH₃), 3,35 (6 H, 2 × OCH₃); ¹³C-NMR (100 MHz, CDCl₃) δ 153.2, 138.0, 133.8, 103,6, 103.3, 60.8, 56.1, 52.9.

2-Methyl-2-naphthyl-4-ethyl-1,3-dioxolane, 3f:⁷ colourless viscous oil; IR (liquid film) 3057, 2965, 2935, 2878, 1600, 1507, 1463, 1442, 1371, 1351, 1272, 1259, 1220, 1189, 1130, 1099, 1069, 1038, 980, 950, 883, 860, 820, 758, 670 cm⁻¹; the two diastereoisomers were separated by flash chromatography (Hexane/AcOEt/TEA = 9.8:0.2:0.1) and characterized as follows:

first diastereoisomer, $R_f = 0.46$ (Hexane/AcOEt/TEA = 9.8:0.2:0.1); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.97 (s, 1 H, 1 x ArH), 7.88-7.83 (m, 3 H, 3 x ArH), 7.61-7.59 (m, 1 H, 1 x ArH), 7.51-7.48 (m, 2 H, 2 x ArH), 3.92 (m, 2 H, diast, H-5), 3.68 (t, *J* = 5.4 Hz, 1 H, H-4), 1.78 (m, 1 H, diast, CH₂CH₃), 1.76 (s, 3 H, CH₃-2), 1.66 (m, 1 H, diast, CH₂CH₃), 0.99 (t, *J* = 7.4 Hz, 3 H, CH₂CH₃); ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 141.4, 133.1, 133.1, 128.4, 128.2, 127.7, 126.2, 126.1, 124.1, 123.9, 109.1, 77.3, 69.3, 28.4, 26.8, 9.8.



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Second diastereoisomer: $R_f = 0.55$ (Hexane/AcOEt/TEA = 9.8:0.2:0.1); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.97 (s, 1 H, 1 x ArH), 7.88-7.83 (m, 3 H, 3 x ArH), 7.61-7.59 (m, 1 H, 1 x ArH), 7.51-7.48 (m, 2 H, 2 x ArH), 3.92 (m, 2 H, diast, H-5), 3.68 (t, *J* = 5.4 Hz, 1 H, H-4), 1.78 (m, 1 H, diast, CH₂CH₃), 1.76 (s, 3 H, CH₃-2), 1.66 (m, 1 H, diast, CH₂CH₃), 0.99 (t, *J* = 7.4 Hz, 3 H, CH₂CH₃); ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 141.37, 133.14, 133.10, 128.37, 128.19, 127.74, 126.21, 126.11, 124.06, 123.88, 109.14, 77.27, 69.26, 28.41, 26.83, 9.83.



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2-[2-[4-(1,1-Dimethylethyl)phenyl]-1-methylethyl]-1,3-dioxolane, **3g**^{.8} Colourless oil. ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.31-7.29 (m, 2 H, ArH-3/5), 7.13-7.11 (m, 2 H, ArH-2/6), 4.76 (d, *J* = 4.0 Hz, 1 H, O-CH-O), 4.00-3.88 (m, 4 H, OCH₂CH₂O), 2.92-2.87 (m, 1 H, diast, C<u>H</u>₂-Ar), 2.41-2.35 (m, 1 H, diast, C<u>H</u>₂-Ar), 2.09-1.99 (m, 1 H, CH), 1.32 (s, 9 H, *tert*-butile), 0.90 (d, J = 6.0 Hz, 3 H, CH₃); ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 148.7, 137.5, 129.0, 125.2, 107.1, 65.3, 65.3, 39.0, 37.3, 34.5, 31.6, 13.5.

2-Methoxy-4-(4-methyl-1,3-dioxolan-2-yl)phenol, 3h:⁹ light yellow oil, diastereoselectivity 65:35 (NH₄HSO₄) or 43:57 (NH₄Br) as determined by ¹H-NMR; ¹H-NMR (400 MHz, CDCl₃) δ (ppm) 1,35 (3 H, d, *J* = 6.4 Hz, CH₃), 1,40 (3 H, d, *J* = 6.0 Hz, CH₃), 3.55, (1 H, t, *J* = 7.2 Hz, CH), 1,61 (3H, d, *J* = 6.4 Hz, CH), 3.90 (3 H, s, CH₃OAr), 3.91 (3 H, s, CH₃OAr), 4.11 (1 H, t, *J* = 7.2 Hz, CH), 4.25-4.42 (2 H + 1 H, m, CH), 5.68 (1 H + 1 H, br s, OH), 5.74 (1 H, s, O-CH-O), 5.87 (1 H, s, O-CH-O), 6.89 (1 H, d, *J* = 2.8 Hz, ArH), 6.91 (1 H, d, *J* = 2.8 Hz, ArH), 6.96-7.03 (2 H + 2 H, m, 2 × ArH); ¹³C NMR (100 MHz, CDCl₃): δ (ppm) 18.5, 18.6, 55.9, 55.9, 71.3, 72.0, 72.2, 73.3, 103.0, 104.1, 108.5, 108.7, 114.0, 114.1, 119.8, 120.2, 129.7, 130.2, 146.4, 146.5, 146.5, 146.6; HRMS (ESI) *m*/*z*: calc. per C₁₁H₁₄O₄H⁺ 211.09649 [M+H]⁺, found: 211.09650; IR (liquid film) 3411, 3072, 2973, 2881, 1675, 1611, 1519, 1464, 1436, 1404, 1377, 1278, 1240, 1190, 1165, 1119, 1088, 1032, 1003, 971, 860, 822, 778, 760, 717, 631 cm⁻¹.



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Ethyl (2-methyl-1,3-dioxolan-2-yl)acetate, 3i:^{1,10} Light yellow oil, bp 105-107 °C/30 mmHg; ¹H-NMR (δ, CDCl₃): 4,16 (q, *J* = 7,2 Hz, 2H), 3,98 (s, 4H), 2,67 (s, 2H), 1,51 (s, 3H), 1,27 (t, *J* = 7,2 Hz, 3H). ¹³C- NMR (δ, CDCl₃): 14.2, 24.5, 44.3, 60.6, 64.8, 107.7, 169.5.

Acetic acid 2-methoxy-4-(4-methyl-1,3-dioxolan-2-yl)phenyl ester, 3j: In a 50 mL flask fitted with a Dean-Stark apparatus and a bubble condenser provided with a calcium chloride valve, vanillin acetate (7.77 g, 40 mmol) was mixed with CPME or toluene (10 mL), ethylene glycol (2.45 mL, 44 mmol, 1.1 eq) and the catalyst (1.2 mmol, 3 mol % of the aldehyde). The mixture was set to reflux for 6 h. WORKUP A (catalysts NH₄Br or NH₄HSO₄): after cooling to room temperature, the mixture was filtered to remove heterogeneous catalyst and a small aliquot was withdrawn, evaporated and submitted to ¹H-NMR analysis (conversion \geq 95%). The solution was kept in the refrigerator overnight and the obtained solid was filtered over Buchner funnel to obtain the product as white crystals (NH₄Br/78% yield; NH₄HSO₄/63% yield). WORKUP B (catalyst *p*-TSA): after cooling to room temperature, a small aliquot was withdrawn, kept 15 minutes over K₂CO₃, evaporated and submitted to ¹H-NMR analysis. The solution was washed with Na₂CO₃ 1M solution (3 × 10 mL), dried over K₂CO₃ and the solvent removed to obtain a gray solid.

White powder (from CPME); ¹H NMR (400 MHz, CDCl₃) δ ppm 2.31 (s, 3 H), 3.85 (s, 3 H), 4.00 - 4.15 (m, 4 H), 5.81 (s, 1 H), 7.01 - 7.08 (m, 2 H), 7.09 - 7.12 (m, 1 H); ¹³C NMR (100 MHz, CDCl₃) δ ppm 168.80, 151.11, 140.31, 136.89, 122.60, 118.86, 110.30, 103.12, 65.19, 55.86, 20.60; HRMS (ESI) calculated for C₁₂H₁₅O₅K ([M+K]⁺) 277,04783 found 277,04715.



2-Methyl-2-(4-hydroxyphenyl)ethyl-1,3-dioxolane, 3k:¹¹Colourless oil. IR (film di liquido) (cm⁻) 3375, 3072, 2982, 2954, 2935, 2884, 1614, 1595, 1516, 1448, 1337, 1225, 1172, 1136, 1086, 1055, 949, 860, 849, 833, 795, 668; ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.06-7.04 (m, 2 H, ArH-3/5), 6.75-6.73 (m, 2 H, ArH-2/4), 5.23 (br s, 1 H, OH), 3.99 (m, 4 H, OCH₂CH₂O), 2.64 (m, 2 H, Ar-C<u>H</u>₂-CH₂-R), 1.93 (m, 2 H, Ar-CH₂-C<u>H</u>₂-R), 1.38 (s, 3 H, CH₃); ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 153.87, 134.28, 129.48, 115.35,

109.99, 64.87, 41.37, 29.45, 24.11. Elemental Analysis: C₁₂H₁₆O₃ requires C, 69.21; H, 7.74; found: C, 69.35; H, 7.93.



2-(4-Methylethylphenyl)-1,3-dioxolane, 31:¹² light yellow oil, bp 95-98 °C/1 mmHg; ¹H-NMR (400 MHz, CDCl₃) δ (ppm) 1.24 (6 H, d, *J* = 6.8 Hz, 2 × CH₃), 2.92 (1 H, ept, *J* = 6.8 Hz, CH), 3.99-4.17 (4 H, m, OCH₂CH₂O), 5.80 (1 H, s), 7.22-7.26 (2 H, m, 2 × ArH), 7.38-7.42 (2 H, m, 2 × ArH); ¹³C NMR (100 MHz, CDCl₃): δ (ppm) 23.9, 34.0, 65.3, 104.0, 126.4, 126.5, 135.4, 150.0.



Synthesis of 1,1-bis(nonyloxy)nonane, 3m: In a 100 mL flask fitted with a Dean-Stark distiller and bubble condenser provided with a CaCl₂ valve, nonanal (**1m**, 11.4 g, 13.8 mL, 80 mmol) was dissolved in CPME (30 mL) together with 1-nonanol (**2e**, 136 mmol, 19.6 g, 23.7 mL mL, 1.7 equiv). After addition of the catalyst (NH₄Br, 235 mg, 2.4 mmol, 3 mol % of the starting material), the reaction mixture was heated in an oil bath under vigorous stirring and allowed to reflux for 6 h, then cooled to rt and the reaction mixture was filtered. The solvent was evaporated under reduced pressure and

purified by fractional distillation, bp 165-170°C/1 mmHg, light yellow oil. IR (liquid film) 2955, 2925, 2855, 1466, 1378, 1349, 1117, 1074 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ (ppm) 4.45 (t, *J* = 5.5 Hz, 1 H, OCHO), 3.56 (q, J = 7.3 Hz, 2 H, OCH₂), 3.40 (q, J = 7.3 Hz, 2 H, OCH₂), 1.55 (m, 11 H), 1.27 (s, 62 H), 0.88 (t, J = 6.1 Hz, 9 H).; ¹³C NMR (100 MHz, CDCl₃) δ (ppm) 103.32, 65.59, 33.64, 32.05, 30.09, 29.75, 29.70, 29.65, 29.45, 29.40, 26.45, 24.96, 22.82, 14.23; Elemental Analysis: C₂₇H₅₆O₂ requires: C, 78.57; H, 13.68; found: C, 79.06; H, 14.01.



2-(Hepten-3-yl)-1,3-dioxolane, 3n:^{1,16} purified by fractional distillation, bp 105 °C/30 mmHg, light yellow oil; ¹H NMR (400 MHz, CDCl₃) δ (ppm) 0.85-0.95 (6 H, m, CH₃), 1.25-1.52 (7 H, m, 3 × CH₂, CH), 3.78-3.97 (4 H, m, OCH₂CH₂O), 4.77 (1 H, d, *J* = 4.0 Hz, O-CH-O); ¹³C NMR (100 MHz, CDCl₃): δ (ppm) 11. 5, 14.1, 21.7, 23.1, 28.2, 29.4, 42.9, 64.8, 106.7.

2-(4-Bromophenyl)-1,3-dioxolane, 30:^{1,13} white powder, mp 36-38 °C (EtOH); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 3.98-4.15 (4 H, m, OCH₂CH₂O), 5.77 (1 H, s, O-CH-O) 7.32-7.38 (2 H, m, 2 × ArH), 7.49-7.54 (2 H, m, 2 × ArH); ¹³C NMR (100 MHz) δ 65.3, 103.0, 123.2, 128.1, 131.5, 137.0.

2-(4-Chlorophenyl)-1,3-dioxolane, **3p**:^{1,14} Purified by fractional distillation, bp 145-148 °C/30 mmHg, olio giallo chiaro; ¹H NMR (400 MHz, CDCl₃) δ (ppm) 3.98-4.15 (4 H, m, OCH₂CH₂O), 5.78 (1 H, s, O-CH-O) 7.32-7.38 (2 H, m, 2 × ArH), 7.39-7.44 (2 H, m, 2 × ArH); ¹³C NMR (100 MHz) δ 65.3, 103.1, 127.9, 128.5, 134.9, 136.5.

Methyl 4-(1,3-dioxolan-2-yl)benzoate, 3q:^{1,15} white powder, mp 31-33 °C (heptane); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 3.92 (3 H, s, CH3O), 4.00-4.18 (4 H, m, OCH₂CH₂O), 5.86, (1 H, s, OCHO), 7.53-7.57 (2 H, m, 2 × ArH), 8.04-8.07 (2 H, m, 2 × ArH); ¹³C NMR (100 MHz) δ 52.1, 65.4, 103.0, 126.4, 129.7, 130.8, 142.7, 166.8.

2-[4-(1-Ethyl-1-hydroxypropyl)phenyl-1,3-dioxolane, 5a:¹⁷ 40 mmol of crude **3q** were synthesized in 20 mL of dry 2-MeTHF as described in the General Procedure and Scheme 3, then transferred under Ar in a dropping funnel and dropwise added at rt to a freshly prepared vigorously stirred solution of EtMgBr in 2-MeTHF (prepared from 120 mmol of EtBr and 132 mg atom of Mg in 60 mL of the solvent). After stirring at rt during 2 h, the reaction mixture was chilled to 0 °C and quenched by slow dropwise addition of a sat. solution of NH₄Cl (60 mL). The resulting mixture was extracted with 2-MeTHF ($3 \times 10 \text{ mL}$), the organic phases were collected, dried (K₂CO₃) and the solvent evaporated to afford of a colourless oil which was purified by flash chromatography and characterized as following:

5a, purified by flash chromatography (Petroleum Ether/AcOEt/Et₃N = 8:2:0.5), colourless oil, 7.6 g (32.4 mmol, 81%); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.48-7.43 (2 H, 2 × ArH), 7.41-7.37 (2 H, 2 × ArH), 5.80 (1 H, s, OCHO), 4.19-4.10 (2 H, m, CH₂O), 4.08-4.00 2 H, m, CH₂O), 1.91-1.75 (4H, m. 2 × CH₂),1.64 (1 H, br s, OH), 0.74 (6 H, t, *J* = 7.4 Hz, 2 x CH₃) ;¹³C NMR (100 MHz, CDCl₃): δ (ppm) 147.1, 135.8, 126.4, 125.7, 103.8, 77.5, 65.4, 35.1, 7.9.

4-(1,3-Dioxolan-2-yl)phenylmethanol, 5b:^{1,18} 40 mmol of crude **3q** were synthesized in 20 mL of dry 2-MeTHF as described in the General Procedure and Scheme 3, then transferred under Ar in a dropping funnel and dropwise added at 0 °C to a vigorously stirred suspension of LiAlH₄ (1.52 g, 40 mmol) in 2-MeTHF (20 mL). The mixture was allowed to reach rt and vigorously stirred overnight. After chilling to 0 °C, the mixture was quenched by slow dropwise addition of H₂O (20 mL, *caution!*) and, after ceasing of the gas evolution, the organic phase was separated. The aqueous phase was diluted with a NaHCO₃ saturated solution (20 mL) and extracted with 2-MeTHF (3 × 10 mL). The organic phases were collected, dried (K₂CO₃) and evaporated to afford a colourless oil which was purified by flash chromatography and characterized as following:

5b, purified by flash chromatography (Petroleum Ether/AcOEt/Et₃N = 7:3:0.5), colourless oil, 5.5 g (30.4 mmol, 76%); ¹H NMR (400 MHz, CDCl₃) δ (ppm) 7.47-7.40 (2 H, m, 2 × ArH), 7.35-7.29 (2 H, m, 2 × ArH), 5.77 (1 H, s, CH), 4.61 (2 H, d, J = 8.0 Hz, CH₂O), 4.13-3.95 (4 H, m, OCH₂CH₂O), 2.30 (1 H, br s, OH); ¹³C NMR (100 MHz, CDCl₃): δ (ppm) 142.2, 137.2, 126.9, 126.7, 103.7, 65.4, 64.9.

1.4 Recovery of reaction solvents.

Both solvents were recovered via evaporation of the reaction mixtures obtained as described in the General Procedure. Evaporation were realized employing a rotatory evaporator operating in vacuo (ca. 50 mmHg), by gently warming (40- 45 °C for CPME; 30-35 °C for 2-MeTHF) the boiling flak with a water bath, condensing the vapour phase with efficient cooling (-5 °C) and chilling the condensate-collecting flask with an ice-salt bath. Solvents recovered from several runs (at least 100 mL) were washed with H₂O, filtered under N₂ pressure over a small pad of acidic alumina, dried (KOH), distilled at atmospheric pressure (CaCl₂ valve) and finally stabilized by addition of BHT (50

ppm for CPME and 200 ppm for 2-MeTHF). The recovered solvents (80 to 85% mass recovery) were analytically pure (¹H- and ¹³C-NMR) and were successfully recycled to successive runs.





1.5 General procedure for the preparation of SiO₂ supported ammonium salts.

Silica supported ammonium salts (25% w/w) were prepared by wet impregnation. 17.4 g of SiO₂ (column chromatographic grade, 60 Å, 200-400 mesh) were added to a stirred solution of 50 mmol of the appropriate ammonium salt dissolved in 30 mL of H₂O. The resulting suspension was stirred at 50 °C during 1 h, followed by solvent evaporation under reduced pressure. The resulting white

powder was dried at 120 °C during 48 h, then transferred and stored in a desiccator over anhydrous CaCl₂.

	$Ph \frac{CH_3}{1a} + HO(CH_3)$	2) ₂ OH Catalyst (3 mol%) CPME 6h, reflux	$= \frac{0}{2} O O O O O O O O O O O O O O O O O O O$
Entry	2a (equivalent)	Catalyst	Product Distribution
	•	5	1a/3a (%) ²
1	1.1	NH4Cl	35/65
2 ³	1.1	NH ₄ Cl	33/67
3 4	1.1	NH ₄ Cl	37/63
4	1.1	NH ₄ Br	21/79
5 ³	1.1	NH ₄ Br	24/76
64	1.1	NH ₄ Br	20/80
7	1.1	HCl.Gly	36/64
8 ³	1.1	HCl.Gly	36/64
9 ⁴	1.1	HCl.Gly	38/62
10	1.1	(NH4)HSO4	10/90
11 ³	1.1	(NH4)HSO4	12/88
12 4	1.1	(NH4)HSO4	9/91
13 5	1.1	(NH4)HSO4	11/89
14 6	1.1	(NH4)HSO4	13/87
15	2.0	(NH4)HSO4	<5/>95
16 ³	2.0	(NH4)HSO4	<5/>95
17 4	2.0	(NH4)HSO4	<5/>95

Table S1. Performance of the recycled catalysts in the synthesis of dioxolane 3a 1.

¹ All reactions were run at reflux for 6 h in the presence of 3 mol% of the catalyst, unless otherwise indicated; ² Determined by ¹H-NMR analyses of crude reaction mixtures; no other reaction products were detected, unless otherwise indicated; ³1st recycling the recovered catalyst; ⁴2nd recycling the recovered catalyst; ⁵3rd recycling the recovered catalyst; ⁶4th recycling the recovered catalyst.

Table 2. Performance of the recycled catalysts in the synthesis of dioxolane 3a in the presence of SiO₂supported ammonium salts 1.

	Ph CH ₃ + HO(CH ₂ 1a 2a	2)2OH RNH ₃ X-SiO ₂ 3 mol% CPME 6h, reflux	$ = \begin{array}{c} & & \\ &$
Entry	2a (equivalent)	Catalyst	Product Distribution
Littiy	zu (equivalent)	Cuturyst	1a/3a (%) ²
1	1.1	HCl.Gly-SiO ₂	35/65
2 ³	1.1	HCl.Gly-SiO ₂	35/65
3 4	1.1	HCl.Gly-SiO ₂	38/62
5	1.1	NH4HSO4-SiO2	14/86
6 ³	1.1	NH4HSO4-SiO2	17/83
74	1.1	NH4HSO4-SiO2	15/85
8 5	1.1	NH4HSO4-SiO2	18/82
9	2.0	NH4HSO4-SiO2	<5/>95
10 ³	2.0	NH4HSO4-SiO2	<5/>95
$11 \ {}^{4}$	2.0	NH4HSO4-SiO2	7/93
12 5	2.0	NH4HSO4-SiO2	<5/>95

¹ All reactions were run at reflux for 6 h in the presence of 3 mol% of the catalyst, unless otherwise indicated; ² Determined by ¹H-NMR analyses of crude reaction mixtures; no other reaction products were detected; ³1st recycling the recovered catalyst; ⁴2nd recycling the recovered catalyst; ⁵3rd recycling the recovered catalyst.



Figure S1. Representative SEM micrograph of the as-received SiO₂ support.



Figure S2. Wide-angle XRD patterns of the as-received SiO₂, (NH₄)HSO₄, HCl Gly and NH₄Br supported systems.

The patterns of the (NH₄)HSO₄ and HCl Gly -based systems, reported in Figure S2, do not show any Bragg crystalline peaks pertaining to these compounds, because both amorphous at room temperature. In fact, only the wide haloes due to the amorphous structures can be clearly visualized. On the other hand, crystalline peaks belonging to NH₄Br cubic phase (space group: Pm-3m) emerged from the background, which proved the crystalline nature of this compound and its presence in the SiO_2 support.



EDX Spectra of SiO₂ supported Ammonium Salts

Figure S3. EDX spectrum of NH4HSO4-SiO2.



Figure S4. EDX spectrum of NH₄Br-SiO₂.



Figure S5. EDX spectrum of HCl.GlyOH-SiO₂.

2. Green Metrics.

In order to evaluate the sustainability of our procedure, we calculated and compared some green metrics for the synthesis of acetals **3c**, **3d**, **3o** and **3j** run with our green solvent/heterogeneous catalyst protocol with literature data for reactions run under the widely diffused procedure employing an aromatic solvent in the presence of p-TSA.¹⁹⁻²⁴, for each of them RME, PMI, AE and EF have been calculated:

• Reaction Mass Efficiency (RME)

RME is the percentage of the mass of the reactants that remain in the product. It is similar to AE but it consider the excess of reactants used²⁵

$$RME = \frac{Mass \ of \ product}{Total \ mass \ of \ reactants} * 100$$

• Process Mass Intensity (PMI)

Process mass intensity is defined as the "total mass of materials used to produce a specified mass of product" where "materials include reactants, reagents, solvents used for reaction and purification, and catalysts"²⁶

$$PMI = \frac{Total \ mass \ in \ process}{Mass \ of \ final \ product}$$

• Atom Economy (AE)

AE is a theoretical number which assumes the use of exact stoichiometric quantities of starting materials and a theoretical chemical yield and disregards substances, such as solvents and auxiliary chemicals which do not appear in the stoichiometric equation. The strength of AE, and what its critics tend to forget, is that it can be applied without the need for experimentation²⁷.

$$AE = \frac{MW \ of \ product}{Total \ MWs \ of \ reactants} * 100$$

• Environmental Factor (EF)

The E factor, in contrast, is the actual amount of waste produced in the process and takes waste from all auxiliary components, for example, solvent losses and chemicals used in workup, into account²⁷. The ideal E Factor is zero and it is possible to reduce its value considering a possible percentage of solvent recovery.

$$E Factor = \frac{Total mass of waste}{Mass of final product}$$

Atom Economy is not useful in this case, since all reactions are run with the same stoichiometric reactants. Due to the lack of literature data concerning the recovery of solvents, E Factor can be calculated by considering that total mass of waste is equal to total mass used in process minus the final mass of product, thus E factor is equal Process Mass Intensity minus one and it doesn't give additional information.

Synthesis of 2-(4-Nitrophenyl)-1,3-dioxolane, 3c







Synthesis of Spiro[1,3-dioxolane-2,3'-indolin]-2'-one, 3d







Synthesis	of 2-	(4-Brom	ophenyl)	-1,3-	dioxol	ane, 3	30
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SM 1. Previous synthesis of acetals and aminals in CPME. Reaction conditions: 4 M solution of 1 in CPME, 1.1 equiv of 2a-d (unless otherwise indicated), 3 mol% of NH₄X (with respect to 1), reflux (Dean-Stark conditions); NH₄X = NH₄Cl, NH₄Br or NH₄HSO₄; percentages represent conversion of the starting materials as determined by ¹H-NMR; no other product, besides starting material, was detected. ^aIn the presence of 1.4 equiv of diol; ^bA comparable result was obtained recycling the recovered catalyst. ^cIn the presence of 2.0 equiv of diol. For more details and product characterization see ref. 1.



Equations S1-S3. Two-steps one-pot reactions in CPME. For more details and product characterizations see ref. 1.

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