JOC The Journal of Organic Chemistry



Article

# Liquid-phase Hydrogenation of Nitriles to Amines Facilitated by a Co(II)/Zn(0)-Pair: A Ligand-free Catalytic Protocol

Daniel Timelthaler, and Christoph Topf

*J. Org. Chem.*, **Just Accepted Manuscript** • DOI: 10.1021/acs.joc.9b01544 • Publication Date (Web): 27 Aug 2019

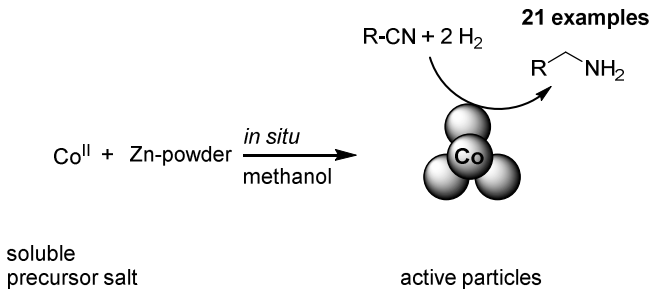
# Liquid-phase Hydrogenation of Nitriles to Amines Facilitated by a Co(II)/Zn(0)-Pair: A Ligand-free Catalytic Protocol

Daniel Timelthaler, Christoph Topf*

Institute of Catalysis (INCA), Johannes Kepler University (JKU), 4040 Linz, Austria

## Abstract

The given report introduces a simple and user-friendly *in situ* method for the production of catalytically active cobalt particles. The approach circumvents the use of air- and moisture-sensitive reductants as well as the application of anhydrous Co-precursor salts. Accordingly, the described catalytic system is readily assembled under open-flask conditions by simply combining the components in the reaction vessel. Therefore, the arduous charging procedure of the reaction-autoclave in a glovebox under an inert gas atmosphere is no longer necessary. In fact, the catalytically active material is obtained upon treatment of readily available $Co(OAc)_2 \cdot 4\,H_2O$ with benign commercial Zn powder. The catalytic performance of the resultant material was tested in the heterogeneous hydrogenation of nitriles to the corresponding primary amines. Both activity and selectivity of the cobalt catalyst are significantly enhanced if a triflate-based Lewis acid and ammonia is added to the reaction mixture.



## Introduction

The use of non-noble cobalt as catalytically competent center in various redox-transformations is intrinsically related to outstanding progress in organic syntheses. This fact and the decent abundance of Co renders it a promising candidate for superseding precious metals in certain catalytic processes. Moreover, the pertinent metal is amenable to both heterogeneous[1] as well as homogeneous[2] catalysis and this point adds a considerable degree of flexibility to the conceived production routes of valuable industrial chemicals and the devised (retro)synthetic plans towards sophisticated target molecules.

In the field of heterogeneous catalysis significant contributions were achieved using pyrolytically synthesized cobalt-borne nanoparticles that are integrated in an *N*-graphitic[3] or a carbonaceous[4] matrix. Such materials were successfully applied in, *inter alia*, the hydrogenation of nitriles, ketones and alkynes. However, the preparation of the catalytically active composites represents an elaborate multistep-process that requires rigorous compliance of the respective production steps and high pyrolysis temperatures. Furthermore, the recently described manufacture of a kindred MOF-derived material implies the use of the high-boiling and toxic dipolar-aprotic solvent dimethylformamide (DMF).[5] Accordingly, the development of more benign and energy-efficient strategies of related augmented solid catalysts is still rewarding and highly sought-after.

Highly reactive bulk metal catalysts such as Rieke Cobalt[6] and RANEY® Co[7] found widespread applications in chemical synthesis but their fabrication and use requires careful handling and special lab-technical precautions. Therefore, the invention of safer and less pyrophoric activated metals is an ongoing endeavor in modern contemporary catalysis research. With respect thereof, the tamed congeneric Urushibara-type[8] alloys are indeed easier to manipulate though their production process entails a lengthy leaching step and water-wasting washing procedures.

Recently, Wolf *et al.* reported on the synthesis and application of recyclable genuine Co nanoparticles that effected the hydrogenation of various alkyne, alkene and polar imine motifs in selected substrates at room temperature and low $H_2$ pressure. The solid cobalt catalyst described therein is prepared through the action of lithium naphthalenide on anhydrous $CoCl_2$ in THF over a period of one day.[9] In a similar vein, Jacobi von Wangelin and coworkers introduced a very active solid cobalt catalyst that is accessible from a $CoBr_2$-$LiEt_3BH$ mixture. The resultant material readily facilitates the hydrogenation

of alkenes, carbonyls, and imine moieties under mild reaction conditions.[10] Soon later, Guan and Dai devised an *in situ* system that produces a related heterogeneous catalyst upon reaction of anhydrous $CoBr_2$ with $NaHBEt_3$ and which was successfully applied in the pressure hydrogenation of nitriles to afford primary amines.[11] Interestingly, if the Co(II)-center in their precursor salt is first complexed with a PNP ligand and then treated with the hydride reagent, a soluble cobalt species is formed which mediates dehydrogenative coupling towards imines.

Regarding homogeneous catalysis, the vast majority of active systems relies on a cobalt central atom held by multidentate phosphorus-based ligands incorporating pincer or tripodal architectures. Besides the title transformation,[12] the well-balanced reactivity-stability relationship of these soluble Co complexes gives rise to a number of other highly relevant catalytic transformations including the hydrogenation of aldehydes,[13,14] ketones,[13] esters,[15] and a variety of atom efficient bond-forming reactions.[16] Strikingly, even the notoriously recalcitrant carboxylic acids are readily hydrogenated with gaseous $H_2$ under the action of a molecularly well-defined Co-triphos assembly.[17]

In a seminal work, Chirik and coworkers demonstrated that Co(II)-bisphosphine complexes are effectively reduced to the corresponding phosphine-ligated Co(I) compounds in the presence of ten molar equivalents of zinc. The thus activated cobalt species facilitate the enantioselective homogeneous hydrogenation of enamides and their catalytic performance even competes with related noble metal-based congeners.[18]

Within renovated context, we adopted this zinc-based *in situ* reduction approach and took advantage of the catalytic activity of finely dispersed cobalt particles in the catalytic hydrogenation of nitriles (*vide supra*). The pertinent catalytic transformation to yield (di)amines commands a privileged position in a hierarchy of chemical processes arranged according to atom efficiency and sustainability. Most importantly, the related products represent pivotal precursors to indispensable commodities as well as specialty chemicals such as polymers, synthetic dyes, agrochemicals and pharmaceuticals.[19]

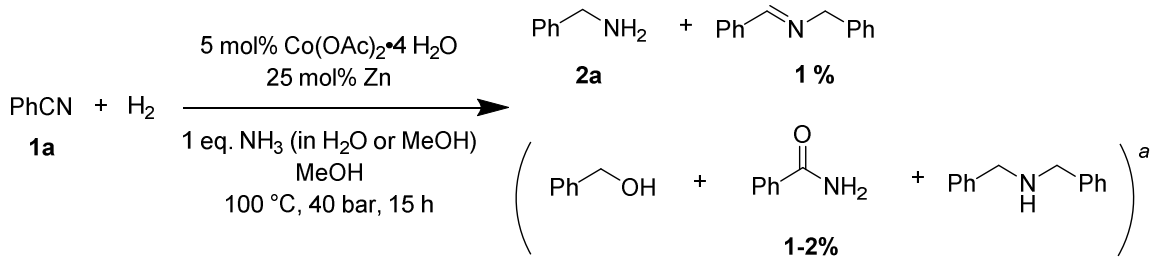
Herein we communicate an exceptionally simple and practical method for the *in situ* preparation of a particulate cobalt catalyst capable of converting (di)nitriles to (di)amines under hydrogen pressure. The catalytically active material is formed upon addition of readily available $Co(OAc)_2 \cdot 4\,H_2O$ and innocuous Zn powder to the reaction mixture during the course of the hydrogenation

process. Noteworthy, both the reaction vessels and the autoclave are charged under an ordinary laboratory atmosphere. Hence, the tedious and time-consuming glovebox-related channel in- and channel out-procedure, which is otherwise mandatory when working with anhydrous $CoX_2$ (X=Cl, Br) and air-sensitive borane reagents, is omitted. Furthermore, ammonia was routinely added as an either aqueous or methanolic solution to the substrate/catalyst-assembly in order to effectively suppress the formation of higher alkylated amines.[20]

**Results and Discussion**

We commenced our study by treating a well-agitated solution of benzonitrile **1a** in methanol with 5 mol% of $Co(OAc)_2 \cdot 4\ H_2O$ and 25 mol% of zinc metal in a 40 bar hydrogen atmosphere at 100 °C for 15 hours (Scheme 1). Delightfully, complete conversion of the nitrile was observed upon GC/MS-analysis of the reaction mixture. However, in accordance with previous reports on catalytic nitrile hydrogenation, the selectivity of benzylamine (**2a**) formation was well below 100% (see Table S1, entry 3 in the supporting information) owing to a consecutive condensation reaction that produces the imine coupling product Ph-CH=N-$CH_2$-Ph. The latter is eventually hydrogenated to afford the corresponding secondary amine. As formation of the pertinent imine necessarily involves the expulsion of one equivalent $NH_3$ from the reaction assembly, we anticipated that addition of ammonia (one equivalent with respect to the substrate) to the reaction mixture would curb imine formation and therefore the selectivity towards the primary amine product is expected to rise significantly (*vide supra*). We examined two commercial diluted ammonia-solutions as additive, namely $NH_3$ in methanol (2 M) and a concentrated aqueous solution (18 M). The catalytic transformation employing the methanolic solution gave rise to a mixture of the amine **2a** and small amounts (1%) of the imine byproduct Ph-CH=N-$CH_2$-Ph. On the other hand, use of an aqueous solution led to the formation of minute quantities (1-2%) of oxygenated side products such as benzylalcohol and benzylamide as well as dibenzylamine (Figure 1). The alcohol and the amide are likely to result from reaction of water with produced **2a** and substrate **1a**. This difference in selectivity rendered the methanolic system favorable for the catalytic hydrogenation of benzonitrile **1a**. However, other nitrile substrates were converted

with higher selectivity on employing aqueous ammonia. Therefore, judicious choice of the ammonia source is crucial for an optimized performance of the catalytic system.




**Scheme 1:** Reaction products of the catalytic hydrogenation of benzonitrile **1a** facilitated by a Co(II)/Zn(0)-couple in the presence of 1 eq. $NH_3$. Depending on the ammonia source, the main product **2a** is accompanied by one and three contaminants, respectively. [a]Formed byproducts if aqueous ammonia was used as additive.

Having identified this potent reaction-setup, we investigated the nature of the catalytically active species thereof. Examination of the reaction solutions after autoclave decompression revealed the formation of ferromagnetic metal particles, which were strongly attracted to the magnetic stirring bar. These observations clearly indicate that the Co(II) ions originating from the precursor salt was reduced to metallic Co(0).[9] In order to establish the heterogeneous *modus operandi* of the pertinent catalyst we performed Maitlis' hot filtration test.[21] As expected, no hydrogenation activity was observed upon filtration of the hot reaction solution through a PTFE-membrane (0.2 µm pore size) after 2 hours (under optimized conditions the reaction reaches completion within 6 h, *vide infra*) and reenacting the catalytic transformation with the filtrate. Noteworthy, addition of fresh zinc to the spent reaction solution did not result in the production of any further catalytically active material. If the depressurized autoclave is transferred into an argon-filled glovebox, opened and then charged with another aliquot of starting material, the Co/Zn-assembly is still active and can be reused directly after the first run. We performed this recycling experiment with benzonitrile under optimized reaction conditions (Figure 1) whereas no loss of catalyst activity was observed.

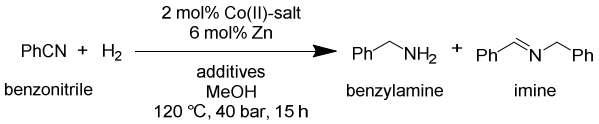
Sole consideration based on the stoichiometry of the reduction reaction Co(II) + Zn(0) → Co(0) + Zn(II) suggests that one equivalent of zinc metal per cobalt should suffice for the complete cementation of metallic Co from its corresponding salt. However, if the catalytic transformation is carried out with one equivalent of Zn *vs.* the precursor salt, incomplete nitrile

conversion is observed (Table S3, entry 3) and residual Co(II) ions were found to be present in the reaction solution as indicated by the associated characteristic pink color of the liquid portion of the reaction mixture. Lest the catalytic performance of the system is compromised by insufficient catalyst formation, zinc was thus used in a threefold molar excess with respect to the Co(II)-source. With this, benzonitrile was almost completely converted to benzylamine upon reaction over night (100 °C, 40 bar $H_2$). Yet, further raising the loading of the reductant (5 equiv.) did not have any impact on the conversion of benzonitrile (Table S3, entries 1 and 2).

Next, we investigated other non-noble metals and metalloids for their potential to bring about the mandatory Co(II)-reduction and to mediate the title transformation, *i.e.* manganese, magnesium, boron, and silicon. Inspection of Table S3 reveals that these four potential reducing agents are heavily outperformed by Zn; only Mn enabled certain conversion of the substrate albeit the pertinent catalytic performance seriously lags behind that of the respective Zn-based system. Reactions conducted with Mg, B and Si as reducing agents were unsuccessful and did not result in any substrate conversion (Table S3, entries 5-8).

Other commercial cobalt salts such as $CoCl_2 \cdot 6\ H_2O$, $Co(BF_4)_2 \cdot 6\ H_2O$, and dry $[Co(NH_3)_6]Cl_3$ were then tested for their suitability to function as precursors to the pertinent catalytically active Co-particles. Among these, the two Co(II)-salts worked as well as hydrated $Co(OAc)_2$ under the same reaction conditions (5 mol% Co(II)-salt, 100 °C, 40 bar, 15 h, 1 eq. $NH_3$) thereby forming benzylamine almost quantitatively. The investigated Co(III)-complex was especially intriguing since this compound would not only represent a source of cobalt but would also provide the crucial ammonia by virtue of its six built-in $NH_3$ ligands. Interestingly, the performance of the respective $[Co(NH_3)_6]Cl_3$-borne catalytic protocol, could only compete with the examined Co(II)-hydrates when both the reaction vessels and the autoclave were charged under an inert gas atmosphere (Ar). On the other hand, full collapse of the catalytic activity was observed when the reaction set-up was assembled on the bench outside the glovebox (Table S2, entries 7 and 8). Since convenient handling and robustness are paramount to the catalytic protocol described herein, we consequently restrained from using $[Co(NH_3)_6]Cl_3$ as a precursor material.

Deterred by the rather high cobalt(II)-salt loading of 5 mol% we decided to add a Lewis acid cocatalyst (zinc triflate[22]) in order to decrease the overall metal content of the reaction solution while still maintaining reasonable catalytic activity. Indeed, addition of 2 mol% of $Zn(OTf)_2$ gave rise to almost quantitative formation of benzylamine with a $Co(OAc)_2$-loading of 2 mol% after reaction overnight whereas only a mediocre yield (75%) was obtained when the analogous transformation was conducted in the absence of any Lewis acid (Figure 1). The use of the latter is also well compatible with the presence of water in the reaction solution and quite remarkably, the catalytic activity of the system was drastically increased when 2 eq. of aqueous $NH_3$-solution were applied; in this case, benzonitrile hydrogenation was complete after 6 hours (Figure 1). Other popular Lewis acids such as $ZnCl_2$ and $Al(OTf)_3$ also proved to be proper cocatalysts for the title transformation (*vide infra*).



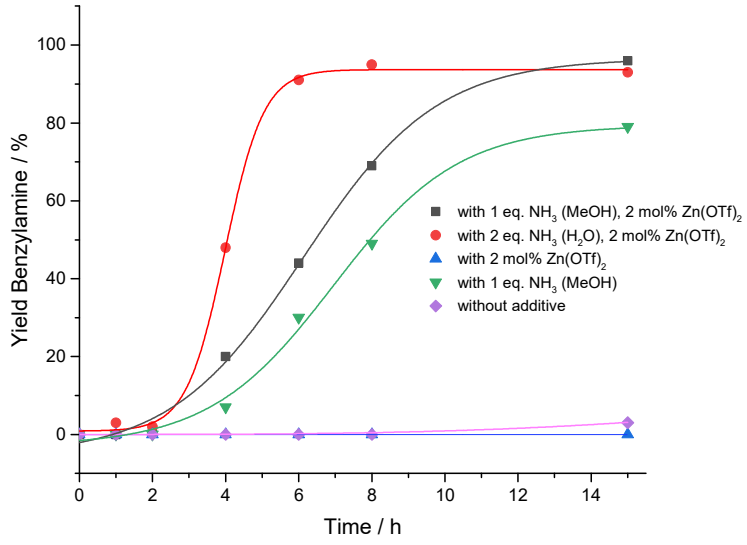



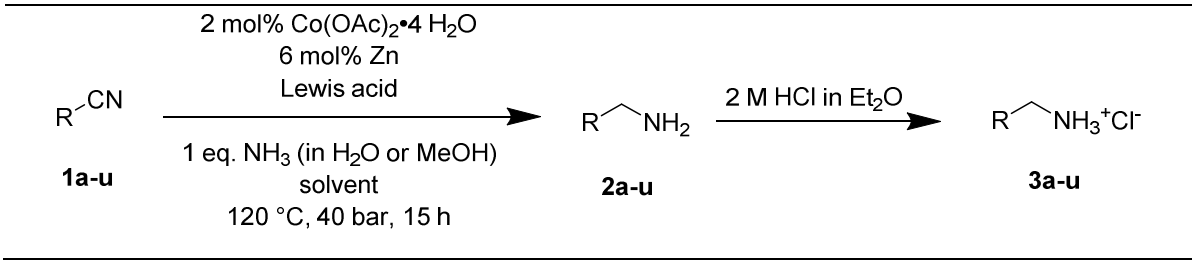

**Figure 1:** Concentration/time diagrams for the pertinent catalytic hydrogenation of benzonitrile. The accelerating effect of the Lewis acid and ammonia concentration is demonstrated. Note that the catalytic system is almost inactive with a catalyst loading of 2 mol% Co without any additive. Furthermore, the presence of ammonia is vital for the component mixture to develop catalytic activity. The sole presence of $Zn(OTf)_2$ does not effect the given hydrogenation reaction. The specified yields were determined by GC-MS-analysis using *n*-hexadecane as internal standard.

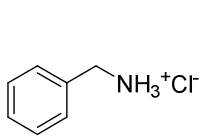
Next, we investigated the influence of the reaction medium on the performance of the catalytic system (Table S1 in the SI). Noteworthy, MeOH proved to be superior among the tested solvents although the differences in product formation are not very distinct in the case of EtOH, *i*-PrOH, MTBE, and *n*-heptane provided that aqueous $NH_3$-solution is used as additive. In this series, benzonitrile was almost completely converted to the desired benzylamine with only minute formation of byproducts. Interestingly, eco-friendly water and the frequently used organic solvents THF and toluene gave rise to only poor results in terms of substrate conversion. However, use of alcohols as solvents proved to be the most promising option. As industrial processes should strive for replacing petroleum-based solvents with mores sustainable analogues that are readily obtained by means of biomass degradation, use of alcohols as solvents is also favorable following the principles of green chemistry. Furthermore, methanol provides excellent solubility for the vast majority of organic substrates that are equipped with polar functional groups.

Eventually, we established the scope of the described Co-catalyzed heterogeneous nitrile-hydrogenation. A broad variety of substrates was treated under similar conditions, striving for low catalyst loadings and selective production of the primary amine. The latter were isolated as their respective hydrochloride salts (**3a-u**) through precipitation from the reaction mixture upon addition of dry hydrochloric acid. An overview of various synthesized organic ammonium salts together with their isolated yields is given in Scheme 2. Inspection of the latter reveals that the introduced *in situ*-prepared heterogeneous Co-catalyst is of general applicability for the hydrogenation of a variety of nitriles by virtue of its decent functional group tolerance. The halogenated benzonitrile derivatives **1f-k** were neatly converted to the respective amines without the occurrence of any intrusive hydrodehalogenation side-reactions. Direct comparison of the hydrogenation outcome of mono-chlorinated substrates **1f**, **1g** and **1h** disclosed an interesting effect; whereas the *ortho*-substituted chlorobenzonitrile showed very selective hydrogenation in a pure methanolic regime, the *meta*- and *para*- substituted products **3g** and **3h** were only obtained in acceptable yield on raising the amount of Lewis acid and using aqueous ammonia solution. This subtle dependence of product yield on the polarity of the reaction medium was also observed on going from the parent benzonitrile to the naphthalene kindred (compounds **3a**, **3c**, and **3d**). The reaction product **2m** proved to be rather

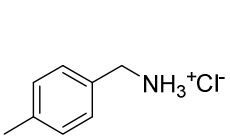
recalcitrant since it could not be isolated neither on precipitation with hydrochloric acid nor through column chromatography owing to decomposition of the amide. The hydrogenation of *α,β*-unsaturated cinnamonitrile **1n** solely produced 3-phenylpropylamine **2n**, indicating that both 1,2- and 1,4-hydrogenation took place. The reduction of acetonitrile **1q** to form ethylamine **2q** was hampered by the high volatility of the latter and the low observed yields are unequivocally attributed to partial evaporation of the product during work-up. Naturally, less volatile aliphatic nitriles such as **1p** were therefore smoothly hydrogenated and the isolated yields are comparable with those obtained upon hydrogenation of their aromatic counterparts. Interestingly, highly relevant adiponitrile **1r** was selectively converted to hexamethylenediamine **2r** if methanol was substituted with $H_2O$ as the reaction medium. Owing to the low miscibility of the nitrile in water, a 2-phase system formed promptly which was gradually transformed into a homogeneous system during the course of the hydrogenation reaction as the corresponding diamine is well soluble in water. This difference in the water-solubility of reactant and product may provide additional thermodynamic bias for the diamine formation. It is worth mentioning here that cobalt cementation with zinc dust is industrially performed for the electrowinning of Zn from aqueous $ZnSO_4$-solutions.[23] Hence, the given *in situ* protocol might be a sound alternative for the large-scale synthesis of the important hexamethylenediamine.

Noteworthy, 3-cyanopyridine did not show any reactivity in the given hydrogenation, presumably because of catalyst deactivation through binding of the reasonably nucleophilic $sp^2$-nitrogen onto the cobalt surface. To cope with this problem, we decided to use an $NH_4Cl/NH_3$-mixture which causes the protonation of the pyridine-nitrogen atom such that it is essentially rendered non-nucleophilic. Indeed, this $NH_4Cl/NH_3$-buffer approach permitted access to the amine-tethered pyridine **2l**, that was isolated as its hydrochloride with good yields on precipitation with etheric HCl solution. Regrettably, on applying this method to related heterocycles, viz. 4-cyanopyridine, 2-furonitrile, and 2-thiophencarbonitrile the reaction was sluggish and no useful reaction product could be isolated.

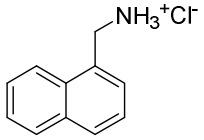


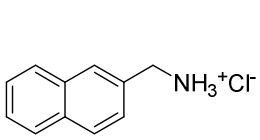
**3a** 94%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($MeOH$), MeOH



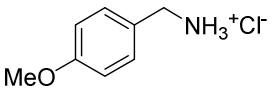
**3b** 72%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($MeOH$), MeOH:THF (2:1)



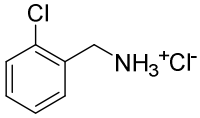
**3c** 82%
4 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



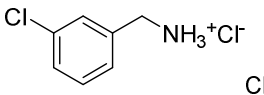
**3d** 80%
4 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



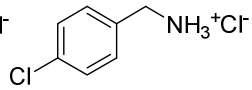
**3e** 86%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



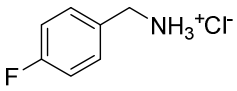
**3f** 91%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($MeOH$), MeOH



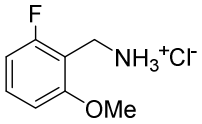
**3g** 86%
4 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



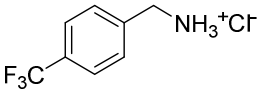
**3h** 87%
4 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



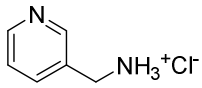
**3i** 92%
4 mol% $Al(OTf)_3$,
$NH_3$ ($H_2O$), MeOH:THF (2:1)



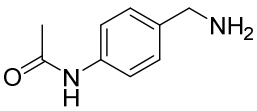
**3j** 85%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



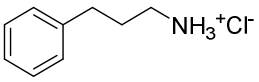
**3k** 84%
4 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH:THF (2:1)



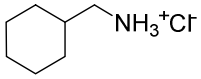
**3l** 75%[b]
5 mol% $Zn(OTf)_2$,
$NH_3(H_2O)$:$NH_4Cl$=1:2
MeOH



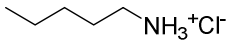
**2m**[b,c]
5 mol% $Al(OTf)_3$,
$NH_3$ ($H_2O$), MeOH



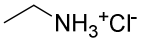
**3n** 97%[d]
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



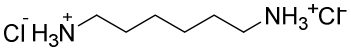
**3o** 80%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), $H_2O$



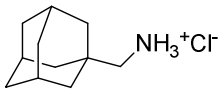
**3p** 96%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($MeOH$), MeOH



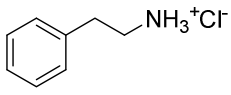
**3q** 48%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



**3r** 90%[b]
5 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), $H_2O$



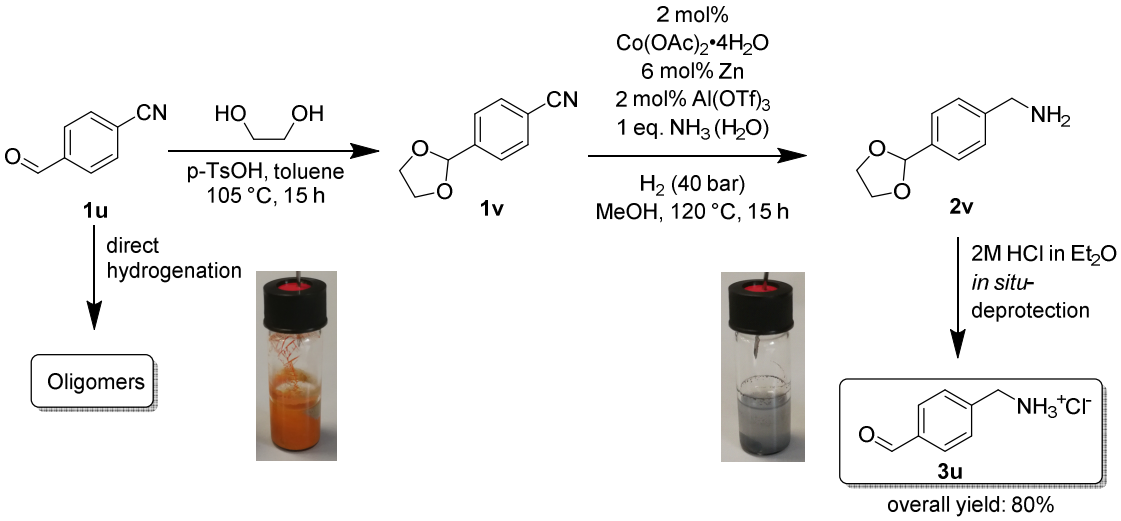
**3s** 94%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH



**3t** 96%
2 mol% $Zn(OTf)_2$,
$NH_3$ ($H_2O$), MeOH

**Scheme 2.** Products of nitrile hydrogenation with isolated yields and applied additive. [a]Reaction conditions: nitrile **1a-u** (0.5 mmol), $Co(OAc)_2{\cdot}4\ H_2O$ (0.01 mmol), zinc powder (0.03 mmol), Lewis acid as indicated, 100 mol% of indicated ammonia solution, in 1.5 mL of solvent as indicated, 120 °C, 40 bar $H_2$, reaction time: 15 h. [b]5 mol% of $Co(OAc)_2{\cdot}4\ H_2O$ were used. [c]Formation only confirmed by GC analysis, decomposition during work-up. [d]Cinnamonitrile was used as substrate.

Oligomerization of initially formed reduction products was further identified as the principal disruptive factor that arises whenever both electro- and nucleophilic motifs are present in the substrate *en route* to amine formation. If, for example, 4-cyanobenzaldehyde **1u** is directly subjected to the given Co-based hydrogenation procedure, an orange insoluble precipitate is formed that escapes analysis *via* routine methods (Scheme 3, left part). In order to circumvent this obtrusive side-reaction, we installed a protecting group, *i.e.* 1,3-dioxolane, to first obtain compound **1v** which was subsequently hydrogenated to the benzylamine derivative **2v**. Indeed, nucleophilic attack of the amine group onto the reactive aldehyde motif was effectively bypassed on using this protection approach and the target ammonium salt **3u** was isolated in 80% yield (Scheme 3, right part). Note, that the dioxolane moiety was cleaved *in situ* during product precipitation and hence a separate deprotection step was not necessary.




**Scheme 3:** Upon hydrogenation of unprotected 4-cyanobenzaldehyde **1u** intensely colored and insoluble high molecular weight products are formed (left image). Protection of the aldehyde motif with ethylene glycol, subsequent hydrogenation and an eventual simultaneous precipitation-deprotection step affords the ammonium salt **3u**. The turbidity in the right reaction vessel originates from the presence of the Co- and Zn-particles.

## Conclusion

We reported on a ligand-free heterogeneous hydrogenation catalyst by *in situ* cementation of cobalt particles from various cheap and readily abundant Co(II)-precursor salts with zinc powder. The catalytically active species thus produced facilitate the hydrogenation of nitriles to yield primary amines. Special equipment (glovebox, Schlenk vacuum manifold, pyrolysis oven) is not necessary, neither for the preparation of the catalyst nor for assembling the reaction setup. Both selectivity and activity of the catalytic system are influenced by the presence of ammonia and Lewis acid. Strikingly, the pertinent Co(II)/Zn(0)-pair enables a water-based synthesis of the industrially relevant hexamethylenediamine.

## Experimental Section

**General Information.** All chemicals were purchased from Merck (including Sigma Aldrich), Acros Organics, Alfa Aesar, VWR, Roth, TCI, Lancaster Synthesis or Chem Lab and were used as received without further purification. Hydrogenation reactions were carried out in a 300 mL autoclave from Parr Instruments GmbH and the employed hydrogen was purchased from Linde Gas GmbH with a purity of 5.0. Inert charging procedures were carried out in a LABmaster pro glovebox from Braun, filled with argon (6.0 purity from Linde Gas GmbH). Dry solvents were received from a MB-SPS-7 solvent system from M. Braun GmbH. GC-MS analysis was carried out on a Shimadzu GC-MS QP-2020 with helium (5.0 purity from Linde Gas GmbH.) as carrier gas. High-resolution mass spectrometry was performed on a Thermo Fisher Scientific LTQ Orbitrap XL or on an Agilent Technologies QTOF 6520 with ESI+ ion source for probes with $m/z < 50$. NMR measurements were performed on a Bruker Avance 300 MHz spectrometer. Spectra for different cores were recorded as follows: 300 MHz for $^{1}$H-NMR, 75.5 MHz for $^{13}$C and 282.4 MHz for $^{19}$F. Chemical shifts are listed in parts per million (ppm) on the delta scale (δ). Axis calibration was performed using the residual non-deuterated solvent for $^{1}$H-NMR as a reference.

*Safety Statement Concerning High Pressure Hydrogenation*

The hydrogen cylinder (200 bar, 50 liters) is placed in a safety storage cabinet that is equipped with an integrated extraction unit. The pressure vessel is attached to a mechanical control panel that allows for fine-adjustment of the desired $H_2$-pressure used for the catalytic transformation. The charging of the autoclaves is performed under an efficient fume hood that incorporates a hydrogen sensor. The latter is electronically connected to a magnetic valve that immediately stops the $H_2$-supply in case of any gas leakage that might occur during the filling procedure. Furthermore, an optical as well as an acoustical alarm signal is triggered as soon as free $H_2$ is detected inside the hood.

**Protocol for screening of *in situ* reactions.** A 4 mL glass vial was initially charged with a magnetic stirring bar, cobalt(II) salt (0.02 – 0.05 mmol), Lewis acid (0.02 – 0.05 mmol), and commercial 100 mesh zinc powder from Alfa Aesar (0.06 – 0.15 mmol). After that, 1.5 mL of solvent were added and to the resulting mixture the substrate (0.5 mmol) as well as ammonia (0.5 – 1.0 mmol) in methanol or water were added. If a solid substrate was tested, it was placed in the vial prior to solvent addition. The reaction vessel was then sealed with a septum cap that was subsequently penetrated with a needle. The glass vials were then placed in a drilled Al-plate with a capacity to accommodate seven vessels. Hereafter, the Al-inlet was transferred into the autoclave which was then tightly sealed. The autoclave was flushed with hydrogen three times before being pressurized. After that, the autoclave was put on a stirring plate and heated up to the required reaction temperature. On completion of the catalytic transformation, the autoclave was allowed to reach room temperature. After that, the $H_2$-pressure was released, and 1 mL of solvent was added to each of the reaction vials. If the reaction was performed in water, 2 mL of methanol were added to ensure homogeneity of the reaction mixture. Thereafter, the solutions were degassed by stirring on air for 30 minutes and an aliquot of 20 µL was then taken from each vial, mixed with 1 mL of methanol and eventually analyzed by GC-MS.

**Synthesis of *N*-(4-cyanophenyl)acetamide (1m).** In a 50 mL Schlenk flask, 575 mg of 4-aminobenzonitrile (4.87 mmol) were dried *in vacuo* and dissolved in 20 mL of dry dichloromethane. The solution was then cooled to 0 °C and 567 µL of acetic anhydride (6.00 mmol, 1.26 eq.) were subsequently added in small portions over a period of 15 minutes. The well-agitated reaction mixture

was allowed to reach room temperature and hereafter stirring was continued for a further 19 h under an atmosphere of $N_2$. On completion of the reaction, the mixture was washed with saturated aqueous $NaHCO_3$ solution which gave rise to a white precipitate that was collected on a glass frit (POR 4) and washed with 10 mL of DCM. The mother liquor was reduced on the rotary evaporator to give an additional portion of the title compound together with a yellow oil that was eventually removed on washing with *n*-heptane.

*N-(4-cyanophenyl)acetamide (1m).* White amorphous powder: 682 mg (4.27 mmol, 88% yield). Analytical data: $^1$H NMR (300 MHz, THF-$d_8$, 20 °C): δ = 9.43 (s, NH), 7.78 (d, *J* = 8.82 Hz, 2H), 7.62 (d, *J* = 8.78 Hz, 2H), 2.10 (s, 3H) ppm; $^{13}$C{$^1$H} NMR (75.5 MHz, THF-$d_8$, 20 °C): δ = 168.1, 143.6, 132.7, 118.7, 118.3, 106.1, 23.2 ppm; HRMS (ESI-Orbitrap) m/z: $[M+H]^+$ Calcd for $C_9H_9N_2O$: 161.0709; Found: 161.0710.

**Protection of 4-formylbenzonitrile (1u).** In a 50 mL round-bottom flask, 700 mg of 4-formylbenzonitrile **1u** (5.34 mmol) and 96 mg of *p*-toluenesulfonic acid monohydrate (0.50 mmol, 0.095 eq.) were dissolved in 14 mL of toluene. After that 580 μL of ethylene glycol (10.4 mmol, 1.95 eq.) were added and the flask was connected to a Dean-Stark apparatus. The reaction mixture was heated up to 105 °C in an oil bath and agitated for 15 h whereas the reaction progress was monitored by GC-MS. On completion of the reaction, the mixture was allowed to reach room temperature and then 10 mL of a saturated aqueous $NaHCO_3$ solution were added. The aqueous phase was then extracted three times with toluene in portions of 10 mL. The combined organic phases were dried with sodium sulfate and the solvent was eventually removed *in vacuo*, affording **6ac** as a yellow oil.

*4-(1,3-dioxolan-2-yl)benzonitrile (1v).* Yellow oil: 838 mg (5.34 mmol, 98% yield). Analytical data: $^1$H NMR (300 MHz, $CDCl_3$, 20 °C): δ = 7.67 (d, *J* = 7.98 Hz, 2H), 7.59 (d, *J* = 8.10 Hz, 2H), 5.85 (s, 1H), 4.14 – 4.02 (m, 4H) ppm; $^{13}$C{$^1$H} NMR (75.5 MHz, $CDCl_3$, 20 °C): δ = 143.1, 132.2, 127.2, 118.6, 112.9, 102.4, 65.4 ppm; HRMS (ESI-Orbitrap) m/z: $[M+H]^+$ Calcd for $C_{10}H_9NO_2$: 176.0706; Found 176.0707.

**General procedure for the isolation of the hydrogenation products.** The methanolic product solution was transferred from the reaction vial to a 25 mL round-bottom flask. The volatiles were removed under reduced pressure and the remains were taken up in 5 mL of dichloromethane (DCM). Hereafter, the flask was rinsed with dichloromethane several times and the resulting organic phase was washed with saturated $NaHCO_3$ solution. The aqueous phase was extracted three times (up to five times for more hydrophilic substrates) with DCM and the combined organic layers were dried with sodium sulfate. Then, 3 mL of 2M hydrochloric acid in diethyl ether were added, resulting in precipitation of a white solid for most compounds. The solid was collected on a glass frit (POR 4) and the mother liquor was concentrated and cooled to -40 °C to afford further precipitation. Finally, the combined white solids were dried on air and weighed.

*Benzylammonium chloride (3a).* Synthesized according to the standard procedure. 51.6 mg (0.500 mmol) of **1a** were used. White crystalline powder: 67.0 mg (0.468 mmol, 94% yield). Analytical data: $^1$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.53-7.45 (m, 5H), 4.20 (s, 2H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 132.6, 129.2, 128.8, 43.1 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_7H_{10}N$: 108.0813; Found: 108.0805.

*4-Methylbenzylammonium chloride (3b).* Synthesized according to the standard procedure. 58.1 mg (0.496 mmol) of **1b** were used. White crystalline powder: 55.9 mg (0.356 mmol, 72% yield). Analytical data: $^1$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.78 (d, $J$ = 8.82 Hz, 2H), 7.62 (d, $J$ = 8.78 Hz, 2H), 4.09 (s, 2H), 2.10 (s, 3H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 139.6, 129.7, 129.5, 128.8, 42.8, 20.2 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_8H_{12}N$: 122.0970; Found: 122.0963.

*1-Naphthylmethylammonium chloride (3c).* Synthesized according to the standard procedure. 78.0 mg (0.509 mmol) of **1c** were used. White crystalline powder: 81.0 mg (0.420 mmol, 82% yield). Analytical data: $^1$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.94-7.83 (m, 3H), 7.63-7.43 (m, 4H), 4.50 (s, 2H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 133.4, 130.3, 129.9, 128.9, 128.1, 127.7, 127.2, 126.5, 125.5, 122.3, 40.1 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_{11}H_{12}N$: 158.0970; Found: 158.0965.

*2-Naphthylmethylammonium chloride (3d).* Synthesized according to the standard procedure. 77.7 mg (0.507 mmol) of **1d** were used. White crystalline powder: 77.9 mg (0.403 mmol, 80% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.98-7.88 (m, 4H), 7.62-7.56 (m, 2H), 7.51 (dd, $J_1$ = 1.41 Hz, $J_2$ = 8.49 Hz, 1H), 4.30 (s, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 132.9, 132.8, 130.1, 128.9, 128.2, 127.9, 127.7, 127.0, 126.9, 125.9, 43.2 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_{11}H_{12}N$: 158.0970; Found: 158.0965.

*4-Methoxybenzylammonium chloride (3e).* Synthesized according to the standard procedure. 66.2 mg (0.497 mmol) of **1e** were used. White crystalline powder: 73.6 mg (0.425 mmol, 86% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.43 (d, $J$ = 8.73 Hz, 2H), 7.05 (d, $J$ = 8.73 Hz, 2H), 4.14 (s, 2H), 3.85 (s, 3H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 159.4, 130.6, 125.1, 114.6, 55.4, 42.6 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_8H_{12}NO$: 138.0919; Found: 138.0913.

*2-Chlorobenzylammonium chloride (3f).* Synthesized according to the standard procedure. 68.5 mg (0.498 mmol) of **1f** were used. White crystalline powder: 80.2 mg (0.453 mmol, 91% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.61 – 7.38 (m, 4H), 4.35 (s, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 133.8, 131.2, 131.1, 130.1, 129.9, 127.8, 40.8 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_7H_9ClN$: 142.0424; Found: 142.0418.

*3-Chlorobenzylammonium chloride (3g).* Synthesized in accordance with the standard procedure. 68.5 mg (0.498 mmol) of **1g** were used. White crystalline powder: 75.8 mg (0.428 mmol, 86% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.54-7.36 (m, 4H), 4.19 (s, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 133.4, 134.1, 130.7, 129.2, 128.7, 127.2, 42.5 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_7H_9ClN$: 142.0424; Found: 142.0418.

*4-Chlorobenzylammonium chloride (3h).* The title compound was synthesized in accordance with the standard procedure. 69.1 mg (0.502 mmol) of **1h** were used. White crystalline powder: 77.4 mg (0.437 mmol, 87% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.66-7.30 (m, 4H),

4.19 (s, 2H) ppm; $^{13}C\{^{1}H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 134.5, 131.2, 130.4, 129.2, 42.4 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_7H_9ClN$: 142.0424; Found: 142.0418.

*4-Fluorobenzylammonium chloride (3i).* Synthesized in accordance with the standard procedure. 59.8 mg (0.494 mmol) of **1i** were used. White crystalline powder: 73.0 mg (0.453 mmol, 92% yield) Analytical data: $^{1}H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 7.50 (d, *J* = 5.61 Hz, 1H), 7.48 (d, *J* = 5.46 Hz, 1H), 7.21 (t, $J_1$ = 8.75, 2H) 4.19 (s, 2H) ppm; $^{13}C\{^{1}H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 162.9 (d, *J* = 246 Hz, 1C), 131.1 (d, *J* = 8.77 Hz, 1C), 128.6 (d, *J* = 3.18 Hz, 1C), 116.0 (d, *J* = 22.0 Hz, 1C) 42.4 ppm; $^{19}F$-NMR (282.4 MHz, $D_2O$, 20 °C): δ = -113.2 (s, Ar-F) ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_7H_9FN$: 126.0719; Found: 126.0713.

*2-Fluoro-6-methoxybenzylammonium chloride (3j).* Synthesized according to the standard procedure. 75.3 mg (0.498 mmol) of **1j** were used. White crystalline powder: 81.3 mg (0.426 mmol, 85% yield). Analytical data: $^{1}H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 7.45 (q, *J* = 7.92 Hz, 2H), 6.95-6.80 (m, 2H), 4.24 (s, 2H) 3.92 (s, 3H) ppm; $^{13}C\{^{1}H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 161.1 (d, *J* = 246 Hz, 1C), 158.8 (d, *J* = 6.86 Hz, 1C), 131.8 (d, *J* = 10.9 Hz, 1C), 107.8 (d, *J* = 22.1 Hz, 1C), 107.8, 107.1 (d, *J* = 2.88 Hz, 1C) 56.1, 31.8 (d, *J* = 5.98 Hz, 1C) ppm; $^{19}F$-NMR (282.4 MHz, $D_2O$, 20 °C): δ = -117.4 (s, Ar-F) ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_8H_{11}FNO$: 156.0825; Found: 156.0820.

*4-(Trifluoromethyl)benzylammonium chloride (3k).* Synthesized according to the standard procedure. 84.0 mg (0.491 mmol) of **1k** were used. White crystalline powder: 87.6 mg (0.415 mmol) 84% yield). Analytical data: $^{1}H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 7.80 (q, *J* = 8.04 Hz, 2H), 7.64 (d, *J* = 8.04 Hz, 2H), 4.29 (s, 2H) ppm; $^{13}C\{^{1}H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 136.6, 130.4 (q, *J* = 32.3 Hz, 1C), 129.3, 126.0 (q, *J* = 6.86 Hz, 1C), 124.0 (d, *J* = 272 Hz, 1C), 42.6 ppm; $^{19}F$-NMR (282.4 MHz, $D_2O$, 20 °C): δ = -62.5 (s, $CF_3$) ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_8H_9F_3N$: 176.0687; Found: 176.0684.

*3-Pyridinmethylammonium chloride (3l).* Synthesized in accordance with the standard procedure. 51.4 mg (0.494 mmol) of **1l** were used. White crystalline powder: 53.7 mg (0.372 mmol, 76% yield).

Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 9.02-8.85 (m, 2H), 8.75 (d, *J* = 8.22 Hz, 1H), 8.18 (t, *J* = 6.99 Hz, 1H), 4.51 (s, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 147.4, 142.0, 141.8, 133.0, 127.8, 39.6 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_6H_9N_2$: 109.0766; Found: 109.0759.

*3-Phenylpropylammonium chloride (3n).* Synthesized according to the standard procedure. 64.6 mg (0.500 mmol) of **1n** were used. White crystalline powder: 82.7 mg (0.483 mmol, 97% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 7.40-7.23 (m, 5H), 2.97 (t, *J* = 7.67 Hz, 2H), 2.70 (t, *J* = 7.67 Hz, 2H), 1.95 (p, *J* = 7.62, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 140.9, 128.8, 128.4, 126.4, 39.0, 31.8, 28.4 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_9H_{14}N$: 136.1126; Found: 136.1122.

*Cyclohexylmethylammonium chloride (3o).* Synthesized according to the standard procedure. 54.6 mg (0.500 mmol) of **1o** were applied. White crystalline powder: 60.0 mg (0.402 mmol, 80% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 2.88 (d, *J* = 6.75 Hz, 2H), 1.83-1.61 (m, 6H), 1.38-1.15 (m, 3H), 1.10-0.94 (m, 2H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 45.2, 35.4, 29.6, 25.6, 25.0 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_7H_{16}N$: 114.1283; Found: 114.1277.

*Pentylammonium chloride (3p).* Synthesized according to the standard procedure. 41.6 mg (0.500 mmol) of **1p** were used. White crystalline powder: 59.2 mg (0.481 mmol, 90% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 3.01 (t, *J* = 7.53 Hz, 2H), 1.68 (p, *J* = 7.29, 2H), 1.42-1.30 (m, 4H), 0.91 (t, *J* = 6.95, 3H) ppm; $^{13}$C{$^{1}$H} NMR (75.5 MHz, $D_2O$, 20 °C): δ = 39.5, 27.7, 26.4, 21.4, 13.1 ppm; HRMS (ESI-Orbitrap) m/z: $[M-Cl]^+$ Calcd for $C_5H_{14}N$: 88.1126; Found: 88.1119.

*Ethylammonium chloride (3q).* The title compound was synthesized according to the standard procedure but the autoclave was cooled down to 0 °C before opening and work-up was performed rapidly using cooled solvents owing to the low boiling point of ethylamine. 20.5 mg (0.500 mmol) of **1q** were used. White crystalline powder: 19.3 mg (0.238 mmol, 48 % yield). Analytical data: $^{1}$H NMR

(300 MHz, $D_2O$, 20 °C): δ = 3.21 (q, *J* = 7.33 Hz, 2H), 1.29 (t, *J* = 7.33 Hz, 3H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 46.7, 8.2 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_2H_8N$: 46.0657; Found: 46.0659.

*1-Adamantylammonium chloride (3s).* Synthesized in accordance with the standard procedure. 80.6 mg (0.500 mmol) of **1s** were applied. White crystalline powder: 94.7 mg (0.471 mmol, 94% yield). Analytical data: $^1H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 2.71 (s, 2H), 2.08-1.98 (m, 3H), 1.72 (q, *J* = 14.37 Hz, 2H), 1.61-1.55 (m, 6H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 50.7, 38.8, 35.9, 31.3, 27.6 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_{11}H_{20}N$: 166.1596; Found: 166.1594.

*2-Phenylethylammonium chloride (3t).* Synthesized according to the standard procedure. 58.6 mg (0.500 mmol) of **1t** were applied. White crystalline powder: 75.6 mg (0.481 mmol, 96% yield). Analytical data: $^1H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 7.49-7.33 (m, 5H), 3.30 (t, *J* = 7.17 Hz, 2H), 3.02 (t, *J* = 7.28 Hz, 2H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 136.6, 129.1, 128.9, 127.3, 40.6, 32.7 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_8H_{12}N$: 122.0970; Found: 122.0965.

*4-Formylbenzylammonium chloride (3u).* Synthesized according to the standard procedure. 87.5 mg (0.500 mmol) of **1v** were used. White crystalline powder: 69.5 mg (0.406 mmol, 81% yield). Analytical data: $^1H$ NMR (300 MHz, $D_2O$, 20 °C): δ = 9.95 (s, 1H), 8.00 (d, *J* = 8.10 Hz, 2H), 7.66 (d, *J* = 8.04 Hz, 2H), 4.31 (s, 2H) ppm; $^{13}C\{^1H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 195.8, 139.6, 136.0, 130.6, 129.4, 42.7 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}Cl]^+$ Calcd for $C_8H_{10}NO$: 136.0762; Found: 136.0757.

**Procedure for the isolation of hexamethylenediammonium chloride (3r).** As the standard procedure led to poor isolated yields for compound **3r** owing to its high hydrophilicity, a different approach was pursued. On completion of the catalytic transformation, the two-phase reaction solution (methanol-water) was transferred from the reaction vial to a 25 mL round-bottom flask. Methanol and ammonia were removed at the pump and the remains were taken up in 5 mL of ethyl acetate. The flask was rinsed with water and ethyl acetate several times and the combined washing phases were filtered

through a pad of celite. The latter was thoroughly washed with ethyl acetate after filtration and to the combined layers, 5 mL of hydrochloric acid in diethyl ether were added. The mixture was shaken vigorously before complete removal of the volatiles *in vacuo*. The title compound was isolated as a white solid.

*1,6-Diammoniumhexyl dichloride (3r).* Synthesized in equivalence to standard procedure. 54.1 mg (0.500 mmol) of **1r** were used. White crystalline powder: 84.7 mg (0.450 mmol, 90% yield). Analytical data: $^{1}$H NMR (300 MHz, $D_2O$, 20 °C): δ = 3.03 (t, *J* = 7.55 Hz, 4H), 1.76 – 1.65 (m, 4H), 1.48 – 1.40 (m, 4H) ppm; $^{13}C\{^{1}H\}$ NMR (75.5 MHz, $D_2O$, 20 °C): δ = 39.4, 26.5, 25.1 ppm; HRMS (ESI-Orbitrap) m/z: $[M\text{-}2Cl\text{-}H]^+$ Calcd for $C_6H_{17}N_2$: 117.1392; Found: 117.1385.

## Associated Content

### Supporting Information

Elucidation of the effect of different solvents on the catalyst performance; description of the influence of various Co-precursors, reaction temperature and $H_2$-pressure on the catalytic activity; study of the aptitude of selected metals and metalloids to function as reducing agents; $^{1}$H-, $^{13}C\{^{1}H\}$-, $^{19}$F NMR, and HR-MS spectra of the isolated products.

## Author Information

### Corresponding Author

*E-mail: christoph.topf@jku.at

### ORCID

Christoph Topf: 0000-0001-7595-3074

### Notes

The authors declare no competing financial interest.

## Acknowledgments

We gratefully thank Univ.-Prof. Dr. Marko Hapke from the INCA for fruitful discussions and the generous support. Moreover, assoc. Univ.-Prof. DI Dr. Markus Himmelsbach from the department of

Analytical Chemistry at the JKU is gratefully acknowledged for performing the HRMS measurements of the isolated products.

**References**

(1) Hagen, J. *Industrial Catalysis: A Practical Approach*; Wiley-VCH: Weinheim, **2015**.

(2) (a) Junge, K.; Papa, V.; Beller, M. Cobalt-Pincer Complexes in Catalysis. *Chem. Eur. J.* **2019**, *25*, 122-143. (b) Klein Gebbink, R. J. M.; Moret, M.-E. (Eds.) *Non-Noble Metal Catalysis: Molecular Approaches and Reactions*; Wiley-VCH: Weinheim, **2019**.

(3) (a) Chen, F.; Topf, C.; Radnik, J.; Kreyenschulte, C.; Lund, H.; Schneider, M.; Surkus, A.-E.; He, L.; Junge, K.; Beller, M. Stable and Inert Cobalt Catalysts for Highly Selective and Practical Hydrogenation of C≡N and C=O Bonds. *J. Am. Chem. Soc.* **2016**, *138*, 8781-8788. (b) Chen, F.; Kreyenschulte C.; Radnik J.; Lund H.; Surkus A.-E.; Junge K.; Beller M. Selective Semihydrogenation of Alkynes with *N*-Graphitic-Modified Cobalt Nanoparticles Supported on Silica. *ACS Catal.* **2017**, *7*, 1526-1532.

(4) Ferraccioli, R.; Borovika, D.; Surkus, A.-E.; Kreyenschulte C.; Topf, C.; Beller M. Synthesis of Cobalt Nanoparticles by Pyrolysis of Vitamin $B_{12}$: a Non-Noble-Metal Catalyst for Efficient Hydrogenation of Nitriles. *Catal. Sci. Technol.* **2018**, *8*, 499-507.

(5) Murugesan, K.; Senthamarai, T.; Sohail, M.; Alshammari A. S.; Pohl, M.-M.; Beller, M.; Jagadeesh, R. V. Cobalt-Based Nanoparticles Prepared from MOF-Carbon Templates as Efficient Hydrogenation Catalysts. *Chem. Sci.* **2018**, *9*, 8553-8560.

(6) Rieke, R. D. *Chemical Synthesis Highly Reactive Metals*; John Wiley & Sons: Hoboken, 2017; pp 429-441.

(7) Banwell, M. G.; Jones, M. T.; Reekie, T. A.; Schwartz, B. D.; Tan, S. H.; White, L. V. RANEY® Cobalt – An Underutilised Reagent for the Selective Cleavage of C−X and N−O Bonds. *Org. Biomol. Chem.* **2014**, *12*, 7433-7444.

(8) Nishimura, S. *Handbook of Heterogeneous Catalytic Hydrogenation for Organic Synthesis*; John Wiley & Sons: New York, 2001; pp 254-285.

(9) Büschelberger, P.; Reyes-Rodriguez, E.; Schöttle, C.; Treptow, J.; Feldmann, C.; Jacobi von Wangelin, A.; Wolf, R. Recyclable Cobalt(0) Nanoparticle Catalysts for Hydrogenations. *Catal. Sci. Technol.* **2018**, *8*, 2648-2653.

(10) Sandl, S.; Schwarzhuber, F.; Pöllath, S.; Zweck, J.; Jacobi von Wangelin, A. Olefin-Stabilized Nanoparticles for C=C, C=O and C=N Hydrogenations. *Chem. Eur. J.* **2018**, *24*, 3403-3407.

(11) Dai, H.; Guan, H. Switching the Selectivity of Cobalt-Catalyzed Hydrogenation of Nitriles. *ACS Catal.* **2018**, *8*, 9125-9130.

(12) (a) Mukherjee, A.; Srimani, D.; Chakraborty, S.; Ben-David, Y.; Milstein, D. Selective Hydrogenation of Nitriles to Primary Amines Catalyzed by a Cobalt Pincer Complex. *J. Am. Chem. Soc.* **2015**, *137*, 8888−8891. (b) Tokmic, K.; Jackson, B. J.; Salazar, A.; Woods, T. J.; Fout, A. R. Cobalt-Catalyzed and Lewis Acid-Assisted Nitrile Hydrogenation to Primary Amines: A Combined Effort. *J. Am. Chem. Soc.* **2017**, *139*, 13554−13561. (c) Adam, R.; Bheeter, C. B.; Cabrero-Antonino, J. R.; Junge, K.; Jackstell, R.; Beller, M. Selective Hydrogenation of Nitriles to Primary Amines by Using a Cobalt Phosphine Catalyst. *ChemSusChem* **2017**, *10*, 842−846. (d) Schneekönig, J.; Tannert, B.; Hornke, H.; Beller, M.; Junge, K. Cobalt Pincer Complexes for Catalytic Reduction of Nitriles to Primary Amines. *Catal. Sci. Technol.* **2019**, *9*, 1779-1783.

(13) Zhang, G.; Scott, B. L.; Hanson, S. K. Mild and Homogeneous Cobalt-Catalyzed Hydrogenation of C=C, C=O, and C=N Bonds. *Angew. Chem. Int. Ed.* **2012**, *51*, 12102-12106.

(14) Zhang, G.; Hanson, S. K. Cobalt-catalyzed Transfer Hydrogenation of C=O and C=N Bonds. *Chem. Commun.* **2013**, *49*, 10151-10153.

(15) (a) Srimani, D.; Mukherjee, A.; Goldberg, A. F. G.; Leitus, G.; Diskin-Posner, Y.; Shimon, L. J. W.; Ben-David, Y.; Milstein, D. Cobalt-Catalyzed Hydrogenation of Esters to Alcohols: Unexpected Reactivity Trend Indicates Ester Enolate Intermediacy. *Angew. Chem. Int. Ed.* **2015**, *54*, 12357-12360. (b) Yuwen, J.; Chakraborty, S.; Brennessel, W. W.; Jones, W. D. Additive-Free Cobalt-Catalyzed Hydrogenation of Esters to Alcohols. *ACS Catal.* **2017**, *7*, 3735-3740. (c) Junge, K.; Wendt, B.; Cingolani, A.; Spannenberg, A.; Wei, Z.; Jiao, H.; Beller, M. Cobalt Pincer Complexes for Catalytic Reduction of Carboxylic Acid Esters. *Chem. Eur. J.* **2018**, *24*, 1046-1052.

(16) (a) Rösler, S.; Ertl, M.; Irrgang, T.; Kempe, R. Cobalt-Catalyzed Alkylation of Aromatic Amines by Alcohols. *Angew. Chem. Int. Ed.* **2015**, *54*, 15046-15050. (b) Mastalir, M.; Tomsu, G.; Pittenauer, E.; Allmaier, G.; Kirchner, K. Co(II) PCP Pincer Complexes as Catalysts for the Alkylation of Aromatic Amines with Primary Alcohols. *Org. Lett.* **2016**, *18*, 3462-3465. (c) Daw, P.; Ben-David Y.; Milstein, D. Direct Synthesis of Benzimidazoles by Dehydrogenative Coupling of Aromatic Diamines and Alcohols Catalyzed by Cobalt. *ACS Catal.* **2017**, *7*, 7456-7460.

(17) Korstanje, T. J.; van der Vlugt, J. I.; Elsevier, C. J.; de Bruin B. Hydrogenation of Carboxylic Acids with a Homogeneous Cobalt Catalyst. *Science* **2015**, *350*, 298-302.

(18) Friedfeld, M. R.; Zhong, H.; Ruck, R. T.; Shevlin, M.; Chirik, P. J. Cobalt-Catalyzed Asymmetric Hydrogenation of Enamides Enabled by Single-electron Reduction. *Science* **2018**, *360*, 888-893.

(19) Downing, R. S.; Kunkeler, P. J.; van Bekkuum, H. Catalytic Amination Reactions. *Catal. Today* **1997**, *37*, 121-136.

(20) (a) Freifelder, M.; A Low Pressure Process for the Reduction of Nitriles. Use of Rhodium Catalyst. *J. Am. Chem. Soc.* **1960**, *82*, 2386-2389. (b) von Braun, J.; Blessing, G.; Zobel, F. Katalytische Hydrierungen unter Druck bei Gegenwart von Nickelsalzen, VI.: Nitrile. *Ber. Dtsch. Chem. Ges.* **1923**, *56*, 1988-2001. (c) Schärringer, P.; Müller, T. E.; Lercher, J. A. Investigations Into the Mechanism of the Liquid-phase Hydrogenation of Nitriles over Raney-Co Catalysts. *J. Catal.* **2008**, *253*, 167-179.

(21) Hamlin, J. E.; Hirai, K.; Millan, A.; Maitlis, P. M., A Simple Practical Test for Distinguishing a Heterogeneous Component in a Homogeneously Catalyzed Reaction. *J. Mol. Catal.* **1980**, *7*, 543-544.

(22) Enthaler, S.; Wu, X.-F. *Zinc Catalysis: Applications in Organic Synthesis*; Wiley-VCH: Weinheim, 2015.

(23) Bøckman, O.; Østvold, T. Products Formed During Cobalt Cementation on Zinc in Zinc Sulfate Electrolytes. *Hydrometallurgy* **2000**, *54*, 65-78.