Electronic Supplementary Material (ESI) for Materials Advances.

Supplementary Information

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

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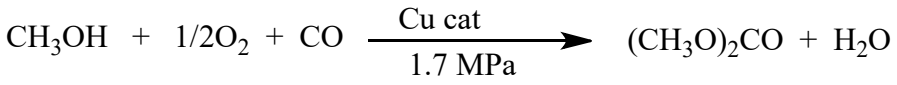
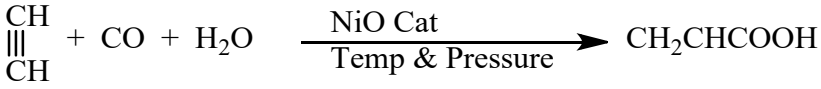
Scheme S1. Some model reactions catalyzed by supported catalysts.

i) Oxidation

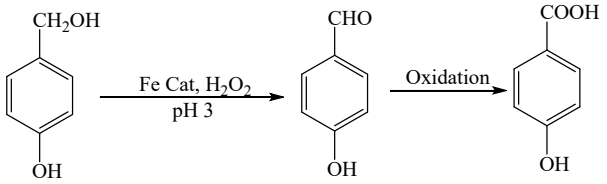
Oxidative carbonylation of methanol[83]



Catalytic carbonylation of acetylene to acrylic acid[164]

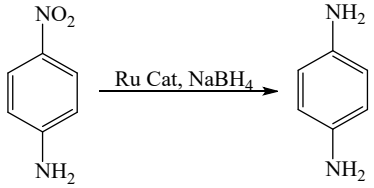


Oxidative degradation of phenol[84]

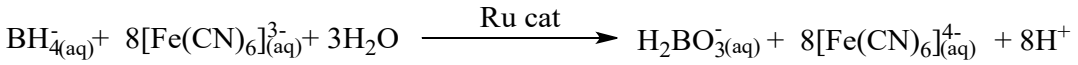


ii) Reduction/Reductive degradation

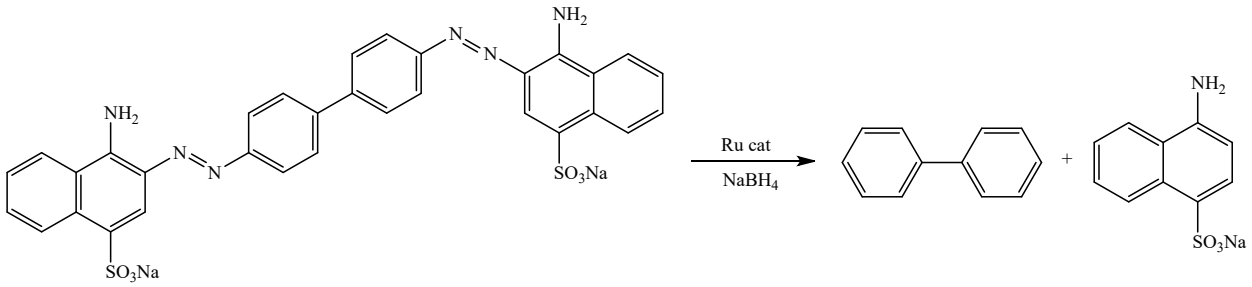
Reduction of *p*-nitoraniline[85]



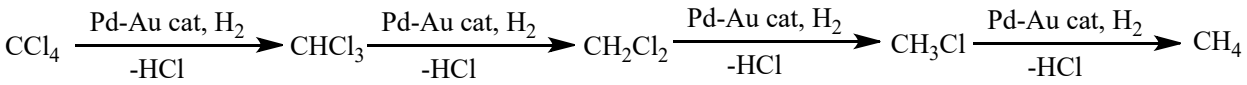
Reduction of potassium hexacyanoferrate(III)[86]



Reductive degradation of congo red[99]

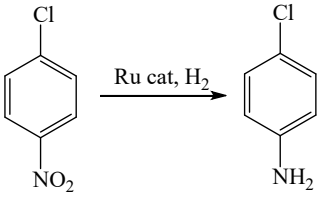


Hydrodechlorination (HdCl) of tetrachloromethane[174]

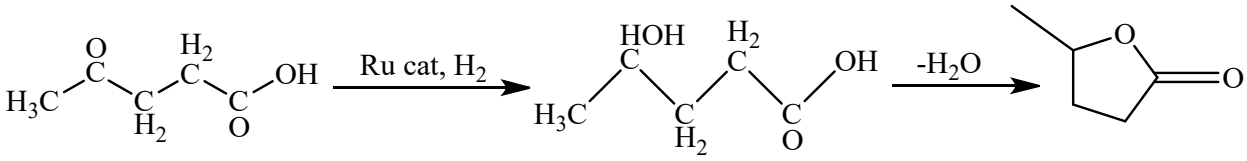


iii) Hydrogenation

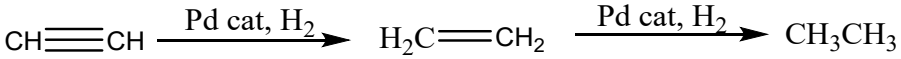
Hydrogenation of *p*-chloronitrobenzene (*p*-CNB)[95,118]



Hydrogenation of levulinic acid[141]

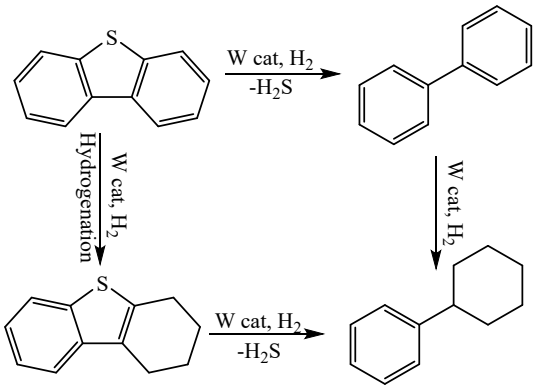


Hydrogenation of acetylene[137]

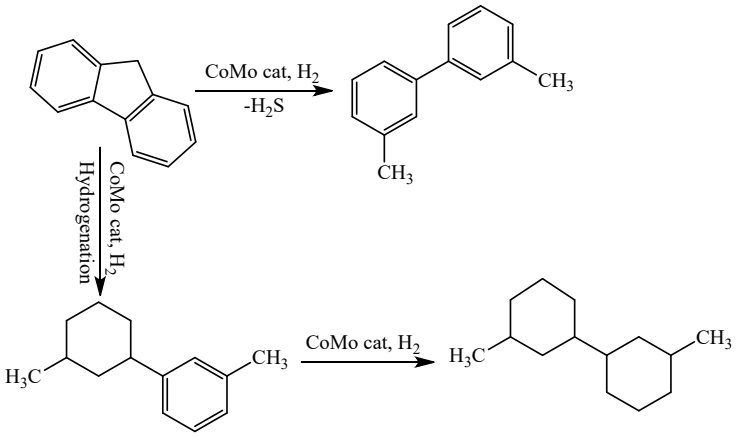


iv) Hydrodesulfurization

Hydrodesulfurization of dibenzothiophene[139]

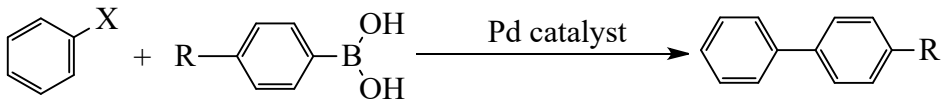


Hydrodesulfurization of 4,6-dimethyldibezothiophene[185]

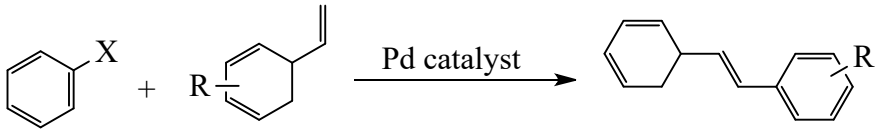


v) Coupling reactions

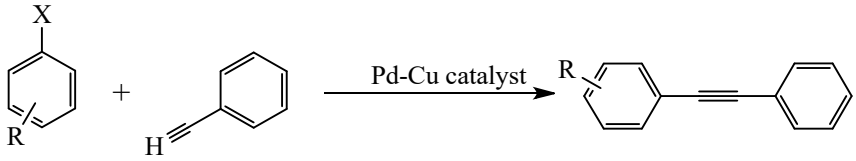
Suzuki-Miyaura coupling reaction[93,107,109,133,183,188]



Mizoroki-Heck coupling reaction[93,134,147]



Sonogashira-Hagihara coupling reaction[134]



vi) Synthesis

Fisher-Tropsch synthesis (FTS)[119,211]

$$(2n+1)H_2 + nCO \xrightarrow{\text{Co cat}} C_nH_{2n+2} + nH_2O$$

Dehydration of ethanol[121]

$$CH_3CH_2OH \xrightarrow[\text{temp.}]{\text{Pt cat, } H_2} CH_2CH_2 + HOH$$

Table S1 Summary of various supported nanocatalysts indifferent reactions.

Oxidation:								
Catalyst	Preparation method	Size (nm) / Shape	Nature of reaction	Reaction conditions	Catalyst amount (mg)	% Conversion (C) / % Yield (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/ $CuCl_2$	Hydrothermal	10-25 / cubic	CO oxidation	1 % CO, 30 L h^{-1} g^{-1}, 180 °C	50	100 (C)	----	201
30 wt % Pd/Co_3O_4/Pd $(NO_3)_2$	MW assisted	--- /---	CO oxidation	Flow rate, 100 cc/min; 127 °C	50	100 (C)	----	127
50 wt % Pd/Fe_3O_4 / $Pd(NO_3)_2$	MW assisted	--- /---	CO oxidation	Flow rate, 100 cc/min; 127 °C	50	100 (C)	----	127
4 Pd/Mn_3O_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_3O_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_3O_4/ Na_2PdCl_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(PVP)/ $Pd(NO_3)_2$	MW assisted	--- / ---	CO oxidation	Flow rate, 100 cc/min; 254 °C	20	98 (C)	-----	131
10% Pd/CeO_2(PEG)/ $Pd(NO_3)_2$	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
10% Pd/ZnO (PVP) / $Pd(NO_3)_2$	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	--- / ---	CO	Flow rate, 100	20	98 (C)	------	131

Au/CeO_2 (PVP) / $HAuCl_4$	assisted		oxidation	cc/min; 267 °C				
10% Au/CeO_2 (PEG) / $HAuCl_4$	MW assisted	--- / ---	CO oxidation	Flow rate, 100 cc/min; 353 °C	20	99 (C)	------	131
10% Au/CuO / $HAuCl_4$	MW assisted	--- / ---	CO oxidation	Flow rate, 100 cc/min; 211 °C	20	100 (C)	-----	131
10% Au/ZnO / $HAuCl_4$	MW assisted	--- / ---	CO oxidation	Flow rate, 100 cc/min; 331 °C	20	100 (C)	----	131
4 Au/Mn_3O_4/ $AuCl_3$	MW assisted	--- / ---	CO oxidation	4 % CO, 20 % O_2,Flow rate, 100 cc/min, 98 °C	50	100 (C)	4 (30 h)	129
4 Au/Mn_3O_4HT / $AuCl_3$	MW assisted	--- / ----	CO oxidation	4 % CO, 20 % O_2,Flow rate, 100 cc/min, 161 °C	50	100 (C)	7 (23 h)	129
CZ40A-CC / $Ce(NO_3)_3$, $ZrO(NO_3)_2$	MW assisted	--- / ----	CO oxidation	Flow rate, 50 mL/min; 2 % CO; 250 °C	20	98 (C)	-----	197
CZ40A-CI / $Ce(NO_3)_3$, $ZrO(NO_3)_2$	IM	--- / ----	CO oxidation	Flow rate, 50 mL/min; 2 % CO; 250 °C	20	< 80 (C)	-----	197
Fe/AC / $Fe(NO_3)_3$	MW assisted	----	Phenol oxidation	500 mL phenol; H_2O_2; 30 °C; 180 min	100	93 (C)	73 (C) (4^{th} cycle	84
Fe/AC / $Fe(NO_3)_3$	CHT	-----	Phenol oxidation	50 mL 100 mg/L phenol , 50 °C, <120 min	25	80 (C)	-----	207
Cat-48-540 (Cu/AC) / $Cu(NO_3)_2$	MW assisted	28.7 / Cube	CH_3OHcarbonylation	Feed gas (O_2:CO) ratio, 1:11; CH_3OH, 0.056 mL min^{-1}; 2 h	250	75-80 (S)	----	82
Cat-360-0(Cu/AC)/ $Cu(NO_3)_2$	MW assisted	51.4 / Hollow sphere	CH_3OHcarbonylation	Feed gas (O_2:CO) ratio, 1:11;CH_3OH, 0.056 mLmin^{-1};	250	100 (S)	-----	83
Cu/AC-4 / $Cu(NO_3)_2$	IM	12 / Sphere	CH_3OHcarbonylation	CH_3OH, 3 mL h^{-1}	800	59.3 (S)	45 (S) (120 h)	204
MW-NiO/2D-Vmt / $Ni(NO_3)_2$	MW assisted	0.25±0.25 / ---	C_2H_2carbonylation	C_2H_2(0.3 MPa), CO (3 MPa), 235 °C, 60 min	1000	86.3 (Y) /~ 80 (S)	42.5 (Y) (6^{th} cycle)	164
MF-NiO/2D-Vmt / $Ni(NO_3)_2$	CHT	0.35±0.35 / ---	C_2H_2carbonylation	C_2H_2(0.3 MPa), CO (3 MPa), 235 °C, 60 min	1000	~ 68 (Y) / ~ 75 (S)	36.1 (Y) (6^{th} cycle)	164
Ag-Fe_3O_4@CMC / $Ag(NH_4)_2$	MW assisted	Fe_3O_4, 15.3 ± 3.5; Ag, 2.3 ± 0.3 / ---	Benzaldehyde oxidation	Air, H_2O (0.17 M), 24 h, 55 °C	6.5 mol%	99 (Y) / 99 (S)	-----	193
Reduction/Reductive degradation:								
Catalyst / Precursor	Preparation method	Size (nm) / Shape	Nature of reaction	Reaction conditions	Catalyst amount (mg)	Conversion(%) or degradation /	Conversion (%) / Cycle No. or time	Ref.

						Time (sec/h)	(h)	
Ru/CPM-1 / $Ru(acac)_3$	MW assisted	2.6 ± 0.5 / Sphere	*p*-NA reduction	1.7 mL (0.1 mM); $NaBH_4$ (0.04 M); room temp.	10	100 / 15 sec	Fairly stable / 5th 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 / 5th cycle	85
PDC@Ru / $Ru(acac)_3$	MW assisted	5±0.2 / Probably sphere	$K_3[Fe(CN)_6]$ reduction	3.0 mL (3×10^{-3} M); $NaBH_4$ / $Na_2S_2O_3$, room temp.	10	98 / <30 sec	75/>6th 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 / 3rd 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 / 3rd cycle	99
PdAu-DR-MW / $[Pd(OAc)_2]_n$, $AuCl_4H_6NO$	MW assisted	3-7 / Sphere	CCl_4HdCl	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 / $[Pd(OAc)_2]_n$, $AuCl_4H_6NO$	Thermal treatment	1-7 / Sphere	CCl_4HdCl	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 / $[Pd(OAc)_2]_n$, $AuCl_4H_6NO$	MW assisted	3-5 / Sphere	CCl_4HdCl	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 / $[Pd(OAc)_2]_n$, $AuCl_4H_6NO$	CHT	1-5 / Sphere	CCl_4HdCl	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_4HdCl	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	---- / ----	CCl_4HdCl	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
Photocatalytic/thermal degradation:								
Catalyst / Precursor	Preparation method	Size (nm) / Shape	Compound	Degradation Condition	Catalyst amount	% Degradation	Recycle	Ref.
Pt/G3 / H_2PtCl_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_2C/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 / $(NH_4)_6H_2W_{12}O_{40}$	Carbothermal 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) / $Ce(NO_3)_3$	MW assisted	8 / Cube	MB	200 ppm; 1h; pH, 7; room temp.	0.4 g/L	99.9	----	162
CeO_2-SiO_2 (H-24 h) / $Ce(NO_3)_3$	HT	15 / Sphere	MB	200 ppm; 1h; pH, 7; room temp.	0.4 g/L	85	----	162

Hydrogenation:

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	*p*-CNB / 0.4	*p*-CAN	0.5 mg Ru, H_2 (4 MPa), CH_3OH, 60 °C, 30 min	100 /100	3 / Stable (data not available	95
Ru/CNT / $RuCl_3$	MW assisted	2.7-3.6 / Sphere	*p*-CNB / 0.4	*p*-CAN	0.5 mg Ru, H_2 (4 MPa), CH_3OH, 60 °C, 30 min	95 /100	-----	95
Ru/CNT / $Ru_3(CO)_{12}$	MW assisted	2-4 /Sphere	CMA / 1.32	HCMA	100 mg cat., cyclohexane, H_2 (3 MPa), 80 °C	72 / 80	-----	96
Pd/G / $[Pd(OAc)_2]_n$	MW assisted	5 / ---	Isophorone / 0.138	DHIPO	2 mg cat., H_2O, H_2 (1.2 MPa), 60 °C, 5 min	97 / 99.8	5 / ~ 99 %	108
Pd/Grp / $[Pd(OAc)_2]_n$	MW assisted	--- /---	Isophorone / 0.138	DHIPO	2 mg cat., H_2O, H_2 (1.2 MPa), 60 °C, 5 min	83.9 / 35.0	--- /---	108
Pt/G / K_2PtCl_6	MW assisted	14 ± 6 /Sphere	Styrene / 1.22	Ethyl benzene	50 mg cat., CH_3OH, H_2 (1520 psi), 100 °C, 60 min	99.66 / 100	--- / ---	110
Pt/AC /---	Commercial	2-5 / ---	Styrene / 1.22	Ethyl benzene	50 mg cat., CH_3OH, H_2 (1520 psi), 100 °C, 60 min	40.31 / 40.31	---- / ---	110
Pd/AC/---	Commercial	3-5 / ---	Styrene / 1.22	Ethyl benzene	50 mg cat., CH_3OH, H_2 (1520 psi), 100 °C, 60 min	99.87 / 100	--- / ----	110
Ni/AB-MW / $Ni(NO_3)_2$	MW assisted drying	--- /---	Nitrobenzene	Aniline	0.5 g cat, LHSV, 6.0 mL g^{-1}_{cat} h^{-1}, GHSV, 4800 mL g^{-1}_{cat} h^{-1}, 300 °C	93.3 / 98.7	--- / ---	118
Ni/AB-CH / $Ni(NO_3)_2$	Tradtional drying	--- / ---	Nitrobenzene	Aniline	0.5 g cat, LHSV, 6.0 mL g^{-1}_{cat} h^{-1}, GHSV, 4800 mL g^{-1}_{cat} h^{-1}, 300 °C	89.5 / 94.4	---- / ----	118
Pd/Al_2O_3(PF-1) / $Pd(NO_3)_2$	Plasma induced MW	---- / Sphere	Acetylene	Ethane	20 mg cat, H_2 (80 mL/min), 320,000 h^{-1}, 120 °C	~ 85 / ~ 95	---- /----	137
Pd/Al_2O_3(CM-1) / $Pd(NO_3)_2$	Plasma induced MW	---- / Sphere	Acetylene	Ethane	20 mg cat, H_2 (80 mL/min), 320,000 h^{-1}, 120 °C	~ 45 / ~ 80	---- /----	137
Ru/TiO_2 (Acac-200-10) / $Ru(acac)_3$	MW assisted	2.35 / Sphere	LA	GVL	50 mg cat, 0.5 g LA, H_2O, 200 °C, 10 min	---- / 69.4	---- / ----	141
Ru/TiO_2 (Cl-150-5) / $RuCl_3$	MW assisted	1.87 / Sphere	LA	GVL	50 mg cat, 0.5 g LA, H_2O, 150 °C, 5 min	---- / 67	---- / ----	141
10 wt% MoO_2/AC / β-Mo_2C	MW assisted	3 / ---	Naphthalene	Tetralin	LHSV, 20 h^{-1}	100 / 80	----- / ----	155

20wt% MoO_2/AC / β-Mo_2C	MW assisted	3 / ---	Naphthalene	Tetralin	LHSV, 14.3 h^{-1}	100 / 95	(60) / > 80	155
30wt% MoO_2/AC / β-Mo_2C	MW assisted	3 / ---	Naphthalene	Tetralin	LHSV, 3.6 h^{-1}	100 / 90	----- / -----	155
Ag-Fe_3O_4@CMC / $Ag(NH_4)_2$	MW assisted	Fe_3O_4, 15.3 ± 3.5; Ag, 2.3 ± 0.3 / ---	Benzaldehyde	Benzylalcohol	6.5 mol % cat., Benzaldehyde, 0.33 mmol, H_2(4 MPa), 100 °C, 24 h	95 / 95	5 / 95	193

Suzuki-Miyaura coupling reaction:

Catalyst / Precursor	Preparation method	Size (nm) /Shape	Conditions	Catalyst amount	Yield (%)			Recycle No./ % yield	Ref.
					RCl	RBr	RI		
Pd/G / $Pd(NO_3)_2$	MW assisted	9.37 / Irregular	K_2CO_3, H_2O: EtOH, 80 °C, 10 min	3 mg	----	100	---	4 / 77	107
Pd/G-C_3N_4 / $Pd(NO_3)_2$	Photodeposition	2.73 / ---	KOH, H_2O:EtOH (1:1), room temp., 40 min	2 mg	----	100	----	5 / > 85	221
Pd-Fe_3O_4/G / $Pd(NO_3)_2$	MW assisted	---- / Sphere	K_2CO_3, H_2O: EtOH, 25°C, 180 min	1 mol %	-----	100	-----	9 / 81	109
Pd-Fe_3O_4/G /$Pd(acac)_2$	HT	---- /----	K_2CO_3, H_2O: EtOH, MW: 120 °C, 10 min	3.5 g	----	100	-----	9 / 82	222
20 wt% Pd/CuO / Cu $(NO_3)_2$	MW assisted	2--40 / ---- Sphere	K_2CO_3, H_2O:EtOH, 150°C, MW heating, 10 min	1 mol %	-----	100	-----	6 / 60	133
Pd-Co/CuO-3 / K_2PdCl_4, $Co(NO_3)_2$	Conventional reduction	4-6 / ---	K_2CO_3, H_2O:EtOH, 25 °C,3 h	3 mg	-----	90	------	------	223
Pd/Ag/SBA-15 / $Pd(OAc)_2$, $AgNO_3$	MW assisted	4.2 / Sphere	K_2CO_3, EtOH, visible light, room temp., 2 h	20 mg	------	-----	~ 40	-----	183
Pd/Au/SBA-15 / $Pd(OAc)_2$, $HAuCl_4$	MW assisted	4.9 / Sphere	K_2CO_3, EtOH, visible light, room temp., 2 h	20 mg	----	------	~ 70	-----	183
Pd-Fe_3O_4/G / $Pd(NO_3)_2$, $Fe(NO_3)_3$	MW assisted	Pd, 35 ± 2, Fe_3O_4, 52 ± 2 / Sphere	K_2CO_3, H_2O: EtOH (1:1),120 °C, 10 min	1 mol%	----	100	----	7 / 76	188
Pd-Co_3O_4/G / $Co(NO_3)_2$, $Fe(NO_3)_3$	MW assisted	Pd, 25 ± 2, Co_3O_4, 45 ± 2 / Sphere	K_2CO_3, H_2O: EtOH (1:1),120 °C, 10 min	1 mol%	----	100	----	---- / ----	188
Pd-$Ni(OH)_2$/ G / $Ni(NO_3)_2$, $Fe(NO_3)_3$	MW assisted	Agglomeration / ---	K_2CO_3, H_2O: EtOH (1:1),120 °C, 10 min	1 mol%	----	< 60	----	---- / ----	188
Pd-Fe_3O_4/G / $Pd(NO_3)_2$, $Fe(NO_3)_3$	MW assisted (Pd7.6 wt%)	Pd, 3-4; Fe_3O_4, 12-16 / Sphere	K_2CO_3, H_2O: EtOH (1:1), room temp., 45 min	0.3 mol%	----	100	----	10 / 80	189

Mizoroki-Heck coupling reaction:

Catalyst / Precursor	Preparation method	Size (nm) /Shape	Conditions	Catalyst amount	Yield (%)			Recycle No./ % yield	Ref.
					RCl	RBr	RI		

20 wt% Pd/CuO / Cu $(NO_3)_2$	MW assisted	25 ± 2 / ---	K_2CO_3, H_2O: EtOH, 150 °C, MW heating, 10 min	2 mol %	----	93	----	5 / 90	134
Pd/SiC (MW3) / $[Pd(OAc)_2]_n$	MW assisted	--- / ---	Triethylamine, acetonitrile, 120 °C, 6 h	---	----	----	95	10 / 100	147
Pd/SiC (OB10) / $[Pd(OAc)_2]_n$	Conventional heating	--- / ---	Triethylamine, acetonitrile, 120 °C, 6 h	---	----	----	100	7 / 44	147
Pd/C	Commercial	--- / ---	Triethylamine, acetonitrile, 120 °C, 6 h	-----	----	----	96	3 / 33	147
Pd/Al_2O_3	Commercial	--- / ---	Triethylamine, acetonitrile, 120 °C, 6 h	-----	----	----	99	6 / 27	147

Synthesis reaction:

Catalyst / Precursor	Preparation method	Size (nm) /Shape	Reactant	Main product	Reaction condition	% Yield / % Conversion (selectivity)	Recycle No. (Time h) / % Conversion	Ref.
MW-2%Ag@AlSBA-15 / $AgNO_3$	MW assisted	--- / ---	Propargylic urea	Imidazolone	0.04 g cat., 72 µmol reactant, toluene, MW treatment	35 / ----	----- / -----	112
BM-2%Ag@AlSBA-15 / $AgNO_3$	Ball milling	--- / ---	Propargylic urea	Imidazolone	0.04 g cat., 72 µmol reactant, toluene, MW treatment	56 / ---	----- / ----	112
AgNCs/SBA-15 / $AgNO_3$	MW assisted	1.2±0.3 / ----	Propargylguanidine	Cyclic-guanidine	0.15 mol Ag, 0.12 mmol reactant, DCM, 50 °C, 3 h	99 / 100	4 / > 90	116
AgNCs/SBA-15 / $AgNO_3$	MW assisted	1.2±0.3 / ----	2-(Phenylethynyl)phenol	2-phenylbenzofuran	0.15 mol Ag, 0.05 mmol reactant, DCM, 70 °C, 3 h	93 / 100	--- / ---	116
Ni20-Al_2O_3-M / $Ni(NO_3)_2$	MW assisted	10 / ---	$CO_2 + H_2$	CH_4	Flow rate, 70 mL/min; 325 °C	--- / 91.6	(72) / ~ 91	136
Ni20-Al_2O_3-I / $Ni(NO_3)_2$	IM	15 / ---	$CO_2 + H_2$	CH_4	Flow rate, 70 mL/min; 350 °C	---- / 84.3	---- / ---	136
Co/Si=1/4-ABC-550 /$Co(NO_3)_2$	MW assisted	--- / ---	$CO + H_2$	Higher hydrocarbon (C_{5+})	150 °C, plasma, 90 W; gas flow rate, 25 mL/min	6.5/100	(175) / 100 %	119
Co/SiO_2 / $Co(NO_3)_2$	MW assisted	10 / Irregula	$CO + H_2$	Higher hydrocarbon (C_{5+})	2 g cat, plasma, 60 W, GHSV, 750 to mL g^{-1}_{cat} h^{-1}	42.1 / 63.2	-----	119
Co/SiO_2 / $Co(NO_3)_2$	Coventionaldyring	2-3 / Irregular	$CO + H_2$	Higher hydrocarbon (C_{5+})	2 g cat, plasma, 60 W, GHSV, 750 to mL g^{-1}_{cat} h^{-1}	68.3 / 50.9	-----	119
Ti-MCM-41-5 / TBOT	MW assisted	3.6 / ---	DMO + Phenol	DPO	DMO:Phenol = 1:3 molar ratio, 180 °C, 2 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 cat, GHSV, 12,000 h^{-1}, gas flow, 65 mL/min, 1.5 MPa, 400 °C	---- / 99.6 (93.8)	---- / ---	163

CHT-NiO/Vmt (Ni, 10 wt%) / $Ni(NO_3)_2$	CHT	6 / ---	$CO + H_2$	CH_4	0.188 g cat, GHSV, 12,000 h^{-1}, gas flow, 65 mL/min, 1.5 MPa, 450 °C	---- / 64.8 (81.1)	---- / ---	163
MW-Cu/Ni-95 / $Cu(NO_3)_2$, $Zn(NO_3)_2$, $Ni(NO_3)_2$	MW assisted	13.68 ± 4.66 / Sphere	CH_3OH	H_2	100 mg cat., 0.1 MPa; Weight HSV, 1.5 h^{-1}; 1 h; 300 °C	----/ 100 (90.5)	(30) / 98.8	196
MW-Cu/ 95 / $Cu(NO_3)_2$, $Zn(NO_3)_2$,	MW assisted	18.37 ± 5.66 / Sphere	CH_3OH	H_2	100 mg cat., 0.1 MPa; Weight HSV, 1.5 h^{-1}; 1 h; 300 °C,	----/ 94.3 (88.2)	(30) / 47.3	196

Electrocatalysis:

Catalyst / Precursor	Prep. method	Size (nm) /Shape	Loading (wt %)	ECSA (m^2/g_{cat})	SA in acidic (mA/cm^2)	SA in basic (mA/cm^2)	MA in acidic (mA/mg)	MA in basic (mA/mg)	Ref.
Pt/AC / H_2PtCl_6	MW assisted	3.8±0.3 / Sphere	18.9	12.2	---	---	---	---	88
Pt/CA	MW assisted	2.7 / Sphere	---	50·04	---	---	---	---	91
Pt/C / $(NH_4)_2PtCl_6$	MW assisted	2.1 / Sphere	23.7	~ 68	0.30±0.002	0.80±0.008	166±1.3	186±1.9	92
Pt/C / H_2PtCl_6	MW assisted	2.0 / Sphere	19.5	~ 66	0.53±0.014	1.03±0.014	147±3.8	176±2.4	92
Pt/C / ---	Commercial	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 / H_2PtCl_6	MW assisted	3 / ---	10	125.24	----	-----	----	----	145
Pt-WC/C-S / H_2PtCl_6	MW assisted	4 /----	10	94.76	----	-----	----	----	145
Pt/C / ----	Commercial	--- / ---	20	62.22	----	-----	----	----	145
$Pt_{20}@WC_{21}$/OMC-MP / H_2PtCl_6	MW assisted	---- / ----	20	---	----	----	354	----	146
$Pt_{20}@WC_{22}$/OMC-MM / H_2PtCl_6	Mechanical mixing	---- / ----	20	---	----	----	488	----	146
PtSn/C / H_2PtCl_6,$SnCl_2$	MW assisted	~ 3 / Sphere	18	81.4	----	----	----	----	171
PtRh/C / H_2PtCl_6,$RhCl_3$	MW assisted	~ 3 / Sphere	16	93.5	----	----	----	----	171
Pt-YO_x/C(A):6:2 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$ $Y(CH_3COO)_3$	MW assisted	2.8±0.4 / ----	90 at % Pt	39	-----	0.503	----	195	172
PtY/C(A)6:2 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$ $Y(CH_3COO)_3$	MW assisted	2.7±0.4 / ---	99.55 at% Pt	33	---	0.491	----	161	172
Pt-YO_x/C(A):5:5 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$ $Y(CH_3COO)_3$	MW assisted	2.7±0.7 /---	63 at% Pt	40	----	0.381	----	152	172

Pt-Y/C(A):5:5 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$ $Y(CH_3COO)_3$	MW assisted	2.7±0.8 / ---	99.10 at% Pt	40	---	0.442	---	175	172
Pt-YO_x/C(B):5:5/ $Pt(C_5H_7O_2)_2$ $Y(CH_3COO)_3$	MW assisted	3.1±0.7 / ---	57 at% Pt	35	----	0.585	-----	205	172
Pt-Y/C(B):5:5/ $Pt(C_5H_7O_2)_2$ $Y(CH_3COO)_3$	MW assisted	3.1±0.6 / ----	99.48 at% Pt	34	-----	0.711	-----	245	172
PtCo/C(A)/C: 24:12 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$, $Co(NO_3)_2$	Chem. Reduction / thermal treatment	---- / ----	86 at% Pt	48	-----	0.512	-----	245	172
PtY/C(A):24: 8 / *cis*-$[Pt(NH_3)_2(NO_2)_2]$ $Y(CH_3COO)_3$	Chem. Reduction / thermal treatment	---- /-----	99.64 at% Pt	34	----	0.349	-----	120	172
PtY/C(B):6:2 / $Pt(C_5H_7O_2)_2$ $Y(CH_3COO)_3$	Thermal treatment	---- /----	99.36 at% Pt	57	----	0.437	----	247	172
Pt_3Cu/C / H_2PtCl_6, $CuCl_2$	MW assisted	2.31 / ---	20 % Pt	49.91	3.23	-----	1610	----	173
Pt/C / H_2PtCl_6	Commercial	---- / ----	-----	60.95	0.65	-----	400	----	173
PtNi/CNT_C_90 / H_2PtCl_6, Ni $(NO_3)_2$	MW / Continuous	3.3 / ---	10.2 % Pt& 2.0 % Ni	48.1	1.28	-----	618.5	-----	180
PtNi/CNT_C_60 / H_2PtCl_6, Ni $(NO_3)_2$	MW / Continuous mode	3.3 / ---	9.8 % Pt& 2.3 % Ni	37.1	1.69	-----	628.8	-----	180
PtNi/CNT_C_40 / H_2PtCl_6, $Ni(NO_3)_2$	MW / Continuous	n.d. / ---	2.2 % Pt& 1.1 % Ni	87.9	0.77	-----	682.2	-----	180
PtNi/CNT_P_6 / H_2PtCl_6, $Ni(NO_3)_2$	MW / Pulsed	2.5 / ---	7.5 % Pt& 0.8 % Ni	33.7	1.39	-----	468.9	-----	180
PtNi/CNT_P_9 / H_2PtCl_6, $Ni(NO_3)_2$	MW / Pulsed	4.7 / ---	8.1 % Pt& 1.6 % Ni	47.1	1.20	-----	570.2	-----	180
PtNi/CNT_P_18 / H_2PtCl_6, Ni $(NO_3)_2$	MW / Pulsed	2.7 / ---	10.2 % Pt& 2.2 % Ni	36.1	0.679	-----	582.9	-----	180
Pt/C/ ----	Commercial	3.1 / ---	19.5 % Pt	45.7	1.05	-----	482.5	-----	180
$Pt_{4.5}Sn_{1.5}Rh_1$ USNP/C / H_2PtCl_6, $RhCl_3$, $SnCl_2$	MW assisted	1.57 ± 0.97 / ---	-----	43.39	10.50	-----	2180		199
20 wt% Pt/C	Commercial	---- / ----	20	69.52	1.09	----	380	----	199

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;