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[2+2+2] Cyclotrimerization of Alkynes and Isocyanates/Isothiocyanates Catalyzed by Ruthenium−Alkylidene Complexes

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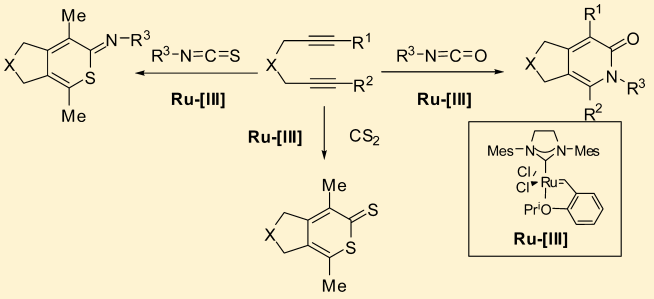
Supporting Information

ABSTRACT: Ruthenium carbene catalysts are able to catalyze crossed [2+2+2] cyclotrimerizations of α,ω-diynes with isocyanates, isothiocyanates, and carbon disulfide. Both aliphatic and aromatic isocyanates can be used to produce fused 2-pyridones, although aliphatic isocyanates were more reactive. Aromatic isocyanates give better results when they bear electron-donating substituents. The reaction of unsymmetrical α,ω-diynes gave a product only with the substituent adjacent to the 2-pyridone nitrogen. Isothiocyanates gave thiopyranimines upon reaction with the C═S bond, whereas CS_2 reacted efficiently to give a thioxothiopyrane.



Metal-catalyzed [2+2+2] cycloadditions are elegant, atom-efficient, and group tolerant reactions catalyzed by complexes of more than 17 metals.[1−11] When this reaction involves an isocyanate, it gives access to valuable heterocycles such as 2-pyridones, which are useful for the production of biologically active products. Pyridones display a variety of interesting biological properties including anticancer, antiviral, and antibacterial activity.[12,13] The transition-metal-mediated cyclotrimerization of two alkynes with isocyanates was first pioneered by Yamazaki[14,15] followed by Vollhardt using Co-mediated methodologies.[16,17] Hoberg reported some nickel-catalyzed reactions in early times.[18] Later, other groups developed catalytic reaction conditions using rhodium[19−22] and nickel[23] complexes that need preactivation. Recently, Takeuchi used $[Ir(cod)Cl]_2$ combined with phosphines as an efficient catalyst for the cycloaddition of α,ω-diynes with isocyanates.[24] A complementary strategy consisting of a [2+2+2] cycloaddition of alkenyl isocyanates with alkynes to give lactams and vinylogous amides has been extensively developed by Rovis using rhodium catalysis.[25−31]

Ruthenium catalysts such as [Cp*RuCl(cod)] are able to catalyze trimerization of alkynes[32−35] and are useful in the [2+2+2] cycloaddition of 1,6-diynes with isocyanates to afford bicyclic pyridones in good yields.[36−39] With isothiocyanates, the reaction products are thiopyranimines instead of the parent thiopyridones, which indicates a selective reaction with the C═S bond.[38,39]

Blechert reported for the first time the use of Grubbs' first generation catalyst [**Ru**]-**I** for the intramolecular cyclotrimerization of triynes.[40] Other groups have shown that [**Ru**]-**I** mediates in cyclotrimerization [2+2+2] reactions for the synthesis of benzene rings.[41−43] Later we disclosed the use of second generation Grubbs' catalysts [**Ru**]-**II** and the Hoveyda−Grubbs' complex [**Ru**]-**III** for the synthesis of fused benzenes.[44] Recently, we have used [**Ru**]-**III** for the efficient synthesis of pyridines.[45]

We present here the synthesis of a wide variety of functionalized 2-pyridones, obtained for the first time through an easy experimental procedure based on ruthenium carbene catalysts. Regioselectivity with unsymmetric diynes is studied as well as the reactions with isothiocyanates and carbon disulfide.

To optimize the reaction, diyne **1a** was reacted with ethyl isocyanate under a variety of reaction conditions (Table 1). The first tests were carried out in dichloroethylene (DCE) with 5 mol % of catalyst [**Ru**]-**III** and 5 equiv of isocyanate. Heating was needed to achieve total conversion and good yields in product **2a** (entries 1 and 2, Table 1). Other solvents gave good results under reflux with acetone being the best option (entries 3−6). The reaction was then performed in a sealed tube as we had observed a favorable effect of this method when developing the reaction of diynes with nitriles.[45] In the present study, 2-pyridone **2a** was isolated in 88% yield after the reaction was carried out in DCE in a sealed tube for 15 min and in 93% when the reaction time was extended to 2 h (entries 7 and 8). When the catalyst loading was reduced to 2 mol %, the reaction still gave good yield of the 2-pyridone but without total conversion (78%, entry 9). Next, for comparison reasons, we used our best conditions (5 equiv of isocyanate, in DCE at 90 °C, sealed tube, procedure A), with [**Ru**]-**I** and [**Ru**]-**II** as the catalysts (entries 10 and 11). Both complexes gave product **2a** with good yields although slightly below that achieved with [**Ru**]-**III**, which was used for the rest of the study.

Our next aim was establishing the scope of the process reacting diynes **1a−d** with different isocyanates (Table 2). 2,7-

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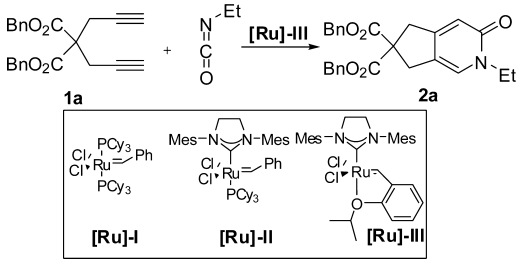
Table 1. Selection of Reaction Conditions for the Cyclotrimerization Reaction of 1a with Ethyl Isocyanate

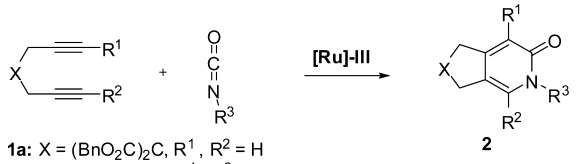


entry	solvent	temp (°C)	time	cat. (mol %)	yield (%)[a] 1a	2a
1	DCE	rt	48 h	5	45	25
2	DCE	83[b]	2 h	5	<5	82
3	acetone	56[b]	2 h	5	<5	91
4	toluene	110[b]	2 h	5	32	66
5	DCM	40[b]	2 h	5	<5	88
6	dioxane	102[b]	2 h	5	25	64
7	DCE	90[c]	15 min	5	<5	88
8	DCE	90[c]	2 h	5	<5	93
9	DCE	90[c]	2 h	2	15	78
10	DCE	90[c]	2 h[d]	5	<5	85
11	DCE	90[c]	2 h[e]	5	7	81

[a]Reactions were conducted, at 0.28 mM concentration of diyne with 5 equiv of isocyanate. [b]Refluxing conditions. [c]Conducted in a sealed tube. [d]With [**Ru**]-**I** as the catalyst. [e]With [**Ru**]-**II** as the catalyst.

Nonadiyne **1b,** in which triple bonds are internal, was submitted to a reaction with ethylisocyanate and gave the corresponding 2-pyridone **2b** albeit in lower yields than the parent **1a** in which triple bonds are terminal (entries 1 and 2). This result is possibly due to steric interactions during complexation with the catalyst. Under the selected procedure A, *N*-tosyl tethered diynes **1c,d** produced pyrrolo[3,4-*c*]-pyridinones **2c,d** in low yields. Slow addition of a solution of the isocyanate to a refluxing mixture of the diyne and the catalyst in DCE over 4 h improved the results and **2c,d** were isolated in moderate yields (entries 3 and 4). For these latter conditions, 2.5 mol % of catalyst was added at the beginning, and an additional 2.5 mol % of catalyst was added after 2 and 4 h of the initial catalyst addition (total 7.5 mol %, procedure B). The reactions of **1a** with other aliphatic isocyanates (entries 5−11) gave good to excellent yields (65−99%) except with (*S*)-1-phenylethyl isocyanate (entry 9) possibly due to steric hindrance. With this reagent, we isolated pyridone (−)-**2h**. In the case of the reaction of diyne **1c** with benzyl isocyanate, acceptable yields in **2k** were reached under condition B (entry 12). On the other hand aromatic isocyanates gave poorer results and showed a marked dependence on the electronic character of the ring. Thus, phenyl isocyanate reacted with **1a** in refluxing acetone to give the corresponding pyridone **2l** in 35% yield. When DCE was used at 90 °C in sealed tube, the yield was raised to 45% (entries 13 and 14). Slow addition of a solution of the isocyanate (procedure B) allowed an increase in yield up to 61% (entry 15). Thus, we used the slow addition procedure with the rest of aromatic isocyanates. Moreover, diyne **1b** reacted poorly with phenyl isocyanate under procedure B (entry 16). In view of this result, we carried out the reaction of **1b** and phenyl isocyanate using [**Ru**]-**I** as the catalyst, which is a less bulky complex (entry 17). These conditions allowed a marginal improvement of the yield in **2m** (from 34 to 41%). The reactions of **1a,b** with *o*- and *p*-methoxyphenyl isocyanates (entries 18−20) gave the corresponding 2-pyridones in improved yields compared with those for the parent phenyl derivatives. In addition, reactions with *p*-methyl and naphthyl isocyanates with **1a** gave positive results (entries 21 and 22). On the other hand, worse results were observed with *p*-chloro and *p*-nitrophenyl isocyanates. (entries 23−25). Thus, aromatic isocyanates with electron-donating groups give better results than those with electron-poor rings.

Table 2. Scope of the 2-Pyridone Synthesis



1a: X = $(BnO_2C)_2C$, R^1, R^2 = H
1b: X = $(BnO_2C)_2C$, R^1, R^2 = Me
1c: X = TsN, R^1, R^2 = H
1d: X = TsN, R^1, R^2 = Me

entry	diyne	R^3	solvent	temp (°C)	product	yield (%)[a,b]
1	**1b**	Et−	DCE	90[c]	**2b**	82
2	**1b**	Et−	acetone	56[d]	**2b**	52
3	**1c**	Et−	DCE	83-slow[e]	**2c**	55
4	**1d**	Et−	DCE	83-slow[e]	**2d**	48
5	**1a**	^{i}Pr−	DCE	90[c]	**2e**	71
6	**1a**	CH_3—$(CH_2)_5$−	DCE	90[c]	**2f**	68
7	**1a**	Cy−	DCE	90[c]	**2g**	75
8	**1a**	Cy−	acetone	56[d]	**2g**	50
9	**1a**	PhCH(CH_3)−	DCE	90[c]	(−)-**2h**	32
10	**1a**	CH_2=CH—CH_2-	DCE	90[c]	**2i**	65
11	**1a**	Bn−[f]	DCE	90[c]	**2j**	93
12	**1c**	Bn−[f]	DCE	83-slow[e]	**2k**	61
13	**1a**	Ph−	acetone	56[d]	**2l**	35
14	**1a**	Ph−	DCE	90[c]	**2l**	45
15	**1a**	Ph−	DCE	83-slow[e]	**2l**	61
16	**1b**	Ph−	DCE	83-slow[e]	**2m**	34
17	**1b**	Ph-	DCE	90[e,g]	**2m**	41
18	**1a**	*o*-MeO−Ph−	DCE	83-slow[e]	**2n**	75
19	**1a**	*p*-MeO−Ph−	DCE	83-slow[e]	**2o**	77
20	**1b**	*p*-MeO−Ph−	DCE	83-slow[e]	**2p**	53
21	**1a**	*p*-Me−Ph−	DCE	83-slow[e]	**2q**	58
22	**1a**	1-naphthyl−	DCE	83-slow[e]	**2r**	52
23	**1a**	*p*-Cl—Ph−	DCE	83-slow[e]	**2s**	43
24	**1a**	*p*-NO_2—Ph−	DCE	83-slow[e]	**2t**	35
25	**1b**	*p*-NO_2—Ph−	DCE	83-slow[e]	**2u**	28

[a]Reactions were conducted at 0.28 mM concentration of diyne with 5 equiv of isocyanate and 5 mol % of [**Ru**]-**III**. [b]Yield (%) of pure product. [c]Conducted in sealed tube, reaction time 2 h. [d]Reflux. [e]Slow addition over 4 h of a solution of the isocyanate to a refluxing solution of the diyne and the catalysts followed by 12 h of reflux. [f]Bn = benzyl. [g]5 mol % of [**Ru**]-**I** was used.

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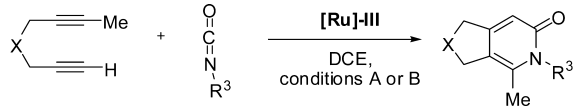
The next step was the study of the regioselectivity of the pyridone synthesis with nonsymmetric diynes. Thus, we reacted diynes **1e,f** with benzyl and phenyl isocyanates (Scheme 1).

Scheme 1. Cyclotrimerization of Nonsymmetric Diynes with Isocyanates



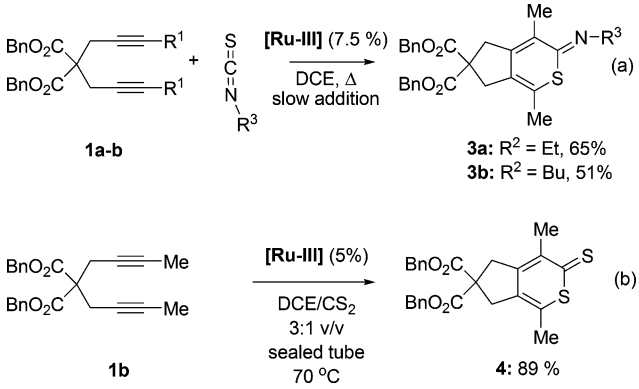
1e: X= $(BnO_2C)_2C$,
1f: X= TsN,

2v: X= $(BnO_2C)_2C$, R^3 = Ph-CH_2-, Cond. A: 61 %
2w: X= $(BnO_2C)_2C$, R^3 = Ph-, Cond. B: 38 %
2x: X= TsN, R^3 = Ph-CH_2-, Cond. A: 67 %
2y: X= TsN, R^3 = Ph- , Cond. B: 42 %

The reactions proceeded with better yields in the case of benzyl isocyanate (**2v**, 61%, **2x**, 67%, procedure A) than with phenyl isocyanate (**2w**, 38%; **2y**, 42%, procedure B), following the tendency observed in the previous study. The reactions were totally regioselective to give the corresponding 2-pyridones as a single product in which the methyl group was adjacent to the nitrogen.[46] This regioselectivity is the same observed with previously published reactions catalyzed by CpRu(cod)Cl.[38] On the other hand, Takeuchi reported recently the Ir-catalyzed reaction for the synthesis of 2-pyridones in which the regioselectivity was opposite to the Ru-catalyzed reaction and the bulky group was situated at the α-position of the carbonyl group.[24]

Our next objective was to explore the [**Ru**]-**III**-catalyzed [2+2+2] cycloaddition of diynes with sulfur containing heterocumulenes. Thus, diynes **1a** and **1b** were treated with ethyl and butyl isothiocyanates and with carbon disulfide. The results are summarized in Scheme 2. One initial observation

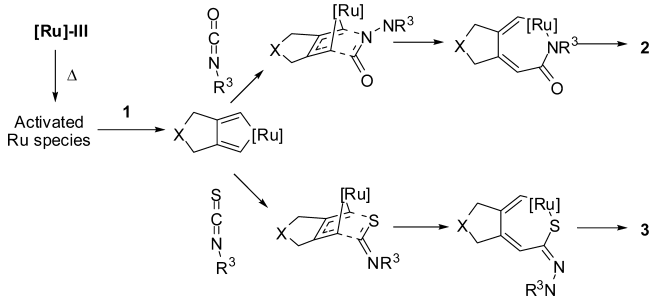
Scheme 2. Reaction of Diynes with Isothiocyanates and with Carbon Disulfide



was that **1a**, with terminal triple bonds, did not give the desired products and only sluggish reaction mixtures were obtained. On the other hand, diyne **1b** reacted with aliphatic isothiocyanates to give thiopyranimines **3a,b** in moderate yields (65–51% procedure B, Scheme 2a). As previously noted by Yamamoto, the C═S bond is more reactive toward coordination with ruthenium and thus the thiopyridone is not obtained. In addition, the same diyne reacted efficiently with carbon disulfide (**1b** was solved in DCE/CS_2, 3:1 v/v, and treated with 5 mol % of **Ru**-[**III**] in a sealed tube at 70 °C for 2 h) to give **4** in excellent yield (89%, Scheme 2b).

Our results show that ruthenium carbenes such as [**Ru**]-**III** are able to catalyze the cyclotrimerizations with isocyanates and isothiocyanates with similar results and limitations as CpRuCl-based complexes.[38] Previous works on cyclotrimerization of alkynes catalyzed by [**Ru**]-**I** assumed a cascade metathetic mechanism.[40] However, we and others have shown that the [**Ru**]-**III** complex produces new activated species when submitted to heat or pressure.[47] Thus, we believe that under our conditions, the carbenic complex is modified and forms a different species that behaves in a similar way as Cp*RuCl. Therefore, a reaction pathway as depicted in Scheme 3 is

Scheme 3. Reaction Course for the 2-Pyridone and Thiopyranimine Formation



plausible. After formation of a ruthenacyclopentadiene, a C═X bond is inserted into a Ru—C bond. In the case of isothiocyanates, the strong coordinating ability of sulfur makes the C═S bond preferred for the coordination. Final reductive elimination of the ruthenium affords the final products **2** and **3**. The origin of the regioselectivity with unsymmetrical diynes is not clear yet but could be due to steric interactions of the substituents of the triple bond with the NHC ligand of the ruthenium catalyst. However, an electronic effect of the diyne substituents on the ruthenacycle cannot be ruled out, and further studies with diynes bearing substituents with different electronic properties will give more data. This and other mechanistic aspects need further studies, which are underway in our group.

In conclusion, we have shown a new nonmetathetic application of ruthenium carbenes as efficient catalysts for crossed diyne-heterocumulene cyclotrimerizations. This methodology offers a new way to synthesize 2-pyridones and other interesting fused heterocycles.

EXPERIMENTAL SECTION

General Procedure for Synthesis of 2-Pyridones 2 and Thiopyranimines 3. Procedure A: A solution of **Ru**-[**III**] (9 mg, 0.014 mmol) in 1,2-dichloroethane (2 mL) was added to a solution of the diyne **1** (0.28 mmol) and the isocyanate (1.40 mmol) in the same solvent (2 mL) contained in a pressure flask. The flask was sealed, introduced in a 90 °C bath, and the resulting mixture was stirred for 2 h. After the flask was cooled to rt, the reaction mixture was filtered through Celite, the solvent was eliminated under reduced pressure, and the residue was purified by silica-gel flash column chromatography with mixed solvents (hexane/ethyl acetate). Evaporation of the solvent afforded the analytically pure pyridones **2**. **Procedure B**: To a solution of the isocyanate (1.40 mmol) and **Ru**-[**III**] (4.5 mg, 0.007 mmol) in refluxing 1,2-dichloroethane (2 mL) was added a solution of the diyne **1** (0.28 mmol) in 1,2-dichloroethane (2 mL) over 4 h using a syringe pump. Two hours and 4 h after initiating the reaction, additional **Ru**-[**III**] (4.5 mg, 0.007 mmol) was added dissolved in 1,2-dichloroethane (1 mL). Reflux was maintained for an additional 12 h. Then, the reaction was cooled to rt, the reaction mixture was filtered through

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Celite, the solvent was eliminated under reduced pressure, and the residue was purified by silica-gel flash column chromatography with mixed solvents (hexane/ethyl acetate). Evaporation of the solvent afforded the analytically pure pyridones **2** or thiopyranimines **3**.

Dibenzyl 2-Ethyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2a. Procedure A: **1a** (100 mg, 0.28 mmol) and isocyanatoethane (100 mg, 1.40 mmol) afforded 112 mg (93%) of **2a** (brown oil). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.31 (t, J = 7.2 Hz, 3H), 3.35 (d, J = 0.9 Hz, 2H), 3.42 (d, J = 1.0 Hz, 2H), 3.91 (q, J = 7.2 Hz, 2H), 5.13 (s, 4H), 6.40 (s, 1H), 7.09 (s, 1H), 7.20−7.24 (m, 4H), 7.30−7.33 (m, 6H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 15.2, 37.0, 40.1, 45.3, 61.3, 68.1, 115.1, 119.6, 128.5, 128.9, 129.0, 131.2, 135.4, 155.3, 162.7, 170.7 ppm. IR (NaCl): 1748, 1667 cm^{-1}. MS (ESI): m/z = 432 $[M + H]^+$, 864 $[2M + 2H]^{2+}$. Anal. Calcd for $C_{26}H_{25}NO_5$: C, 72.37; H, 5.84; N, 3.25. Found: C, 72.46; H, 5.72; N, 3.36.

Dibenzyl 2-Ethyl-1,4-dimethyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2b. Procedure A: **1b** (110 mg, 0.28 mmol) and isocyanatoethane (100 mg, 1.40 mmol) afforded 105 mg (82%) of **2b** (brown oil). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.26 (t, J = 7.1 Hz, 3H), 2.02 (s, 3H), 2.25 (s, 3H), 3.36 (s, 2H), 3.41 (s, 2H), 4.06 (q, J = 7.1 Hz, 2H), 5.13 (s, 4H), 7.20−7.24 (m, 4H), 7.30−7.33 (m, 6H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.4, 13.8, 16.8, 37.8, 39.2, 39.8, 59.5, 67.7, 116.9, 120.2, 128.1, 128.5, 128.6, 135.2, 135.7, 149.0, 163.3, 170.8 ppm. IR (NaCl): 1747, 1667 cm^{-1}. MS (ESI): m/z = 460 $[M + H]^+$, 461 $[M + 2H]^{2+}$. Anal. Calcd for $C_{28}H_{29}NO_5$: C, 73.18; H, 6.36; N, 3.05. Found: C, 73.02; H, 6.48; N, 2.87.

5-Ethyl-2-tosyl-2,3-dihydro-1*H*-pyrrolo[3,4-*c*]pyridin-6(5*H*)-one, 2c. Procedure B: **1c** (70 mg, 0.28 mmol) and isocyanatoethane (100 mg, 1.40 mmol) afforded 49 mg (55%) of **2c** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.30 (t, J = 7.2 Hz, 3H), 2.43 (s, 3H), 3.92 (q, J = 7.2 Hz, 2H), 4.37 (s, 2H), 4.38 (s, 2H), 6.37 (s, 1H), 7.14 (s, 1H), 7.34 (d, J = 8.0 Hz, 2H), 7.74 (d, J = 8.3 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.7, 20.5, 44.2, 49.1, 51.2, 112.3, 114.8, 126.6, 129.0, 129.4, 132.0, 143.2, 149.8, 160.8 ppm. IR (NaCl): 2926, 2857, 1733, 1551 cm^{-1}. MS (ESI): m/z = 319 $[M + H]^+$, 320 $[M + 2H]^{2+}$. Anal. Calcd for $C_{16}H_{18}N_2O_3S$: C, 60.36; H, 5.70; N, 8.80. Found: C, 60.49; H, 5.85; N, 8.70.

5-Ethyl-4,7-dimethyl-2-tosyl-2,3-dihydro-1*H*-pyrrolo[3,4-*c*]-pyridin-6(5*H*)-one, 2d. Procedure B: **1d** (78 mg, 0.28 mmol) and isocyanatoethane (100 mg, 1.40 mmol) afforded 46 mg (48%) of **2d** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.24 (t, J = 7.1 Hz, 3H), 1.97 (s, 3H), 2.23 (s, 3H), 2.43 (s, 3H), 4.05 (q, J = 7.1 Hz, 2H), 4.37 (s, 4H), 7.35 (d, J = 8.0 Hz, 2H), 7.76 (d, J = 8.3 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.3, 13.7, 16.9, 21.6, 39.8, 51.4, 52.3, 113.5, 119.1, 127.6, 130.0, 133.2, 135.5, 144.1, 145.0, 162.9 ppm. IR (NaCl): 2915, 1678, 1552 cm^{-1}. MS (ESI): m/z = 347 $[M + H]^+$, 348 $[M + 2H]^{2+}$. Anal. Calcd for $C_{18}H_{22}N_2O_3S$: C, 62.40; H, 6.40; N, 8.09. Found: C, 62.29; H, 6.61; N, 7.97.

Dibenzyl 2-Isopropyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2e. Procedure A: **1a** (100 mg, 0.28 mmol) and 2-isocyanatopropane (120 mg, 1.40 mmol) afforded 88 mg (71%) of **2e** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.30 (d, J = 6.8 Hz, 6H), 3.37 (d, J = 1.0 Hz, 2H), 3.42 (d, J = 1.1 Hz, 2H), 5.13 (s, 4H), 5.19−5.29 (m, 1H), 6.39 (s, 1H), 7.12 (s, 1H), 7.21−7.23 (m, 4H), 7.30−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 22.1, 36.8, 39.7, 46.1, 60.8, 67.7, 114.3, 119.2, 126.5, 128.0, 128.5, 128.6, 135.1, 153.9, 162.1, 170.4 ppm. IR (NaCl): 1733, 1679, 1606 cm^{-1}. MS (ESI): m/z = 446 $[M + H]^+$, 447 $[M + 2H]^{2+}$. Anal. Calcd for $C_{27}H_{27}NO_5$: C, 72.79; H, 6.11; N, 3.14. Found: C, 73.00; H, 5.98; N, 3.25.

Dibenzyl 2-Hexyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2f. Procedure A: **1a** (100 mg, 0.28 mmol) and 1-isocyanatohexane (178 mg, 1.40 mmol) afforded 93 mg (68%) of **2f** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.87 (t, J = 6.8 Hz, 3H), 1.25−1.30 (m, 6H), 1.65−1.70 (m, 2H), 3.34 (d, J = 0.9 Hz, 2H), 3.42 (d, J = 1.1 Hz, 2H), 3.83 (t, J = 7.5 Hz, 2H), 5.13 (s, 4H), 6.39 (s, 1H), 7.06 (s, 1H), 7.20−7.23 (m, 4H), 7.30−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.0, 22.5, 26.4, 29.4, 31.4, 36.6, 39.7, 50.0, 60.9, 67.7, 114.7, 118.9, 128.1, 128.5, 128.6, 131.3, 135.1, 154.7, 162.4, 170.4 ppm. IR (NaCl): 2930, 2857, 1733, 1674, 1601, 1560 cm^{-1}. MS (ESI): m/z = 488 $[M + H]^+$, 489 $[M + 2H]^{2+}$. Anal. Calcd for $C_{30}H_{33}NO_5$: C, 73.90; H, 6.82; N, 2.87. Found: C, 73.64; H, 6.71; N, 3.00.

Dibenzyl 2-Cyclohexyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2g. Procedure A: **1a** (100 mg, 0.28 mmol) and isocyanatocyclohexane (175 mg, 1.40 mmol) afforded 102 mg (75%) of **2g** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.16−1.78 (m, 6H), 1.84−1.91 (m, 4H), 3.36 (d, J = 1.1 Hz, 2H), 3.42 (d, J = 1.3 Hz, 2H), 4.81−4.88 (m, 1H), 5.13 (s, 4H), 6.39 (s, 1H), 7.14 (s, 1H), 7.20−7.26 (m, 4H), 7.30−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.5, 25.8, 32.8, 36.8, 39.7, 53.7, 60.9, 67.7, 114.3, 118.9, 127.3, 128.0, 128.5, 128.6, 135.1, 153.8, 162.1, 170.4 ppm. IR (NaCl): 2926, 2853, 1733, 1674, 1606 cm^{-1}. MS (ESI): m/z = 486 $[M + H]^+$, 487 $[M + 2H]^{2+}$. Anal. Calcd for $C_{30}H_{31}NO_5$: C, 74.21; H, 6.43; N, 2.88. Found: C, 74.02; H, 6.58; N, 2.75.

Dibenzyl (*S*)-3-Oxo-2-(1-phenylethyl)-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, (−)-2h. Procedure A: **1a** (100 mg, 0.28 mmol) and (*S*)-(1-isocyanatoethyl)benzene (206 mg, 1.40 mmol) afforded 46 mg (32%) of (−)-**2h** (brown oil), $[\alpha]^{25}_D$ −66.5 (c 0.02, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.66 (d, J = 7.1 Hz, 3H), 3.21 (dd, J_1 = 16.0 Hz, J_2 = 1.3 Hz, 1H), 3.22 (d, J = 17.1 Hz, 1H), 3.41 (d, J = 1.2 Hz, 2H), 5.10 (s, 2H), 5.12 (s, 2H), 6.41 (q, J = 7.0 Hz, 1H), 6.44 (s, 1H), 6.88 (s, 1H), 7.18−7.22 (m, 4H), 7.28−7.37 (m, 11H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 19.1, 36.7, 39.7, 52.3, 60.7, 67.6, 67.7, 114.3, 119.4, 127.5, 127.9, 128.0, 128.4, 128.5, 128.6, 128.8, 135.1, 140.4, 154.3, 162.2, 170.3, 170.4 ppm. IR (NaCl): 1738, 1678 cm^{-1}. MS (ESI): m/z = 508 $[M + H]^+$, 509 $[M + 2H]^{2+}$. Anal. Calcd for $C_{32}H_{29}NO_5$: C, 75.72; H, 5.76; N, 2.76. Found: C, 75.64; H, 5.58; N, 2.61.

Dibenzyl 2-Allyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2i. Procedure A: **1a** (100 mg, 0.28 mmol) and 3-isocyanatoprop-1-ene (116 mg, 1.40 mmol) afforded 81 mg (65%) of **2i** (brown oil).^{1}H NMR (400 MHz, $CDCl_3$): δ 3.34 (d, J = 1.1 Hz, 2H), 3.42 (d, J = 1.1 Hz, 2H), 4.50 (d, J = 5.8 Hz, 2H), 5.13 (s, 4H), 5.16 (dd, J_1 = 17.1 Hz, J_2 = 1.2 Hz, 1H), 5.24 (dd, J_1 = 10.2 Hz, J_2 = 1.2 Hz, 1H), 5.86−5.96 (m, 1H), 6.42 (s, 1H), 7.06 (s, 1H), 7.21−7.23 (m, 4H), 7.31−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 36.5, 39.7, 51.1, 60.9, 67.7, 114.7, 118.4, 119.2, 128.0, 128.5, 128.6, 130.8, 132.8, 135.0, 155.1, 162.2, 170.3 ppm. IR (NaCl): 2930, 2853, 1733, 1678, 1606 cm^{-1}. MS (ESI): m/z = 444 $[M + H]^+$, 445 $[M + 2H]^{2+}$. Anal. Calcd for $C_{27}H_{25}NO_5$: C, 73.12; H, 5.68; N, 3.16. Found: C, 72.95; H, 5.47; N, 2.98.

Dibenzyl 2-Benzyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2j. Procedure A: **1a** (100 mg, 0.28 mmol) and (isocyanatomethyl)benzene (186 mg, 1.40 mmol) afforded 128 mg (93%) of **2j** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.29 (s, 2H), 3.40 (s, 2H), 5.02 (s, 2H), 5.11 (s, 4H), 6.37 (s, 1H), 7.04 (s, 1H), 7.19−7.32 (m, 15H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 36.5, 39.7, 51.9, 60.8, 67.7, 114.7, 119.5, 127.5, 128.0, 128.1, 128.5, 128.6, 128.9, 130.9, 135.0, 136.5, 155.2, 162.5, 170.3 ppm. IR (NaCl): 1746, 1728, 1669, 1588 cm^{-1}. MS (ESI): m/z = 494 $[M + H]^+$, 495 $[M + 2H]^{2+}$. Anal. Calcd for $C_{31}H_{27}NO_5$: C, 75.44; H, 5.51; N, 2.84. Found: C, 75.13; H, 5.38; N, 2.70.

5-Benzyl-2-tosyl-2,3-dihydro-1*H*-pyrrolo[3,4-*c*]pyridin-6(5*H*)-one, 2k. Procedure B: **1c** (70 mg, 0.28 mmol) and (isocyanatomethyl)benzene (186 mg, 1.40 mmol) afforded 65 mg (61%) of **2k** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.42 (s, 3H), 4.31 (s, 2H), 4.37 (s, 2H), 5.07 (s, 2H), 6.40 (s, 1H), 7.11 (s, 1H), 7.23−7.33 (m, 7H), 7.72 (d, J = 8.3 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.6, 50.1, 52.1, 52.2, 113.4, 116.0, 127.7, 128.2, 128.2, 129.0, 130.0, 130.5, 133.0, 136.1, 144.2, 150.9, 162.0 ppm. IR (NaCl): 1678, 1587 cm^{-1}. MS (ESI): m/z = 381 $[M + H]^+$, 382 $[M + 2H]^{2+}$. Anal. Calcd for $C_{21}H_{20}N_2O_3S$: C, 66.29; H, 5.30; N, 7.36. Found: C, 66.39; H, 5.43; N, 7.13.

Dibenzyl 3-Oxo-2-phenyl-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2l. Procedure B: **1a** (100 mg, 0.28 mmol) and isocyanatobenzene (167 mg, 1.40 mmol) afforded 82 mg (61%) of **2l** (brown oil). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.38

(s, 2H), 3.48 (d, J = 1.1 Hz, 2H), 5.15 (s, 4H), 6.49 (s, 1H), 7.15 (s, 1H), 7.21−7.25 (m, 4H), 7.31−7.35 (m, 8H), 7.38−7.49 (m, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 36.5, 39.8, 60.9, 67.8, 115.4, 119.1, 126.7, 128.1, 128.4, 128.6, 128.7, 129.3, 131.8, 135.1, 141.3, 155.7, 162.3, 170.3 ppm. IR (NaCl): 1745, 1667 cm^{-1}. MS (ESI): m/z = 480 $[M + H]^+$, 481 $[M + 2H]^{2+}$. Anal. Calcd for $C_{30}H_{25}NO_5$: C, 75.14; H, 5.25; N, 2.92. Found: C, 75.41; H, 5.14; N, 2.89.

Dibenzyl 1,4-Dimethyl-3-oxo-2-phenyl-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2m. Procedure A: (catalyst: 5 mol % of [**Ru**]-**I**) **1b** (110 mg, 0.28 mmol) and isocyanatobenzene (167 mg, 1.40 mmol) afforded 58 mg (41%) of **2m** (yellow oil). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.82 (s, 3H), 2.04 (s, 3H), 3.38 (s, 2H), 3.47 (s, 2H), 5.16 (s, 4H), 7.14 (d, J = 8.5 Hz, 2H), 7.23−7.28 (m, 4H), 7.31−7.34 (m, 6H), 7.40−7.51 (m, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.6, 18.7, 37.9, 39.7, 60.0, 68.1, 116.9, 121.3, 128.5 (2C), 128.8, 128.9, 129.0, 130.0, 135.5, 136.6, 139.9, 150.4, 164.4, 171.2 ppm. IR (NaCl): 1750, 1672 cm^{-1}. MS (ESI): m/z = 308 $[M + H]^+$, 309 $[M + 2H]^{2+}$. Anal. Calcd for $C_{32}H_{29}NO_5$: C, 75.72; H, 5.76; N, 2.76. Found: C, 75.63; H, 5.62; N, 2.58.

Dibenzyl 2-(2-Methoxyphenyl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2n. Procedure B: **1a** (100 mg, 0.28 mmol) and 1-isocyanato-2-methoxybenzene (210 mg, 1.40 mmol) afforded 107 mg (75%) of **2n** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.38 (s, 2H), 3.49 (d, J = 1.2 Hz, 2H), 3.79 (s, 3H), 5.15 (s, 4H), 6.49 (s, 1H), 7.01−7.05 (m, 3H), 7.20−7.26 (m, 5H), 7.31−7.33 (m, 6H), 7.37−7.41 (td, J_1 = 8.2 Hz, J_2 = 1.7 Hz, 1H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 36.5, 39.9, 55.9, 60.9, 67.7, 112.4, 115.2, 118.6, 120.9, 128.1, 128.5, 128.6, 128.7, 130.0, 130.1, 132.6, 135.1, 154.4, 155.8, 162.2, 170.3, 170.5 ppm. IR (NaCl): 1742, 1669, 1638, 1587 cm^{-1}. MS (ESI): m/z = 510 $[M + H]^+$, 511 $[M + 2H]^{2+}$. Anal. Calcd for $C_{31}H_{27}NO_6$: C, 73.07; H, 5.34; N, 2.75. Found: C, 73.18; H, 5.45; N, 2.63.

Dibenzyl 2-(4-Methoxyphenyl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2o. Procedure B: **1a** (100 mg, 0.28 mmol) and 1-isocyanato-4-methoxybenzene (210 mg, 1.40 mmol) afforded 110 mg (77%) of **2o** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.37 (d, J = 0.7 Hz, 2H), 3.47 (d, J = 0.7 Hz, 2H), 3.82 (s, 3H), 5.15 (s, 4H), 6.48 (s, 1H), 6.96 (d, J = 8.9 Hz, 2H), 7.13 (s, 1H), 7.23−7.25 (m, 6H), 7.31−7.33 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 36.4, 39.8, 55.5, 60.9, 67.7, 114.5, 115.2, 119.0, 127.7, 128.1, 128.5, 128.6, 132.1, 134.1, 135.0, 155.6, 159.3, 162.6, 170.3 ppm. IR (NaCl): 1738, 1674, 1642, 1605 cm^{-1}. MS (ESI): m/z = 510 $[M + H]^+$, 511 $[M + 2H]^{2+}$. Anal. Calcd for $C_{31}H_{27}NO_6$: C, 73.07; H, 5.34; N, 2.75. Found: C, 72.98; H, 5.27; N, 2.93.

Dibenzyl 2-(4-Methoxyphenyl)-1,4-dimethyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2p. Procedure B: **1b** (110 mg, 0.28 mmol) and 1-isocyanato-4-methoxybenzene (210 mg, 1.40 mmol) afforded 80 mg (53%) of **2p** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.83 (s, 3H), 2.03 (s, 3H), 3.38 (s, 2H), 3.46 (s, 2H), 3.84 (s, 3H), 5.16 (s, 4H), 6.98 (d, J = 8.9 Hz, 2H), 7.04 (d, J = 8.9 Hz, 2H), 7.23−7.26 (m, 4H), 7.31−7.33 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.2, 18.3, 37.6, 39.3, 55.5, 59.6, 67.7, 114.8, 116.3, 120.7, 128.1, 128.5, 128.6, 129.0, 132.2, 135.2, 136.7, 149.9, 159.3, 164.3, 170.8 ppm. IR (NaCl): 1729, 1546 cm^{-1}. MS (ESI): m/z = 538 $[M + H]^+$, 539 $[M + 2H]^{2+}$. Anal. Calcd for $C_{33}H_{31}NO_6$: C, 73.73; H, 5.81; N, 2.61. Found: C, 73.51; H, 5.92; N, 2.38.

Dibenzyl 3-Oxo-2-*p*-tolyl-5,7-dihydro-2*H*-cyclopenta[*c*]-pyridine-6,6(3*H*)-dicarboxylate, 2q. Procedure B: the reaction of **1a** (100 mg, 0.28 mmol) and 1-isocyanato-4-methylbenzene (186 mg, 1.40 mmol) afforded 80 mg (58%) of **2q** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.39 (s, 3H), 3.37 (d, J = 1.1 Hz, 2H), 3.47 (d, J = 1.2 Hz, 2H), 5.15 (s, 4H), 6.49 (s, 1H), 7.13 (s, 1H), 7.19−7.22 (m, 8H), 7.31−7.33 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.2, 36.5, 39.8, 60.9, 67.8, 115.3, 119.0, 126.4, 128.1, 128.5, 128.6, 129.9, 131.9, 135.1, 138.3, 138.7, 155.6, 162.5, 170.3 ppm. IR (NaCl): 1742, 1669, 1637, 1587 cm^{-1}. MS (ESI): m/z = 494 $[M + H]^+$, 495 $[M + 2H]^{2+}$. Anal. Calcd for $C_{31}H_{27}NO_5$: C, 75.44; H, 5.51; N, 2.84. Found: C, 75.63; H, 5.48; N, 2.73.

Dibenzyl 2-(Naphthalen-1-yl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2r. Procedure B: **1a** (100 mg, 0.28 mmol) and 1-isocyanatonaphthalene (237 mg, 1.40 mmol) afforded 77 mg (52%) of **2r** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 3.41 (s, 2H), 3.57 (s, 2H), 5.17 (s, 2H), 5.18 (s, 2H), 6.59 (s, 1H), 7.11 (s, 1H), 7.24−7.27 (m, 4H), 7.32−7.34 (m, 6H), 7.38−7.53 (m, 5H), 7.88−7.91 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$) δ = 36.4, 39.9, 60.9, 67.8, 67.8, 115.4, 119.0, 122.5, 125.2, 125.5, 126.6, 127.4, 128.1, 128.1 128.4, 128.5, 128.6 (2C), 129.4, 132.6 (2C), 134.4, 135.1 (2C), 138.1, 156.2, 162.6, 170.3, 170.4 ppm. IR (NaCl): 1733, 1683, 1628, 1560 cm^{-1}. MS (ESI): m/z = 530 $[M + H]^+$, 531 $[M + 2H]^{2+}$. Anal. Calc. for $C_{34}H_{27}NO_5$: C, 77.11; H, 5.14; N, 2.64. Found: C, 76.99; H, 5.02; N, 2.83.

Dibenzyl 2-(4-Chlorophenyl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2s. Procedure B: **1a** (100 mg, 0.28 mmol) and 1-isocyanato-4-chlorobenzene (215 mg, 1.40 mmol) afforded 62 mg (43%) of **2s** (yellow oil). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.37 (s, 2H), 3.47 (s, 2H), 5.15 (s, 4H), 6.48 (s, 1H), 7.11 (s, 1H), 7.21−7.27 (m, 4H), 7.29−7.35 (m, 8H), 7.43 (d, J = 8.7 Hz, 2H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 36.4, 39.8, 60.8, 67.8, 115.4, 119.5, 128.1, 128.1, 128.6, 128.7, 129.5, 131.3, 134.3, 135.0, 139.6, 156.0, 162.2, 170.2 ppm. IR (NaCl): 1745, 1670 cm^{-1}. MS (ESI): m/z = 514 $[M + H]^+$, 516 $[M + 3H]^{3+}$. Anal. Calcd for $C_{30}H_{24}ClNO_5$: C, 70.11; H, 4.71; N, 2.73. Found: C, 70.02; H, 4.59; N, 2.96.

Dibenzyl 2-(4-Nitrophenyl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2t. Procedure B: **1a** (100 mg, 0.28 mmol) and 1-isocyanato-4-nitrobenzene (230 mg, 1.40 mmol) afforded 51 mg (35%) of **2t** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.39 (s, 2H), 3.49 (d, J = 1.2 Hz, 2H), 5.15 (s, 4H), 6.50 (s, 1H), 7.14 (s, 1H), 7.23−7.26 (m, 4H), 7.32−7.34 (m, 6H), 7.57 (d, J = 8.9 Hz, 2H), 8.34 (d, J = 8.9 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 36.4, 39.8, 60.8, 67.9, 115.7, 120.4, 124.7, 127.7, 128.1, 128.6, 128.7, 130.3, 134.9, 146.3, 147.1, 156.7, 161.7, 170.1 ppm. IR (NaCl): 1729, 1673 cm^{-1}. MS (ESI): m/z = 525 $[M + H]^+$, 526 $[M + 2H]^{2+}$. Anal. Calcd for $C_{30}H_{24}N_2O_7$: C, 68.70; H, 4.61; N, 5.34. Found: C, 68.62; H, 4.49; N, 4.96.

Dibenzyl 1,4-Dimethyl-2-(4-nitrophenyl)-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2u. Procedure B: **1b** (110 mg, 0.28 mmol) and 1-isocyanato-4-nitrobenzene (230 mg, 1.40 mmol) afforded 43 mg (28%) of **2u** (brown oil).^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.83 (s, 3H), 2.04 (s, 3H), 3.39 (s, 2H), 3.48 (s, 2H), 5.16 (s, 4H), 7.23−7.26 (m, 4H), 7.32−7.36 (m, 8H), 8.36 (d, J = 8.8 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.1, 18.2, 37.4, 39.3, 59.5, 67.8, 117.5, 121.3, 125.0, 128.1, 128.5, 128.6, 128.7, 134.9, 135.1, 145.2, 147.6, 150.9, 163.6, 171.2 ppm. IR (NaCl): 2930, 1738, 1674, 1546 cm^{-1}. MS (ESI): m/z = 553 $[M + H]^+$, 554 $[M + 2H]^{2+}$. Anal. Calcd for $C_{32}H_{28}N_2O_7$: C, 69.55; H, 5.11; N, 5.07. Found: C, 69.31; H, 5.13; N, 5.21.

Dibenzyl 2-Benzyl-1-methyl-3-oxo-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2v. Procedure A: **1e** (105 mg, 0.28 mmol) and (isocyanatomethyl)benzene (186 mg, 1.40 mmol) afforded 87 mg (61%) of **2v** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.15 (s, 3H), 3.32 (s, 2H), 3.46 (d, J = 1.2 Hz, 2H), 5.13 (s, 4H), 5.30 (s, 2H), 6.41 (s, 1H), 7.12 (d, J = 7.0 Hz, 2H), 7.21−7.31 (m, 13H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.5, 37.4, 40.0, 47.2, 59.8, 67.7, 111.8, 117.8, 126.5, 127.3, 128.1, 128.5, 128.6, 128.8, 135.1, 136.6, 140.2, 154.0, 163.8, 170.5 ppm. IR (NaCl): 2954, 1737, 1678, 1610, 1569 cm^{-1}. MS (ESI): m/z = 508 $[M + H]^+$, 509 $[M + 2H]^{2+}$. Anal. Calcd for $C_{32}H_{29}NO_5$: C, 75.72; H, 5.76; N, 2.76. Found: C, 75.62; H, 5.68; N, 2.82.

Dibenzyl 1-Methyl-3-oxo-2-phenyl-5,7-dihydro-2*H*-cyclopenta[*c*]pyridine-6,6(3*H*)-dicarboxylate, 2w. Procedure B: **1e** (105 mg, 0.28 mmol) and isocyanatobenzene (167 mg, 1.40 mmol) afforded 52 mg (38%) of **2w** (brown oil). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.84 (s, 3H), 3.36 (s, 2H), 3.49 (s, 2H), 5.16 (s, 4H), 6.39 (s, 1H), 7.15 (d, J = 7.6 Hz, 2H), 7.23−7.26 (m, 4H), 7.31−7.33 (m, 6H), 7.42−7.52 (m, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 18.5, 37.2, 40.1, 59.9, 67.7, 112.4, 117.2, 128.0, 128.1, 128.5, 128.6, 128.7, 129.8, 135.1, 139.0, 139.9, 154.6, 163.9, 170.5 ppm. IR (NaCl):

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2962, 2930, 2857, 1733, 1674, 1610 cm^{-1}. MS (ESI): m/z = 494 $[M + H]^+$, 495 $[M + 2H]^{2+}$. Anal. Calcd for $C_{31}H_{27}NO_5$: C, 75.44; H, 5.51; N, 2.84. Found: C, 75.32; H, 5.59; N, 2.92.

5-Benzyl-4-methyl-2-tosyl-2,3-dihydro-1*H*-pyrrolo[3,4-*c*]-pyridin-6(5*H*)-one, 2x. Procedure A: **1f** (75 mg, 0.28 mmol) and (isocyanatomethyl)benzene (186 mg, 1.40 mmol) afforded 74 mg (67%) of **2x** (brown oil). ^1H NMR (400 MHz, $CDCl_3$): δ = 2.13 (s, 3H), 2.43 (s, 3H), 4.32 (s, 2H), 4.42 (s, 2H), 5.29 (s, 2H), 6.36 (s, 1H), 7.10 (d, J = 7.0 Hz, 2H), 7.21−7.31 (m, 3H), 7.35 (d, J = 8.0 Hz, 2H), 7.75 (d, J = 8.2 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.6, 21.6, 47.2, 50.9, 52.6, 110.3, 114.5, 126.4, 127.5, 127.7, 128.9, 130.0, 133.1, 136.1, 140.1, 144.2, 149.7, 163.3 ppm. IR (NaCl): 1682, 1577, 1551 cm^{-1}. MS (ESI): m/z = 395 $[M + H]^+$, 396 $[M + 2H]^{2+}$. Anal. Calcd for $C_{22}H_{22}N_2O_3S$: C, 66.98; H, 5.62; N, 7.10. Found: C, 66.83; H, 5.55; N, 7.01.

4-Methyl-5-phenyl-2-tosyl-2,3-dihydro-1*H*-pyrrolo[3,4-*c*]-pyridin-6(5*H*)-one, 2y. Procedure B: **1f** (75 mg, 0.28 mmol) and isocyanatobenzene (167 mg, 1.40 mmol) afforded 45 mg (42%) of **2y** (brown oil). ^1H NMR (400 MHz, $CDCl_3$): δ = 1.82 (s, 3H), 2.45 (s, 3H), 4.37 (s, 2H), 4.45 (s, 2H), 6.35 (s, 1H), 7.10 (d, J = 7.2 Hz, 2H), 7.37 (d, J = 8.0 Hz, 2H), 7.48−7.51 (m, 3H), 7.78 (d, J = 8.2 Hz, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 18.6, 21.6, 50.7, 52.7, 110.9, 114.0, 127.7, 127.8, 129.0, 129.9, 130.0, 133.2, 138.3, 139.9, 144.2, 150.4, 163.5 ppm. IR (NaCl): 1673, 1543 cm^{-1}. MS (ESI): m/z = 381 $[M + H]^+$, 382 $[M + 2H]^{2+}$. Anal. Calcd for $C_{21}H_{20}N_2O_3S$: C, 66.29; H, 5.30; N, 7.36. Found: C, 66.37; H, 5.43; N, 7.31.

Dibenzyl 3-(Ethylimino)-1,4-dimethyl-5,7-dihydrocyclopenta[*c*]thiopyran-6,6(3*H*)-dicarboxylate, 3a. Procedure B: **1b** (110 mg, 0.28 mmol) and isothiocyanatoethane (122 mg, 1.40 mmol) afforded 86 mg (65%) of **3a** (brown oil). ^1H NMR (400 MHz, $CDCl_3$): δ = 1.36 (t, J = 7.2 Hz, 3H), 2.05 (s, 3H), 2.11 (s, 3H), 3.17−3.23 (m, 2H), 3.26 (s, 2H), 3.35 (s, 2H), 5.13 (s, 4H), 7.21−7.24 (m, 4H), 7.30−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 15.3, 15.4, 19.9, 39.0, 40.6, 47.7, 58.2, 67.6, 125.5, 126.8, 128.0, 128.4, 128.6, 128.7, 135.2, 142.5, 156.7, 170.6 ppm. IR (NaCl): 2924, 1740, 1552 cm^{-1}. MS (ESI): m/z = 476 $[M + H]^+$, 477 $[M + 2H]^{2+}$, 478 $[M + 3H]^{2+}$. Anal. Calcd for $C_{28}H_{29}NO_4S$: C, 70.71; H, 6.15; N, 2.95. Found: C, 70.62; H, 6.29; N, 2.83.

Dibenzyl 3-(Butylimino)-1,4-dimethyl-5,7-dihydrocyclopenta[*c*]thiopyran-6,6(3*H*)-dicarboxylate, 3b. Procedure B: **1b** (110 mg, 0.28 mmol) and 1-isothiocyanatobutane (160 mg, 1.40 mmol) afforded 72 mg (51%) of **3b** (brown oil). ^1H NMR (400 MHz, $CDCl_3$): δ = 0.96 (t, J = 7.3 Hz, 3H), 1.41−1.50 (m, 2H), 1.71−1.78 (m, 2H), 2.03 (s, 3H), 2.09 (s, 3H), 3.13 (t, J = 5.2 Hz, 2H), 3.25 (s, 2H), 3.34 (s, 2H), 5.13 (s, 4H), 7.21−7.23 (m, 4H), 7.30−7.32 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.0, 15.4, 19.9, 20.8, 29.7, 39.0, 40.6, 53.2, 58.2, 67.6, 125.6, 127.9, 128.0, 128.4, 128.5, 128.6, 135.2, 142.2, 156.7, 170.6 ppm. IR (NaCl): 2960, 2924, 1736, 1552 cm^{-1}. MS (ESI): m/z = 504 $[M + H]^+$. Anal. Calcd for $C_{30}H_{33}NO_4S$: C, 71.54; H, 6.60; N, 2.78. Found: C, 71.69; H, 6.49; N, 2.85.

Dibenzyl 1,4-Dimethyl-3-thioxo-5,7-dihydrocyclopenta[*c*]-thiopyran-6,6(3*H*)-dicarboxylate, 4. A solution of **Ru-[III]** (9 mg, 0.014 mmol) in 1,2-dichloroethane (1.5 mL) was added to a solution of the diyne **1b** (110 mg, 0.28 mmol) in 1.5 mL of same solvent and 1 mL of CS_2 contained in a pressure flask. The flask was sealed, introduced in a 70 °C bath, and the resulting mixture was stirred for 12 h. After the flask was cooled to rt, the reaction mixture was filtered through Celite, the solvent was eliminated under reduced pressure, and the residue was purified by silica-gel flash column chromatography with mixed solvents (hexane/ethyl acetate). Evaporation of the solvent afforded 116 mg (89%) of **4** (red oil). ^1H NMR (400 MHz, $CDCl_3$): δ 2.20 (s, 3H), 2.24 (s, 3H), 3.42 (s, 2H), 3.48 (s, 2H), 5.15 (s, 4H), 7.21−7.23 (m, 4H), 7.32−7.34 (m, 6H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.8, 19.1, 39.5, 40.1, 58.6, 67.6, 128.2, 128.6, 128.7, 134.0, 134.9, 139.8, 147.2, 149.5, 170.1, 204.2 ppm. IR (NaCl): 3033, 2961, 1735, 1606, 1529 cm^{-1}. MS (ESI): m/z = 465 $[M + H]^+$, 466 $[M + 2H]^{2+}$. Anal. Calcd for $C_{26}H_{24}O_4S_2$: C, 67.21; H, 5.21. Found: C, 67.16; H, 5.36.

■ ASSOCIATED CONTENT

Supporting Information

Copies of ^1H and ^{13}C NMR spectra for compounds **2**−**4**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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