Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Supporting information for:

A Room Temperature Cyanation of (Hetero)aromatic Chlorides by an Air Stable Nickel(II) XantPhos Precatalyst and $Zn(CN)_2$

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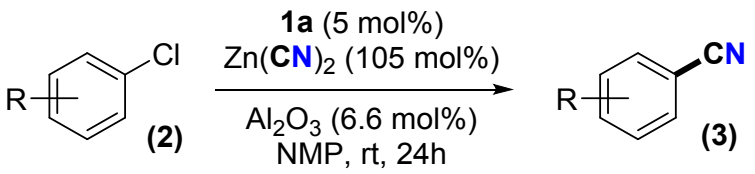
General Considerations

All experiments were carried out employing standard Schlenk techniques under an atmosphere of dry argon employing degassed, dried solvents. Note that reaction glassware ***was not*** dried prior to use. $NiCl_2$(dme), $NiCl_2 \cdot 6H_2O$, zinc metal, $Zn(CN)_2$, MCN (M = Cu, K, Na), $K_4[FeCN_6]$, 4,5-bis(diphenylphosphino)-9,9-dimethylxanthene (XantPhos), 2,2'-bis(diphenylphosphino)-1,1'-binaphthyl (BINAP), 1,1'-bis(diphenylphosphanyl) ferrocene (dppf), 1,2-bis(diphenylphosphino)ethane (dppe), (*o*-tol)MgCl, Celite®, and all reaction substrates (Ar-Cl) were purchased and used as received. [Al_2O_3] was prepared from drying $AlCl_3 \cdot 6H_2O$ in a tubular schlenk flask over 2 nights at 120°C under high vacuum.[1] Complexes **1a-1d** were prepared according to literature procedures (*see representative spectra of **1a** below*).[2] N-methyl-2-pyrrolidone (NMP, HPLC grade) was dried over activated molecular sieves and degassed by extended sparging with argon (>2 h). Distillation and degassing of NMP by freeze-pump-thaw cycles afforded the same conversions under reaction conditions. $CDCl_3$ was purchased from Cambridge Isotope Laboratories Inc., and used as received. Column solvents heptanes, pentane, ethyl acetate (EtOAc), and dichloromethane (DCM) were purchased and used as received.

Instrumentation

NMR spectra were recorded on Bruker Avance 300 and Bruker ARX 400 spectrometers. ^{1}H NMR spectra are reported in parts per million (ppm) and were referenced[3] to residual solvent: ^{1}H($CHCl_3$): δ 7.26; ^{13}C($CHCl_3$): δ 77.16; J-coupling constants are reported in Hz. ^{13}C NMR spectra were performed as proton-decoupled experiments and are reported in ppm. The multiplicities are abbreviated as follows: s = singlet, d = doublet, dd = doublet of doublets, ddd = doublet of doublets of doublets, t = triplet, sept = septet, m = multiplet. NMR spectra are shown using MestReNova 6.0.2 NMR processing software. Electron impact mass spectra (EI-MS) were recorded on an AMD 402 mass spectrometer (70 ev). High resolution mass spectra (HRMS) were recorded on Agilent 6210 and the data are given as mass units per charge (m/z). Gas chromatography analysis was performed on an Agilent HP-5890 instrument with a FID detector and HP-5 capillary column (polydimethylsiloxane with 5 % phenyl groups, 30 m, 0.32 mm i.d., 0.25 μm film thickness) using argon as carrier gas. Most products were isolated from the reaction mixture by column chromatography on silica gel 60, 0.063-0.2 mm, 70-230 mesh (Merck). Others were isolated using a Teledyne Isco Combiflash Rf automated column chromatography system.

General Procedure for Cyanation of Aryl Chlorides



To a 10 mL Schlenk tube equipped with a Teflon stir bar was added **1a** (38.2 mg, 0.05 mmol), $Zn(CN)_2$ (123.3 mg, 1.05 mmol), and Al_2O_3 (6.7 mg, 0.066 mmol). The Schlenk tube was sealed and the contents were evacuated on a Schlenk line for 1 h. After refilling and evacuating 3 times, the starting (hetero)aryl chloride (1 mmol) and solvent (NMP, 2.5 mL, 0.4 M) were added to the reaction flask under a flow of argon. Once the flask was resealed, it was stirred (~600 rpm) without heating for 24 h. The reaction contents were then added to a small (50 mL) separatory funnel. EtOAc (2 x 10 mL) was added to the reaction flask, then into the separatory funnel. The organic layer was then washed with distilled water (2 x 5 mL), and saturated brine (5 mL). Finally, a back extraction from the combined aqueous layers was performed with EtOAc (15 mL), and the organic layers were combined and dried over Na_2SO_4. After filtering through filter paper and concentrating the organic fractions to *ca.* 2 mL *in vacuo*, the crude mixture was adsorbed onto a small portion of silica gel for chromatography purposes. After removing the solvent from the silica-adsorbed product mixture *in vacuo*, the silica sample was then dry-loaded onto a silica column (Heptane or pentane/EtOAc, pentane/DCM), or Teledyne Isco Combiflash Rf, and the product was purified using standard flash-chromatographic techniques. Aqueous layers and all glassware were washed with solutions of Na_2CO_3 with $FeSO_4$ prior to disposal. The resulting $Na_4[FeCN_6]$ solutions were disposed off using accepted protocols.[4]

Notes on Procedure:

i) $Zn(CN)_2$ is toxic and should only be handled with care.

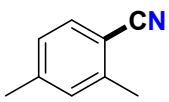
ii) Larger Schlenk tubes may be used for the reaction, but care should be taken to wash the sides of the flask with solvent to ensure all reagents and catalyst enter reaction mixture.

iii) In our hands stirring was an important variable: stirring between 500-700 (rpm) gave optimal results during the screening process.

Isolation and Characterization of Nitrile Products

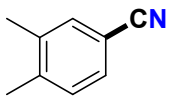
All products were prepared and isolated according to the general procedure:

2,4-dimethylbenzonitrile (3a)



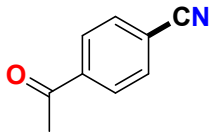
Column conditions 50:1 (pentane:EtOAc), average yield: 62%, [**run 1**: 78 mg, 59%, **run 2**: 85 65%]. The analytical data was consistent with literature.[5] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.47 (d, $J_{H,H}$ = 7.9 Hz, 1H), 7.12 (d, $J_{H,H}$ = 0.7 Hz, 1H), 7.08 (dd, $J_{H,H}$ = 7.9, 0.7 Hz, 1H) , 2.49 (s, 3H), 2.37 (s, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 143.5, 141.7, 132.4, 131.0, 127.1, 118.5, 109.6, 21.7, 20.3.

3,4-dimethylbenzonitrile (3b)



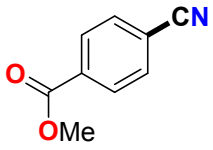
Column conditions 50:1 (heptane:EtOAc), average yield 97%, [**run 1**: 129 mg, 98%, **run 2**: 126 mg, 96%]. The analytical data was consistent with literature.[5] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.37 (m, 2H), 7.20 (d, $J_{H,H}$ = 7.7 Hz, 1H), 2.31 (s, 3H), 2.27 (s, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 142.6, 138.0, 132.9, 130.4, 129.7, 119.4, 109.6, 20.2, 19.6.

4-acetylbenzonitrile (3c)



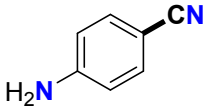
Column conditions 10:1 (pentane:EtOAc), average yield 96%, [**run 1**: 136 mg, 93%, **run 2**: 142 mg, 98%]. The analytical data was consistent with literature.[6] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 8.04 (dd, $J_{H,H}$ = 8.2, 1.9 Hz, 2H), 7.76 (dd, $J_{H,H}$ = 8.2, 1.9 Hz, 2H), 2.64 (s, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 196.7, 140.0, 132.6, 128.8, 118.0, 116.5, 26.9.

methyl 4-cyanobenzoate (3d)



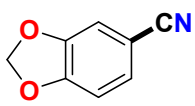
Column conditions 10:1 (pentane:EtOAc), average yield 95%, [**run 1**: 155 mg, 96%, **run 2**: 153 mg, 95%]. The analytical data was consistent with literature.[7] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 8.12 (dd, $J_{H,H}$ = 8.2, 1.9 Hz, 2H), 7.73 (dd, $J_{H,H}$ = 8.2, 1.9 Hz, 2H), 3.94 (d, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 165.5, 134.0, 132.3, 130.2, 118.0, 116.5, 52.8.

4-aminobenzonitrile (3e)



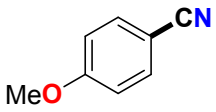
Column conditions 1:1 (pentane:DCM), average yield 78%, [**run 1**: 95 mg, 80%, **run 2**: 89 mg, 75%]. The analytical data was consistent with literature.[8] **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.39 (dd, $J_{H,H}$ = 9.1, 2.0 Hz, 2H), 6.64 (dd, $J_{H,H}$ = 9.1, 2.0 Hz, 2H), 4.22 (s, 2H); **^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$)** δ 150.6, 133.8, 120.3, 114.5, 100.0.

benzo[d][1,3]dioxole-5-carbonitrile (3f)



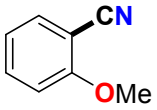
Column conditions 10:1 (pentane:EtOAc), average yield 91%, [**run 1**: 136 mg, 92%, **run 2**: 131 mg, 89%]. The analytical data was consistent with literature.[6] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.22 (ddd, $J_{H,H}$ = 8.1, 1.5, 1.4 Hz, 1H), 7.02 (dd, $J_{H,H}$ = 1.4, 1.5 Hz, 1H), 6.86 (dd, $J_{H,H}$ = 8.1, 0.5 Hz, 1H), 6.06 (d, $J_{H,H}$ = 0.6 Hz, 2H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 151.6, 148.1, 128.3, 119.0, 111.5, 109.2, 105.0, 102.3.

4-methoxybenzonitrile (3g)



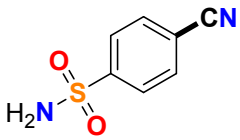
Column conditions 10:1 (pentane:EtOAc), average yield 89%, [**run 1**: 119 mg, 90%, **run 2**: 118 mg, 88%]. The analytical data was consistent with literature.[6] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.56 (dd, $J_{H,H}$ = 9.6, 2.1 Hz, 2H), 6.93 (dd, $J_{H,H}$ = 9.6, 2.1 Hz, 2H), 3.84 (s, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 162.9, 134.0, 119.3, 114.8, 103.9, 55.6.

2-methoxybenzonitrile (3h)



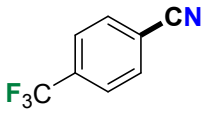
Combiflash separation, (heptane:EtOAc, gradient – up to 30% EtOAc), average yield 69%, [**run 1**: 91 mg, 68%, **run 2**: 92 mg, 69%]. The analytical data was consistent with literature.[9] **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.53 (m, 2H), 6.99 (m, 2H), 3.92 (s, 3H); **^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$)** δ 161.3, 134.5, 133.8, 120.8, 116.6, 111.4, 101.8, 56.1.

4-cyanobenzenesulfonamide (3i)



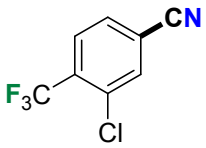
Combiflash separation, (heptane:EtOAc, gradient – up to 100% EtOAc), average yield 91%, [**run 1**: 160 mg, 88%, **run 2**: 171 mg, 94%]. The analytical data was consistent with literature.[10] **^{1}H NMR (300 MHz, DMSO)** δ 8.07 (d, $J_{H,H}$ = 8.3 Hz, 2H), 7.98 (d, $J_{H,H}$ = 8.3 Hz, 2H), 7.66 (s, 2H); **^{13}C{^{1}H} NMR (75 MHz, DMSO)** δ 148.0, 133.3, 126.5, 117.9, 114.4.

4-trifluoromethylbenzonitrile (3j)



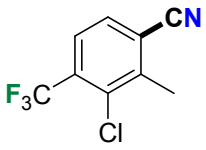
Combiflash separation, (heptane:EtOAc, gradient – up to 20% EtOAc), average yield 69%, [**run 1**: 125 mg, 73%, **run 2**: 113 mg, 66%].The analytical data was consistent with literature.[8] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.81 (d, $J_{H,H}$ = 8.4 Hz, 2H), 7.76 (d, $J_{H,H}$ = 8.4 Hz, 2H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 134.9 (q, $J_{F,C}$ = 32.8 Hz), 132.8, 126.3 (q, $J_{F,C}$ = 3.6 Hz), 123.2 (q, $J_{F,C}$ = 273.8 Hz), 117.6, 116.2; **^{19}F{^{1}H} NMR (282 MHz, $CDCl_3$)** δ -63.1.

3-chloro-4-trifluoromethylbenzonitrile (3k)



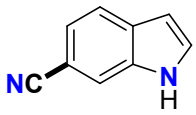
Column conditions 20:1 (heptane:EtOAc), average yield 63%, [**run 1**: 132 mg, 64%, **run 2**: 127 mg, 62%]. **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.83 (m, 2H), 7.69 (m, 1H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 134.8, 133.9, 132.7 (q, $J_{F,C}$ = 32.7 Hz), 130.5, 128.6 (q, $J_{F,C}$ = 5.3 Hz), 122.0 (q, $J_{F,C}$ = 274.0 Hz), 117.4, 116.3. **^{19}F{^{1}H} NMR (282 MHz, $CDCl_3$)** δ -63.1. **HRMS** (EI) m/z calculated for $C_8H_3ClF_3N$ $[M]^+$: 204.99006; found: 204.99020.

3-chloro-2-methyl-4-trifluoromethylbenzonitrile (3l)



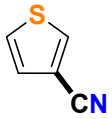
Column conditions 50:1 (heptane:EtOAc), average yield 92%, [**run 1**: 202 mg, 92%, **run 2**: 204 mg, 93%]. **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.64 (m, 2H), 2.66 (s, 3H); **^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$)** δ 142.6, 134.1, 133.3 (q, $J_{F,C}$ = 31.7 Hz), 130.7, 125.6 (q, $J_{F,C}$ = 5.5 Hz) 122.2 (q, $J_{F,C}$ = 274.5 Hz), 118.16, 116.46, 19.34. **^{19}F{^{1}H} NMR (282 MHz, $CDzCl_3$)** δ -63.1. **HRMS** (ESI-TOF) m/z calculated for $C_9H_5ClF_3N$ $[M-H]^-$: 217.99899; found: 217.99865.

1*H*-indole-6-carbonitrile (3q)



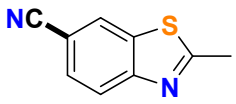
Column conditions 5:1 (heptane:EtOAc), average yield 70%, [**run 1**: 100 mg, 70%, **run 2**: 100 mg, 70%]. The analytical data was consistent with literature.[11] **^{1}H NMR (400 MHz, $CDCl_3$)** δ 8.75 (s, 1H), 7.78 (m, 1H), 7.70 (d, $J_{H,H}$ = 8.2 Hz, 1H), 7.43 (d, $J_{H,H}$ = 8.2, 1.4 Hz, 1H), 7.35 (dd, J = 8.2, 1.4 Hz, 1H), 6.63 (m, 1H); **^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$)** δ 134.7, 131.3, 128.3, 122.8, 121.6, 120.9, 116.2, 104.2, 103.5.

3-cyanothiophene (3r)



Column conditions 25:1 (heptane:EtOAc), average yield 72%, [**run 1**: 79 mg, 72%, **run 2**: 80 mg, 73%]. The analytical data was consistent with literature.[8] **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.95 (dd, $J_{H,H}$ = 3.0, 1.2 Hz, 1H), 7.44 (dd, $J_{H,H}$ = 5.1, 3.0 Hz, 1H), 7.30 (dd, $J_{H,H}$ = 5.1, 1.2 Hz, 1H); **^{13}C{^{1}H} NMR (101 MHz, $CDCl_3$)** δ 135.5, 128.7, 127.4, 115.2, 110.6.

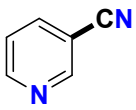
2-methylbenzo[d]thiazole-6-carbonitrile (3s)



Combiflash separation, (heptane:EtOAc, gradient – up to 70% EtOAc), average yield 86%, [**run 1**: 145 mg, 83%, **run 2**: 155 mg, 89%]. The analytical data was consistent with literature.[12] **^{1}H NMR (300 MHz, $CDCl_3$)** δ 8.18 (s, 1H), 7.89 (d, $J_{H,H}$ = 1.5 Hz, 1H), 7.54 (m,

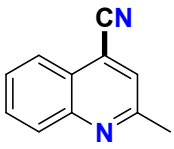
1H), 2.85 (d, $J_{H,H}$ = 1.6 Hz, 3H); **$^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$)** δ 169.8, 153.1, 140.7, 127.2, 126.5, 122.6, 118.9, 109.7, 20.3.

3-cyanopyridine (3t)



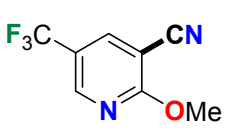
Column conditions 5:1 (heptane:EtOAc), average yield 68%, [**run 1**: 70 mg, 67%, **run 2**: 72 mg, 69%]. The analytical data was consistent with literature.[13] **^1H NMR (300 MHz, $CDCl_3$)** δ 8.90 (dd, $J_{H,H}$ = 2.1, 0.8 Hz, 1 H), 8.82 (dd, $J_{H,H}$ = 5.0, 1.6 Hz, 1 H), 7.98 (dd, $J_{H,H}$ = 8.0, 1.9 Hz, 1 H), 7.45 (ddd, $J_{H,H}$ = 8.0, 5.0, 0.9 Hz, 1 H); **$^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$)** δ 153.2, 152.6, 139.4, 123.8, 116.6, 110.3.

2-methylquinoline-4-carbonitrile (3u)



Combiflash separation, (heptane:EtOAc, gradient – up to 40% EtOAc), average yield 94%, [**run 1**: 161 mg, 96%, **run 2**: 156 mg, 93%]. The analytical data was consistent with literature.[13] **^1H NMR (300 MHz, $CDCl_3$)** δ 8.10 (m, 2H), 7.81 (m, 1H), 7.67 (m, 1H), 7.61 (s, 1H), 2.79 (s, 3H); **$^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$)** δ 158.5, 147.9, 131.2, 129.6, 128.3, 126.0, 124.8, 124.1, 119.0, 115.8, 25.3.

2-methoxy-5-(trifluoromethyl)nicotinonitrile (3v)

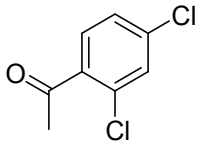


Combiflash separation, (pentane:EtOAc, gradient – up to 60% EtOAc), average yield 76%, [**run 1**: 151 mg, 75%, **run 2**: 157 mg, 78%]. **^1H NMR (300 MHz, $CDCl_3$)** δ 8.62 (dq, $J_{H,H}$ = 2.5 Hz, $J_{H,F}$ = 0.89 Hz, 1H), 8.10 (d, $J_{H,H}$ = 2.5 Hz, 1H), 4.13(s, 3H); **$^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$)** δ 165.9, 149.1 (q, $J_{F,C}$ = 4.0 Hz), 140.1 (q, $J_{F,C}$ = 3.2 Hz), 122.9 (q, $J_{F,C}$ = 271.6 Hz), 120.4 (q, $J_{F,C}$ = 34.5 Hz), 113.8, 97.5, 55.6. **$^{19}F\{^1H\}$ NMR (282 MHz, $CDCl_3$)** δ -61.3. **HRMS** (EI) m/z calculated for $C_8H_5O_1F_3N_2$ $[M]^+$: 202.03485; found: 202.03446.

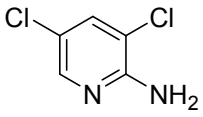
Problematic Substrates

All substrates were tested under the optimized conditions. Substrates were then tested with heating to increase conversion of difficult substrates.

Chloro compounds (optimized conditions, or with heating - 50°C)



~ 50% conv.



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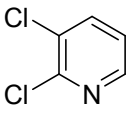

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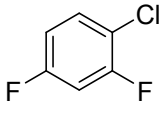

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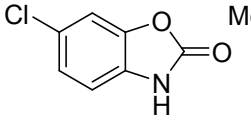

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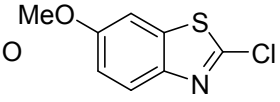

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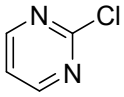

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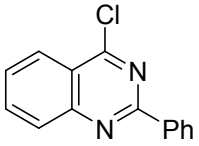

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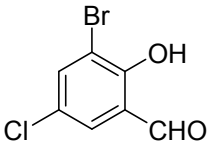
Chloro-bromo Compounds (optimized conditions, or with heating - 50°C)



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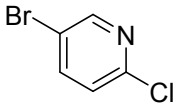

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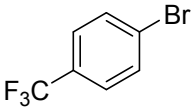
Bromo compounds (optimized conditions, or with heating - 50°C)



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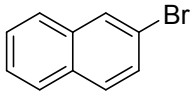

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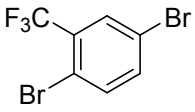

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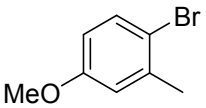

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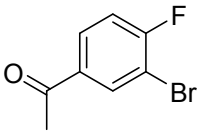

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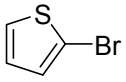

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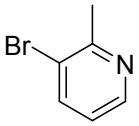

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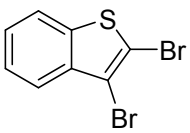

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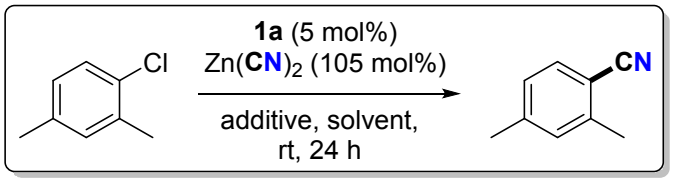
Further Reaction Screening Conditions

This section is designed to aid chemists in their pursuit to improve this reaction further. *Reactions run on a 0.2 mmol scale.* We have chosen to include the most important experiments.



(1) Controls:

Conditions	Yield (%)
Under air	0
No stirring	3
Stir 250 rpm	30
500-700 rpm	70
Stir 900 rpm	40
Stir 1250 rpm	36
Sonicate (no stirring)	6

(2) Solvents:

No product (0%) was observed by GC-MS using precatalyst **1a**, under standard conditions, using the following list of solvents/solutions:

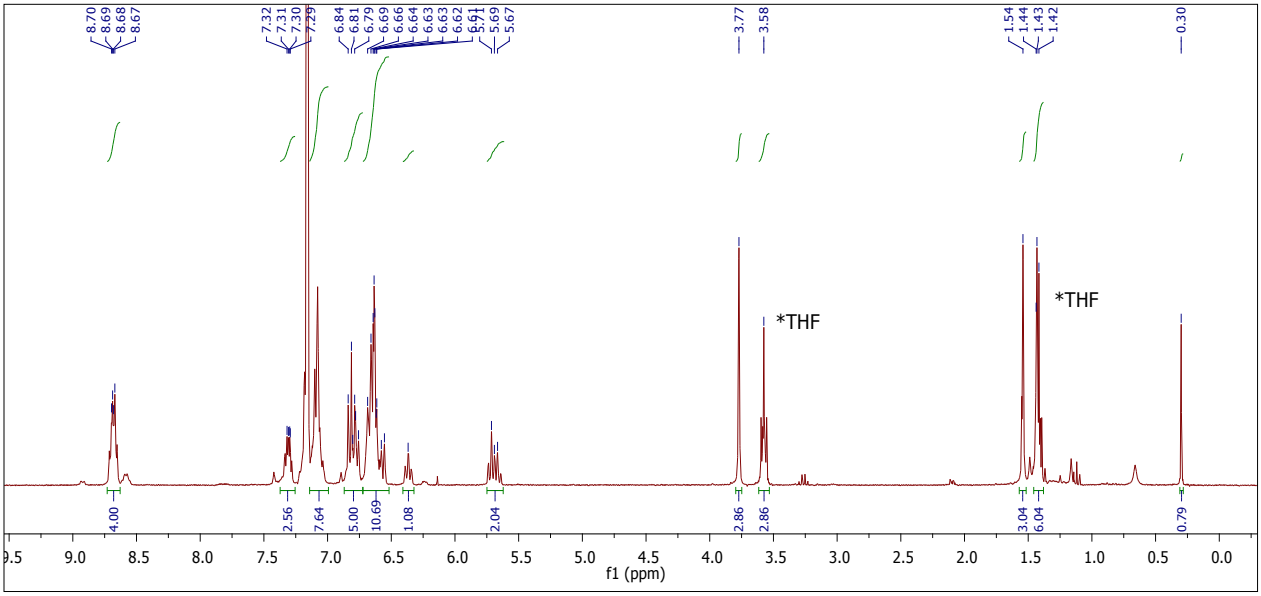
- toluene
- acetone
- dichloromethane
- Water
- Water:THF (1:1)
- Water:NMP (1:4, 2:3)
- *N,N,N'N'*-tetramethylurea
- n-BuOH
- dimethylsulfoxide
- acetonitrile
- 1,4-dioxane
- dimethoxyethane
- NMP:solvent (1:9)
    - solvent = acetonitrile, toluene, n-BuOH, THF, DCM, acetone, water

(3) Additives:

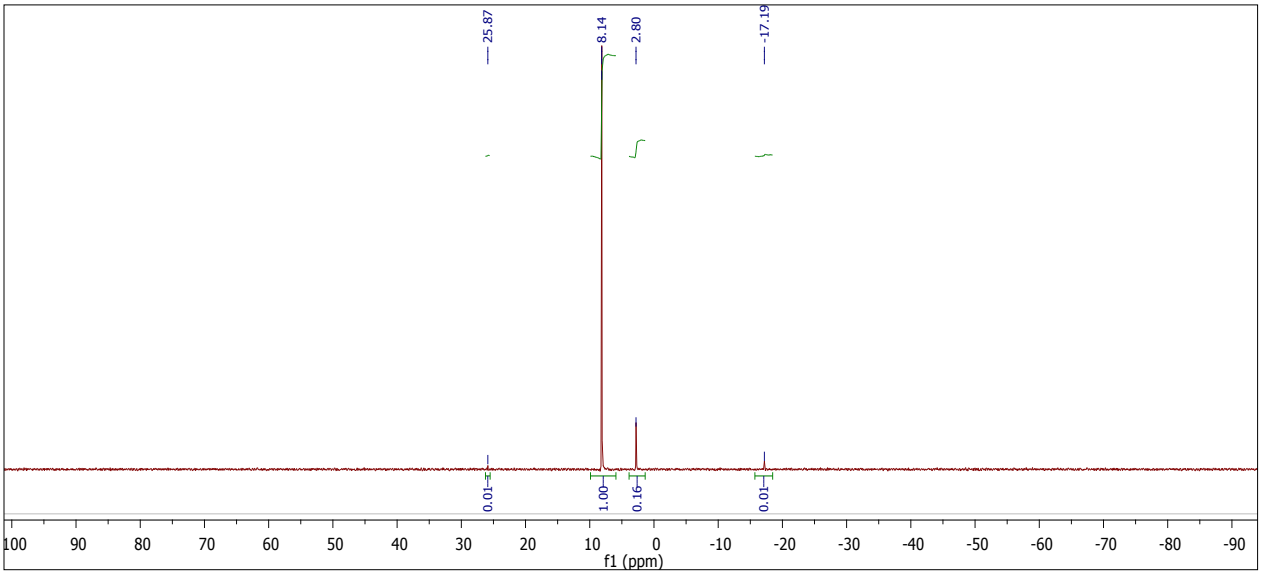
Additives	**Yield (%)**
Na_2CO_3 (10 mol%)	47
K_2CO_3 (10 mol%)	33
Cs_2CO_3 (10 mol%)	41
CsOPiv (10 mol%)	0
KOAc (10 mol%)	3
Citric acid (10 mol%)	0
trpytamineHCl (10 mol%)	0
Pivalic acid (10 mol%)	36%
TEMPO (10 mol%)	30%
Zn(0) (5%)	38%

Representative Spectra of Complex 1a

In our hands the synthesis of complexes **1a** was consistent with literature methods.[2] Moreover, the catalytic efficiency was reliable from multiple syntheses of **1a**. Below are representative ^{1}H (300MHz, C_6D_6, 298K) and ^{31}P (121.5 MHz, C_6D_6, 298K) NMR spectra.



^{1}H NMR Spectrum (300MHz, C_6D_6, 298K) of complex **1a**.



^{31}P NMR Spectrum (121.5MHz, C_6D_6, 298K) of complex **1a**.

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NMR Spectra of Nitrile Products

Figure S1. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3a**)

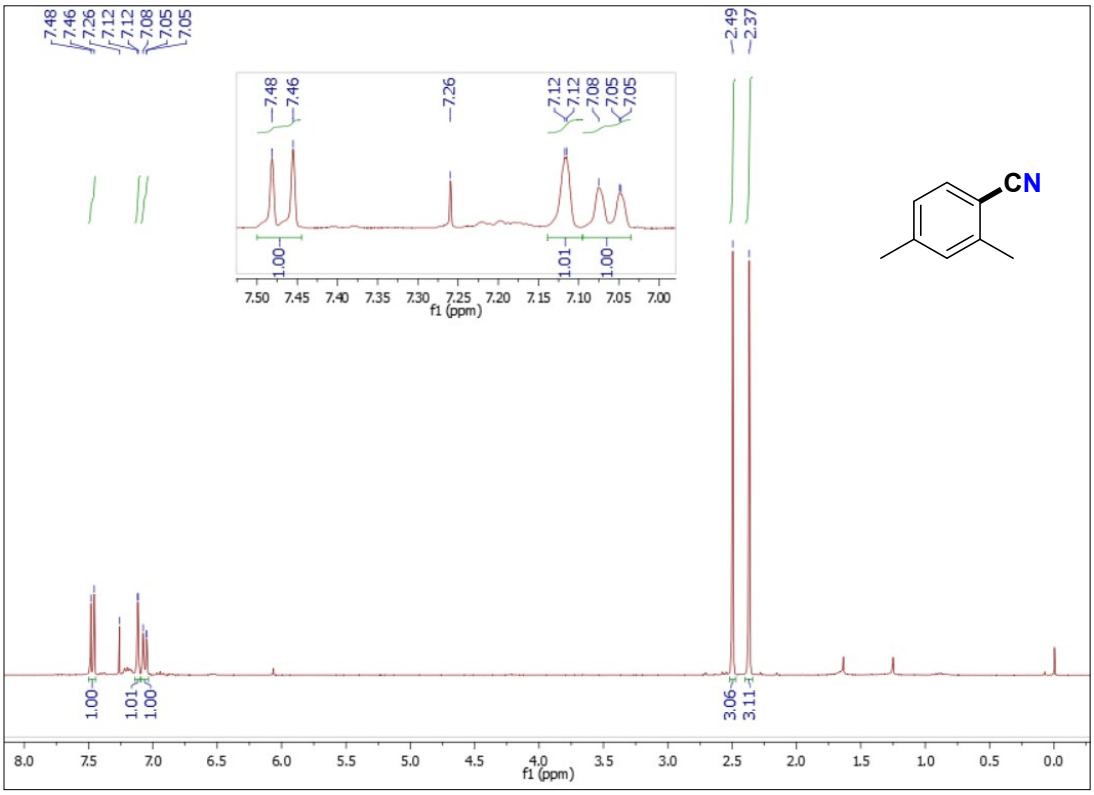


Figure S2. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3a**)

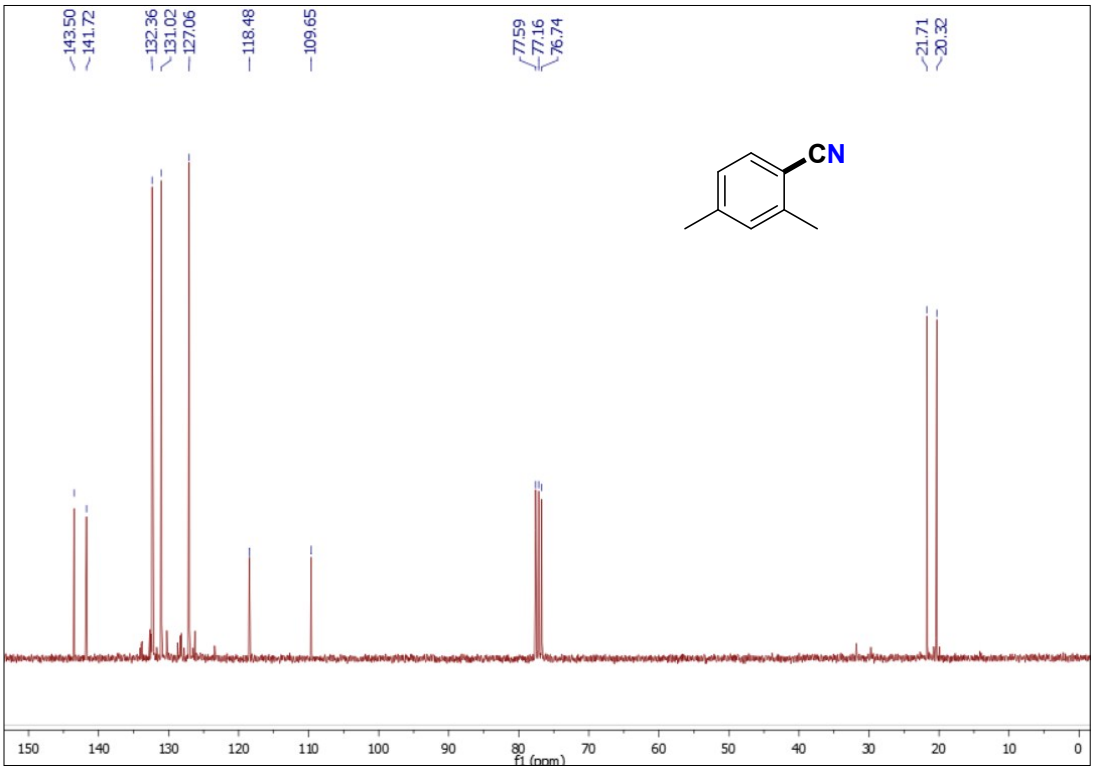


Figure S3. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3b**)

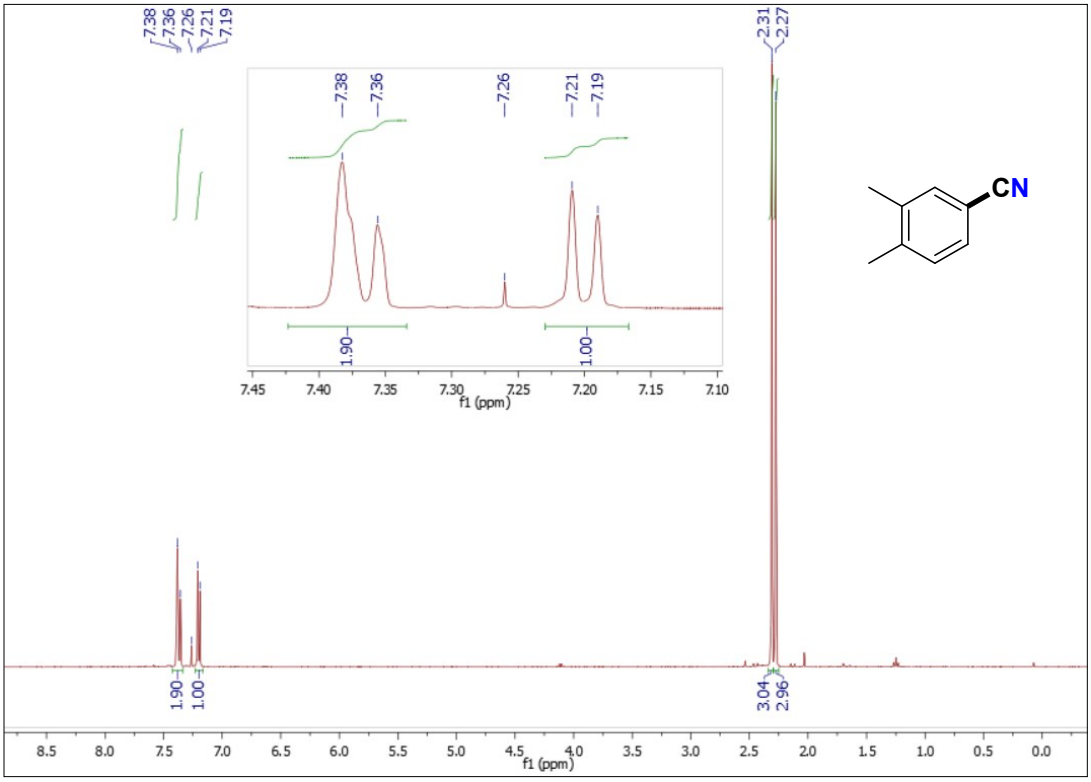


Figure S4. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3b**)

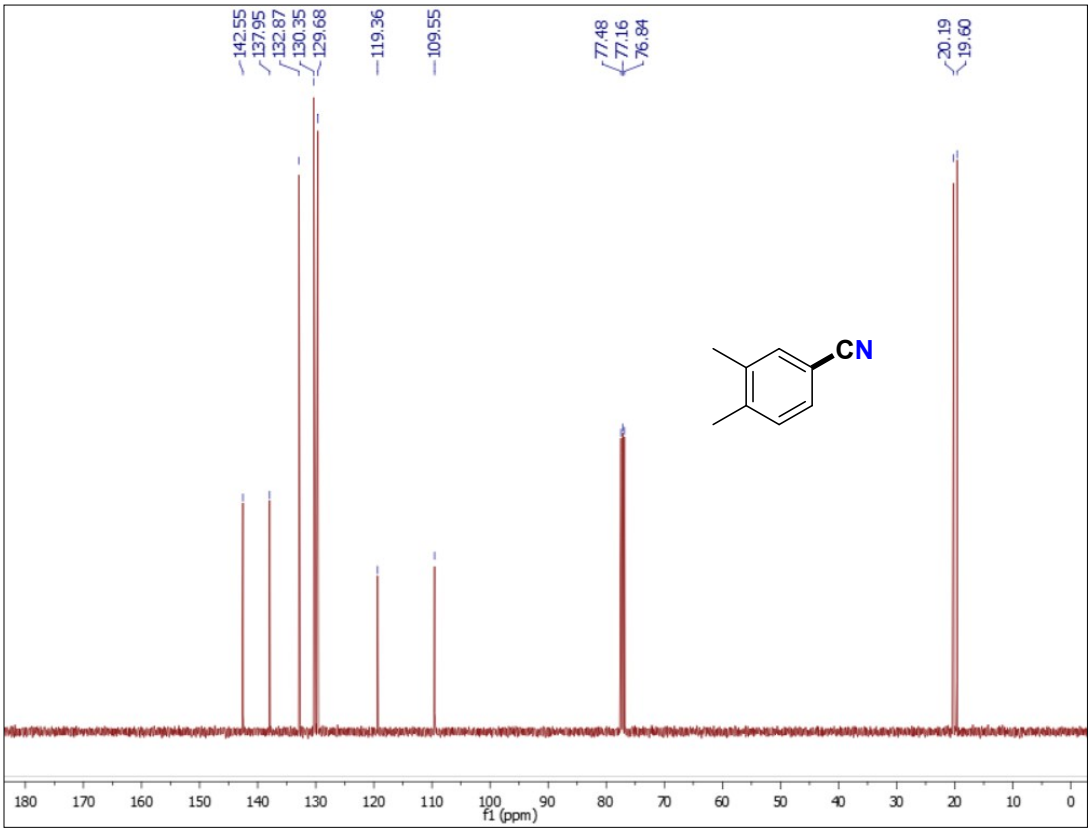


Figure S5. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3c**)

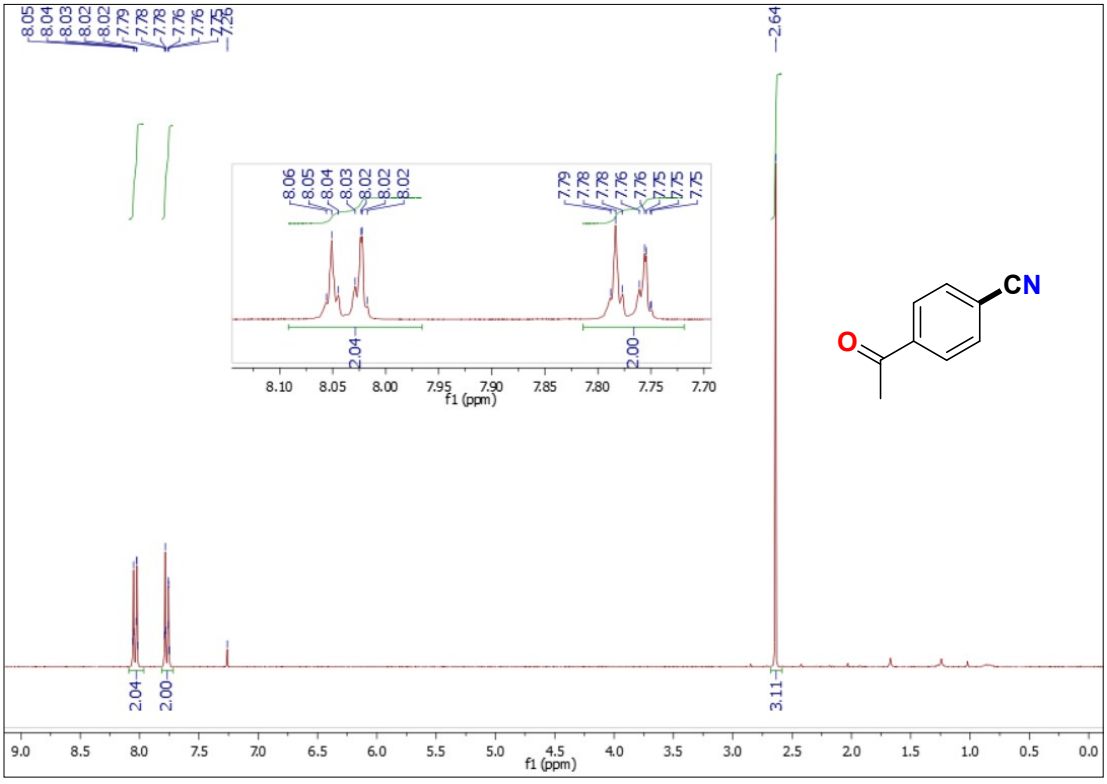


Figure S6. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3c**)

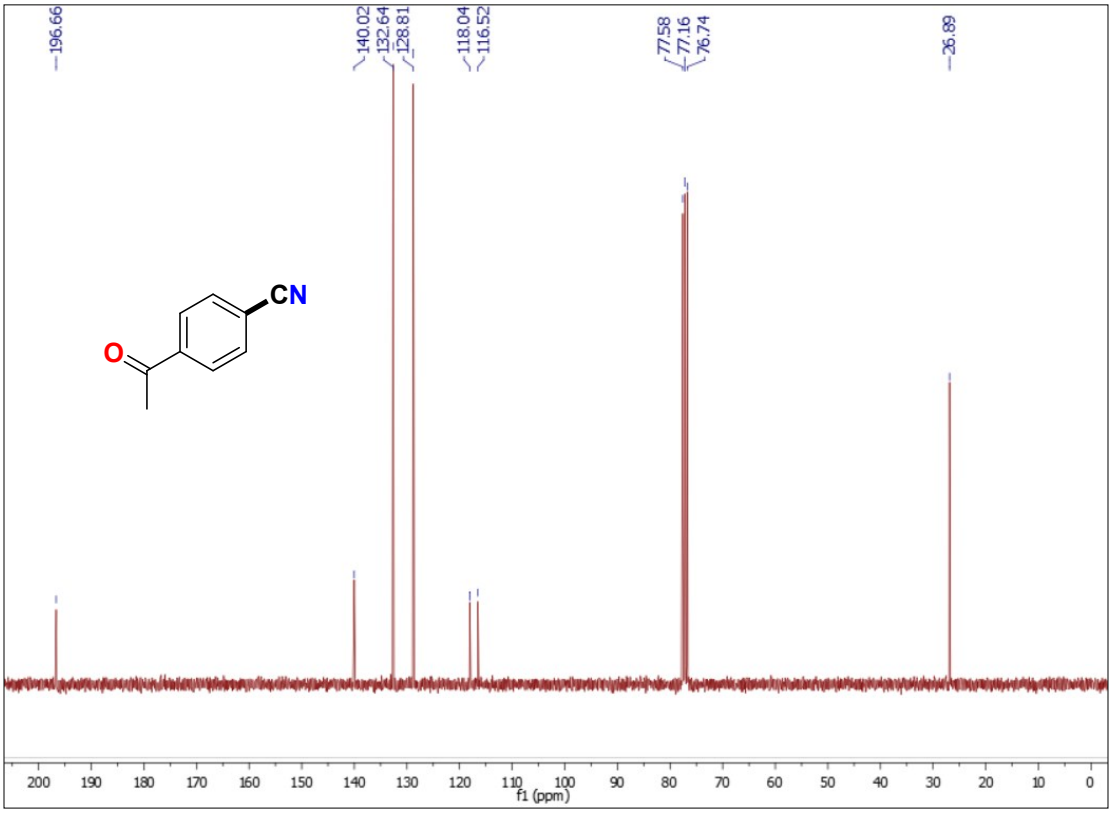


Figure S7. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3d**)

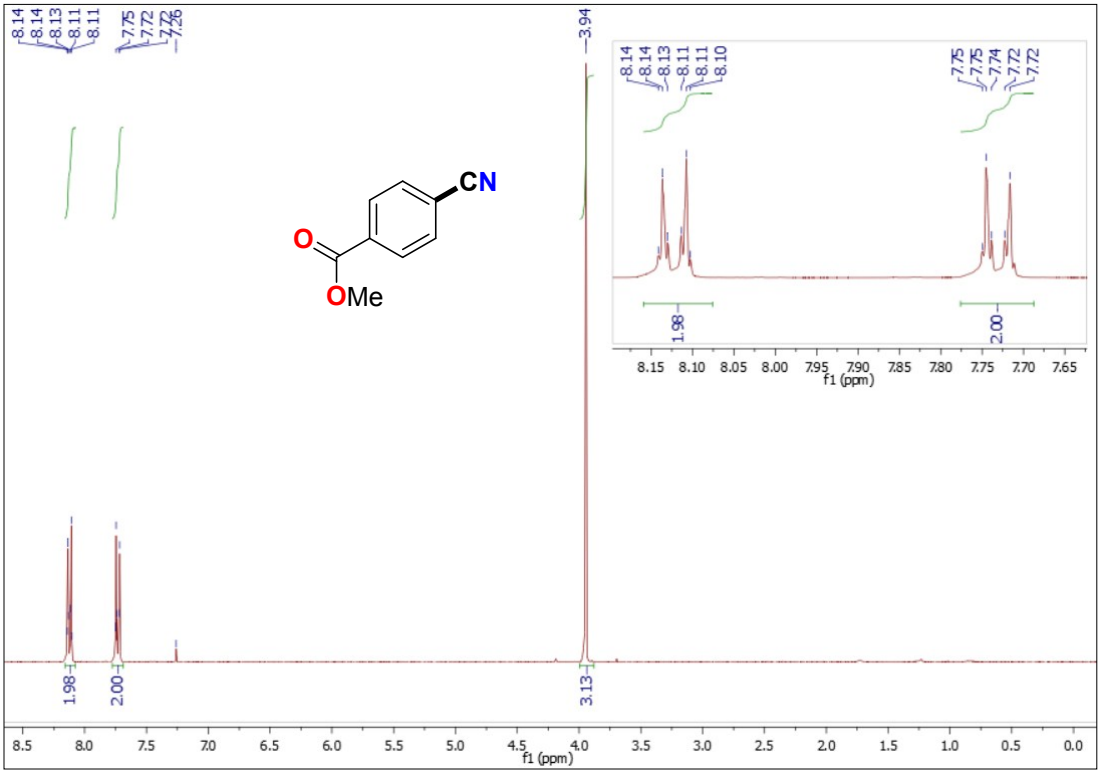


Figure S8. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3d**)

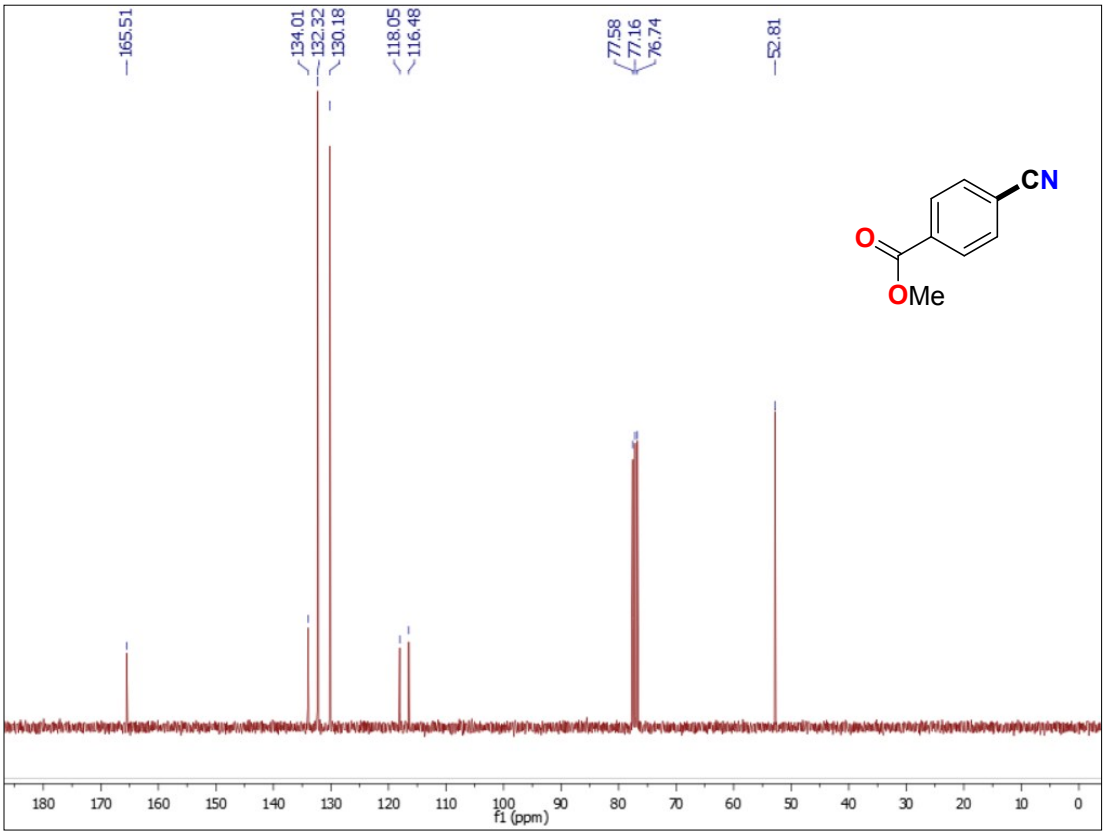


Figure S9. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound (**3e**)

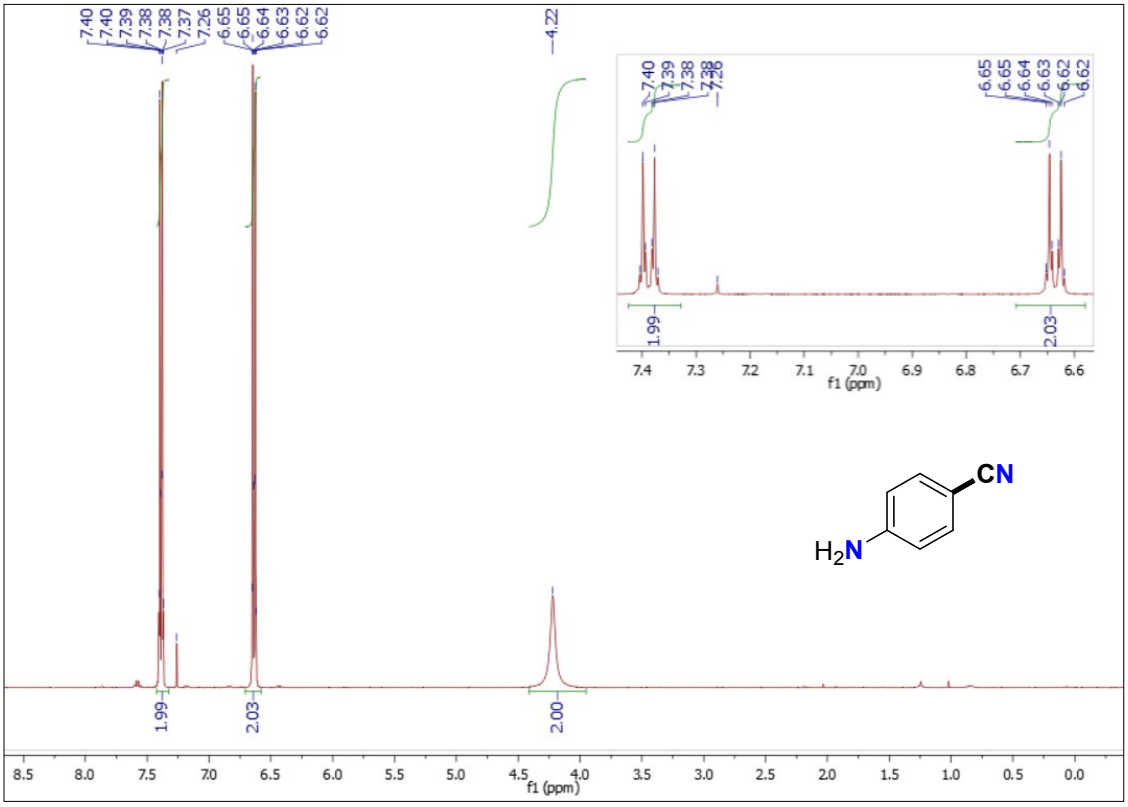


Figure S10. $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) spectrum of compound (**3e**)

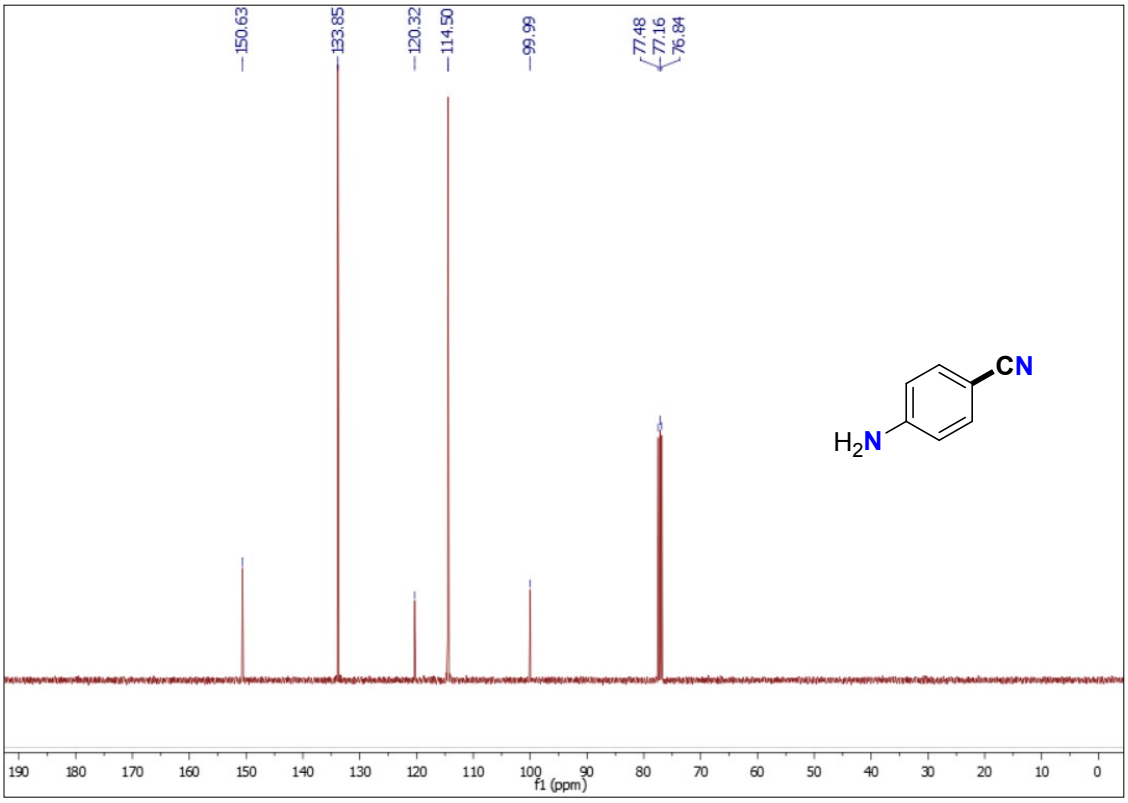
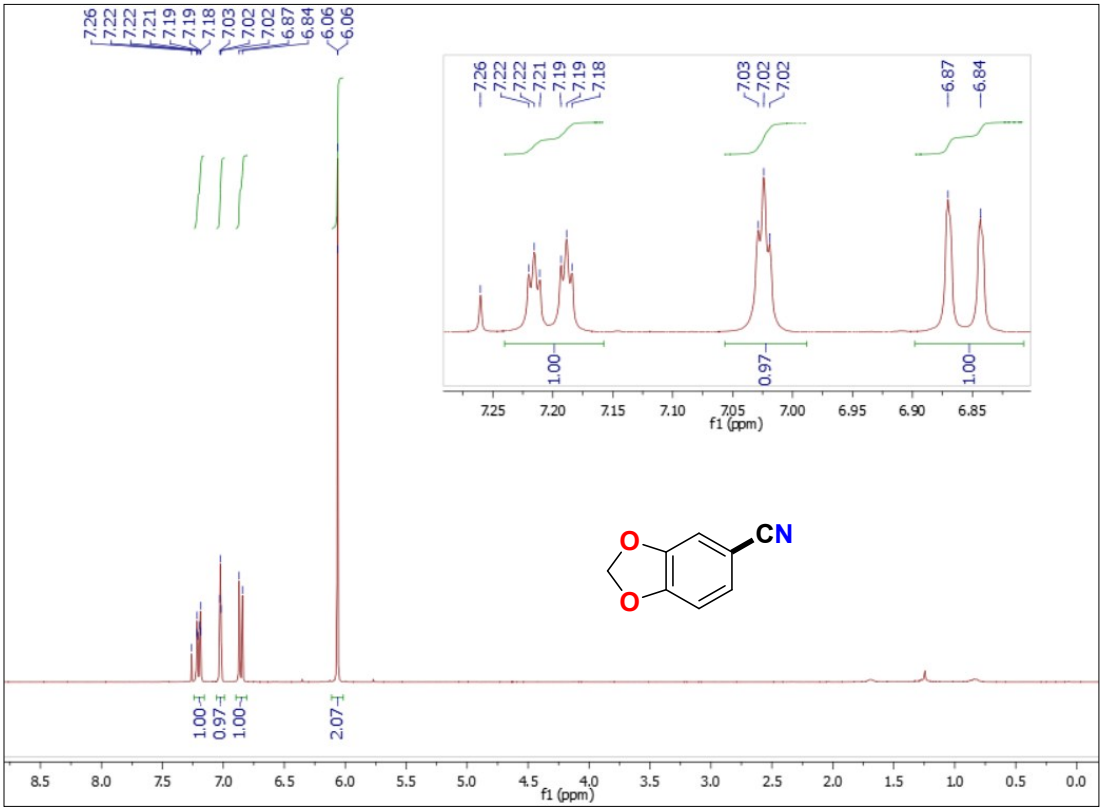


Figure S11. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3f**)



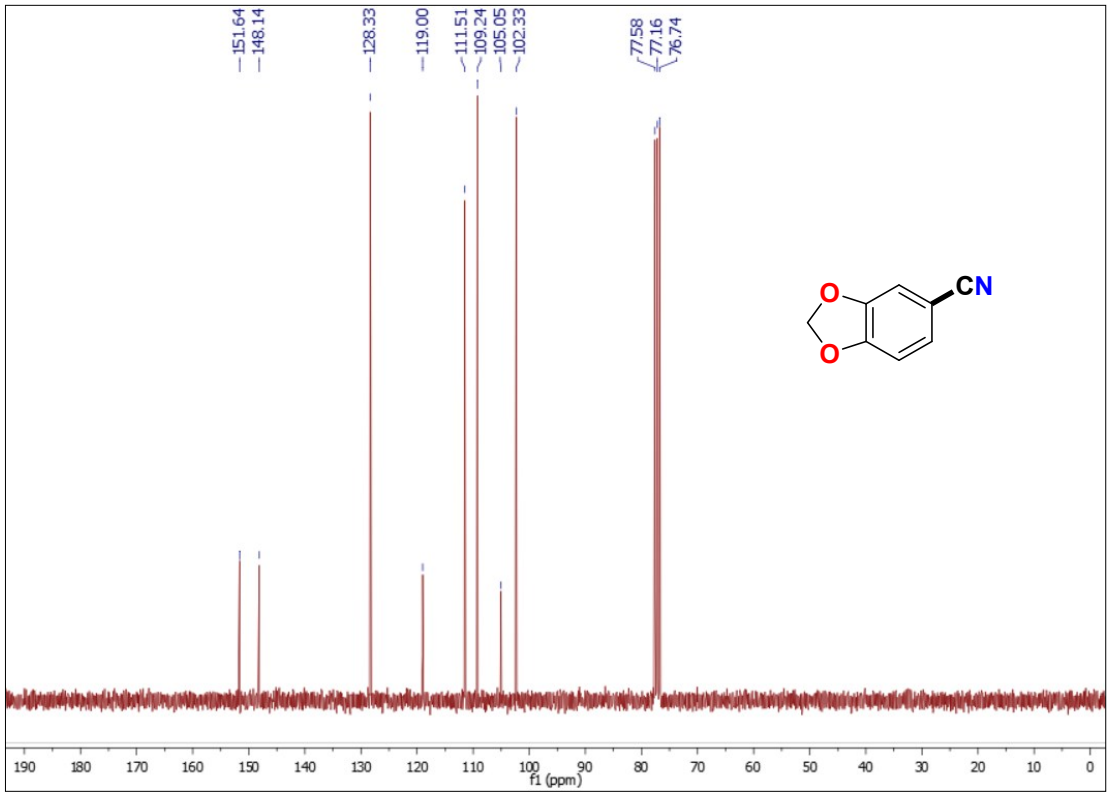


Figure S12. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3f**)

Figure S13. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3g**)

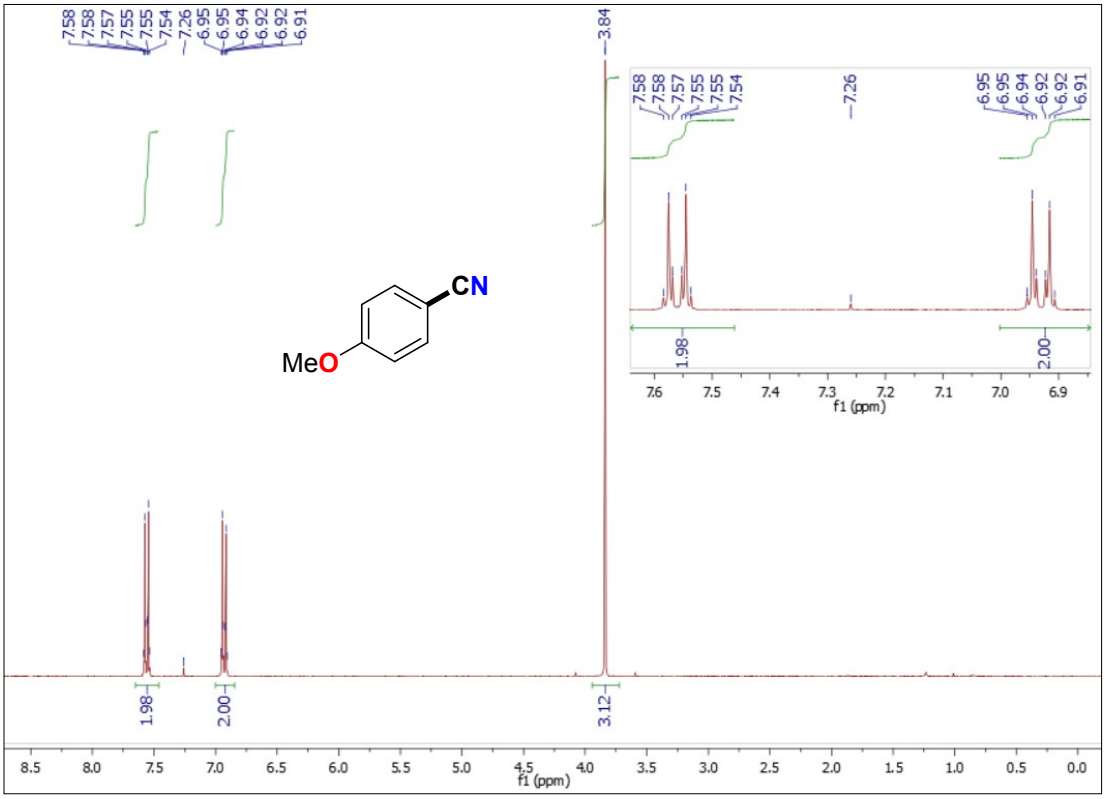


Figure S14. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3g**)

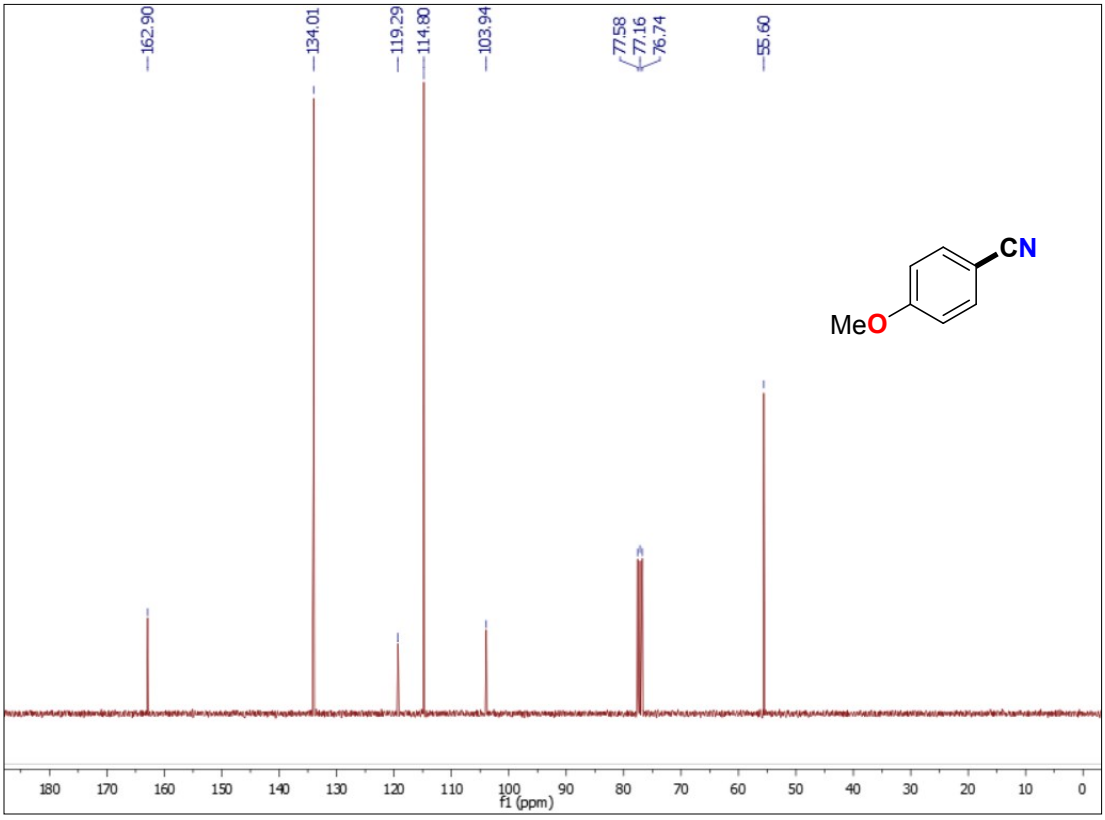


Figure S15. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound (**3h**)

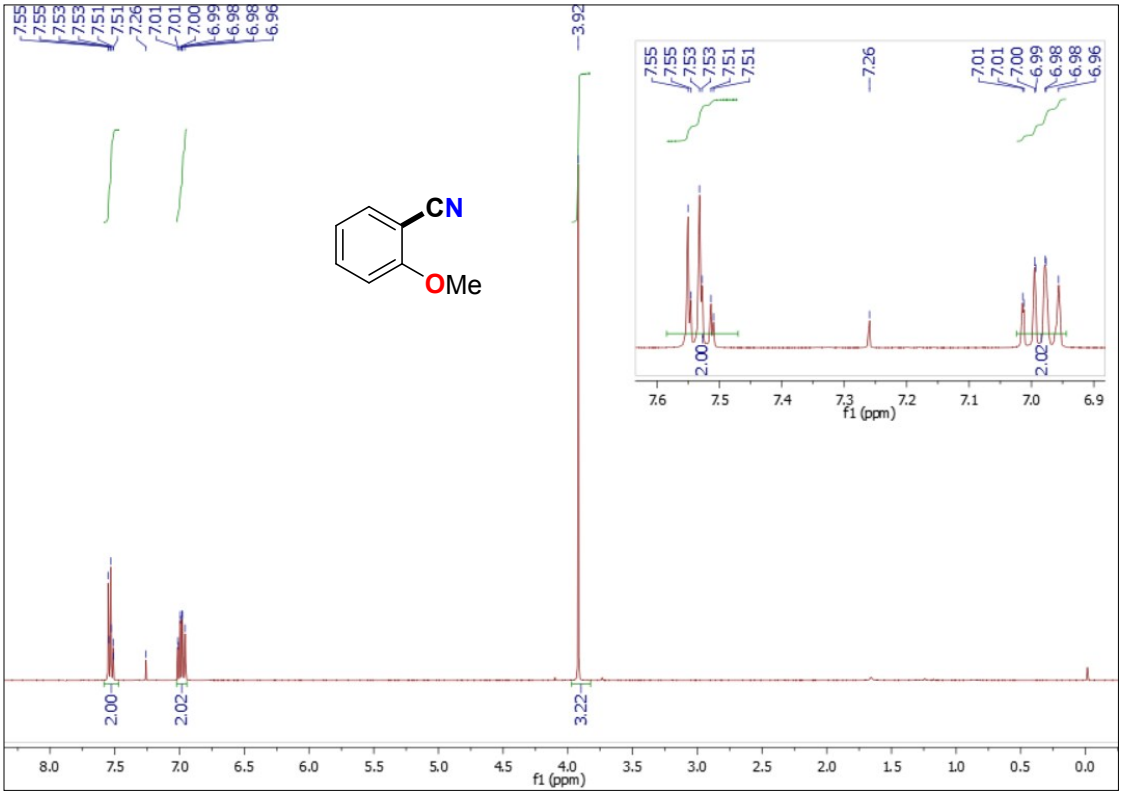


Figure S16. $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) spectrum of compound (**3h**)

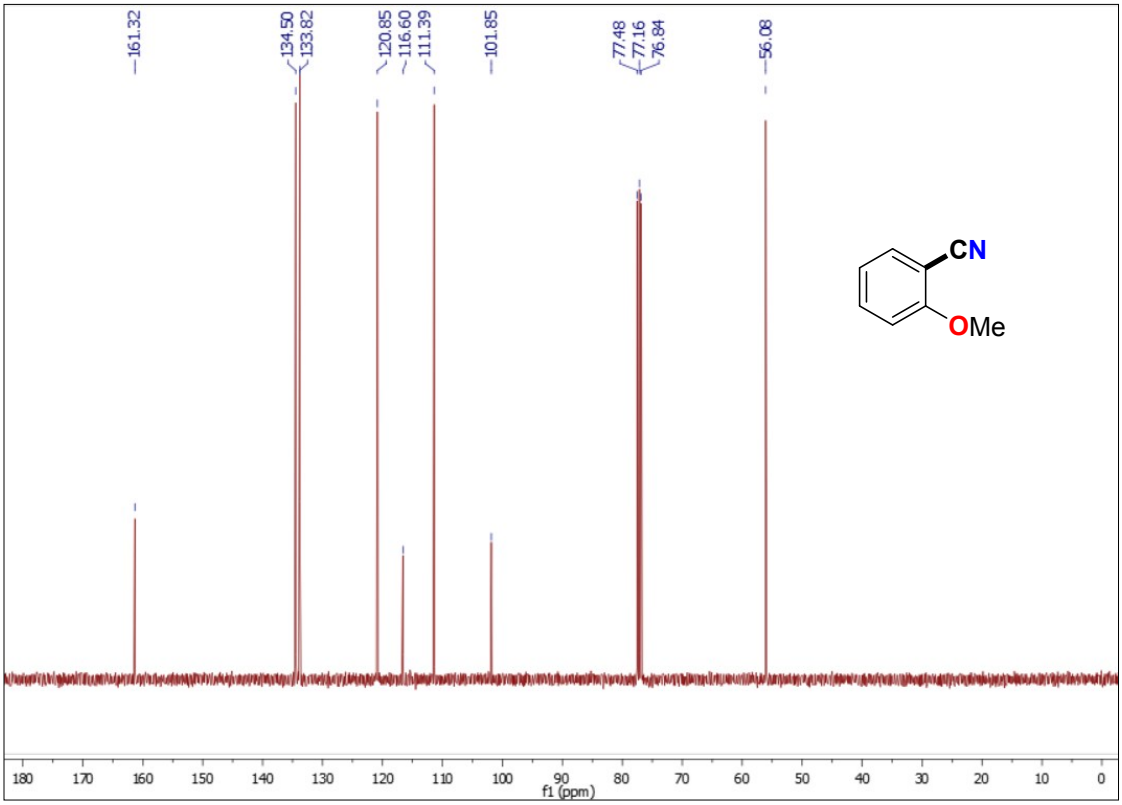


Figure S17. ^{1}H NMR (300 MHz, DMSO) spectrum of compound (**3i**)

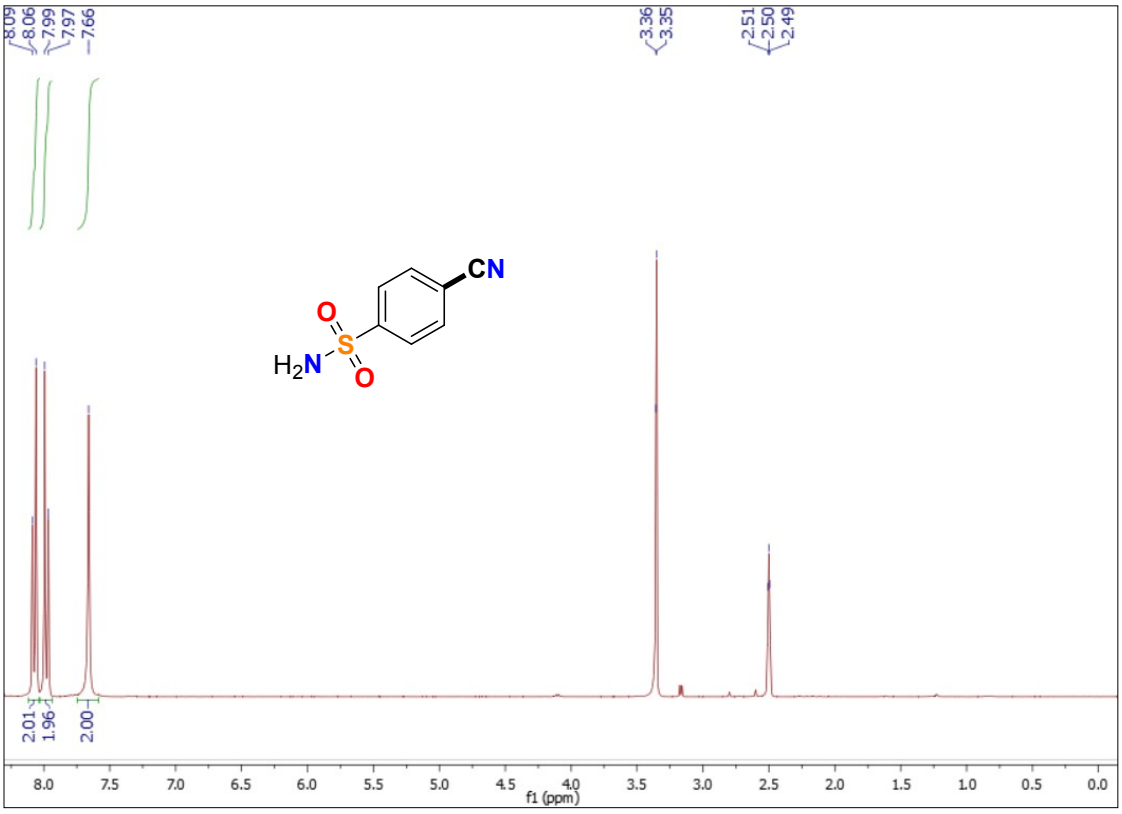


Figure S18. $^{13}C\{^{1}H\}$ NMR (75 MHz, DMSO) spectrum of compound (**3i**)

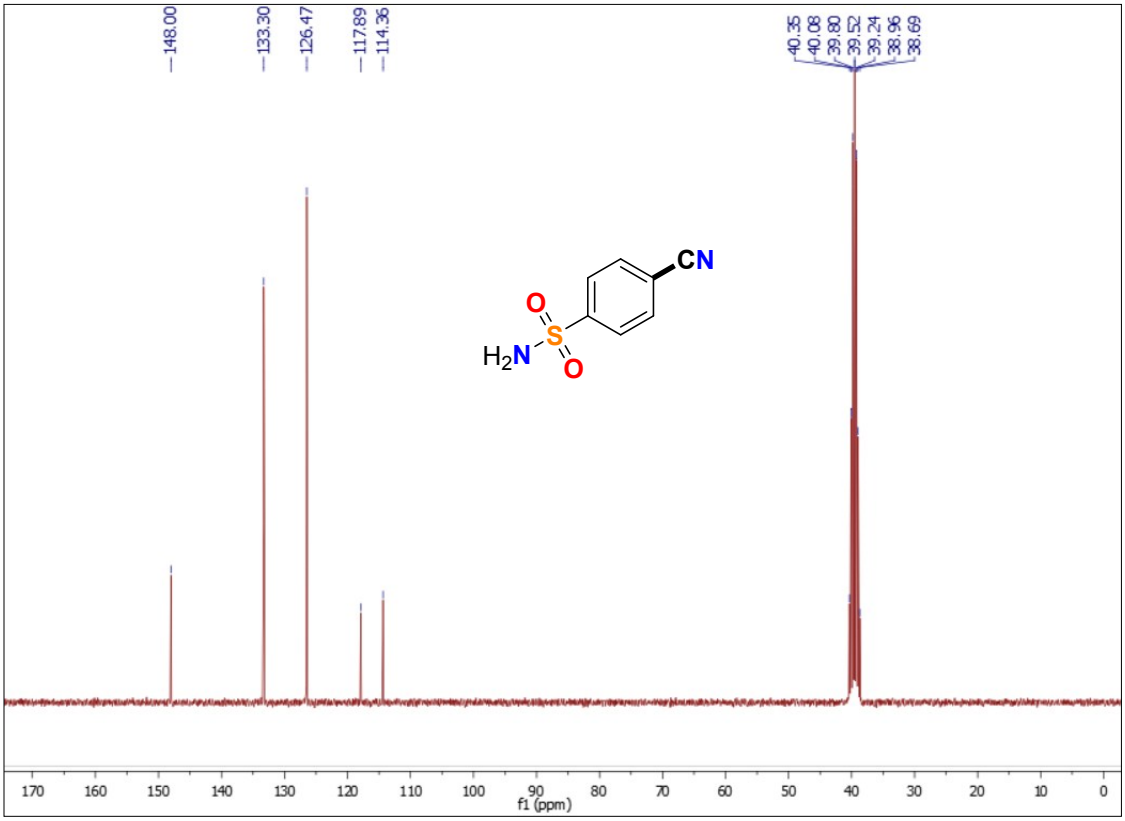


Figure S19. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3j**)

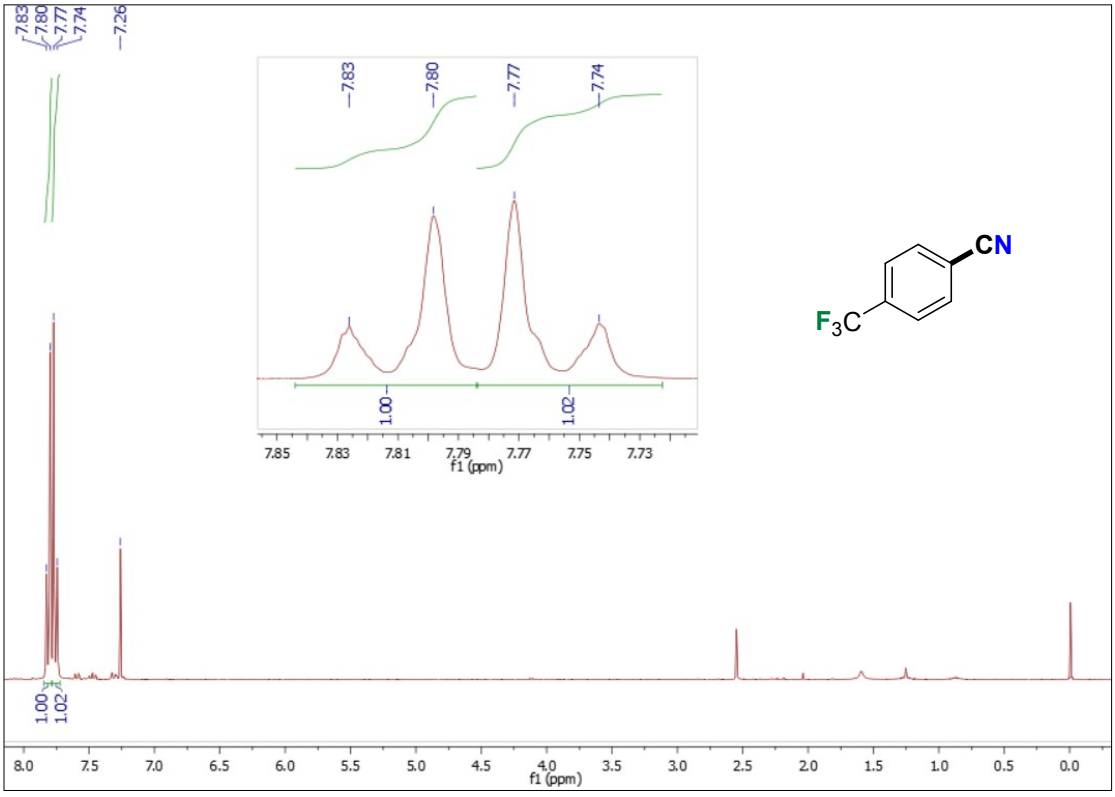


Figure S20. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3j**)

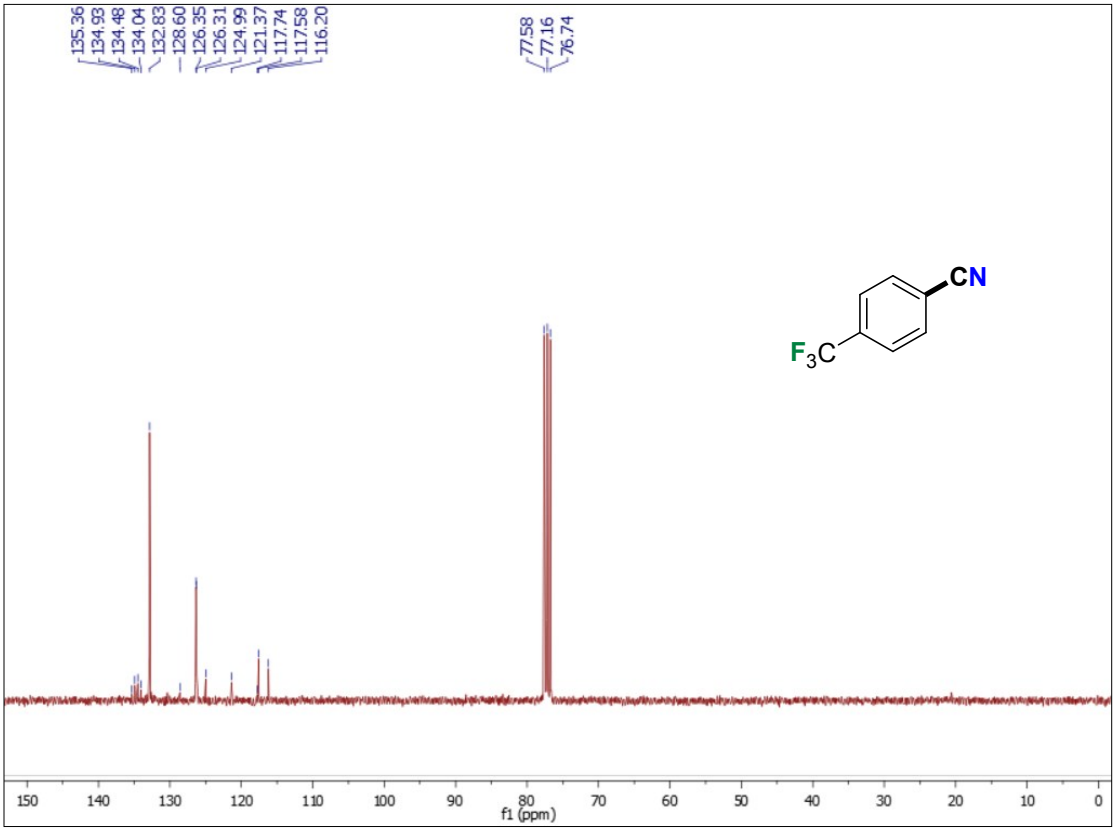


Figure S21. $^{19}F\{^{1}H\}$ NMR (282 MHz, $CDCl_3$) spectrum of compound (**3j**)

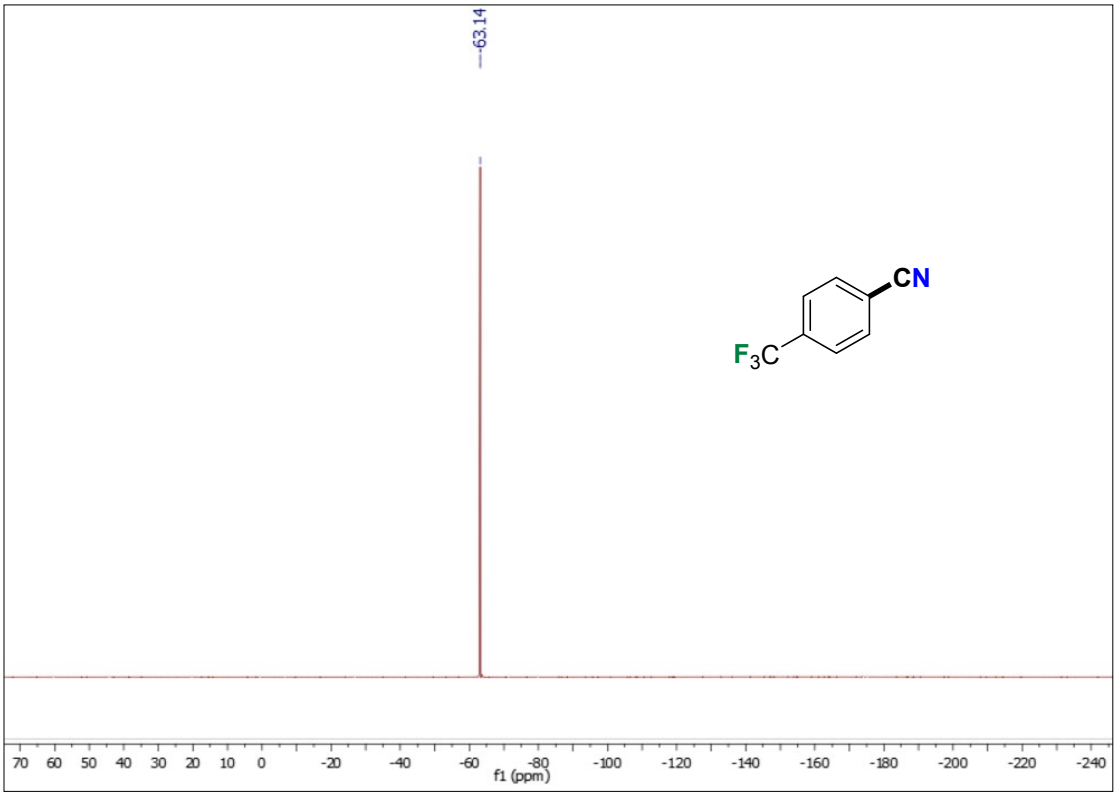


Figure S22. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3k**)

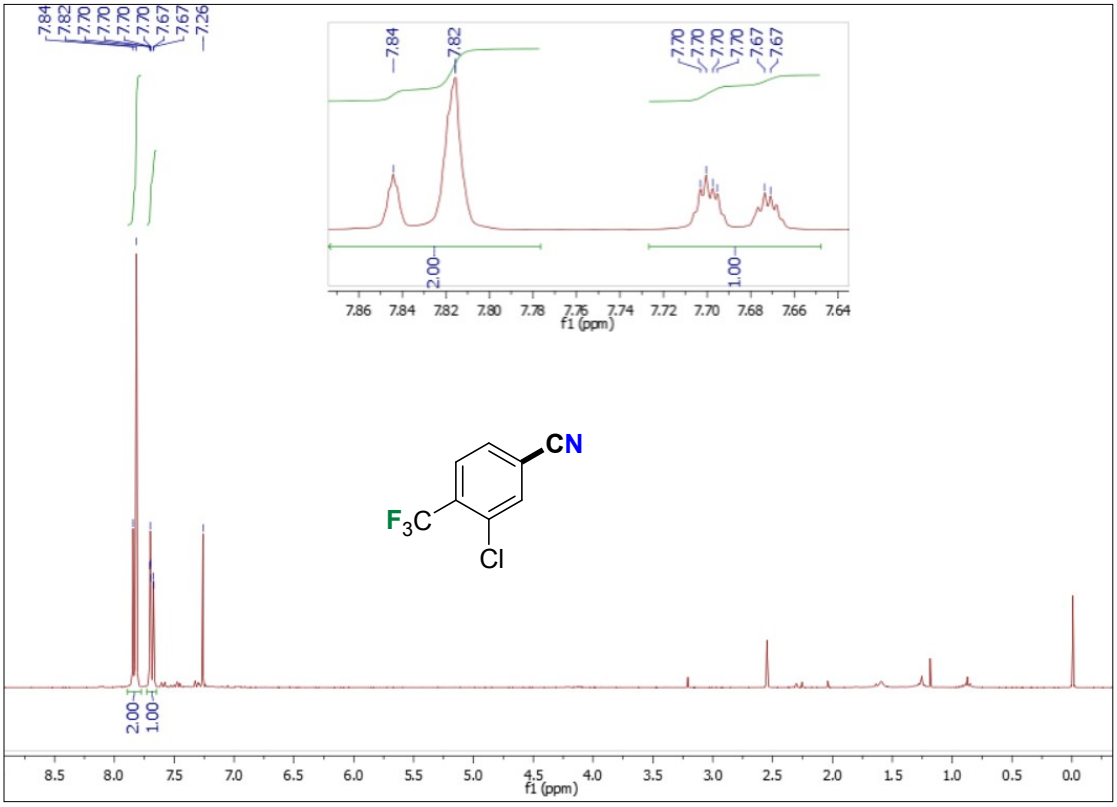


Figure S23. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3k**)

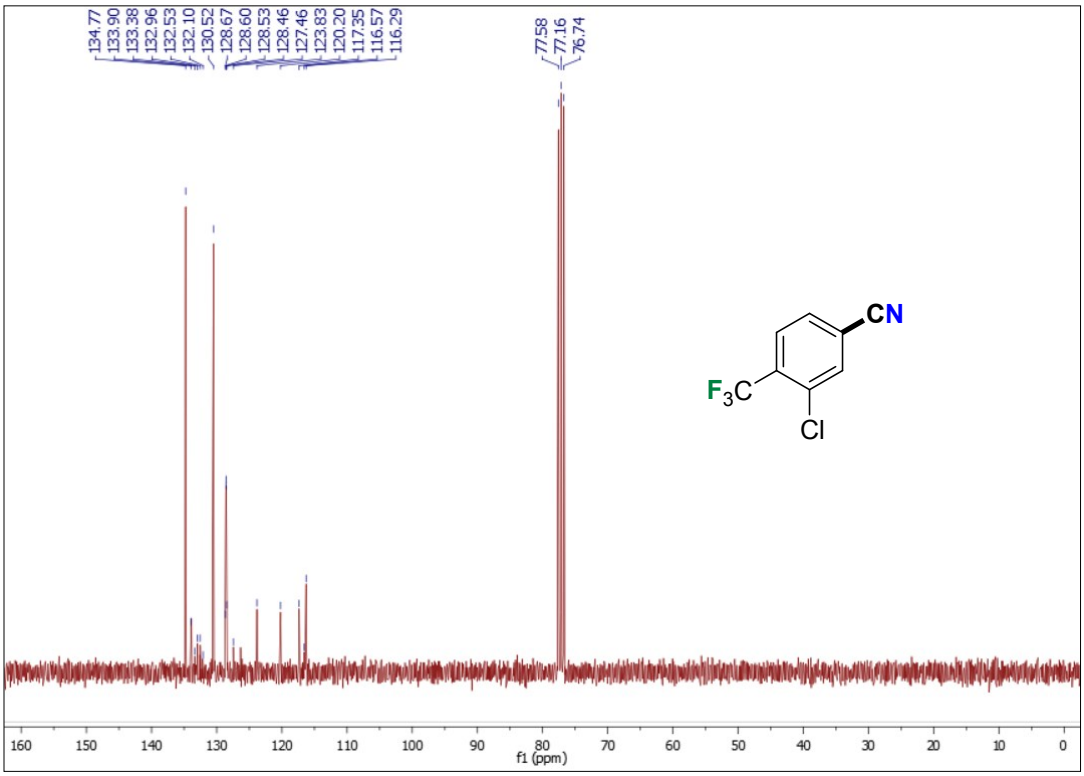


Figure S24. $^{19}F\{^{1}H\}$ NMR (282 MHz, $CDCl_3$) spectrum of compound (**3k**)

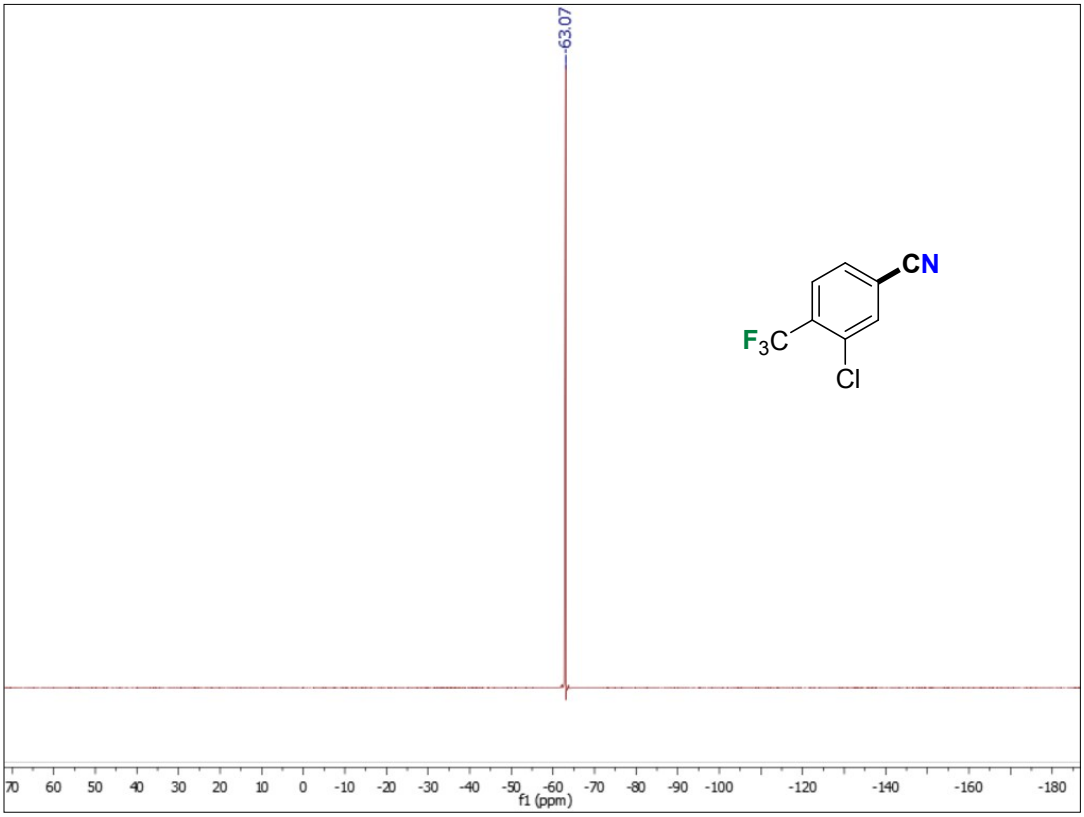


Figure S25. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3l**)

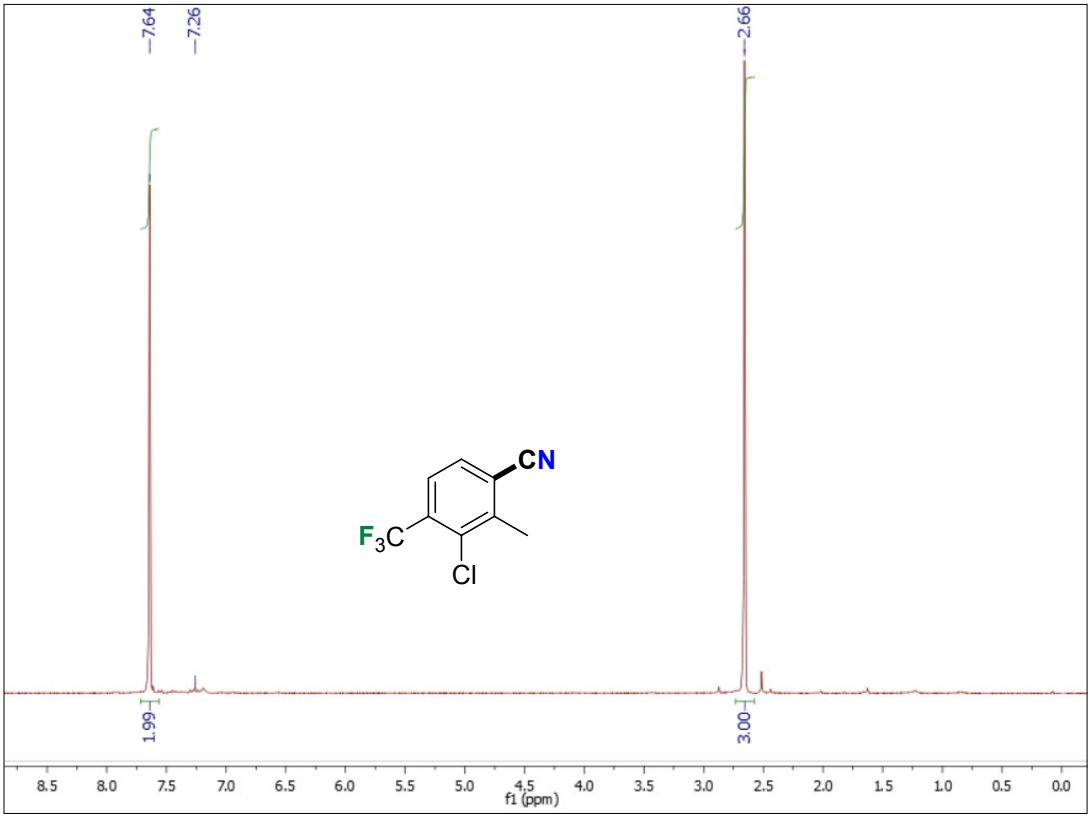


Figure S26. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3l**)

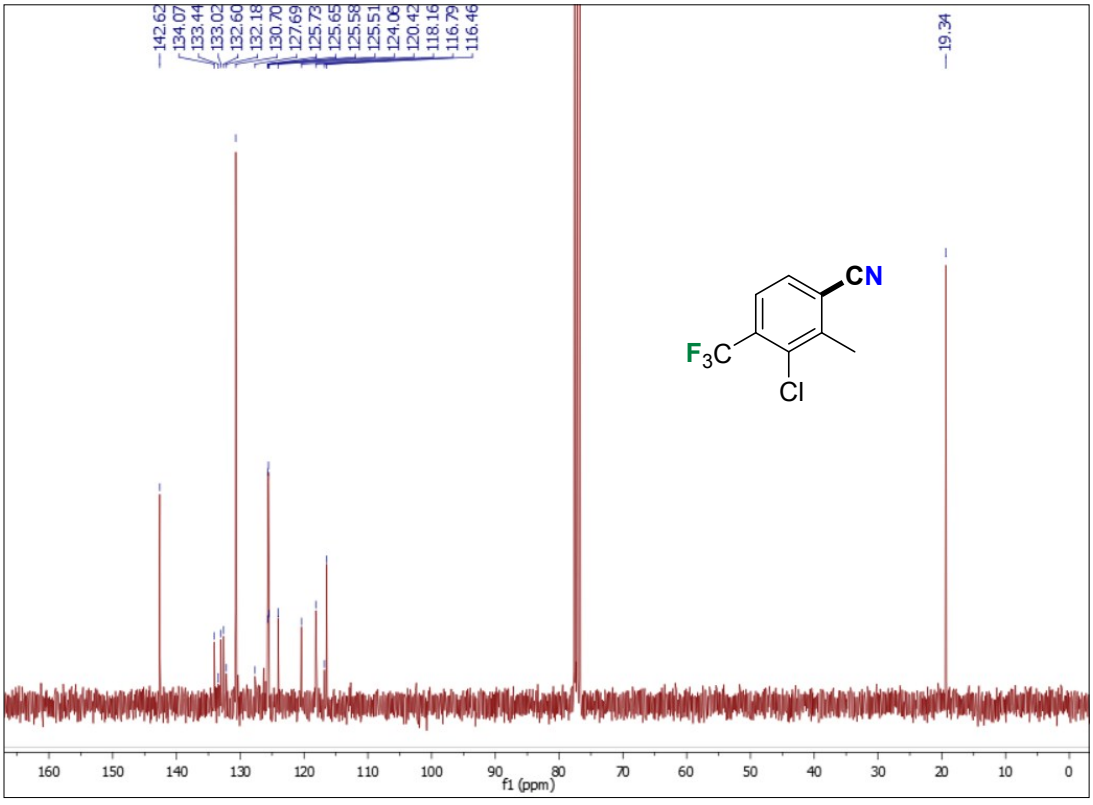


Figure S27. $^{19}F\{^{1}H\}$ NMR (282 MHz, $CDCl_3$) spectrum of compound (**3l**)

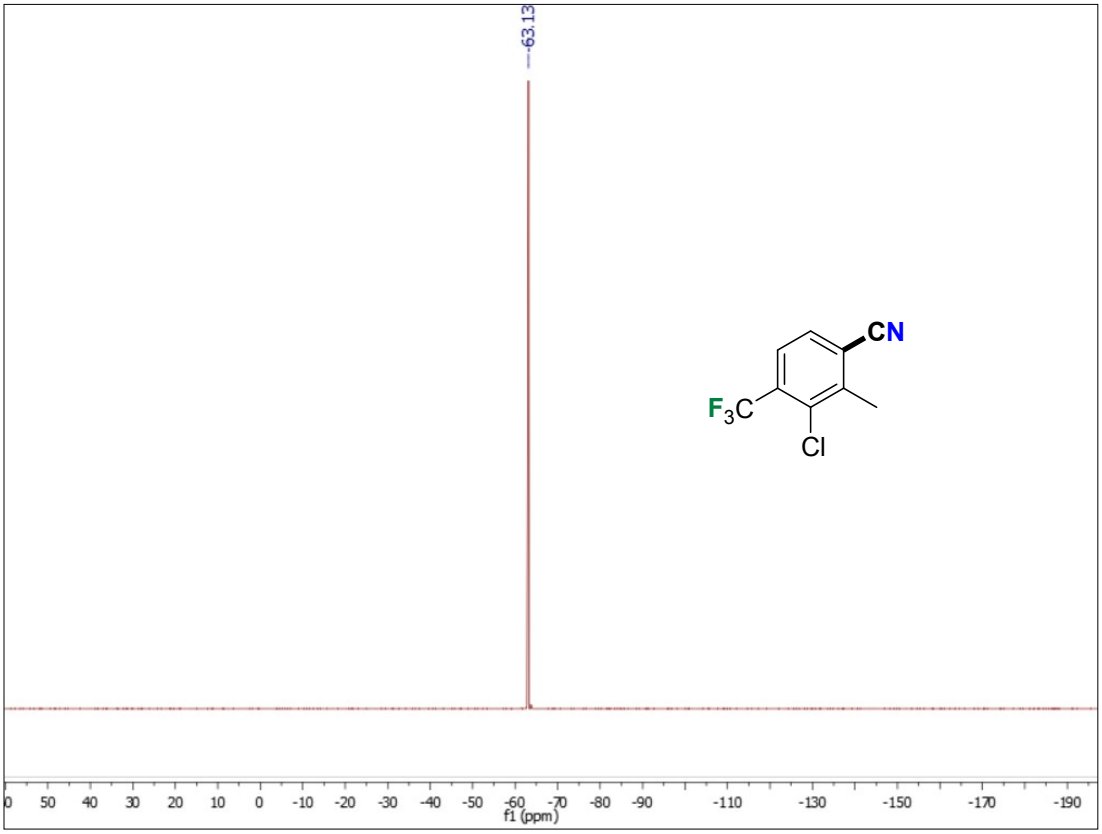


Figure S28. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound (**3q**)

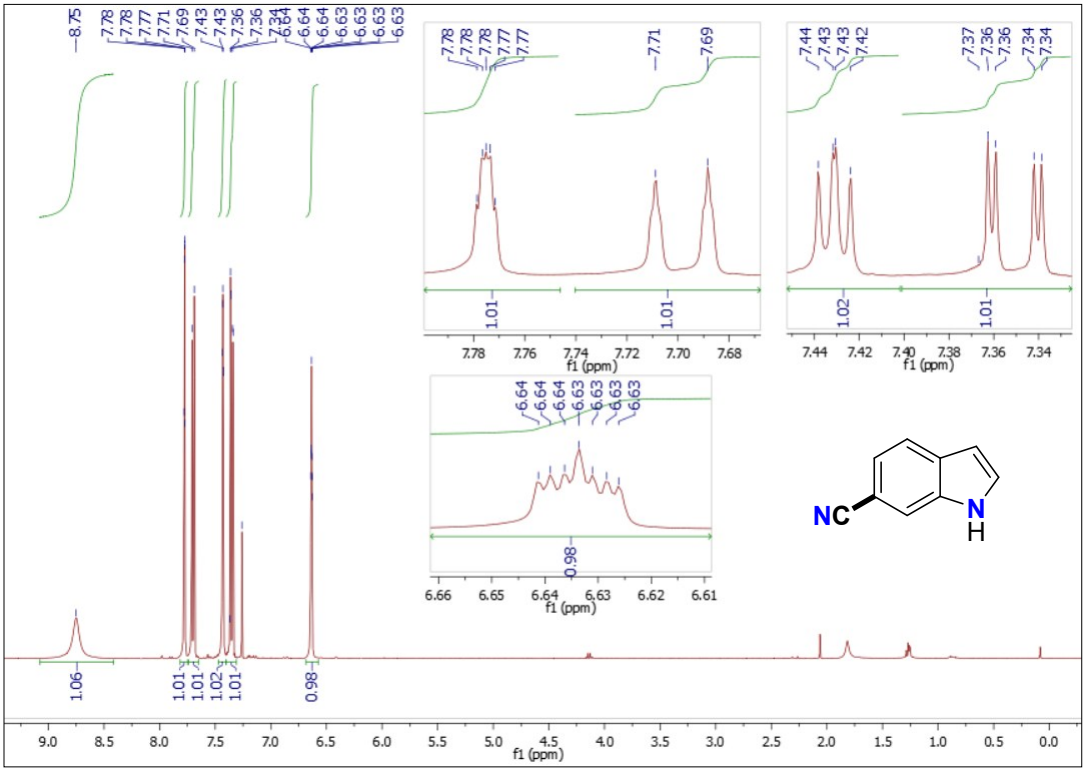


Figure S29. $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) spectrum of compound (**3q**)

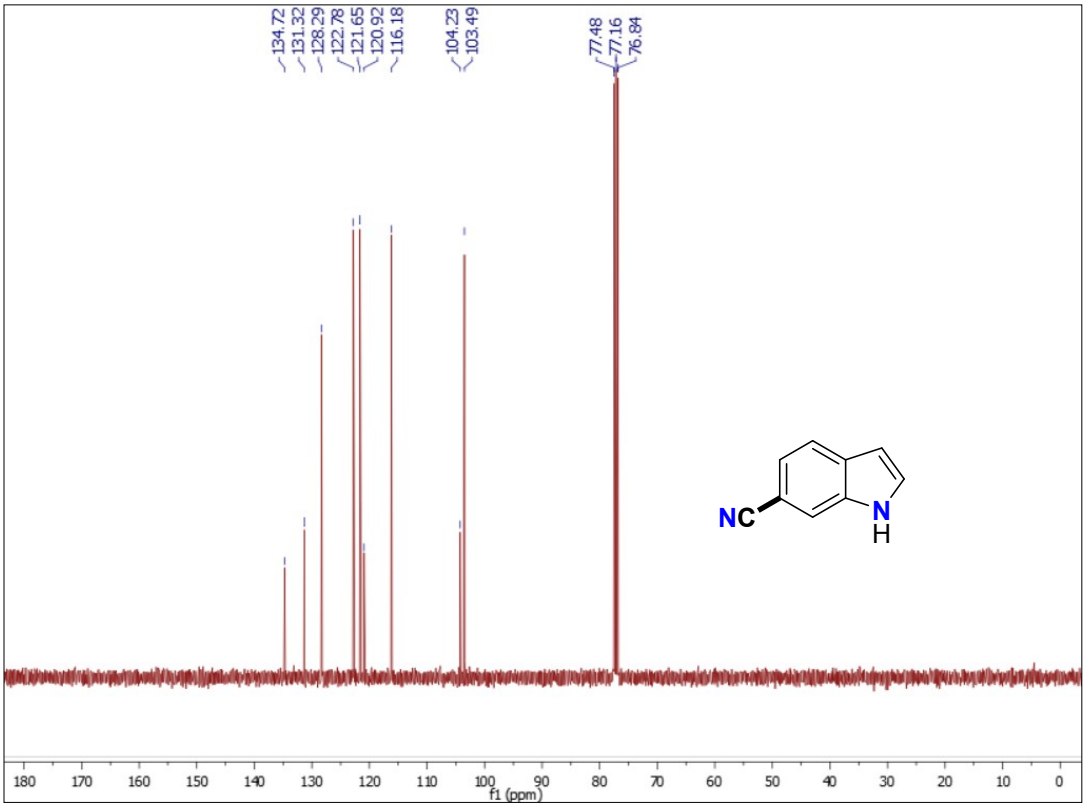


Figure S30. ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound (**3r**)

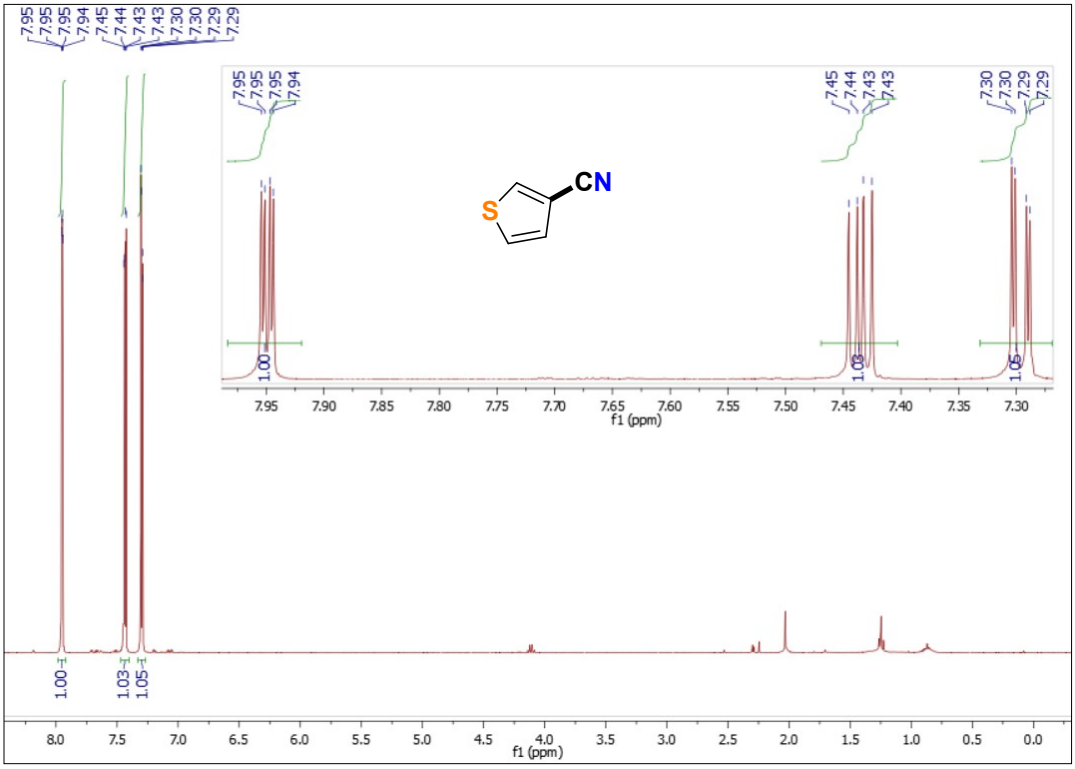


Figure S31. $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) spectrum of compound (**3r**)

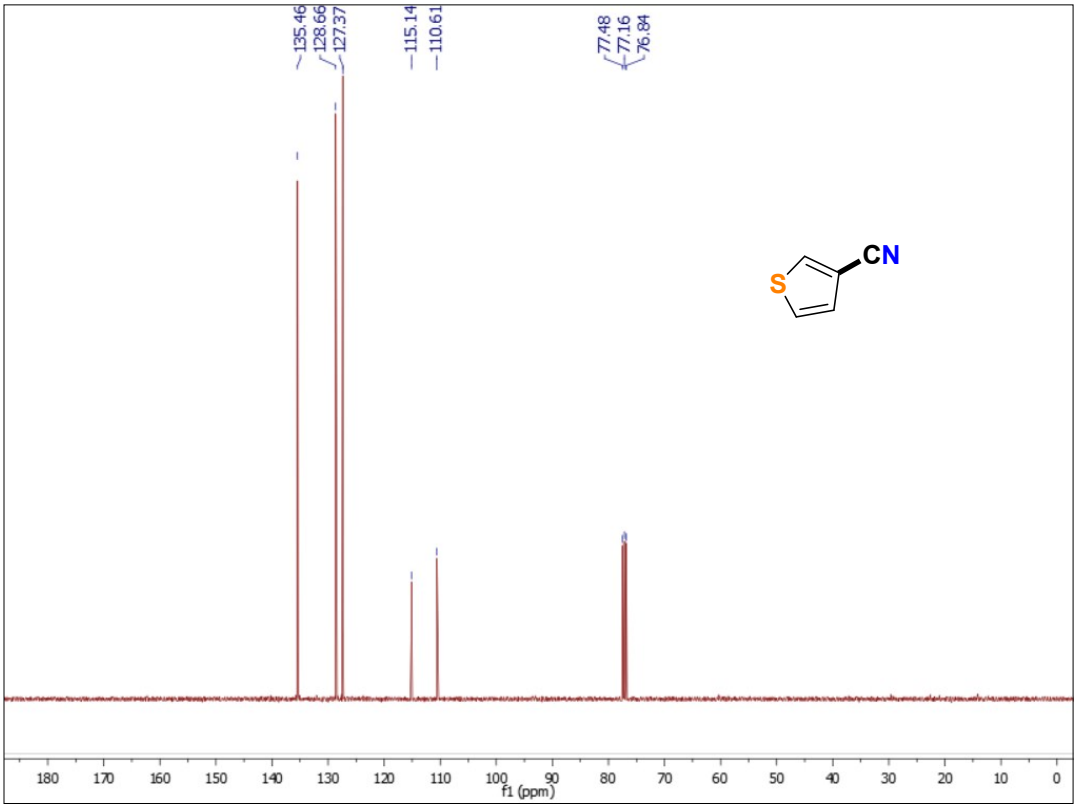


Figure S32. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3s**)

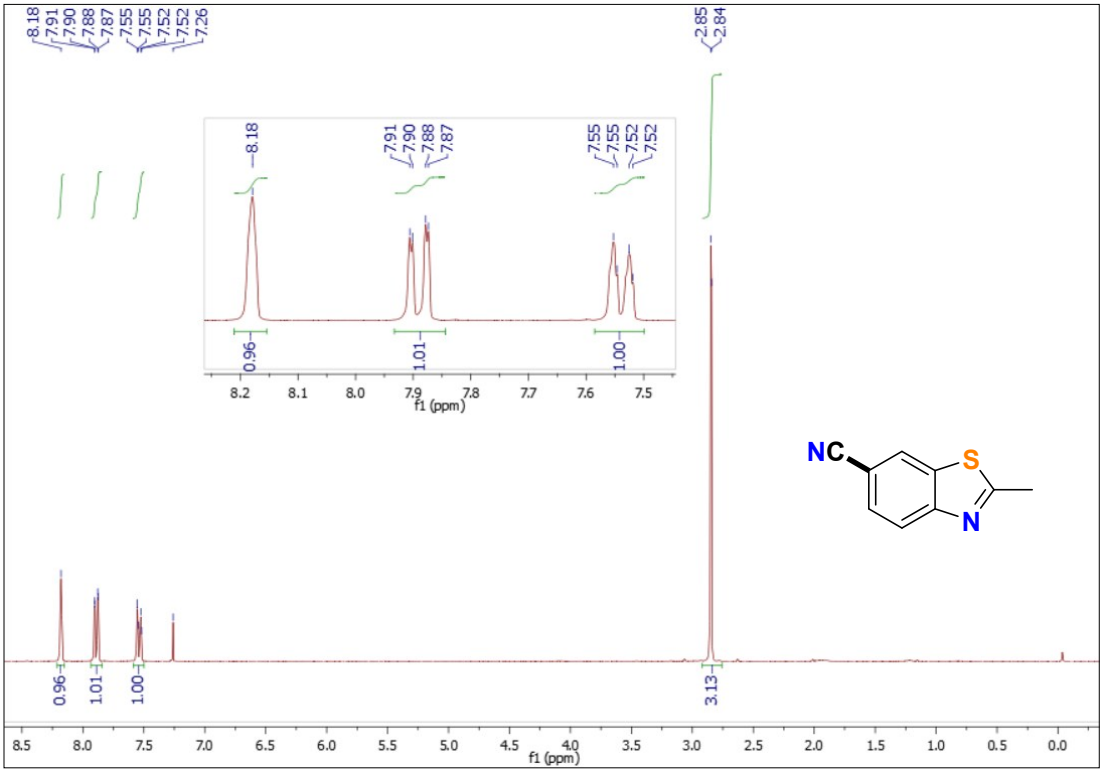


Figure S33. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3s**)

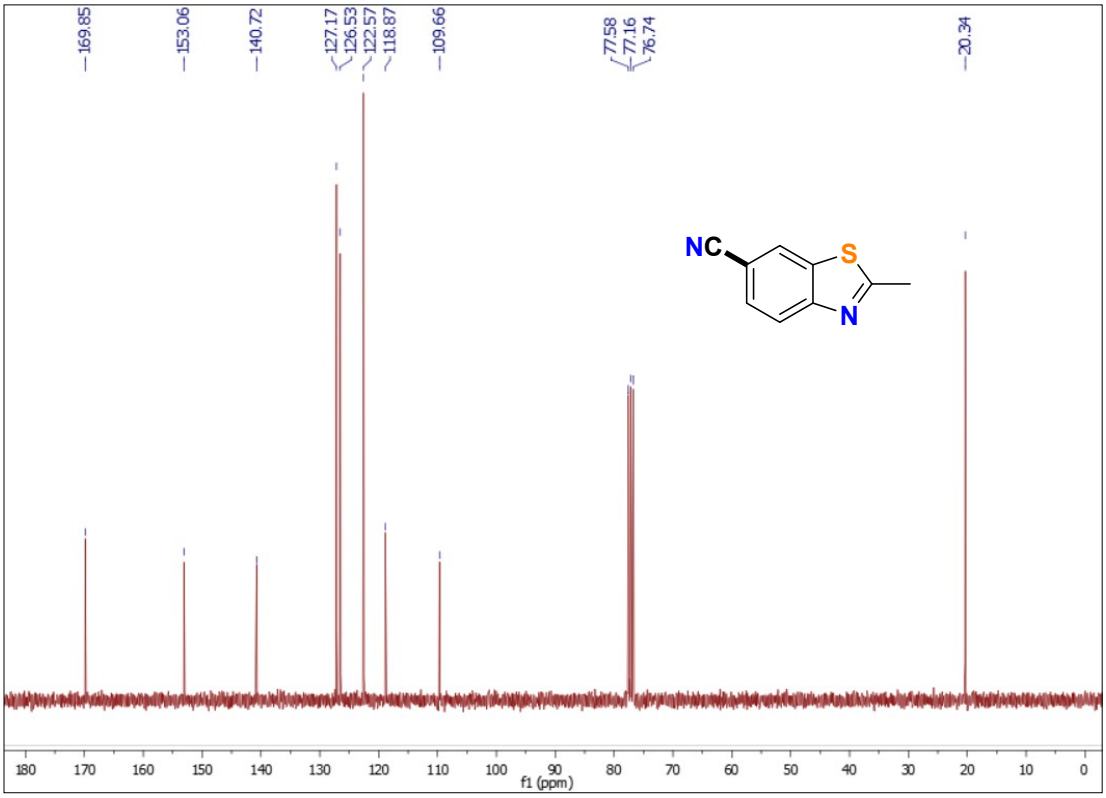


Figure S34. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3t**)

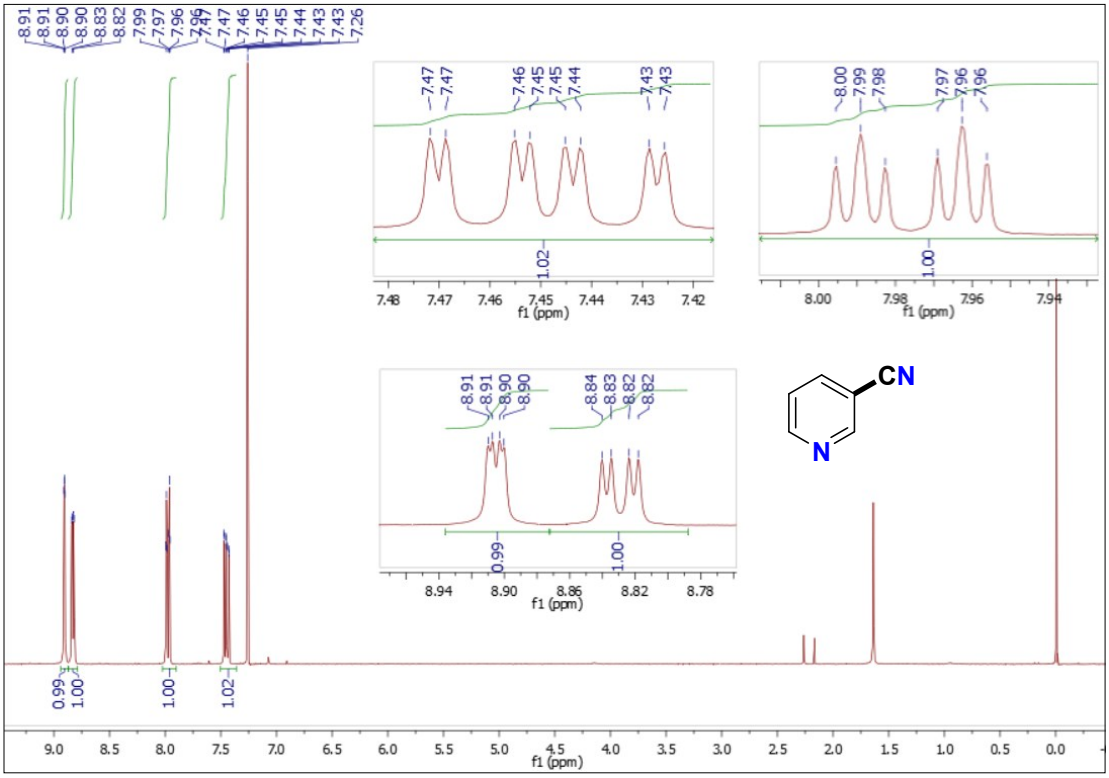


Figure S35. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3t**)

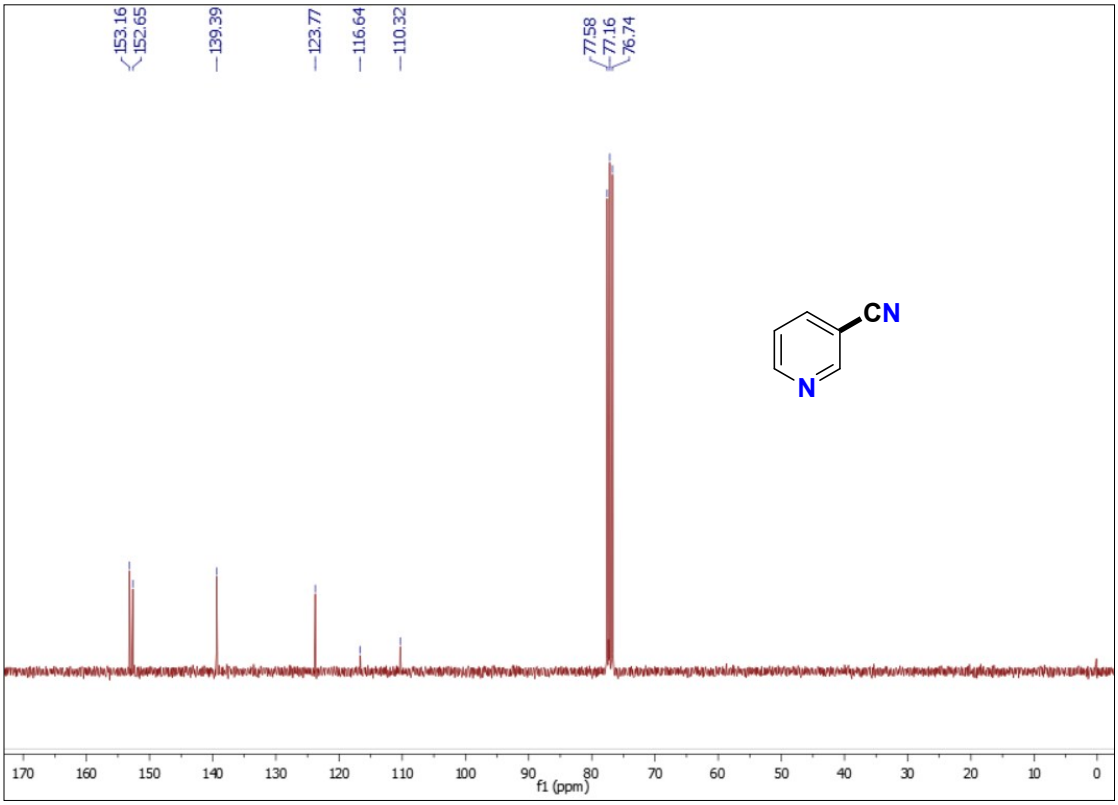


Figure S36. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3u**)

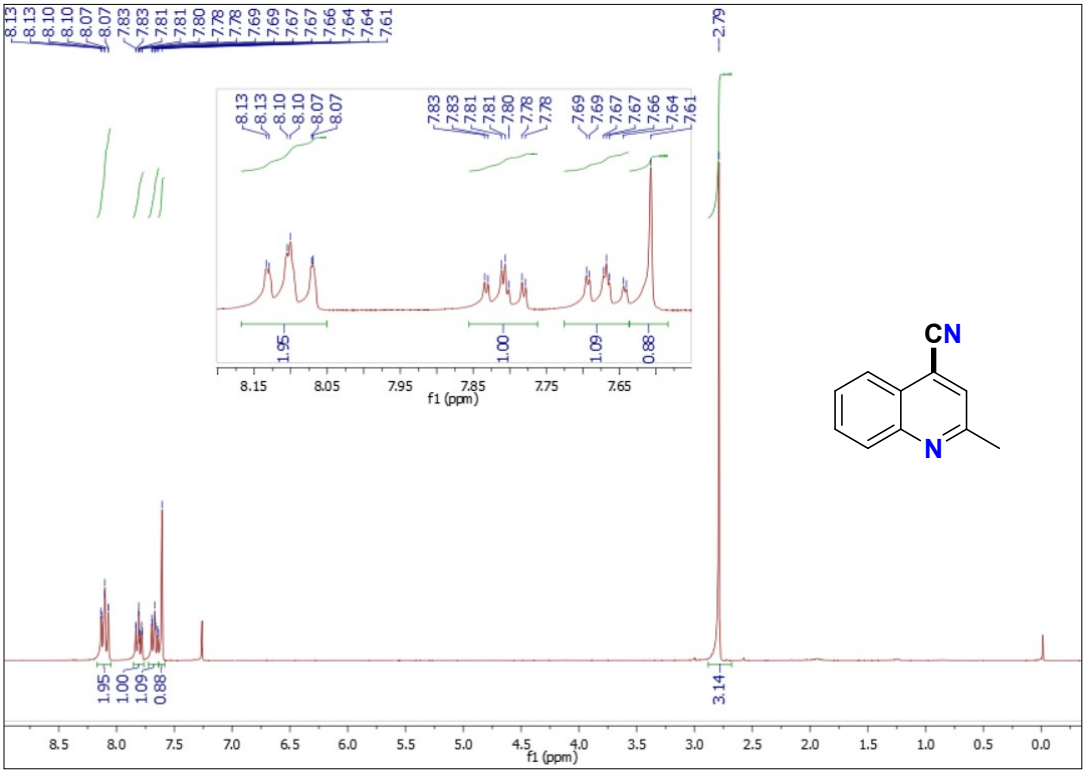


Figure S37. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3u**)

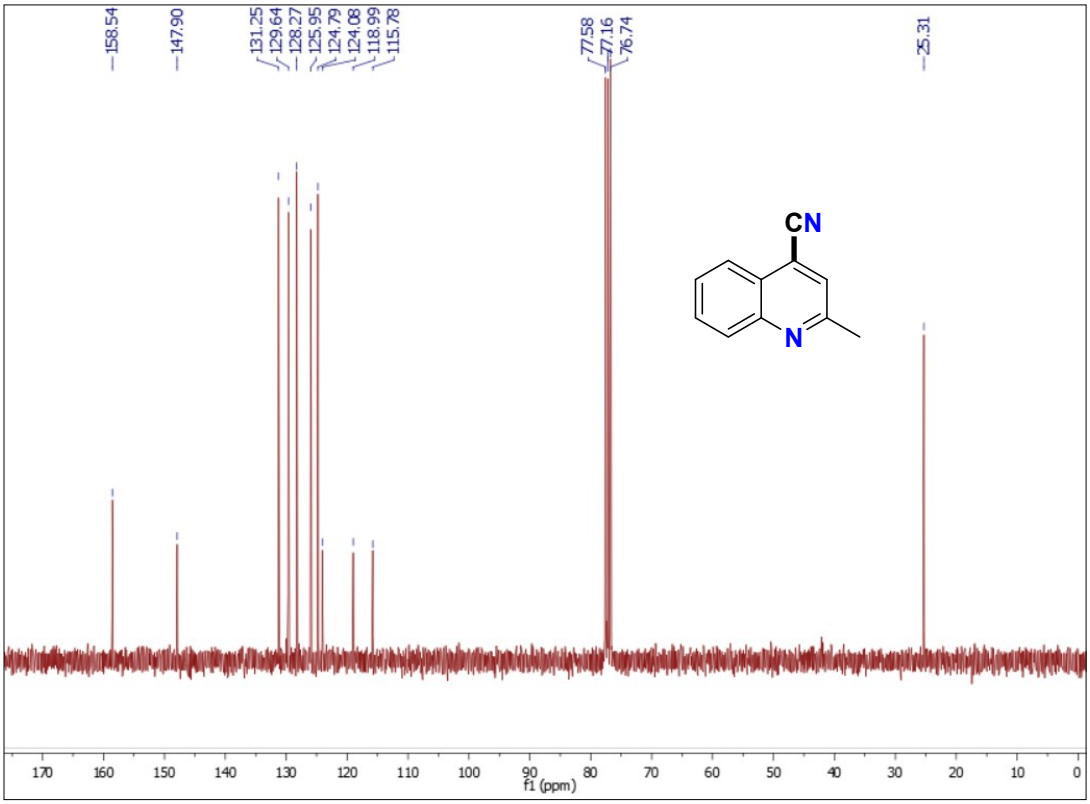


Figure S38. ^{1}H NMR (300 MHz, $CDCl_3$) spectrum of compound (**3v**)

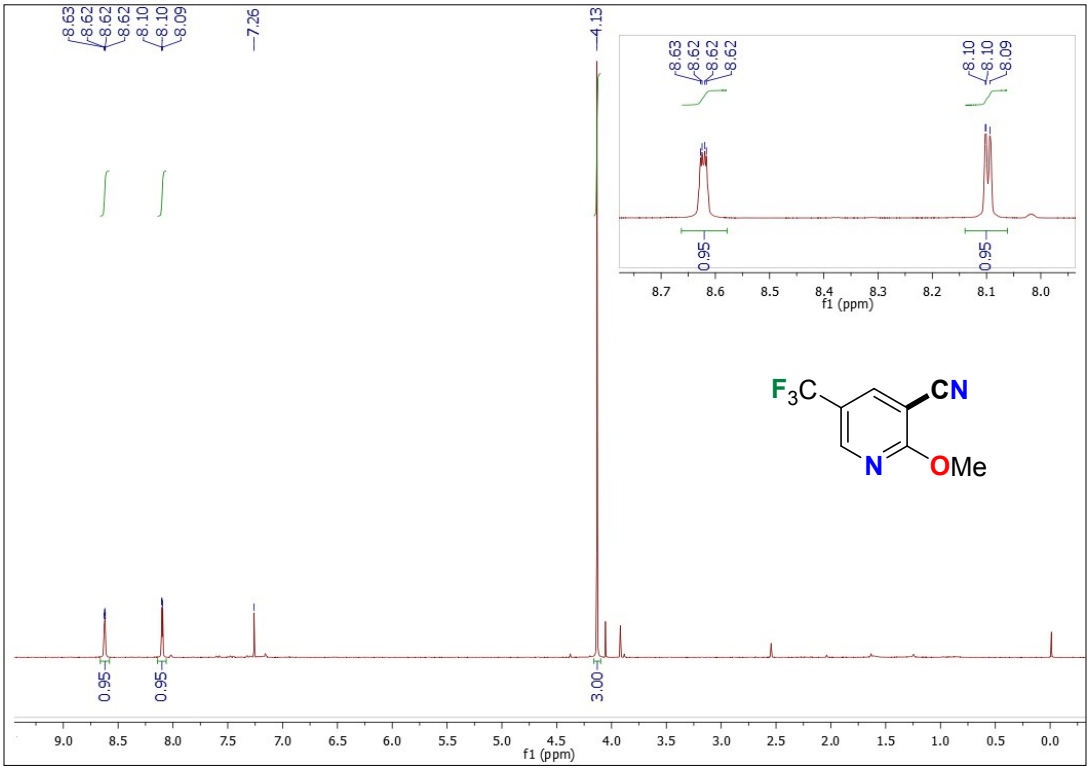


Figure S39. $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$) spectrum of compound (**3v**)

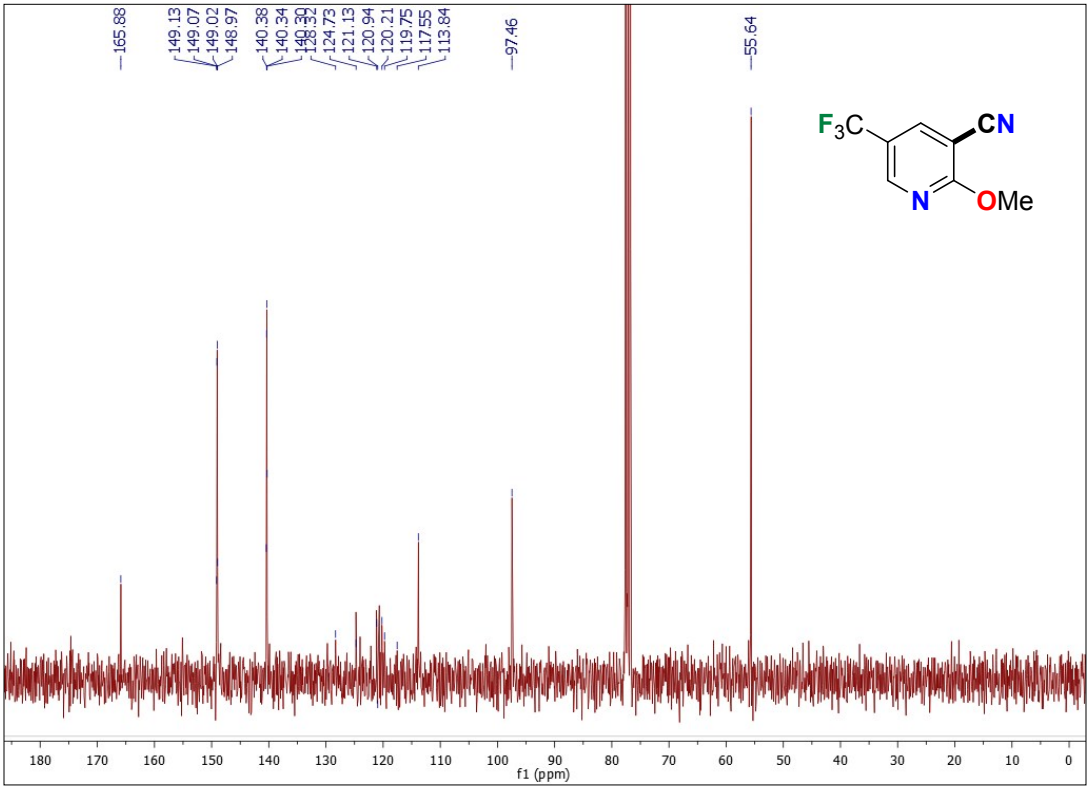


Figure S40. $^{19}F\{^{1}H\}$ NMR (282 MHz, $CDCl_3$) spectrum of compound (**3v**)