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Photoinduced Kochi Decarboxylative Elimination for the Synthesis of Enamides and Enecarbamates from *N*-Acyl Amino Acids

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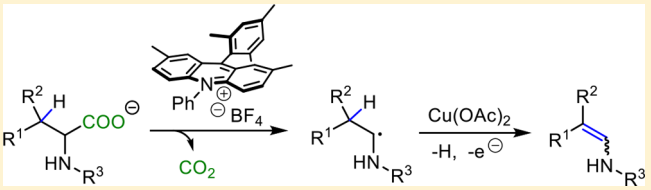
Supporting Information

ABSTRACT: Decarboxylative elimination of easily accessible *N*-acyl amino acids to provide enamide and enecarbamate building blocks has been realized through the combination of an organophotoredox catalyst and copper acetate as the terminal oxidant. This operationally simple process utilizes inexpensive and readily available reagents without preactivation of the carboxylic acid. Enamides and enecarbamates are now accessible directly from N-acyl amino acids consequently improving upon the utility of Kochi's oxidative decarboxylation of carboxylic acids.



INTRODUCTION

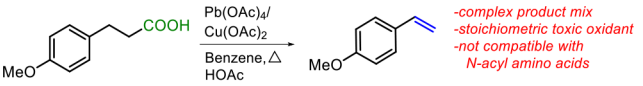
The plethora of nitrogen-containing, biologically active natural products has led to significant interest in the development of methods toward the incorporation of nitrogen moieties. One strategy involves the use of enamides and enecarbamates which have proven to be valuable nucleophilic building blocks with versatile applications in the synthesis of complex molecules.[1] As such, many efforts in the development of methods toward enamide synthesis have been reported. Classical methods include condensation reactions of amines with aldehydes,[2] the Curtius rearrangement of acyl azides,[3] Wittig reactions of amides,[4] and the addition of Grignard reagents to isocyanates or *N*,*N*-dialkyl formamides.[5] Modern routes toward enamide and enecarbamate synthesis include transition metal-catalyzed cross coupling reactions,[6] isomerization of allylamines,[7] hydrogenation of ynamides,[8] and hydroamination of alkynes.[9,10] Despite the vast attention enamide synthesis has received, the methods reported do not meet all ideal requirements, such as operational simplicity, easily accessible starting materials, configurational selectivity, mild and environmentally benign reaction conditions, as well as being economical.

Amino acids are readily available, inexpensive, and possess a variety of side chain functionalities. Thus, operationally simple methods offering direct conversion of these substrates into synthetically useful enamines would be advantageous. Consequently, several reports of methods following this design have emerged including decarbonylation reactions of aminothioesters with Pd and Ni catalysts.[11]

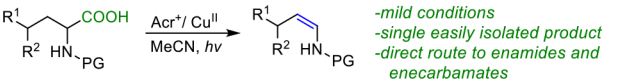
Likewise, decarboxylation reactions of this manifold inspired by Kochi's decarboxylative elimination have been reported for the synthesis of alkenes.[12] Kochi's pioneering work employed lead tetraacetate as the oxidant to achieve decarboxylation along with catalytic copper(II) acetate for further oxidation to the alkene (Scheme 1A).[13]

Scheme 1. Strategies for Decarboxylative Elimination

A. Kochi Decarboxylative Elimination



B. Photo-induced Kochi Decarboxylative Elimination (This Work)



Modern advancements of this method include Liu's use of stoichiometric hypervalent iodide under microwave conditions[14] as well as Glorius who employed the use of redox active esters to achieve the decarboxylation under milder conditions in a dual catalytic system.[15] However, these methods were not shown to be applicable to amino acids.

Recently, our group and the Ritter group simultaneously reported a direct decarboxylative elimination that utilizes the combination of photoredox catalysis and cobaloxime to provide alkenes without the need for preactivation of the carboxylic acid moiety or a stoichiometric oxidant.[16] Although highly efficient and elegant in their design, some drawbacks to these methods include the complex reagent mixtures and the production of hydrogen gas, which can be problematic upon scale-up.

We sought to develop a complementary direct decarboxylative elimination method that is mild, operationally simple, and economical. In addition, we wanted to forge a method that would be compatible with *N*-acyl amino acids of interest for enamide synthesis.[12e] Herein, a new alternative protocol that makes use of an acridinium photocatalyst, $Cu(OAc)_2$, and blue

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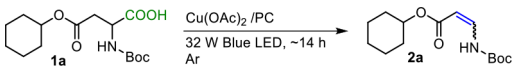
light to efficiently generate enamides from unactivated amino acids is described (Scheme 1B).

RESULTS AND DISSCUSSION

Initial efforts toward developing a photoinduced decarboxylative elimination of *N*-acyl amino acids were conducted with an aspartic acid derivative and $Cu(OAc)_2$ as the inexpensive and readily available terminal oxidant (Table 1). The

Table 1. Optimization of Reaction Conditions

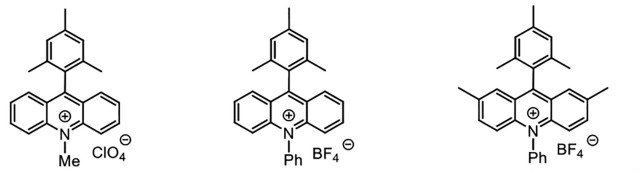


entry	$Cu(OAc)_2$(equiv)	photocatalyst	solvent (4 mL)	yield[b]	isomer ratio[c] (E:Z)
1	2.7	PC3 (5 mol %)	MeCN	91%[d]	52:48
2	2.7	PC1 (5 mol %)	MeCN	71%[d]	59:41
3	2.7	PC2 (5 mol %)	MeCN	65%[d]	49:51
4	2.7	PC3 (5 mol %)	MeCN	90%	36:64
5	2.7	PC3 (5 mol %)	THF	24%	46:54
6	2.7	PC3 (5 mol %)	DCM	19%	37:63
7	2.7	PC3 (5 mol %)	DME	18%	0:100
8	2.7	PC3 (5 mol %)	toluene	91%	45:55
9	2.7	PC3 (5 mol %)	DMF	29%	38:62
10	2.7	PC3 (5 mol %)	ether	87%	38:62
11	2.7	PC3 (5 mol %)	MeOH	66%	88:12
12	2.7	PC3 (5 mol %)	MeCN	83%	36:64
13	2.7	PC3 (5 mol %)	MeCN	95%	42:58
14	2.7	PC3 (5 mol %)	MeCN	93%	40:60
15	2.7	PC3 (5 mol %)	MeCN	94%	34:66
16	0.75	PC3 (5 mol %)	MeCN	72%	35:65
17		PC3 (5 mol %)	MeCN	0%	-
18	1.5		MeCN	8%	50:50
19	1.5	PC3 (2.5 mol %)	MeCN	85%[e]	42:58

[a]Reactions performed on 0.2 mmol scale. [b]Isolated yields. [c]Isomers isolated separately. [d]Reactions contain Na_2CO_3 (0.4 mmol). [e]Performed under air.

Fukuzumi family of acridinium photocatalysts[17] was chosen because of their favorable oxidation potential for amino carboxylates (>+2.0 V and ~+0.95 V vs SCE, respectively, Figure 1).[18]

A quick screen of various photocatalysts from this family showed that, when paired with light and cupric acetate, the 9-mesityl-2,7-dimethyl-10-phenylacridinium (Mes-2,7-Me_2-Acr-$Ph^+BF_4^-$; PC3) photocatalyst provided the highest yield of decarboxylative elimination (Table 1, entry 1).[19] Additionally, the reaction was found to produce comparable yield in the



Mes-Acr-Me$^+$ (PC1)
$E_{1/2}(P^*/P^-)$ = +2.06 V
$E_{1/2}(P^-/P)$ = -0.57 V

Mes-Acr-Ph$^+$ (PC2)
$E_{1/2}(P^*/P^-)$ = +2.17 V

Mes-2,7-Me_2-Acr-Ph$^+$ (PC3)
$E_{1/2}(P^*/P^-)$ = +2.09 V

Figure 1. Acridinium photocatalyst.

absence of base, indicating additional base is not needed under these conditions to generate the carboxylate (Table 1, entry 4).

A solvent screen revealed that the highest yields were achieved with acetonitrile, toluene, and diethyl ether, but the *E*/*Z*-isomer ratio was variable (Table 1, entries 5−10). Specifically, acetonitrile and diethyl ether, provided greater *Z*-selectivity than toluene. Along these lines, it is interesting to note that, although poor yields were observed when the reaction was performed in DME, only the *Z*-isomer was observed (Table 1, entry 7).

Ultimately, the $Cu(OAc)_2$ and photocatalyst loadings could be decreased to 1.5 equiv and 2.5 mol %, respectively, without any loss in yield (Table 1, entry 15). Since 2 equiv of $Cu(OAc)_2$ should be necessary as the terminal oxidant, the high yield at lower loading suggests that either (A) CuOAc may also be performing the oxidation to ultimately produce Cu(0) or (B) CuOAc could be reoxidized to $Cu(OAc)_2$ by the photocatalyst. Further decreases in the $Cu(OAc)_2$ and photocatalyst resulted in lower yield (Table 1, entry 16). A catalytic loading of $Cu(OAc)_2$ (33 mol %) was able to effect decarboxylative elimination through cycling the Cu(I) back to Cu(II) under O_2.[20] However, the reaction with stoichiometric Cu(II) is more operationally simple and is thus preferable.

With optimized conditions established, several control experiments were conducted (Table 1). It was found that no product was produced in the absence of $Cu(OAc)_2$, and only 8% yield was achieved in the absence of photocatalyst (Table 1, entries 17 and 18). Additionally, the reaction could be readily performed under aerobic conditions (Table 1, entry 19).

In addition to $Cu(OAc)_2$, a variety of copper sources were screened in the model reaction (Table 2). Surprisingly, it was found that the *E*/*Z*-selectivity varied depending on the copper salt. Of the copper salts examined, $Cu(OAc)_2$, $Cu(acac)_2$, and Cu(thiophene-2-carboxylate)$_2$ gave excellent yields. However, $Cu(acac)_2$ displayed inverse *E*/*Z*-selectivity to that seen with $Cu(OAc)_2$ and Cu(thiophene-2-carboxylate)$_2$. Conversely, the copper halide salts did not perform well, suggesting that a counterion dependence exists for this transformation. Despite the success of Cu(thiophene-2-carboxylate)$_2$, $Cu(OAc)_2$ was chosen for further exploration of this reaction due to its lower expense.

Monitoring the model reaction over time revealed the reaction reaches completion after 14 h of irradiation (Figure 2).[21] The *E*-isomer was found to predominate at the onset of the reaction, but as the reaction progressed, the *Z*-isomer prevails with a maximum selectivity of 34:66 *E*:*Z* being observed after 14 h of irradiation. Allowing the reaction to be irradiated further did not lead to significant changes in the yield or isomer ratio.

An assortment of *N*-protected amino acids were next subjected to the established reaction conditions (Table 3).

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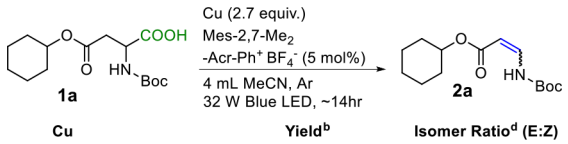
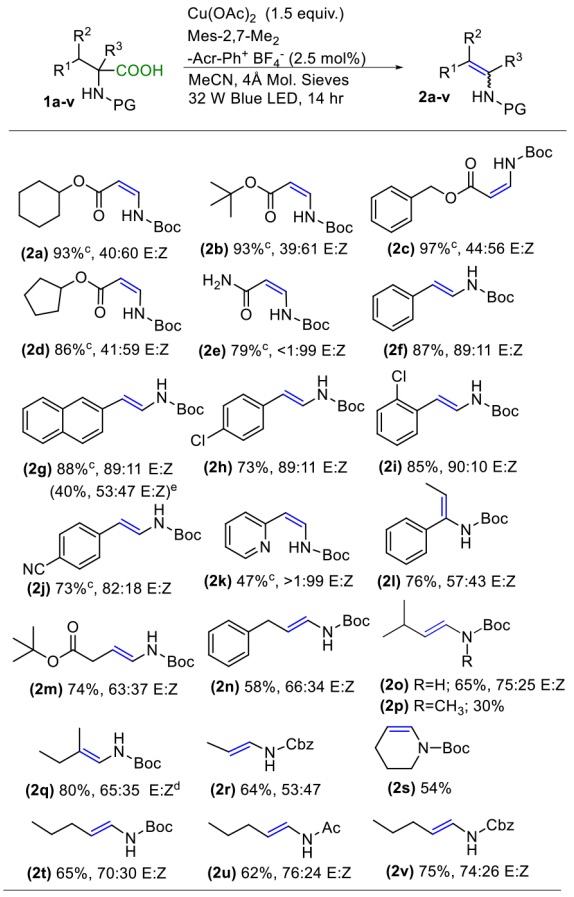
Table 2. Copper Salt Screen



Cu	yield[b]	isomer ratio[d] (E:Z)
$Cu(OAc)_2$	90%	36:64
$Cu(acac)_2$	98%	68:32
$Cu(thiophene\text{-}2\text{-}carboxylate)_2$	98%	38:62
$Cu(CL)_2$		
$Cu(Sulfate)_2$		
Cu(OAc)	83%	39:61
Cu(2-ethylhexanoate)	69%[c]	48:52
Cu(l)	12%	33:67
Cu(Br)	17%[c]	47:53
$Cu(phthalocyanide)_2$	13%	62:38
$Cu(OTf)_2$		

[a]Reactions performed on 0.2 mmol scale. [b]Isolated yields. [c]Yield determined by q[1]HNMR. [d]Isomers isolated separately.

Table 3. Reaction Scope



[a]Reactions were performed on 0.4 mmol scale. [b]Isomer ratios of mixed products were determined by HNMR. [c]Isomers were isolated separately. [d]Major determined by NOESY (see the Supporting Information). [e]Reaction on 1 mmol scale with Mes-Acr-Ph$^+$ BF_4^- photocatalyst.

These reactions were found to perform best with the addition of 4 Å molecular sieves to prevent hydrolysis.[12e,22] Aspartic acid derivatives produced excellent yields and displayed a small preference for the *Z*-isomer (**2a**−**d**). Likewise, *N*-Boc asparagine provided a high yield of the corresponding enecarbamate and generated predominately the *Z*-isomer while only trace amounts of the *E*-isomer were observed (**2e**). Phenylalanine and its derivatives reacted smoothly, but these substrates favored the *E*-isomer (**2f**−**j**). Conversely, when a pendant pyridine was present, the *Z*-isomer predominated while only trace amounts of the *E*-isomer were observed (**2k**). The variation in the isomer ratios is suspected to be a result of the hydrogen bonding ability of the amide proton with a nearby heteroatom, providing a thermodynamic preference for the *Z*-isomer. Other aliphatic amino acids with various functionalities (**2m**−**s**), as well as a tertiary amino acid (**2p**), were able to undergo elimination. In addition to screening various amino acids, the influences of several nitrogen protecting groups on alkene formation were evaluated using norleucine as the reaction platform. This revealed that Boc, Cbz, and Ac protecting groups all provide similar yields and selectivities (**2t**−**v**). However, when unprotected phenylalanine was subjected to the elimination conditions, no alkene product was observed. To explore the scalability of this reaction, the elimination of 1 mmol of **1g** was performed providing 40% yield of **2g**. It is also worthwhile to note that

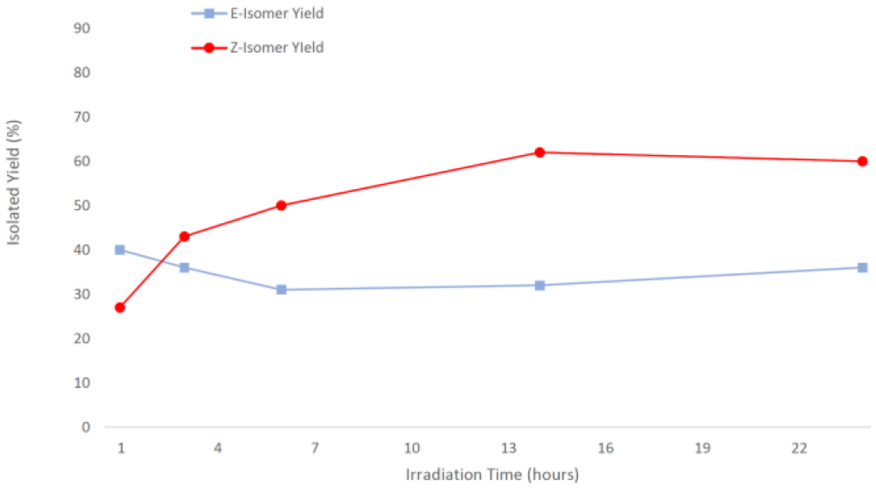


Figure 2. Reaction time.

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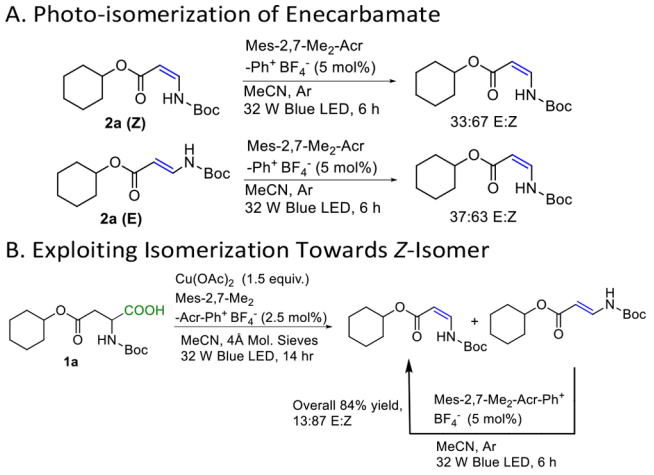
these reactions produced the alkenes as the sole product which are easily separated from the remaining starting material, copper, and photocatalyst with a silica plug.

To gain further insight into the observed isomer ratios, several additional experiments were conducted (Scheme 2).

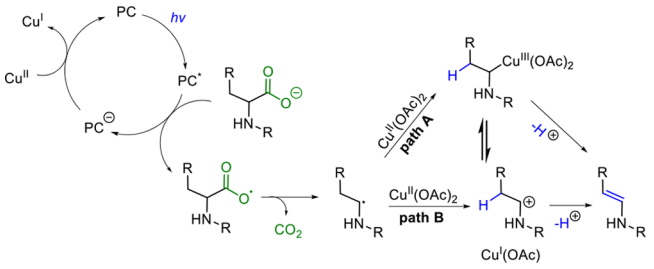
Scheme 2. Isomerization Studies



We previously observed that the *E*/*Z*-isomer ratios were an artifact of a photoisomerization[16b] similar to one described by Weaver[23] with iridium photosensitizers. Independently subjecting pure *E* and *Z* isomers of **2a** to the Mes-2,7-Me_2-Acr-$Ph^+BF_4^-$ photocatalyst revealed that both single configurations isomerized to the same *E*/*Z*-ratio, which also coincides with the ratio observed in the model reaction (Scheme 2A). Importantly, when the model reaction was charged with additional photocatalyst after the 14 h reaction time and irradiated, no change in the isomer ratio was observed. In order to evaluate the thermal influence on the isomerization, both isomers were separately irradiated as well as heated at 50 °C in the absence of photocatalyst and no isomerization was observed. Taken together, it was concluded that a photoisomerization of the enamine products is occurring in the elimination reactions and the observed isomer ratio is a result of an equilibrium established under the reaction conditions.

Two general reaction pathways have been envisioned for the elimination (Scheme 3). Initially, irradiation provides the

Scheme 3. Proposed Reaction Pathways



excited state photocatalyst which then oxidizes the carboxylate by a single electron.[17a,24] Facile radical decarboxylation produces a stabilized α-amino alkyl radical.[25] The photocatalyst can then be reoxidized by $Cu(OAc)_2$ to return to the ground state and complete the catalytic cycle. From this point, the alkyl radical can either form a copper−carbon bond, generating an alkyl Cu(III) species (path A) or be oxidized further to a cation by Cu(II) (path B).[13a,26] If the reaction proceeds via path A, either β-hydride elimination or an E2-type elimination of Cu would provide the alkene product. Dissociation of the alkyl Cu(III) intermediate in path A could also provide the cationic intermediate in path B. Kochi has previously shown that carbon radicals are oxidized by Cu in a near diffusion-controlled reaction that produces an intermediate alkyl copper species.[13,27] However, α-amino radicals are much more easily oxidized to cations than the radicals investigated by Kochi.[28]

CONCLUSION

In conclusion, a photoinduced oxidative decarboxylation has been developed as a mild, inexpensive, and simple method for the generation of enamides from amino acids. The use of an acridinium photocatalyst replaces the need for toxic lead tetraacetate and allows the reaction to proceed using visible light as an economical and environmentally friendly energy input. Moreover, this process offers a potentially attractive route toward enamide and enecarbamate synthesis.

EXPERIMENTAL SECTION

General Methods. Purification was accomplished with column chromatography using silica gel (60 Å porosity, 230 × 400 mesh, standard grade) which was purchased from Sorbent Technologies (catalog no. 30930M-25). TLC analysis was performed (fluorescence quenching and potassium permanganate acid stain) with silica gel HL TLC plates with UV254 purchased from Sorbent Technologies. Celite C212-500 (545 Filter Aid) was purchased from Fisher. ^1H and ^{13}C NMR spectra were obtained on a Bruker ADVANCE 500 DRX equipped with a QNP cryoprobe. These spectra were referenced to residual protio solvent signals. HRMS data was obtained on an ESI LC-TOF Micromass LCT (Waters). HRMS data was collected using ESI mass spectrometry. Melting points were obtained with Digimelt MPA 160 SRS (no. 111278) and samples were loaded with borosilicate glass Kimble tube capillaries (no. 34505−9a). All carboxylic acid starting materials are commercially available. Photocatalysts Mes-Acr-Ph and Mes-2,7-Me_2-Mes-Acr-Ph were purchased from Sigma-Aldrich. Photocatalyst Mes-Acr-Me was purchased from TCI. All copper salts used are commercially available. Anhydrous MeCN was purchased from Acros. Final decarboxylative elimination reactions were run in borosilicate glass Biotage microwave vials (Biotage no. 355631), with Biotage caps (Biotage no. 352298), and were sealed with crimper (no. 356671). Kessil H150 Blue LED grow lights provided 450 nm light. Reactions were run in the presence of 4 Å molecular sieves (3−5 mm beads) purchased from Alfa Aesar.

Amino acid *N*-Boc Protections. *(tert-Butoxycarbonyl)leucine (**1o**).* was synthesized via boc-protection of leucine following literature procedure and optained NMR spectra matched previously reported values.[29] ^1H NMR (500 MHz, CD_3CN): δ [5.51, broad s, 1H], [4.08, q, 1H], [1.68, m, 2H], [1.53, m, 1H], [1.41, s, 9H], [0.92, d, 6H]. $^{13}C\{1H\}$ NMR (126 MHz, CD_3CN): δ 51.9, 40.1, 27.5, 24.6, 22.1, 20.7.

*2-((tert-Butoxycarbonyl)amino)-2-phenylbutanoic acid (**1l**).* 2-Amino-2-phenylbutanoic acid (900 mg, 5.02 mmol) and K_2CO_3 (714 mg, 5.17 mmol) were added to a 100 mL flask equipped with magnetic stir bar. Then, H_2O (18 mL) was added and the solution stirred for 2 h. The flask was then charged with a solution of Boc_2O (1.73 mL, 7.5 mmol) in THF (20 mL), and the reaction mixture was allowed to stir for ∼14 h. After, the reaction was refluxed for 2 days. Post reflux, the THF was removed in vacuo. To the aqueous solution, 10% NaOH was added until pH 12. The aqueous layer was then washed with DCM (∼10 mL, 2×) and acidified with citric acid until pH 3. The resulting solution was extracted with $EtOAc_2$ (∼20 mL, 3×), washed with H_2O, dried with $MgSO_4$, and condensed. The white solid isolated was washed with hexanes and used without further

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purification. ^{1}H NMR (500 MHz, CD_3CN): δ [7.44, d, 2H], [7.36, t, 2H], [7.30, t, 1H], [6.18, broad s, 1H], [2.52−2.36, m, 2H], [1.37, s, 9H], [0.85, t, 3H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): δ 129.2, 128.5, 127.0, 80.2, 66.3, 28.4, 28.2, 8.7.

General Decarboxylative Elimination Procedure for the Synthesis of Compounds 2. A microwave vial with stir bar was charged with amino acid (0.4 mmol, 1 equiv), $Cu(OAc)_2$ (109 mg, 0.6 mmol, 1.5 equiv), and Mes-2,7-Me_2-Acr-Ph^+ BF_4^- (4.9 mg, 2.5 mol %). Anhydrous MeCN (8 mL) was added to the vial followed by the addition of microwave oven activated 4 Å molecular sieves. The vial was then sealed and sparged with argon for 5 min though the septa using a 20 gage needle to bubble gas through the solvent and another needle to vent the vial. After the flask was sparged, the cap was wrapped with parafilm. The reaction was placed in front of a 450 nm 32 W blue LED light with no distance between the front of the light source and the glass wall of the reaction vessel for 14 h. After irradiation, the reaction mixture was filtered through a Celite plug using EtOAc as the wash solvent (∼10 mL) to remove Cu salts. The filtrate was concentrated and purified via flash column chromatography on silica with 1:10−1:20 EtOAc:Hexanes. Note: Enamide products were found to degrade in chloroform.

*Cyclohexyl (E/Z)-3-((tert-butoxycarbonyl)amino)acrylate (**2a**).* Isolated 60.6 mg of *Z* isomer (major) as a white solid, mp = 58−60 °C, and 39.8 mg of *E* isomer (minor) as a white solid, mp = 110−112 °C, in 93% combined yield, 40:60 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): Z isomer (major): δ [9.58 (s, 1H)], [7.22 (dd, J = 11.71, 8.86 Hz, 1H)], [4.96 (d J = 8.96, 1H)], [4.76 (m, 1H)], [1.84 (m, 2H), 1.71 (m, 2H), 1.53 (m, 1H), 1.38 (m, 4H), 1.26 (m, 1H) Σ10], [1.47 (s, 9H)]. E Isomer (minor): δ [7.95 (s, 1H)], [7.64 (dd, J = 14.07, 11.78 Hz, 1H)], [5.31 (d, J = 14.05 Hz, 1H)], [4.72 (m, 1H), 1.83 (m, 2H) 1.69 (m, 2H), 1.53 (m, 1H), 1.36 (m, 4H), 1.27 (m, 1H), Σ10], [1.44 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Z isomer: δ 169.4, 152.8, 141.2, 95.1, 82.6, 73.1, 32.2, 28.2, 26.0, 24.4. E isomer: δ 167.6, 153.3, 140.8, 99.3, 82.3, 72.6, 32.4, 28.2, 26.1, 24.5. IR (film): 3335, 2978, 2936, 2861, 1740, 1680, 1632, 1483, 1454, 1389, 1368, 1207, 1148, 1038, 1017, 970, 860 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{14}H_{23}NO_4Na$ $(M+Na)^+$ 292.1525; Found = 292.1536.

*tert-Butyl (E/Z)-3-((tert-butoxycarbonyl)amino)acrylate (**2b**).* Isolated 55.4 mg of *Z* isomer (major) as a colorless oil and 34.6 mg of *E* isomer (minor) as a white solid, mp = 100−102 °C, in 93% combined yield, 39:61 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): *Z* isomer: δ [9.61 (s, 1H)], [7.17 (dd, J = 11.65, 8.87 Hz, 1H)], [4.89 (d, J = 8.87, 1H)], [1.47 (s, 9H)], [1.45 (s, 9H)]. E isomer (minor): δ [7.89 (s, 1H)], [7.56 (dd, J = 14.09, 11.75 Hz, 1H)], [5.25 (d, J = 14.05, 1H)], [1.45 (s, 9H)], [1.44 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): *Z* isomer: δ 169.8, 152.9, 140.7, 96.3, 82.5, 81.2, 28.4, 28.2. *E* isomer: δ 167.6, 153.1, 140.2, 100.6, 82.2, 80.0, 28.4, 28.2. IR (film): 3337, 2978, 1740, 1678, 1632, 1481, 1381, 1368, 1238, 1219, 1146, 1055, 951, 872 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{12}H_{21}NO_4Na$ $(M+Na)^+$ 266.1368; Found = 266.1368.

*Benzyl (E/Z)-3-((tert-butoxycarbonyl)amino)acrylate (**2c**).* Isolated 60.0 mg of *Z* isomer (major) as a colorless oil and 47.3 mg of *E* isomer (minor) as a colorless oil in 97% combined yield, 44:56 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): *Z* isomer: δ [9.54 (s, 1H)], [7.38 (d, 4H), 7.34 (m, 1H), Σ5H], [7.28 (dd, J = 11.81, 8.84 Hz, 1H)], [5.15 (s, 2H)], [5.05 (d, J = 8.88 Hz, 1H)], [1.48 (s, 9H)]. *E* isomer: δ [8.02 (s, 1H)], [7.70 (dd, J = 14.02, 11.87 Hz, 1H)], [7.37 (d, 4H), 7.33 (m, 1H), Σ5H], [5.40 (d, J = 14.05, 1H)], [5.13 (s, 2H)], [1.45 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): *Z* isomer: δ 169.7, 152.7, 142.0, 137.4, 129.5, 129.1, 94.1, 82.8, 66.4, 28.2. *E* isomer: δ 168.0, 153.0, 141.5, 137.9, 129.4, 128.9, 98.3, 82.4, 66.2, 28.2. IR (film): 3341, 2980, 2936, 1740, 1686, 1632, 1485, 1456, 1391, 1368, 1196, 1148, 1057, 976, 860 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{15}H_{19}NO_4Na$ $(M+Na)^+$ 300.1212; Found = 300.1223.

*Cyclopentyl (E/Z)-3-((tert-butoxycarbonyl)amino)acrylate (**2d**).* Isolated 52.4 mg of *Z* isomer (major) as a colorless oil and 35.6 mg of *E* isomer (minor) as a white solid, mp = 109−112 °C, in 86% combined yield, 41:59 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): *Z* isomer: δ [9.58 (s, 1H)], [7.21 (dd, J = 11.68, 8.84 Hz, 1H)], [5.15 (m, 1H)], [4.94 (d, J= 8.86 Hz, 1H)], [1.87 (m, 2H), 1.67 (m, 6H), Σ8H], [1.47 (s, 9H)]. *E* isomer: δ [7.95 (s, 1H)], [7.61 (dd, J = 14.09, 11.76 Hz, 1H)], [5.30 (d, J = 14.08 Hz, 1H)], [5.13 (m, 1H)], [1.84 (m, 2H), 1.66 (m, 6H), Σ5H], [1.45 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): *Z* isomer: δ 169.8, 152.8, 141.2, 95.1, 82.6, 77.6, 33.3, 28.2, 24.4. *E* isomer: δ 167.9, 153.1, 140.7, 99.3, 82.3, 77.1, 33.3, 28.2, 24.4. IR (film): 3335, 2972, 2872, 1740, 1682, 1630, 1481, 1387, 1370, 1211, 1148, 1055, 1032, 974, 760 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{13}H_{21}NO_4Na$ $(M+Na)^+$ 278.1368; Found = 278.1374.

*tert-Butyl (Z)-(3-amino-3-oxoprop-1-en-1-yl)carbamate (**2e**).* Isolated 58.6 mg of *Z* isomer exclusively as a white solid, mp = 147−149 °C, in 79% yield. ^{1}H NMR (500 MHz, CD_3CN): δ [10.39 (s, 1H)], [7.06 (dd, J = 11.00, 8.76 Hz, 1H)], [6.10 (s, 1H), 5.57 (s, 1H), Σ2H], [4.99 (d, J = 8.79 Hz, 1H)], [1.45 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): δ 171.8, 153.2, 138.6, 97.0, 82.0, 28.2. IR (film): 3630, 3366, 3279, 3090, 2261, 1728, 1668, 1630, 1595, 1391, 1267, 1221, 1157, 1036, 843 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_8H_{14}N_2O_3Na$ $(M+Na)^+$ 209.0902; Found = 209.0898.

*tert-Butyl (E/Z)-styrylcarbamate (**2f**).* Isolated 76.2 mg as a mix of *E*/*Z* isomers as a colorless oil in 87% yield, 89:11 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.54 (s, Σ1H)], [7.38−7.11 (m, Σ5H)], [7.17 (dd, J = 15.0, 10.0 Hz, maj.) and 6.60 (dd, J = 11.38, 9.81 Hz, min.), Σ1H], [6.01 (d, J = 14.69 Hz, maj.) and 5.55 (d, J = 9.78 Hz, min), Σ1H], [1.46 (s, Σ9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of E/Z isomers δ 153.9, 138.0, 129.7, 129.5, 128.8, 127.3, 126.7, 125.9, 110.0, 80.8, 66.2, 28.4. IR (film): 3630, 3538, 3368, 3277, 3090, 2980, 2936, 2261, 2114, 1944, 1881, 1701, 1483, 1451, 1370, 1153, 1101, 1030 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{13}H_{17}NO_2Na$ $(M+Na)^+$ 242.1157; Found = 242.1156.

*tert-Butyl (E/Z)-(2-(naphthalen-2-yl)vinyl)carbamate (**2g**).* Isolated 85.2 mg of *E* isomer (major) as a tan solid, mp = 158−160 °C, and 10.2 mg of *Z* isomer (minor) as a yellow oil in 88% combined yield, 89:11 E:Z. ^{1}H NMR (500 MHz, CD_3CN): *E* isomer: δ [7.79 (m, 3H), 7.67 (m, 1H), 7.57 (dd, 1H), 7.42 (dddd, 2H), Σ7H], [7.33 (dd, J = 14.65, 10.68 Hz, 1H)], [6.17 (d, J = 14.70 Hz, 1H)], [1.48 (s, 9H)]. *Z* isomer: δ [7.85 (ddd, 3H), 7.80 (m, 1H), 7.49 (m, 2H), 7.42 (dd, 1H), Σ7H], [6.70 (dd, J = 11.39, 9.77 Hz, 1H)], [5.69 (d, J = 9.85, 1H)], [1.47 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): *E* isomer: δ 135.7, 134.8, 133.0, 129.4, 129.0, 128.4, 127.2, 126.1, 124.6, 124.6, 124.0, 110.1, 28.4. *Z* isomer: δ 129.9, 129.1, 128.6, 128.4, 127.6, 127.2, 127.0, 126.7, 28.3. IR (film): 3630, 3538, 3368, 3279, 3090, 2980, 2261, 2114, 1709, 1695, 1655, 1628, 1508, 1370, 1157, 1030, 858, 847 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{17}H_{19}NO_2Na$ $(M+Na)^+$ 292.1313; Found 292.1300.

*tert-Butyl (E/Z)-(4-chlorostyryl)carbamate (**2h**).* Isolated 73.7 mg as a mix of *E*/*Z* isomers as an amorphous white solid in 73% yield, 89:11 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.58 (m Σ1H)], [7.37−7.23 (m, Σ4H)], [7.18 (dd, J = 14.71, 10.65 Hz, maj.) and 6.62 (dd, J = 11.40, 9.83 Hz, min.) Σ1H], [5.98 (d, J = 14.70 Hz, maj.) and 5.51 (d, J = 9.83, min.), Σ1H], [1.45 (s, -Σ9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 153.8, 137.0, 131.47, 129.4, 127.4, 126.6, 108.7, 81.0, 28.3. IR (film): 3621, 3538, 3368, 3090, 2359, 2340, 2261, 2116, 1944, 1883, 1719, 1701, 1657, 1508, 1489, 1370, 1192, 1159, 1091, 1030, 843 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{14}H_{16}N2O_2Na$ $(M+Na)^+$ 267.1109; Found 267.1123.

*tert-Butyl (E/Z)-(2-chlorostyryl)carbamate (**2i**).* Isolated 86.3 mg as a mix of *E*/*Z* isomers as a white solid, mp = 109−111 °C, in 85% yield, 90:10 E:Z. ^{1}H NMR (500 MHz, CD_3CN): δ [7.70 (s, Σ1H)], [7.56 (d) and 7.47 (ddd) and 7.38 (dd) and 7.34 (dd) and 7.20 (m) and 7.16 (td), Σ4H], [7.21 (m, maj.) and 6.77 (dd, J = 11.52, 9.67 Hz, min.), Σ1H], [6.40 (d, J = 14.65 Hz, maj.) and 5.64 (d, J = 9.69 Hz, min.), Σ1H], [1.49 (s, Σ9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 153.8, 135.8, 132.1, 130.8, 130.5, 130.4, 129.1, 128.1, 128.0, 126.3, 105.8, 81.1, 28.3.IR (film): 3304, 2978, 1701, 1653, 1508, 1466, 1368, 1316, 1273, 1246, 1155, 1055, 1034, 716 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{13}H_{16}ClNO_2Na$ $(M+Na)^+$ 276.0767; Found 276.0778.

*tert-Butyl (E/Z)-(4-cyanostyryl)carbamate (**2j**).* Isolated 58.6 mg of *E* isomer (major) as an amorphous white solid and the 12.9 mg of *Z* isomer (minor) as a colorless oil in 73% combined yield, 82:18 E:Z.

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^{1}H NMR (500 MHz, CD_3CN): *E* isomer: δ [7.57 (d, 2H)], [7.46 (d, 2H)], [7.36 (dd, J = 14.65, 10.88 Hz, 1H)], [6.02 (d, J = 14.61 Hz, 1H)], [1.46 (s, 9H)]. *Z* isomer: δ [7.67 (d, 2H)], [7.44 (d, 2H)], [6.73 (dd, J = 11.56, 9.85 Hz, 1H)], [5.55 (d, J = 9.83, 1H)], [1.46 (s, 9H). ^{13}C{1H} NMR (126 MHz, CD_3CN): *E* isomer: δ 153.6, 143.3, 133.3, 129.3, 126.3, 120.0, 109.1, 108.3, 81.3, 28.3. Z isomer: δ 153.9, 142.0, 133.4, 129.4, 127.1, 119.8, 109.9, 106.1, 81.5, 28.2. IR (film): 3323, 2978, 2226, 1728, 1715, 1653, 1603, 1479, 1395, 1368, 1260, 1236, 1155, 1055, 1024, 764, 750 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{14}H_{16}N_2O_2Na$ $(M+Na)^+$ 267.1109; Found 267.1123.

tert-Butyl (Z)-(2-(pyridin-2-yl)vinyl)carbamate (**2k**). Isolated 37.6 mg of *Z* isomer exclusively as a yellow oil in 47% yield. ^{1}H NMR (500 MHz, CD_3CN): δ [11.1 (s, 1H)], [8.50 (ddd, 1H), 7.68 (td, 1H), 7.15 (d, 1H), 7.10 (ddd, 1H), Σ4H], [6.95 (t, J = 9.95 Hz, 1H)], [5.53 (d, J = 9.14 Hz, 1H)], [1.49 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): δ 158.7, 153.8, 148.9, 137.8, 130.4, 123.9, 121.1, 104.1, 81.4, 28.4. IR (film): 2979, 1724, 1648, 1592, 1557, 1472, 1392, 1368, 1272, 1224, 1148, 1050, 1024, 863 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{12}H_{16}N_2O_2Na$ $(M+Na)^+$ 243.1109; Found = 243.1113.

tert-Butyl (E)-(1-phenylprop-1-en-1-yl)carbamate (**2l**). Isolated 35.5 mg as a mix of *E*/*Z* isomers as a colorless oil in 76% yield, 57:43 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.41−7.24 (m, Σ5H)], [6.70 (broad d), Σ1H], [5.76 (broad s), Σ1H], [1.69 (dd, Σ3H)], [1.37 (broad d, Σ9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of E/Z isomers δ 154.6, 129.6, 129.2, 129.0, 128.5, 128.2, 126.3, 79.8, 28.4, 13.8, 13.6. IR (film): 2978, 2931, 2262, 1698, 1654, 1492, 1446, 1366, 1242, 1164, 1164, 1089, 1043, 1031 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{14}H_{19}NO_2Na$ $(M+Na)^+$ 256.1313; Found = 256.1321.

tert-butyl (E/Z)-4-((tert-butoxycarbonyl)amino)but-3-enoate (**2m**). Isolated 76.1 mg as a mix of *E*/*Z* isomer. Isolated as a colorless oil in 74% yield, 63:37 E:Z. ^{1}H NMR (500 MHz, CD_3CN): δ [7.24 (s, Σ1H)], [6.43 (dd, J = 14.40, 10.51 Hz, Σ1H), [5.04 (dt, J = 14.08, 7.12 Hz, maj.) and 4.65 (q, J = 7.86 Hz, min.), Σ1H], [2.91 (dd) and 2.87 (dd), Σ2H], [1.43 (s) and 1.42 (s), Σ18H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 172.3, 171.7, 153.9, 127.5, 126.0, 102.7, 100.6, 81.3, 80.9, 80.7, 80.4, 36.9, 33.4, 28.4, 28.2. IR (film): 3337, 2978, 2934, 2359, 2261, 1726, 1713, 1608, 1508, 1456, 1393, 1368, 1290, 1244, 1147, 1069, 1045, 1018, 951, 866, 843 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{13}H_{23}NO_4Na$ $(M+Na)^+$ 280.1525; Found = 280.1535.

tert-Butyl (E/Z)-(3-phenylprop-1-en-1-yl)carbamate (**2n**). Isolated 54.2 mg as a mix of *E*/*Z* isomers as a colorless oil in 58% yield, 66:34 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.33−7.14 (m, Σ5H)], [6.43 (dd, J = 14.01, 10.93 Hz, Σ1H], [5.16 (dt, J = 14.51, 7.25 Hz, maj.) and 4.70 (q, J = 8.16 Hz, min.), Σ1H], [3.34 (d) and 3.29 (d), Σ2H], [1.45 (s) and 1.42 (s), Σ9H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 153.9, 142.4, 141.9, 129.4, 129.3, 129.2, 129.0, 126.8, 125.9, 123.9, 109.4, 107.6, 80.2, 36.5, 32.2, 28.4. IR (film): 3621, 3530, 3366, 3090, 2261, 1944, 1881, 1719, 1676, 1495, 1452, 1368, 1236, 1163, 1042 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{14}H_{19}NO_2Na$ $(M+Na)^+$ 256.1313; Found = 256.1303.

tert-Butyl (E/Z)-(3-methylbut-1-en-1-yl)carbamate (**2o**). Isolated 48.4 mg as a mix of *E*/*Z* isomers as a white solid, mp = 76−78 °C, in 65% yield, 75:25 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.00 (s, Σ1H)], [6.32 (dd, J = 14.09, 10.68 Hz, maj.) and 6.21 (t, J = 10.05 Hz, min.), Σ1H], [5.00 (dd, J = 14.32, 7.09 Hz, maj.) and 4.38 (t, J = 9.34 Hz, min.), Σ1H], [2.49 (m, min.) and 2.25 (m, maj.), Σ1H], [1.44 (s) and 1.42 (s), Σ9H], [0.96 (d, maj.) and 0.93 (d, min.), Σ6H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 154.1, 122.8, 117.8, 80.1, 29.7, 28.5, 23.4. IR (film): 3621, 3530, 3366, 3279, 3090, 2261, 1944, 1881, 1719, 1676, 1494, 1452, 1368, 1236, 1163, 1042 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{10}H_{19}NO_2Na$ $(M+Na)^+$ 208.1313; Found = 208.1323.

tert-Butyl (E)-methyl(3-methylbut-1-en-1-yl)carbamate (**2p**). Isolated 23.6 mg as a colorless oil in 30% yield. ^{1}H NMR (500 MHz, CD_3CN): δ [6.87 (broad s, Σ1H)], [4.82 (broad s, Σ1H)], [2.92 (s, Σ3H)], [2.33 (broad s, Σ1H)], [1.46 (s, Σ9H)], [0.99 (d, Σ6H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of E/Z isomers δ 127.3, 116.7, 81.2, 30.3, 28.4, 23.9. IR (film): 3105, 2959, 2930, 2862, 2358, 2278, 2138, 2083, 1701, 1654, 1388, 1367, 1326, 1150 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{11}H_{22}NO_2Na$ $(M+Na)^+$ 223.1548; Found = 223.1560.

tert-Butyl (E/Z)-(2-methylbut-1-en-1-yl)carbamate (**2q**). Isolated 59.1 mg as a mix of *E*/*Z* isomers as a colorless oil in 80% yield, 65:37 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [6.68 (s, Σ1H)], [6.15 (d, maj.) and 6.10 (d, min.), Σ1H], [1.97 (m, Σ2H)], [1.63 (d, maj.) and 1.55 (d, min.), Σ3H], [1.43 (s, Σ9H)], [0.97 (t, maj.) and 0.94 (t, min.), CH_3CH_2−, Σ3H] (confirmed E/Z assignments by NOESY, see the Supporting Information for 2D spectra). ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 154.3, 79.9, 30.1, 28.4, 24.0, 19.7, 14.6, 13.3, 12.3. IR (film): 2978, 2937, 1701, 1497, 1368, 1153, 1051, 809 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{10}H_{19}NO_2Na$ $(M+Na)^+$ 208.1313; Found = 208.1340.

Benzyl (E/Z)-prop-1-en-1-ylcarbamate (**2r**). Isolated 48.9 mg as a mix of *E*/*Z* isomers as a yellow oil in 64% yield, 53:47 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.47−7.26 (m, Σ5H), [6.40 (m, Σ1H)], [5.11 (m, Σ2H)], [5.11 (m, maj.) and 4.67 (p, min.), Σ1H], [1.62 (dd, Σ3H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 155.0, 154.6, 137.9, 129.4, 128.9, 128.7, 125.4, 124.1, 106.2, 104.5, 167.3, 167.1, 14.9, 11.1. IR (film): 3312, 3065, 3032, 2857, 1703, 1682, 1518, 1454, 1294, 1234, 1116, 1028, 947 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{11}H_{13}NO_2Na$ $(M+Na)^+$ 214.0844; Found = 214.0854.

tert-Butyl 3,4-dihydropyridine-1(2H)-carboxylate (**2s**). Isolated 39.9 mg as a colorless oil in 54% yield. ^{1}H NMR (500 MHz, CD_3CN): δ [6.74 (dd, 1H)], [4.84 (d, 1H)], [3.50 (s, 2H)], [1.99 (m, 2H)], [1.77 (m, 2H)], [1.44 (s, 9H)]. ^{13}C{1H} NMR (126 MHz, CD_3CN): δ 153.4, 152.9, 126.4, 125.9, 106.6, 106.0, 80.9, 43.3, 42.2, 28.4, 22.5. IR (film): 3458, 2976, 2934, 1697, 1651, 1406, 1368, 1302, 1254, 1234, 1167, 1115, 1072, 1053, 993, 878 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{10}H_{16}NO_2$ (M-H) 182.1181; Found = 182.1184.

tert-Butyl (E/Z)-pent-1-en-1-ylcarbamate (**2t**). Isolated 48.3 mg as a mix of *E*/*Z* isomers as a colorless oil in 65% yield, 70:30 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.08 (s, maj.) and 6.96 (s, min.), Σ1H], [6.34 (m, Σ1H)], [5.00 (dt, J = 14.34, 7.20 Hz, maj.) and 5.12 (q, J = 7.99 Hz, min.), Σ1H], [1.94 (m, Σ2H), *overlaps with CH_3CN*], [1.43 (s) and 1.41 (s), Σ9H], [1.35 (m, Σ2H)], [0.90 (t) and 0.87 (t), Σ3H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 154.0, 124.9, 123.2, 110.3, 109.1, 80.0, 32.5, 28.4, 24.0, 23.4, 13.8. IR (film): 3327, 2961, 2930, 2872, 1701, 1676, 1508, 1452, 1368, 1242, 1165, 1047, 1022, 951 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{10}H_{19}NO_2Na$ $(M+Na)^+$ 208.1313; Found = 208.1311.

(E/Z)-N-(Pent-1-en-1-yl)acetamide (**2u**). Isolated 31.7 mg as a mix of *E*/*Z* isomers as a colorless oil in 62% yield, 76:24 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [8.07 (s) and 7.89 (s), Σ1H], [6.62 (m, maj.) and 6.58 (m, min.), Σ1H], [5.15 (dt, J = 14.43, 7.23 Hz, maj.) and 4.64 (dt, J = 9.15, 7.64 Hz, min), Σ1H], [2.05−1.96 (m, Σ2H)], [1.96 (s) and 1.88 (s), Σ3H], [1.37 (m, Σ2H)], [0.92 (t) and 0.87 (t), Σ3H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 168.5, 167.9, 123.9, 122.0, 112.4, 111.2, 32.5, 28.4, 23.8, 23.4, 22.9, 13.8. IR (film): 3279, 3200, 3063, 2959, 2928, 2872, 1657, 1528, 1460, 1437, 1371, 1302, 1282, 1172, 1038, 955 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_7H_{13}NONa$ $(M+Na)^+$ 150.0895; Found = 150.0888.

Benzyl (E/Z)-pent-1-en-1-ylcarbamate (**2v**). Isolated 65.6 mg as a mix of *E*/*Z* isomers as a colorless oil in 75% yield, 74:26 *E*:*Z*. ^{1}H NMR (500 MHz, CD_3CN): δ [7.45−7.29 (m, Σ5H)], [6.38 (m, Σ1H)], [5.10 (m, Σ2H)], [5.09 (m, maj.) and 4.60 (q, J = 7.99 Hz, min), Σ1H], [1.96 (m, Σ2H)], [1.35 (m, Σ2H)], [0.89 (t) and 0.87 (t), Σ3H]. ^{13}C{1H} NMR (126 MHz, CD_3CN): Mix of *E*/*Z* isomers δ 155.0, 154.6, 137.9, 129.4, 128.9, 128.7, 124.8, 123.1, 111.5, 110.4, 67.1, 32.4, 28.4, 23.9, 23.4, 13.8. IR (film): 2963, 2123, 1714, 1679, 1521, 1237, 1051, 831 cm^{-1}. HRMS (ESI-TOF) *m*/*z*: Calc'd for $C_{13}H_{17}NO_2Na$ $(M+Na)^+$ 242.1157; Found = 242.1149.

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■ ASSOCIATED CONTENT

Supporting Information

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^{1}H, ^{13}C, and NOESY NMR spectra and photo of decarboxylative elimination reaction setup (PDF)

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Notes

The authors declare no competing financial interest.

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