1,3,2-Diazaphospholene-Catalyzed Reductive Cyclizations of Organohalides

Johannes Klett, Dr. Łukasz Woźniak and Prof. Dr. Nicolai Cramer*[a]

Abstract: 1,3,2-diazaphospholenes hydrides (DAP-Hs) are highly nucleophilic organic hydrides serving as main-group catalysts for a range of attractive transformations. DAP hydrides can act as stoichiometric hydrogen atom transfer agents in radical reactions. Herein, we report a DAP-catalyzed reductive radical cyclization of a broad range of aryl and alkyl halides under mild conditions. The pivotal DAP catalyst turnover was achieved by a DBU-assisted α-bond metathesis between the formed DAP hydride and HBpin rapidly regenerating DAP-H. The transformation is significantly accelerated by irradiation with visible light. Mechanistic investigations indicate that visible light irradiation leads to the formation of DAP dimers which are in equilibrium with the DAP radicals accelerating the cyclization. The direct use of (DAP)_2 enabled a catalytic protocol in the absence of light.

Discovered in the 1980s, 1,3,2-diazaphospholenes (DAPs)[1,2] represent a class of electron-rich heterocycles with a great application potential as versatile main-group catalysts.[2] For instance, diazaphospholene hydrides (DAP-Hs) are powerful nucleophiles and weakly basic organic hydride donors.[3] They are very capable to reduce carbonyl compounds[3] and in conjugate fashion α,β-unsaturated amides,[4,5] esters,[6] ketones[5] and acids.[7] A α-bond metathesis between the alkoxy-substituted DAPs and pinacol borane (HBpin) regenerating DAP-H rendered these processes catalytic.[8] Reports by Kinjo and Speed utilized metathesis between the P–N and B–H bonds employing HBpin and ammonia borane to enable catalytic reductions of azobenzenes[9] and imines.[10] Cheng et al. demonstrated the cleavage of the P–F bond in DAP fluorides by phenylsilane enabling hydrodefluorination of trifluoromethyl alkenes[10] and polyfluoro arenes.[11] The reactivity of DAP-Hs is not limited to the two electron transfer processes.[12] These electron-rich heterocycles can engage in reductions of alkyl and aryl halides[13] and α-carboxy ketones[14] via radical pathways. However, radical processes that can use catalytic amounts of DAPs are very scarce. A single report of deoxygenation of α-carboxy ketones employs diazaphosphinane as catalyst and AIBN as an initiator.[15] It capitalizes on the α-bond metathesis between the P–O and B–H bonds for the catalyst’s regeneration. In contrast to the DAP-F, the related halide bearing DAP-X (X = I, Br, Cl) do not undergo α-bond metathesis with borane or silane reagents. This represent a relevant reactivity gap hampering the closure of catalytic cycles. To exploit the full potential of DAPs in radical chemistry with organohalides, it is essential to render the transformations catalytic.

Radical cyclizations of organohalides across olefins are highly useful transformations to access diverse cyclic skeletons.[15] Typically, reductive cyclization of organohalides operating by radical mechanism require stoichiometric amounts of toxic organostannanes[16] and radical initiators such as e.g. AIBN[17] or Et₂B(OEt)₂.[18] Advances in photochemical methods provided some alternatives including the use of metal- and organic photocatalysts[19] as well as electron-donor reagents.[20] The high affinity of DAPs towards organohalides makes them very attractive for activating this broad compounds class.[21]

Speed demonstrated the functionalization of organo iodides and bromides.[22] However, catalytic variants of these processes remain so far elusive. A rapid and efficient regeneration of the DAP-H from DAP-X under mild conditions would be an essential gateway to catalytic transformations with organohalide substrate. Herein, we report an efficient Lewis-base promoted regeneration of DAP-H from DAP-X and its application for reductive radical cyclizations of aryl and alkyl halides under catalytic conditions.

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Scheme 1. a) DAPs in catalysis: Regeneration of DAP-H to close catalytic cycles. b) Landscape of reduction options for DAP-Y into DAP-H and the underlying catalytic processes c) DAP-catalyzed reductive radical cyclization of organohalides.

To explore the ways to close the catalytic cycle, we first investigated the possibility to reliably regenerate the pivotal DAP-H species from the formed DAP-I of the stoichiometric process. Mixing DAP-I and HBpin in CD₃CN does not lead to any
meaning formation of DAP-H after 16 h (Scheme 2). We hypothesized that activation of the borane by a suitable Lewis base could facilitate the $\sigma$-bond metathesis between the DAP-I and HBpin. To our delight, adding the 1,8-diazabicyclo[5.4.0]undec-7-ene to the DAP-I/HBpin mixture in CD$_2$CN triggered the quantitative generation of DAP-H in less than ten minutes. DMAP or N-methyl imidazole were as well competent (see SI for details).

![Scheme 2. Fast regeneration of DAP-H with the DBU/HBpin system.](image)

With the rapid DAP-H regeneration from DAP-X solved by the DBU-assisted $\sigma$-bond metathesis, we turned our efforts towards a fully catalytic transformation for the cyclization of aryl iodide 1a and aryl bromide 2a (Table 1, for a comprehensive optimization study, see SI). Employing 5 mol% of the robust and conveniently usable secondary phosphine oxide (SPO) as the pre-catalyst in combination with the HBpin/DBU mixture in MeCN, gave cyclization product 4a in 23 % yield (entry 1). This corresponds to over four catalyst turnovers. During our optimization studies, we noticed that the reaction rate and progress is highly sensitive to light. While still taking place under the careful exclusion of light (entry 2), the yield of 4a almost quadrupled when irradiating the reaction mixture with white LEDs (entry 3). This effect was even more pronounced with aryl bromide 2a. However, no reaction took place in the absence of light (entry 4). The use of white LEDs restored some reactivity giving 4a in 12% yield (entry 5). Switching to a more powerful a Kessil lamp (427 nm) allowed to increase the yield of 4a to 91% (entry 6).

Control experiments omitting SPO, DBU and HBpin showed their indispensable role in the transformation (entries 7-9). Aryl chloride 3a did not react under the current conditions (entry 10).

Table 1. Optimization of the DAP-catalyzed cyclization of 1-2a.[4]

<table>
<thead>
<tr>
<th>entry</th>
<th>substrate</th>
<th>light</th>
<th>% yield$^{[a]}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1a</td>
<td>ambient</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>1a</td>
<td>exclusion of light</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>1a</td>
<td>white LEDs</td>
<td>89</td>
</tr>
<tr>
<td>4</td>
<td>2a</td>
<td>exclusion of light</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>2a</td>
<td>white LEDs</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>2a</td>
<td>Kessil lamp (427 nm)</td>
<td>91</td>
</tr>
</tbody>
</table>

$^{[a]}$ Conditions: 0.1 mmol 1a, 5 µmol SPO, 0.11 mmol HBpin, 0.1 mmol DBU. 2 M (0.8 M for 2a and 3a) in MeCN at 26 °C for 16 h. Yields determined by $^1$H-NMR with an internal standard; [c] no SPO; [d] no DBU; [d] no HBpin.

Next, we evaluated the scope of the DAP-catalyzed reductive cyclization of a broad set of substituted aryl halide substrates (Scheme 3). Dihydrobenzofuran 4a was isolated in excellent yields (92 % from 1a and 96 % from 2a). The transformation is tolerant to potential reactive functional groups like methyl esters, free phenols and carboxylic acids reliably delivering products 4b-4g. Notably, a switch from the Kessil lamp (427 nm) to white LEDs allowed for a selective cyclization originating from the aryl iodide moiety of 1j in the presence of the adjacent bromide substituent in 97 % yield. Along the same lines, the reaction of aryl bromide 2h cleanly proceeded in the presence of an adjacent chloride moiety under standard conditions. The reaction of the bromo pyridine 2i cyclized to product 4i without DAP-catalyzed reduction of its pyridine core. Aryl bromides bearing different alkenyl tethers reacted well. For instance, styrene 2k underwent cyclization in 86 % yield. The nature of the olefin acceptor portion was as well modifiable (4l-4n). Substrates which pass through 1° or 2° alkyl radical intermediates reacted in reduced yields (4i and 4m). Besides the formation of the five-membered rings, the process enabled the 6-exo-trig cyclizations as demonstrated for 4-isopropyl/chromane 4o. Aniline substrates were readily converted into functionalized indolines 4p-4r. Next, we explored the potential of alkyl halide substrates for the cyclization. In this respect, iodo acetics 1s and bromo 2s smoothly reacted providing bicyclic product 4s. Primary alkyl bromides 2u and 2t cyclized to the corresponding tetrahydrofuran 4u and cyclopentane 4t in moderate yields. The cyclization of substituted alkyl enamin amines led to pyrrolidines 4v-4w in good yield. A secondary alkyl bromide analogue formed disubstituted pyrrolidine 4y in 91% yield and 65:35 dr. Noteworthy, substrates bearing a trichloroalkyl group engaged in the transformation providing dichloro-substituted pyrrolidine 4z and piperidine 4za in 82% and 69% yield, respectively.
We next conducted mechanistic investigations to better understand the effect the light plays in this transformation. The stoichiometric reactions indicate that the cyclizations of 1a and 2a take as well place in the dark. However, irradiation by a Kessil lamp (427 nm) accelerates the transformations (Scheme 4). In contrast, the catalytic reaction with substrate 2a occurs only under irradiation. Aryl bromide 2a still cyclized to 4a in the dark, albeit with poor efficiency. The direct reaction of DAP-H and CCl₄ does not require activation by strong light sources affording DAP-Cl and a mixture of chloromethanes CH₃Cl₄ (m=0-3) [21]. This P–H/C–Cl bond metathesis proceeds eventually through a radical mechanism. Substrate 3z was exposed to 1 equiv. of DAP-H under exclusion of light yielding 75% of product 4z. Attempts to inhibit the hypothesized radical mechanism by the addition of 20 mol% TEMPO were futile. TEMPO rapidly reacts with DAP-H and after consumption of all added TEMPO, the remaining amount of DAP-H produced 4z in 54% yield. To gain mechanistic insight of the light-enhanced reaction, we first identified which species absorb light in the visible spectrum. The absorption spectra of DAPs and 2a indicates that only DAP-H and DAP-Br absorb light at wavelengths above 400 nm, which is an emission tail of the Kessil lamp (427 nm). No ground state associations between the DAPs and 2a were found (see SI). Based on this information, two scenarios in which visible light accelerates the cyclization of 2a are plausible. In scenario I, a photoexcitation of DAP-H triggers a SET from the excited DAP-H⁺ to 2a. Scenario II involves a photophysical process of triplet states of DAP-H leading to a 1,3,2-diazaphospholene radical (DAP⁺). On the basis of electrochemical and spectroscopic measurements, we estimated the redox potential of the excited DAP-H⁺ is −3.14 V (vs. Fe⁺/Fe in MeCN), indicating that a SET between DAP-H⁺ and 2a (E₀ox 2a/2a⁻=−3.36 V vs. Fe⁺/Fe in MeCN) is endergonic. For these reasons, we examined the generation of DAP⁺ radical species by excitation of DAP-H. We hypothesized that visible light from the Kessil lamp (427 nm) could trigger a reductive dimerization of DAP-H. This was previously reported by Gudat et al. using UV light from a medium-pressure Hg-lamp. [20] The resulting (DAP)₂ species, described as a weakly σ-bonded dimer, would dissociate in solution to give the persistent 7π-radical DAP⁺ species. [27] Indeed, 31P-NMR analysis confirmed formation of (DAP)₂ from DAP-H upon irradiation by a Kessil lamp (427 nm) (Scheme 5). This evidence supports the suggestion of an initiation of a radical chain process through the immediacy of (DAP)₂.

**Scheme 3**: Scope of the DAP-catalyzed cyclization of organohalides. Conditions: 0.20 mmol 1x-3x, 10 μmol SPO, 0.22 mmol HBpin, 0.20 mmol DBU in MeCN (1x=0.2 M, 2x=3x=0.8 M) in MeCN at 26 °C for 16 h. [a] white LEDs instead of the Kessil lamp 427 nm. [b] 2.5 equiv. HBpin, [c] 10 mol% SPO, 2.2 equiv. HBpin and 2.0 equiv. DBU.

**Scheme 4**: Evaluation of the light influence or TEMPO on the cyclization efficiency and absorption spectra of the reaction components. Next, we tested the influence of (DAP)₂ on the cyclizations reaction rate of 2a with one equivalent of DAP-H in the dark.
Notably, already 2 mol% of (DAP)$_2$ remarkably accelerates the cyclization. This observation clearly supports the outlined scenario II. Both findings let to the hypothesis that an exchange of the SPO catalyst by (DAP)$_2$ would enable a catalytic process without the visible light activation. Remarkably, 5 mol% (DAP)$_2$ promoted a catalytic reaction in the absence of light forming 4a in 54 % yield.

I) Reductive dimerization of DAP-H to (DAP)$_2$ under visible light irradiation

\[
\text{Kessil lamp (427 nm)} \\
\text{CD$_2$CN, 29 °C, 5 h} \\
\rightarrow \\
\text{quantitative}
\]

II) Influence of (DAP)$_2$ on the reaction rates of the cyclization of 2a

\[
\begin{array}{c}
\text{Br} \\
\text{Me} \\
\text{DAP-H} \\
\text{CD$_2$CN, 26 °C, exclusion of light} \\
\rightarrow \\
\text{5, 2 or 10 mol% (DAP)$_2$} \\
\text{1 equiv. DAP-H} \\
\rightarrow \\
\text{NMR yield [%]} \\
\text{Time [h]} \\
\end{array}
\]

III) The use of (DAP)$_2$ as competent catalyst for the dark reaction

\[
\begin{array}{c}
\text{Br} \\
\text{Me} \\
\text{Me} \\
\text{2a} \\
\text{CD$_2$CN, 26 °C, 16 h} \\
\rightarrow \\
\text{DAP-H} \\
\text{MeCN, 28 °C} \\
\rightarrow \\
\text{5 mol% (DAP)$_2$} \\
\text{1.1 equiv. HBpin} \\
\text{1.0 equiv. DBU} \\
\rightarrow \\
\text{Dark Kessil lamp (427 nm)} \\
\rightarrow \\
\text{54 %} \\
\text{80 %} \\
\end{array}
\]

Scheme 5. Illustration of the role of (DAP)$_2$ in the DAP-catalyzed cyclizations.

Further mechanistic experiments comprised initial-rate kinetic studies of the model reaction across a range of concentrations for each reaction component under visible light irradiation (see SI for details). A first-order dependence was inferred for DAP-H and a half order for substrate 2a, supporting a radical chain mechanism. The zeroth-order dependence on the concentration of HBpin and of DBU indicate that the regeneration of the DAP-H is not a turnover limiting step. Moreover, the reaction rates increase with the increasing light intensity (see SI). Deuterium labelling studies with 1a using DAP·D in CH$_2$CN or DAP-H in CD$_2$CN confirm the origin of the hydrogen atom of 4a from the catalyst.

\[
\begin{array}{c}
\text{Br} \\
\text{Me} \\
\text{Me} \\
\text{2a} \\
\text{Kessil lamp (427 nm)} \\
\rightarrow \\
\text{5 mol% DAP-H} \\
\text{1.1 equiv. HBpin} \\
\text{1.0 equiv. DBU} \\
\text{MeCN, 26 °C} \\
\rightarrow \\
\text{component rate order} \\
\text{2a} \\
\text{DAP-H} \\
\text{HBpin} \\
\text{DBU} \\
\text{half} \\
\text{first} \\
\text{zero} \\
\end{array}
\]

Scheme 6. Initial-rate kinetics for the DAP-catalyzed cyclization and deuterium labelling studies.

Taking all mechanistic experiments into account, the catalytic cycle can be portrayed (Scheme 7). With SPO as the pre-catalyst, the process is initiated by the reduction with HBpin forming DAP-H. Visible light irradiation converts DAP-H to (DAP)$_2$. The dissociation equilibrium of (DAP)$_2$ into two molecules of DAP initiates a radical chain process by bromine atom abstraction from 2a.$^{[28]}$ The resulting ary radical 1 adds across the C–C bond in a 5-exo-trig fashion forming radical species II. In turn, II abstracts the hydrogen atom from DAP-H delivering product 4a and DAP·. Enabled by DBU, DAP·Br is converted back to DAP-H with HBpin. Employing (DAP)$_2$ as catalyst allows entering the catalytic cycle bypassing the light activation step. However, the reduced yield of the (DAP)$_2$-catalyzed reaction in the dark indicates that light can heal the catalytic cycle by regeneration DAP· after radical chain terminations.

Scheme 7. Proposed mechanism of the DAP-catalyzed cyclization of organohalides.

In summary, we developed a DAP-catalyzed reductive radical cyclization of organohalides. The DAP catalyst turnover was achieved by implementation of a DBU-assisted σ-bond metathesis between DAP-X (X=I, Br, Cl) and HBpin providing a fast regeneration of DAP-H. The transformation is significantly accelerated by the irradiation with visible light. The developed process allowed the efficient reductive cyclizations of a broad range of aryl and alkyl halides under mild and convenient conditions. Detailed mechanistic investigations revealed that visible light leads to the formation of (DAP)$_2$ which is in equilibrium with DAP· accelerating the cyclization. The direct use (DAP)$_2$ enabled a catalytic protocol in the absence of light. These findings will serve as blueprint and accelerator for the further developments of DAP-catalyzed radical processes.

Acknowledgements

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Keywords: DAP Catalysis • Phosphorous • Cyclization • Radical Chemistry


[28] An alternative mechanism involving SET from DAP+ (E_{\text{DAP}^+} = -1.76 V vs. Fe^+/Fe in MeCN)) to 2a (E_{\text{DAP}^+}^\bullet = -3.36 V vs. Fe^+/Fe in MeCN) is thermodynamically prohibited (see SI for details).
1,3,2-diazaphospholene hydrides (DAP-H) are shown as efficient catalysts for reductive radical cyclization of aryl and alkyl halides under mild conditions and accelerated by irradiation with visible light. The pivotal DAP catalyst turnover was achieved by a DBU-assisted σ-bond metathesis between the formed DAP halide and HBpin rapidly regenerating DAP-H.
Supporting Information

1,3,2-Diazaphospholene-Catalyzed Reductive Cyclizations of Organohalides

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Table of Contents

1. Experimental Procedures ...........................................................................................................................................2
   1.1 General and Materials .......................................................................................................................................2
   1.2 Condition Screening .............................................................................................................................................5
   1.3 Mechanistic Investigations .................................................................................................................................6
      1.3.1 Cyclic Voltammetry ......................................................................................................................................6
      1.3.2 UV/VIS measurements .................................................................................................................................10
      1.3.3 Formation of DAP-H from DAP-I with DBU as an Activator ................................................................. 13
      1.3.4 Kinetic Investigations .....................................................................................................................................15
      1.3.5 Deuterated experiments ...............................................................................................................................22
      1.3.6 Formation of (DAP)_2 from DAP-H under Irradiation ............................................................................ 24
      1.3.7 Attempts to inhibit the reductive cyclization by TEMPO ..........................................................................25
   1.4 DAP Synthesis ......................................................................................................................................................26
   1.5 Substrate Synthesis .............................................................................................................................................31
   1.6 Intramolecular Reductive Cyclization ..................................................................................................................55
   1.7 Non-working Substrates .......................................................................................................................................68
2. References .................................................................................................................................................................69
3. NMR Spectra .............................................................................................................................................................71
1. Experimental Procedures

1.1 General and Materials

Experimental Techniques

All reactions were carried out under an atmosphere of nitrogen in oven-dried glassware with magnetic stirring inside a glove box or using Schlenk technique, unless otherwise indicated. Chemicals were used as obtained from the suppliers unless otherwise indicated.

Drying, Degassing and Purification of Solvents

CH$_2$Cl$_2$, THF and MeCN were purified by an Innovative Technology Solvent Delivery System. n-Hexane was distilled over CaH$_2$ under nitrogen atmosphere. Before being transferred into a nitrogen-filled glove box to be stored over 4 Å molecular sieves, all solvents were degassed via freeze-pump-thaw technique. 1,8-diazabicyclo(5.4.0)undec-7-ene (DBU) was distilled over CaH$_2$ under nitrogen atmosphere, degassed via freeze-pump-thaw technique and stored inside the glovebox.

Flash Chromatography

Flash chromatography was performed with SiliaFlash silica gel P60 (40-63 μm grade). Analytical thin-layer chromatography was performed with commercial glass plates coated with 0.25 mm silica gel (E. Merck, Kieselgel 60 F$_254$). Compounds were either visualized under UV-light at 254 nm and/or by dipping the plates in KMnO$_4$ stain: (KMnO$_4$ (3.0 g), Na$_2$CO$_3$ (20 g), aq NaOH solution (5 wt %, 5.0 mL) in H$_2$O (300 mL)) or Vanillin stain: vanillin (10 g) and H$_2$SO$_4$ (conc., 1 mL) in EtOH (250 mL)) followed by heating.

NMR Spectroscopy

$^1$H NMR data was acquired on a Bruker AVANCE400 (400 MHz), Bruker DRX-400 (400 MHz) or Bruker AVANCEIII-400 (400 MHz) spectrometer. Chemical shifts ($\delta$) are reported in parts per million (ppm) relative to incompletely deuterated CDCl$_3$ (s, 7.26 ppm), C$_6$D$_6$ (s, 7.16 ppm), or CD$_3$CN (quint, 1.94 ppm). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; hept, hepted; m, multiplet; br, broad. Proton-decoupled $^{13}$C NMR data were acquired on a Bruker AVANCE400 (101 MHz), Bruker DRX-400 (101 MHz) or Bruker AVANCEIII-400 (101 MHz). Chemical shifts are reported in ppm relative to CDCl$_3$ (77.16 ppm) or C$_6$D$_6$ (128.06 ppm).$^{31}$P NMR data was acquired on a Bruker AVANCE400 (162 MHz) spectrometer. $^{19}$F NMR data was acquired on a Bruker AVANCE400 (376 MHz) spectrometer. Chemical shifts ($\delta$) are reported in parts per million (ppm) and were referenced using the $\Xi$-scales with 85% H$_3$PO$_4$ ($\Xi$=40.480747 MHz, $^{31}$P) and CCl$_3$F ($\Xi$=94.094011 MHz, $^{19}$F) as secondary references.

Cyclic Voltammetry

Cyclic voltammetry data was acquired on a BioLogic SP-150 Potentiostat. Bu$_4$NPF$_6$ was recrystallized from EtOH and dried in vacuo prior use. All measurements were performed under nitrogen atmosphere inside a glovebox. Supporting electrolyte: Bu$_4$NPF$_6$ (0.1 M in MeCN), working electrode: glassy carbon disc ($\phi$=0.3 mm), counter electrode platinum wire, reference electrode: 0.1 M AgNO$_3$/Ag (in 0.1 M Bu$_4$NPF$_6$-MeCN), scanrate: 100 mV/s, analyte concentration: 10 mM. All spectra are referenced against the ferrocene/ferrocene$^+$ couple as an internal standard.
UV/VIS Spectroscopy

UV/VIS data was acquired on a Agilent Cary 60 UV-Vis. All measurements were performed in an oven-dried, sealable quartz glass cuvette, which was charged inside and nitrogen-filled glovebox with the analytes and solvent. The concentration of the analytes was $c = 0.04$ M in MeCN.

Infrared Spectroscopy

Infrared (IR) data was recorded on an Alpha-P Bruker FT-IR Spectrometer. Absorbance frequencies are reported in reciprocal centimeters (cm$^{-1}$). The intensity of the absorbance frequencies is indicated with: (w), weak, (m), medium; (s), strong and (br), broad.

Melting Points

Melting points (Mp) were measured on a Büchi Melting Point B-540 and are uncorrected.

Mass Spectrometry

HRMS ESI measurements were performed by an Agilent LC-MS TOF and XEVO G2-S QTOF mass spectrometers. APPI/LTQ-Orbitrap-FT-MS analyses were performed on a Thermo Orbitrap Elite and LTQ Orbitrap FTMS instrument. High resolution mass values are given in m/z.
Irradiation Setups

a) The setup for the irradiation with white LEDs consisted of a photoreactor made out of a metal drum (h=26 cm, ø=14 cm), in which white LED stripes from Ledxon were attached. On top of the drum, a fan was installed. For irradiation of a vial, it was held in a beaker on a stirring plate and the drum was placed over the stirring plate. The distance between the LEDs and the reaction vial was 6 cm. The reaction chamber was cooled by the fan.

b) The setup for the irradiation with the Kessil PR-160 lamps (427 and 390 nm), consisted of the specific lamp, a stirring plate, a clamp to hold the vial in place and a fan. To ensure efficient cooling two tubes, connected to a compressed air outlet, were directly pointed to the reaction vial. The distance between the Kessil lamps and the reaction vial was 2 cm. For all irradiation setups, thermo-coupled experiments showed a constant reaction temperature of 26 °C.

Figure S1: Setup for the irradiation with white LEDs: a) view into the photoreactor, a’) closed reactor. Setup for the irradiation with Kessil lamps (390 nm and 427 nm): without b) and with irradiation b’).
1.2 Condition Screening

**General Procedure A:**

A 1 mL microwave vial, equipped with a stir bar was charged with 10 µmol substrate and transferred into the glovebox. MeCN was added, followed by the additive, DAP and 110 µmol HBpin. The vial was capped, removed from the glovebox and irradiated for 16 h at rt. Volatiles were removed under reduced pressure and the residue was directly subjected to $^1$H NMR analysis.

**Table S1: Condition Screening for DAP catalyzed reductive Cyclizations of 1-3a.[a]**
[a] GP A; conditions: 100 µmol 1a-3a, 2.5-150 µmol DAP, 110 µmol HBpin, 100-200 µmol additive in MeCN (0.1 M) at 26 °C for 16 h. [b] Determined by 1H-NMR using 1,3,5-trimethoxybenzene as an internal standard. [c] no HBpin. [d] 2 h reaction time. [e] 4 h reaction time. [f] 0.33 equiv. PhSiH₃ instead of HBpin. [g] c(substrate)=0.8 M in MeCN.

1.3 Mechanistic Investigations

1.3.1 Cyclic Voltammetry

![Cyclic voltammetry of substrate 1a. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -2.88 V.](image1)

Figure S2: Cyclic voltammetry of substrate 1a. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -2.88 V.

![Cyclic voltammetry of substrate 2a. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -3.36 V.](image2)

Figure S3: Cyclic voltammetry of substrate 2a. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -3.36 V.
Figure S4: Cyclic voltammetry of substrate 3a. Its reduction peak was found to be outside the solvent window.

Figure S5: Cyclic voltammetry of substrate 2v. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -3.03 V.
Figure S6: Cyclic voltammetry of substrate 3v. The irreversible reduction peak potential $E_{p}^{\text{red}}$ was determined to be at -2.98 V.

Figure S7: Cyclic voltammetry of substrate 3z. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -2.83 V.
Figure S8: Cyclic voltammetry of DAP-H. The irreversible oxidation peak potential $E_{\text{ox}}$ was determined to be at -0.32 V.

Figure S9: Cyclic voltammetry of DAP-OTf. The irreversible reduction peak potential $E_{\text{red}}$ was determined to be at -1.76 V.
1.3.2 UV/VIS measurements

UV/Vis spectra of 1a and DAP-I

**Figure S10**: UV-Vis absorption spectra of 1a (blue, full line), DAP-I (orange, dashed line) and a mixture of 1a and DAP-I (grey, dotted line). Analyte concentration: 0.04 M in MeCN. No formation of an EDA complex was observed.

UV/Vis spectra of 1a and DAP-H

**Figure S11**: UV-Vis absorption spectra of 1a (blue, full line), DAP-H (orange, dashed line), a mixture of 1a and DAP-H (grey, dotted line) and DAP-I (yellow, long dashed line). Analyte concentration: 0.04 M in MeCN. Rapid reaction of 1a and DAP-H resulting in formation of DAP-I was observed.
UV/Vis spectra of 2a and DAP-Br

Figure S12: UV-Vis absorption spectra of 2a (blue, full line), DAP-Br (orange, dashed line) and a mixture of 2a and DAP-Br (grey, dotted line). Analyte concentration: 0.04 M in MeCN. No formation of an EDA complex was observed.

UV/Vis spectra of 2a and DAP-H

Figure S13: UV-Vis absorption spectra of 2a (blue, full line), DAP-H (orange, dashed line) and a mixture of 2a and DAP-H (grey, dotted line). Analyte concentration: 0.04 M in MeCN. No formation of an EDA complex was observed.
Estimation of Excited State Oxidation Potential of DAP-H.

The estimated excited state oxidation potential $E^0(DAP-H^*/DAP-H^+)$ was calculated according to equation (1)\cite{1,2}:

$$E^0(DAP-H^*/DAP-H^+) = E^0(DAP-H^+/DAP-H) - E_{00}(DAP-H^*/DAP-H)$$

(1)

Since the electrochemical oxidation of DAP-H was irreversible (see Figure S8), the irreversible peak potential $E_{ox}$ was used for $E^0(DAP-H^+/DAP-H)$. $E_{00}(DAP-H^*/DAP-H)$, which is the excited state energy of the DAP-H, was estimated spectroscopically from the position of the long wavelength tail of the absorption spectrum (see Figure S14) recorded in MeCN, the same solvent used for the electrochemical analysis.

For DAP-H, $E_{ox}$ was measured to be $-0.32$ V, which provides $E^0(DAP-H^+/DAP-H) = -0.32$ V. The position of the long wavelength tail of the absorption spectrum corresponds to 440 nm, which translates into an $E_{00}(DAP-H^*/DAP-H)$ of 2.82 eV.

$$E^0(DAP-H^*/DAP-H^+) = -0.32 \text{ V} - 2.82 \text{ V} = -3.14 \text{ V}$$

The estimated excited state oxidation potential $E^0(DAP-H^*/DAP-H^+) = -3.14$ V shows the SET from DAP-H* to substrate 1a ($E_{red} = -2.88$ V) to be exergonic and for 2b ($E_{red} = -3.36$ V) to be endergonic.

![Figure S14: Zoom of the UV/Vis absorption spectra of DAP-H depicted in Figure S13. Analyte concentration: 0.04 M in MeCN. The long wavelength tail of the absorption of DAP-H was determined to be at 440 nm.](image-url)
1.3.3 Formation of DAP-H from DAP-I with DBU as an Activator

A dried J-Young NMR tube was charged with a solution of DAP-I (8.00 mg, 24.5 µmol, 1.00 equiv.) and HBpin (3.56 µL, 3.14 mg, 24.5 µmol, 1.00 equiv.) in CD$_3$CN (0.7 mL) inside the glovebox. The tube was sealed and submitted to NMR analysis. No reaction towards DAP-H was observed, even after 16 h. DAP-I was the only detectable species in $^{31}$P NMR at $\delta = 199.20$ ppm (Figure S15 a).

A dried J-Young NMR tube was charged with a solution of DAP-I (16.3 mg, 50.0 µmol, 1.00 equiv.), DBU (14.9 µL, 15.2 mg, 100 µmol, 2.00 equiv.) and HBpin (7.25 µL, 6.40 mg, 50.0 µmol, 1.00 equiv.) in CD$_3$CN (1.0 mL) inside the glovebox. The tube was sealed and submitted to NMR analysis. In $^{31}$P NMR, rapid conversion of DAP-I to DAP-H as the only detectable species at $\delta = 56.79$ ppm was observed (Figure S15 b).
Figure S15: $^{31}$P NMR spectra of: a) a mixture of DAP-I (1.00 equiv.) and HBpin (1.00 equiv.) in CD$_3$CN and b) DAP-I (1.00 equiv.), DBU (2.00 equiv.) and HBpin (1.00 equiv.) in CD$_3$CN.
1.3.4 Kinetic Investigations

**General procedure B**

A flame dried 10 ml microwave vial was charged with substrate 2a (120.6 mg, 0.5 mmol, 1 equiv.) and 1,3,5-trimethoxybenzene NMR standard (28.0 mg, 0.166 mmol, 0.33 equiv.) under air and the vial was introduced inside the glovebox. Next, dry and degassed MeCN (0.625 ml), DBU (76.1 mg, 75.0 µL, 0.50 mmol, 1.00 equiv.), HBpin (70.4 mg, 80.0 µL, 0.55 mmol, 1.10 equiv.) and DAP-H (5.0 mg, 0.025 mmol, 0.05 equiv.) were added. The tube was sealed and stirred under the irradiation of a Kessil lamp (427 nm). Samples of 50 µL of this mixture were taken under a nitrogen atmosphere at specific times. The solvent was evaporated and the samples were analyzed by $^1$H NMR.

![Reaction profile](image)

**Figure S16:** Reaction profile of DAP catalyzed cyclization of 2a.

The reaction shows a linear kinetic behavior at the initial stage of the reaction and no substantial induction period is observed.
GP B was used with the following modifications: The amount of DAP-H (2.5 - 10 mg, 0.0125 - 0.010 mmol, 0.025 - 0.100 equiv.) was varied.

a)

b)

Figure S17: a) Reaction profiles at different initial concentrations of DAP-H showing a first-order dependence in DAP-H. Rate constants calculated from the slope of the plots. [2a] = 0.8 M; [DBU] = 0.8 M; [HBpin] = 0.88 M; [DAP-H] = 0.02 M (blue line), [DAP-H] = 0.04 M (orange line), [DAP-H] = 0.06 M (grey line), [DAP-H] = 0.08 M (blue line). b) Plot of initial rate (mmol/min) versus DAP-H (mmol) with fit to \( y = ax^b \) where, \( y = [4a]/[t], x = \text{[DAP-H]}, b = \text{reaction order.} \)
Order dependence in substrate 2a

GP B was used with the following modifications: The amount of 2a (60.0 – 242 mg, 0.25 – 1.00 mmol, 0.50 – 2.00 equiv.) was varied.

a)

b)

Figure S18: a) Reaction profiles at different initial concentrations of 2a showing a half-order dependence in 2a. Rate constants calculated from the slope of the plots. [DBU] = 0.8 M; [HBpin] = 0.88 M; [DAP-H] = 0.04 M; [2a] = 0.40 M; (grey line), [2a] = 0.8 M; (orange line), [2a] = 1.6 M; (blue line). b) Plot of initial rate (mmol/min) versus 1 (mmol) with fit to y = ax^b where, y = Δ[4a]/ Δ[t, x = [2a], b = reaction order.
GP B was used with the following modifications: The amount of DBU (38.0 – 152 mg, 38.0 – 151 µL, 0.25 – 1.00 mmol, 0.5 – 2.0 equiv.) was varied.

**Figure S19:** a) Reaction profiles at different initial concentrations of DBU showing a zero-order dependence in DBU. Rate constants calculated from the slope of the plots. [2a] = 0.8 M; [HBpin] = 0.88 M; [DAP-H] = 0.04 M; [DBU] = 0.40 M (grey line), [DBU] = 0.8 M; (orange line), [DBU] = 1.6 M; (blue line). b) Plot of initial rate (mmol/min) versus DBU (mmol) with fit to $y = ax^b$ where, $y = \Delta [4a]/\Delta t$, $x =$ [DBU], $b =$ reaction order.
GP B was used with the following modifications: The amount of HBpin (35.0 – 141 mg, 40.0 – 160 µL, 0.275 – 1.10 mmol, 0.55 – 2.20 equiv.) was varied.

a) Reaction profiles at different initial concentrations of HBpin showing a zero-order dependence in HBpin. Rate constants calculated from the slope of the plots. [2a] = 0.80 M; [DBU] = 0.8 M; [DAP-H] = 0.04 M; [HBpin] = 0.44 M (grey line), [HBpin] = 0.88 M; (orange line), [HBpin] = 1.76 M; (blue line).

b) Plot of initial rate (mmol/min) versus HBpin (mmol) with fit to \( y = ax^b \) where, \( y = \Delta[4a]/\Delta t \), \( x = [\text{HBpin}] \), \( b \) = reaction order.

Figure S20: a) Reaction profiles at different initial concentrations of HBpin showing a zero-order dependence in HBpin. Rate constants calculated from the slope of the plots. [2a] = 0.80 M; [DBU] = 0.8 M; [DAP-H] = 0.04 M; [HBpin] = 0.44 M (grey line), [HBpin] = 0.88 M; (orange line), [HBpin] = 1.76 M; (blue line). b) Plot of initial rate (mmol/min) versus HBpin (mmol) with fit to \( y = ax^b \) where, \( y = \Delta[4a]/\Delta t \), \( x = [\text{HBpin}] \), \( b \) = reaction order.
Effect of the (DAP)$_2$ additive on the stoichiometric reaction

A dried J-Young NMR tube was charged with substrate 2a (120.6 mg, 0.50 mmol, 1.00 equiv.) and 1,3,5-trimethoxybenzene (28.0 mg, 0.17 mmol, 0.33 equiv.) under air and the tube was introduced inside the glovebox. Next, dry and degassed CD$_3$CN (0.625 ml) was added followed by addition of DAP-H (100 mg, 0.50 mmol, 1.00 equiv.) and (DAP)$_2$ (0.0 – 10 mol%) under exclusion of light. The tube sealed and the reaction progress was monitored by $^1$H NMR.

Figure S21: Reaction profiles with different amounts of (DAP)$_2$. [2a] = 0.8 M; [DAP-H] = 0.8 M; (DAP)$_2$ = 0.0 mol%; (orange line), (DAP)$_2$ = 2.0 mol%; (grey line), (DAP)$_2$ = 10 mol%; (blue line).
GP B was used with the following modifications: The power of the light source was varied.

**Figure S22:** Reaction profiles at different irradiance. [2a] = 0.8 M; [DBU] = 0.8 M; [DAP-H] = 0.04; [HBpin] = 0.88 M. Kessil lamp (427 nm) 50% power (dark blue line), Kessil lamp (427 nm) 75% power (orange line), Kessil lamp (427 nm) 100% power (grey line), 2×Kessil lamp (427 nm) 100% power (yellow line), Kessil lamp (390 nm) 100% power (light blue line).
1.3.5 Deuterated experiments

Exclusion of HAT from the Solvent

A stirred mixture of 1a (28.8 mg, 100 µmol, 1.00 equiv.), SPO (1.08 mg, 5.00 µmol, 0.05 equiv.), DBU (15.2 mg, 100 µmol, 1.00 equiv.) and HBpin (14.1 mg, 110 µmol, 1.10 equiv.) in CD$_3$CN (1 mL) was irradiated with white LEDs for 16 h. Volatiles were removed under reduced pressure and the residue was purified by flash chromatography (n-pentane:EA=40:1) to afford 4a as a colorless oil. A H incorporation greater than 99% was determined by $^1$H NMR.

![Image of reaction scheme]

**Figure S23:** Zoom of the $^1$H NMR spectra of isolated 4a.
Proof of possible HAT from a DAP species

A stirred mixture of 1a (57.6 mg, 0.20 mmol, 1.00 equiv.) and DAP-D (44.3 mg, 0.22 mmol, 1.10 equiv.) in MeCN (2 mL) was irradiated with white LEDs for 30 min. Volatiles were removed under reduced pressure and the residue was purified by flash chromatography (n-pentane:EA=40:1) to afford 4a-D as a colorless oil. An incorporation of D:H = 90:10 was determined by $^1$H NMR.

Figure S24: Zoom of the $^1$H NMR spectra of isolated 4a-D.
1.3.6  Formation of (DAP)$_2$ from DAP-H under Irradiation

A dried J-Young NMR tube was charged with a solution of DAP-H (10 mg, 50 µmol) in CD$_3$CN (0.5 mL) inside the glovebox. The tube was sealed and submitted to NMR analysis. In $^{31}$P NMR, only DAP-H was detected at $\delta = 56.86$ ppm (Figure S25a). The tube was irradiated with a Kessil lamp (427 nm) for 5 h. After irradiation, a solid precipitate was observed, presumably (DAP)$_2$, which was found to be poorly soluble in MeCN and CD$_3$CN. $^{31}$P NMR analysis showed complete conversion of DAP-H and the new signal at $\delta = 78.20$ ppm corresponded to (DAP)$_2$ (Figure S25b).

Figure S25: $^{31}$P NMR spectra of a solution of DAP-H in CD$_3$CN a) before and b) after irradiation with Kessil lamp (427 nm) to access (DAP)$_2$. 
1.3.7 Attempts to inhibit the reductive cyclization by TEMPO

Two separate 1 mL microwave vial, equipped with a stir bar were charged with 3z (37.1 mg, 100 µmol, 1.00 equiv.), to one vial was added (2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) (3.13 mg, 20 µmol, 0.20 equiv.) and both vials were transferred into the glovebox. MeCN (125 µL) was added, followed by DAP-H (20.0 Mg, 100 µmol, 1.00 equiv.) under strict exclusion of light. The vials were capped and the reaction mixtures were stirred for 16 h at 26 °C. Volatiles were removed under reduced pressure and the residue was directly subjected to $^1$H NMR analysis with 1,3,5-trimethoxybenzene as an internal standard.

Note: DAP-H reacts rapidly with TEMPO, thus inhibition of hypothesized radical intermediates could not be observed.
1.4 DAP Synthesis

General Overview

\[
\text{SI-1} \xrightarrow{a)} \text{DAP-Br} \xrightarrow{b)} \text{SPO} \xrightarrow{c)} \text{(DAP)\_2} \xrightarrow{d) / e)} \text{DAP-H} \xrightarrow{g)} \text{DAP-D} \xrightarrow{f)} \text{DAP-OTf}
\]

\text{N^1, N^2-Di-tert-butylethane-1,2-diimine (SI-1)}

To a stirred solution of oxaldehyde (2.90 g, 20.0 mmol, 1.00 equiv.) in H\_2O (20 w-%) was added tert-butyamine (2.09 mL, 1.46 g, 20.0 mmol, 2.00 equiv.) at 0°C under air. Instantly a white precipitate formed and the reaction mixture solidified. The mixture was sonicated for 15 min. The solid was filtered, washed several times with H\_2O, dissolved in CH\_2Cl\_2 (20 mL) and dried over Na\_2SO\_4. All volatiles were removed under reduced pressure to afford SI-1 (1.19 g, 7.04 mmol, 70 %) as a white solid with a wet appearance, which was used in the next step without further purification.

Analytical data of SI-1:

\text{\textsuperscript{1}H NMR (400 MHz, CDCl\_3): } \delta = 7.93 (s, 2H), 1.26 (s, 18H) ppm.

\text{\textsuperscript{13}C NMR (100 MHz, CDCl\_3): } \delta = 158.1, 58.4, 29.5 ppm.

All spectroscopic data corresponded to the reported literature values.\[3\]
2-Bromo-1,3-di-tert-butyl-2,3-dihydro-1H-1,3,2-diazaphosphole (DAP-Br)

a) To a stirred solution of diimine SI-1 (505 mg, 3.00 mmol, 1.00 equiv.) in dry Et₂O (5 mL) was added cyclohexene (912 µL, 739 mg, 9.00 mmol, 3.00 equiv.), followed by PBr₃ (285 µL, 812 mg, 3.00 mmol, 1.00 equiv.) at rt. The mixture was stirred for 20 h at rt and all volatiles were removed in vacuo. The solid residue was transferred into the glovebox, filtered, and washed with Et₂O to afford the title compound (623 mg, 2.23 mmol, 74%) as a faint yellow powder.

Analytical data of DAP-Br:

\(^1\)H NMR (400 MHz, CDCl₃): δ = 7.21 (s, 2H), 1.73 (s, 19H) ppm.

\(^{13}\)C NMR (100 MHz, CDCl₃): δ = 124.3 (d, \(J = 7.2\) Hz), 59.3 (d, \(J = 7.4\) Hz), 30.3 (d, \(J = 10.0\) Hz) ppm.

\(^{31}\)P NMR (162 MHz, CDCl₃): δ = 185.89 ppm.

All spectroscopic data corresponded to the reported literature values.\[^4\]

1,3-Di-tert-butyl-1,3-dihydro-1,3,2-diazaphosphole 2-oxide (SPO)

b) SPO was synthesized according to a known procedure.\[^5\] To a stirred solution of DAP-Br (500 mg, 1.79 mmol, 1.00 equiv.) in CH₂Cl₂ (5 mL) was added NEt₃ (250 µL, 181 mg, 1.79 mmol, 1.00 equiv.) at rt. The resulting mixture was stirred for 5 min and quenched by the addition of H₂O (10 mL). After stirring for 1 h, the reaction mixture was extracted with CH₂Cl₂ (2 × 15 mL). Organic layers were dried over Na₂SO₄ and all volatiles were removed under reduced pressure to afford the title compound (349 mg, 1.61 mmol, 90%) as an ivory solid.

Analytical data of SPO:

\(^1\)H NMR (400 MHz, CDCl₃): δ = 8.60 (dt, \(J = 646.9, 1.8\) Hz, 1H), 5.95 (dd, \(J = 16.0, 1.7\) Hz, 2H), 1.43 (s, 18H) ppm.

\(^{13}\)C NMR (100 MHz, CDCl₃): δ = 110.6 (d, \(J = 10.2\) Hz), 53.6 (d, \(J = 4.3\) Hz), 30.2 (d, \(J = 4.0\) Hz).

\(^{31}\)P NMR (162 MHz, CDCl₃): δ = 3.36 ppm.

All spectroscopic data corresponded to the reported literature values.\[^5\]
1,1',3,3'-Tetra-tert-butyl-1,1',3,3'-tetrahydro-2,2'-bi(1,3,2-diazaphosphole) (DAP)$_2$

c) (DAP)$_2$ was synthesized according to a known procedure.[6] To a stirred suspension of DAP-Br (4.02 g, 14.4 mmol, 1.00 equiv.) and Mg (turnings, 1.05 g, 43.2 mmol, 3.00 equiv.) in dry THF (12 mL) inside a Schlenk flask, was added iodine (366 mg, 1.44 mmol, 0.10 equiv.) at rt. The mixture was stirred for 4 h and all volatiles were removed in vacuo. The flask was transferred into the glovebox and the residue was suspended in n-pentane (20 mL). The resulting mixture was filtered over celite and the remaining solid was washed with n-pentane (2 x 20 mL). All volatiles were removed in vacuo to afford the title compound (2.55 g, 6.41 mmol, 44 %) as an off-white solid.

Analytical data of (DAP)$_2$:

$^1$H NMR (400 MHz, C$_6$D$_6$): $\delta = 5.94$ (t, $J = 1.9$ Hz, 4H), 1.26 (s, 36H) ppm.

$^{13}$C NMR (100 MHz, C$_6$D$_6$): $\delta = 121.3$, 54.2 (t, $J = 7.7$ Hz), 30.3 (t, $J = 4.0$ Hz) ppm.

$^{31}$P NMR (162 MHz, C$_6$D$_6$): $\delta = 79.86$ ppm.

$^1$H NMR (400 MHz, CD$_3$CN): $\delta = 5.95$ (t, $J = 2.0$ Hz, 4H), 1.18 (s, 36H) ppm.

$^{31}$P NMR (162 MHz, CD$_3$CN): $\delta = 78.20$ ppm.

All spectroscopic data (acquired in C$_6$D$_6$) corresponded to the reported literature values.[6]

1,3-Di-tert-butyl-2,3-dihydro-1H-1,3,2-diazaphosphole (DAP-H)

d) To a stirred suspension of DAP-Br (2.70 g, 10.0 mmol, 1.00 equiv.) in dry and degassed THF (70 mL) inside a Schlenk flask was added LiAlH$_4$ (1.25 mL, 2.4 M in THF, 114 mg, 3.00 mmol, 0.30 equiv.) at $-78 \, ^\circ$C. The mixture was stirred for 30 min at $-78 \, ^\circ$C. The cooling bath was removed and the mixture was stirred for further 2 h. All volatiles were removed in vacuo and the flask was transferred into the glovebox. The residue was suspended in n-hexane (15 mL) and filtered over celite. The remaining residue inside the flask was washed with additional n-hexane (2 x 20 mL). Volatiles were removed in vacuo to afford a yellow oil. Distillation (1 mbar, 73 $^\circ$C) afforded the title compound (1.19 g, 5.94 mmol, 59%) as a faint yellow liquid.

Analytical data of DAP-H:

$^1$H NMR (400 MHz, C$_6$D$_6$): $\delta = 6.16$ (d, $J = 184.2$ Hz, 1H), 6.00 (d, $J = 3.9$ Hz, 2H), 1.16 (s, 18H) ppm.

$^{31}$P NMR (162 MHz, C$_6$D$_6$): $\delta = 57.49$ ppm.

$^1$H NMR (400 MHz, CD$_3$CN): $\delta = 6.08$ (d, $J = 4.0$ Hz, 2H), 1.21 (d, $J = 1.0$ Hz, 18H) ppm.

$^{31}$P NMR (162 MHz, CD$_3$CN): $\delta = 56.81$ ppm.

All spectroscopic data in C$_6$D$_6$[7] and CD$_3$CN[8] corresponded to the reported literature values.
A solution of LiAlD$_4$ was prepared by a modified literature procedure$^9$:

Inside the glovebox, LiD (186 mg, 20.6 mmol, 2.06 equiv.) and LiAlD$_4$ (23.6 mg, 0.56 mmol, 0.06 equiv.) were thoroughly ground separately and suspended in Et$_2$O (2 mL). Under stirring, a solution of AlCl$_3$ (500 mg, 3.75 mmol, 0.38 equiv.) in Et$_2$O (5 mL) was added dropwise. The reaction was stirred for further 30 min and filtered over a short plug of celite. This solution of LiAlD$_4$ was used without further analysis or purification in the next step.

Outside the glovebox, the prior obtained solution of LiAlD$_4$ in Et$_2$O was added to a stirred solution of DAP-Br (2.79 g, 10.0 mmol, 1.00 equiv.) in THF (70 mL) inside a Schlenk tube at –78 °C. The mixture was stirred for further 30 min at this temperature and was allowed to reach rt, at which the stirring was continued for additional 2 h. All volatiles were removed in vacuo and the Schlenk tube was transferred into the glovebox. The yellow residue was suspended in n-hexane (15 mL), filtered over celite and washed with n-hexane (2×15 mL). The volatiles were removed in vacuo and the remaining yellow liquid residue was distilled under reduced pressure (0.08 mbar, 70 °C) to afford the title compound as a highly air and moisture sensitive, faint yellow liquid (657 mg, 3.28 mmol, 33%, D incorporation > 95%)

Analytical data of DAP-D:

$^1$H NMR (400 MHz, C$_6$D$_6$): δ = 6.00 (d, J = 4.0 Hz, 2H), 1.16 (d, J = 1.0 Hz, 18H) ppm.

$^{13}$C NMR (101 MHz, C$_6$D$_6$): δ = 121.1 (d, J = 6.8 Hz), 53.7 (d, J = 13.5 Hz), 29.7 (d, J = 8.8 Hz) ppm.

$^{31}$P NMR (162 MHz, C$_6$D$_6$): δ = 55.84 – 55.47 (m) ppm.

$^1$H NMR (400 MHz, CD$_3$CN): δ = 6.08 (d, J = 4.0 Hz, 2H), 1.21 (d, J = 1.0 Hz, 18H) ppm.

$^{13}$C NMR (101 MHz, CD$_3$CN): δ = 121.5 (d, J = 7.1 Hz), 54.2 (d, J = 12.2 Hz), 29.8 (d, J = 8.9 Hz) ppm.

$^{31}$P NMR (162 MHz, CD$_3$CN): δ = 55.94 ppm.

HRMS (ESI): calcd. for [C$_{10}$H$_{20}$^2H$_2$P]^+: [M]$^+$/2: 201.1500; found: 201.1508.
f) To a stirred solution of DAP-Br (1.00 g, 3.58 mmol, 1.00 equiv.) in dry and degassed THF (30 mL) was added trimethylsilyl trifluoromethanesulfonate (647 µL, 796 mg, 3.58 mmol, 1.00 equiv.) at rt. The yellow solution turned immediately colorless and precipitation was observed. The mixture was stirred for 2 h and the precipitate was removed by filtration over celite. All volatiles were removed in vacuo to afford DAP-OTf (1.03 g, 2.95 mmol, 82%) as a white solid.

**Analytical data of DAP-OTf:**

\(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta = 8.23\) (s, 2 H), 1.80 (d, \(J = 1.9\) Hz, 18H) ppm.

\(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta = 132.9\) (d, \(J = 3.6\) Hz), 62.8 (d, \(J = 7.6\) Hz), 31.4 (d, \(J = 9.4\) Hz) ppm.

\(^{31}\)P NMR (162 MHz, CDCl\(_3\)): \(\delta = 202.10\) ppm.

All spectroscopic data corresponded to the reported literature values.\[^{10}\]

**1,3-Di-tert-butyl-2,3-dihydro-1H-1,3,2-diazaphosphole (DAP-I)**

g) To a stirred suspension of (DAP)_2 (797 mg, 2.00 mmol, 1.00 equiv.) in MeCN (6 mL) was added iodobenzene (223 µL, 408 mg, 1.00 mmol, 1.00 equiv.) at rt. The mixture was stirred for 2 h and all volatiles were removed in vacuo. The bright yellow solid residue was washed with n-pentane and dried in vacuo to afford DAP-I (608 mg, 1.86 mmol, 93%) as a bright yellow solid.

**Analytical data of DAP-I:**

\(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta = 7.33\) (s, 2H), 1.75 (d, \(J = 2.0\) Hz, 19H) ppm.

\(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta = 125.9\) (d, \(J = 6.5\) Hz), 60.1 (d, \(J = 7.1\) Hz), 29.8 (d, \(J = 9.6\) Hz) ppm.

\(^{31}\)P NMR (162 MHz, CDCl\(_3\)): \(\delta = 194.35\) ppm.

\(^1\)H NMR (400 MHz, CD\(_3\)CN): \(\delta = 7.84\) (d, \(J = 3.3\) Hz, 2H), 1.71 (d, \(J = 2.0\) Hz, 20H) ppm.

\(^{31}\)P NMR (162 MHz, CD\(_3\)CN): \(\delta = 199.31\) ppm.

All spectroscopic data (acquired in CDCl\(_3\)) corresponded to the reported literature values.\[^{6}\]
1.5 Substrate Synthesis

**General Procedure C:**
Without exclusion of moisture or oxygen. To a stirred suspension of K$_2$CO$_3$ (2.00 – 3.00 equiv.) and alcohol (1.00 equiv.) in DMF (0.5 M) was added alkyl halide (1.1 – 1.3 equiv.) at rt. The reaction was stirred for 16 h and diluted with H$_2$O (2 mL per mmol alcohol) and aq. NaOH (2 M, 2 mL per mmol alcohol). The mixture was extracted with EtOAc or n-pentane (3x) and the combined organic layers were washed with sat. aq. Na$_2$S$_2$O$_3$, followed by brine. After drying over Na$_2$SO$_4$, all volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO$_2$, n-pentane:EtOAc).

**General Procedure D:**
A stirred suspension of amide (1.00 equiv.), K$_2$CO$_3$ (2.00 equiv.), KI (10 mol%) and alkyl bromide (1.30 equiv.) in acetone (0.5 M) was heated to 60 °C. After 18 h, the mixture was cooled to rt, diluted with H$_2$O (10 mL per mmol amide) and extracted with Et$_2$O (3 x 10 mL per mmol amide). After drying the combined organic layers over Na$_2$SO$_4$, all volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO$_2$, n-pentane:EtOAc).

**General Procedure E:**
To a stirred solution of PPh$_3$ (3.00 equiv.) in dry THF (0.5 M) was added CBr$_4$ (3.00 equiv.) at 0 °C. The resulting mixture was stirred for 5 min, followed by the addition of alcohol (1.00 equiv., dissolved in 1-2 mL dry THF). The reaction was allowed to reach rt, stirred for 18 h and quenched by the addition of H$_2$O (20 mL per mmol alcohol). The mixture was extracted with CH$_2$Cl$_2$ (3 x 20 mL per mmol alcohol), combined organic layers were dried over MgSO$_4$ and all volatiles were removed under reduced pressure. Purification of the residue by flash chromatography (SiO$_2$, n-pentane:EtOAc) afforded the desired products.
1-Iodo-2-((3-methylbut-2-en-1-yl)oxy)benzene (1a)

\[
\begin{align*}
\text{Iodo-} & \quad \text{(3-methylbut-2-en-1-yl)oxy)benzene (1a)} \\
\end{align*}
\]

Synthesized according to GP C from 2-iodophenol (1.10 g, 5.00 mmol, 1.00 equiv.), K₂CO₃ (2.07 g, 15.0 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (654 µL, 820 mg, 5.50 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 1a (1.25 g, 4.35 mmol, 87%) as a colourless liquid.

**Analytical data of 1a:**

TLC (SiO₂): Rᵢ (n-pentane: EtOAc = 40:1) = 0.43

¹H NMR (400 MHz, CDCl₃): δ = 7.77 (dd, J = 7.8, 1.6 Hz, 1H), 7.32 – 7.23 (m, 1H), 6.83 (dd, J = 8.2, 1.4 Hz, 1H), 6.70 (td, J = 7.6, 1.4 Hz, 1H), 5.54 – 5.49 (m, 1H), 4.59 (d, J = 6.5 Hz, 2H), 1.80 (s, 3H), 1.75 (s, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 157.6, 139.6, 138.1, 129.5, 122.6, 119.7, 112.8, 87.1, 66.4, 25.9, 18.5 ppm.

All spectroscopic data corresponded to the reported literature values.[⁶]

1-Bromo-2-((3-methylbut-2-en-1-yl)oxy)benzene (2a)

\[
\begin{align*}
\text{Bromo-} & \quad \text{(3-methylbut-2-en-1-yl)oxy)benzene (2a)} \\
\end{align*}
\]

Synthesized according to GP C from 2-bromophenol (1.59 mL, 2.56 g, 15.0 mmol, 1.11 equiv.), K₂CO₃ (6.22 g, 45.0 mmol, 3.33 equiv.) and 1-bromo-3-methylbut-2-ene (1.58 mL, 2.01 g, 13.5 mmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 2a (2.79 g, 11.6 mmol, 86%) as a colourless liquid.

**Analytical data of 2a:**

TLC (SiO₂): Rᵢ (n-pentane: EtOAc = 40:1) = 0.42

¹H NMR (400 MHz, CDCl₃): δ = 7.53 (dd, J = 7.8, 1.6 Hz, 1H), 7.29 – 7.20 (m, 1H), 6.91 (dd, J = 8.3, 1.4 Hz, 1H), 6.82 (td, J = 7.6, 1.4 Hz, 1H), 5.56 – 5.46 (m, 1H), 4.60 (d, J = 6.5 Hz, 2H), 1.80 (s, 3H), 1.75 (s, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 155.4, 139.6, 138.1, 129.5, 122.6, 119.7, 112.8, 87.1, 66.4, 25.9, 18.5 ppm.

All spectroscopic data corresponded to the reported literature values.[¹¹]

1-Chloro-2-((3-methylbut-2-en-1-yl)oxy)benzene (3a)

\[
\begin{align*}
\text{Chloro-} & \quad \text{(3-methylbut-2-en-1-yl)oxy)benzene (3a)} \\
\end{align*}
\]

Synthesized according to GP C from 2-chlorophenol (3.36 µL, 424 mg, 3.30 mmol, 1.10 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (352 µL, 447 mg, 3.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 3a (506 mg, 2.57 mmol, 86%) as a colourless liquid.
Analytical data of 3a:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.42

¹H NMR (400 MHz, CDCl₃): δ = 7.36 (dd, J = 7.9, 1.7 Hz, 1H), 7.24 – 7.15 (m, 1H), 6.93 (dd, J = 8.3, 1.4 Hz, 1H), 6.93 – 6.84 (m, 1H), 5.56 – 5.47 (m, 1H), 4.60 (d, J = 6.6 Hz, 2H), 1.79 (s, 3H), 1.75 (s, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 154.5, 138.4, 133.4, 127.7, 121.4, 119.6, 114.0, 66.2, 26.0, 18.4 ppm.


All spectroscopic data corresponded to the reported literature values.[12]

1-Bromo-4-methoxy-2-((3-methylbut-2-en-1-yl)oxy)benzene (2b)

Synthesized according to GP C from 2-bromo-5-methoxyphenol (374 µL, 609 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (387µL, 492 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 20:1) afforded 2b (650 mg, 2.40 mmol, 80%) as a colourless liquid.

Analytical data of 2b:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 20:1) = 0.48

¹H NMR (400 MHz, CDCl₃): δ = 7.11 (d, J = 3.0 Hz, 1H), 6.89 – 6.75 (m, 2H), 5.54 – 5.45 (m, 1H), 4.52 (d, J = 7.0 Hz, 2H), 3.76 (s, 3H), 1.78 (s, 3H), 1.72 (s, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 154.3, 149.8, 138.2, 119.9, 118.9, 115.7, 113.8, 113.3, 67.3, 56.0, 26.0, 18.4 ppm.

IR (ATR): 2968 (w), 2935 (w), 1491 (s), 1440 (w) 1273 (m), 1212 (s), 1039 (s), 996 (w), 757 (w) cm⁻¹.


2-Bromo-1-((3-methylbut-2-en-1-yl)oxy)-4-(trifluoromethyl)benzene (2c)

Synthesized according to GP C from 2-bromo-4-(trifluoromethyl)phenol (723 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (387µL, 492 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 2c (649 mg, 2.01 mmol, 70%) as a colourless liquid.

Analytical data of 2c:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.64

¹H NMR (400 MHz, CDCl₃): δ = 7.80 (d, J = 1.9 Hz, 1H), 7.55 – 7.47 (m, 1H), 6.94 (d, J = 8.6 Hz, 1H), 5.53 – 5.44 (m, 1H), 4.65 (d, J = 6.5 Hz, 2H), 1.80 (s, 3H), 1.76 (s, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 157.9, 139.2, 130.7 (q, J₁₂C = 3.8 Hz), 125.9 (q, J₋₁₂C = 3.9 Hz), 123.8 (q, J₋₁₂C = 33.2 Hz), 123.7 (q, J₋₁₂C = 271.6 Hz), 118.7, 112.9, 112.5, 66.5, 26.0, 18.5 ppm.
\[^{19}\text{F NMR}\ (376\ \text{MHz, CDCl}_3)\ \delta = -61.67\ \text{ppm}.\]

\[^{1}\text{H NMR}\ (400\ \text{MHz, CDCl}_3):\ \delta = 7.14 (t, J = 8.3\ \text{Hz}, 1\text{H}), 6.67 (dd, J = 8.3, 1.3\ \text{Hz}, 1\text{H}), 6.48 (dd, J = 8.3, 1.3\ \text{Hz}, 1\text{H}), 5.62 (s, 1\text{H}), 5.55 - 5.46 (m, 1\text{H}), 4.58 (d, J = 6.5\ \text{Hz}, 2\text{H}), 1.80 (s, 3\text{H}), 1.75 (s, 3\text{H})\ \text{ppm}.\]

\[^{13}\text{C NMR}\ (101\ \text{MHz, CDCl}_3):\ \delta = 156.0, 153.6, 138.4, 128.7, 119.5, 108.5, 105.3, 100.8, 66.4, 26.0, 18.5\ \text{ppm}.\]

\[^{1}\text{H NMR}\ (400\ \text{MHz, CDCl}_3):\ \delta = 7.16 (t, J = 8.3\ \text{Hz}, 1\text{H}), 6.56 (d, J = 8.3\ \text{Hz}, 2\text{H}), 5.57 - 5.44 (m, 2\text{H}), 4.59 (dt, J = 6.5, 1.0\ \text{Hz}, 4\text{H}), 1.78 (s, 6\text{H}), 1.74 (s, 6\text{H})\ \text{ppm}.\]

\[^{13}\text{C NMR}\ (101\ \text{MHz, CDCl}_3):\ \delta = 156.8 (2\text{C}), 138.0 (2\text{C}), 128.0, 119.8 (2\text{C}), 106.4 (2\text{C}), 102.6, 66.5 (2\text{C}), 26.0 (2\text{C}), 18.5 (2\text{C})\ \text{ppm}.\]
IR (ATR): 2973 (w), 2913 (w), 1589 (m), 1252 (m), 1234 (m), 1074 (s), 1036 (m), 760 (m) cm⁻¹.


3-Bromo-4-((3-methylbut-2-en-1-yl)oxy)benzoic acid (2f)

To a stirred solution of methyl 3-bromo-4-((3-methylbut-2-en-1-yl)oxy)benzoate (2g) (299 mg, 1.00 mmol, 1.00 equiv.) in THF/MeOH (1:1, 4 mL) was added NaOH (44 mg, 1.10 mmol, 1.10 equiv.) dissolved in H₂O (1 mL). The resulting mixture was heated to 60 °C for 19 h. After the reaction was cooled to rt, aq. HCl (1 M, 10 mL) were added, and the resulting mixture was extracted with EtOAc (3 × 15 mL). Combined organic layers were dried over Na₂SO₄ and all volatiles were removed under reduced pressure to afford the title compound 2f (276 mg, 968 µmol, 97%) as a white solid.

Analytical data of 2f:
Mp: 155.8 – 157.9 °C.
¹H NMR (400 MHz, CDCl₃): δ = 11.98 (br s, 1H), 8.30 (d, J = 2.1 Hz, 1H), 8.02 (dd, J = 8.7, 2.1 Hz, 1H), 6.93 (d, J = 8.7 Hz, 1H), 5.54 – 5.46 (m, 1H), 4.68 (d, J = 6.6 Hz, 2H), 1.81 (s, 3H), 1.77 (s, 3H) ppm.
¹³C NMR (101 MHz, CDCl₃): δ = 170.6, 159.8, 139.3, 135.7, 131.3, 122.6, 118.7, 112.5, 112.2, 66.5, 26.0, 18.6 ppm.
IR (ATR): 2913 (br), 1678 (s), 1596 (s), 1427 (m), 1318 (m), 1274 (s), 1046 (w), 802 (m) cm⁻¹.


Methyl 3-bromo-4-((3-methylbut-2-en-1-yl)oxy)benzoate (2g)

Synthesized according to GP C from 3-bromo-4-hydroxybenzoate (693 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (415 mg, 3.00 mmol, 1.00 equiv.) and 1-bromo-3-methylbut-2-ene (387 µL, 492 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 20:1) afforded 2g (639 mg, 2.14 mmol, 71%) as a white solid.

Analytical data of 2g:
TLC (SiO₂): Rₗ (n-pentane:EtOAc = 20:1) = 0.27
¹H NMR (400 MHz, CDCl₃): δ = 8.23 (d, J = 2.1 Hz, 1H), 7.95 (dd, J = 8.6, 2.1 Hz, 1H), 6.90 (d, J = 8.7 Hz, 1H), 5.54 – 5.44 (m, 1H), 4.66 (d, J = 6.5 Hz, 2H), 3.89 (s, 3H), 1.80 (s, 3H), 1.76 (s, 3H) ppm.
¹³C NMR (101 MHz, CDCl₃): δ = 165.9, 159.0, 139.0, 135.0, 130.6, 123.6, 118.8, 112.4, 112.1, 66.4, 52.3, 26.0, 18.5 ppm.
All spectroscopic data corresponded to the reported literature values.¹²
1-Bromo-3-chloro-2-((3-methylbut-2-en-1-yl)oxy)benzene (2h)

![Structure of 2h](image)

Synthesized according to GP C from 2-bromo-6-chlorophenol (622 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (387 μL, 492 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 2h (103 mg, 281 μmol, 84%) as a colourless oil.

**Analytical data of 2h:**

**TLC** (SiO₂): Rᵥ (n-pentane:EtOAc = 40:1) = 0.64

**¹H NMR** (400 MHz, CDCl₃): δ = 7.45 (dd, J = 8.1, 1.5 Hz, 1H), 7.33 (dd, J = 8.0, 1.5 Hz, 1H), 6.91 (t, J = 8.0 Hz, 1H), 5.69 – 5.59 (m, 1H), 4.55 (dt, J = 7.4, 0.8 Hz, 2H), 1.80 (s, 3H), 1.75 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 152.5, 139.9, 132.0, 129.8, 129.8, 125.7, 119.5, 119.3, 70.1, 26.0, 18.2 ppm.

**IR** (ATR): 2930 (br), 1674 (w), 1559 (w), 1435 (s), 1379 (m), 1240 (s), 1068 (w), 946 (s), 766 (s), 752 (s) cm⁻¹.


2-Bromo-3-((3-methylbut-2-en-1-yl)oxy)pyridine (2i)

![Structure of 2i](image)

Synthesized according to GP C from 2-bromopyridin-3-ol (522 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (387 μL, 492 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 2i (580 mg, 2.40 mmol, 80%) as a colourless liquid.

**Analytical data of 2i:**

**TLC** (SiO₂): Rᵥ (n-pentane:EtOAc = 10:1) = 0.26

**¹H NMR** (400 MHz, CDCl₃): δ = 7.96 (dd, J = 4.7, 1.5 Hz, 1H), 7.22 – 7.14 (m, 1H), 7.12 (dd, J = 8.1, 1.6 Hz, 1H), 5.51 – 5.40 (m, 1H), 4.61 (d, J = 6.6 Hz, 2H), 1.79 (s, 3H), 1.75 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 152.4, 139.9, 132.0, 129.8, 129.8, 125.7, 119.5, 119.3, 70.1, 26.0, 18.2 ppm.

All spectroscopic data corresponded to the reported literature values[¹²]

1-Bromo-3-iodo-2-((3-methylbut-2-en-1-yl)oxy)benzene (1j)

![Structure of 1j](image)

To a stirred solution of 2-bromo-6-iodophenol (100 mg, 335 μmol, 1.00 equiv.), triphenylphosphane (87.7 mg, 335 μmol, 1.00 equiv.) and 3-methylbut-2-en-1-ol (40.8 μL, 34.6 mg, 401 μmol, 1.20 equiv.) in THF (2 mL) was added
DIAD (65.7 μL, 67.6 mg, 335 μmol, 1.00 equiv.) at rt. The resulting mixture was heated to 80 °C for 18 h. The reaction was cooled to rt and all volatiles were removed under reduced pressure. Purification of the residue by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 1j (103 mg, 281 µmol, 84%) as a colourless oil.

**Analytical data of 1j:**

**TLC (SiO₂):** R_f (n-pentane:EtOAc = 40:1) = 0.34

**1H NMR** (400 MHz, CDCl₃): δ = 7.73 (dd, J = 7.9, 1.5 Hz, 1H), 7.53 (dd, J = 7.9, 1.5 Hz, 1H), 6.70 (t, J = 7.9 Hz, 1H), 5.73 – 5.63 (m, 1H), 4.53 (d, J = 7.3 Hz, 2H), 1.82 (s, 3H), 1.79 (s, 3H) ppm.

**13C NMR** (101 MHz, CDCl₃): δ = 155.7, 139.8, 138.8, 133.9, 127.1, 119.6, 117.5, 93.4, 70.2, 26.0, 18.5 ppm.

**IR (ATR):** 2930 (br), 1550 (w), 1429 (s), 1378 (m), 1234 (m), 1068 (w), 945 (s), 766 (s), 703 (s) cm⁻¹.


(E)-1-Bromo-2-(cinnamyoxy)benzene (2k)

Synthesized according to GP C from 2-bromophenol (531 µL, 865 mg, 5.00 mmol, 1.00 equiv.), K₂CO₃ (2.07 g, 15.0 mmol, 3.00 equiv.) and [((E)-3-bromoprop-1-enyl]benzene (1.08 g, 5.50 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1 – 20:1) afforded 2k (2.79 g, 11.6 mmol, 86%) as a colourless oil.

**Analytical data of 2k:**

**TLC (SiO₂):** R_f (n-pentane:EtOAc = 40:1) = 0.35

**1H NMR** (400 MHz, CDCl₃): δ = 7.56 (dd, J = 7.9, 1.6 Hz, 1H), 7.45 – 7.40 (m, 2H), 7.36 – 7.31 (m, 2H), 7.29 – 7.23 (m, 2H), 6.96 (dd, J = 8.2, 1.4 Hz, 1H), 6.85 (td, J = 7.6, 1.4 Hz, 1H), 6.79 (dt, J = 15.9, 1.7 Hz, 1H), 6.43 (dt, J = 15.9, 5.6 Hz, 1H), 4.79 (dd, J = 5.6, 1.6 Hz, 2H) ppm.

**13C NMR** (101 MHz, CDCl₃): δ = 155.2, 136.5, 133.6, 133.2, 128.8, 128.6, 128.1, 126.8, 124.1, 122.3, 114.0, 112.6, 69.9 ppm.

All spectroscopic data corresponded to the reported literature values.¹³

1-Bromo-2-((2-methylallyl)oxy)benzene (2l)

Synthesized according to GP C from 2-bromophenol (318 µL, 519 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (1.24 g, 9.00 mmol, 3.00 equiv.) and 3-bromo-2-methylprop-1-ene (332 µL, 446 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 2l (676 mg, 2.98 mmol, 99%) as a colourless liquid.

**Analytical data of 2l:**

**TLC (SiO₂):** R_f (n-pentane:EtOAc = 40:1) = 0.42
\[ ^1H \text{NMR} \ (400 \text{ MHz, CDCl}_3): \delta = 7.54 \ (d, J = 7.9, 1H), 7.28 – 7.19 \ (m, 1H), 6.89 \ (d, J = 8.3, 1H), 6.83 \ (t, J = 7.6, 1H), 5.20 – 5.14 \ (m, 1H), 5.05 – 4.96 \ (m, 1H), 4.50 \ (s, 2H), 1.86 \ (s, 3H) \text{ ppm.} \]

\[ ^{13}C \text{NMR} \ (101 \text{ MHz, CDCl}_3): \delta = 155.1, 140.4, 133.5, 128.5, 122.0, 113.6, 113.0, 112.4, 72.6, 19.5 \text{ ppm.} \]

All spectroscopic data corresponded to the reported literature values.\[14\]

**Cyclohex-1-en-1-ylmethanol (SI-2)**

To a stirred solution of LiAlH\(_4\) (1.14 g, 12.5 mL, 30.0 mmol, 2.40 M in THF, 3.00 equiv.) was added a solution of cyclohexene-1-carboxylic acid (1.26 g, 10.0 mmol, 1.00 equiv.) in Et\(_2\)O (25 mL) dropwise at 0 °C. The mixture was stirred for 3 h and quenched by the careful addition of H\(_2\)O (10 mL). Aq. NaOH (2 M, 30 mL), EtOAc (30 mL) and CH\(_2\)Cl\(_2\) (50 mL) was added. Filtration over a pad of celite, allowed to separate the layers. The organic layer was dried over Na\(_2\)SO\(_4\), volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO\(_2\), n-pentane:EtOAc = 10:1 – 3:1) to afford SI-2 (780 mg, 6.95 mmol, 70 %) as a faint yellow liquid.

**Analytical data of SI-2:**

**TLC** (SiO\(_2\)): R\(_f\) (n-pentane: EtOAc = 10:1) = 0.20

\[ ^1H \text{NMR} \ (400 \text{ MHz, CDCl}_3): \delta = 5.71 – 5.64 \ (m, 1H), 3.97 \ (s, 2H), 2.07 – 1.96 \ (m, 4H), 1.71 – 1.52 \ (m, 4H) \text{ ppm.} \]

\[ ^{13}C \text{NMR} \ (101 \text{ MHz, CDCl}_3): \delta = 137.7, 123.2, 67.8, 25.7, 25.1, 22.7, 22.6 \text{ ppm.} \]

All spectroscopic data corresponded to the reported literature values.\[15\]

**1-Bromo-2-(cyclohex-1-en-1-ylmethoxy)benzene (2m)**

To a stirred solution of cyclohexen-1-ylmethanol (SI-2) (123 mg, 1.10 mmol, 1.10 equiv.uiv) in dry Et\(_2\)O (5 mL) was added PBr\(_3\) (104 μL, 298 mg, 1.10 mmol, 1.10 equiv.) at 0 °C. The reaction mixture was stirred for 1 h and carefully quenched by the addition of sat. aq. NH\(_4\)Cl (5 mL). The layers were separated and the organic layer, containing the corresponding bromide, was directly used in GP C with 2-bromophenol (116 μL, 173 mg, 1.00 mmol, 1.00 equiv.) and K\(_2\)CO\(_3\) (415 mg, 3.00 mmol, 3.00 equiv.). Purification by flash chromatography (SiO\(_2\), n-pentane:EtOAc = 40:1) afforded 2m (92 mg, 344 μmol, 34%) as a colourless oil.

**Analytical data of 2m:**

**TLC** (SiO\(_2\)): R\(_f\) (n-pentane: EtOAc = 40:1) = 0.50

\[ ^1H \text{NMR} \ (400 \text{ MHz, CDCl}_3): \delta = 7.53 \ (dd, J = 7.8, 1.6 \text{ Hz}, 1H), 7.23 \ (ddd, J = 8.2, 7.4, 1.6 \text{ Hz}, 1H), 6.90 \ (dd, J = 8.3, 1.4 \text{ Hz}, 1H), 6.82 \ (td, J = 7.6, 1.4 \text{ Hz}, 1H), 5.89 – 5.82 \ (m, 1H), 4.44 \ (s, 2H), 2.16 – 2.03 \ (m, 4H), 1.76 – 1.65 \ (m, 2H), 1.65 – 1.57 \ (m, 2H) \text{ ppm.} \]
$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 155.4, 133.4, 133.4, 128.4, 125.6, 121.9, 113.8, 112.5, 73.7, 25.8, 25.1, 22.5, 22.4$ ppm.

IR (ATR): 2926 (m), 1585 (w), 1478 (s), 1442 (m), 1291 (s), 1247 (s), 1049 (m), 1030 (s), 999 (m), 745 (s) cm$^{-1}$.


**(E)-1-Bromo-2-((3,7-dimethylocta-2,6-dien-1-yl)oxy)benzene (2n)**

![Structure of 2n](image)

To a stirred solution of (3E)-4,8-dimethylnona-3,7-dien-1-ol (989 μL, 879 mg, 5.23 mmol, 1.10 equiv.) in dry Et$_2$O (13 mL) was added tribromophosphane (1.48 g, 519 μL, 5.46 mmol, 1.15 equiv.) at 0 °C and exclusion of light. The mixture was stirred for 15 min and quenched by the careful addition of sat. aq. NH$_4$Cl (13 mL). Layers were separated and the organic layer, containing the corresponding alkyl bromide, was directly used in GP C to synthesize 2n from 2-bromophenol (548 μL, 822 mg, 4.75 mmol, 1.00 equiv.) and K$_2$CO$_3$ (2.63 g, 19.0 mmol, 4.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 1:0 – 40:1) afforded the title compound (985 mg, 3.19 mmol, 67%) as a colourless liquid.

**Analytical data of 2n:**

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 40:1) = 0.43

$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.53$ (dd, $J = 7.8, 1.6$ Hz, 1H), 7.28 – 7.19 (m, 1H), 6.90 (dd, $J = 8.2, 1.4$ Hz, 1H), 6.82 (td, $J = 7.6, 1.4$ Hz, 1H), 5.54 – 5.47 (m, 1H), 5.13 – 5.05 (m, 1H), 4.63 (d, $J = 6.4$ Hz, 2H), 2.18 – 2.03 (m, 4H), 1.74 (s, 3H), 1.67 (s, 3H), 1.61 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 155.4, 141.3, 133.5, 132.0, 128.4, 123.9, 121.9, 119.5, 114.0, 112.6, 66.4, 39.7, 26.4, 25.8, 17.9, 16.9$ ppm.

IR (ATR): 2917 (m), 1586 (w), 1477 (s), 1442 (m), 1276 (m), 1235 (m), 1031 (m), 994 (m), 746 (s) cm$^{-1}$.


Synthesized according to GP C from 2-bromophenol (265 μL, 433 mg, 2.50 mmol, 1.49 equiv.), K$_2$CO$_3$ (1.04 g, 7.5 mmol, 4.47 equiv.) and 5-bromo-2-methylpent-2-en (255 μL, 274 mg, 1.68 mmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 1:0 – 40:1) afforded 2o (256 mg, 1.00 mmol, 60%) as a colourless liquid.

**Analytical data of 2o:**

TLC (SiO$_2$): $R_f$ (n-pentane: EtOAc = 40:1) = 0.50
$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.53$ (dd, $J = 7.9, 1.6$ Hz, 1H), 7.28 – 7.19 (m, 1H), 6.88 (dd, $J = 8.3, 1.4$ Hz, 1H), 6.81 (td, $J = 7.6, 1.4$ Hz, 1H), 5.29 – 5.19 (m, 1H), 3.99 (t, $J = 7.1$ Hz, 2H), 2.59 – 2.49 (m, 2H), 1.74 (s, 3H), 1.68 (s, 3H).

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 155.5, 134.8, 133.5, 128.5, 121.8, 119.4, 113.4, 112.4, 77.5, 77.2, 76.8, 68.9, 28.3, 26.0, 18.0$ ppm.

IR (ATR): 2989 (w), 2916 (w), 2877 (w), 1586 (w), 1481 (m), 1442 (m), 1293 (m), 1247 (s), 1051 (s), 1030 (s), 745 (s) cm$^{-1}$.


$N$-(2-Bromophenyl)acetamide (SI-3)

To a stirred solution of 2-bromoaniline (1.72 g, 10.0 mmol, 1.00 equiv.uiv) and DMAP (61.1 mg, 500 μmol, 5mol%) in CHCl$_3$ (40 mL) was Ac$_2$O (945 μL 1.02 g, 10.0 mmol, 1.00 equiv.uiv) dropwise. The mixture was refluxed for 3 h, cooled down to rt and washed with H$_2$O (40 mL). The organic layer was dried over MgSO$_4$ and all volatiles were removed under reduced pressure. Purification of the residue by flash chromatography (SiO$_2$, n-pentane:EtOAc = 3:1) afforded SI-3 (1.91 g, 8.93 mmol, 89%) as a white solid.

Analytical data of SI-3:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 3:1) = 0.43

$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 8.33$ (d, $J = 8.2$ Hz, 1H), 7.60 (br s, 1H), 7.53 (d, $J = 8.1$Hz, 1H), 7.34 – 7.28 (m, 1H), 7.03 – 6.94 (m, 1H), 2.24 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 168.4, 135.8, 132.3, 128.5, 125.3, 122.1, 113.3, 25.0$ ppm.

All spectroscopic data corresponded to the reported literature values.$^{[16]}$

$N$-(2-Bromophenyl)-$N$-(3-methylbut-2-en-1-yl)acetamide (2p)

To a stirred solution of $N$-(2-bromophenyl)acetamide (SI-3) (642 mg, 3.00 mmol, 1.00 equiv.) in THF (9 mL) was added sodium hydride (120 mg, 3.00 mmol, 1.00 equiv.) (60 wt% in mineral oil) at 0 °C. The mixture was stirred for 5 min and 1-bromo-3-methylbut-2-ene (387 μL, 492 mg, 3.30 mmol, 1.10 equiv.) was added. The reaction was allowed to reach rt, stirred for further 5 h and quenched by the addition of H$_2$O (10 mL). The resulting mixture was extracted with EtOAc (3 × 15 mL). Combined organic layers were dried over Na$_2$SO$_4$ and all volatiles were removed under reduced pressure. Purification of the residue by flash chromatography (SiO$_2$, n-pentane:EtOAc = 3:1) afforded 2p (778 mg, 2.76 mmol, 92%) as a colourless liquid.

Analytical data of 2p:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 3:1) = 0.50
$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.66$ (dd, $J = 7.9$, 1.5 Hz, 1H), 7.34 (td, $J = 7.6$, 1.5 Hz, 1H), 7.22 (td, $J = 7.8$, 1.7 Hz, 1H), 7.17 (dd, $J = 7.7$, 1.7 Hz, 1H), 5.28 – 5.18 (m, 1H), 4.73 – 4.63 (m, 1H), 3.81 (dd, $J = 14.5$, 8.2 Hz, 1H), 1.79 (s, 3H), 1.64 (s, 3H), 1.39 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 170.0$, 141.6, 137.0, 133.8, 131.3, 129.7, 128.5, 124.2, 118.9, 45.3, 25.8, 22.6, 17.6 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[12]}$

To a stirred solution of 2-bromoaniline (516 mg, 3.00 mmol, 1.00 equiv.) in dry THF (10 mL) was added LDA (1.50 mL, 3.00 mmol, 2.00 M in THF, 1.00 equiv.) at $\sim$78 °C. After 5 min, 1-bromo-3-methylbut-2-ene (312 μL, 402 mg, 2.70 mmol, 0.900 equiv.) was added dropwise. The reaction was allowed to warm to rt and quenched by the addition of aq. sat. NH$_4$Cl (10 mL). Layers were separated and the aqueous layer was extracted with $n$-pentane (3 × 20 mL). Combined organic layers were dried over Na$_2$SO$_4$ and all volatiles were removed under reduced pressure. Purification by flash chromatography (SiO$_2$, $n$-pentane:EtOAc = 40:1) afforded SI-4 (581 mg, 2.42 mmol, 81%) as a colourless oil.

Analytical data of SI-4:
TLC (SiO$_2$): $R_f$ ($n$-pentane:EtOAc = 40:1) = 0.54

$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.42$ (dd, $J = 7.8$, 1.5 Hz, 1H), 7.21 – 7.15 (m, 1H), 6.63 (dd, $J = 8.2$, 1.5 Hz, 1H), 6.57 (td, $J = 7.6$, 1.5 Hz, 1H), 5.39 – 5.30 (m, 1H), 4.24 (br s, 1H), 3.77 – 3.71 (m, 2H), 1.78 (s, 3H), 1.74 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 145.2$, 136.3, 132.5, 128.6, 121.2, 117.7, 111.5, 109.8, 42.0, 25.9, 18.2 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[17]}$

2-Bromo-N,N-bis(3-methylbut-2-en-1-yl)aniline (2q)

Synthesized according to GP C from 2-bromo-N-(3-methylbut-2-en-1-yl)aniline (SI-4) (240 mg, 1.00 mmol, 1.00 equiv.), K$_2$CO$_3$ (276 mg, 2.00 mmol, 2.00 equiv.) and 1-bromo-3-methylbut-2-ene (127 μL, 164 mg, 1.10 mmol, 1.10 equiv.). Purification by flash chromatography (SiO$_2$, $n$-pentane:EtOAc = 40:1) afforded 2q (239 mg, 775 μmol, 78%) as a colourless oil.

Analytical data of 2q:
TLC (SiO2): Rf (n-pentane:EtOAc = 40:1) = 0.54

1H NMR (400 MHz, CDCl3): δ = 7.55 (dd, J = 7.9, 1.5 Hz, 1H), 7.21 (ddd, J = 8.4, 7.3, 1.6 Hz, 1H), 6.98 (dd, J = 8.0, 1.6 Hz, 1H), 6.87 (td, J = 7.6, 1.6 Hz, 1H), 5.25 – 5.16 (m, 2H), 3.63 (d, J = 7.5 Hz, 4H), 1.68 (s, 6H), 1.60 (s, 6H) ppm.

13C NMR (101 MHz, CDCl3): δ = 149.8, 134.8 (2C), 133.8, 127.5, 124.0, 123.9, 121.5 (2C), 121.3, 50.4 (2C), 25.9 (2C), 18.1 (2C) ppm.

IR (ATR): 2969 (m), 2926 (m), 2812 (m), 1583 (w), 1473 (s), 1376 (m), 1226 (w), 1089 (m), 1026 (s), 753 (s) cm⁻¹.


2,6-Dibromo-N,N-bis(3-methylbut-2-en-1-yl)aniline (2r)

Synthesized according to GP C from 2,6-dibromoaniline (753 mg, 3.00 mmol, 1.00 equiv.), K₂CO₃ (2.07 g, 15.0 mmol, 5.00 equiv.) and 3-bromo-2-methylprop-1-ene (809 µL, 1.04 g, 6.30 mmol, 2.10 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 1:0 – 20:1) afforded 2r (391 mg, 1.01 mmol, 34%) as a colourless liquid.

Analytical data of 2r:

TLC (SiO₂): Rf (n-pentane:EtOAc = 40:1) = 0.89

1H NMR (400 MHz, CDCl₃): δ = 7.49 (d, J = 8.0 Hz, 2H), 6.81 (t, J = 7.9 Hz, 1H), 5.34 – 5.25 (m, 2H), 3.74 (d, J = 6.9, 4H), 1.66 (s, 6H), 1.59 (s, 6H) ppm.

13C NMR (101 MHz, CDCl₃): δ = 147.6, 134.1 (2C), 132.9 (2C), 127.7 (2C), 127.2, 122.8 (2C), 49.9 (2C), 26.0 (2C), 17.9 (2C) ppm.

IR (ATR): 2969 (w), 2911 (m), 1672 (w), 1544 (m), 1424 (s), 1375 (m), 1189 (w), 1133 (w), 925 (w), 843 (w), 769 (s), 715 (s) cm⁻¹.


3-Iodo-2-((3-methylbut-2-en-1-yl)oxy)tetrahydro-2H-pyran (1s)

Synthesized according to a literature known procedure.[18] To a stirred solution of 3-methylbut-2-en-1-ol (1.02 mL, 861 mg, 10.0 mmol, 1.00 equiv.) and 3,4-dihydro-2H-pyran (998 µL, 925 mg, 11.0 mmol, 1.10 equiv.) in dry CH₂Cl₂ (10 mL) was added 1-iodopyrrolidine-2,5-dione (2.25 g, 10.0 mmol, 1.00 equiv.) at – 30 °C. The reaction was stirred for 3 h, diluted with CH₂Cl₂ (20 mL), washed with H₂O (20 mL), aq. Na₂S₂O₃ (10%, 20 mL), brine
(20 mL) and dried over Na$_2$SO$_4$. Volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) to afford 1s (2.68 g, 9.03 mmol, 90%) as a colourless oil.

**Analytical data of 1s:**

TLC (SiO$_2$): R$_f$ (n-pentane: EtOAc = 10:1) = 0.58

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 5.41 – 5.32 (m, 1H), 4.65 (d, J = 5.4 Hz, 1H), 4.22 (dd, J = 11.6, 6.6 Hz, 1H), 4.14 – 4.02 (m, 2H), 4.04 – 3.94 (m, 1H), 3.58 (ddd, J = 11.2, 3.5 Hz, 1H), 2.42 – 2.33 (m, 1H), 2.06 – 1.97 (m, 1H), 1.80 – 1.72 (m, 1H), 1.76 (s, 3H), 1.69 (s, 3H), 1.55 – 1.45 (m, 1H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 138.2, 120.2, 101.5, 65.7, 63.6, 33.0, 29.8, 26.0, 25.7, 18.2 ppm.

All spectroscopic data corresponded to the reported literature values.\[18\]

**3-Bromo-2-((3-methylbut-2-en-1-yl)oxy)tetrahydro-2H-pyran (2s)**

![2s](image)

To a stirred solution of 3-methylbut-2-en-1-ol (508 μL, 431 mg, 5.00 mmol, 1.00 equiv.) and 3,4-dihydro-2H-pyran (499 μL, 463 mg, 5.50 mmol, 1.10 equiv.) in CH$_2$Cl$_2$ (5 mL) was added 1-bromopyrrolidine-2,5-dione (890 mg, 5.00 mmol, 1.00 equiv.) at 0 °C. The mixture was stirred for 22 h at rt, followed by the addition of CH$_2$Cl$_2$ (10 mL). The organic layer was washed with H$_2$O (15 mL), aq. Na$_2$S$_2$O$_3$ (10%, 20 mL), brine (20 mL) and dried over Na$_2$SO$_4$. Volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) to afford 2s (905 mg, 3.63 mmol, 73 %) as a colourless oil.

**Analytical data of 2s:**

TLC (SiO$_2$): R$_f$ (n-pentane: EtOAc = 10:1) = 0.70

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 5.40 – 5.31 (m, 1H), 4.63 (d, J = 4.4 Hz, 1H), 4.28 – 4.17 (m, 2H), 4.07 (dd, J = 11.8, 7.6 Hz, 1H), 3.98 (dt, J = 6.6, 4.3 Hz, 1H), 3.98 – 3.88 (m, 1H), 3.63 – 3.53 (m, 1H), 2.45 – 2.34 (m, 1H), 2.02 – 1.86 (m, 2H), 1.76 (s, 3H), 1.69 (s, 3H), 1.58 – 1.46 (m, 1H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 138.3, 120.2, 100.1, 64.5, 62.6, 49.8, 30.3, 26.0, 23.5, 18.2 ppm.

All spectroscopic data corresponded to the reported literature values.\[19\]

**5-Hydroxypentyl)triphenylphosphonium bromide (SI-5)**

![SI-5](image)

Prepared according to the literature procedure.\[20\] A stirred suspension of PPh$_3$ (4.46 g, 17.0 mmol, 1.00 equiv.), 5-bromopentan-1-ol (2.84 g, 17.0 mmol, 1.00 equiv.) and K$_2$CO$_3$ (2.35 g, 17.0 mmol, 1.00 equiv.) in MeCN (15 mL) was heated to reflux for 4 h. The reaction mixture was cooled to rt, filtered, and treated with Et$_2$O (150 mL) upon which a white gum precipitated. The solvents were decanted off and the remaining residue was washed with Et$_2$O (50 mL). The gum was dried in vacuo to afford SI-5 (2.55 g, 5.95 mmol, 35%) as a white solid.
Analytical data of SI-5:

\(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta = 7.87 – 7.67 (m, 15H), 3.77 – 3.68 (m, 4H), 3.15 (br s, 1H), 1.81 – 1.63 (m, 6H)\) ppm.

\(^{13}\)C NMR (101 MHz, CDCl\(_3\)): \(\delta = 135.2, 135.1, 130.7, 130.6, 119.0, 61.8, 31.1, 27.2, 27.0, 23.1, 22.6 \) ppm.

All spectroscopic data corresponded to the reported literature values.\(^{[21]}\)

\((E/Z)-6\)-Phenylhex-5-en-1-ol (SI-6)

Prepared according to the literature procedure.\(^{[22]}\) To a stirred suspension of (5-hydroxypentyl) triphenylphosphonium bromide (SI-5) (2.15 g, 5.00 mmol, 1.00 equiv.) in dry THF (7.5 mL) was added nBuLi (6.25 mL, 1.60 M in n-hexane, 641 mg, 10.0 mmol, 2.00 equiv.) at 0 °C. A red coloured suspension was obtained, to which a solution of benzaldehyde (531 μL, 557 mg, 5.25 mmol, 1.05 equiv.) in dry THF (4 mL) was added dropwise. After 5 min the red colour vanished and an ivory, thick suspension was obtained. The mixture stirred for 4 h at rt and was poured into a mixture of H\(_2\)O (25 mL) and EtOAc (25 mL). The layers were separated, and the aqueous layer was extracted with EtOAc (1 × 10 mL). Combined organic layers were washed with brine (1 × 15 mL) and dried over Na2SO4. All volatiles were removed under reduced pressure and purification by flash chromatography (SiO\(_2\), n-pentane:EtOAc = 3:1) afforded SI-6 (415 mg, 2.36 mmol, 47%, \(E:Z=79:21\)) as a faint yellow oil.

Analytical data of SI-6:

TLC (SiO\(_2\)): \(R_f\) (n-pentane:EtOAc = 3:1) = 0.45

\(^1\)H NMR (400 MHz, CDCl\(_3\)): \((E)\)-isomer: \(\delta = 7.39 – 7.17 (m, 5H), 6.47 – 6.36 (m, 1H), 6.22 (dt, \(J = 15.8, 6.9 \) Hz, 1H), 3.68 (t, \(J = 6.4 \) Hz, 2H), 2.26 (qd, \(J = 7.1, 1.4 \) Hz, 2H), 1.70 – 1.49 (m, 4H), 1.33 (br s, 1H); \((Z)\)-isomer: \(\delta = 7.39 – 7.17 (m, 5H), 6.47 – 6.36 (m, 1H), 5.66 (dt, \(J = 11.7, 7.2 \) Hz, 1H), 3.63 (t, \(J = 6.4 \) Hz, 2H), 2.37 (qd, \(J = 7.2, 1.8 \) Hz, 2H), 1.70 – 1.49 (m, 4H), 1.33 (s, 1H) ppm.

\(^{13}\)C NMR (101 MHz, CDCl\(_3\)): \(\delta = 137.9, 137.8, 132.8, 130.7, 130.3, 129.3, 128.9, 128.6, 127.1, 126.7, 126.1, 63.0, 62.9, 32.9, 32.5, 32.4, 28.6, 26.2, 25.6 \) ppm.

All spectroscopic data corresponded to the reported literature values.\(^{[22,23]}\)

\((E/Z)-(6\)-Bromohex-1-en-1-yl\)benzene (2t)

Prepared according to the literature procedure.\(^{[22]}\) A solution of PPh\(_3\) (628 mg, 2.39 mmol, 1.05 equiv.) in dry CH\(_2\)Cl\(_2\) (3 mL) was slowly added to a solution of \((E/Z)-6\)-phenylhex-5-en-1-ol (402 mg, 2.28 mmol, 1.00 equiv.) and CBr\(_4\) (832 mg, 2.51 mmol, 1.10 equiv.) in dry CH\(_2\)Cl\(_2\) (11 mL) at rt. The reaction mixture was stirred for 22 h and quenched by the addition of H\(_2\)O (5 mL). The resulting mixture was extracted with CH\(_2\)Cl\(_2\) (3 × 10 mL),
combined organic layers were dried over MgSO₄ and all volatiles were removed under reduced pressure. Purification by flash chromatography (SiO₂, petroleum ether) afforded 2t (419 mg, 1.75 mmol, 77%, E:Z=78:22) as a colourless liquid.

**Analytical data of 2t:**

<table>
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<th>Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC (SiO₂): Rₜ (petroleum ether)</td>
<td>0.21</td>
</tr>
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</table>

**¹H NMR** (400 MHz, CDCl₃): (E)-isomer: δ = 7.37 – 7.17 (m, 5H), 6.45 – 6.36 (m, 1H), 6.20 (dt, J = 15.8, 6.9 Hz, 1H), 3.44 (t, J = 6.8 Hz, 2H), 2.26 (qd, J = 7.3, 1.4 Hz, 2H), 2.00 – 1.85 (m, 2H), 1.72 – 1.57 (m, 2H); (Z)-isomer: δ = 7.38 – 7.16 (m, 5H), 6.46 (d, J = 11.7 Hz, 1H), 5.65 (dt, J = 11.7, 7.2 Hz, 1H), 3.39 (t, J = 6.8 Hz, 2H), 2.37 (qd, J = 7.4, 1.9 Hz, 2H), 2.00 – 1.85 (m, 2H), 1.71 – 1.56 (m, 2H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 137.8, 132.2, 130.6, 130.1, 129.6, 128.9, 128.7, 128.3, 127.1, 126.7, 126.1, 33.9, 33.8, 32.4, 32.2, 28.5, 28.0, 27.8 ppm.

All spectroscopic data corresponded to the reported literature values.[22]

**Prepared according to the literature procedure**: To a stirred solution of 2-bromoethanol (355 μL, 625 mg, 5.00 mmol, 1.00 equiv.) in dry THF (2.5 mL) was added ZnEt₂ (2.50 mL, 1.00 M in THF, 309 mg, 2.50 mmol, 0.500 equiv.) dropwise at rt. The mixture was stirred for 15 min, and [(E)-3-phenylprop-2-enyl] acetate (881 mg, 5.00 mmol, 1.00 equiv.) and Pd(PPh₃)₄ (289 mg, 250 μmol, 5 mol%) were added. The resulting mixture was stirred for 3 h and all volatiles were removed under reduced pressure. Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 20:1) afforded 2u (692 mg, 2.87 mmol, 57%) as a colourless liquid.

**Analytical data of 2u:**

<table>
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<th>Method</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>TLC (SiO₂): Rₜ (n-pentane:EtOAc = 20:1)</td>
<td>0.57</td>
</tr>
</tbody>
</table>

**¹H NMR** (400 MHz, CDCl₃): δ = 7.42 – 7.38 (m, 2H), 7.35 – 7.30 (m, 2H), 7.28 – 7.23 (m, 1H), 6.63 (d, J = 15.8 Hz, 1H), 6.29 (dt, J = 15.9, 6.1 Hz, 1H), 4.23 (dd, J = 6.1, 1.5 Hz, 2H), 3.82 (t, J = 6.2 Hz, 2H), 3.51 (t, J = 6.2 Hz, 2H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 136.6, 133.1, 128.7, 128.0, 126.7, 125.6, 71.9, 70.1, 30.6 ppm.

All spectroscopic data corresponded to the reported literature values.[24]

**N-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-7)**

A solution of 2-aminoethanol (2.40 mL, 2.44 g, 40.0 mmol, 1.00 equiv.) and TsCl (7.63 g, 40.0 mmol, 1.00 equiv.) in CH₂Cl₂ (100 mL) was stirred for 10 min at 0 °C, followed by the dropwise addition of NEt₃ (5.58 mL, 4.05 g, 40.0 mmol, 1.00 equiv.). The reaction was stirred for 6 h at rt and washed with H₂O (3 × 100 mL) and brine (100
mL). The organic layer was dried over Na₂SO₄ and all volatiles were removed under reduced pressure to afford the title compound SI-7 (5.65 g, 26.2 mmol, 66%) as a white solid, which was used in the next step without further purification.

**Analytical data of SI-7:**

**¹H NMR** (400 MHz, CDCl₃): δ = 7.76 (d, J = 8.3 Hz, 2H), 7.32 (d, J = 8.0 Hz, 3H), 5.06 (br s, 1H), 3.69 (d, J = 4.8 Hz, 2H), 3.09 (d, J = 5.2 Hz, 2H), 2.43 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 143., 136.8, 129.9 (2C), 127.3 (2C), 61.5, 45.2, 21.7 ppm.

All spectroscopic data corresponded to the reported literature values.[25]

**N-(2-Hydroxyethyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (SI-8)**

Synthesized according to GP D from N-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-7) (1.08 g, 5.00 mmol, 1.00 equiv.), K²CO₃ (1.38 g, 10.0 mmol, 2.00 equiv.), KI (83 mg, 500 µmol, 5 mol%) and 1-bromo-3-methylbut-2-ene (847 µL, 1.08 g, 6.50 mmol, 1.30 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 3:1 – 1:1) afforded SI-8 (1.22 g, 4.31 mmol, 86%) as a colourless oil.

**Analytical data of SI-8:**

**TLC** (SiO₂): Rf (n-pentane:EtOAc = 3:1) = 0.22

**¹H NMR** (400 MHz, CDCl₃): δ = 7.70 (d, J = 8.3 Hz, 2H), 7.31 (d, J = 7.9 Hz, 2H), 5.07 – 4.98 (m, 1H), 3.83 (d, J = 7.1 Hz, 2H), 3.72 (m, 2H), 3.20 (t, J = 5.3 Hz, 2H), 2.43 (s, 3H), 2.26 (br s, 1H), 1.67 (s, 3H), 1.62 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 143.6, 137.7, 136.5, 129.8 (2C), 127.5 (2C), 119.0, 61.4, 49.9, 47.2, 25.9, 21.7, 18.0 ppm.

All spectroscopic data corresponded to the reported literature values.[26]

**N-(2-Bromoethyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (2v)**

Synthesized according to GP E from N-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-8) (567 mg, 2.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 2v (614 mg, 1.77 mmol, 89%) as a colourless oil.

**Analytical data of 2v:**

**TLC** (SiO₂): Rf (n-pentane:EtOAc = 10:1) = 0.42

**¹H NMR** (400 MHz, CDCl₃): δ = 7.70 (d, J = 8.3 Hz, 2H), 7.31 (d, J = 8.0 Hz, 2H), 5.06 – 4.98 (m, 1H), 3.80 (d, J = 7.2 Hz, 2H), 3.49 – 3.33 (m, 4H), 2.43 (s, 3H), 1.69 (s, 3H), 1.63 (s, 3H) ppm.
$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 143.7, 138.2, 136.6, 129.9$ (2C), $127.4$ (2C), $118.8, 49.0, 46.9, 29.8, 26.0, 21.7, 18.0$ ppm. 

All spectroscopic data corresponded to the reported literature values.$^{[26]}$ 

$N$-(2-Chloroethyl)-4-methyl-$N$-(3-methylbut-2-en-1-yl)benzenesulfonamide (3v)

Synthesized according to GP E from PPh$_3$ (787 mg, 3.00 mmol, 3.00 equiv.), CCl$_4$ (290 µL, 461 mg, 3.00 mmol, 3.00 equiv.) and $N$-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-8) (283 mg, 1.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 3v (76 mg, 251 µmol, 25%) as a colourless oil.

Analytical data of 3v:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 10:1) = 0.35

$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.70$ (d, $J = 8.3$ Hz, 2H), 7.31 (d, $J = 7.9$ Hz, 2H), 5.06 – 4.97 (m, 1H), 3.81 (d, $J = 7.2$ Hz, 2H), 3.61 (dd, $J = 8.1, 6.9$ Hz, 2H), 3.33 (dd, $J = 8.1, 6.8$ Hz, 2H), 2.44 (s, 3H), 1.69 (s, 3H), 1.63 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 143.6, 138.2, 136.7, 129.9$ (2C), 127.4 (2C), 118.8, 48.8, 47.0, 42.2, 26.0, 21.7, 18.0 ppm.

IR (ATR): 2971 (m), 2919 (m), 1451 (w), 1342 (m), 1158 (s), 1091 (m), 723 (m), 653 (m), 549 (m) cm$^{-1}$.

HRMS (ESI): calcd. for [C$_{14}$H$_{20}$ClNO$_2$S+Na]$^+$, [M+Na]$^+$: 324.0795; found: 324.0794.

$N$-Allyl-$N$-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-9)

Synthesized according to GP D from $N$-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-7) (646 g, 3.00 mmol, 1.00 equiv.), K$_2$CO$_3$ (829 mg, 6.00 mmol, 2.00 equiv.), KI (50 mg, 300 µmol, 10 mol%) and 3-bromoprop-1-ene (337 µL, 427 mg, 3.90 mmol, 1.30 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 3:1 – 1:1) afforded SI-9 (734 mg, 2.88 mmol, 96%) as a colourless oil.

Analytical data of SI-9:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 3:1) = 0.22

$^1$H NMR (400 MHz, CDCl$_3$): $\delta = 7.71$ (d, $J = 8.3$ Hz, 2H), 7.32 (d, $J = 8.0$ Hz, 2H), 5.74 – 5.62 (m, 1H), 5.22 – 5.15 (m, 2H), 3.85 (d, $J = 6.4$ Hz, 2H), 3.73 (q, $J = 5.5$ Hz, 2H), 3.24 (t, $J = 5.4$ Hz, 2H), 2.43 (s, 3H), 2.27 – 2.18 (m, 1H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta = 143.7, 136.3, 133.2, 123.0$ (2C), $127.4$ (2C), $119.5, 61.3, 52.4, 49.9, 21.7$ ppm.

All spectroscopic data corresponded to the reported literature values.$^{[27]}$
*N*-Allyl-*N*-(2-bromoethyl)-4-methylbenzenesulfonamide (2w)

![Chemical structure of 2w](image)

Synthesized according to GP E from *N*-allyl-*N*-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-9) (511 mg, 2.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO2, *n*-pentane:EtOAc = 10:1) afforded 2w (367 mg, 1.15 mmol, 58%) as a faint yellow oil.

**Analytical data of 2w:**

**TLC** (SiO2): Rf (*n*-pentane:EtOAc = 3:1) = 0.33

**1H NMR** (400 MHz, CDCl3): \(\delta = 7.71 (d, J = 8.3 \text{ Hz}, 2H), 7.32 (d, J = 7.9 \text{ Hz}, 2H), 5.72 – 5.62 (m, 1H), 5.21 (dq, \(J = 6.4, 1.3 \text{ Hz}, 1H), 5.18 (t, J = 1.3 \text{ Hz}, 1H), 3.81 (d, J = 6.5 \text{ Hz}, 2H), 3.50 – 3.39 (m, 4H), 2.44 (s, 3H) ppm.

**13C NMR** (101 MHz, CDCl3): \(\delta = 143.9, 136.4, 133.0, 130.0 (2C), 127.3 (2C), 119.8, 52.2, 49.1, 29.4, 21.7 \text{ ppm.}

All spectroscopic data corresponded to the reported literature values.[27]

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**N**-(Cyclohex-1-en-1-ylmethyl)-*N*-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-10)

![Chemical structure of SI-10](image)

To a stirred solution of cyclohexen-1-ylmethanol (SI-2) (280 mg, 2.50 mmol, 1.00 equiv.) in dry Et2O (12 mL) was added PBr3 (119 µL, 338 mg, 1.25 mmol, 0.50 equiv.) at 0 °C. The reaction mixture was stirred for 2 h and added to aq. sat. K2CO3 (10 mL). Layers were separated and the aqueous layer was extracted with Et2O (2 × 10 mL). The combined organic layers were dried over MgSO4, and all volatiles were removed under reduced pressure to afford crude 1-(bromomethyl)cyclohex-1-ene which was directly used in GP C with *N*-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-7) (503 mg, 2.50 mmol, 1.00 equiv.) and K2CO3 (1.04 g, 7.50 mmol, 3.00 equiv.). Purification by flash chromatography (SiO2, *n*-pentane:EtOAc = 3:1) afforded SI-10 (302 mg, 976 µmol, 39%) as a colourless oil.

**Analytical data of SI-10:**

**TLC** (SiO2): Rf (*n*-pentane:EtOAc = 3:1) = 0.63

**1H NMR** (400 MHz, CDCl3): \(\delta = 7.70 (d, J = 8.3 \text{ Hz}, 2H), 7.31 (d, J = 8.0 \text{ Hz}, 2H), 5.62 – 5.56 (m, 1H), 3.67 (dd, \(J = 11.1, 5.6 \text{ Hz}, 4H), 3.16 (t, J = 5.4 \text{ Hz}, 2H), 2.43 (s, 3H), 2.37 – 2.29 (m, 1H), 2.03 – 1.93 (m, 4H), 1.64 – 1.51 (m, 4H) ppm.

**13C NMR** (101 MHz, CDCl3): \(\delta = 143.6, 136.1, 133.4, 129.9 (2C), 127.5 (2C), 127.2, 61.5, 57.0, 50.5, 26.1, 25.4, 22.5, 22.3, 21.7 \text{ ppm.}

**IR** (ATR): 3517 (br), 2926 (m), 1446 (w), 1307 (m), 1158 (s), 655 (m), 549 (m) cm⁻¹.

N-(2-Bromoethyl)-N-(cyclohex-1-en-1-ylmethyl)-4-methylbenzenesulfonamide (2x)

Synthesized according to GP E from N-(cyclohex-1-en-1-ylmethyl)-N-(2-hydroxyethyl)-4-methylbenzenesulfonamide (SI-10) (250 mg, 808 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 2x (214 mg, 574 µmol, 71%) as a white solid.

Analytical data of 2x:

TLC (SiO₂): Rf (n-pentane: EtOAc = 3:1) = 0.48
Mp: 69.2 – 70.4 °C.

1H NMR (400 MHz, CDCl₃): δ = 7.69 (d, J = 8.3 Hz, 2H), 7.31 (d, J = 7.7 Hz, 2H), 5.65 – 5.58 (m, 1H), 3.62 (s, 2H), 3.43 – 3.29 (m, 4H), 2.43 (s, 3H), 2.05 – 1.92 (m, 4H), 1.67 – 1.51 (m, 4H) ppm.

13C NMR (101 MHz, CDCl₃): δ = 143.7, 136.4, 133.2, 129.9 (2C), 127.7, 127.3 (2C), 56.5, 49.5, 29.4, 26.1, 25.4, 22.6, 22.3, 21.7 ppm.

IR (ATR): 2927 (m), 1447 (w), 1340 (s), 1160 (s), 1091 (w), 932 (w), 549 (m) cm⁻¹.


(±)-N-(2-Hydroxypropyl)-4-methylbenzenesulfonamide (SI-11)

A solution of 1-aminopropan-2-ol (3.10 mL, 3.00 g, 40.0 mmol, 1.00 equiv.) and TsCl (7.63 g, 40.0 mmol, 1.00 equiv.) in CH₂Cl₂ (100 mL) was stirred for 10 min at 0°C, followed by the dropwise addition of NEt₃ (5.58 mL, 4.05 g, 40.0 mmol, 1.00 equiv.). The reaction was stirred for 18 h at rt and washed with H₂O (3 × 100 mL) and brine (100 mL). The organic layer was dried over Na₂SO₄ and all volatiles were removed under reduced pressure to afford the title compound SI-11 (7.30 g, 31.8 mmol, 80%) as a white solid, which was used in the next step without further purification.

Analytical data of SI-11:

1H NMR (400 MHz, CDCl₃): δ = 7.75 (d, J = 8.3 Hz, 2H), 7.32 (d, J = 8.2 Hz, 2H), 4.88 (s, 1H), 3.97 – 3.84 (m, 1H), 3.11 – 3.00 (m, 1H), 2.77 (dd, J = 13.1, 8.1 Hz, 1H), 2.43 (s, 3H), 1.91 (s, 1H), 1.16 (d, J = 6.3 Hz, 3H) ppm.

13C NMR (101 MHz, CDCl₃): δ = 143.7, 136.8, 129.9 (2C), 127.2 (2C), 66.7, 50.1, 21.7, 20.9 ppm.

All spectroscopic data corresponded to the reported literature values.[25]
(±)-N-(2-Hydroxypropyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (SI-12)

![SI-12](image)

Synthesized according to GP D from N-(2-hydroxypropyl)-4-methylbenzenesulfonamide (SI-11) (688 g, 3.00 mmol, 1.00 equiv.), K$_2$CO$_3$ (829 mg, 6.00 mmol, 2.00 equiv.), KI (50 mg, 300 µmol, 10 mol%) and 3-bromoprop-1-ene (337 µL, 427 mg, 3.90 mmol, 1.30 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 3:1) afforded SI-12 (651 mg, 2.19 mmol, 73%) as a colourless oil.

**Analytical data of SI-12:**

TLC (SiO$_2$): R$_f$ (n-pentane:EtOAc = 3:1) = 0.42

$^1$H NMR (400 MHz, CDCl$_3$): δ = 7.70 (d, J = 8.3 Hz, 1H), 7.31 (d, J = 8.0 Hz, 1H), 5.05 – 4.95 (m, 1H), 4.05 – 3.92 (m, 1H), 3.84 (d, J = 7.1 Hz, 2H), 3.05 (dd, J = 14.6, 8.6 Hz, 1H), 2.93 (dd, J = 14.6, 3.1 Hz, 1H), 2.60 (br s, 1H), 2.43 (s, 3H), 1.66 (s, 2H), 1.61 (s, 3H), 1.14 (d, J = 6.3 Hz, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): δ = 143.6, 137.7, 136.5, 129.8 (2C), 127.5 (2C), 118.9, 66.4, 55.3, 47.6, 25.9, 21.7, 20.5, 17.9 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[12]}$

(±)-N-(2-Bromopropyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (2y)

![2y](image)

Synthesized according to GP E from N-(2-hydroxypropyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (SI-12) (297 mg, 1.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 2y (270 mg, 749 µmol, 75%) as a colourless gum.

**Analytical data of 2y:**

TLC (SiO$_2$): R$_f$ (n-pentane:EtOAc = 3:1) = 0.55

$^1$H NMR (400 MHz, CDCl$_3$): δ = 7.69 (d, J = 8.3 Hz, 2H), 7.31 (d, J = 7.7 Hz, 2H), 4.98 – 4.88 (m, 1H), 4.35 – 4.20 (m, 1H), 3.93 – 3.72 (m, 2H), 3.38 (dd, J = 14.5, 8.4 Hz, 1H), 3.29 (dd, J = 14.6, 6.1 Hz, 1H), 2.43 (s, 3H), 1.72 (d, J = 6.7 Hz, 3H), 1.65 (s, 3H), 1.62 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): δ = 143.6, 137.9, 136.5, 129.8 (2C), 127.5 (2C), 118.6, 55.3, 47.4, 47.3, 25.9, 23.5, 21.7, 17.9 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[12]}$
A solution of 2,2,2-trichloroethan-1-amine[28] (6.12 mL, 5.94 g, 40.0 mmol, 1.00 equiv.) and TsCl (7.63 g, 40.0 mmol, 1.00 equiv.) in CH$_2$Cl$_2$ (100 mL) was stirred for 10 min at 0 °C, followed by the dropwise addition of NEt$_3$ (5.58 mL, 4.05 g, 40.0 mmol, 1.00 equiv.). The reaction was stirred for 17 h at rt and washed with H$_2$O (3 × 100 mL) and brine (100 mL). The organic layer was dried over Na$_2$SO$_4$ and all volatiles were removed under reduced pressure to afford a brown solid, which was purified in a first step by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1 – 3:1) to afford an off-white solid. Recrystallization from EtOAc at –33 °C afforded SI-13 (5.86 g, 19.4 mmol, 48%) as a white solid.

**Analytical data of SI-13:**

TLC (SiO$_2$): R$_f$ (n-pentane: EtOAc = 10:1) = 0.17

Mp: 140.1 – 141.8 °C.

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.79 (d, $J$ = 8.3 Hz, 2H), 7.33 (d, $J$ = 7.9 Hz, 2H), 5.30 (t, $J$ = 7.0 Hz, 1H), 3.97 (d, $J$ = 7.0 Hz, 2H), 2.44 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 144.3, 137.4, 130.0 (2C), 127.2 (2C), 96.9, 61.2, 21.7 ppm.

IR (ATR): 3255 (br), 2972 (m), 2901 (m), 1447 (w), 1324 (m), 1158 (s), 1046 (s), 877 (m), 707 (m), 534 (m) cm$^{-1}$.

HRMS (ESI): calcd. for [C$_9$H$_{10}$Cl$_3$NO$_2$S+H]$^+$, [M+H]$^+$: 301.9571; found: 301.9569.

4-Methyl-N-(3-methylbut-2-en-1-yl)-N-(2,2,2-trichloroethyl)benzenesulfonamide (3z)

Synthesized according to GP C from 4-methyl-N-(2,2,2-trichloroethyl)benzenesulfonamide (SI-13) (908 mg, 3.00 mmol, 1.00 equiv.), K$_2$CO$_3$ (1.24 g, 9.00 mmol, 3.00 equiv.) and 3-bromo-2-methylprop-1-ene (332 µL, 446 mg, 3.30 mmol, 1.10 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 3z (1.03 g, 2.78 mmol, 93%) as a white solid.

**Analytical data of 3z:**

TLC (SiO$_2$): R$_f$ (n-pentane: EtOAc = 10:1) = 0.59

Mp: 68.8 – 69.8 °C.

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.79 – 7.75 (m, 2H), 7.32 – 7.30 (m, 2H), 4.87 – 4.79 (m, 1H), 4.28 (s, 2H), 4.15 (d, $J$ = 7.0 Hz, 2H), 2.44 (s, 3H), 1.65 (s, 3H), 1.59 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 144.0, 138.9, 137.4, 129.8 (2C), 127.9 (2C), 118.1, 98.7, 62.6, 47.3, 26.1, 21.7, 18.1 ppm.

IR (ATR): 2926 (w), 1447 (w), 1340 (m), 1160 (s), 1092 (m), 907 (s), 814 (s), 732 (s), 546 (m) cm$^{-1}$.

HRMS (ESI): calcd. for [C$_{14}$H$_{18}$Cl$_3$NO$_2$S+Na]$^+$, [M+Na]$^+$: 392.0016; found: 392.0016.
4-Methyl-N-(4-methylpent-3-en-1-yl)-N-(2,2,2-trichloroethyl)benzenesulfonamide (3za)

Synthesized according to GP C from 4-methyl-N-(2,2,2-trichloroethyl)benzenesulfonamide (SI-13) (605 mg, 2.00 mmol, 1.00 equiv.), K$_2$CO$_3$ (829 mg, 6.00 mmol, 3.00 equiv.) and 5-bromo-2-methylpent-2-ene (295 µL, 359 mg, 2.20 mmol, 1.10 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 3za (474 mg, 1.23 mmol, 62%) as a white solid.

**Analytical data of 3za:**

TLC (SiO$_2$): R$_f$ (n-pentane:EtOAc = 10:1) = 0.52

Mp: 67.7 – 69.9 °C.

$^1$H NMR (400 MHz, CDCl$_3$): δ = 7.78 – 7.70 (m, 2H), 7.36 – 7.29 (m, 2H), 4.89 – 4.80 (m, 1H), 4.30 (s, 2H), 3.41 – 3.32 (m, 2H), 2.44 (s, 3H), 2.37 – 2.26 (m, 2H), 1.63 (s, 3H), 1.55 (s, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): δ = 144.0, 136.8, 135.0, 129.9 (2C), 127.7 (2C), 119.5, 98.4, 64.4, 49.0, 26.9, 25.8, 21.7, 17.9 ppm.

IR (ATR): 2971 (w), 2922 (w), 1598 (w), 1342 (s), 1162 (s), 1092 (m), 923 (m), 815 (m), 727 (s), 653 (m), 548 (s) cm$^{-1}$.

HRMS (ESI): calcd. for [C$_{15}$H$_{20}$Cl$_3$NO$_2$S+H]$^+$, [M+H]$^+$: 384.0353; found: 384.0362.

1-Bromo-2-((3-methylbut-2-en-1-yl)oxy)-4-nitrobenzene (SI-14)

Synthesized according to GP C from 2-bromo-5-nitrophenol (323 µL, 527 mg, 2.42 mmol, 1.00 equiv.), K$_2$CO$_3$ (1.00 g, 7.25 mmol, 3.00 equiv.) and 1-bromo-3-methylbut-2-ene (312 µL, 396 mg, 2.66 mmol, 1.10 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 20:1) afforded SI-14 (599 mg, 2.09 mmol, 87%) as an off white solid.

**Analytical data of SI-14:**

TLC (SiO$_2$): R$_f$ (n-pentane:EtOAc = 20:1) = 0.57

Mp: 65.8 – 67.7 °C.

$^1$H NMR (400 MHz, CDCl$_3$): δ = 7.75 – 7.67 (m, 3H), 5.55 – 5.40 (m, 1H), 4.70 (d, $J = 6.7$ Hz, 2H), 1.84 – 1.78 (m, 6H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): δ = 155.8, 148.1, 140.0, 133.7, 120.3, 118.2, 116.5, 108.0, 66.9, 26.0, 18.6 ppm.

IR (ATR): 2970 (w), 2914 (w), 1569 (w), 1512 (s), 1473 (w), 1352 (m) 1262 (m), 1038 (m), 987 (s), 864 (m), 736 (s) cm$^{-1}$.

2-((3-Methylbut-2-en-1-yl)oxy)benzaldehyde (SI-15)

![SI-15](image)

To a stirred solution of 3-methylbut-2-en-1-ol (2.23 mL, 1.89 g, 22.0 mmol, 1.10 equiv.) in dry Et₂O (11 mL) was added PBr₃ (2.09 mL, 5.96 g, 22.0 mmol, 1.10 equiv.) at 0 °C. The mixture was stirred for 1 h until TLC control showed complete consumption of the alcohol. The reaction mixture was carefully quenched by the addition of sat. aq. NH₄Cl (15 mL) and the layers were separated. The organic layer, containing the corresponding bromide, was directly used in GPC with 2-hydroxybenzaldehyde (2.09 mL, 2.44 g, 20.0 mmol, 1.00 equiv.) and K₂CO₃ (11.1 g, 80.0 mmol, 4.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded SI-15 (3.03 g, 15.9 mmol, 80%) as a yellow liquid.

**Analytical data of SI-15:**

TLC (SiO₂): Rₓ (n-pentane:EtOAc = 10:1) = 0.56

**¹H NMR** (400 MHz, CDCl₃): δ = 10.50 (s, 1H), 7.83 (dd, J = 7.7, 1.9 Hz, 1H), 7.52 (ddd, J = 8.4, 7.3, 1.9 Hz, 1H), 7.05 – 6.95 (m, 2H), 5.54 – 5.46 (m, 1H), 4.64 (d, J = 6.3 Hz, 2H), 1.81 (s, 3H), 1.76 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 157.0, 138.4, 129.5, 129.0, 128.9, 120.7, 119.7, 111.6, 65.1, 62.7, 25.9, 18.4 ppm.

All spectroscopic data corresponded to the reported literature values.[29]

(2-((3-Methylbut-2-en-1-yl)oxy)phenyl)methanol (SI-16)

![SI-16](image)

To a stirred solution of 2-(3-methylbut-2-en-1-ol (1.04 g, 5.48 mmol, 1.00 equiv.) in dry MeOH (20 mL) was added NaBH₄ (207 mg, 5.48 mmol, 1.00 equiv.) at 0 °C. The reaction mixture was allowed to reach rt and stirred for 18 h, followed by the addition of EtOAc (20 mL) and sat. aq. NH₄Cl (20 mL). The resulting mixture was extracted with EtOAc (2 × 20 mL). Combined organic layers were dried over Na₂SO₄, volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO₂, n-pentane:EtOAc = 3:1) to afford SI-16 (942 mg, 4.90 mmol, 89%) as a colourless liquid.

**Analytical data of SI-16:**

TLC (SiO₂): Rₓ (n-pentane:EtOAc = 3:1) = 0.78

**¹H NMR** (400 MHz, CDCl₃): δ = 7.30 – 7.21 (m, 2H), 6.98 – 6.86 (m, 2H), 5.53 – 5.44 (m, 1H), 4.69 (d, J = 6.4 Hz, 2H), 4.57 (d, J = 6.6 Hz, 2H), 2.49 (t, J = 6.6 Hz, 1H), 1.80 (s, 3H), 1.74 (s, 3H) ppm.

**¹³C NMR** (101 MHz, CDCl₃): δ = 157.0, 138.4, 129.5, 129.0, 128.9, 120.7, 119.7, 111.6, 65.1, 62.7, 25.9, 18.4 ppm.

**IR** (ATR): 3385 (br), 2972 (w), 2914 (m), 1602 (m), 1490 (m), 1454 (s), 1382 (w), 1232 (s), 1043 (m), 1003 (s), 751 (s) cm⁻¹.
HRMS (ESI): calcd. for [C\textsubscript{12}H\textsubscript{16}O\textsubscript{2}Na]\textsuperscript{+}, [M+Na]\textsuperscript{+}: 215.1043; found: 215.1041.

1-(Bromomethyl)-2-((3-methylbut-2-en-1-yl)oxy)benzene (SI-17)

![Chemical Structure Image]

Synthesized according to GP E from (2-((3-methylbut-2-en-1-yl)oxy)phenyl)methanol (SI-16) (385 mg, 2.00 mmol, 1.00 equiv.). Purification by flash chromatography (SiO\textsubscript{2}, n-pentane:CH\textsubscript{2}Cl\textsubscript{2} = 8:1) afforded SI-17 (145 mg, 568 µmol, 28%) as a colourless oil.

*Analytical data of SI-17:*

**TLC** (SiO\textsubscript{2}): R\textsubscript{f} (n-pentane: CH\textsubscript{2}Cl\textsubscript{2} = 8:1) = 0.30

**\textsuperscript{1}H NMR** (400 MHz, CDCl\textsubscript{3}): \(\delta = 7.34\) (dd, \(J = 7.5, 1.8\) Hz, 1H), 7.31 – 7.22 (m, 1H), 6.96 – 6.85 (m, 2H), 5.56 – 5.47 (m, 1H), 4.63 – 4.57 (m, 2H), 4.59 (s, 2H), 1.80 (s, 3H), 1.76 (s, 3H) ppm.

**\textsuperscript{13}C NMR** (101 MHz, CDCl\textsubscript{3}): \(\delta = 156.9, 137.9, 131.1, 130.2, 126.6, 120.7, 119.9, 112.5, 65.5, 29.4, 25.9, 18.5\) ppm.

**IR** (ATR): 2973 (s), 2912 (m), 1601 (m), 1491 (s), 1455 (s), 1230 (s), 1047 (m), 1001 (m), 751 (s), 607 (w) cm\textsuperscript{-1}.

HRMS (APPI/LTQ-Orbitrap): calcd. for [C\textsubscript{12}H\textsubscript{15}BrO]\textsuperscript{+}, [M]\textsuperscript{+}: 254.0301; found: 254.0298.
1.6 Intramolecular Reductive Cyclization

General Procedure F:

An oven-dried microwave vial, equipped with a stir bar, was charged with the aryl or alkyl halide (200 µmol, 1.00 equiv.) and transferred into the glovebox. MeCN (0.2 M for iodides; 0.8 M for bromides and chlorides) was added, followed by DBU (30.0 µL, 30.5 mg, 200 µmol, 1.00 equiv.), SPO (43.3 µL, as a 50 mg/mL MeCN stock solution, 2.16 mg, 10.0 µmol, 5 mol%) and HBpin (32.0 µL, 28.2 mg, 220 µmol, 1.10 equiv.), unless otherwise stated. The vial was closed, removed from the glovebox, and irradiated (for iodides: white LEDs; for bromides and chlorides: Kessil lamp 427 nm) for 16 h at 26 °C. Volatiles were removed under reduced pressure and the residue was purified by flash chromatography (SiO₂, n-pentane:EtOAc).

3-Isopropyl-2,3-dihydrobenzofuran (4a)

Synthesized according to GP F (white LEDs) from 1-iodo-2-((3-methylbut-2-en-1-yl)oxy)benzene (1a) (57.6 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4a (30 mg, 184 µmol, 92%) as a colourless liquid.

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-2-((3-methylbut-2-en-1-yl)oxy)benzene (2a) (48.2 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4a (31 mg, 191 µmol, 96%) as a colourless liquid.

Analytical data of 4a:
TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.43

¹H NMR (400 MHz, CDCl₃): δ = 7.22 – 7.15 (m, 1H), 7.17 – 7.08 (m, 1H), 6.85 (td, J = 7.4, 1.0 Hz, 1H), 6.81 – 6.74 (m, 1H), 4.52 (t, J = 9.1 Hz, 1H), 4.38 (dd, J = 9.0, 5.1 Hz, 1H), 3.38 – 3.28 (m, 1H), 2.05 – 1.89 (m, 1H), 0.96 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 160.5, 129.6, 128.3, 125.2, 120.2, 109.5, 74.0, 48.3, 31.8, 20.0, 18.6 ppm.

All spectroscopic data corresponded to the reported literature values.[30]
3-Isopropyl-6-methoxy-2,3-dihydrobenzofuran (4b)

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-4-methoxy-2-((3-methylbut-2-en-1-yl)oxy)benzene (2b) (54.2 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4b (34 mg, 177 µmol, 88%) as a colourless liquid.

Analytical data of 4b:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.29

¹H NMR (400 MHz, CDCl₃): δ = 6.79 – 6.74 (m, 1H), 6.69 – 6.64 (m, 2H), 4.50 (t, J = 9.0 Hz, 1H), 4.36 (dd, J = 9.0, 5.2 Hz, 1H), 3.76 (s, 3H), 3.35 – 3.25 (m, 1H), 2.03 – 1.90 (m, 1H), 0.96 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 6.9 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 154.7, 154.0, 130.7, 112.9, 111.7, 109.2, 74.2, 56.2, 48.7, 31.7, 20.0, 18.5 ppm.

IR (ATR): 2957 (m), 2901 (w), 1603 (w), 1487 (s), 1464 (m), 1274 (m), 1216 (m), 1194 (m), 1179 (m), 1034 (m), 959 (m), 804 (m), 713 (w) cm⁻¹.


3-Isopropyl-5-(trifluoromethyl)-2,3-dihydrobenzofuran (4c)

Synthesized according to GP F (Kessil lamp 427 nm) from 2-bromo-1-((3-methylbut-2-en-1-yl)oxy)-(trifluoromethyl)benzene (2c). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4c (44 mg, 0.19 mmol, 96%) as a colourless liquid.

Analytical data of 4c:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.36

¹H NMR (400 MHz, CDCl₃): δ = 7.44 – 7.36 (m, 2H), 6.85 – 6.78 (m, 1H), 4.60 (t, J = 9.3 Hz, 1H), 4.46 (dd, J = 9.2, 5.2 Hz, 1H), 3.37 (dt, J = 9.5, 5.1 Hz, 1H), 1.99 (heptd, J = 6.8, 4.9 Hz, 1H), 0.96 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 163.2, 130.5, 126.3 (q, ³JFC = 3.9 Hz), 124.8 (q, ¹JFC = 271.0 Hz), 122.7 (q, ²JFC = 32.2 Hz), 122.4 (q, ³JFC = 3.9 Hz), 109.5, 74.8, 47.8, 31.8, 19.8, 18.5 ppm.

¹⁹F NMR (376 MHz, CDCl₃) δ = – 60.96 ppm.

IR (ATR): 2963 (w), 1619 (2), 1499 (w), 1317 (s), 1154 (s), 1108 (s), 1057 (m), 956 (w), 824 (m), 662 (w) cm⁻¹.

3-Isopropyl-2,3-dihydrobenzofuran-4-ol (4d)

Synthesized according to GP F (Kessil lamp 427 nm) from 2-bromo-3-((3-methylbut-2-en-1-yl)oxy)phenol (2d) (46.0 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 20:1) afforded 4d (21 mg, 118 µmol, 66%) as a colourless gum.

**Analytical data of 4d:**

TLC (SiO₂): Rₙ (n-pentane:EtOAc = 20:1) = 0.12

¹H NMR (400 MHz, CDCl₃): δ = 6.99 (td, J = 8.0, 0.6 Hz, 1H), 6.43 – 6.36 (m, 1H), 6.28 (dd, J = 8.1, 0.8 Hz, 1H), 4.67 (s, 1H), 4.48 – 4.41 (m, 2H), 3.54 – 3.45 (m, 1H), 2.25 (heptd, J = 6.9, 4.1 Hz, 1H), 0.97 (d, J = 6.9 Hz, 3H), 0.81 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 162.2, 153.0, 129.4, 115.3, 107.9, 102.6, 73.1, 46.5, 29.9, 20.8, 17.3 ppm.

IR (ATR): 3401 (br), 2958 (m), 1611 (m), 1458 (s), 1280 (m), 1014 (s), 949 (w), 784 (w) cm⁻¹.


3-Isopropyl-4-((3-methylbut-2-en-1-yl)oxy)-2,3-dihydrobenzofuran (4e)

Synthesized according to GP F (Kessil lamp 427 nm) from 2-bromo-1,3-bis((3-methylbut-2-en-1-yl)oxy)benzene (2e) (65.1 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4e (31 mg, 126 µmol, 63%) as a colourless oil.

**Analytical data of 4e:**

TLC (SiO₂): Rₙ (n-pentane:EtOAc = 40:1) = 0.26

¹H NMR (400 MHz, CDCl₃): δ = 7.10 – 7.02 (m, 1H), 6.42 (dd, J = 8.1, 3.6 Hz, 2H), 5.51 – 5.42 (m, 1H), 4.61 – 4.48 (m, 2H), 4.46 – 4.39 (m, 2H), 3.56 – 3.47 (m, 1H), 2.31 (heptd, J = 6.9, 3.9 Hz, 1H), 1.79 (s, 3H), 1.73 (s, 3H), 0.95 (d, J = 6.9 Hz, 3H), 0.75 (d, J = 6.9 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 161.7, 156.5, 137.3, 129.1, 120.3, 117.0, 104.3, 102.7, 72.8, 65.0, 46.8, 29.2, 25.9, 20.9, 18.4, 17.0 ppm.

IR (ATR): 2957 (m), 1605 (m), 1453 (m), 1269 (m), 1252 (m), 1058 (s), 782 (w), 745 (w) cm⁻¹.

3-Isopropyl-2,3-dihydrobenzofuran-5-carboxylic acid (4f)

Synthesized according to GP F (Kessil lamp 427 nm) from 3-bromo-4-((3-methylbut-2-en-1-yl)oxy)benzoic acid (2f) (57.0 mg, 200 µmol, 1.00 equiv.) and HBpin (72.5 µL, 64.0 mg, 500 µmol, 2.50 equiv.). After 16 h, all volatiles were remove under reduced pressure and the residue was washed with n-pentane to afford 4f (35 mg, 170 µmol, 85%) as a white solid.

Analytical data of 4f:

TLC (SiO₂): Rₜ (n-pentane:Et₂O = 1:1) = 0.40
Mp: 142.1 – 143.7 °C.

¹H NMR (400 MHz, CDCl₃): δ = 12.28 (br s, 1H), 8.03 – 7.89 (m, 2H), 6.81 (d, J = 8.4 Hz, 1H), 4.63 (t, J = 9.3 Hz, 1H), 4.48 (dd, J = 9.3, 5.2 Hz, 1H), 3.44 – 3.34 (m, 1H), 2.05 – 1.97 (m, 1H), 0.97 (d, J = 6.8 Hz, 3H), 0.89 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 172.1, 165.5, 132.3, 130.3, 127.7, 121.6, 109.4, 75.2, 47.5, 31.8, 19.8, 18.3 ppm.

IR (ATR): 3641 (w), 2967 (m), 1678 (s), 1607 (m), 1411 (m), 1296 (m), 1245 (m), 1052 (w), 952 (w) cm⁻¹.


Methyl 3-isopropyl-2,3-dihydrobenzofuran-5-carboxylate (4g)

Synthesized according to GP F (Kessil lamp 427 nm) from methyl 3-bromo-4-((3-methylbut-2-en-1-yl)oxy)benzoate (2g) (59.8 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4g (37 mg, 168 µmol, 84%) as a white solid.

Analytical data of 4g:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.19
Mp: 50.2 – 52.1 °C.

¹H NMR (400 MHz, CDCl₃): δ = 7.90 – 7.85 (m, 2H), 6.79 – 6.75 (m, 1H), 4.59 (t, J = 9.3 Hz, 1H), 4.45 (dd, J = 9.2, 5.2 Hz, 1H), 3.87 (s, 3H), 3.40 – 3.33 (m, 1H), 1.99 (heptd, J = 6.8, 4.9 Hz, 1H), 0.95 (d, J = 6.8 Hz, 3H), 0.86 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 167.2, 164.7, 131.4, 130.0, 127.0, 122.5, 109.2, 75.0, 51.9, 47.6, 31.7, 19.8, 18.3 ppm.

IR (ATR): 2957 (m), 1710 (s), 1608 (m), 1491 (m), 1437 (m), 1256 (s), 1157 (m), 1108 (s), 952 (s), 834 (w), 767 (m), 667 (w) cm⁻¹.
HRMS (ESI): calcd. for [C_{13}H_{16}O_{3}+H]^+, [M+H]^+: 221.1172; found: 221.1142.

7-Chloro-3-isopropyl-2,3-dihydrobenzofuran (4h)

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-3-chloro-2-((3-methylbut-2-en-1-yl)oxy)benzene (2h) (55.1 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 1:0 – 40:1) afforded 4h (32 mg, 162 µmol, 81%) as a colourless oil.

Analytical data of 4h:
TLC (SiO₂): Rₖ (n-pentane:EtOAc = 40:1) = 0.36

^1H NMR (400 MHz, CDCl₃): δ = 7.13 (d, J = 7.9 Hz, 1H), 7.06 (d, J = 7.4 Hz, 1H), 6.79 (dd, J = 8.0, 7.4 Hz, 1H), 4.62 (t, J = 9.2 Hz, 1H), 4.48 (dd, J = 9.2, 5.3 Hz, 1H), 3.41 (dtt, J = 9.3, 5.3, 0.9 Hz, 1H), 1.98 (heptd, J = 6.9, 5.0 Hz, 1H), 0.95 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 6.9 Hz, 3H) ppm.

^13C NMR (101 MHz, CDCl₃): δ = 156.3, 131.4, 128.6, 123.5, 121.3, 115.1, 74.7, 49.0, 31.8, 19.9, 18.5 ppm.

IR (ATR): 2961 (s), 2901 (m), 1605 (w), 1449 (s), 1220 (m), 1076 (m), 1055 (m), 955 (m), 889 (w) cm⁻¹.


All spectroscopic data corresponded to the reported literature values.[31]

3-Isopropyl-2,3-dihydrofuro[3,2-b]pyidine (4i)

Synthesized according to GP F (Kessil lamp 427 nm) from 2-bromo-3-((3-methylbut-2-en-1-yl)oxy)pyridine (2i) (48.4 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 3:1) afforded 4i (20 mg, 123 µmol, 61%) as a colourless oil.

Analytical data of 4i:
TLC (SiO₂): Rₖ (n-pentane:EtOAc = 3:1) = 0.63

^1H NMR (400 MHz, CDCl₃): δ = 8.06 (dd, J = 3.8, 2.4 Hz, 1H), 7.02 – 6.97 (m, 2H), 4.62 (t, J = 9.4 Hz, 1H), 4.46 (dd, J = 9.3, 5.8 Hz, 1H), 3.43 – 3.34 (m, 1H), 2.21 (heptd, J = 6.9, 4.8 Hz, 1H), 1.02 (d, J = 6.9 Hz, 3H), 0.86 (d, J = 6.8 Hz, 3H) ppm.

^13C NMR (101 MHz, CDCl₃): δ = 154.2, 153.1, 141.6, 122.4, 115.6, 73.3, 48.1, 31.0, 20.2, 18.0 ppm.

IR (ATR): 2958 (m), 1575 (w), 1426 (s), 1261 (m), 1157 (w), 1103 (w), 945 (s), 783 (m) cm⁻¹.


All spectroscopic data corresponded to the reported literature values.[31]
7-Bromo-3-isopropyl-2,3-dihydrobenzofuran (4j)

Synthesized according to GP F (white LEDs) from 1-bromo-3-iodo-2-((3-methylbut-2-en-1-yl)oxy)benzene (1j) (70.4 mg, 191 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4j (45 mg, 186 µmol, 97%) as a colourless oil.

Analytical data of 4j:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.37

$^1$H NMR (400 MHz, CDCl₃): $\delta$ = 7.28 (d, $J = 8.0$ Hz, 1H), 7.10 (d, $J = 7.4$ Hz, 1H), 6.73 (dd, $J = 8.0, 7.3$ Hz, 1H), 4.62 (t, $J = 9.2$ Hz, 1H), 4.47 (dd, $J = 9.2, 5.4$ Hz, 1H), 3.44 (dtt, $J = 9.3, 5.3, 0.9$ Hz, 1H), 1.98 (heptd, $J = 6.8, 4.9$ Hz, 1H), 0.95 (d, $J = 6.9$ Hz, 3H), 0.88 (d, $J = 6.8$ Hz, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl₃): $\delta$ = 157.7, 131.4, 131.1, 124.2, 121.7, 102.7, 74.4, 49.2, 31.8, 19.9, 18.5 ppm.

All spectroscopic data corresponded to the reported literature values.\(^{[32]}\)

3-Benzyl-2,3-dihydrobenzofuran (4k)

Synthesized according to GP F (KESSIL lamp) from (E)-1-bromo-2-(cinnamyl)oxy)benzene (2k) (57.8 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4k (36 mg, 171 µmol, 86%) as a colourless oil.

Analytical data of 4k:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.26

$^1$H NMR (400 MHz, CDCl₃): $\delta$ = 7.37 – 7.28 (m, 2H), 7.30 – 7.21 (m, 1H), 7.24 – 7.17 (m, 2H), 7.19 – 7.10 (m, 1H), 7.02 – 6.95 (m, 1H), 6.87 – 6.78 (m, 2H), 4.54 (t, $J = 8.9$ Hz, 1H), 4.30 (dd, $J = 8.9, 6.0$ Hz, 1H), 3.77 (tt, $J = 8.9, 6.1$ Hz, 1H), 3.08 (dd, $J = 13.8, 6.4$ Hz, 1H), 2.86 (dd, $J = 13.8, 8.9$ Hz, 1H) ppm.

$^{13}$C NMR (101 MHz, CDCl₃): $\delta$ = 160.1, 139.3, 130.4, 129.1, 128.7, 128.5, 126.6, 124.7, 120.4, 109.8, 76.5, 43.6, 41.2 ppm.

All spectroscopic data corresponded to the reported literature values.\(^{[30]}\)
3,3-Dimethyl-2,3-dihydrobenzofuran (4l)

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-2-((2-methylallyl)oxy)benzene (2l) (45.4 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4l (8 mg, 54.0 µmol, 27%) as a colourless oil.

**Analytical data of 4l:**

TLC (SiO₂): Rₖ (n-pentane:EtOAc = 40:1) = 0.52

¹H NMR (400 MHz, CDCl₃): δ = 7.17 – 7.07 (m, 2H), 6.93 – 6.84 (m, 1H), 6.83 – 6.76 (m, 1H), 4.23 (s, 2H), 1.35 (s, 6H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 159.3, 136.7, 128.0, 122.4, 120.7, 109.8, 84.5, 42.0, 27.7 (2C) ppm.

All spectroscopic data corresponded to the reported literature values.[33]

2H-spiro[benzofuran-3,1’-cyclohexane] (4m)

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-2-(cyclohex-1-en-1-ylmethoxy)benzene (2m) (51.0 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 1:0 – 40:1) afforded 4m (9 mg, 47 µmol, 24%) as a colourless liquid.

**Analytical data of 4m:**

TLC (SiO₂): Rₖ (n-pentane:EtOAc = 40:1) = 0.65

¹H NMR (400 MHz, CDCl₃): δ = 7.16 – 7.07 (m, 2H), 6.87 (td, J = 7.4, 1.0 Hz, 1H), 6.82 – 6.75 (m, 1H), 4.36 (s, 2H), 1.82 – 1.58 (m, 7H), 1.40 – 1.31 (m, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 159.4, 136.4, 128.2, 123.0, 120.5, 109.8, 81.1, 46.3, 36.9 (2C), 25.6, 23.5 (2C) ppm.

IR (ATR): 2925 (s), 2852 (m), 1599 (w), 1479 (s), 1449 (m), 1228 (s), 977 (s) 749 (s) cm⁻¹.


3-(6-Methylhept-5-en-2-yl)-2,3-dihydrobenzofuran (4n)
Synthesized according to GP F (Kessil lamp 427 nm) from (E)-1-bromo-2-((3,7-dimethylocta-2,6-dien-1-yloxy)benzene (2n) (61.9 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4n (40 mg, 173 µmol, 87%) as a colourless oil (d.r. = 50:50).

Analytical data of 4n:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.41

¹H NMR (400 MHz, CDCl₃): δ = 7.20 – 7.07 (m, 2H), 6.89 – 6.80 (m, 1H), 6.77 (d, J = 8.0 Hz, 1H), 5.15 – 5.01 (m, 1H), 4.55 (t, J = 9.2 Hz, 1/2H), 4.50 (t, J = 9.3 Hz, 1/2H), 4.36 (ddd, J = 9.0, 6.9, 5.4 Hz, 1H), 3.50 (dt, J = 9.7, 4.9 Hz, 1/2H), 3.42 (dt, J = 9.5, 4.8 Hz, 1/2H), 2.14 – 1.73 (m, 3H), 1.70 (s, 3/2H), 1.68 (s, 3/2H), 1.62 (s, 3/2H), 1.59 (s, 3/2H), 1.51 – 1.31 (m, 1H), 1.32 – 1.14 (m, 1H), 0.89 (d, J = 6.8 Hz, 3/2H), 0.81 (d, J = 6.9 Hz, 3/2H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 160.77, 160.52, 131.84, 131.78, 129.85, 128.98, 128.27, 128.19, 125.40, 124.78, 124.50, 124.41, 124.31, 120.17, 109.47, 109.42, 74.86, 73.04, 47.29, 46.75, 36.54, 36.03, 34.73, 33.31, 25.98, 25.92, 25.89, 25.85, 17.86, 17.82, 16.44, 14.94 ppm.

IR (ATR): 2963 (m), 2914 (m), 1595 (m), 1483 (s), 1459 (m), 1229 (s), 958 (w), 749 (s) cm⁻¹.


4-Isopropylchromane (4o)

Synthesized according to GP F (Kessil lamp 427 nm) from 1-bromo-2-((4-methylpent-3-en-1-yloxy)benzene (2o) (51.0 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4o (16 mg, 91 µmol, 45%) as a colourless liquid.

Analytical data of 4o:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 40:1) = 0.47

¹H NMR (400 MHz, CDCl₃): δ = 7.19 – 7.12 (m, 1H), 7.13 – 7.04 (m, 1H), 6.86 (td, J = 7.5, 1.4 Hz, 1H), 6.80 (dd, J = 8.1, 1.3 Hz, 1H), 4.27 (ddd, J = 10.7, 6.1, 4.5 Hz, 1H), 4.15 – 4.08 (m, 1H), 2.73 (q, J = 6.5 Hz, 1H), 2.32 – 2.14 (m, 1H), 1.92 (tdd, J = 6.2, 4.3, 2.2 Hz, 2H), 1.06 (d, J = 6.8 Hz, 3H), 0.80 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 155.2, 129.0, 127.2, 125.8, 120.1, 116.9, 65.0, 39.8, 30.7, 23.0, 21.2, 17.6 ppm.

IR (ATR): 2965 (s), 2871 (m), 1580 (w), 1488 (s), 1451 (m), 1223 (s), 1068 (s), 752 (s) cm⁻¹.


1-(3-Isopropylindolin-1-yl)ethan-1-one (4p)

Synthesized according to GP F (Kessil lamp 427 nm) from (E)-1-bromo-2-((4-methylpent-3-en-1-yl)oxy)benzene (2o) (51.0 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4o (16 mg, 91 µmol, 45%) as a colourless liquid.

Analytical data of 4o:

TLC (SiO₂): Rₜ (n-pentane:EtOAc = 1:0 – 40:1) = 0.47

¹H NMR (400 MHz, CDCl₃): δ = 7.19 – 7.12 (m, 1H), 7.13 – 7.04 (m, 1H), 6.86 (td, J = 7.5, 1.4 Hz, 1H), 6.80 (dd, J = 8.1, 1.3 Hz, 1H), 4.27 (ddd, J = 10.7, 6.1, 4.5 Hz, 1H), 4.15 – 4.08 (m, 1H), 2.73 (q, J = 6.5 Hz, 1H), 2.32 – 2.14 (m, 1H), 1.92 (tdd, J = 6.2, 4.3, 2.2 Hz, 2H), 1.06 (d, J = 6.8 Hz, 3H), 0.80 (d, J = 6.8 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 155.2, 129.0, 127.2, 125.8, 120.1, 116.9, 65.0, 39.8, 30.7, 23.0, 21.2, 17.6 ppm.

IR (ATR): 2958 (s), 2871 (m), 1580 (w), 1488 (s), 1451 (m), 1223 (s), 1068 (s), 752 (s) cm⁻¹.

Synthesized according to GP F (Kessil lamp 427) from N-(2-bromophenyl)-N-(3-methylbut-2-en-1-yl)acetamide (2p) (56.4 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 1:1) afforded 4p (37 mg, 182 µmol, 91%) as a colourless oil.

Analytical data of 4p:
TLC (SiO₂): Rf (n-pentane:EtOAc = 1:1) = 0.59

³¹H NMR (400 MHz, CDCl₃): δ = 8.20 (d, J = 8.1 Hz, 1H), 7.25 – 7.13 (m, 2H), 7.02 (td, J = 7.5, 1.1 Hz, 1H), 4.00 (t, J = 10.2 Hz, 1H), 3.79 (dd, J = 10.6, 5.0 Hz, 1H), 3.35 (dt, J = 9.6, 4.7 Hz, 1H), 2.24 (s, 3H), 2.13 – 1.99 (m, 1H), 0.98 (d, J = 6.9 Hz, 3H), 0.80 (d, J = 6.9 Hz, 3H) ppm.

³¹C NMR (101 MHz, CDCl₃): δ = 168.7, 143.3, 133.9, 128.0, 124.5, 123.6, 116.9, 51.3, 46.1, 32.0, 24.4, 20.2, 17.5 ppm.

All spectroscopic data corresponded to the reported literature values.[34]

3-Isopropyl-1-(3-methylbut-2-en-1-yl)indoline (4q)

Synthesized according to GP F (Kessil lamp 427) from 2-bromo-N,N-bis(3-methylbut-2-en-1-yl)aniline (2q) (61.7 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1) afforded 4q (44 mg, 191 µmol, 96%) as a colourless liquid.

Analytical data of 4q:
TLC (SiO₂): Rf (n-pentane:EtOAc = 40:1) = 0.32

³¹H NMR (400 MHz, CDCl₃): δ = 7.10 – 7.02 (m, 2H), 6.64 (td, J = 7.4, 1.0 Hz, 1H), 6.48 (dd, J = 8.2, 1.0 Hz, 1H), 5.32 – 5.23 (m, 1H), 3.71 – 3.64 (m, 2H), 3.41 – 3.29 (m, 1H), 3.19 – 3.05 (m, 2H), 2.10 – 1.96 (m, 1H), 1.75 (s, 3H), 1.72 (s, 3H), 0.99 (d, J = 6.8 Hz, 3H), 0.88 (d, J = 6.8 Hz, 3H) ppm.

³¹C NMR (101 MHz, CDCl₃): δ = 152.9, 135.3, 132.9, 127.5, 124.6, 120.4, 117.1, 107.2, 55.2, 47.0, 46.6, 30.8, 25.9, 20.7, 18.9, 18.1 ppm.

All spectroscopic data corresponded to the reported literature values.[35]

1,5-Diisopropyl-1,2,4,5-tetrahydropyrrolo[3,2,1-hij]indole (4r)

Synthesized according to GP F (Kessil lamp 427 nm) from 2,6-dibromo-N,N-bis(3-methylbut-2-en-1-yl)aniline (2r) (77.4 mg, 200 µmol, 1.00 equiv.), DBU (59.7 µL, 60.9 mg, 400 µmol, 2.00 equiv.), SPO (86.6 µL, 50 mg/mL
in MeCN stock solution, 4.33 mg, 20 µmol, 10 mol%) and HBpin (63.8 µL, 56.3 mg, 440 µmol, 2.20 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 40:1 – 20:1) afforded 4r (13 mg, 56 µmol, 28%) as a faint yellow oil (d.r. = 1:1).

Analytical data of 4r:

**TLC** (SiO₂): Rᵣ (n-pentane:EtOAc = 40:1) = 0.22

1H NMR (400 MHz, CDCl₃): δ = 6.96 (d, J = 7.3 Hz, 2H), 6.63 (td, J = 7.3, 2.3 Hz, 1H), 3.44 – 3.21 (m, 4H), 3.03 (dd, J = 8.6, 6.5 Hz, 1H), 2.92 (dd, J = 8.4, 7.0 Hz, 1H), 1.99 (dpd, J = 13.5, 6.8, 2.4 Hz, 2H), 1.08 (d, J = 4.3 Hz, 3H), 1.07 (d, J = 4.3 Hz, 3H), 0.99 (d, J = 5.0 Hz, 3H), 0.97 (d, J = 5.0 Hz, 3H) ppm.

13C NMR (101 MHz, CDCl₃): δ = 164.6, 126.1, 126.0, 123.0, 122.9, 119.6, 62.0, 61.9, 55.6, 55.5, 30.9, 30.9, 21.0, 20.9, 20.9, 20.8 ppm.

IR (ATR): 2956 (s), 2869 (m), 2818 (w), 1585 (m), 1487 (m), 1450 (m), 1047 (w), 749 (s) cm⁻¹.


3-Isopropylhexahydro-4H-furo[2,3-b]pyran (4s)

Synthesized according to GP F (white LEDs) from 3-iodo-2-((3-methylbut-2-en-1-yl)oxy)tetrahydro-2H-pyran (1s) (59.2 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 4s (22.0 mg, 129 µmol, 65%) as a colourless oil (cis/trans = 64:36).

Synthesized according to GP F (Kessil lamp 427 nm) from 3-bromo-2-((3-methylbut-2-en-1-yl)oxy)tetrahydro-2H-pyran (2s) (49.8 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 4s (20.0 mg, 118 µmol, 59%) as a colourless oil (cis/trans = 64:36).

Analytical data of 4s:

**TLC** (SiO₂): Rᵣ (n-pentane:EtOAc = 3:1) = 0.58

1H NMR (400 MHz, CDCl₃): *cis*: δ = 5.29 (d, J = 3.2 Hz, 1H), 3.94 (t, J = 7.8 Hz, 1H), 3.71 – 3.62 (m, 3H), 1.96 – 1.82 (m, 2H), 1.71 – 1.54 (m, 4H), 1.42 – 1.32 (m, 1H), 0.93 (d, J = 6.5 Hz, 3H), 0.80 (d, J = 6.6 Hz, 3H) ppm. *trans*: δ = 4.99 (d, J = 3.6 Hz, 1H), 4.18 (t, J = 8.6 Hz, 1H), 3.93 – 3.83 (m, 1H), 3.67 – 3.61 (m, 1H), 3.46 – 3.39 (m, 1H), 2.15 – 2.06 (m, 1H), 1.90 – 1.76 (m, 3H), 1.71 – 1.54 (m, 2H), 1.42 – 1.32 (m, 1H), 0.95 (d, J = 6.9 Hz, 3H), 0.87 (d, J = 6.7 Hz, 3H) ppm.

13C NMR (101 MHz, CDCl₃): *cis*: δ = 102.3, 69.2, 60.9, 49.1, 35.9, 26.5, 23.5, 21.9, 21.2, 19.0 ppm. *trans*: δ = 102.7, 71.3, 64.5, 44.5, 41.5, 30.3, 23.7, 21.7, 20.9, 19.7 ppm.

All spectroscopic data corresponded to the reported literature values. [36–38]
(Cyclopentylmethyl)benzene (4t)

Synthesized according to GP F (Kessil lamp 427 nm) from [(E)-6-bromohex-1-enyl]benzene (47.8 mg, 200 μmol, 1.00 equiv.) 2t. Purification by flash chromatography (SiO2, n-pentane:EtOAc = 40:1) afforded an inseparable mixture of 4t and 2t. The mixture was analysed by qualitative NMR analysis with 1,3,5-trimethoxybenzene as internal standard to determine the NMR yield for 4t to be 39%. The characteristic product signals matched those reported in literature.[39]

Analytical data of 4t:

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.30 – 7.24 (m, 2H), 7.22 – 7.13 (m, 3H), 2.61 (d, $J$ = 7.4 Hz, 2H), 2.15 – 2.03 (m, 1H), 1.75 – 1.67 (m, 2H), 1.66 – 1.59 (m, 2H), 1.59 – 1.45 (m, 2H), 1.27 – 1.13 (m, 2H) ppm.

3-Benzyttetrahydrofuran (4u)

Synthesized according to GP F (Kessil lamp 427 nm) from (E)-(3-(2-bromoethoxy)prop-1-enyl)benzene (48.2 mg, 200 μmol, 1.00 equiv.) (2u). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 20:1) afforded 4u (12.0 mg, 74.0 μmol, 37%) as a colourless oil.

Analytical data of 4u:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 6:1) = 0.33

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.33 – 7.27 (m, 2H), 7.23 – 7.16 (m, 3H), 3.91 (td, $J$ = 8.2, 5.0 Hz, 1H), 3.84 (dd, $J$ = 8.4, 6.9 Hz, 1H), 3.76 (dt, $J$ = 8.4, 7.4 Hz, 1H), 3.47 (dd, $J$ = 8.4, 6.6 Hz, 1H), 2.70 (dd, $J$ = 7.7, 2.2 Hz, 2H), 2.52 (hept, $J$ = 7.1 Hz, 1H), 2.00 (dt, $J$ = 12.5, 7.6, 5.0 Hz, 1H), 1.70 – 1.57 (m, 1H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 140.9, 128.8 (2C), 128.6 (2C), 126.2, 73.5, 68.0, 41.1, 39.5, 32.3 ppm.

All spectroscopic data corresponded to the reported literature values.[40]

3-Isopropyl-1-tosylpyrrolidine (4v)

Synthesized according to GP F (Kessil lamp 427 nm) from N-(2-bromoethyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (2v) (69.3 mg, 200 μmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 4v (41.0 mg, 153 μmol, 77%) as a colourless oil.

Analytical data of 4v:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 10:1) = 0.31
$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.70 (d, $J = 8.2$ Hz, 2H), 7.31 (d, $J = 8.1$ Hz, 2H), 3.44 (dd, $J = 9.7$, 7.7 Hz, 1H), 3.36 (ddd, $J = 9.7$, 8.5, 2.3 Hz, 1H), 3.14 (td, $J = 9.9$, 6.8 Hz, 1H), 2.77 (t, $J = 9.6$ Hz, 1H), 2.42 (s, 3H), 1.95 – 1.85 (m, 1H), 1.74 – 1.62 (m, 1H), 1.41 – 1.29 (m, 2H), 0.84 (d, $J = 1.1$ Hz, 3H), 0.82 (d, $J = 1.1$ Hz, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 143.4, 134.0, 129.7 (2C), 127.7 (2C), 52.2, 48.2, 46.5, 31.9, 30.1, 21.6, 21.4, 21.1 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[40]}$

3-Methyl-1-tosylpyrrolidine (4w)

Synthesized according to GP F (Kessil lamp 427 nm) from $N$-allyl-$N$-(2-bromoethyl)-4-methylbenzenesulfonamide (2w) (63.7 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 6:1) afforded 4w (26.0 mg, 109 µmol, 54%) as a white solid.

Analytical data of 4w:

TLC (SiO$_2$): $R_f$ (n-pentane:EtO = 6:1) = 0.33

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.71 (d, $J = 8.3$ Hz, 2H), 7.32 (d, $J = 8.1$ Hz, 2H), 3.42 (dd, $J = 9.7$, 7.1 Hz, 1H), 3.34 (ddd, $J = 9.9$, 8.2, 4.1 Hz, 1H), 3.22 (ddd, $J = 9.8$, 8.2, 7.2 Hz, 1H), 2.75 (dd, $J = 9.7$, 7.8 Hz, 1H), 2.43 (s, 3H), 2.18 – 2.05 (m, 1H), 1.96 – 1.84 (m, 1H), 1.35 (dq, $J = 12.3$, 8.4 Hz, 1H), 0.92 (d, $J = 6.7$ Hz, 3H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 143.4, 134.2, 129.7 (2C), 127.7 (2C), 54.9, 47.8, 33.5, 33.4, 21.7, 17.8 ppm.

All spectroscopic data corresponded to the reported literature values.$^{[41]}$

2-Tosyl-2-azaspiro[4.5]decane (4x)

Synthesized according to GP F (Kessil lamp 427 nm) from $N$-(cyclohex-1-en-1-ylmethyl)-$N$-(2-hydroxyethyl)-4-methylbenzenesulfonamide (2x) (74.5 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO$_2$, n-pentane:EtOAc = 10:1) afforded 4x (30.0 mg, 102 µmol, 51%) as a colourless oil.

Analytical data of 4x:

TLC (SiO$_2$): $R_f$ (n-pentane:EtOAc = 10:1) = 0.28

$^1$H NMR (400 MHz, CDCl$_3$): $\delta$ = 7.71 (d, $J = 8.3$ Hz, 2H), 7.31 (d, $J = 7.7$ Hz, 2H), 3.25 (t, $J = 7.1$ Hz, 2H), 3.04 (s, 2H), 2.42 (s, 3H), 1.64 – 1.51 (m, 2H), 1.43 – 1.17 (m, 10H) ppm.

$^{13}$C NMR (101 MHz, CDCl$_3$): $\delta$ = 143.3, 134.0, 129.7 (2C), 127.6 (2C), 57.9, 46.5, 42.6, 37.1, 35.5, 26.0, 23.4, 21.7 ppm.

IR (ATR): 2922 (m), 2853 (w), 1450 (m), 1342 (s), 1158 (s), 1095 (s), 816 (w), 662 (s), 588 (s), 545 (s) cm$^{-1}$. 

66
HRMS (ESI): calcd. for \([\text{C}_{16}\text{H}_{23}\text{NO}_2+\text{H}]^+\), \([\text{M+H}]^+\): 294.1528; found: 294.1506.

\[3\text{-Isopropyl-4-methyl-1-tosylpyrrolidine (4y)}\]

Synthesized according to GP F (Kessil lamp 427 nm) from (±)-N-(2-hydroxypropyl)-4-methyl-N-(3-methylbut-2-en-1-yl)benzenesulfonamide (2y) (72.1 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 4y (51.0 mg, 181 µmol, 91%) as a colourless oil (d.r. = 65:35).

**Analytical data of 4y:**

TLC (SiO₂): Rf (n-pentane:EtOAc = 10:1) = 0.29

\[^1\text{H NMR (400 MHz, CDCl}_3\):}\ \delta = 7.70 (d, J = 8.2 Hz, 2H), 7.30 (d, J = 8.3 Hz, 2H), 3.41 (dd, J = 9.5, 7.7 Hz, 1H), 3.29 (dd, J = 9.9, 5.7 Hz, 1H), 3.15 (d, J = 9.7 Hz, 1H), 2.87 (dd, J = 11.2, 9.7 Hz, 1H), 2.42 (s, 3H), 2.23 – 2.11 (m, 1H), 1.65 – 1.52 (m, 1H), 1.49 – 1.38 (m, 1H), 0.82 (t, J = 6.7 Hz, 6H), 0.62 (d, J = 7.0 Hz, 3H) ppm.

**Minor:** \(\delta = 7.69 (d, J = 8.0 Hz, 2H), 7.31 (d, J = 9.2 Hz, 2H), 3.42 (d, J = 9.5 Hz, 1H), 3.36 – 3.27 (m, 1H), 2.92 (dd, J = 10.0, 8.8 Hz, 1H), 2.72 (dd, J = 9.6, 8.3 Hz, 1H), 2.42 (s, 3H), 1.93 – 1.80 (m, 1H), 1.67 – 1.57 (m, 1H), 1.49 – 1.42 (m, 1H), 0.91 (d, J = 6.6 Hz, 3H), 0.86 (d, J = 6.8 Hz, 3H), 0.76 (d, J = 6.7 Hz, 3H) ppm.

\[^{13}\text{C NMR (101 MHz, CDCl}_3):}\ \delta = 143.4, 143.3, 134.5, 133.6, 129.7, 127.7, 127.4, 56.1, 55.5, 52.0, 50.3, 50.1, 49.8, 36.0, 34.0, 28.8, 27.4, 21.9, 21.6, 21.5, 21.1, 18.5, 17.7, 13.0 ppm.

All spectroscopic data corresponded to the reported literature values.\(^{[42]}\)

\[3,3\text{-Dichloro-4-isopropyl-1-tosylpyrrolidine (4z)}\]

Synthesized according to GP F (Kessil lamp 427 nm) from 4-methyl-N-(3-methylbut-2-en-1-yl)-N-(2,2,2-trichloroethyl)benzenesulfonamide (3z) (74.1 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 20:1) afforded 4z (55.0 mg, 163 µmol, 82%) as a white solid.

**Analytical data of 4z:**

TLC (SiO₂): Rf (n-pentane:EtOAc = 20:1) = 0.19

Mp: 135.5 – 136.2 °C.

\[^1\text{H NMR (400 MHz, CDCl}_3):}\ \delta = 7.72 (d, J = 8.3 Hz, 2H), 7.34 (d, J = 8.0 Hz, 2H), 4.11 (d, J = 11.9 Hz, 1H), 3.89 (d, J = 11.8 Hz, 1H), 3.69 (dd, J = 9.6, 7.9 Hz, 1H), 3.05 (dd, J = 10.5, 9.6 Hz, 1H), 2.44 (s, 3H), 2.30 – 2.15 (m, 1H), 1.99 – 1.84 (m, 1H), 1.15 (d, J = 6.6 Hz, 3H), 0.91 (d, J = 6.7 Hz, 3H) ppm.

\[^{13}\text{C NMR (101 MHz, CDCl}_3):}\ \delta = 144.1, 134.0, 129.9 (2C), 127.7 (2C), 87.8, 66.7, 59.1, 51.2, 29.6, 21.8 (2C), 21.2 ppm.

IR (ATR): 2966 (m), 1351 (m), 1167 (s), 1064 (m), 814 (w), 665 (s), 595 (m), 549 (m) cm\(^{-1}\).

3,3-Dichloro-4-isopropyl-1-tosylpiperidine (4za)

Synthesized according to GP F (Kessil lamp 427 nm) from 4-methyl-N-(4-methylpent-3-en-1-yl)-N-(2,2,2-trichloroethyl)benzenesulfonamide (3za) (77.0 mg, 200 µmol, 1.00 equiv.). Purification by flash chromatography (SiO₂, n-pentane:EtOAc = 10:1) afforded 4za (48.0 mg, 137 µmol, 69%) as a white solid.

Analytical data of 4za:

TLC (SiO₂): Rf (n-pentane:EtOAc = 10:1) = 0.33

Mp: 131.6 – 133.0 °C.

¹H NMR (400 MHz, CDCl₃): δ = 7.67 (d, J = 8.3 Hz, 2H), 7.33 (d, J = 8.0 Hz, 2H), 4.27 (dd, J = 12.5, 2.2 Hz, 1H), 3.89 (ddt, J = 11.8, 4.6, 2.3 Hz, 1H), 2.82 (d, J = 12.5 Hz, 1H), 2.44 (s, 3H), 2.46 – 2.36 (m, 1H), 2.34 (td, J = 12.1, 2.8 Hz, 1H), 1.90 – 1.74 (m, 1H), 1.68 – 1.56 (m, 2H), 0.98 (d, J = 4.5 Hz, 3H), 0.96 (d, J = 4.7 Hz, 3H) ppm.

¹³C NMR (101 MHz, CDCl₃): δ = 144.1, 134.0, 130.0, 127.7, 90.9, 62.0, 55.5, 46.3, 27.7, 24.2, 24.0, 21.7, 18.3 ppm.

IR (ATR): 2961 (w), 1391 (m), 1262 (w), 1162 (s), 1091 (m), 946 (m), 815 (m), 743 (s), 548 (s) cm⁻¹.


1.7 Non-working Substrates

Following compounds were used in GP F. However, no desired intramolecular cyclization reaction was observed.

![Diagram of compounds 3a, 3v, SI-17, SI-14, SI-4 with notes on reactivity and observations.]}
2. References


3. NMR Spectra

$^1$H NMR, 400 MHz, CD$_3$CN

$^{31}$P NMR, 162 MHz, CD$_3$CN
$^1$H NMR, 400 MHz, $CD_6$

$^{13}$C NMR, 101 MHz, $CD_6$
$^{31}$P NMR, 162 MHz, $\text{C}_2\text{D}_6$

$^1$H NMR, 400 MHz, $\text{CD}_3\text{CN}$
$^{13}$C NMR, 101 MHz, CD$_3$CN

$^{31}$P NMR, 162 MHz, CD$_3$CN
$^1$H NMR, 400 MHz, CD$_3$CN

$^{31}$P NMR, 162 MHz, CD$_3$CN
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$\text{F}_3\text{C}$

$\text{Br}$

Me

Me

2c

$^{19}\text{F} \text{NMR, 376 MHz, CDCl}_3$
$^1$H NMR, 400 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
SI-13

$^1$H NMR, 400 MHz, CDCl$_3$

SI-13

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^{1}H$ NMR, 400 MHz, CDCl$_3$

$^{13}C$ NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$
SI-16

$^1$H NMR, 400 MHz, CDCl$_3$

SI-16

$^{13}$C NMR, 101 MHz, CDCl$_3$
SI-17

$^1$H NMR, 400 MHz, CDCl$_3$

SI-17

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^{19\text{F}}\text{NMR, 376 MHz, CDCl}_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^{1}H$ NMR, 400 MHz, CDCl$_3$

$^{13}C$ NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^{1}H$ NMR, 400 MHz, CDCl$_3$

$^{13}C$ NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$
$^1$H NMR, 400 MHz, CDCl$_3$

$^{13}$C NMR, 101 MHz, CDCl$_3$