Concave Reagents, 45.[1] 2,6-Di-*tert*-butylpyridine-Loaded Dendrimers and Their Use in Vinyl Triflate Synthesis

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Dedicated to Prof. Dr. Bernd Giese on the occasion of his 65th birthday

Abstract: 2,6-Di-*tert*-butyl-pyridine (DTBP) has been connected with dendrons and dendrimers of the Fréchet type. Four dendrimers, both first and second generation derivatives have been synthesized and used as non-nucleophilic, recyclable bases in the formation of cyclohexenyl-1-triflate from cyclohexanone.

Keywords: steric hindrance, dendrimers, triflate, base catalysis, recycling

Palladium-catalyzed cross-coupling reactions (e.g., Suzuki, Stille, Heck, Sonogashira) have become more and more important in organic synthesis.[2,3] Besides halogenated compounds, aryl, and vinyl triflates are also valuable starting materials. A one step synthesis of vinyl triflates developed by Stang[4] requires 2,6-di-*tert*-butylpyridine (DTBP, **2a**) or its 4-methyl derivative **2b** as a sterically hindered, non-nucleophilic base (Figure 1). With triflic anhydride (Tf$_2$O), standard bases like pyridine form salts such as **1** and thus lead to heterogeneous reaction mixtures. When using nucleophilic tertiary bases such as pyridine, the triflated quarternary ions such as **1** become the triflating agents, while the use of DTBPs **2** leaves Tf$_2$O as the triflating agent.[5]

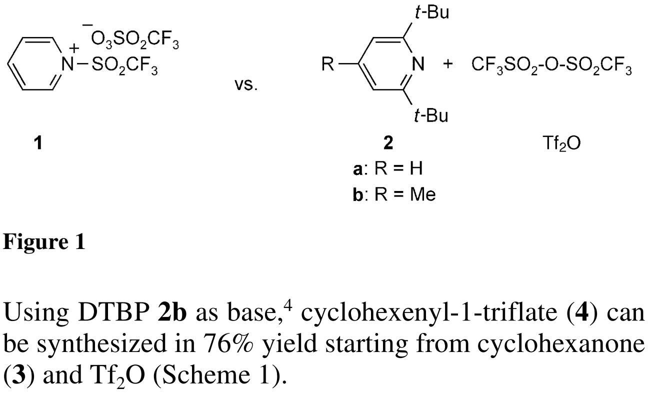
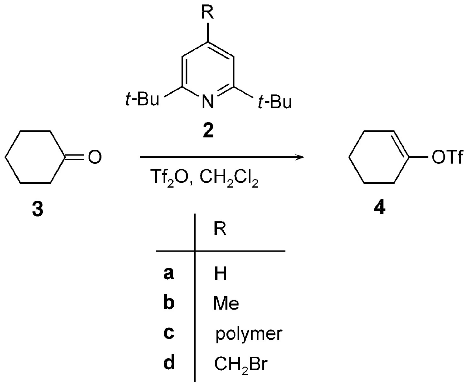


Figure 1

Using DTBP **2b** as base,[4] cyclohexenyl-1-triflate (**4**) can be synthesized in 76% yield starting from cyclohexanone (**3**) and Tf$_2$O (Scheme 1).

In this reaction, the base **2b** has to be used in at least equimolar quantities, and it is expensive. Therefore a polymer-bound version **2c** had been developed[5] but disappointingly, a lower yield (57%) and the formation of a dimeric side product **16** (Scheme 5) were observed (18%).



Scheme 1

An alternative to polymer bound reagents are dendrimers loaded with reagents.[6–8] In relation to sterically hindered bases, concave pyridines[9,10] have been connected[11,12] with Fréchet-type dendrimers. Following this route, it should be possible to connect DTBPs **2** to a Fréchet-type dendrimer by an analogous synthesis.

Starting from 2,6-di-*tert*-butyl-4-methyl-pyridine[13] (**2b**), the methyl group was functionalized by NBS bromination to give bromide **2d** in 70% yield.[14] Slightly more than two equivalents of **2d** were then reacted with 3,5-dihydroxybenzyl alcohol (**5**) to give the branched DTBP dimer **6** in 77% yield; the same reaction conditions were chosen as those established for the dendrimer synthesis of the concave pyridines (anhydrous acetone, K$_2$CO$_3$, 18-C-6).[11,12] The hydroxy group of **6** was then exchanged for a bromine atom, using tetrabromomethane triphenylphosphine, to give **7** in 87% yield, ready for further elaboration into dendrimers (Scheme 2).

Starting from the bromo-substituted DTBP dimer **7**, four dendrimers, both first- and second-generation **10**, **11**, **14**, and **15** have then been synthesized. Reaction of the bromide **7** with the diphenol **8** or the triphenol **9** in acetone using potassium carbonate and 18-crown-6 gave first-generation dendrimers **10** and **11** in 81% and 72% yield, respectively (Scheme 3).

The reaction of two equivalents of the bromide **7** with 3,5-dihydroxybenzyl alcohol (**5**) in anhydrous acetone using potassium carbonate and 18-crown-6 resulted in second-generation dendrons, first as the hydroxy derivative **12** (58% yield), which was then brominated to give 84% of

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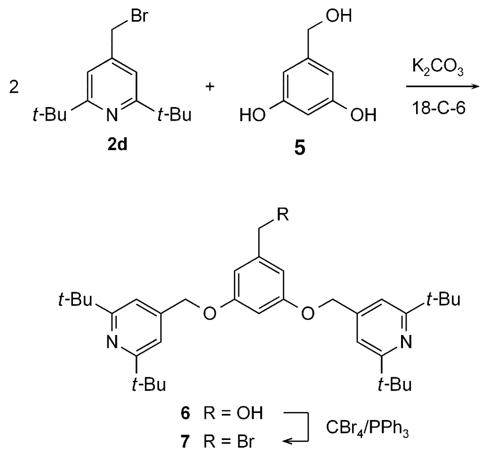
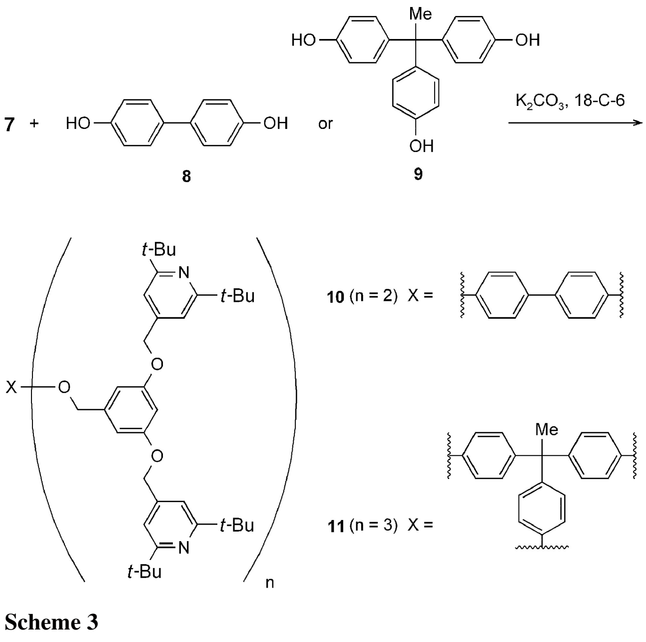


Scheme 2



Scheme 3

the bromide **13** using tetrabromomethane and triphenylphosphine (Scheme 4).

This dendron **13** was then reacted with core molecules, the diphenol **8** and the triphenol **9**, using conditions as discussed for the first-generation dendrimers. Thus, two second-generation dendrimers **14** and **15** could be synthesized in 63% and 58% yield, respectively (Scheme 5).

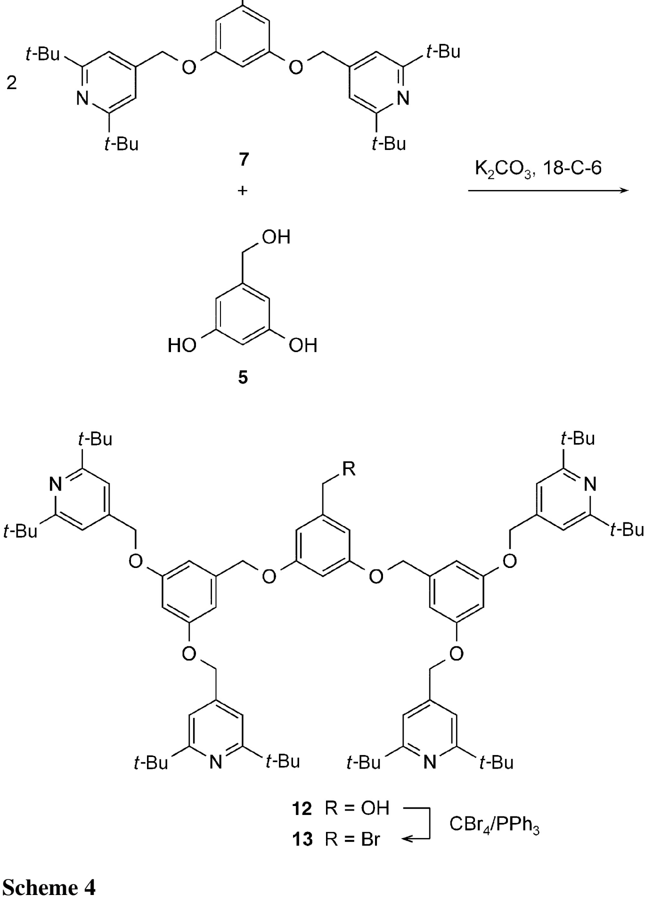
These second-generation dendrimers **14** and **15** carry up to twelve DTBP units on their surface and possess a molecular weight of up to 3845 g/mol which was verified by MALDI-MS. The dendrimers could be isolated in 100 mg batches. Spectroscopy as well as microanalyses showed no inclusion of solvent.

Application in Vinyl Triflate Synthesis

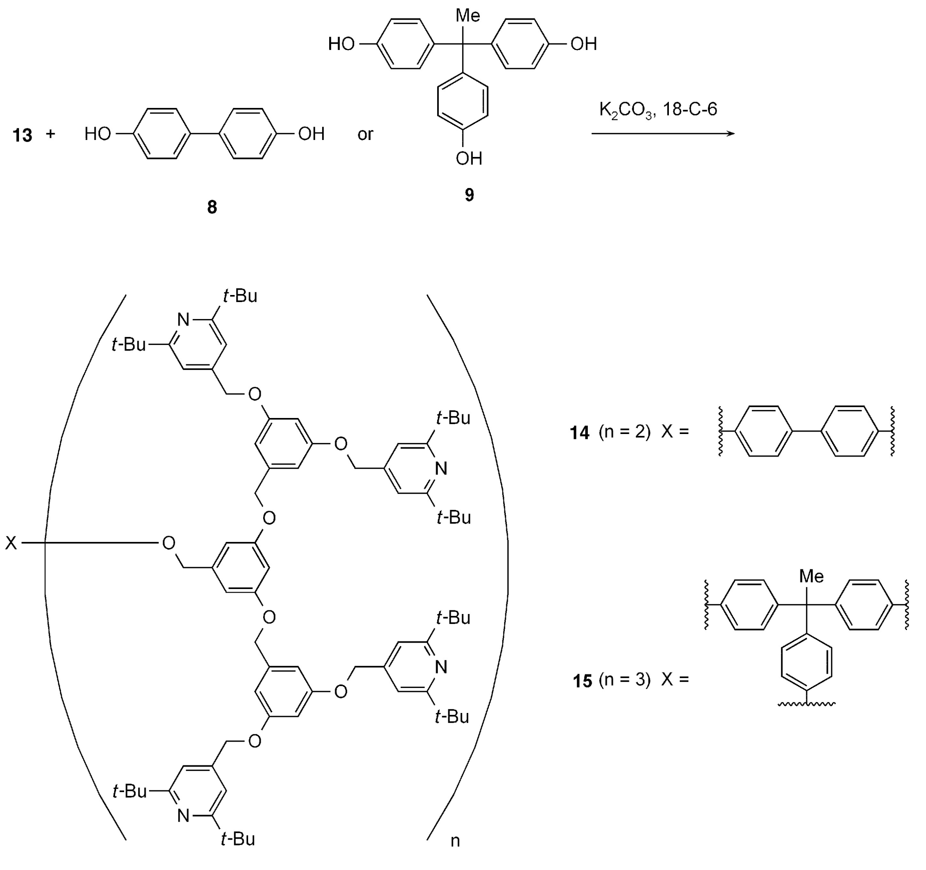
To test the ability of the DTBP-loaded dendrimers **10**, **11**, **14**, and **15** to act as shielded bases, the synthesis of cyclohexenyl-1-triflate (**4**) from cyclohexanone (**3**) and Tf_2O was carried out as described in the literature.[4] Table 1 compares the yields of **4** when different DTBPs were used, including the dendrimers **10**, **11**, **14**, and **15**.

In contrast to the polymer **2c**, DTBP **2b** and all dendritic DTBPs **10**, **11**, **14**, and **15** produced the vinyl triflates **4** in 70–76% yield, and no dimeric side product **16** was found. The dendritic DTBPs **10**, **11**, **14**, and **15** could be recovered in yields of up to 90% (see Experimental, Table 2). Thus they offer an alternative to the single use of expensive **2b**, and in contrast to the polymer bound DTBP **2c**, they give the desired triflate **4** in yields comparable to **2b**.

Melting points were determined on a Büchi hot-stage apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer Paragon FT-IR-spectrometer. ^1H NMR spectra were recorded in $CDCl_3$ or CCl_4 solutions on Bruker AC 200 (200 MHz) and AM 300 (300 MHz) spectrometers with TMS as internal standard. ^{13}C NMR spectra were recorded at 50 MHz or 75 MHz on a Bruker AC 200 or AM 300 with $CDCl_3$ or CCl_4 as solvent using the TMS carbon signal as internal standard. Mass spectra (EI or CI) were obtained on a Finnigan MAT 44S. MALDI spectra were recorded on a Bruker Biflex III instrument. Analytical TLC was performed on commercial Merck plates coated with silica gel GF_{254} (0.25 mm thick). Column chromatography was performed on silica gel, Merck Kieselgel (0.063–0.2 μm). Size-exclusion chromatography (GPC) was carried out with a Waters 510 HPLC pump and a Waters 486 tunable UV-detector; data analysis was performed with Millennium 2000 soft-



Scheme 4



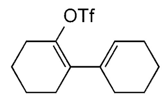
Scheme 5

ware; column was from MZ laboratories (300 × 8 mm; pore size: 500 Å) with THF as solvent. Elemental analyses were carried out on VarioEl, Elementaranalysensysteme GmbH. 2,6-Di-*tert*-butyl-4-methylpyridine (**2b**) was synthesized according to the literature.[13] All other starting materials were purchased and used without further purification.

Table 1 Comparison of the Yields of Cyclohexenyl-1-triflate (**4**) in the Reaction of Cyclohexanone (**3**) with Tf$_2$O Using a Range of DTBPs as Bases

Base	Yield of **4** (%)
2b (4-Me-DTBP)	70, 76[4]
2c (polymeric DTBP)	57[5,a]
10 (1st-generation, 4 DTBPs)	74
11 (1st-generation, 6 DTBPs)	72
14 (2nd-generation, 8 DTBPs)	74
15 (2nd-generation, 12 DTBPs)	75

[a] The dimer **16** was found in 18% yield besides the desired product **4**.



16

4-(Bromomethyl)-2,6-di-*tert*-butylpyridine (2d)

NBS (3.6 g, 21 mmol) and AIBN (ca. 100 mg) were added to a solution of 2,6-di-*tert*-butyl-4-methylpyridine (**2b**, 4 g, 20 mmol) in anhyd CCl$_4$ (200 mL). The solution was heated to reflux for 4 h. During this time, AIBN (3 × ca. 100 mg) was added (after 1 h, 2 h, and 3 h). When all NBS had reacted and only succinimide was floating on the solution (there was no more insoluble NBS at the bottom of the reaction vessel), the solid was filtered off and the solvent was evaporated in vacuo. Distillation in vacuo gave 4 g (70%) of **2d** as a colorless oily liquid.

Bp 68 °C/0.02 Torr (Lit.[14] 94 °C/2 Torr).

IR (KBr): 2957, 2921, 2865 (CH), 1599 (Ar), 1479, 1416, 1360, 1249, 1219, 1164, 853, 698, 674 cm^{-1}.

^{1}H NMR (CCl$_4$, 200 MHz): δ = 1.37 [s, 18 H, C(CH_3)$_3$], 4.35 (s, 2 H, ArCH_2Br), 7.08 (s, 2 H, PyH).

^{13}C NMR (CCl$_4$, 50 MHz): δ = 30.4 [q, C(CH$_3$)$_3$], 37.8 [s, C(CH$_3$)$_3$], 40.0 (t, ArCH$_2$Br), 115.4 [d, Py(C-3,5)], 140.9 [s, Py(C-4)], 168.5 [s, Py(C-2,6)].

MS (CI, isobutane): *m/z* (%) = 284 (100) [M$^+$ + 1], 282 [M$^+$ + 1] (70), 204 (21), 100 (31).

Dendrons 6 and 12; General Procedure

A mixture of the (dendritic) benzylbromide **2d**[14] or **7** (2.1–2.4 equiv), 3,5-dihydroxybenzyl alcohol (**5**, 1.0 equiv), anhyd K$_2$CO$_3$ (2.5–3.0 equiv) and 18-C-6 (0.2–0.6 equiv) was heated to reflux under nitrogen in anhyd acetone (100 mL). The progress of the reaction was monitored by TLC, and the reaction was stopped after 4–8 d when no starting material could be detected, or when no further conversion could be detected.

After evaporation of the solvent, H_2O (90 mL) and CH_2Cl_2 (30 mL) were added, and the aqueous layer was extracted with CH_2Cl_2 (3–5 × 20–100 mL). After drying with $MgSO_4$ and evaporation of the solvent in vacuo, the crude product was purified by chromatography (200–500-fold excess of silica gel).

3,5-Bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyl Alcohol (6)

According to the general procedure, 4-(bromomethyl)2,6-di-*tert*-butylpyridine (**2d**, 650 mg, 2.28 mmol), 3,5-dihydroxybenzyl alcohol (**5**, 155 mg, 1.11 mmol), anhyd K_2CO_3 (336 mg, 2.44 mmol), and 18-C-6 (58 mg, 0.20 mmol) were reacted for 3 d. Chromatography (cyclohexane–Et_2O, 2:1, R_f 0.2), gave 470 mg (77%) of **6** as a colorless, glassy solid.

Mp 45–48 °C.

IR (KBr): 3343 (OH), 2959, 2865 (CH), 1597, 1570.1 (Ar), 1477, 1453, 1419, 1361, 1292, 1258, 1201, 1170, 1067, 1012, 942, 864, 849, 829 cm^{-1}.

^{1}H NMR ($CDCl_3$, 200 MHz): δ = 1.38 [s, 36 H, C(CH_3)$_3$], 4.65 (s, 2 H, ArCH_2OH), 4.99 (s, 4 H, PyCH_2OAr), 6.59 (t, ^4J = 2.2 Hz, 1 H, ArH), 6.67 (d, ^4J = 2.2 Hz, 2 H, ArH), 7.15 (s, 4 H, PyH).

^{13}C NMR ($CDCl_3$, 75 MHz): δ = 30.1 [q, C(CH$_3$)$_3$], 37.7 [s, C(CH_3)$_3$], 65.2 (t, ArCH$_2$OH), 69.5 (t, PyCH$_2$OAr), 101.2 [d, Ar(CH)], 105.8 [d, Ar(CH)], 113.7 [d, Py(CH)], 143.6 [s, Ar(C-1)], 145.2 [Py(C-4)], 160.0 [s, Ar(C-3,5)], 168.1 [s, Py(C-2,6)].

MS (EI, 70 eV): *m/z* (%) = 546 (100) [M$^+$], 531 (31), 504 (20), 203 (23), 189 (34), 147 (7), 71 (8).

Anal. Calcd for $C_{35}H_{50}N_2O_3$ (546.81): C, 76.88; H, 9.22; N, 5.12. Found: C, 76.76; H, 9.10; N, 4.99.

3,5-Bis[3,5-bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyloxy]benzyl Alcohol (12)

According to the general procedure, **7** (4.54 g, 7.46 mmol), 3,5-dihydroxybenzyl alcohol (**5**, 0.5 g, 3.3 mmol), anhyd K_2CO_3 (1.24 g, 9.00 mmol) and 18-C-6 (0.44 g, 1.66 mmol) were reacted for 7 d. Chromatography (cyclohexane–Et_2O, 4:1; R_f 0.15) gave 2.3 g (58%) of **12** as a slightly yellow, glassy solid.

Mp 45–49 °C.

IR (KBr): 3450 (OH), 2957, 2863, (CH), 1597, 1570 (Ar), 1456, 1418, 1360, 1255, 1203, 1163, 1054, 900, 857, 822 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.33 [s, 72 H, C(CH_3)$_3$], 4.66 (s, 2 H, ArCH_2OH), 4.98 (br s, 12 H, PyCH_2OAr, ArCH_2OAr), 6.57 [m$_c$ (t), ^4J = 2.2 Hz, 1 H, ArH], 6.60 (t, ^4J = 2.2 Hz, 2 H, ArH), 6.66 [m$_c$ (d), ^4J = 2.2 Hz, 2 H, ArH], 6.71 (d, ^4J = 2.2 Hz, 4 H, ArH), 7.15 (br s, 8 H, PyH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.1 [q, C(CH$_3$)$_3$], 37.7 [s, C(CH_3)$_3$], 65.2 (t, ArCH$_2$OH), 69.6, 70.1 (2 t, PyCH$_2$OAr, ArCH$_2$OAr), 101.3, 101.5, 105.6, 106.5, 113.7 [several d, ArCH, Py(C-3,5)], 139.4 [s, Ar(C-1)], 143.5 [s, Ar(C)CH$_2$OH], 145.1 [s, Py(C-4), 160.1 [s, Ar(C-3,5)], 168.1 [s, Py(C-2,6)].

MS (EI, 70 eV): *m/z* (%) = 1197 (43) [M$^+$], 992 (18), 607 (12), 598 (11), 529 (38), 203 (100), 189 (39).

Anal. Calcd for $C_{77}H_{104}N_4O_7$ (1197.73): C, 77.21; H, 8.75; N, 4.68. Found: C, 77.40; H, 8.72; N, 4.66.

Dendrons 7 and 13; General Procedure

Dendritic benzyl alcohol **6** or **12** (1.0 equiv) was dissolved in as little freshly distilled, anhyd THF as necessary to give a clear solution. Under nitrogen, PPh_3 (1.2–1.3 equiv) and CBr_4 (1.2–1.3 equiv) were added, and the mixture was stirred at r.t. The reaction was stopped when TLC showed no more starting material or the mixture turned yellow due to the formation of decomposition products; this usually took 15–200 min. If starting material could still be detected after 30 min by TLC, PPh_3 (0.6 equiv) and CBr_4 (0.6 equiv) were added and stirring was continued. The reaction was quenched by the addition of a large excess of H_2O (ca. 30 mL), and the aqueous layer was extracted with CH_2Cl_2 (3–5 × 15–100 mL). The combined organic layer was dried with $MgSO_4$, and after evaporation of the solvent, the crude product was purified by chromatography (200–500-fold excess of silica gel).

3,5-Bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyl Bromide (7)

According to the general procedure, **6** (2.6 g, 4.7 mmol), CBr_4 (2.0 g, 6.0 mmol) and PPh_3 (1.6 g, 6.0 mmol) were reacted for 30 min. Chromatography (CH_2Cl_2–EtOH, 15:1; R_f 0.85) gave 2.6 g (87%) of **7** as a slightly yellow, glassy solid.

Mp 47–50 °C.

IR (KBr): 2958, 2859 (C-H), 1593, 1570 (Ar), 1479, 1447, 1420, 1358, 1202, 1166, 1070, 859 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.36 [s, 36 H, C(CH_3)$_3$], 4.43 (s, 2 H, ArCH_2Br), 5.03 (s, 4 H, PyCH_2OAr), 6.60 (t, ^4J = 2.2 Hz, 1 H, ArH), 6.68 (d, ^4J = 2.2 Hz, 2 H, ArH), 7.13 (s, 4 H, PyH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.1 [q, C(CH$_3$)$_3$], 33.4 (t, ArCH$_2$OH), 37.7 [s, C(CH_3)$_3$], 69.6 (t, PyCH$_2$OAr), 102.2 [d, Ar(CH)], 108.3 [d, Ar(CH)], 113.7 [d, Py(CH)], 139.9 [s, Ar(C-1)], 145.0 [s, Py(C-4)], 159.9 [s, Ar(C-3,5)], 168.1 [s, Py(C-2,6)].

MS (EI, 70 eV): *m/z* (%) = 610 (100) [M$^+$], 608 (98) [M$^+$], 595 (17), 593 (18), 529 (36), 486 (13), 203 (70), 189 (74), 174 (16), 148 (14).

Anal. Calcd for $C_{35}H_{49}BrN_2O_2$ (609.71): C, 68.95; H, 8.10; N, 4.59. Found: C, 69.14; H, 8.05; N, 4.44.

3,5-Bis[3,5-bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyloxy]benzyl Bromide (13)

According to the general procedure, **12** (620 mg, 517 μmol), CBr_4 (216 mg, 650 μmol) and PPh_3 (171 mg, 650 μmol) were reacted. After 30 min, additional CBr_4 (108 mg, 325 μmol) and PPh_3 (86 mg, 325 mol) were added because TLC showed unreacted starting material. After a further 30 min, the mixture was worked up as described. Chromatography (cyclohexane–Et_2O, 4:1; R_f 0.6) gave 549 mg (84%) of **13** as a colorless, glassy solid.

Mp 48–52 °C.

IR (KBr): 2956, 2862 (CH), 1597, 1571 (Ar), 1457, 1418, 1360, 1255, 1202, 1162, 1054, 900, 857, 821 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.32 [s, 72 H, C(CH_3)$_3$], 4.42 (s, 2 H, ArCH_2Br), 5.00 (br s, 12 H, PyCH_2OAr, ArCH_2OAr), 6.56 [m$_c$ (t), ^4J = 2.2 Hz, 1 H, ArH), 6.61 (t, ^4J = 2.2 Hz, 2 H, ArH), 6.66 [m$_c$ (d), ^4J = 2.2 Hz, 2 H, ArH], 6.72 (d, ^4J = 2.2 Hz, 4 H, ArH), 7.14 (br s, 8 H, PyH).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 30.1 [q, C(CH$_3$)$_3$], 37.7 [s, C(CH_3)$_3$], 65.2 (t, ArCH$_2$Br), 69.6, 70.1 (2 × t, PyCH$_2$OAr, ArCH$_2$OAr), 101.3, 101.5, 105.6, 106.5, 113.7 [several d, ArCH, Py(C-3,5)], 139.4 [s, Ar(C-1)], 143.5 (s, ArCCH$_2$Br), 145.1 [s, Py(C-4)], 160.1 (s, Ar(C-3,5)], 168.1 [s, Py(C-2,6)].

MS (EI, 70 eV): *m/z* (%) = 1260 (43%) [M$^+$], 992 (18), 607 (12), 598 (11), 529 (38), 203 (100), 189 (39).

Anal. Calcd. for $C_{77}H_{103}BrN_4O_6$ (1260.63): C, 73.36; H, 8.23; N, 4.44. Found: C, 73.31; H, 8.19; N, 4.50.

Dendrimers 10 and 14; General Procedure

A mixture of dendritic benzylbromide **7** or **13** (2.2–2.3 equiv), 4,4′-dihydroxybiphenyl (**8**, 1 equiv), anhyd K_2CO_3 (3.0–3.3 equiv), and 18-C-6 (0.3–0.6 equiv) was dissolved in anhyd acetone (50 mL) and heated to reflux under nitrogen for 3–8 d, until no further conversion was observed by TLC. After cooling to r.t. and evaporation of the solvent, the solid residue was dissolved in a threefold excess of H_2O (30 mL) and CH_2Cl_2 (30 mL). The aqueous layer was extracted with

$\mathrm{CH_2Cl_2}$ (3–6 × 10–50 mL). The combined organic layer was dried with $\mathrm{MgSO_4}$, and after evaporation of the solvent, the crude product was purified by chromatography (300–500-fold excess of silica gel).

4,4′-Bis[3,5-bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyloxy]biphenyl (10)

According to the general procedure, **7** (120 mg, 197 μmol), 4,4′-dihydroxybiphenyl (**8**, 17 mg, 94 μmol), anhyd $\mathrm{K_2CO_3}$ (32.0 mg, 235 μmol), and 18-C-6 (8.0 mg, 28 μmol) were reacted for 6 d. Chromatography (cyclohexane–$\mathrm{Et_2O}$, 5:1; R_f 0.35) gave 100 mg (81%) of **10** as a colorless, glassy solid.

Mp 60–65 °C.

IR (KBr): 2958, 2860 (CH), 1597, 1570 (Ar), 1497, 1456, 1418, 1359, 1280, 1213, 1163, 1058, 901, 856, 825 $\mathrm{cm^{-1}}$.

^{1}H NMR (200 MHz, $\mathrm{CDCl_3}$): $\delta = 1.35$ [s, 72 H, $\mathrm{C(C}H_3)_3$], 5.01 (s, 8 H, Py$\mathrm{C}H_2$OAr), 5.06 (s, 4 H, Ar$\mathrm{C}H_2$O–core), 6.61 (t, $^4J = 2.2$ Hz, 2 H, ArH), 6.74 (d, $^4J = 2.2$ Hz, 4 H, ArH), 7.01 (d, $^3J = 8$ Hz, 4 H, core-H), 7.15 (s, 8 H, PyH), 7.42 (d, $^3J = 8$ Hz, 4 H, core-H).

^{13}C NMR (75 MHz, $\mathrm{CDCl_3}$): $\delta = 30.1$ [q, $\mathrm{C(}C\mathrm{H_3)_3}$], 37.7 [s, $C\mathrm{(CH_3)_3}$], 69.6 (t, Ar$C\mathrm{H_2}$O–core), 69.9 (t, Py$C\mathrm{H_2}$OAr), 102.2 [d, Ar(CH)], 106.6 [d, core(CH)], 108.3 [d, Ar(CH)], 113.3 [d, Py(C-3,5)], 129.7 [d, core(CH)], 139.9 [s, Ar(C-1)], 142.1 [s, core(C-1,1′), 145.0 [s, Py(C-4)], 156.8 [s, core(C-4,4′), 159.9 [s, Ar(C-3,5)], 168.1 [s, Py(C-2, 6)].

MS (EI, 70 eV): *m*/*z* (%) = 1243 (25) [$\mathrm{M^+}$], 714 (6), 529 (56), 325 (10), 203 (100).

Anal. Calcd for $\mathrm{C_{82}H_{106}N_4O_6}$ (1243.81): C, 79.18; H, 8.59; N, 4.50. Found: C, 79.00; H, 8.40; N, 4.63.

4,4′-Bis{3,5-bis[3,5-bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyloxy]benzyloxy}biphenyl (14)

According to the general procedure, **13** (250 mg, 198 μmol), 4,4′-dihydroxybiphenyl (**8**, 17 mg, 94 μmol), anhyd $\mathrm{K_2CO_3}$ (36 mg, 262 μmol) and 18-C-6 (10 mg, 38 μmol) were reacted for 6 d. Chromatography (cyclohexane–$\mathrm{Et_2O}$, 4:1; R_f 0.8) gave 135 mg (63%) of **14** as a slightly yellow, glassy solid.

Mp 63–68 °C.

IR (KBr): 2961, 2922, 2860 (CH), 1597, 1570 (Ar), 1498, 1457, 1418, 1360, 1261, 1163, 1095, 1021, 900, 858, 802, 682 $\mathrm{cm^{-1}}$.

^{1}H NMR (300 MHz, $\mathrm{CDCl_3}$): $\delta = 1.34$ [s, 144 H, $\mathrm{C(C}H_3)_3$], 5.02 (br s, 28 H, Ar$\mathrm{C}H_2$O–core, Ar$\mathrm{C}H_2$OAr, Py$\mathrm{C}H_2$OAr), 6.60 [$\mathrm{m_c}$ (t) $^4J =$ 2.2 Hz, 6 H, ArH], 6.73 [$\mathrm{m_c}$, (d), $^4J = 2.2$ Hz, 12 H, ArH), 7.00 (d, $^3J = 8$ Hz, 4 H, core-H), 7.15 (s, 16 H, PyH), 7.44 (d, $^3J = 8$ Hz, 4 H, core-H).

^{13}C NMR (75 MHz, $\mathrm{CDCl_3}$): $\delta = 30.1$ [q, $\mathrm{C(}C\mathrm{H_3)_3}$], 37.8 [s, $C\mathrm{(CH_3)_3}$], 69.6, 69.7 (2 t, Ar$C\mathrm{H_2}$OAr, Ar$C\mathrm{H_2}$O–core, Py$C\mathrm{H_2}$OAr), 101.6, 106.6, 106.7, 113.8, 115.1, 127.7, 133.2 [several d, ArCH, core-CH, Py(C-3,5)], 139.3 [s, Ar(C-1)], 141.3 [s, core(C-1,1′), 145.1 [s, Py(C-4)], 157.1 [s, core(C-4,4′)], 160.0 [s, Ar(C-3,5)], 168.1 [s, Py(C-2,6)].

MS (MALDI-TOF, THF, dithranol as matrix): *m*/*z* = 2544 [$\mathrm{M^+}$], 2421, 2341, 2219, 2107, 2016, 1894, 1691, 1365, 1179, 1130, 1069, 1040, 870, 715, 642, 532, 505, 477, 450, 438, 422.[15]

Anal. Calcd for $\mathrm{C_{166}H_{214}N_8O_{14}}$ (2543.63): C, 78.32; H, 8.47; N, 4.40. Found: C, 78.19; H, 8.50; N, 4.44.

Dendrimers 10 and 15; General Procedure

A mixture of the dendritic benzylbromide **7** or **13** (3.2–3.3 equiv), 1,1,1-tris(4-hydroxyphenyl)ethane (**9**, 1 equiv), anhyd $\mathrm{K_2CO_3}$ (4.5–5.0 equiv), and 18-C-6 (0.5–0.7 equiv) was dissolved in anhyd acetone (70 mL). The mixture was heated to reflux for 5–8 d until no further reaction was observed by TLC. The solvent was evaporated in vacuo, the residue was dissolved in a threefold excess of $\mathrm{H_2O}$ (30 mL) and $\mathrm{CH_2Cl_2}$ (30 mL). The aqueous layer was extracted with $\mathrm{CH_2Cl_2}$ (6 × 10–50 mL). The combined organic layer was dried with $\mathrm{MgSO_4}$ and the solvent was evaporated in vacuo. The crude product was purified by chromatography (500-fold excess of silica gel).

1,1,1-Tris{4-[3,5-bis(2,6-di-*tert*-butylpyridin-4-ylmethoxy)benzyloxy]phenyl}ethane (11)

According to the general procedure, **7** (120 mg (197 μmol), 1,1,1-tris(4-hydroxyphenyl)ethane (**9**, 18 mg, 60 μmol), anhyd $\mathrm{K_2CO_3}$ (33 mg, 240 μmol), and 18-C-6 (5 mg, 20 μmol) were reacted for 6 d. Chromatography (cyclohexane–$\mathrm{Et_2O}$, 4:1; R_f 0.75) gave 80 mg (72%) of **11** colorless, glassy solid.

Mp 60–64 °C.

IR (KBr): 2956, 2864 (C-H), 1597, 1570, 1507 (Ar), 1457, 1418, 1360, 1294, 1247, 1165, 1063, 1018, 942, 900, 858, 830 $\mathrm{cm^{-1}}$.

^{1}H NMR (200 MHz, $\mathrm{CDCl_3}$): $\delta = 1.35$ [s, 108 H, $\mathrm{C(C}H_3)_3$], 2.1 (s, 3 H, core–$\mathrm{C}CH_3$), 4.98 (s, 6 H, Ar$\mathrm{C}H_2$O–core), 5.02 (s, 12 H, Py$\mathrm{C}H_2$OAr), 6.60 (t, $^4J = 2.2$ Hz, 3 H, ArH), 6.72 (d, $^4J = 2.2$ Hz, 6 H, ArH), 6.87 (d, $^3J = 8$ Hz, 6 H, core-H), 6.87 (d, $^3J = 8$ Hz, 6 H, core-H), 7.13 (s, 12 H, PyH).

^{13}C NMR (75 MHz, $\mathrm{CDCl_3}$): $\delta = 29.7$ (q, core–$\mathrm{C}C\mathrm{H_3}$), 30.1 [q, $\mathrm{C(}C\mathrm{H_3)_3}$], 37.7 [s, $C\mathrm{(CH_3)_3}$], 69.6 (t, Ar$C\mathrm{H_2}$O–core), 69.9 (t, Py$C\mathrm{H_2}$OAr), 101.5 [d, Ar(CH)], 106.4 [d, Ar(CH)], 113.8 [d, Py(C-3,5)], 115.1 [d, core(CH)], 127.7 [d, core(CH)], 133.7 [s, core(C-1)], 139.7 [s, Ar(C-1)], 145.1 [s, Py(C-4), 157.8 [s, core(C-4)], 160.1 [s, Ar(C-3,5)], 168.1 [Py(C-2,6)].

MS (CI, isobutane): *m*/*z* (%) = 1893 (8) [$\mathrm{M^+} + 1$], 1362 (9), 622 (5), 531 (22), 515 (17), 203 (100), 190 (32), 174 (11), 163 (20), 149 (18).

Anal. Calcd for $\mathrm{C_{125}H_{162}N_6O_9}$ (1892.76): C, 79.32; H, 8.63; N, 4.44. Found: C, 79.18; H, 8.80; N, 4.31.

1,1,1-Tris(4-{3,5-bis[3,5-bis(2,6-di-*tert*-butyl-pyridin-4-ylmethoxy)benzyloxy]benzyloxy}-phenyl)ethane (15)

According to the general procedure, **13** (110 mg, 120 μmol), 1,1,1-tris(4-hydroxyphenyl)ethane (**9**, 11 mg, 36 μmol), anhyd $\mathrm{K_2CO_3}$ (20 mg, 144 μmol), and 18-C-6 (8 mg, 15 μmol) were reacted for 8 d. Chromatography (cyclohexane–$\mathrm{Et_2O}$, 4:1; R_f 0.8.) gave 86 mg (58%) of **15** as a colorless glassy solid.

Mp 68–71 °C.

IR (KBr): 2958, 2923, 2861 (CH), 1597, 1570, 1497 (Ar), 1458, 1419, 1360, 1257, 1203, 1161, 1049, 900, 856, 828, 770, 681 $\mathrm{cm^{-1}}$.

^{1}H NMR (300 MHz, $\mathrm{CDCl_3}$): $\delta = 1.34$ [s, 216 H, $\mathrm{C(C}H_3)_3$], 2.06 (s, 3 H, core-$\mathrm{CCH_3}$), 4.99 (br s, 42 H, Ar$\mathrm{C}H_2$O–core, Ar$\mathrm{C}H_2$OAr, Py$\mathrm{C}H_2$OAr), 6.60 [$\mathrm{m_c}$ (t), $^4J = 2.2$ Hz, 9 H, ArH], 6.71 [$\mathrm{m_c}$ (d), $^4J = 2.2$ Hz, 18 H, ArH), 6.86 (d, $^3J = 8$ Hz, 6 H, core-H), 7.00 (d, $^3J = 8$ Hz, 6 H, core-H), 7.14 (br s, 24 H, PyH).

^{13}C NMR (75 MHz, $\mathrm{CDCl_3}$): $\delta = 28.9$ (q, core-$\mathrm{C}C\mathrm{H_3}$), 29.9 [q, $\mathrm{C(}C\mathrm{H_3)_3}$], 36.7 [s, $C\mathrm{(CH_3)_3}$], 49.6 (s, core-$C\mathrm{CH_3}$), 66.2, 68.7, 69.5 (several t, Ar$C\mathrm{H_2}$OAr, Ar$C\mathrm{H_2}$O–core, Py$C\mathrm{H_2}$OAr), 100.5, 105.5, 106.6, 112.6, 113.0, 128.7 [several d, ArCH, core-CH, Py(C-3,5)], 138.5 [s, Ar(C-1)], 141.1 [s, core(C-1)], 144.1 [s, Py(C-4)], 155.8 [s, core(C-4)], 159.0 [s, Ar(C-3,5)], 167.0 [s, Py(C-2,6)].

MS (MALDI-TOF, THF, dithranol as matrix): *m*/*z* = 3845 [$\mathrm{M^+}$], 2992, 2868, 2721, 2396, 2015, 1850, 1747, 1612, 1196, 870, 656, 642, 614, 580, 545, 532, 505, 477, 463, 454, 438, 422, 408, 394.[16]

Anal. Calcd for $\mathrm{C_{251}H_{324}N_{12}O_{21}}$ (3845.53): C, 78.40; H, 8.49; N, 4.37. Found: C, 78.45; H, 8.49; N, 4.33.

Synthesis of Cyclohexenyl-1-triflate (4) from 2b

2,6-Di-*tert*-butyl-4-methylpyridine (**2b**, 4.1 g, 20 mmol) was dissolved in anhyd $\mathrm{CH_2Cl_2}$ (15 mL); cyclohexanone (**3**, 1.8 g, 18 mmol) and Tf_2O (5.4 mg, 19 mmol) were added. The mixture was stirred at r.t. under argon for 24 h, towards the end of the reaction a precipitate formed. The solvent was evaporated in vacuo and the residue was dissolved in *n*-pentane (ca. 100 mL). The remaining solid was filtered off and washed several times with *n*-pentane (3 × 30 mL). The combined organic layer was washed with cold 1 N HCl (ca. 50 mL) and brine (ca. 50 mL). After drying with anhyd K_2CO_3 the solvent was evaporated in vacuo and the residue was distilled (70–72 °C/14 Torr, Lit.[4,17] 75–78 °C/15 Torr) yielding 3.0 g (70%, Lit.[4,5] 76%) of **4** as a colorless liquid in 98.5% purity by GC [column: Optima 1.25 m; temperature program: 5 min at 50 °C, 5 °C/min until 200 °C, 15 min at 200 °C, 20 °C/min until 250 °C, 20 min at 250 °C; cyclohexanone (**3**): t_R 4.6 min, cyclohexenyl-1-triflate **4**: t_R 10.1 min, 2,6-di-*tert*-butyl-4-methylpyridine (**2b**): t_R 17.7 min, internal standard (*n*-hexadecane): t_R 26.1 min].

^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.56 (m, 2 H), 1.73 (m, 2 H), 2.13 (m, 2 H), 2.29 (m, 2 H), 5.71 (m, 1 H).

MS (EI, 70 eV): m/z = 230 (M^+).

Synthesis of Cyclohexenyl-1-triflate (4) with a Range of DTBPs

All reactions were carried out in 5 mL vials sealed with teflon septa. The reagents were added in the following sequence: **2b** (1.1 equiv), or the analogous dendrimers **10**, **11**, **14**, or **15** [calculated on a DTBP unit per of cyclohexanone (**3**), see Table 2)], cyclohexanone (**3**, 10 mg, 100 μmol), anhyd CH_2Cl_2 (2 mL), and Tf_2O (30 mg, 106 μmol). The vial was flushed with argon and sealed, a needle connected to an argon balloon was pierced through the septum. The mixtures were stirred for 6 h at r.t. Near the end of the reaction, precipitated solid was filtered off. The filtrate was evaporated in vacuo, the residue was dissolved in *n*-pentane (ca. 20 mL), filtered through basic Al_2O_3 which was washed with *n*-pentane (ca. 20 mL). After evaporation of the solvent, a known amount of *n*-hexadecane was added (Table 2). Then, the mixture was diluted with CH_2Cl_2 to give a total volume of 50 mL. The yields were determined by GC as described above.

Recycling of the Dendritic Bases 10, 11, 14, and 15

The residues of the reactions using the dendrimer-fixed DTBPs **10**, **11**, **14**, and **15** were mixed with *i*-Pr_2NH–benzene solution (1:4, 5 mL) and stirred for 10 min at r.t. The reaction was quenched with H_2O (10 mL). After filtration, the aqueous layer was extracted with CH_2Cl_2 (3 × 10 mL) and the combined organic layer was dried with $MgSO_4$. After evaporation of the solvent, the combined residues were stirred with a THF–*i*-Pr_2NH solution (9:1, 5 mL) for 10 min at r.t. The reaction was quenched with H_2O (10 mL) and filtered. The aqueous layer was extracted with CH_2Cl_2 (3 × 30 mL), the combined organic layer was dried with $MgSO_4$, and the solvents were evaporated in vacuo. Thus 70–80% of the dendrimers **10**, **11**, **14**, and **15** could be regenerated. Further material could be extracted from Al_2O_3 thus increasing the yield to 80–90% (Table 2).[18]

All dendrimer-fixed DTBPs **10**, **11**, **14**, and **15** remained active in the triflate reaction over several reaction/recovery cycles, however, a change of color from colorless to dark yellow slowly occurred. This is in accordance with the observation that the dendrimer-fixed DTBPs decomposed slowly when stored for months. In these cases, the purity of the yellow compounds was checked by GPC and GPC purification was carried out if necessary.

For better recovery of the dendrimer-fixed DTBPs, the reaction time was reduced to 5 h in order to avoid decomposition in the strong acidic medium.

Table 2 Batch Sizes for the Syntheses of Cyclohexen-1-yl Triflate (**4**) from Cyclohexanone (**3**) with Tf_2O

DTBP	Amount [mg (μmol)]	n-$C_{16}H_{34}$ (mg)	Yield [mg (%)]	Recovery [mg (%)]
2b	23 (110)	17.9	17.7 (77)	
10	34 (27)	42	17.0 (74)	28.5 (85)
11	35 (18)	32	16.6 (72)	28.0 (80)
14	35 (14)	41	17.1 (74)	30.4 (87)
15	35 (9)	27	17.3 (75)	29.8 (85)

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