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Covalent Ladder Formation Becomes Kinetically Trapped Beyond Four Rungs

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Supporting Information

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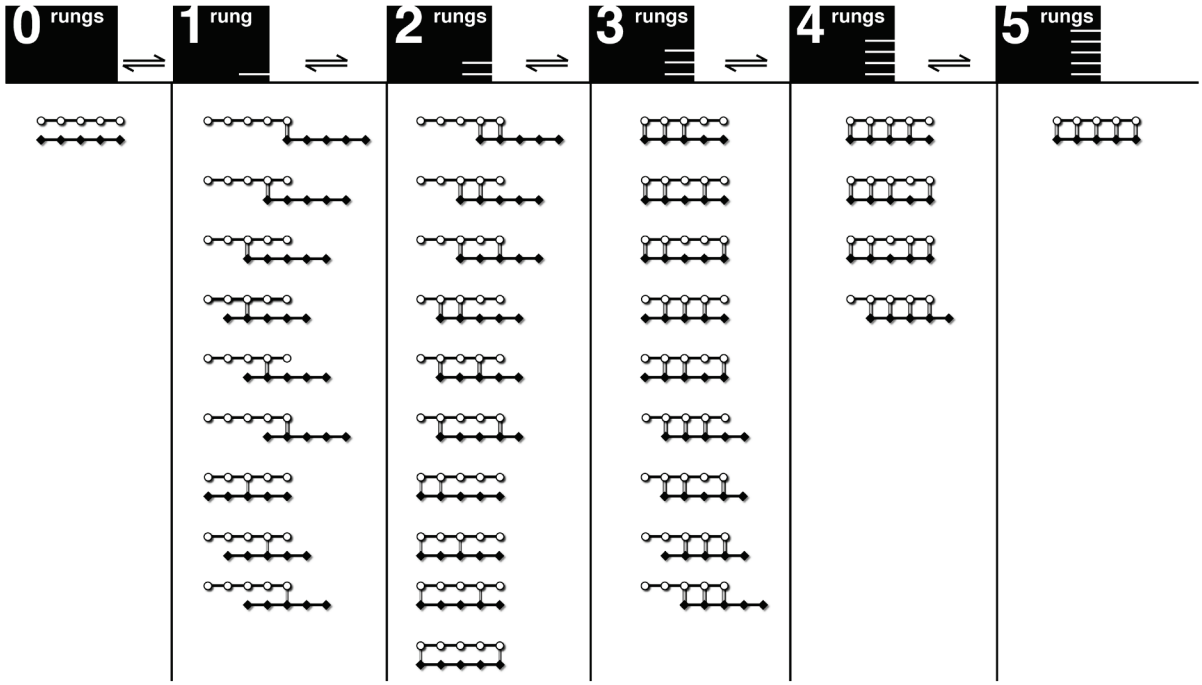


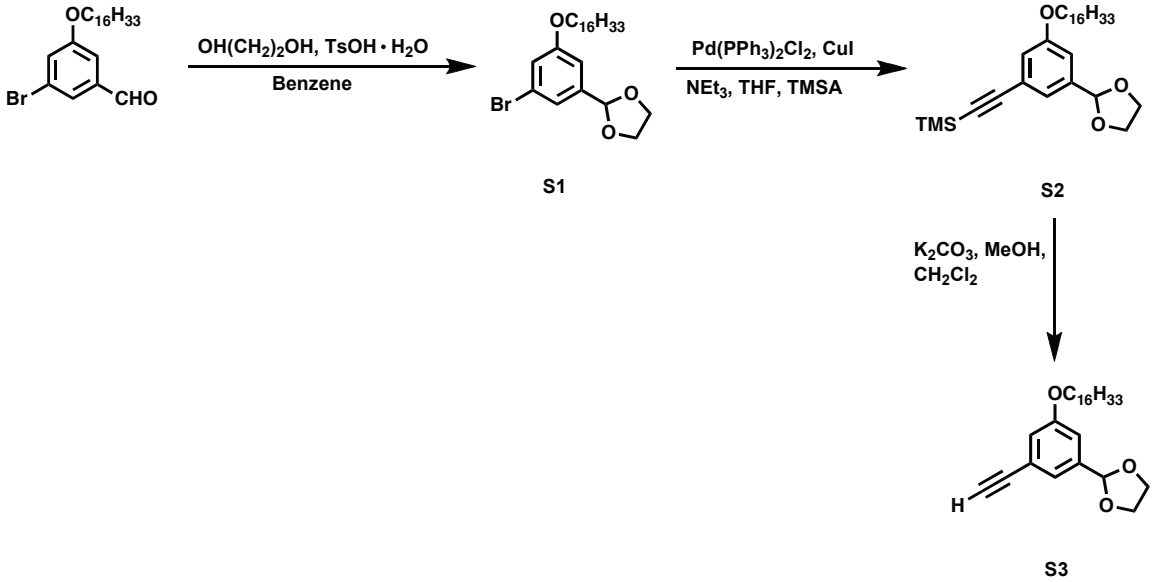
Figure S1 Cartoon representation of possible productive and non-productive species present from 0–5 rungs in 5-rung ladder formation. Note: only two strand species are depicted but other transient species containing more than two strands are most likely present.

General Procedures

All starting materials were purchased from commercially available sources unless otherwise noted. The ^{1}H NMR spectra were recorded at 500 or 400 MHz and ^{13}C NMR spectra were recorded at 125 or 100 MHz. Chemical shifts are expressed in ppm (δ) using residual solvent protons as internal reference. Mass spectrometry was performed by the University of Illinois MicroAnalytical Services. MALDI mass spectra of oligomers were carried out using the HABA matrix (2-(4-hydroxyphenylazo)benzoic acid). MALDI mass spectra of the ladders were carried out using the TCNQ matrix (tetra-cyanoquinodimethane). Oligomer fragments were synthesized using an iterative solid-phase methodology previously reported by our group. Flash chromatography was performed using 60 Å silica gel from Silicycle Inc. Analytical Gel Permeation Chromatography (GPC) was performed using a Waters 515 HPLC pump, a Thermo Separation Products Spectraseries AS100 autosampler, a Viscotek TDA Model 300 triple detector array, and a series of Viscotek Viscogel Columns (7.8 X 300 mm, 2 GMHXL16141 and 1 G3000HXL16136 columns) with THF as the eluant. The analytical GPC was calibrated using monodisperse polystyrene standards. Preparatory GPC was carried out using a Waters 515 HPLC pump, a Waters 410 Differential Diffractometer, and a series of three Waters columns (19 X 300 mm, Ultrastyragel 104 Å THF, 103 Å THF, and 500 Å THF columns) with THF (HPLC grade, inhibitor free) as the eluant. Preparatory GPC was also carried out using a Model LC-9201R/U LC-9204R/U recycling preparative GPC using two Jaigel H Series Columns (1-H and 2-H) in series with chloroform stabilized with amylenes as the eluant.

Monomer Synthesis

Synthesis of the trifluoroacetamide monomer fragments can be found in a previously reported manuscript.[1,2]

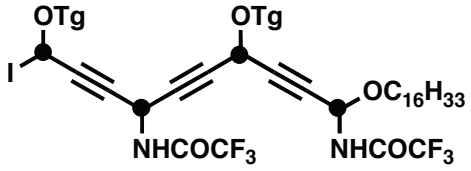


2-(3-Bromo-5hexadecyloxy-phenyl)-[1,3]dioxolane (S1). A stirred mixture of 3-Bromo-5-(hexadcyloxy)-benzaldehyde (1.00g, 2.35 mmol), TsOH•H_2O (13.8 mg, 0.071 mmol), and ethylene glycol (1.31 mL, 23.5 mmol) in benzene (8 mL) was fitted with a Dean-Stark trap and heated to reflux overnight. The reaction mixture was then cooled, poured into satd. aq. $NaHCO_3$ (10 mL), and extracted with EtOAc (3 x10 mL). The combined organic layers were collected, dried ($MgSO_4$), filtered, and concentrated. Purification by flash chromatography (9:1 *n*-hexane:EtOAc) gave **S1** (0.93g, 1.98 mmol, 84%) as a white solid; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.19 (t, J = 1.51 Hz, 1H), 7.03-7.025 (m, 1H), 6.94-6.93 (m, 1H), 5.75 (s, 1H), 4.11-4.01 (m, 4H), 3.93 (t, J = 6.6 Hz, 2H), 1.77-1.74 (m, 2H), 1.43-1.41 (m, 2H), 1.33-1.26 (m, 24H), 0.88 (t, J = 7 Hz); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 160.2, 141.3, 122.9, 121.8, 118.6, 111.7, 102.9, 68.6, 65.5, 32.1, 29.9, 29.89, 29.88, 29.79, 29.77, 29.58, 29.54, 29.31, 26.2, 22.9, 14.3. HRMS (EI) calc'd for $C_{25}H_{41}BrO_3[M^+]$ 468.22, found 468.22; anal. calc'd for $C_{25}H_{41}BrO_3$ C 63.96, H 8.80, found C 64.26, H 9.06.

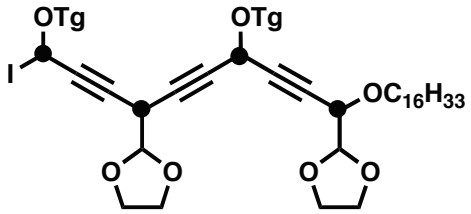
(3-[1,3]Dioxolan-2-yl-5-hexadcyloxy-phenylethynyl)-trimethylsilane (S2). A sealed tube was charged with a stir bar, $Pd(PPh_3)_2Cl_2$ (169 mg, 0.24 mmol) and CuI (46 mg, 0.24 mmol) and degassed and re-filled with N_2 three times. A scintillation vial containing **S1** (2.25 g, 4.82 mmol) was dissolved in NEt_3 (24 mL) and was added to the sealed tube. This mixture was then put through three freeze-pump-thaw cycles. Under a flow of N_2, trimethylsilyacetylene (5 mL, 48 mmol) was added to the sealed tube and then sealed and heated to 70˚C overnight. The following day the reaction mixture was cooled to rt, diluted with EtOAc (35 mL) and filtered through a frit. Purification by flash chromatography (2:1 $CHCl_3$: *n*-hexane) yielded **S2** as a yellow solid (1.96g, 4.03 mmol, 84%); ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.17 (t, *J* = 1.26 Hz, 1H), 6.98-6.96 (m, 2H), 5.75 (s, 1H), 4.11-4.01 (m, 4H), 3.94 (t, *J* = 6.6 Hz, 2H), 1.77-1.74 (m, 2H), 1.43-1.41 (m, 2H), 1.33-1.26 (m, 24H), 0.88 (t, *J* = 7 Hz, 3H), 0.24 (s, 9H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 159.2, 139.9, 124.3, 122.6, 118.2, 113.8, 105.0, 103.3, 68.4, 65.5, 29.90, 29.89, 29.87, 29.81, 29.78, 29.57, 29.56, 29.38, 26.2, 22.9, 14.3, 0.1. HRMS (EI) calc'd for $C_{30}H_{50}O_3Si[M^+]$ 486.80, found 486.35; anal. calc'd for $C_{30}H_{50}O_3Si$ C 74.02, H 10.35, found C 74.02, H 10.55.

2-(3-Ethynyl-5-hexadecyloxy-phenyl)-[1,3]dioxolane (S3). A mixture of **S2** (0.50 g, 1.1 mmol), K_2CO_3 (14.2 mg, 0.10 mmol), MeOH (3.42 mL) and CH_2Cl_2 (2.59 mL) was stirred at rt for 2 h. The reaction mixture was then transferred to a separation funnel containing satd. NH_4Cl (6 mL). The organic layer was collected, dried ($MgSO_4$), filtered and concentrated to give **S3** (0.64 g, 1.54 mmol, 89%) as a white solid; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.196-7.193 (m, 1H), 7.02-7.00 (m, 2H), 5.75 (s, 1H), 4.09-4.00 (m, 4H), 3.94 (t, *J* = 6.6 Hz, 2H), 3.05 (s, 1H), 1.78-1.75 (m, 2H), 1.45-1.42 (m, 2H), 1.33-1.23 (m, 24H), 0.89 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 159.2, 140.1, 123.3, 122.7, 118.7, 113.8, 103.2, 83.6, 77.2, 68.4, 65.5, 32.2, 29.941, 29.920, 29.895, 29.838, 29.80, 29.61, 29.60, 29.4, 26.2, 22.9, 14.3. HRMS (EI) calc'd for $C_{27}H_{42}O_3[M^+]$ 414.62, found 414.31; anal. calc'd for $C_{27}H_{42}O_3$ C 78.21, H 10.21, found C 78.46, H 10.47.

General Procedure for the Solid Phase Synthesis of Oligomers (S4-S5). A previously reported solid phase method was utilized.[3] Oligomers were purified by preparatory GPC.



Oligomer S4. 0.082g (0.064 mmol, 53%) of **S4** was obtained as a yellow wax; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 9.11 (s, 1H), 8.73 (s, 1H), 7.75-7.74 (m, 2H), 7.40 (t, *J* = 1.35 Hz, 1H), 7.33 (t, *J* = 1.29 Hz, 1H), 7.30 (m, 1H), 7.28-7.27 (m, 1H), 7.18-7.16 (m, 2H), 6.87-6.85(m, 3H), 6.81-6.80 (m, 1H), 4.01-3.98 (m, 4H), 3.90 (t, *J* = 6.6 Hz, 2H), 3.84-3.80 (m, 4H), 3.78-3.65 (m, 12H), 3.55-3.53 (m, 4H), 3.32 (s, 3H), 3.30 (s, 3H), 1.77-1.72 (m, 2H), 1.43-1.39 (m, 2H), 1.33-1.21 (m, 24H), 0.87 (t, *J* = 7 Hz, 3H). MS (MALDI) calc'd for $C_{64}H_{77}F_6IN_2O_{11}$ ([M+Na^+]) 1314.19, found 1314.00.

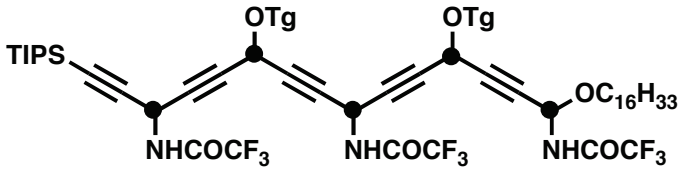


Oligomer S5. 0.097 mg (0.08 mmol, 66%) of **S5** was obtained as a yellow wax; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.65 (t, *J* = 1.58 Hz, 1H), 7.61-7.60 (m, 1H), 7.592-7.58 (m, 1H), 7.46 (t, *J* = 1.48 Hz, 1H), 7.30-7.29 (m, 1H), 7.27-7.26 (m, 1H), 7.32-7.23 (m, 1H) 7.07-7.00 (m, 5H), 5.82 (s, 1H), 5.78 (s, 1H), 4.17-4.08 (m, 8H), 4.07-4.00 (m, 4H), 3.97(t, *J* = 6.6 Hz, 2H), 3.88-3.83 (m, 4H), 3.76-3.71 (m, 4H), 3.70-3.64 (m, 8H), 3.56-3.53 (m, 4H), 3.372 (s, 3H), 3.370 (s, 3H), 1.80-1.76 (m, 2H), 1.46-1.43 (m, 2H), 1.32-1.21 (m, 24H), 0.87 (t, *J* = 7Hz, 3H). MS (MALDI) calc'd for $C_{66}H_{85}F_6IO_{13}$ ([M+Na^+]) 1236.27, found 1235.94.

General Procedure for the Sonogashira Coupling of Oligomers with Monomer Units to Synthesize Protected Oligomers of S6-S13. In a glove box under an argon atmosphere, a scintillation vial containing the oligomer was treated with $Pd(PPh_3)_4$ (10 mol % per coupling), CuI (10 mol % per coupling) and piperidine (10 eq.). A solution of the ethynyl or mono-protected bis-ethynyl monomer (1 eq.) in DMF was then added, and the mixture stirred overnight. The mixture was then removed from the glove box and partitioned between satd. NH_4Cl and $CHCl_3$. The aqueous layer was extracted with $CHCl_3$ (3X), and the combined organic layers, dried (over $MgSO_4$), filtered and concentrated. The crude product was then deprotected without further purification or purified with prep-GPC and then directly deprotected.

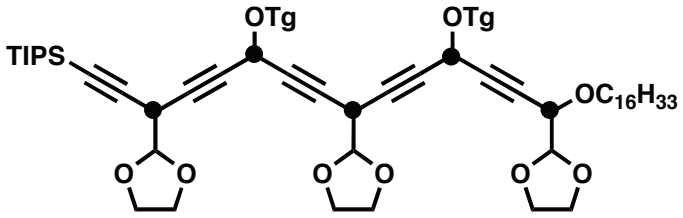
General Procedure for the Deprotection of Acetal-Functionalized Oligomers. A 0.05 M solution of the protected oligomer in THF was treated with concentrated HCl (3 drops) and stirred at room temperature for 24–48 h. The reaction mixture was then partitioned between $NaHCO_3$ and $CHCl_3$ and the aqueous layer washed with $CHCl_3$ (2X). The organic layers were combined, dried ($MgSO_4$), filtered and concentrated. The crude product was then purified with prep-GPC.

General Procedure for the Deprotection of Trifluoroacetamide-Functionalized Oligomers. In a sealed tube a solution of oligomer (50-100 mg) in THF (2.0 mL) obtained from the still was treated with 10% aq. NaOH (0.2 mL) and heated to reflux overnight. The reaction mixture was then cooled, poured into satd. aq. NH_4Cl and extracted with $CHCl_3$ (4X). The combined organic layers were dried ($MgSO_4$), filtered and concentrated. The crude products were used without further purification. The material is pure after work-up except for a trace amount of high molecular weight material as evidenced by ^1H NMR, analytical GPC and MALDI.



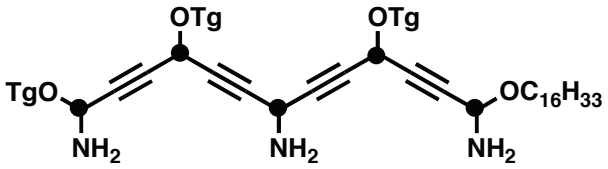
(S6)

Oligomer S6. 0.071 mg (0.046, 72%) of **S6** was obtained as a waxy yellow solid; ^1H NMR ($CDCl_3$, 500 MHz) δ 7.76-7.30 (m, 4H), 7.405-7.400 (m, 1H), 7.33 (s, 1H), 7.30 (s, 1H), 7.28 (s, 1H), 7.13 (s, 1H), 7.11 (s, 1H), 6.88-6.81 (m, 5H), 4.00 (m, 4H), 3.88 (t, J = 6.6 Hz, 2H), 3.81 (m, 4H), 3.74-3.73 (m, 4H), 3.71-3.69 (m, 4H), 3.66-3.65 (m, 4H), 3.54-3.52 (m, 4H), 3.30 (m, 6H), 1.74-1.71 (m, 2H), 1.39-1.38 (m, 2H), 1.29-1.24 (m, 24H), 1.11 (s, 21H), 0.86 (t, J = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{85}H_{102}F_9N_3O_{12}Si$ ([M+Na^+]) 1579.79, found 1578.97.



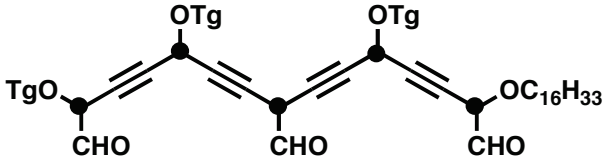
(S7)

Oligomer S7. 0.083 mg (0.058, 72%) of **S7** was obtained as an amber oil; ^1H NMR ($CDCl_3$, 500 MHz) δ 7.68-7.67 (m, 1H), 7.63-7.62 (m, 1H), 7.61-7.60 (m, 2H), 7.58 (m, 1H), 7.53 (m, 1H), 7.29 (m, 2H), 7.23 (m, 1H), 7.07-7.00 (m, 6H), 5.83 (s, 1H), 5.79 (s, 1H), 5.78 (s, 1H), 4.17-4.09 (m, 12H), 4.07-4.01 (m, 4H), 3.97 (t, J = 6.6 Hz, 2H), 3.88-3.86 (m, 4H), 3.75-3.72 (m, 4H), 3.69-3.65 (m, 8H), 3.56-3.54 (m, 4H), 3.37 (s, 6H), 1.78-1.75 (m, 2H), 1.44-1.43(m, 2H), 1.33-1.24 (m, 24H), 1.12 (s, 21H), 0.86 (t, J = 7 Hz, 3H); MS (MALDI) calc'd for $C_{88}H_{114}O_{15}Si$ ([M+Na^+]) 1462.91, found 1461.81.



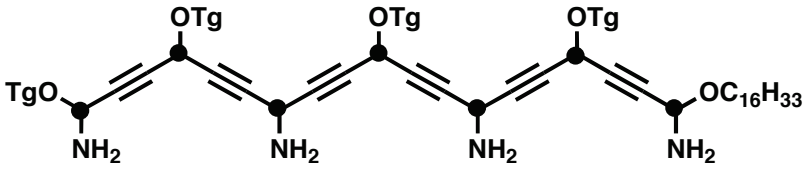
(S8)

Oligomer S8. 0.067mg (0.054 mmol, 48%) of **S8** was obtained as a tan solid; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.27-7.26 (m, 3H), 7.10 (m, 1H), 7.02 (s, 4H), 6.808-6.806 (m, 2H), 6.49-6.46 (m, 3H), 6.26 (t, *J* = 2.0 Hz, 1H), 6.23 (t, *J* = 2.0 Hz, 1H), 4.16-4.09 (m, 6H), 3.91 (t, *J* = 6.6 Hz, 2H), 3.87-3.82 (m, 6H), 3.78-3.72 (m, 6H), 3.70-3.61 (m, 12H), 3.56-3.51 (m, 6H), 3.38 (s, 9H), 1.76-1.73 (m, 2H), 1.43-1.41 (m, 2H), 1.33-1.21 (m, 24H), 0.86 (t, *J* = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{75}H_{99}N_3O_{13}$ ([M+Na$^+$]) 1273.59, found 1272.17.



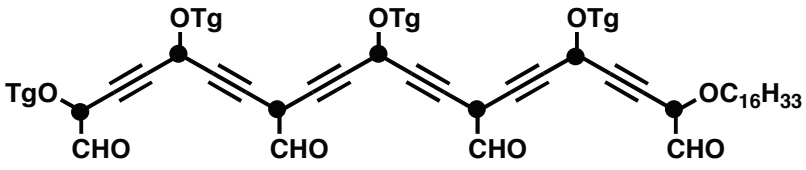
(S9)

Oligomer S9. 0.034g (0.026 mmol, 21%) of **S9** was obtained as a yellow wax; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 10.03 (s, 1H), 9.96 (s, 1H), 9.96 (s, 1H), 7.99-7.98 (m, 2H), 7.92-7.91(m, 2H), 7.62-7.60 (m, 2H), 7.41-7.40 (m, 1H), 7.38-7.37(m, 1H), 7.34-7.33 (m, 2H), 7.31-7.29 (m, 2H), 7.10-7.07 (m, 4H), 4.22-4.18 (m, 6H), 4.03 (t, *J* = 6.6 Hz, 2H), 3.90-3.88 (m, 6H), 3.77-3.75 (m, 6H), 3.71-3.65 (m, 12H), 3.57-3.54 (m, 6H), 3.38 (s, 6H), 3.38 (s, 3H), 1.83-1.80 (m, 2H), 1.46-1.44 (m, 2H), 1.36-1.20 (m, 24H), 0.87 (t, *J* = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{78}H_{96}O_{16}$ ([M+Na$^+$]) 1312.58, found 1311.08.



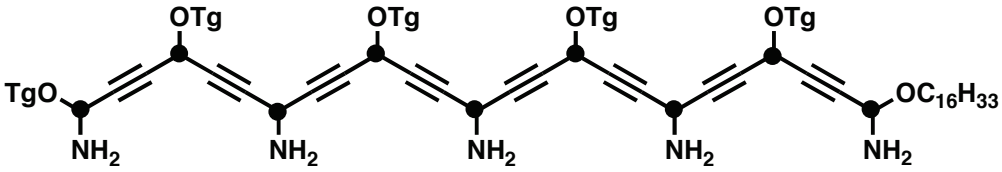
(S10)

Oligomer S10. 0.083 mg (0.051 mmol, 58%) of **S10** was obtained as a dark brown solid; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.279 (s, 1H), 7.270 (s, 1H), 7.11 (s, 2H), 7.04-6.98 (m, 4H), 6.80 (s, 4H), 6.49-6.46 (m, 4H), 6.26 (t, *J* = 2.0 Hz, 1H), 6.23 (t, *J* = 2.0 Hz, 1H), 4.17-4.08 (m, 8H), 3.92 (t, *J* = 6.6 Hz, 2H), 3.88-3.80 (m, 8H), 3.75-3.72 (m, 8H), 3.70-3.65 (m, 16H), 3.54-3.52 (m, 8H), 3.38 (s, 12H), 1.77-1.73 (m, 2H), 1.42-1.41 (m, 2H), 1.27-1.21 (m, 24H), 0.87 (t, *J* = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{98}H_{122}N_4O_{17}$ ([M+Na$^+$]) 1651.02, found 1648.51.



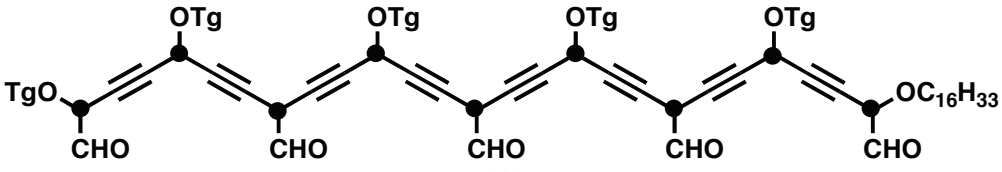
(S11)

Oligomer S11. 0.069 mg (0.041, 32%) of **S11** was obtained as a yellow wax; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 10.02 (s, 2H), 9.954 (s, 1H), 9.952 (s, 1H), 7.989-7.985 (m, 4H), 7.92-7.91 (m, 2H), 7.62-7.61 (m, 1H), 7.60-7.59 (m, 1H), 7.40-7.39 (m, 1H), 7.37-7.36 (m, 1H), 7.35-7.32 (4H), 7.30-7.29 (m, 1H), 7.11-7.07 (m, 6H), 4.22-4.15 (m, 8H), 4.02 (t, *J* = 6.6 Hz, 2H), 3.91-3.88 (m, 8H), 3.77-3.73 (m, 8H), 3.71-3.65 (m, 16H), 3.59-3.54 (m, 8H), 3.379 (s, 3H), 3.377 (s, 6H), 3.374 (s, 3H), 1.82-1.76 (m, 2H), 1.47-1.44 (m, 2H), 1.33-1.21 (m, 24H), 0.87 (t, *J* = 7.0 Hz, 3H);); MS (MALDI) calc'd for $C_{102}H_{118}O_{21}$ ([M+Na$^+$]) 1703.01, found 1701.86.



(S12)

Oligomer S12. 0.056 mg (0.028 mmol, 52%) of **S12** was obtained as a brown solid; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.263-7.25 (m, 4H), 7.10-7.08 (m, 3H), 7.03-7.01 (m, 8H), 6.82-6.81 (m, 6H), 6.47-6.45 (m, 4H), 6.26 (t, J = 2.0 Hz, 1H), 6.23 (t, J = 2.0 Hz, 1H), 4.16-4.08 (m, 10H), 3.90 (t, J = 6.6 Hz, 2H), 3.87-3.81 (m, 10H), 3.75-3.71 (m, 10H), 3.70-3.64 (m 20H), 3.55-3.51 (m, 10H), 3.36 (s, 15H), 1.68-1.62 (m, 2H), 1.42-1.41 (m, 2H), 1.28-1.20 (m, 24H), 0.88 (t, J = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{121}H_{145}N_5O_{21}$ ([M+HABA]) 2247.70, found 2244.40.



(S13)

Oligomer S13. 0.059 mg (0.028 mmol, 56%) of **S13** was obtained as a yellow wax; ; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 10.02 (s, 1H), 10.01 (s, 2H), 9.945 (s, 1H), 9.944 (s, 1H), 7.98-7.96 (m, 6H), 7.92-7.90 (m, 2H), 7.60-7.58 (m, 2H), 7.387-.7385 (m, 1H), 7.360-7.355 (m, 1H), 7.338-7.333 (m, 2H), 7.322-7.317 (m, 4H), 7.297-7.284 (m, 1H), 7.10-7.05 (m, 8H), 4.21-4.16 (m, 10H), 4.01 (t, J = 6.6 Hz, 2H), 3.90-3.87 (m, 10H), 3.77-3.73 (m, 10H), 3.71-3.68 (m, 10H), 3.67-3.64 (m, 20H), 3.56-3.54 (m, 10H), 3.37 (s, 15H), 1.80-1.78 (m, 2H), 1.45-1.44 (m, 2H), 1.33-1.24 (m, 24H), 0.86 (t, J = 7.0 Hz, 3H); MS (MALDI) calc'd for $C_{126}H_{140}O_{26}$ ([M+Na^+]) 2093.43, found 2092.87.

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2. Hartley, C. S.; Moore, J. S. *J. Am. Chem. Soc.* **2007**, *129*, 11682.
3. Elliott, E. L; Ray, C. R.; Kraft, S.; Atkins, J. R.; Moore, J. S. *J. Org. Chem.* **2006**, *71*, 5282.