Synthesis of Imidazole-Derived Ionic Liquids from Monoterpenes by Means of the Sonogashira Reaction

Marcelo G. Speziali,* Adriano L. Monteiro

Instituto de Química, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, 91501-570, CP 15003, Porto Alegre, RS, Brazil
Fax +55(51)33087304; E-mail: marcelo.speziali@ufrgs.br

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Abstract: This work reports the functionalization of monoterpenoids with 2-iodo-1-methyl-1*H*-imidazole using Sonogashira cross-coupling reactions. Natural monoterpenes were also modified to obtain the corresponding alkynes which were used in the cross-coupling step. After a sequence of cross-coupling–hydrogenation–N-alkylation–ion metathesis, novel ionic liquids were obtained in reasonable yields. The obtained products can be used as scaffolds for the further synthesis of new ionic liquids derived from terpenoids and for new, potentially bioactive materials, e.g. polycyclic monocationic scaffolds. All obtained products show the characteristics of a room temperature ionic liquid (RTIL).

Key words: terpenoids, cross-coupling, palladium, ionic liquids, catalysis

Metal-catalyzed cross-coupling reactions are powerful tools for the selective formation of C–C and C–X bonds with applications in the synthesis of complex molecules, drugs, special polymers and new materials.[1] The potential synthetic applications have allowed researchers to envisage new or alternative routes to obtain products of interest with applications as aromas, sunscreens, ionic liquids and fine chemicals in general.[1,2] Ionic liquids (ILs), also called 'molten salts', are defined by convention as salts with a melting point below the boiling temperature of water.[3] They are formed by ion pairs with a side chain that can be skillfully shaped to obtain different ionic liquids with many distinct physical and chemical properties.[3] Because of this structural versatility, ionic liquids have a wide range of features that are directly reflected by their applications, such as solvents with special properties,[4] electrolytes,[5] solar cells,[6] in gas storage,[7] organometallic catalysts[4] and enzymes,[8] lubricants[9] and hydraulic fluids.[10]

Another important class of substances are the monoterpenes and naturally occurring monoterpenoids. These olefins are widely available, inexpensive and generally used in pharmaceutical compositions, perfumes and flavors.[11] The chemistry of monoterpenes is incredibly rich; the number of reactions by which this type of substance may be subjected to, resulting in products with special features, is widely described in the literature.[12]

The availability of structural and chemically rich raw materials is a cornerstone for the creation of new ionic liquids that could incorporate properties of the terpenes, such as chirality[13] and biocompatibility; however, there are few reported studies that have employed monoterpenes for the synthesis of ionic liquids. Therefore, their application as chiral solvents, ligands and even as liquid crystals[14] is a promising field with potentially fruitful possibilities.[13a]

In the present work, we report the synthesis of new room temperature ionic liquids (RTILs) derived from linalool oxide, dehydrolinalool and citronellal. To the best of our knowledge, no attempts to obtain ionic liquids via cross-coupling reactions employing monoterpenes have been reported so far. We decided to apply Sonogashira coupling at the 2-position of the imidazole ring. The resulting structure is quite chemically rich and several different further reactions can generate very interesting products. For instance, it has been reported that some 1,2-dialkynylimidazoles are cytotoxic against a wide range of cancer cells and induce apoptosis in A549 cells.[15] Also, Čižková and co-workers[16] have reported that 1,2-dialkynylimidazoles can undergo a [2+2+2]-cycloaddition reaction towards the formation of bioactive compounds. After the 2-alkynylimidazoles are obtained by Sonogashira coupling with terpene-based alkynes, hydrogenation of the triple bond followed by N-quaternization and subsequent anion metathesis results in the new ionic liquids. The use of a natural raw material can open a window to possibilities in the innovative products sector.

Although a number of different natural olefins, e.g. monoterpenes, can be found in nature, in some cases in large amounts and at low cost, cross-coupling between imidazoles and olefins remains a challenge and an almost unexplored field. A few successful examples of Heck reactions between halogenated imidazoles and electron-poor olefins have been reported.[17] When 2-iodo-1-trityl-1*H*-imidazole was used, 5,5-diphenyl-5*H*-imidazo[2,1-*a*]isoindole was surprisingly obtained by an intramolecular arylation, a reaction occurring with many 1-benzylimidazole derivatives.[18]

In an exploratory study, we tried to react 2-iodo-1-methyl-1*H*-imidazole (**3**) with linalool oxide [**1**; 2-(5-methyl-5-vinyltetrahydrofuran-2-yl)propan-2-ol] or citronellal (**2**) under Heck conditions (Scheme 1). All attempts using $Pd(OAc)_2$ as the catalyst precursor and Ph_3P as the ligand failed, and the substrates remained unchanged even after 48 hours. When Cy_3P was used as the ligand, only the reduction of 2-iodo-1-methyl-1*H*-imidazole (**3**) to 1-meth-

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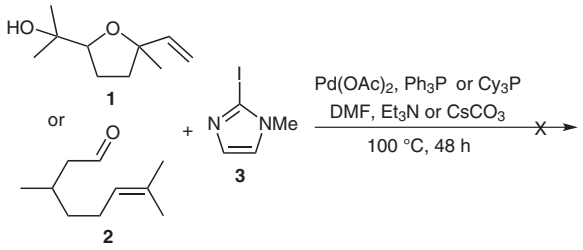
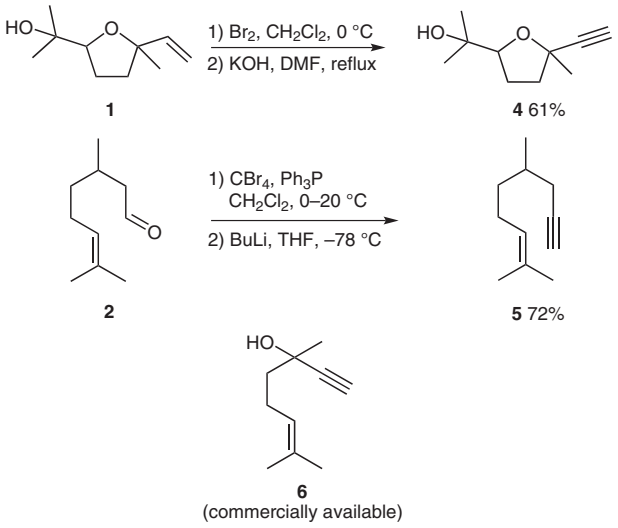
yl-1*H*-imidazole was observed to a low extent (trace amounts detected by GC).



Scheme 1

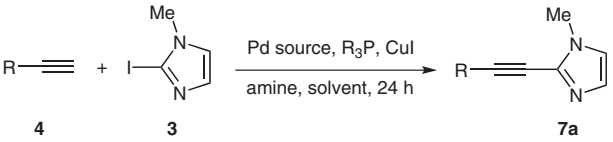
Next, we decided to use the Sonogashira reaction as an alternative to functionalize the 2-position of the imidazole ring. For this, a monoterpenoid, linalool oxide, was submitted to a bromination–dehydrobromination sequence. Linalool oxide was used as a natural stereoisomeric mixture. The corresponding yields and analysis of the products were obtained taking into account the mixture of *cis*/*trans*-isomers. Starting from an equimolar *cis*/*trans*-mixture, the recovered purified product after the bromination–dehydrobromination sequence was a 7:3-mixture of isomers, as confirmed by GC and ^{1}H NMR analysis. Although considerable efforts were made to determine which isomer corresponded to the major product, this could not be determined with certainty, and it was decided to use the mixture as a whole. The yield for alkyne **4** derived from linalool oxide was 61% (Scheme 2). Citronellal (**2**) was submitted to a Corey–Fuchs sequence, to afford the respective alkyne **5** in 72% yield for the two steps. The third alkyne, dehydrolinalool (**6**), is commercially available.



Scheme 2

A short screening of Sonogashira coupling systems was performed with alkyne **4** to determine the optimal conditions for other substrates. When the reaction was carried out in *N*,*N*-dimethylformamide as the solvent at 80 °C, the best yield was obtained using a mixture of $Pd(OAc)_2$ with Ph_3P as the catalyst and triethylamine as the base (Table 1, entries 1–3). The bases triethylamine and diisopropylamine could also be used as the solvent, and good yields were obtained using $Pd(OAc)_2$ with Ph_3P (3 mol% Pd) or $Pd(PPh_3)_2Cl_2$ (3 mol% Pd) (Table 1, entries 4–7). No cross-coupling product was observed when the reactions were carried out at room temperature, and the only product detected was the diyne formed from the homocoupling of the alkyne **4** (Table 1, entries 8–10). In the absence of palladium, neither the cross-coupling product nor the homocoupling product was observed (Table 1, entry 11).

Table 1 Screening of Sonogashira Conditions[a]



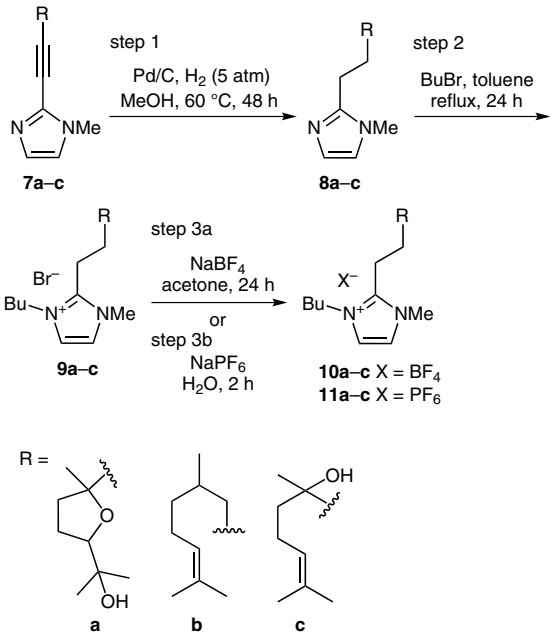
4 **3** **7a**

Run	Catalyst	Solvent	Base	Temp (°C)	Yield[b] (%)
1	$Pd(OAc)_2/Ph_3P$	DMF	Et_3N	80	73
2	$Pd(PPh_3)_2Cl_2$	DMF	Et_3N	80	54
3	$Pd(OAc)_2/Ph_3P$	DMF	*i*-Pr_2NH	80	50
4[c]	$Pd(OAc)_2/Ph_3P$	–	*i*-Pr_2NH	80	54
5[c]	$Pd(OAc)_2/Ph_3P$	–	Et_3N	80	45
6[c,d]	$Pd(OAc)_2/Ph_3P$	–	Et_3N	80	68
7[c]	$Pd(PPh_3)_2Cl_2$	–	Et_3N	80	69
8	$Pd(PPh_3)_2Cl_2$	DMF	Et_3N	r.t.	–
9	$Pd(OAc)_2/Ph_3P$	DMF	Et_3N	r.t.	–
10	$Pd(OAc)_2/Ph_3P$	THF	Et_3N	r.t.	–
11[c]	–	–	Et_3N	80	–

[a] Reaction conditions: imidazole **3** (3 mmol), alkyne **4** (7 mmol), $Pd(OAc)_2$ (0.1 mmol) with Ph_3P (0.5 mmol) or $Pd(PPh_3)_2Cl_2$ (0.1 mmol), CuI (0.1 mmol), amine (35 mmoL), DMF (20 mL), 24 h.
[b] Yields were determined on the isolated product.
[c] 20 mL of Et_3N or *i*-Pr_2NH.
[d] 10% $Pd(OAc)_2$.

After the conditions for the Sonogashira coupling were established, the cross-coupling product was submitted to hydrogenation of the triple bond, followed by N-alkylation and anion metathesis to afford the terpene-based ionic liquids (Scheme 3). The same optimized conditions for the Sonogashira reaction (Table 1, run 1) were applied for the couplings between 2-iodo-1-methyl-1*H*-imidazole (**3**) and the alkyne **5** obtained from citronellal or the alkyne **6** (dehydrolinalool). The coupling products **7** obtained from these alkynes were directly hydrogenated without isolation and purification steps; purified products **8** were obtained after the hydrogenation step. The hydrogenation step occurred under mild conditions with each of the al-

kynes obtained in the Sonogashira step. Even after 48 hours, the internal unsaturation of the terpenic part of the molecule remained unreacted. Comparative results for each step of the production of the ionic liquids for the three different alkyne substrates are outlined in Table 2.



Scheme 3

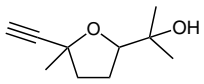
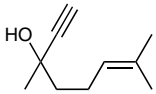
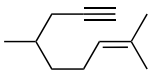
The ionic liquids **9a**–**c** containing bromide as the counteranion showed some degree of hygroscopicity. The anion could be exchanged using a common method described in the literature[19] for anion metathesis of simple ionic liquids such as those derived from butylmethylimidazole (BMIM) (Scheme 3). The products containing BF_4^- (**10a**–**c**) or PF_6^- (**11a**–**c**) as the counteranion presented a highly viscous liquid behavior. The synthetic pathway presented in this paper could be extended to other terpenoids.

In conclusion, some natural raw materials, namely linalool oxide, dehydrolinalool and citronellal, were successfully used in the synthesis of new ionic liquids. Sonogashira reactions were used as a valuable tool for selective functionalization at the 2-position of the imidazole ring. Thus, the ionic liquids obtained through this pathway have the most common part of the traditional ionic liquid derived from imidazole (BMIM) with a novel terpenic part. The overall yields, taking into account the three compounds used as substrates, are good. The presence of the terpenic part may indicate the potential for interesting bioproperties beyond the presence of a chiral center. The synthetic pathway developed in this work could be easily extended to chiral compounds and to other natural raw materials derived from terpenes. The physical properties of these new ionic liquids are currently under investigation in our laboratory.

Volatile compounds were identified by GC-MS using an Agilent 6890 gas chromatograph fitted with a HP-5 30-m capillary column and an Agilent 5973 MS detector. Products were characterized by ^1H and ^{13}C NMR spectroscopy (360.13 and 90.56 MHz, respectively) and, when necessary, ^{11}B and ^{31}P NMR spectroscopy (Avance 360 and 500 instruments; $CDCl_3$, tetramethylsilane; DEPT, COSY, HMQC, HMBC and NOESY experiments). Atom-numbering used in the NMR characterization is shown in Figure 1. Spectroscopic simulations performed with the ACD/HNMR and ACD/CNMR programs were in agreement with the observed spectra. High-resolution mass spectra were obtained on a Thermo Finnigan LTQ FT system (ESI-HRMS). Products were purified by flash column chromatography using silica gel as the stationary phase, unless otherwise indicated.

2-Iodo-1-methyl-1*H*-imidazole (**3**) was synthesized in 60% yield[20] and 4,8-dimethylnon-7-en-1-yne (**5**) was synthesized in 72% yield[21] using well-known literature methods.

Table 2 Comparative Results for the Alkynes Studied[a]

	Yield (%) of step shown in Scheme 3			
Alkyne	**1** (Sonogashira–hydrogenation)[b]	**2** (N-alkylation)[c]	**3a** (metathesis: BF_4)[d]	**3b** (metathesis: PF_6)[e]
	57	60	quant	58
	70	69	quant	84
	48	30	quant	79

[a] Yields were determined on the isolated product.
[b] Step 1: Sonogashira coupling, then hydrogenation: crude product **7** from the Sonogashira step, Pd/C (0.25 g), H_2 (5 atm), MeOH (25 mL), 60 °C, 48 h.
[c] Step 2: Substrate **8** (3 mmol), 1-bromobutane (4.35 mmol), toluene (10 mL), reflux, 24 h.
[d] Step 3a: Substrate **9** (0.52 mmol), $NaBF_4$ (0.57 mmol), acetone (2 mL), r.t., 24 h.
[e] Step 3b: Substrate **9** (0.52 mmol), $NaPF_6$ (0.57 mmol), H_2O (2 mL), r.t., 2 h.

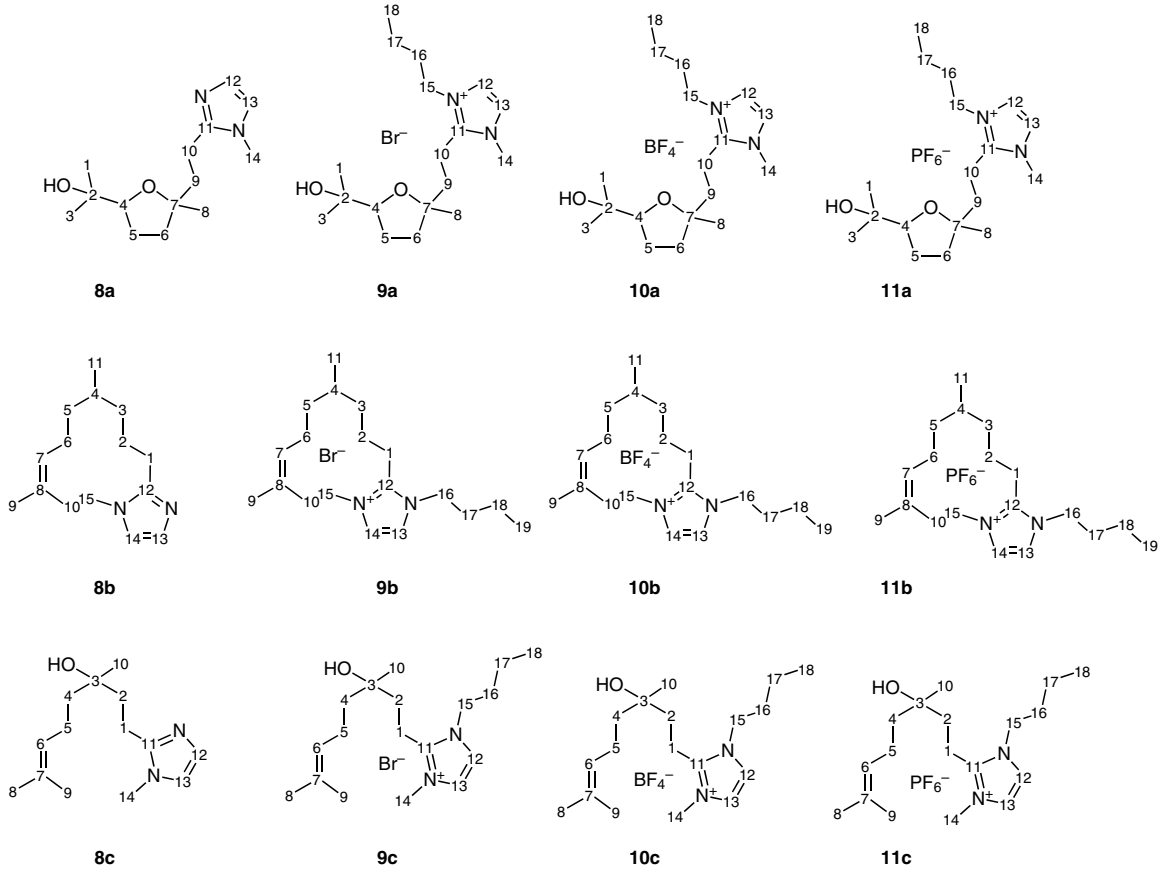


Figure 1

2-(5-Ethynyl-5-methyltetrahydrofuran-2-yl)propan-2-ol (4)

A soln of Br_2 (5.75 g, 36 mmol) in CH_2Cl_2 (10 mL) was slowly added to a soln of linalool oxide (**1**; 5.10 g, 30 mmol) in CH_2Cl_2 (10 mL) at 0 °C over 3 h under constant stirring. Then, excess Br_2 was destroyed with sat. aq sodium thiocyanate (20 mL). The mixture was extracted with CH_2Cl_2 (2 × 20 mL) and the combined organic phase was washed with brine (20 mL), dried over Na_2SO_4 and filtered. The volatiles were evaporated. The dibromide, 2-[5-(1,2-dibromoethyl)-5-methyltetrahydrofuran-2-yl]propan-2-ol, was obtained as a light yellow oil in 97% yield and was used without further purification.

The dibromide was dissolved in DMF (69 mL). KOH (5.0 g, 90 mmol) was added to the mixture which was further stirred under reflux for 3 h. The mixture was then allowed to cool to r.t., taken up in Et_2O (40 mL), washed with 10% aq KOH (20 mL) and brine (20 mL), dried over $MgSO_4$ and filtered. The volatiles were evaporated and the crude product was distilled under reduced pressure to afford the alkyne **4** as a colorless oil; yield: 3.07 g (61%); bp 98–110 °C/30 mmHg.

Sonogashira Coupling; General Procedure

Under an argon atmosphere, 2-iodo-1-methyl-1*H*-imidazole (**3**; 624 mg, 3 mmol) was added to a soln of $Pd(OAc)_2$ (22.5 mg, 0.1 mmol), CuI (19.0 mg, 0.1 mmol), Ph_3P (131 mg, 0.5 mmol) and Et_3N (3.54 g, 35 mmol) in anhydrous and degassed DMF (20 mL). The solution was stirred at r.t. for 2 min. Next, an alkyne (7 mmol) was added to the mixture which was further stirred in an oil bath at 80 °C for 24 h. The mixture was then allowed to cool to r.t., taken up in CH_2Cl_2 (20 mL), and washed with brine (9 × 20 mL). The combined organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The resultant crude product **7** was used in the next step (hydrogenation) without any further purification.

Hydrogenation; General Procedure

Reactions were carried out in a 100-mL Inox steel reactor using an oil bath and magnetic stirring. In a typical run, a mixture of the crude product **7** obtained in the Sonogashira step was dissolved in MeOH (25 mL) containing Pd/C (0.25 g), and the mixture was intensively stirred at 60 °C under a hydrogen pressure of 5 atm for 48 h. The solution was filtered over Celite® and the solvent was evaporated under reduced pressure. The product **8** was purified by column chromatography (EtOAc–hexane, 1:1).

2-{5-Methyl-5-[2-(1-methyl-1*H*-imidazol-2-yl)ethyl]tetrahydrofuran-2-yl}propan-2-ol (8a)

Light yellow oil; yield: 431.5 mg (1.71 mmol, 57%).

Major Isomer

^{1}H NMR: δ = 1.09, 1.17 (2 s, 6 H, H-1, H-3), 1.23 (s, 3 H, H-8), 1.70–2.07 (m, 6 H, H-5, H-6, H-9), 2.72–2.85 (m, 2 H, H-10), 3.60 (s, 3 H, H-14), 3.77 (t, ^3J = 7.3 Hz, 1 H, H-4), 6.93 (br s, 1 H, H-13), 7.82 (br s, 1 H, H-12).

^{13}C NMR: δ = 18.97, 25.61, 25.61, 26.20, 27.36, 35.13, 37.65, 38.49, 70.75, 82.28, 85.29, 120.57, 125.61, 146.82.

GC-MS: *m*/*z* (%) = 237 (20) $[M - CH_3]^+$, 193 (100), 151 (21), 109 (91), 96 (92).

Minor Isomer

^{1}H NMR: δ = 1.09, 1.16 (2 s, 6 H, H-1, H-3), 1.23 (s, 3 H, H-8), 1.70–2.07 (m, 6 H, H-5, H-6, H-9), 2.72–2.85 (m, 2 H, H-10), 3.60 (s, 3 H, H-14), 3.70 (t, ^3J = 7.3 Hz, 1 H, H-4), 6.93 (br s, 1 H, H-13), 7.82 (br s, 1 H, H-12).

^{13}C NMR: δ = 18.97, 25.61, 25.61, 26.20, 27.36, 35.13, 37.65, 38.25, 70.75, 82.28, 85.73, 120.57, 125.61, 146.82.

GC-MS: *m*/*z* (%) = 237 (20) $[M - CH_3]^+$, 193 (100), 151 (21), 109 (91), 96 (92).

2-(4,8-Dimethylnon-7-en-1-yl)-1-methyl-1*H*-imidazole (8b)
Light yellow oil; yield: 337.5 mg (1.44 mmol, 48%).

^{1}H NMR: δ = 0.85 (d, ^3J = 5.5 Hz, 3 H, H-11), 1.10–1.60 (m, 5 H, H-3, H-4, H-5), 1.58 (s, 3 H, H-10), 1.66 (s, 3 H, H-9), 1.69–1.99 (m, 4 H, H-2, H-6), 2.64 (t, ^3J = 7.6 Hz, 2 H, H-1), 3.57 (s, 3 H, H-15), 5.07 (tt, ^3J = 7.2, 1.4 Hz, 1 H, H-7), 6.78 (br s, 1 H, H-14), 6.92 (br s, 1 H, H-13).

^{13}C NMR: δ = 17.62, 19.58, 22.58, 25.49, 26.95, 27.93, 30.22, 32.61, 36.94, 39.27, 120.28, 124.87, 126.32, 130.98, 148.59.

GC-MS: *m*/*z* (%) = 234 (1) $[M]^+$, 165 (35), 134 (34), 123 (22), 109 (21), 96 (24), 49 (100).

3,7-Dimethyl-1-(1-methyl-1*H*-imidazol-2-yl)oct-6-en-3-ol (8c)
Light yellow oil; yield: 496.3 mg (2.1 mmol, 70%).

^{1}H NMR: δ = 1.21 (s, 3 H, H-10), 1.54 (m, 2 H, H-4), 1.60 (s, 3 H, H-9), 1.66 (s, 3 H, H-8), 1.87–1.98 (m, 2 H, H-2), 2.03–2.10 (m, 2 H, H-5), 2.78 (t, ^3J = 7.5 Hz, 2 H, H-1), 3.57 (s, 3 H, H-14), 5.10 (t, ^3J = 7 Hz, 1 H, H-6), 6.78 (s, 1 H, H-13), 6.85 (s, 1 H, H-12).

^{13}C NMR: δ = 17.66, 21.29, 22.79, 25.68, 26.51, 32.63, 38.31, 42.40, 71.42, 120.42, 124.60, 126.13, 133.86, 148.63.

This product could not be detected by GC-MS, although the fragmentation of the preceding alkyne could be detected.

GC-MS (alkyne): *m*/*z* (%) = 232 (1) $[M]^+$, 217 (96), 213 (79), 199 (85), 189 (66), 173 (70), 161 (100), 147 (39), 123 (40), 107 (86).

N-Alkylation
The N-alkylated products were synthesized using a well-known literature method.[22]

1-Butyl-2-{2-[5-(1-hydroxy-1-methylethyl)-2-methyltetrahydrofuran-2-yl]ethyl}-3-methyl-1*H*-imidazol-3-ium Bromide (9a)
Light brown oil; yield: 700.8 mg (1.80 mmol, 60%).

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}BrN_2O_2$: 309.25420; found: 309.25386; *m*/*z* $[2\,M + X]^+$ calcd: 697.42674; found: 697.42668.

Major Isomer

^{1}H NMR: δ = 0.97 (t, ^3J = 7.4 Hz, 3 H, H-18), 1.08, 1.17 (2 s, 6 H, H-1, H-3), 1.24 (s, 3 H, H-8), 1.36 (sextet, ^3J = 7.5 Hz, 2 H, H-17), 1.69–1.99 (m, 8 H, H-5, H-6, H-9, H-16), 3.09–3.26 (m, 2 H, H-10), 3.37 (s, 1 H, OH), 3.75 (dd, ^3J = 8, 7 Hz, 1 H, H-4), 3.98 (s, 3 H, H-14), 4.10–4.24 (m, 2 H, H-15), 7.48 (d, ^3J = 2 Hz, 1 H, H-13), 7.70 (d, ^3J = 2 Hz, 1 H, H-12).

^{13}C NMR: δ = 13.46, 18.97, 19.56, 25.36, 25.77, 26.15, 27.21, 32.04, 35.97, 37.63, 37.76, 48.33, 70.87, 81.24, 85.56, 121.01, 123.33, 146.83.

Minor Isomer

^{1}H NMR: δ = 0.97 (t, ^3J = 7.4 Hz, 3 H, H-18), 1.07, 1.27 (2 s, 6 H, H-1, H-3), 1.23 (s, 3 H, H-8), 1.36 (sextet, ^3J = 7.5 Hz, 2 H, H-17), 1.69–1.99 (m, 8 H, H-5, H-6, H-9, H-16), 3.09–3.26 (m, 2 H, H-10), 3.37 (s, 1 H, OH), 3.69 (dd, ^3J = 8.2, 6.9 Hz, 1 H, H-4), 3.99 (s, 3 H, H-14), 4.10–4.24 (m, 2 H, H-15), 7.53 (d, ^3J = 2 Hz, 1 H, H-13), 7.75 (d, ^3J = 2 Hz, 1 H, H-12).

^{13}C NMR: δ = 13.46, 18.97, 18.98, 24.11, 25.36, 26.15, 27.21, 32.04, 35.86, 37.49, 37.54, 48.33, 70.56, 81.67, 86.51, 121.01, 123.33, 146.83.

1-Butyl-2-(4,8-dimethylnon-7-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Bromide (9b)
Light brown oil; yield: 334.2 mg (0.90 mmol, 30%).

^{1}H NMR: δ = 0.83 (d, ^3J = 5.5 Hz, 3 H, H-11), 0.93 (t, ^3J = 7 Hz, 3 H, H-19), 1.13–1.36 (m, 9 H, H-3, H-4, H-5, H-17, H-18), 1.55 (s, 3 H, H-9), 1.60–1.94 (m, 4 H, H-2, H-6), 1.63 (s, 3 H, H-10), 3.03 (t, ^3J = 8 Hz, 2 H, H-1), 4.00 (s, 3 H, H-15), 4.15 (t, ^3J = 7.5 Hz, 2 H, H-16), 5.01 (t, ^3J = 6.5 Hz, 1 H, H-7), 7.62 (d, ^3J = 1.5 Hz, 1 H, H-14), 7.88 (d, ^3J = 1.5 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.53, 17.64, 19.18, 19.66, 24.17, 24.87, 25.34, 25.67, 31.97, 32.19, 35.97, 36.50, 36.73, 48.43, 121.26, 123.63, 124.29, 131.47, 146.40.

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{19}H_{35}BrN_2$: 291.28002; found: 291.27969; *m*/*z* $[2\,M + X]^+$ calcd: 661.47838; found: 661.47834.

1-Butyl-2-(3-hydroxy-3,7-dimethyloct-6-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Bromide (9c)
Light brown solid; yield: 772.8 mg (2.07 mmol, 69%).

^{1}H NMR: δ = 0.86 (t, ^3J = 7.4 Hz, 3 H, H-18), 1.29 (s, 3 H, H-10), 1.39–1.45 (m, 2 H, H-17), 1.52–1.64 (m, 4 H, H-4, H-16), 1.61 (s, 3 H, H-8), 1.68 (s, 3 H, H-9), 1.80–1.93 (m, 4 H, H-2, H-5), 3.21 (m, 2 H, H-1), 4.06 (s, 3 H, H-14), 4.23 (t, ^3J = 7.5 Hz, 2 H, H-15), 5.11 (m, 1 H, H-6), 7.43 (d, ^3J = 2 Hz, 1 H, H-12), 7.67 (d, ^3J = 2 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.57, 17.74, 18.65, 19.70, 22.87, 25.68, 29.90, 31.11, 36.26, 38.23, 41.68, 48.54, 71.73, 120.82, 124.16, 124.16, 131.76, 147.42.

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}BrN_2O$: 293.25929; found: 293.25885; *m*/*z* $[2\,M + X]^+$ calcd: 665.43691; found: 665.43695.

$ILBF_4$ by Anion Metathesis; General Procedure
Brominated ionic liquid (0.52 mmol) was reacted with $NaBF_4$ (62.6 mg, 0.57 mmol) in acetone (2.0 mL) at r.t. for 24 h; the newly formed IL remained in solution while insoluble NaBr was formed. The precipitate was removed by filtration and the solution was concentrated under reduced pressure.

1-Butyl-2-{2-[5-(1-hydroxy-1-methylethyl)-2-methyltetrahydrofuran-2-yl]ethyl}-3-methyl-1*H*-imidazol-3-ium Tetrafluoroborate (10a)
Light brown oil; yield: 206.1 mg (0.52 mmol, quant).

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}BF_4N_2O_2$: 309.25420; found: 309.25384; *m*/*z* $[2\,M + X]^+$ calcd: 705.51132; found: 705.51129.

Major Isomer

^{1}H NMR: δ = 0.95 (t, ^3J = 7.5 Hz, 3 H, H-18), 1.10, 1.19 (2 s, 6 H, H-1, H-3), 1.27 (s, 3 H, H-8), 1.37 (sextet, ^3J = 7.5 Hz, 2 H, H-17), 1.72–1.92 (m, 8 H, H-5, H-6, H-9, H-16), 3.00–3.14 (m, 2 H, H-10), 3.79 (t, ^3J = 7 Hz, 1 H, H-4), 3.85 (s, 3 H, H-14), 4.02–4.14 (m, 2 H, H-15), 7.27 (d, ^3J = 2 Hz, 1 H, H-12), 7.36 (d, ^3J = 2 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.44, 18.97, 19.53, 25.16, 25.52, 26.14, 27.06, 31.92, 35.13, 37.35, 37.58, 48.11, 70.96, 81.38, 85.32, 120.86, 123.01, 146.82.

^{11}B NMR (115.54 MHz, $CDCl_3$): δ = 1.90.

Minor Isomer

^{1}H NMR: δ = 0.95 (t, ^3J = 7.5 Hz, 3 H, H-18), 1.10, 1.17 (2 s, 6 H, H-1, H-3), 1.26 (s, 3 H, H-8), 1.37 (sextet, ^3J = 7.5 Hz, 2 H, H-17), 1.72–1.92 (m, 8 H, H-5, H-6, H-9, H-16), 3.00–3.14 (m, 2 H, H-10), 3.71 (dd, ^3J = 8, 6.5 Hz, 1 H, H-4), 3.85 (s, 3 H, H-14), 4.02–4.14 (m, 2 H, H-15), 7.29 (d, ^3J = 2 Hz, 1 H, H-12), 7.38 (d, ^3J = 2 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.44, 18.49, 18.97, 24.14, 25.52, 26.31, 27.22, 30.86, 35.04, 37.26, 37.58, 48.11, 70.55, 81.75, 86.06, 120.86, 123.01, 146.82.

^{11}B NMR (115.54 MHz, $CDCl_3$): δ = 1.90.

1-Butyl-2-(4,8-dimethylnon-7-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Tetrafluoroborate (10b)
Light brown oil; yield: 196.7 mg (0.52 mmol, quant).

^{1}H NMR: δ = 0.86 (d, ^3J = 6.1 Hz, 3 H, H-11), 0.97 (t, ^3J = 7.2 Hz, 3 H, H-19), 1.09–1.21 (m, 2 H, H-18), 1.21–1.48 (m, 5 H, H-3, H-4, H-5), 1.59 (s, 3 H, H-9), 1.61–1.72 (m, 2 H, H-17), 1.67 (s, 3 H, H-10), 1.77–1.85 (m, 2 H, H-2, H-6), 2.97 (t, ^3J = 7.9 Hz, 2 H, H-1), 3.86 (s, 3 H, H-15), 4.07 (t, ^3J = 7.6 Hz, 2 H, H-16), 5.07 (t, ^3J = 7.2 Hz, 1 H, H-7), 7.36 (d, ^3J = 2.2 Hz, 1 H, H-14), 7.45 (d, ^3J = 2.2 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.47, 17.64, 19.17, 19.60, 23.48, 24.20, 25.37, 25.37, 25.69, 31.98, 36.20, 36.49, 36.77, 48.22, 120.98, 123.19, 124.36, 131.46, 146.54.

^{11}B NMR (115.54 MHz, $CDCl_3$): δ = 2.08.

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{19}H_{35}BF_4N_2$: 291.28002; found: 291.27946; *m*/*z* $[2\,M + X]^+$ calcd: 669.56296; found: 669.56271.

1-Butyl-2-(3-hydroxy-3,7-dimethyloct-6-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Tetrafluoroborate (10c)
Light brown oil; yield: 197.7 mg (0.52 mmol, quant).

^{1}H NMR: δ = 0.97 (t, ^3J = 7.2 Hz, 3 H, H-18), 1.26 (s, 3 H, H-10), 1.40 (sextet, ^3J = 7.2 Hz, 2 H, H-17), 1.51–1.59 (m, 2 H, H-16), 1.63 (s, 3 H, H-8), 1.69 (s, 3 H, H-9), 1.73–1.86 (m, 4 H, H-2, H-4), 1.99–2.06 (m, 2 H, H-5), 3.09 (dd, ^3J = 10, 6.5 Hz, 2 H, H-1), 3.62 (s, 1 H, OH), 3.87 (s, 3 H, H-14), 4.10 (t, ^3J = 7.5 Hz, 2 H, H-15), 5.12 (t, ^3J = 7 Hz, 1 H, H-6), 7.28 (d, ^3J = 2 Hz, 1 H, H-12), 7.36 (d, ^3J = 2 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.48, 17.69, 17.90, 19.60, 22.73, 25.67, 25.69, 31.95, 35.21, 38.00, 41.52, 48.18, 71.41, 120.77, 123.01, 123.94, 132.05, 147.12.

^{11}B NMR (115.54 MHz, $CDCl_3$): δ = 2.05.

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}BF_4N_2O$: 293.25929; found: 293.25885; *m*/*z* $[2\,M + X]^+$ calcd: 673.52149; found: 673.52122.

ILPF$_6$ by Anion Metathesis; General Procedure
Brominated ionic liquid (0.52 mmol) and $NaPF_6$ (95.7 mg, 0.57 mmol) were dissolved in a small amount of distilled H_2O (2.0 mL) and the reaction mixture remained under constant stirring at r.t. for 2 h; a second phase was formed. The organic phase was washed with H_2O (3 × 5.0 mL) and then dried under reduced pressure. To obtain a completely dried product, the newly dried organic phase was dissolved in CH_2Cl_2 (10 mL) and dried over Na_2SO_4. Then, the mixture was filtered and the volatile materials were removed under reduced pressure.

1-Butyl-2-{2-[5-(1-hydroxy-1-methylethyl)-2-methyltetrahydrofuran-2-yl]ethyl}-3-methyl-1*H*-imidazol-3-ium Hexafluorophosphate (11a)
Light brown oil; yield: 136.3 mg (0.30 mmol, 58%).

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}PF_6N_2O_2$: 309.25420; found: 309.25346; *m*/*z* $[2\,M + X]^+$ calcd: 763.47259; found: 763.47199.

Major Isomer

^{1}H NMR: δ = 0.96 (t, ^3J = 7.3 Hz, 3 H, H-18), 1.12, 1.21 (2 s, 6 H, H-1, H-3), 1.28 (s, 3 H, H-8), 1.39 (sextet, ^3J = 7.3 Hz, 2 H, H-17), 1.76–1.96 (m, 8 H, H-5, H-6, H-9, H-16), 3.07–3.12 (m, 2 H, H-10), 3.80 (m, 1 H, H-4), 3.82 (s, 3 H, H-14), 4.00–4.14 (m, 2 H, H-15), 7.22 (br s, 1 H, H-12), 7.25 (br s, 1 H, H-13).

^{13}C NMR: δ = 13.45, 18.97, 19.55, 24.99, 25.35, 26.25, 26.99, 31.87, 34.94, 37.33, 37.33, 48.19, 71.26, 81.50, 85.22, 120.83, 122.89, 146.82.

^{31}P NMR (145.78 MHz, $CDCl_3$): δ = –41.14 (septet, PF_6).

Minor Isomer

^{1}H NMR: δ = 0.96 (t, ^3J = 7.3 Hz, 3 H, H-18), 1.12, 1.21 (2 s, 6 H, H-1, H-3), 1.27 (s, 3 H, H-8), 1.39 (sextet, ^3J = 7.3 Hz, 2 H, H-17), 1.76–1.96 (m, 8 H, H-5, H-6, H-9, H-16), 3.07–3.12 (m, 2 H, H-10), 3.73 (t, ^3J = 7.2 Hz, 1 H, H-4), 3.82 (s, 3 H, H-14), 4.00–4.14 (m, 2 H, H-15), 7.22 (br s, 1 H, H-12), 7.24 (br s, 1 H, H-13).

^{13}C NMR: δ = 13.45, 18.50, 18.97, 24.16, 24.99, 26.05, 27.32, 31.85, 34.94, 37.58, 37.58, 48.19, 70.68, 81.82, 86.49, 120.83, 122.89, 146.82.

^{31}P NMR (145.78 MHz, $CDCl_3$): δ = –41.14 (septet, PF_6).

1-Butyl-2-(4,8-dimethylnon-7-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Hexafluorophosphate (11b)
Light brown oil; yield: 178.9 mg (0.41 mmol, 79%).

^{1}H NMR: δ = 0.88 (d, ^3J = 6.5 Hz, 3 H, H-11), 0.97 (t, ^3J = 7.2 Hz, 3 H, H-19), 1.11–1.23 (m, 2 H, H-17), 1.23–1.47 (m, 7 H, H-3, H-4, H-5, H-18), 1.59 (s, 3 H, H-9), 1.68 (s, 3 H, H-10), 1.77–1.85 (m, 2 H, H-2), 1.91–2.03 (m, 2 H, H-6), 2.93 (t, ^3J = 7.9 Hz, 2 H, H-1), 3.81 (s, 3 H, H-15), 4.04 (t, ^3J = 7.6 Hz, 2 H, H-16), 5.07 (t, ^3J = 7.2 Hz, 1 H, H-7), 7.25 (d, ^3J = 2.1 Hz, 1 H, H-14), 7.28 (d, ^3J = 2.0 Hz, 1 H, H-13).

^{13}C NMR: δ = 13.38, 17.58, 19.09, 19.42, 22.62, 23.31, 24.62, 25.64, 31.87, 36.00, 36.39, 36.73, 48.18, 120.81, 122.90, 124.37, 131.96, 146.52.

^{31}P NMR (145.78 MHz, $CDCl_3$): δ = –40.87 (septet, PF_6).

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{19}H_{35}PF_6N_2$: 291.28002; found: 291.27944; *m*/*z* $[2\,M + X]^+$ calcd: 727.52423; found: 727.52372.

1-Butyl-2-(3-hydroxy-3,7-dimethyloct-6-en-1-yl)-3-methyl-1*H*-imidazol-3-ium Hexafluorophosphate (11c)
Light brown oil; yield: 192.9 mg (0.44 mmol, 84%).

^{1}H NMR: δ = 0.96 (t, ^3J = 7.4 Hz, 3 H, H-18), 1.26 (s, 3 H, H-10), 1.34–1.44 (m, 2 H, H-17), 1.52–1.58 (m, 2 H, H-16), 1.63 (s, 3 H, H-8), 1.69 (s, 3 H, H-9), 1.73–1.85 (m, 2 H, H-4), 2.02–2.20 (m, 4 H, H-2, H-5), 3.06 (dd, ^3J = 9.7, 7 Hz, 2 H, H-1), 3.62 (s, 1 H, OH), 3.81 (s, 3 H, H-14), 4.06 (t, ^3J = 7.5 Hz, 2 H, H-15), 5.12 (t, ^3J = 7 Hz, 1 H, H-6), 7.24 (d, ^3J = 2 Hz, 1 H, H-13), 7.43 (d, ^3J = 2 Hz, 1 H, H-12).

^{13}C NMR: δ = 13.42, 17.67, 17.74, 19.54, 22.68, 25.68, 25.69, 31.84, 34.97, 37.90, 41.53, 48.15, 71.61, 120.73, 122.83, 123.80, 132.22, 147.01.

^{31}P NMR (145.78 MHz, $CDCl_3$): δ = –40.96 (septet, PF_6).

HRMS (EI, 70 eV): *m*/*z* $[M]^+$ calcd for $C_{18}H_{33}PF_6N_2O$: 293.25929; found: 293.25855; *m*/*z* $[2\,M + X]^+$ calcd: 731.48276; found: 731.48163.

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