Supplementary Information

Supported nanocatalysts: recent developments in microwave synthesis for application in heterogeneous catalysis

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ORCID Hasan Ahmad: 0000-0003-1499-167X Scheme S1. Some model reactions catalyzed by supported catalysts.

i) Oxidation

Oxidative carbonylation of methanol⁸³

 $CH_{3}OH + 1/2O_{2} + CO \xrightarrow{Cu cat} (CH_{3}O)_{2}CO + H_{2}O$

Catalytic carbonylation of acetylene to acrylic acid¹⁶⁴

 $\begin{array}{c} CH \\ \parallel \\ CH \end{array} + CO + H_2O \qquad \underbrace{\text{NiO Cat}}_{\text{Temp & Pressure}} \blacktriangleright CH_2CHCOOH \end{array}$

Oxidative degradation of phenol⁸⁴



ii) Reduction/Reductive degradation

Reduction of *p*-nitoraniline⁸⁵



Reduction of potassium hexacyanoferrate(III)86

 $BH_{4(aq)}^{-}+ 8[Fe(CN)_{6}]_{(aq)}^{3-}+ 3H_{2}O \xrightarrow{Ru \ cat} H_{2}BO_{3(aq)}^{-}+ 8[Fe(CN)_{6}]_{(aq)}^{4-}+ 8H^{+}$

Reductive degradation of congo red⁹⁹



Hydrodechlorination (HdCl) of tetrachloromethane¹⁷⁴

$$CCl_{4} \xrightarrow{Pd-Au \text{ cat, } H_{2}} CHCl_{3} \xrightarrow{Pd-Au \text{ cat, } H_{2}} CH_{2}Cl_{2} \xrightarrow{Pd-Au \text{ cat, } H_{2}} CH_{3}Cl \xrightarrow{Pd-Au \text{ cat, } H_{2}} CH_{4}CH_{3}Cl \xrightarrow{Pd-Au \text{ cat, } H_{2}} CH_{4}CH_{4$$

iii) Hydrogenation

Hydrogenation of *p*-chloronitrobenzene (*p*-CNB)^{95,118}



Hydrogenation of levulinic acid¹⁴¹



Hydrogenation of acetylene¹³⁷

 $CH \longrightarrow CH \xrightarrow{Pd cat, H_2} H_2C \longrightarrow CH_2 \xrightarrow{Pd cat, H_2} CH_3CH_3$

iv) Hydrodesulfurization

Hydrodesulfurization of dibenzothiophene¹³⁹



Hydrodesulfurization of 4,6-dimethyldibezothiophene¹⁸⁵



v) Coupling reactions

Suzuki-Miyaura coupling reaction^{93,107,109,133,183,188}

$$\begin{array}{|c|c|} & X & + & R & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & & \\ & & & &$$

Mizoroki-Heck coupling reaction^{93,134,147}



Sonogashira-Hagihara coupling reaction¹³⁴



vi) Synthesis

Fisher-Tropsch synthesis (FTS)^{119,211}

$$(2n+1)H_2 + nCO \longrightarrow C_nH_{2n+2} + nH_2O$$

Dehydration of ethanol¹²¹

 $CH_{3}CH_{2}OH \xrightarrow{Pt cat, H_{2}} CH_{2}CH_{2} + HOH$

Table S1 Summary of various supported nanocatalysts indifferent reactions.

Oxidation:								
Catalyst	Preparation method	Size (nm) / Shape	Nature of reaction	Reaction conditions	Catalyst % Conversion amount (C) / % Yield (mg) (Y) / % Selectivity (S)		Deactivation degree (%) (Time h / Cycle No)	Ref.
Cu/AC-700 W-60 sec-12 / Cu(NO ₃)	MW assisted	16 / Cube	CO oxidation	500 ppm of CO; Space velocity, 25,000 h ⁻¹ ; 175 °C	ca. 1000	~ 100 (C)		81
Cu/CeO ₂ -TD / Cu(NO ₃) ₂	MW assisted	33 / Sphere	CO oxidation	0.4% CO, 1% O ₂ , and 50% H ₂ , 500 cc/min, 150 °C	1000	100 (C)		132
Cu/CeO ₂ / Cu(NO ₃) ₂	IM	/ nanorod	CO oxidation	3 % CO, 15 % O ₂ , 100 cc/min, 100 °C	200	99 (C)		200
Cu-CeO ₂ / CuCl ₂	Hydrother mal	10-25 / cubic	CO oxidation	1 % CO, 30 L h ⁻ ¹ g ⁻¹ , 180 °C	50	100 (C)		201
30 wt % Pd/Co ₃ O ₄ /Pd (NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 127 °C	50	100 (C)		127
50 wt % Pd/Fe ₃ O ₄ / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 127 °C	50	100 (C)		127
4 Pd/Mn ₃ O _{4 /} Pd(NO ₃) ₂	MW assisted	/	CO oxidation	4 % CO, 20 % O ₂ ,Flow rate, 50 mL/min, 20 °C	50	100 (C)	No deactivation (30 h)	130
4 Pd/Mn ₃ O ₄ HT / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	4 % CO, 20 % O ₂ ,Flow rate, 50 mL/min, 73 °C	50	100 (C)		130
Pd/Mn ₃ O ₄ / Na ₂ PdCl ₄	IM	/	CO oxidation	1 % CO, 20 % O ₂ , Flow rate, 50 mL/min, 22 °C	200	100 (C)	No deactivation (30 h)	203
10% Pd/CeO ₂ / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 173 °C	20	100 (C)		131
10% Pd/CeO ₂ (PV P)/ Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 254 °C	20	98 (C)		131
10% Pd/CeO ₂ (PE G)/ Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 138 °C	20	99 (C)		131
10% Pd/CuO / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 192 °C	20	97 (C)		131
10% Pd/ZnO / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 194 °C	20	99 (C)		131
$\frac{10\% \text{ Pd/ZnO}}{(\text{PVP}) /}$	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 223 °C	20	99 (C)		131
10% Pd/ZnO (PEG) / Pd(NO ₃) ₂	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 136 °C	20	99 (C)		131
10% Au/CeO ₂ / HAuCl ₄	MW assisted	/	CO oxidation	Flow rate, 100 cc/min; 156 °C	20	97 (C)		131
10%	MW	/	СО	Flow rate, 100	20	98 (C)		131

(PVP) / HAACL, AUCCO; (PEG) / HAACL, (PEG)	Au/CeO ₂	assisted		oxidation	cc/min; 267 °C				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	(PVP) /								
	HAuCl ₄								
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	10%	MW	/	CO	Flow rate, 100	20	99 (C)		131
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Au/CeO ₂	assisted		oxidation	cc/min; 353 °C				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	(PEG)/								
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$HAUCI_4$	NA337	/		Elouvento 100	20	100 (C)		121
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$/ H\Delta \mu C l_{4}$	assisted	/	ovidation	r low rate, 100	20	100 (C)		151
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	10% Au/ZnO	MW	/	CO	Flow rate 100	20	100 (C)		131
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	/HAuCl ₄	assisted	,	oxidation	cc/min: 331 °C	20	100 (0)		151
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	4 Au/Mn ₃ O ₄ /	MW	/	СО	4 % CO, 20 %	50	100 (C)	4 (30 h)	129
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	AuCl ₃	assisted		oxidation	O ₂ ,Flow rate,				
Image: constraint of the section of the se					100 cc/min, 98				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $					°C				
Au/Mn,O ₄ H T / AuCl ₃ assisted oxidation O ₅ /Flow rate, 100 cc/min, 161 °C O ₆ O ₇ <tho<sub>7 O₇ O₇ <tho<sub>7 <tho<sub>7 <tho<sub>7</tho<sub></tho<sub></tho<sub></tho<sub>	4	MW	/	СО	4 % CO, 20 %	50	100 (C)	7 (23 h)	129
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Au/Mn ₃ O ₄ H	assisted		oxidation	O ₂ ,Flow rate,				
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	T / AuCl ₃				100 cc/min,				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $					161 °C				
$ \begin{array}{cccc} Ce(NO_2)_{2,2} \\ ZrO(NO_2)_{2,2} \\ ZrO(NO_2)_{2,2} \\ ZrO(NO_2)_{2,2} \\ CZ40A-CI / \\ CV(NO_3)_{3,2} \\ ZrO(NO_3)_{5,2} \\ ZrO(NO_3$	CZ40A-CC/	MW	/	СО	Flow rate, 50	20	98 (C)		197
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$Ce(NO_3)_3$,	assisted		oxidation	mL/min; 2 %				
$ \begin{array}{c cccc} C240-C1/ \\ Cc(NO_3)_2 \\ Terms (AC / Car No_3)_2 \\ Fe/AC / \\ Fe(AC /)_3 \\ Fe(AC /)_3 \\ Fe(NO_3)_3 \\ Fe(AC /)_4 \\ Fe(NO_3)_3 \\ Fe(AC /)_5 \\ F$	$ZrO(NO_3)_2$				CO; 250 °C				
$ \begin{array}{c cc} Cc(NO_3)_5, \\ ZrO(NO_3)_2 \\ Fe(AC/ \\ Fe(NO_3)_3 \\ Sisted \\ Perform (AC/)_{O(AC/)$	CZ40A-CI/	IM	/	CO	Flow rate, 50	20	< 80 (C)		197
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$Ce(NO_3)_3,$			oxidation	mL/min; 2 %				
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$ZrO(NO_3)_2$	1017		DI 1	CO; 250 °C	100		73 (C) (4th	0.4
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Fe/AC /	MW		Phenol	500 mL phenol;	100	93 (C)	73 (C) (4 th	84
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$Fe(NO_3)_3$	assisted		oxidation	$H_2O_2; 30 °C;$			cycle	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Fe/AC /	СНТ		Phenol	50 mJ 100	25	80 (C)		207
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Fe(NO ₂) ₂			oxidation	mg/L nhenol	25	80 (C)		207
$ \begin{array}{c} \hline Cat-48-540 \\ (Cu/AC) / \\ Cu(NO_3)_2 \\ \hline Cat-360 \\ O(Cu/AC) / \\ Cu(NO_3)_2 \\ \hline Cu(NO_3)$	10(1103)3			onidución	50 °C, <120 min				
$ \begin{array}{c c} (Cu/AC) / \\ Cu(NO_3)_2 \\ Cu(NO_3)_2 \\ Cu(NO_3)_2 \\ Cu(NO_3)_2 \\ Cu(NO_3)_2 \\ Cu(AC) / \\ Cu(NO_3)_2 \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3)$	Cat-48-540	MW	28.7 /	CH ₃ OHcar	Feed gas	250	75-80 (S)		82
$ \begin{array}{c c} Cu(NO_3)_2 \\ Cu(NO_3)_2 \\ Cat-360- \\ O(Cu/AC)/ \\ cu(NO_3)_2 \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3) \\ Cu(NO_3)$	(Cu/AC) /	assisted	Cube	bonylation	(O ₂ :CO) ratio,				
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$Cu(NO_3)_2$			-	1:11;				
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$					CH ₃ OH, 0.056				
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$					mL min ⁻¹ ;				
$ \begin{array}{c c} Cat-360- \\ O(Cu/AC)/ \\ Cu(NO_3)_2 \end{array} & MW & 51.4 / \\ O(Cu/AC)/ \\ assisted & Hollow \\ sphere \end{array} & honylation \\ Denylation \end{array} & Peed gas \\ phore \end{array} & Ch_3OHcar \\ O(2:CO) ratio, \\ 1:11;CH_3OH, \\ 0.056 mLmin^{-1}; \end{array} & Point \\ Do of S & Point \\ $	G + 2(0	N 4337	51.4.(CILOU	2 h	250	100 (5)		02
$\begin{array}{c c} U(AC)' & assisted & Honow sphere & bonylation & (0_2'CO)' rato, \\ 1:11;CH_3OH, \\ 0.056 mLmin^{-1}; & & & & & & & \\ \hline Cu(NO_3)_2 & & & & & \\ IM & & 12 / \\ Cu(NO_3)_2 & & & & & \\ IM & & & 12 / \\ Cu(NO_3)_2 & & & & & \\ Sphere & & \\ Sph$	Cat-360-	MW	51.4/	CH ₃ OHcar	Feed gas	250	100 (S)		83
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	0(Cu/AC)/	assisted	nollow	bonylation	$(O_2:CO)$ ratio,				
$ \begin{array}{c ccc} Cu/AC-4/\\ Cu(NO_3)_2 \\ \hline MW \\ NiO_2D-Vmt \\ NiO_2D-Vmt \\ Ni(NO_3)_2 \\ \hline MF-NiO/2D-\\ Vmt/\\ Ni(NO_3)_2 \\ \hline MW \\ Fe_3O_4, \\ 15.3 \pm \\ 3.5; Ag, \\ 2.3 \pm 0.3 / \\ \hline MW \\ Fe_3O_4, \\ Sisted \\ \hline Sisted \\ 15.3 \pm \\ 3.5; Ag, \\ 2.3 \pm 0.3 / \\ \hline MS-NiO_2D-\\ Vmt/\\ \hline MS-NiO/2D-\\ Vmt/\\ \hline MF-NiO/2D-\\ \hline M$			sphere		$0.056 \text{ mL min}^{-1}$				
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Cu/AC-4/	IM	12/	CH ₂ OHcar	$CH_2OH_3 mL_h^-$	800	593(S)	45 (S) (120	204
NW- NiO/2D-Vmt /Ni(NO_3)2MW assisted 0.25 ± 0.25 / C_2H_2 (arbon ylation $C_2H_2(0.3 \text{ MPa}),$ $CO (3 MPa),$ $235 °C, 60 min1000(S)86.3 (Y) /\sim 80(S)42.5 (Y) (6^{th})cycle)164cycle)MF-NiO/2D-Vmt /Ni(NO_3)2CHT/0.35\pm0.35/C_2H_2(arbonylationC_2H_2(0.3 \text{ MPa}),C_2H_2(0.3 MPa),235 °C, 60 min1000CO (3 MPa),235 °C, 60 min\sim 68 (Y) /\sim75 (S)36.1 (Y) (6^{th})cycle)164cycle)MF-NiO/2D-Vmt /Ni(NO_3)2CHT/0.35\pm0.35J.3.5 + 3g,2.3 \pm 0.3 /2.3 \pm 0.3 /BenzaldehydeoxidationAir, H_2O (0.17)M), 24 h, 55 °C6.5mol%99 (Y) / 99(S)193Ag-Fe_3O_4@CMC /Ag(NH_4)2Fe_3O_4,2.3 \pm 0.3 /BenzaldehydeoxidationAir, H_2O (0.17)M), 24 h, 55 °C6.5mol%99 (Y) / 99(S)193Reduction/Reductive degradation:193Catalyst /PrecursorPreparationmethodSize (nm)/ ShapeNature ofreactionReactionconditionsCatalystamount(mg)Conversion(%Or or (%) / CycleNo. or timeConversion(%) / CycleNo. or time$	$Cu(NO_3)_2$	1111	Sphere	bonvlation	1		59.5 (5)	h)	201
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	(3)2		-					,	
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$									
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	MW-	MW	0.25±0.25	C ₂ H ₂ carbon	C ₂ H ₂ (0.3 MPa),	1000	86.3 (Y) /~ 80	42.5 (Y) (6 th	164
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	NiO/2D-Vmt	assisted	/	ylation	CO (3 MPa),		(S)	cycle)	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$/Ni(NO_3)_2$				235 °C, 60 min				
Vmt / Ni(NO_3)2/ /ylationCO (3 MPa), 235 °C, 60 min/ / 5 (S)cycle)Ag- Fe ₃ O ₄ @CM Ag(NH ₄)2MWFe ₃ O ₄ , 15.3 \pm 0.3 / 2.3 \pm 0.3 /Benzaldehy de oxidationAir, H ₂ O (0.17 M), 24 h, 55 °C6.5 mol%99 (Y) / 99 (S)193Reduction/Reductive degradation:2.3 \pm 0.3 / Nature of reactionReaction conditionsCatalyst (mg)Conversion(% (%) / Cycle No. or timeConversion (%) / Cycle	MF-NiO/2D-	СНТ	0.35±0.35	C_2H_2 carbon	$C_2H_2(0.3 \text{ MPa}),$	1000	$\sim 68 (Y) / \sim$	$36.1(Y)(6^{tm})$	164
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Vmt/		/	ylation	CO (3 MPa),		/5 (8)	cycle)	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Δq_{-}	MW	FeaO	Benzeldehu	255 C, 60 mm	6.5	99 (V) / 99		102
$\frac{C}{C} = \frac{1}{2} + \frac{1}$	Fean Com	assisted	15304,	de	M) 24 h 55 °C	mol%	(S)		195
Ag(NH_4)2 $2.3 \pm 0.3 / 2.3 \pm 0.3 \pm 0.$	C/	assisted	3 5. Ag	oxidation	NI), 24 II, 55 C	1110170			
Reduction/Reductive degradation: Image: Conversion (%) Conversion (%) Conversion (%) Conversion (%) Ref. Catalyst / Precursor Preparation method / Shape Reaction reaction Conditions Catalyst (mg) Conversion(%) Conversion (%) Ref.	Ag(NH ₄) ₂		2.3 ± 0.3 /						
Reduction/Reductive degradation: Catalyst / Preparation method Size (nm) / Shape Nature of reaction conditions Reaction conditions Catalyst / Conversion(% Conversion (% / Cycle method) / Cycle Ref. Precursor // Shape // Shape // Shape // Conversion (% / Cycle // Cycle /									
Catalyst / Precursor Preparation method Size (nm) / Shape Nature of reaction Reaction conditions Catalyst amount Conversion(% (%) / Cycle Conversion Ref. (mg) degradation / No. or time	Reduction/Re	ductive degra	dation:						
Precursor method / Shape reaction conditions amount) or (%) / Cycle (mg) degradation / No. or time	Catalvet /	Preparation	Size (nm)	Nature of	Reaction	Catalvet	Conversion ^{(0/2}	Conversion	Ref
(mg) degradation / No. or time	Precursor	method	/ Shape	reaction	conditions	amount) or	(%) / Cvcle	1.01.
			Simpo			(mg)	degradation /	No. or time	

						Time (sec/h)	(h)	
Ru/CPM-1 / Ru(acac) ₃	MW assisted	2.6 ± 0.5 / Sphere	<i>p</i> -NA reduction	1.7 mL (0.1 mM); NaBH ₄ (0.04 M); room temp.	10	100 / 15 sec	Fairly stable / 5 th cycle	85
Ru/CPM-1 / Ru(acac) ₃	MW assisted	2.6 ± 0.5 / Sphere	CV reduction	1.7 mL (0.1 mM); NaBH ₄ (0.04 M); room temp.	10	100 / 30 sec	Fairly stable / 5 th cycle	85
PDC@Ru / Ru(acac) ₃	MW assisted	5±0.2 / Probably sphere	K ₃ [Fe(CN) ₆] reduction	$\begin{array}{c} 3.0 \text{ mL } (3 \times 10^{-3} \\ \text{M}); \text{ NaBH}_4 / \\ \text{Na}_2 \text{S}_2 \text{O}_3; \text{room} \\ \text{temp.} \end{array}$	10	98 / <30 sec	75/>6 th cycle	86
SWCNT-Ru / RuCl ₃	MW assisted	2.0 ± 0.5 / Sphere	CR degradation	2.0 mL (0.06 mM); NaBH ₄ ; room temp.	0.5	91 / 192 sec	Stable / 3 rd cycle	98
SWCNT-Ru / RuCl ₃	MW assisted	2.0 ± 0.5 / Sphere	CR degradation	0.05 mM; NaBH ₄ ; room temp.	0.3	98.2 / 240 sec	90 / 3 rd cycle	99
PdAu-DR- MW / [Pd(OAc) ₂] _n , AuCl ₄ H ₆ NO	MW assisted	3-7 / Sphere	CCl₄HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to ~ 4 h	43.4 / 22 h	174
PdAu-DR- 653 K / $[Pd(OAc)_2]_n$, AuCl ₄ H ₆ NO	Thermal treatment	1-7 / Sphere	CCl₄HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to ~ 3 h	34.6 / 22 h	174
PdAu-IMP- MW / [Pd(OAc) ₂] _n , AuCl ₄ H ₆ NO	MW assisted	3-5 / Sphere	CCl₄HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to ~ 3 h	35.8 / 22 h	174
PdAu-IMP- 653 K / [Pd(OAc) ₂] _n , AuCl ₄ H ₆ NO	CHT	1-5 / Sphere	CCl4HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to few min	8.3 / 22 h	174
Pd-IMP-MW / [Pd(OAc) ₂] _n ,	MW assisted	/	CCl ₄ HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to ~ 3.5 h	14.9 / 22 h	174
Pd-IMP-653 K / [Pd(OAc) ₂] _n ,	Thermal treatment	/	CCl₄HdCl	CCl ₄ ,4.3 kPa; H ₂ , 60.5 kPa;Ar, 36.5 kPa; 90 °C,	200	100 / up to ~ 2 h	0.5 / 22 h	174
Photocatalyti	c/thermal deg	gradation:				1		
Catalyst / Precursor	Preparation method	Size (nm) / Shape	Compound	Degradation Condition	Catalyst amount	% Degradation	Recycle	Ref.
Pt/G3 / H ₂ PtCl ₆	MW assisted	~ 7-11 / Sphere	MB	100 mL (0.1 mg mL ⁻¹); 150 min; room temp.	10 mg	~ 60		111
TiO ₂ /G 2.5 / Ti{OCH(CH 3) ₂ } ₄	MW assisted	/ Sphere	MB & RB	100 mL (1x10-5 M); room temp; 60 min	50 mg	~ 80		161
Mo ₂ C/C / MoO ₂	MW assisted	50-70 / Sphere	Hydrazine	MW, 180 W, ~ 70 °C, 4 min	500 mg	100		156
WC/C / WO ₂	MW assisted	300-500 / Sphere	Hydrazine	MW, 180 W, ~ 70 °C 4 min	500 mg	~ 55		156
WC/AC-H / (NH ₄) ₆ H ₂ W ₁ ₂ O ₄₀	Carbotherm al hydrogen reduction	~ 10 nm / Sphere	Hydrazine	0.49 g/s, 50 °C	670 mg	100		208
18.3 wt% WC/CNT / W(CO) ₆	MW assisted	3.5 / Sphere	Hydrazine	30 - 120 °C	20 mg	100		157

CeO ₂ -SiO ₂ (M-30) / Ce(NO ₃) ₂	MW assisted	8 / Cube	MB	200 pp pH, 7; temp.	m; 1h; room	0.4 g/L	99.9		162
CeO ₂ -SiO ₂ (H-24 h) / Ce(NO ₃) ₃	HT	15 / Sphere	MB	200 pp pH, 7; temp.	m; 1h; 0.4 g/L room		85		162
Hydrogena	tion:								
Catalyst / Precursor	Preparation method	Size (nm) / Shape	Reactant / Amount (g)	Main product	Reaction	condition	% Selectivity / % Conversion	Recycle No. (Time h) / % Conversion	Ref.
Ru/FCNT / RuCl ₃	MW assisted	2.7-3.6 / Sphere	<i>p</i> -CNB / 0.4	<i>p</i> -CAN	0.5 mg R MPa), CH °C, 30 mi	u, H ₂ (4 H ₃ OH, 60 in	100 /100	3 / Stable (data not available	95
Ru/CNT / RuCl ₃	MW assisted	2.7-3.6 / Sphere	<i>p</i> -CNB / 0.4	<i>p</i> -CAN	0.5 mg R MPa), CH °C, 30 mi	u, H ₂ (4 H ₃ OH, 60 in	95 /100		95
Ru/CNT / Ru ₃ (CO) ₁₂	MW assisted	2-4 /Sphere	CMA / 1.32	НСМА	100 mg c cyclohexa MPa), 80	at., ane, H ₂ (3 °C	72 / 80		96
Pd/G / [Pd(OAc) ₂]	MW assisted	5 /	Isophorone / 0.138	DHIPO	2 mg cat., H ₂ O, H ₂ (1.2 MPa), 60 °C, 5 min		97 / 99.8	5 /~99 %	108
Pd/Grp / [Pd(OAc) ₂]	MW assisted	/	Isophorone / 0.138	DHIPO	2 mg cat., H ₂ O, H ₂ (1.2 MPa), 60 °C, 5 min		83.9 / 35.0	/	108
Pt/G / K ₂ PtCl ₆	MW assisted	14 ± 6 /Sphere	Styrene / 1.22	Ethyl benzene	50 mg cat., CH ₃ OH, H ₂ (1520 psi), 100 °C, 60 min		99.66 / 100	/	110
Pt/AC /	Commercia 1	2-5 /	Styrene / 1.22	Ethyl benzene	50 mg cat., CH ₃ OH, H ₂ (1520 psi), 100 °C, 60 min		40.31 / 40.31	/	110
Pd/AC/	Commercia 1	3-5 /	Styrene / 1.22	Ethyl benzene	50 mg ca CH ₃ OH, psi), 100 min	t., H ₂ (1520 °C, 60	99.87 / 100	/	110
Ni/AB- MW / Ni(NO ₃) ₂	MW assisted drying	/	Nitrobenzene	Aniline	0.5 g cat, 6.0 mL g GHSV, 4 g ⁻¹ _{cat} h ⁻¹ ,	LHSV, ⁻¹ _{cat} h ⁻¹ , 800 mL 300 °C	93.3 / 98.7	/	118
Ni/AB-CH / Ni(NO ₃) ₂	Tradtional drying	/	Nitrobenzene	Aniline	0.5 g cat, 6.0 mL g GHSV, 4 g ⁻¹ _{cat} h ⁻¹ ,	LHSV, ⁻¹ _{cat} h ⁻¹ , 800 mL 300 °C	89.5 / 94.4	/	118
Pd/Al ₂ O ₃ (PF-1) / Pd(NO ₃) ₂	Plasma induced MW	/ Sphere	Acetylene	Ethane	20 mg ca mL/min), h ⁻¹ , 120 °	t, H ₂ (80 , 320,000 C	~ 85 / ~ 95	/	137
Pd/Al ₂ O ₃ (CM-1) / Pd(NO ₃) ₂	Plasma induced MW	/ Sphere	Acetylene	Ethane	20 mg ca mL/min), h ⁻¹ , 120 °	t, $\overline{H_2}$ (80 , 320,000 C	~ 45 / ~ 80	/	137
Ru/TiO ₂ (Acac- 200-10) / Ru(acac) ₃	MW assisted	2.35 / Sphere	LA	GVL	50 mg ca LA, H ₂ O 10 min	t, 0.5 g , 200 °C,	/ 69.4	/	141
Ru/TiO ₂ (Cl-150-5) / RuCl ₃	MW assisted	1.87 / Sphere	LA	GVL	50 mg ca LA, H ₂ O 5 min	t, 0.5 g , 150 °C,	/ 67	/	141
10 wt% MoO ₂ /AC /β-Mo ₂ C	MW assisted	3 /	Naphthalen e	Tetralin	LHSV, 2	0 h ⁻¹	100 / 80	/	155

20wt% MoO ₂ /AC /β-Mo ₂ C	MW assisted	3 /	Naphthalen e	Tetralin	LHSV, 14.3 h ⁻¹		100	/ 95	(60) / > 80	155
30wt% MoO ₂ /AC /β-Mo ₂ C	MW assisted	3 /	Naphthalen Tetralin e		LHSV, 3.	6 h ⁻¹	100	/ 90	/	155
Ag- Fe ₃ O ₄ @C MC / Ag(NH ₄) ₂	MW assisted	Fe ₃ O ₄ , 15.3 ± 3.5; Ag, 2.3 ± 0.3 /	Benzaldehy Benzyla de lcohol		6.5 mol % Benzaldel 0.33 mmo MPa), 10	o cat., 95 / 95 1yde, bl, H ₂ (4 0 °C, 24 h		5/95	193	
Suzuki-Miy	aura coupling	g reaction:		•	•				,	
Catalyst / Precursor	Preparation method	Size (nm) /Shape	Conditi	ions	Catalyst amount	RC1	ield (% RBr) RI	Recycle No./ % yield	Ref.
Pd/G / Pd(NO ₃) ₂	MW assisted	9.37 / Irregular	K ₂ CO ₃ , H ₂ O: EtOH, 80 °C.	10 min	3 mg		100		4 / 77	107
$\frac{Pd/G}{C_3N_4/}$ $Pd(NO_3)_2$	Photodepos ition	2.73 /	KOH, H ₂ O:E (1:1), room te min	tOH emp., 40	2 mg		100		5 / > 85	221
Pd- Fe ₃ O ₄ /G / Pd(NO ₃) ₂	MW assisted	/ Sphere	K ₂ CO ₃ , H ₂ O: EtOH, 25°C, 180 min		1 mol %		100		9 / 81	109
Pd- Fe ₃ O ₄ /G /Pd(acac) ₂	HT	/	K ₂ CO ₃ , H ₂ O: EtOH, MW: 120 °C, 10 min		3.5 g		100		9 / 82	222
20 wt% Pd/CuO / Cu (NO ₃) ₂	MW assisted	240 / Sphere	K ₂ CO ₃ , H ₂ O:EtOH, 150°C, MW heating, 10 min		1 mol %		100		6 / 60	133
Pd- Co/CuO-3 / K ₂ PdCl ₄ , Co(NO ₃) ₂	Convention al reduction	4-6 /	K ₂ CO ₃ , H ₂ O:EtOH, 25 °C,3 h		3 mg		90			223
Pd/Ag/SB A-15 / Pd(OAc) ₂ , AgNO ₃	MW assisted	4.2 / Sphere	K ₂ CO ₃ , EtOH, visible light, room temp., 2 h		20 mg			~ 40		183
Pd/Au/SB A-15 / Pd(OAc) ₂ , HAuCl ₄	MW assisted	4.9 / Sphere	K ₂ CO ₃ , EtOH light, room te	I, visible mp., 2 h	20 mg			~ 70		183
Pd- Fe ₃ O ₄ /G / Pd(NO ₃) ₂ , Fe(NO ₃) ₃	MW assisted	Pd, 35 ± 2, Fe ₃ O ₄ , 52 ± 2 / Sphere	K ₂ CO ₃ , H ₂ O: EtOH (1:1),12 min	20 °C, 10	1 mol%		100		7 / 76	188
Pd- Co ₃ O ₄ /G / Co(NO ₃) ₂ , Fe(NO ₃) ₃	MW assisted	$\begin{array}{l} Pd, 25 \pm \\ 2, Co_{3}O_{4}, \\ 45 \pm 2 \ / \\ Sphere \end{array}$	K ₂ CO ₃ , H ₂ O: EtOH (1:1),12 min	20 °C, 10	1 mol%		100		/	188
Pd- Ni(OH) ₂ / G / Ni(NO ₃) ₂ , Fe(NO ₃) ₃	MW assisted	Agglomer ation /	K ₂ CO ₃ , H ₂ O: EtOH (1:1),120 °C, 10 min		1 mol%		< 60		/	188
Pd- Fe ₃ O ₄ /G / Pd(NO ₃) ₂ , Fe(NO ₃) ₃	MW assisted (Pd7.6 wt%)	Pd, 3-4; Fe ₃ O ₄ , 12- 16 / Sphere	K ₂ CO ₃ , H ₂ O: EtOH (1:1), room temp., 45 min		0.3 mol%		100		10 / 80	189
Mizoroki-H	leck coupling	reaction:	C 1'.'		Cataland	×	7:-1.1 (0/)	Deerrol- No. /	Pof
Precursor	method	/Shape		IONS	amount	RC1	RBr	RI	% yield	KC1.

20 wt%	MW	25 ± 2 /	K ₂ CO ₃ , H ₂ C): °C MW	2 mol %		93		5 / 90	134
$Cu (NO_3)_2$	assisted		heating, 10	min						
Pd/SiC (MW3) / [Pd(OAc) ₂] _n	MW assisted	/	Triethylamin acetonitrile, h	Triethylamine, acetonitrile, 120 °C, 6 h				95	10 / 100	147
Pd/SiC (OB10) / [Pd(OAc) ₂] _n	Convention al heating	/	Triethylamin acetonitrile, h	ne, 120 °C, 6				100	7 / 44	147
Pd/C	Commercia 1	/	Triethylamin acetonitrile, h	ne, 120 °C, 6				96	3/33	147
Pd/Al ₂ O ₃	Commercia 1	/	Triethylamin acetonitrile, h	ne, 120 °C, 6				99	6 / 27	147
Synthesis r	eaction:							•		
Catalyst / Precursor	Preparation method	Size (nm) /Shape	Reactant	Main product	Reaction condition		% Yi Conv (selec	eld / % ersion tivity)	Recycle No. (Time h) / % Conversion	Ref.
MW- 2%Ag@A ISBA-15 / AgNO ₃	MW assisted	/	Propargylic urea	Imidazol one	0.04 g cat., 72 μmol reactant, toluene, MW treatment		35 / -		/	112
BM- 2%Ag@A lSBA-15 / AgNO ₃	Ball milling	/	Propargylic urea	Imidazol one	0.04 g cat., 72 μmol reactant, toluene, MW treatment		56 / -		/	112
AgNCs/S BA-15 / AgNO ₃	MW assisted	1.2±0.3 /	Propargylg uanidine	Cyclic- guanidin e	0.15 mol Ag, 0.12 mmol reactant, DCM, 50 °C, 3 h		99 / 1	00	4 />90	116
AgNCs/S BA-15 / AgNO ₃	MW assisted	1.2±0.3 /	2- (Phenyleth ynyl)pheno l	2- phenylbe nzofuran	0.15 mol Ag, 0.05 mmol reactant, DCM, 70 °C, 3 h		93 / 1	00	/	116
Ni20- Al ₂ O ₃ -M / Ni(NO ₃) ₂	MW assisted	10 /	$CO_2 + H_2$	CH ₄	Flow rat mL/min;	e, 70 ; 325 °C	/ 9	1.6	(72)/~91	136
Ni20- Al ₂ O ₃ -I / Ni(NO ₃) ₂	IM	15 /	$CO_2 + H_2$	CH ₄	Flow rat mL/min;	e, 70 ; 350 °C	/	84.3	/	136
Co/Si=1/4 -ABC-550 /Co(NO ₃) ₂	MW assisted	/	$CO + H_2$	Higher hydrocar bon (C ₅₊)	150 °C, p 90 W; gas rate, 25 m	lasma, s flow 1L/min	6.5/1	00	(175) / 100 %	119
Co/SiO ₂ / Co(NO ₃) ₂	MW assisted	10 / Irregula	$\rm CO + H_2$	Higher hydrocar bon (C ₅₊)	2 g cat, pl 60 W, GH 750 to ml	2 g cat, plasma, 60 W, GHSV, 750 to mL g ⁻¹ _{cat} h ⁻		63.2		119
Co/SiO ₂ / Co(NO ₃) ₂	Coventiona ldyring	2-3 / Irregular	$\rm CO + H_2$	Higher hydrocar bon (C ₅₊)	2 g cat, pl 60 W, GF 750 to ml	2 g cat, plasma, 60 W, GHSV, 750 to mL g ⁻¹ _{cat} h ⁻		50.9		119
Ti-MCM- 41-5 / TBOT	MW assisted	3.6 /	DMO + Phenol	DPO	DMO:Pho 1:3 molar 180 °C, 2	enol = ratio, h	17.1	67.4	/	122
MW- NiO/Vmt (Ni, 10 wt%) / Ni(NO ₃) ₂	MW assisted	3 /	$CO + H_2$	CH ₄	0.188 g ca GHSV, 11 ¹ , gas flow mL/min, MPa, 400	at, 2,000 h ⁻ w, 65 1.5) °C	(93.8)	99.6)	/	163

CHT- NiO/Vmt (Ni, 10 wt%) /	CHT		6 /	$CO + H_2$	CH ₄	0.18 GH ¹ , ga mL	38 g ca SV, 12 as flow /min, 1	t, 2,000 h ⁻ 7, 65 .5	/ 64.8 (81.1)			- /	163
Ni(NO ₃) ₂						MP	MPa, 450 °C						
MW- Cu/Ni-95 / Cu(NO ₃) ₂ , Zn(NO ₃) ₂ , Ni(NO ₃) ₂	MW assisted		13.68 ± 4.66 / Sphere	СН ₃ ОН	H ₂	100 MP HS 300	100 mg cat., 0.1 MPa; Weight HSV, 1.5 h ⁻¹ ; 1 h; 300 °C		/ 100 (90.5)		(30	0) / 98.8	196
MW-Cu/ 95 / Cu(NO ₃) ₂ , Zn(NO ₃) ₂ ,	MW assisted		18.37 ± 5.66 / Sphere	CH ₃ OH	H ₂	100 MP HS 300	100 mg cat., 0.1 MPa; Weight HSV, 1.5 h ⁻¹ ; 1 h; 300 °C,		/ (88.	/ 94.3 (88.2)		0) / 47.3	196
Electrocata	ılysis:												
Catalyst / Precursor	Prep. metho	1	Size (nm) /Shape	Loading (wt %)	$\frac{\text{ECSA}}{(m^2/g_{cat})}$	SA in acidic (mA/c	cm ²)	SA in basic (mA/cn	n ²)	MA in acidic (mA/mg	g)	MA in basic (mA/mg)	Ref.
Pt/AC /	MW	A	3.8±0.3 /	18.9	12.2								88
Pt/CA	MW	u d	2.7 /		50.04								91
Pt/C / (NH ₄) ₂ PtCl ₆	MW assiste	d	2.1 / Sphere	23.7	~ 68	0.30±	0.002	0.80±0.	0.80±0.008		3	186±1.9	92
Pt/C / H ₂ PtC	l ₆ MW	d	2.0 / Sphere	19.5	~ 66	0.53±	0.014	1.03±0.014		147±3.8		176±2.4	92
Pt/C /	Comm	erc	2.3 / Sphere	18.8	< 60	0.33±	0.002	0.75±0.012		134±1.0		146±2.5	92
Pt-WC/C-F	/ MW assiste	đ	3 /	10	125.24								145
Pt-WC/C-S /	/ MW assiste	d	4 /	10	94.76								145
Pt/C /	Comm	erc	/	20	62.22								145
Pt ₂₀ @WC ₂₁ / MC-MP / H ₂ PtCl ₆	O MW assiste	d	/	20						354			146
Pt ₂₀ @WC ₂₂ / MC-MM / H ₂ PtCl ₆	O Mecha al mix	nic ng	/	20						488			146
PtSn/C / H ₂ PtCl ₆ ,SnC	MW Cl ₂ assiste	d	$\sim 3 /$ Sphere	18	81.4								171
PtRh/C / H ₂ PtCl ₆ ,RhC	MW 21 ₃ assiste	d	~ 3 / Sphere	16	93.5								171
Pt- YO _x /C(A):6: / cis - [Pt(NH ₃) ₂ (N	:2 MW O	d	2.8±0.4 /	90 at % Pt	39			0.503				195	172
^{2)2]} Y(CH ₃ COO))3												
PtY/C(A)6:2 <i>cis</i> - [Pt(NH ₃) ₂ (N 2) ₂] Y(CH ₃ COO)	2 / MW assiste O	d	2.7±0.4 /	99.55 at% Pt	33			0.491				161	172
Pt- YO _x /C(A):55 / <i>cis-</i> [Pt(NH ₃) ₂ (N 2) ₂] Y(CH ₃ COO	MW assiste	d	2.7±0.7 /	63 at% Pt	40			0.381				152	172

Pt-Y/C(A):5:5	MW	2.7±0.8 /	99.10	40		0.442		175	172
$\int cis$ -	assisted		at% Pt						
$Y(CH_3COO)_3$									
Pt-	MW	3.1±0.7 /	57 at%	35		0.585		205	172
YO _x /C(B):5:5/	assisted		Pt						
$Pt(C_5H_7O_2)_2$									
Y(CH ₃ COO) ₃									
Pt-	MW	3.1±0.6 /	99.48	34		0.711		245	172
Y/C(B):5:5/	assisted		at% Pt						
$Pt(C_5H_7O_2)_2$									
$PtCo/C(\Lambda)/C$	Chem	/	86 at%	18		0.512		245	172
24.12 / cis-	Reduction	/	Pt	40		0.312		243	1/2
$[Pt(NH_3)_2(NO)]$	/ thermal		10						
$_{2}^{2}$, Co(NO ₃) ₂	treatment								
PtY/C(A):24:	Chem.	/	99.64	34		0.349		120	172
8 / cis-	Reduction		at% Pt						
[Pt(NH ₃) ₂ (NO	/ thermal								
2)2]	treatment								
Y(CH ₃ COO) ₃			00.04			0.425			1.50
PtY/C(B):6:2	Thermal	/	99.36	57		0.437		247	172
$7 Pt(C_5H_7O_2)_2$	treatment		at% Pt						
$Pt_{1}Cn/C/$	MW	2 31 /	20 % Dt	/0.01	3.23		1610		173
H ₂ PtCl _c	assisted	2.317	20 /011	49.91	5.25		1010		1/5
CuCl ₂	assisted								
Pt/C / H ₂ PtCl ₆	Commerc	/		60.95	0.65		400		173
	ial								
PtNi/CNT_C_	MW /	3.3 /	10.2 %	48.1	1.28		618.5		180
$90 / H_2 PtCl_6$,	Continuo		Pt& 2.0						
$Ni (NO_3)_2$	us	0.01	% Ni	27.1	1.60		(20.0		100
$PtN_1/CNT_C_$	MW/	3.3 /	9.8%	37.1	1.69		628.8		180
H_2PICI_6 ,	Continuo		Pl& 2.5						
$\frac{1}{1}$ $\frac{1}$	MW/	nd /	2 2 0/2	87.0	0.77		682.2		180
$40 / H_2 PtCL$	Continuo	n.u. /	2.2 /0 Pt& 1 1	07.9	0.77		082.2		100
$Ni(NO_3)_2$	us		% Ni						
PtNi/CNT P	MW /	2.5 /	7.5 %	33.7	1.39		468.9		180
$6 / H_2 PtCl_6^-$	Pulsed		Pt& 0.8						
Ni(NO ₃) ₂			% Ni						
PtNi/CNT_P_	MW /	4.7 /	8.1 %	47.1	1.20		570.2		180
$9 / H_2 PtCl_6$,	Pulsed		Pt& 1.6						
$Ni(NO_3)_2$			% Ni						100
PtN_1/CNT_P_1	MW/	2.7 /	10.2 %	36.1	0.679		582.9		180
$18 / H_2 PtCl_6$,	Pulsed		Pt& 2.2						
Pt/C/	Commerce	31/	70 INI 10 5 %	45.7	1.05		182.5		180
100/	ial	5.17	19.5 70 Pt	43.7	1.05		402.5		100
$Pt_{4.5}Sn_{1.5}Rh_{1}$	MW	1.57 ±		43.39	10.50		2180		199
USNP/C /	assisted	0.97 /							
H ₂ PtCl ₆ ,									
RhCl ₃ , SnCl ₂									
$20 xyt^{0/2} Dt/C$	Commoro	/	20	69.52	1.09		380		199
20 wt/010C	Commerc	/	20				200		

Abbreviations: AC, activated carbon; IM, impregnation method; CHT, conventional heat treatment; HT, hydrothermal treatment; PVP, poly(*N*-vinyl-2-pyrrolidone); PEG, poly(ethylene glycol); CPM, 3D ordered mesoporous carbon materials; *p*-NA, *p*-nitro aniline; CV, crystal violet; PDC, plastic derived carbon; SWCNT, single walled carbon nanotube; CR, congo red; DR, direct redox; HdCl, hydrodechlorination; G, graphene; MB, methylene blue, RB, rose Bengal; CNT, carbon nanotube; FCNT, functional CNT; *p*-CNB, *p*-chloronitrobenzene; *p*-CAN, *p*-chloroaniline; CMA, cinnamaldehyde; HCMA, hydrocinnamaldehyde; DHIPO, 3,3,5-

trimethylcyclohexanone;Grp, graphite; LHSV, liquid hourly space velocity; GHSV, gas hourly space velocity; LA, levulinic acid; GVL, γ -valerolactone; DCM, dichloromethane; RCl, aryl chloride; RI, aryl iodide; RBr, aryl bromide; DMO, dimethyl oxalate; DPO, diphenyl oxalate; TBOT, tributyltitanate; ECSA, electrochemical surface area; SA, surface specific activity; MA, mass activity; CA, carbon aerogel;