# The Direct Synthesis of $H_2O_2$ Using TS-1 Supported Catalysts.

Richard J. Lewis,[a] Kenji Ueura,[b] Yukimasa Fukuta,[b] Simon J. Freakley,[a,c] Liqun Kang,[d] Ryan Wang,[d] Qian He,[a] Jennifer. K. Edwards,[a] David J. Morgan,[a,e] Yasushi Yamamoto[b] and Graham J. Hutchings*[a]

[a] Cardiff Catalysis Institute, School of Chemistry, Cardiff University, Main Building, Park Place, Cardiff, CF10 3AT, United Kingdom .

[b] UBE Industries, 1978-5, Kogushi, Ube, Yamaguchi 755-8633, Japan.

[c]Department of Chemistry, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom.

[d] Department of Chemical Engineering, University College London, Roberts Building, Torrington Place, London WC1E 7JE, United Kingdom.

[e] HarwellXPS, Research Complex at Harwell (RCaH), Didcot, OX11 0FA, United Kingdom.

* Hutch@cardiff.ac.uk

## Supplementary information

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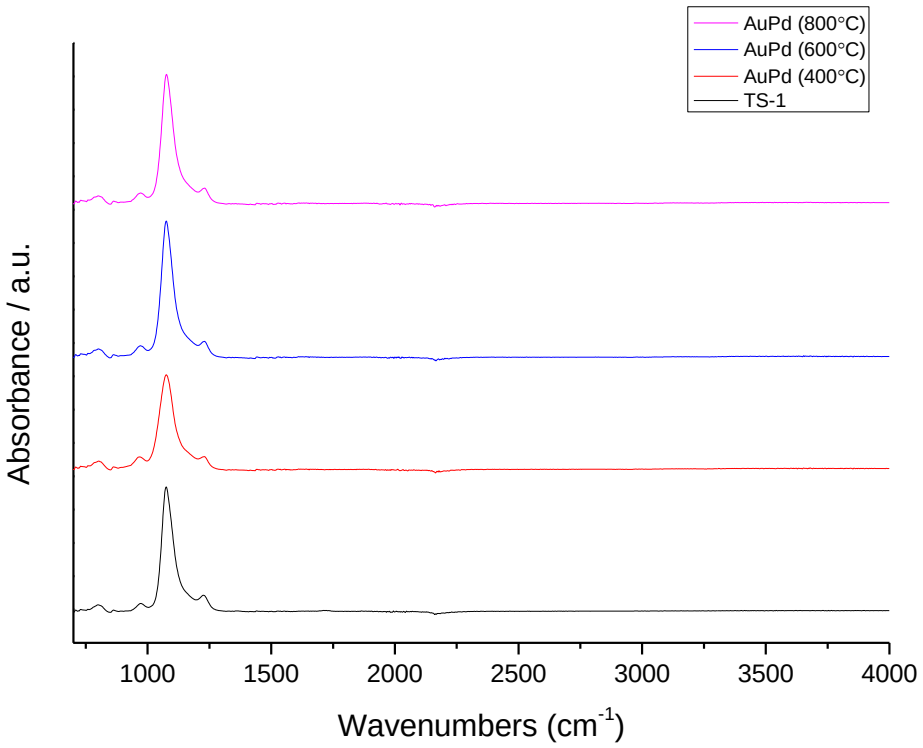



**Figure S.1**. FTIR spectra of 2.5% Au – 2.5% Pd / TS-1 catalysts calcined at 400 – 800 °C (3 h, static air, 20 °C min $^{-1}$).

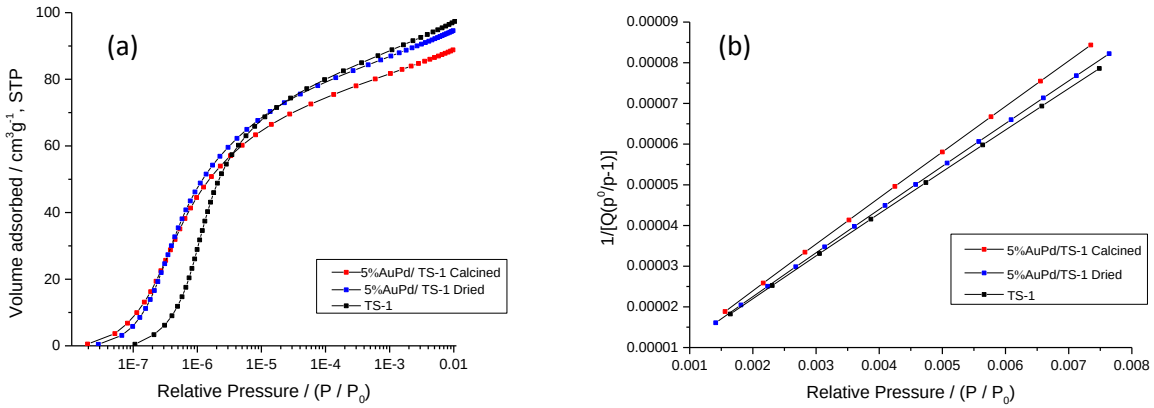



**Figure S.2**. (a) Nitrogen adsorption isotherms (BET) and (b) BET analysis plots for 5%AuPd/TS-1 calcined (400 °C, 3 h, static air), 5%AuPd/TS-1 dried (110 °C, 16 h, static air) and TS-1.

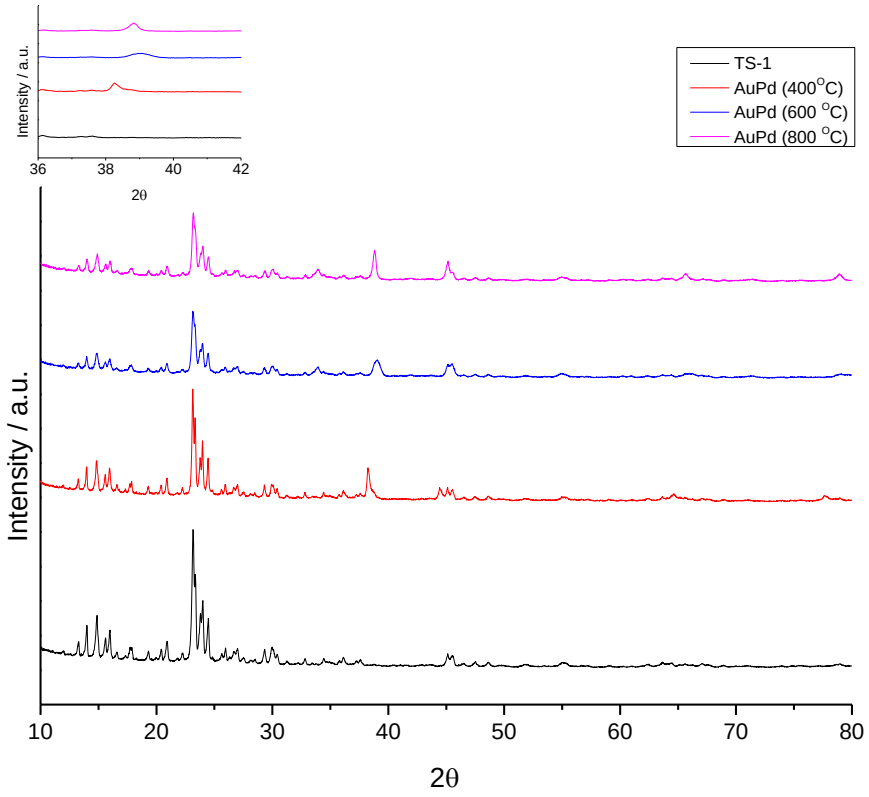
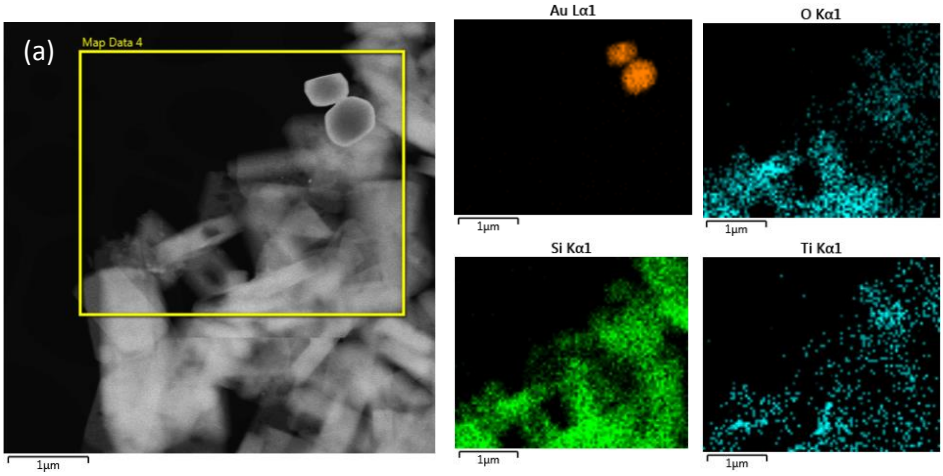



**Figure S.3.** X-ray diffractograms of 2.5% Au- 2.5 % Pd / TS-1 prepared by wet impregnation, calcined at various temperatures (400 – 800 °C), 3 h, static air, ramp rate = 20 °C $min^{-1}$. . Inset shows the magnified difractogram patterns between 36-42°.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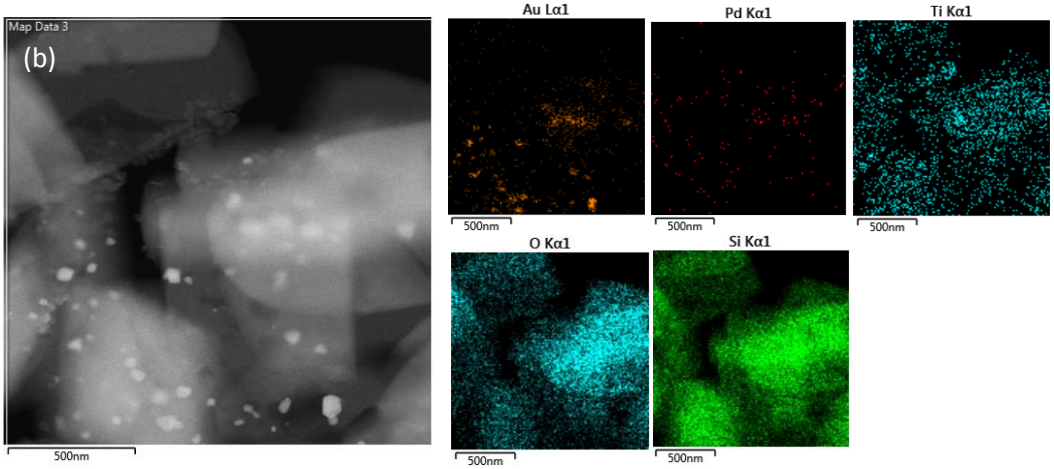
1µm
O Kα1
1µm
Si Kα1
1µm
Ti Kα1
1µm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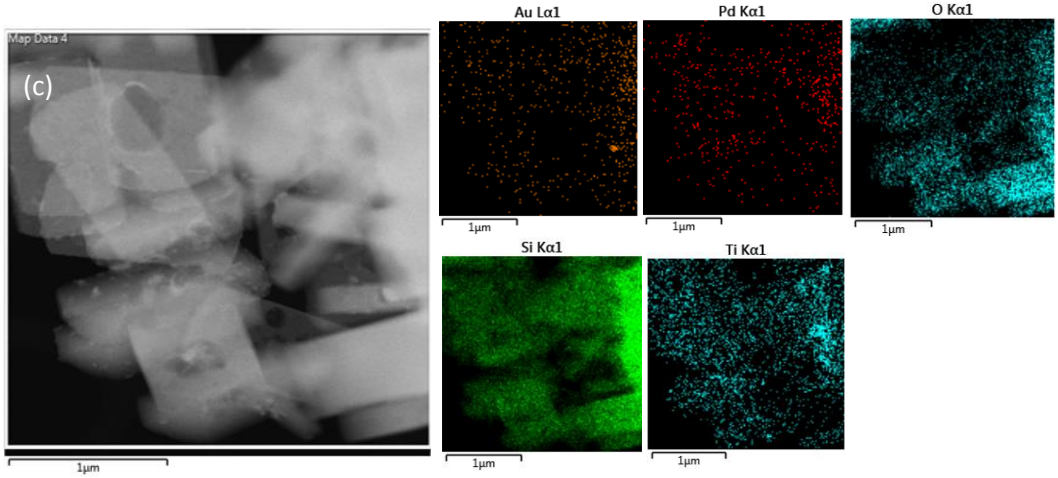
500nm
Pd Kα1
500nm
Ti Kα1
500nm
O Kα1
500nm
Si Kα1
500nm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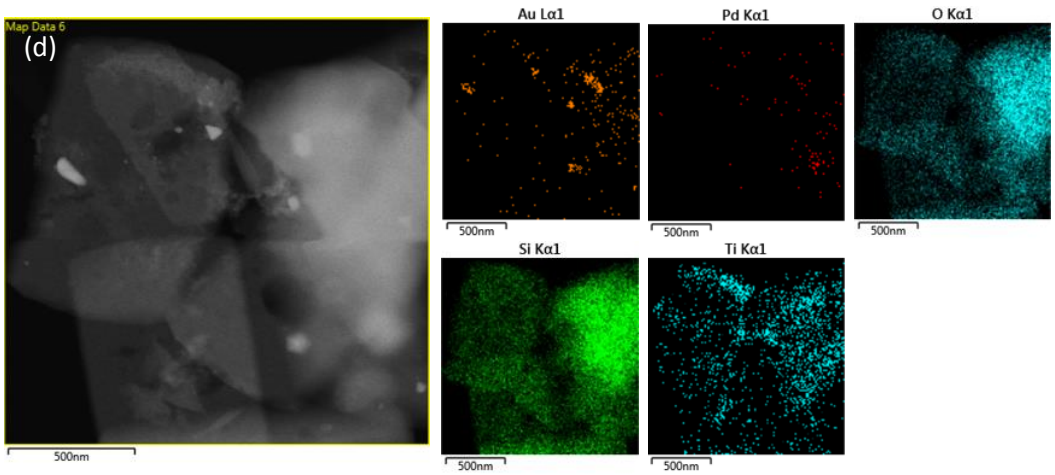
1µm
O Kα1
1µm
Si Kα1
1µm
Ti Kα1
1µm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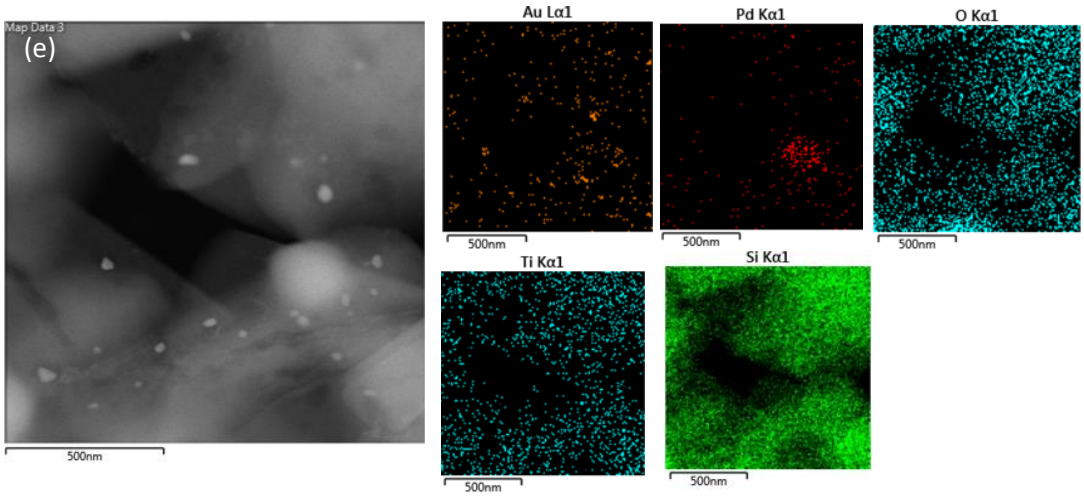
Pd Kα1
500nm
O Kα1
500nm
Si Kα1
500nm
Ti Kα1
500nm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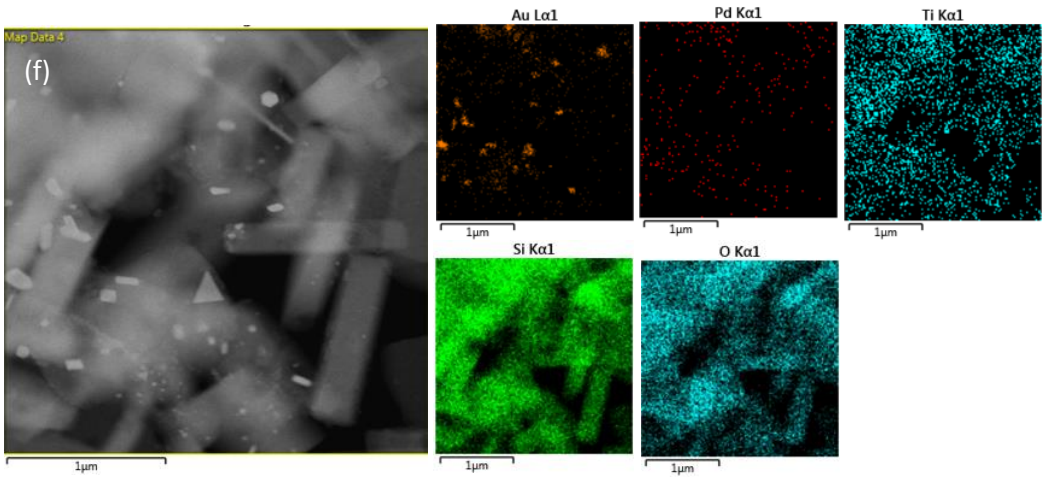
500nm
O Kα1
500nm
Ti Kα1
500nm
Si Kα1
500nm


Map Data 4
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1µm
Pd Kα1
1µm
Ti Kα1
1µm
Si Kα1
1µm
O Kα1
1µm

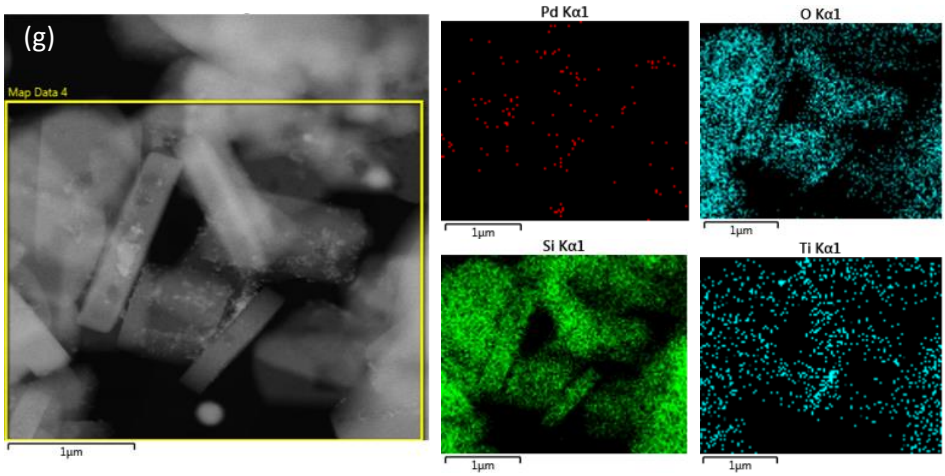


**Figure S.4.** Energy dispersive X-ray analysis of 5% Au-Pd / TS-1, varying Au :Pd, catalysts prepared by wet impregnation, calcined at 400 °C, 3 h, static air, ramp rate = 20 °C min
(a) 5% Au / TS-1 (b) 4% Au – 1% Pd / TS-1 (c) 3% Au – 2% Pd / TS-1
(d) 2.5% Au – 2.5% Pd / TS-1 (e) 2% Au – 3% Pd / TS-1 (f) 1% Au – 4% Pd / TS-1
(g) 5% Pd / TS-1

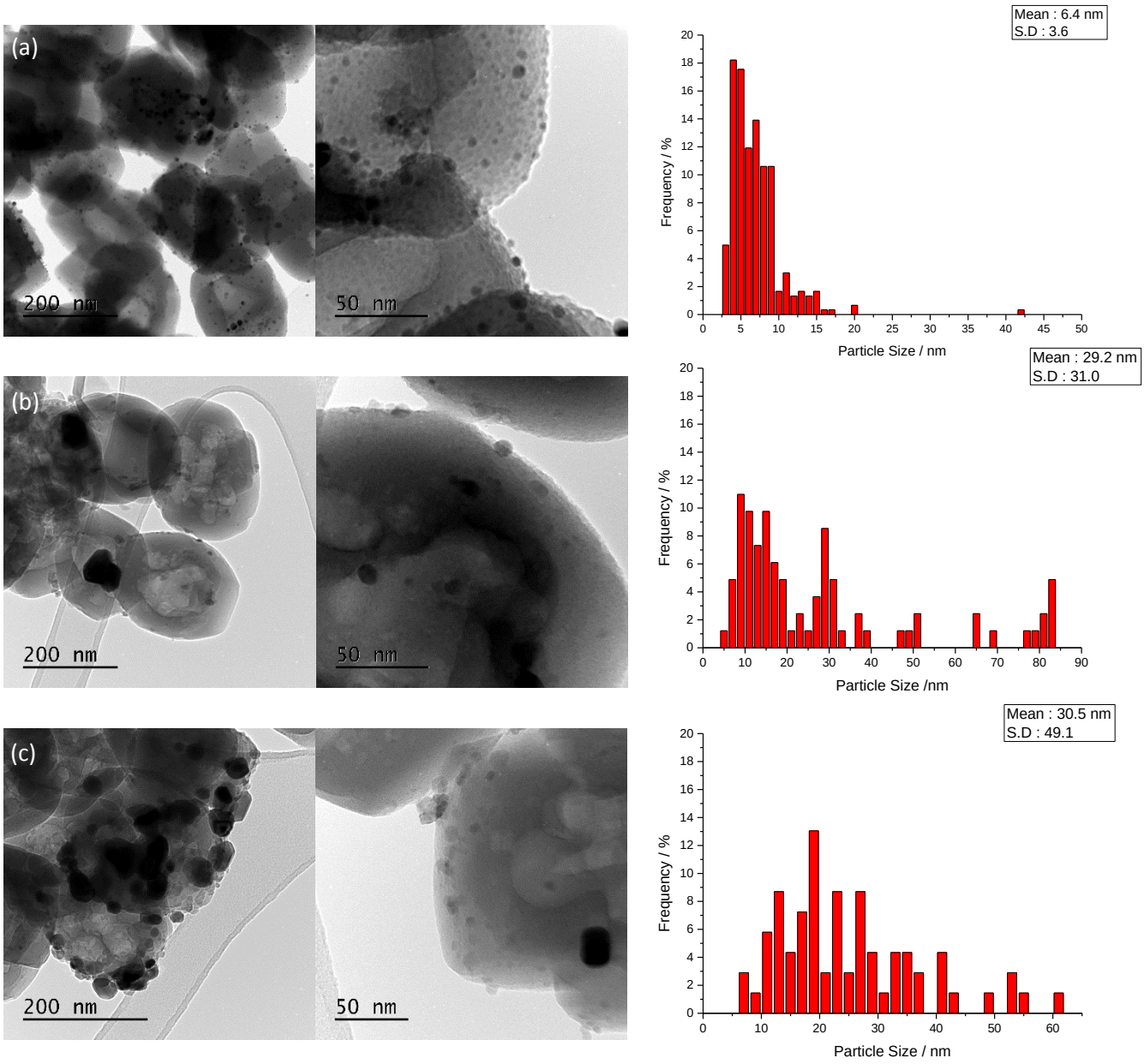


**Figure S.5.** Transmission electron microscopy of 2.5% Au- 2.5% Pd / TS-1 prepared by wet impregnation, calcined at various temperatures (400 – 800 $^{o}$C), 3h, static air, ramp rate = 20 $^{o}$C min$^{-1}$. (a) 400 $^{0}$C, (b) 600 $^{0}$C, (c) 800 $^{0}$C

**Table S.1.** The effect of calcination temperature on Au : Pd molar ratio of 2.5% Au- 2.5% Pd / TS-1 as determined by XPS analysis.

| Calcination temperature / $^0$C | Composition / At. % | | | | | | Pd :Au |
|---|---|---|---|---|---|---|---|
| | Pd 3d | Au 4f | O 1s | Si 2p | Ti 2p | C 1s | |
| Dried Only | 0.12 | 0.24 | 51.50 | 21.94 | 0.40 | 1.55 | 0.5 |
| 400 | 0.19 | 0.01 | 50.82 | 21.51 | 0.45 | 1.54 | 19 |
| 600 | 0.21 | 0.03 | 62.52 | 35.32 | 0.54 | 1.39 | 7.0 |
| 800 | 0.13 | 0.05 | 62.35 | 35.4 | 0.49 | 1.58 | 2.6 |

**Table S.2.** Leaching of Au and Pd in 2.5% Au-2.5% Pd / $TiO_2$ catalyst after $H_2O_2$ synthesis reaction as a function of calcination temperature.

| Pre-treatment | Leaching of metal from Au-Pd/$TiO_2$ | |
|---|---|---|
| | Loss of Au / % | Loss of Pd / % |
| Dried only* | 32 | 77 |
| Air, 300 $^o$C, 3 h | 10 | 18 |
| Air, 400 $^o$C, 3 h | 2 | 1 |
| Air, 600 $^o$C, 3 h | 0 | 0 |
| Air, 800 $^o$C, 3 h | 0 | 0 |

* Dried, 85 $^o$C, 16 h.

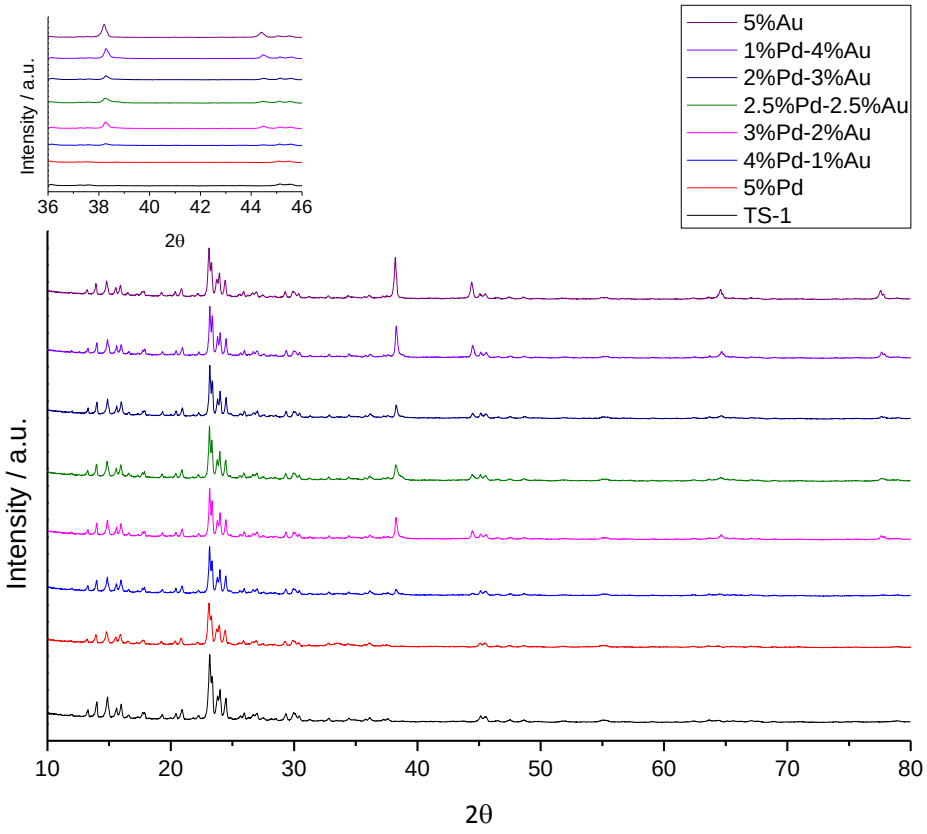


**Figure S.6.** X-ray diffractograms of 5% Au-Pd / TS-1, varying Au :Pd, catalysts prepared by wet impregnation, calcined at 400 $^o$C, 3 h, static air, ramp rate = 20 $^o$C min$^{-1}$. Inset shows the magnified difractogram patterns between 36-46°.

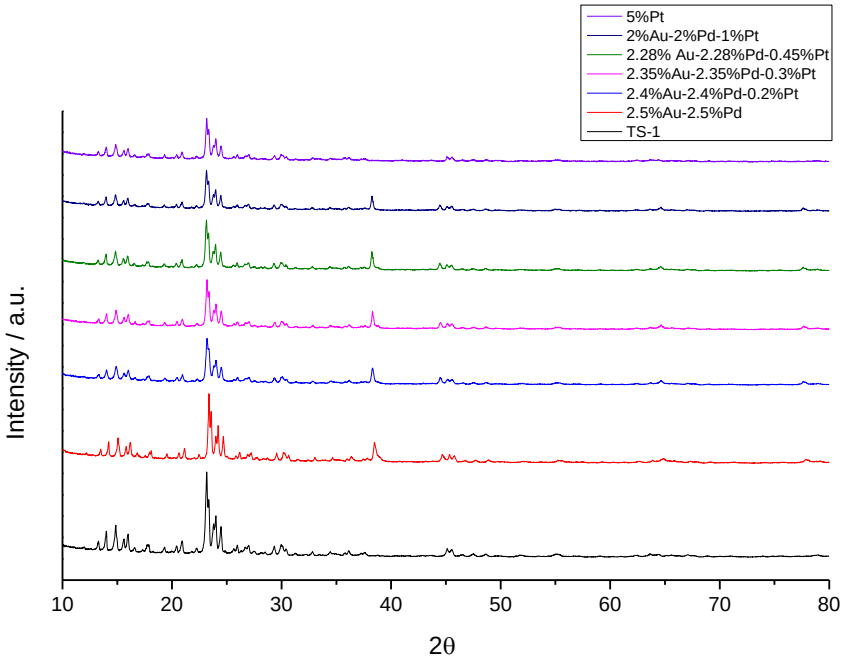


**Figure S.7.** X-ray diffractograms of 5% AuPdPt / TS-1, varying Pt content, catalysts prepared by wet impregnation, calcined at 400 $^{o}$C, 3 h, static air, ramp rate = 20 $^{o}$C min$^{-1}$.

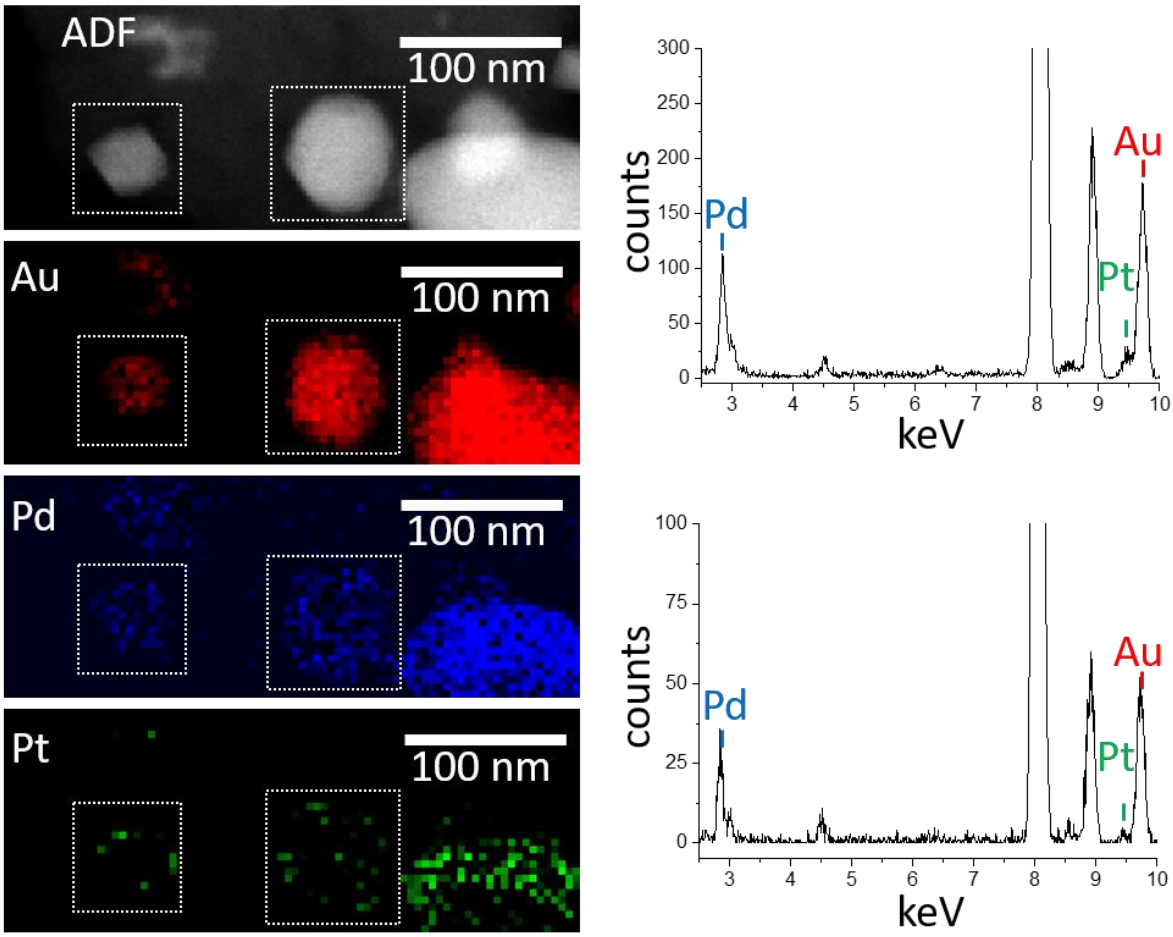


**Figure S.8.** Representative annular dark field (ADF) image and X-EDS map of nanoparticles in the 2.4% Au – 2.4% Pd -0.2% Pt / TS-1 catalyst. The Au, Pd, and Pt maps and the ADF image are shown in panel (a). The corresponding sum spectra are shown in (b) and (c) for the highlighted particle, indicating the presence of Au, Pd and Pt in the particles.

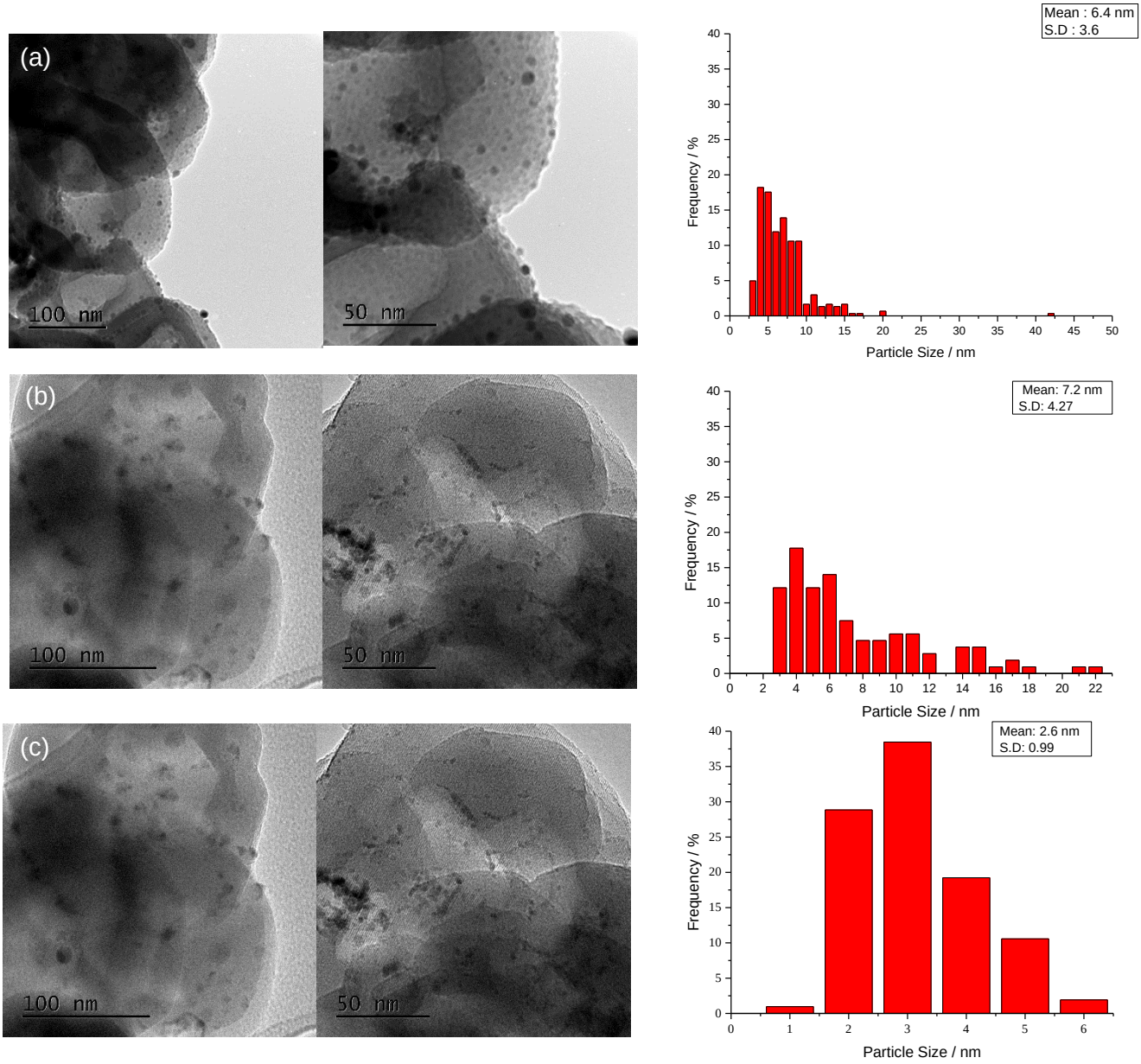


**Figure S.9.** Transmission electron microscopy of 5% AuPdPt / TS-1, varying Pt content, catalysts prepared by wet impregnation, calcined at 400 °C, 3 h, static air, ramp rate = 20 °C $min^{-1}$. (a) 2.5% Au – 2.5% Pd / TS-1, (b) 2.4% Au – 2.4% Pd – 0.2% Pt / TS-1, (c) 2% Au – 2% Pd – 1% Pt / TS-1.

**Table S.3.** Total amount of Au, Pd and Pt metal lost from 2.4% Au – 2.4% Pd – 0.2% Pt / TS-1 catalyst over multiple uses.

| Use number | Productivity / $mol_{H2O2}kg_{cat}^{-1}h^{-1}$ | Au Leaching / % | Pd Leaching / % | Pt Leaching /% |
|---|---|---|---|---|
| 1 | 167 | 0 | 2.6 | 1.9 |
| 2 | 158 | 0 | 0 | 0.2 |
| 3 | 156 | 0 | 0 | 0 |