Electronic Supplementary Information

Material Characterizations

Transmission electron microscopy (TEM) and high-resolution TEM were performed on a TECNAI G2 20 S-Twin operated at 200 kV and TECNAI G2 F30 operated at 300 kV. X-ray diffraction (XRD) patterns were collected with a Rigaku Ultima III diffractometer system using a graphite-monochromatized Cu-Kα radiation at 40 kV and 40 mA.

Experimental Section

Preparation of thin Pt₃Ni nanorod (Figure 3a): A slurry of Pt(acac)₂ (0.06 mmol), Ni(acac)₂ (0.02 mmol), ethylene glycol (1.86 mmol) and octadecylamine (15 mmol) was prepared in a 15 mL two-neck round bottom flask with a magnetic stirring. After being evacuated for 120 min with stirring at 80 °C, the resulting solution was charged by CO gas, then heated up to 150 °C, and kept at that temperature for 120 min under CO gas. Finally, dark brown precipitates could be obtained by cooling down the solution to room temperature and then by centrifugation with added methanol / toluene (v / v = 15 mL / 15 mL).

\[
\text{Pt(acac)}_3 \quad \text{Ni(acac)}_2 \quad \text{Pt(acac)}_3 \quad \text{Ni(acac)}_2
\]

Preparation of short Pt₃Ni nanorod (Figure 2a): The method is similar to the preparation of thin Pt₃Ni nanorod, except for the evacuation time of 30 min and reaction temperature of 200 °C.

\[
\text{Pt(acac)}_3 \quad \text{Ni(acac)}_2 \quad \text{Pt(acac)}_3 \quad \text{Ni(acac)}_2
\]

Preparation of Pt₃Ni@Rh pentagon (Figure 2b, S1a, S4): Short Pt₃Ni nanorods (~ 1 mg) were dispersed in a mixture of Rh(acac)₃ (0.05 mmol), ethylene glycol (1.86 mmol), stearic acid (0.15 mmol), and octadecylamine (15 mmol) in a 100 mL Schlenk tube equipped with a bubbler with a magnetic stirring at 100 °C. After being evacuated for 10 min with stirring at 100 °C, the solution was heated up to 130 °C and kept at the same temperature for 10 h under Ar gas condition. The resulting solution was further heated at 180 °C for 10 h. Finally, dark brown precipitates could be obtained by cooling down the solution to room temperature and then by centrifugation with added methanol / toluene (v / v = 15 / 15 mL).
Preparation of Rh-Pt₃Ni-Rh barbell (Figure 3b): Thin Pt₃Ni nanorods (~ 2 mg) were dispersed in a mixture of Rh(acac)₃ (0.05 mmol), ethylene glycol (1.86 mmol), and octadecylamine (15 mmol) in a 15 mL two-neck round bottom flask with a bubbler by magnetic stirring at 100 °C. After being evacuated for 10 min with stirring at 100 °C, the solution was heated up to 130 °C and kept at the same temperature for 20 h under Ar gas condition. Finally, dark brown precipitates could be obtained by cooling down the solution to room temperature and then by centrifugation with added methanol / toluene (v / v = 15 / 15 mL).

Preparation of Pt₃Ni@Rh nanostar (Figure 2c): Pt₃Ni@Rh pentagons (~ 2 mg) were dispersed in a mixture of Rh(acac)₃ (0.05 mmol), 1,2-hexadecanediol (0.93 mmol), and octadecylamine (10 mmol) in a two-neck round bottom flask (15 mL) with a magnetic stirring at 80 °C. After being evacuated for 10 min with stirring at 80 °C, the resulting solution was heated up to 130 °C and kept at the same temperature for 14 h under Ar gas condition. Finally, dark brown precipitates could be obtained by cooling down the solution to room temperature and then by centrifugation with added methanol / toluene (v / v = 15 / 15 mL).
Preparation of nanopaddlewheel (Figure 3c): The method is similar to the preparation of Pt$_3$Ni@Rh-Rh star, except that Rh-Pt$_3$Ni-Rh barbell (2 mg) was used as seed.
**Fig. S1.** (a) HRTEM of a Pt$_3$Ni@Rh pentagon. The blue lines denote twinning boundaries. FFT images of (b) area in the blue rectangle and (c) area in the red pentagon.
Fig. S2. a) TEM image of Pt$_3$Ni@Rh nanopentagons; b, c, d) The shapes of Pt$_3$Ni@Rh nanostars at the reaction time of 3 h, 5 h and 14 h.
Fig. S3. TEM images of Pt$_3$Ni@Rh nanostars prepared by using mass ratios of (a) 10/1 [Pt$_3$Ni@Rh pentagon/Rh(acac)$_3$] and of (b) 15/1 [Pt$_3$Ni@Rh pentagon/Rh(acac)$_3$].

Fig. S4. Additional HRTEM images of (a) Pt$_3$Ni@Rh pentagon and (b) Pt$_3$Ni@Rh nanostar (b). A small pentagon is visible at the center of Pt$_3$Ni@Rh nanostar.
Fig. S5. HRTEM images of (a) a nanopaddlewheel standing vertically and (b) a nanopaddlewheel lying down horizontally.

Fig. S6. Additional TEM image for nanopaddlewheels. Most of them are standing up.
Fig. S7. X-ray diffraction patterns: a) thin Pt$_3$Ni nanorod; b) Pt$_3$Ni@Rh nanopentagon; c) Pt$_3$Ni@Rh nanostar; d) Rh nanoparticles (JCPDS card no 001-1214).

Fig. S8. TEM image of a) Ir nanocrystallites grown on a Pt$_3$Ni nanorod at 220 °C. TEM images of Pd nanocrystallites grown on a Pt$_3$Ni nanorod at (b) 90 °C and (c) 200 °C. In the case of Pd phase formed at 200 °C, independently grown Pd nanocrystals are observed.
Fig. S9. NMR spectra of compound 5

$^1$H NMR (CDCl$_3$)

$^1$C NMR (CDCl$_3$)

Fig. S10. TEM of a) Pt$_3$Ni@Rh pentagon, b) Pt$_3$Ni@Rh-Rh nanostar, c) nanopaddlewheel nanostructures supported on carbon black after catalytic application for reduction of a phenyl ring of phthalimide. No discernable structural deformations are observed after the catalysis.

Fig. S11. Energy dispersive X-ray spectra and corresponding HAADF STEM images of a) Pt$_3$Ni@Rh pentagon, b) Pt$_3$Ni@Rh-Rh starfish, c) nanopaddlewheel. The Ni content could not be quantified due to the marginal amount under the detection limit.
Calculation of surface area/volume of Pt$_3$Ni@Rh pentagon.

Fig. S12. Model of Pt$_3$Ni@Rh pentagon.

In geometry, a pentagon (decahedron or pentagonal dipyramid) is a polyhedron with ten faces, 15 edges and 7 vertices, symmetry group (D$_{5h}$).

The regular pentagonal dipyramid has a base that is a regular pentagon and lateral faces that are equilateral triangles. Its height $h$, from the midpoint of the pentagonal face to the apex, (as a function of $a$, where $a$ is the side length), can be computed as:

$$h = \frac{\sqrt{5}-\sqrt{5}}{\sqrt{10}}a$$

Surface area of pentagon, $S$, can be computed as the area of ten times the area of one triangle:

$$S = 10 \frac{\sqrt{3}}{4}a^2 = \frac{5\sqrt{3}}{2}a^2$$

Its volume ($V$) when an edge length is known can be figured out with this formula:

$$V = \frac{5 + \sqrt{5}}{12}a^3$$

$m_{\text{pentagon}} = \rho_{\text{pentagon}} * V$

Where $\rho_{\text{pentagon}}$: densities of pentagon, which can computed by formula:

$$\frac{100}{\rho_{\text{pentagon}}} = \frac{x}{\rho_{\text{Ni}}} + \frac{y}{\rho_{\text{Rh}}} + \frac{z}{\rho_{\text{Pt}}}$$

$x$, $y$, $z$ and $\rho_{\text{Ni}}$, $\rho_{\text{Rh}}$, $\rho_{\text{Pt}}$ are % by weight and densities of Ni, Rh, and Pt, respectively

**Apply for Pt$_3$Ni@Rh pentagon:** (standard deviations measured from 50 NPs)

$$a = 7.94 \pm 0.43 \text{ nm}$$

$$S_{\text{Pt$_3$Ni@Rh pentagon}} = \frac{5\sqrt{3}}{2}(7.94)^2 \approx 272.99 \text{ (nm$^2$)}$$

$$V_{\text{Pt$_3$Ni@Rh pentagon}} = \frac{5 + \sqrt{5}}{12}(7.94)^3 \approx 301.84 \text{ (nm$^3$)}$$
The energy dispersive X-ray spectroscopy (EDAX) analysis of Pt₃Ni@Rh pentagon nanostructures showed the % weight of Ni, Rh and Pt: ~ 0 %, 61.676 % and 38.323 % (Figure S9a). Density of Ni, Rh and Pt: 8.90*10⁻²¹ g.nm⁻³, 12.41*10⁻²¹ g.nm⁻³, 21.45*10⁻²¹ g.nm⁻³

$$\rho_{Pt_3Ni@Rh\ pentagon} \approx 14.80 \times 10^{-21} \text{ g.nm}^{-3}$$

$$m_{Pt_3Ni@Rh\ pentagon} = 14.80 \times 10^{-21} \times 301.84 \approx 4467.23 \times 10^{-21} g$$

$$\frac{\text{surface area}}{\text{weight}} = \frac{272.99 \text{ nm}^2}{4467.23 \times 10^{-21} g} \approx 6.11 \times 10^{19} \left(\frac{\text{nm}^2}{g}\right) \approx 61.1 \left(\frac{\text{m}^2}{g}\right)$$

$$\frac{\text{surface area}}{\text{volume}} = \frac{272.99 \text{ nm}^2}{301.84 \text{ nm}^3} \approx 0.90 \left(\frac{1}{\text{nm}}\right)$$

**Calculation of surface area/volume of Pt₃Ni@Rh-Rh star shape.**

**Fig. S13.** Model of a) Pt₃Ni@Rh star shape (Only one arm is shown for clarity. But for calculation, all five arms are considered.), b) projection of starshape on ABCDE plane.
With star shape, surface area has two parts: 1) area of pentagon part with five corners cut by arms and 2) area of five arms (For simplicity, only one arm is shown in Fig. S10.).

For pentagon part: Surface area can be computed as the area of ten times the area of one truncated triangle. Area of truncated triangle can be computed by formula.

\[ S_{\text{truncated triangle}} = S_{\text{ABO}} - 2*S_{\text{GBJ}} \rightarrow S_{\text{pentagon part}} = 10(S_{\text{ABO}} - 2*S_{\text{GBJ}}) \]

\[ ABO \text{ is equilateral triangles with } a \text{ as the given side length: } AB = AO = BO = a \rightarrow S_{\text{ABO}} = \frac{\sqrt{3}}{4}a^2 \]

\[ GBJ \text{ is also equilateral triangles with } a_1 \text{ as the given side length, } BG = JG = BJ = a_1 \]

\[ \frac{a_1}{a} = \frac{BG}{BA} \rightarrow \frac{GI}{AC} = \frac{a_1}{a} \]

\[ ABCDE \text{ is pentagon } \rightarrow AC = 2*AB*sin(0.3\pi) = 2*a*sin(0.3\pi) \]

\[ \rightarrow a_1 = \frac{GI * sin(0.3\pi)}{2} \rightarrow S_{\text{GBJ}} = \frac{\sqrt{3}}{4}a_1^2 = \frac{\sqrt{3}}{4}\left(GI * sin(0.3\pi)\right)^2 \]

For arm part: arm is right prism GHIJG\(_1\),H\(_1\)I\(_1\)J\(_1\) with tetrahedronal base have side length \(a_1 = GJ\), the height \(l = GG_1\) and pyramid QG\(_1\),H\(_1\)I\(_1\)J\(_1\) (Fig. S9).

\[ S_{\text{arm}} = S_{\text{GHIJG}_1,H_1I_1J_1} + S_{\text{QG}_1,H_1I_1J_1} \]

\[ S_{\text{GHIJG}_1,H_1I_1J_1} = GG_1(GJ + JI + IH + GH) = 4G_1 * GJ = 4G_1 * a_1 \]

\[ S_{\text{QG}_1,H_1I_1J_1} = S_{\text{QG}_1,H_1I_1} + S_{\text{QG}_1,J_1I_1} + S_{\text{QG}_1,I_1J_1} = 4S_{\text{QG}_1,H_1} \]

\[ S_{\text{star}} = S_{\text{pentagon part}} + 5* S_{\text{arm}} = 10(S_{\text{ABO}} - 2*S_{\text{GBJ}}) + 5(4G_1 * a_1 + 4 S_{\text{QG}_1,H_1}) \]

Other hand: \( S_{\text{GBJ}} = S_{\text{QG}_1,H_1} \)

\[ S_{\text{star}} = 10S_{\text{ABO}} + 20G_1 * a_1 = S_{\text{pentagon}} + 20G_1 * a_1 = \frac{5\sqrt{3}}{2}a^2 + 10G_1 * GI * sin(0.3\pi) \]

Same method for volume:

\[ V_{\text{star}} = V_{\text{pentagon}} + 5 * V_{\text{arm}} = V_{\text{pentagon}} + 5 * V_{\text{GHIJG}_1,H_1I_1J_1} \]

\[ V_{\text{pentagon}} = \frac{5 + \sqrt{5}}{12}a^3 = \frac{5 + \sqrt{5}}{12}AB^3 \]

\[ V_{\text{GHIJG}_1,H_1I_1J_1} = G_1 * S_{\text{GHIJ}} = G_1 * \left(\frac{1}{2} * GI * JH\right) \]

\[ \frac{JH}{OO'} = \frac{BJ}{BO} = \frac{GI}{AC} \rightarrow JH = OO \cdot \frac{GI}{AC} = \frac{5 - \sqrt{5}}{10}a \cdot \frac{GI}{2 \sin(0.3\pi)} = \frac{5 - \sqrt{5}}{10} \cdot \frac{GI}{2 \sin(0.3\pi)} \]
\[ V_{GHJG_1I_1J_1} = GG_1 \cdot \left( \frac{1}{2} \cdot GL \cdot \sqrt{\frac{5 - \sqrt{5}}{10} \cdot GL} \right) = \frac{5 - \sqrt{5}}{10} \cdot \frac{GL^2GG_1}{4\sin (0.3\pi)} \]

\[ V_{\text{star}} = \frac{5 + \sqrt{5}}{12} \cdot AB^3 + 5 \cdot \frac{5 - \sqrt{5}}{10} \cdot \frac{GL^2GG_1}{4\sin (0.3\pi)} \]

**Apply for Pt\textsubscript{3}Ni@Rh-Rh star**: (standard deviations measured from 50 NPs)

\[ \bar{AB} = a = 9.96 \pm 0.97 \text{ nm}; \bar{GI} = 5.16 \pm 0.26 \text{ nm}; \bar{GI}_1 = 13.66 \pm 1.33 \text{ nm}; \]

\[ S_{Pt_3Ni@Rh - Rh \text{ star}} \approx 999.80 \text{ (nm}^2) \]

\[ V_{Pt_3Ni@Rh - Rh \text{ star}} \approx 891.24 \text{ (nm}^3) \]

The energy dispersive X-ray spectroscopy (EDAX) analysis of Pt\textsubscript{3}Ni@Rh-Rh star nanostructures showed the % weight of Ni, Rh and Pt: ~ 0 %, 75.351 % and 24.648 % (Figure S9b). Density of Ni, Rh and Pt: \(8.90 \times 10^{-21} \text{ g.nm}^{-3}\), \(12.41 \times 10^{-21} \text{ g.nm}^{-3}\), \(21.45 \times 10^{-21} \text{ g.nm}^{-3}\)

\[ \rho_{Pt_3Ni@Rh \text{ pentagon}} \approx 13.85 \times 10^{-21} \text{ g.nm}^{-3} \]

\[ m_{Pt_3Ni@Rh \text{ pentagon}} = 13.85 \times 10^{-21} \times 891.24 \approx 12342.48 \times 10^{-21} \text{ g} \]

\[ \frac{\text{surface area}}{\text{weight}} = \frac{999.80 \text{ nm}^2}{12342.48 \times 10^{-21} \text{ g}} \approx 8.10 \times 10^{19} \left( \frac{\text{nm}^2}{\text{g}} \right) \approx 81.0 \left( \frac{\text{m}^2}{\text{g}} \right) \]

\[ \frac{\text{surface area}}{\text{volume}} = \frac{999.80 \text{ nm}^2}{891.24 \text{ nm}^3} \approx 1.12 \left( \frac{1}{\text{nm}} \right) \]

**Calculation of surface area/volume of paddlewheel.**
Fig. S14. Model of a) nanopaddlewheel (Only one arm is shown for clarity. But for calculation, all five arms are considered.), b) a five-fold twinned Pt$_3$Ni@Rh nanorod part, and c) one tip without arm.

**Paddlewheel has two structural components: rod part and stars at the tips**

**Rod part** is right prism with pentagon base have side length \( t \) and \( h = EE_1 \) is the height (Fig. S11b).

\[ \frac{(n-2)\pi}{n} = \frac{(5-2)\pi}{5} = 0.6\pi \]

where \( n \): number sided regular polygons; angle \( \hat{EQI} = 0.3\ \pi \)

we can get \( EF \) from TEM image (see maximum length on the TEM image and see Fig. S11b).

\[ t = \frac{EI}{\sin \hat{EQI}} = \frac{EF}{2\sin(0.3\pi)} \]

\( \rightarrow \) the surface area of rod part is lateral area of prism:

\[ S_{rod\ part} = n.t.h = 5.\frac{EF}{2\sin(0.3\pi)}EE_1 \]

\[ V_{rod\ part} = \frac{n.h.t^2}{4\tan \frac{\pi}{n}} = \frac{5.EE_1}{4\tan \frac{0.2\pi}{n}}\left( \frac{EF}{2\sin 0.3\pi} \right)^2 \]

**Star at tip has 3 parts:** one part is shaped as pyramid and other are frustum and five arms (see Fig. S11).

Same method for calculation of a star shape.

**Lateral surface area of star at tip = Lateral surface area of pentagon pyramid ABZYDX + Lateral surface area of frustum BZYDXEZ,FD,XI + 5*Lateral surface area of GHIJG,H,J,I,J**

**Volume of star at tip = Volume of pentagon pyramid ABZYDX + Volume of frustum BZYDXEZ,FD,XI + 5*Volume of GHIJG,H,J,I,J**

For pentagon pyramid ABZYDX

Pyramid is pentagonal with base side length \( t_1 = \frac{BD}{2\sin(0.3\pi)} \) and slant height AC
\[ AC = \sqrt{l^2 + r_1^2} \]

Where \( l \) is the pyramid altitude, \( l = AO \), \( r_1 \) is the radius of the base.

\[
r_1 = \frac{t_1}{2 \sin \frac{\pi}{n}} = \frac{BD}{4 \sin \frac{\pi}{n} \sin(0.3\pi)} \quad \Rightarrow \quad AC = \sqrt{AO^2 + \frac{BD^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

→ lateral surface area of pyramid part:

\[
S_{ABZYDX} = \frac{n}{2} t_1 AC = 5. \frac{BD}{4 \sin(0.3\pi)} \sqrt{AO^2 + \frac{BD^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

\[
V_{ABZYDX} = \frac{n}{12} l t_1^2 \frac{\pi}{n} = \frac{5}{12} AO \left( \frac{BD}{2 \sin(0.3\pi)} \right)^2 \cot \frac{\pi}{5} = \frac{5 \cot(0.2\pi)}{48(\sin(0.3\pi))^2} AO \times BD^2
\]

For frustum BZYDXEZ \_FD\_X_t:

Frustum part is the portion of a pyramid that lies between two parallel planes cutting it. Bases of frustum are pentagon with side \( t \) and \( t_1 \) (\( t_1 > t \)).

**Lateral surface area of frustum is lateral surface area of big pyramid** (apex is \( A' \) and base is pentagon containing the point BDC, center O) **subtraction lateral surface area of small pyramid** (apex is \( A' \) and base is pentagon containing the point EFC', center P).

**lateral surface area of big pyramid**

\[
5. \frac{BD}{4 \sin(0.3\pi)} \sqrt{AO^2 + \frac{BD^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

Same method for calculation of pyramid part.

\[
\Rightarrow \text{lateral surface area of small pyramid}
\]

\[
= \frac{t A' C'}{2} = 5. \frac{EF}{4 \sin(0.3\pi)} \sqrt{A' P^2 + \frac{EF^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

where \( A' P = A' O - OP = AO - OP \)

\[
\Rightarrow \text{lateral surface area of small pyramid}
\]

\[
= 5. \frac{EF}{4 \sin(0.3\pi)} \sqrt{(AO - OP)^2 + \frac{EF^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

\[
\Rightarrow \text{lateral surface area of frustum part:}
\]

\[
S_{BZYDXEZ_{FD_X}} = 5. \frac{BD}{4 \sin(0.3\pi)} \sqrt{AO^2 + \frac{BD^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}} - EF \sqrt{(AO - OP)^2 + \frac{EF^2}{(4 \sin(0.2\pi) \sin(0.3\pi))^2}}
\]

\[
\frac{A' P}{AO} = \frac{A'E}{BD} \Rightarrow A' P = \frac{EF}{BD} A' O = \frac{EF}{BD} AO - OP = AO - \frac{EF}{BD} AO
\]
Volume of frustum BZYDXEZ\(,\)\(FD, \)\(X_1\) is volume of big pyramid (apex is \(A'\) and base is pentagon containing the point BDC, center O) subtraction volume of small pyramid (apex is \(A'\) and base is pentagon containing the point EFC’, center P).

\[
V_{BZYDXEZ, FD, x_1} = \frac{5}{12}AO \left( \frac{BD}{2\sin(0.3\pi)} \right)^2 \cot(0.2\pi) - \frac{5}{12}AP \left( \frac{EF}{2\sin(0.3\pi)} \right)^2 \cot(0.2\pi) = \frac{5\cot(0.2\pi)}{48(\sin(0.3\pi))}.
\]

→ Lateral surface area of one tip can be computed as:

\[
S_{\text{tip}} = S_{ABZYDX} + S_{BZYDXEZFD, x_1} + 5 \times S_{GHIJG_1} + 11 = \frac{5}{4\sin(0.3\pi)} \left( \frac{2BD}{AO} \right)^2 + \frac{5}{4\sin(0.3\pi)} \left( \frac{BD^2}{(4\sin(0.2\pi))} \right).
\]

Total surface area of paddlewheel:

\[
S_{\text{PW}} = S_{\text{rod part}} + 2 \times S_{\text{tip}} = \frac{EF}{2\sin(0.3\pi)} EE_1 + \frac{5}{2\sin(0.3\pi)} \left( \frac{2BD}{AO} \right)^2 + \frac{5}{2\sin(0.3\pi)} \left( \frac{BD^2}{(4\sin(0.2\pi))} \right).
\]

Volume of paddlewheel = Volume of rod part + 2*Volume of star on the tip

\[
V_{\text{PW}} = V_{ABZYDX} + V_{BZYDXEZFD, x_1} + 5 \times V_{GHIJG_1} + 11 = \frac{5\cot(0.2\pi)}{48(\sin(0.3\pi))} \left( \frac{AO}{BD^2} \right)^2 + \frac{5\cot(0.2\pi)}{48(\sin(0.3\pi))} \left( \frac{2AO}{(4\sin(0.3\pi))} \right)^2.
\]

Apply for nanopaddlewheel: (standard deviations measured from 50 NPs)

\(\overline{BD} = a = 5.85 \pm 0.32 \text{ nm}; \overline{GI} = 5.42 \pm 0.24 \text{ nm}; \overline{GG_1} = 11.46 \pm 1.12 \text{ nm};\)

\(\overline{EF} = 3.76 \pm 0.27 \text{ nm}; \overline{EE_1} = 21.44 \pm 1.97 \text{ nm};\)

\(\overline{AO} = h = \frac{5 - \sqrt{5}}{10}a \approx 3.08 \text{ nm}\)

\(\overline{BD} = 2a \times \sin(0.3\pi) \approx 9.47 \text{ (nm)}\)

\(\overline{OP} = AO - \frac{EF}{BD}AO \approx 1.96 \text{ (nm)}\)

\(S_{\text{PW}} \approx 1570.37 \text{ (nm}^2)\)
The energy dispersive X-ray spectroscopy (EDAX) analysis of paddlewheel nanostructures showed that % weight of Ni, Rh and Pt are ~ 0 %, 65.164 % and 34.835 % (Figure S9c).

density of Ni, Rh and Pt: \(8.90 \times 10^{-21} \text{ g.nm}^{-3}\), \(12.41 \times 10^{-21} \text{ g.nm}^{-3}\), \(21.45 \times 10^{-21} \text{ g.nm}^{-3}\)

\[
\rho_{Pt_3Ni@Rh_pentagon} \approx 14.55 \times 10^{-21} \text{ g.nm}^{-3}
\]

\[
m_{Pt_3Ni@Rh_pentagon} = 14.55 \times 10^{-21} \times 938.96 \approx 13661.87 \times 10^{-21} \text{ g}
\]

\[
\frac{\text{surface area}}{\text{weight}} = \frac{1570.37 \text{ nm}^2}{13661.87 \times 10^{-21} \text{ g}} \approx 11.49 \times 10^{19} \left(\frac{\text{nm}^2}{\text{g}}\right) \approx 114.90 \left(\frac{\text{m}^2}{\text{g}}\right)
\]

\[
\frac{\text{surface area}}{\text{volume}} = \frac{1570.37 \text{ nm}^2}{938.96 \text{ nm}^3} \approx 1.67 \left(\frac{1}{\text{nm}}\right)
\]

\[
V_{PW} \approx 938.96 (\text{nm}^3)
\]