CLAIMS:

1. A method of leaching about 40% or more, or about 50% or more of palladium from a spent catalyst comprising palladium in about 20 min or less, the method comprising contacting the spent catalyst with a leach mixture comprising:

an metal iodide ligand source,
an inorganic oxidizing agent,
an acid catalyst,
an optional stabilizer, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach the palladium from the spent catalyst;
leaching the palladium from the spent catalyst; and
forming a leach solution comprising leached palladium.

2. A method of leaching palladium from a spent catalyst comprising palladium at a leaching rate about an order of magnitude faster than aqua regia, the method comprising contacting the spent catalyst with a leach mixture comprising:

an metal iodide ligand source,
an inorganic oxidizing agent,
an acid catalyst,
an optional stabilizer, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach the palladium from the spent catalyst;
leaching the palladium from the spent catalyst; and
forming a leach solution comprising leached palladium.

3. The method of claim 1 or 2, wherein:

the metal iodide ligand source NaI, KI, or a combination thereof, wherein the metal iodide ligand source optionally has a concentration of about 0.1 M to about 0.5 M, 0.1 to about 0.4 M, or about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M in the acetic acid solvent;

the inorganic oxidizing agent comprises O_2, bubbled air, I_2, H_2O_2, $CuCl_2$, or a combination thereof, wherein the inorganic oxidizing agent optionally has a concentration of from about 0.01 M to about 0.1 M in the acetic acid solvent, preferably a concentration from about 0.01 to about 0.05 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.5 M;

the carboxylic acid stabilizer comprises citric acid, acetic acid, or a combination thereof, wherein carboxylic acid stabilizer optionally has a concentration of from about 0.1 M to about 1

M in the acetic acid solvent, preferably a concentration from about 0.1 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach the palladium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 20 min, at a temperature of about 20 °C to about 30 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 15 min, or about 1 min to about 10 min, or about 1 min to about 8 min, or about 1 min to about 5 min; and the temperature is about 20 °C to about 25 °C and optionally the conditions to leach the palladium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach the palladium are tolerant of up to about 10 wt% water.

4. The method of any one of claims 1 to 3, wherein the spent catalyst further comprises oxidized palladium, and the method further comprises contacting the spent catalyst with a reductant under conditions to at least partially reduce the oxidized palladium; and at least partially reducing the oxidized palladium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium of the spent catalyst comprises a contaminant, the method further comprising contacting the spent catalyst with a chelating agent under conditions to at least partially remove the contaminant, and at least partially decontaminating the palladium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof, and/or

the conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

5. The method of any one of claims 1 to 4, wherein the method leaches about 40% to about 100%, or about 50% to about 99.9%, or about 60% to about 99.9%, or about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9% of the palladium in the spent catalyst.

6. The method of any one of claims 1 to 5, further comprising:

adding an oxidant and a polyatomic salt to the leach solution under conditions to precipitate the leached palladium, and precipitating the leached palladium;

wherein preferably

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof, and/or

the conditions to precipitate the leached palladium comprise contacting the leach solution with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the method optionally further comprising

contacting the leached palladium with a reducing agent under conditions to reduce the leached palladium to palladium metal, and reducing the leached palladium to palladium metal, wherein

contacting the leached palladium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium to palladium metal optionally comprises contacting the leached palladium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the method optionally further comprising

contacting the palladium metal with a refining mixture under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

the palladium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

7. The method of any one of claims 1 to 6, wherein the spent catalyst:

further comprises platinum and/or rhodium, and the method selectively leaches the palladium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit form.

8. Use of a leach mixture for leaching about 40% or more, or about 50% or more of palladium from a spent catalyst comprising palladium in about 20 min or less, under conditions to leach the palladium from the spent catalyst, and form a leach solution comprising leached palladium, the leach mixture comprising:

an metal iodide ligand source,
an inorganic oxidizing agent,
an acid catalyst,
an optional stabilizer, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid.

9. Use of a leach mixture for leaching palladium from a spent catalyst comprising palladium at a leaching rate about an order of magnitude faster than aqua regia, under conditions to leach the palladium from the spent catalyst, and form a leach solution comprising leached palladium, the leach mixture comprising:

an metal iodide ligand source,
an inorganic oxidizing agent,
an acid catalyst,
an optional stabilizer, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid.

10. The use of claim 8 or 9, wherein:

the metal iodide ligand source NaI, KI, or a combination thereof, wherein the metal iodide ligand source optionally has a concentration of about 0.1 M to about 0.5 M, 0.1 to about 0.4 M, or about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M in the acetic acid solvent;

the inorganic oxidizing agent comprises O_2, bubbled air, I_2, H_2O_2, $CuCl_2$, or a combination thereof, wherein the inorganic oxidizing agent optionally has a concentration of from about 0.01 M to about 0.1 M in the acetic acid solvent, preferably a concentration from about 0.01 to about 0.05 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.5 M;

the carboxylic acid stabilizer comprises citric acid, acetic acid, or a combination thereof, preferably citric acid, wherein carboxylic acid stabilizer optionally has a concentration of from about 0.1 M to about 1 M in the acetic acid solvent, preferably a concentration from about 0.1 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach the palladium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 20 min, at a temperature of about 20 °C to about 30 °C, under ambient pressure; wherein preferably, the

time is about 1 min to about 15 min, or about 1 min to about 10 min, or about 1 min to about 8 min, or about 1 min to about 5 min; and the temperature is about 20 °C to about 25 °C,

and optionally the conditions to leach the palladium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach the palladium are tolerant of up to about 10 wt% water.

11. The use of any one of claims 8 to 10, wherein the spent catalyst further comprises oxidized palladium, and the use further comprises use of a reductant for contacting the spent catalyst under conditions to at least partially reduce the oxidized palladium; and at least partially reducing the oxidized palladium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium of the spent catalyst comprises a contaminant, the use further comprising use of a chelating agent for contacting the spent catalyst under conditions to at least partially remove the contaminant; and at least partially decontaminating the palladium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof, and/or

the conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

12. The use of any one of claims 8 to 11, wherein the leach mixture leaches about 40% to about 100%, or about 50% to about 99.9%, or about 60% to about 99.9%, or about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9% of the palladium in the spent catalyst.

13. The use of any one of claims 8 to 12, further comprising:

use of an oxidant and a polyatomic salt for precipitating the leached palladium by adding the oxidant and polyatomic salt to the leach solution under conditions to precipitate the leached palladium; and precipitating the leached palladium;

wherein preferably,

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof, and/or

the conditions to precipitate the leached palladium comprise contacting the spent catalyst with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the use optionally further comprising

use of a reducing agent for reducing the leached palladium to palladium metal by contacting the leached palladium with a reducing agent under conditions to reduce the leached palladium to palladium metal, and reducing the leached palladium to palladium metal, wherein

contacting the leached palladium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium to palladium metal optionally comprises contacting the leached palladium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the use optionally further comprising

use of a refining mixture for refining the palladium metal under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

the palladium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

14. The use of any one of claims 8 to 13, wherein the spent catalyst:

further comprises platinum and/or rhodium, and the leach mixture selectively leaches the palladium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit form.

15. A process of recycling palladium from a spent catalyst comprising palladium, the process comprising:

contacting the spent catalyst with a leach mixture comprising
an metal iodide ligand source,
an inorganic oxidizing agent,
an acid catalyst,
an optional stabilizer, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach the palladium from the spent catalyst comprising palladium;

leaching about 40% or more, or about 50% or more of the palladium from the spent catalyst in about 20 min or less to form a leach solution comprising leached palladium and a leached spent catalyst; and

separating the leach solution from the leached spent catalyst; and

treating the leach solution comprising leached palladium under conditions to form palladium metal.

16. A process of recycling palladium from a spent catalyst comprising palladium, the process comprising:

contacting the spent catalyst with a leach mixture comprising

an metal iodide ligand source,

an inorganic oxidizing agent,

an acid catalyst,

an optional stabilizer, and

acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach the palladium from the spent catalyst comprising palladium;

leaching the palladium from the spent catalyst at a leaching rate of about an order or magnitude faster than aqua regia to form a leach solution comprising leached palladium and a leached spent catalyst; and

separating the leach solution from the leached spent catalyst; and

treating the leach solution comprising leached palladium under conditions to form palladium metal.

17. The process of claim 15 or 16, wherein:

the metal iodide ligand source NaI, KI, or a combination thereof, wherein the metal iodide ligand source optionally has a concentration of about 0.1 M to about 0.5 M, 0.1 to about 0.4 M, or about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M in the acetic acid solvent;

the inorganic oxidizing agent comprises O_2, bubbled air, I_2, H_2O_2, $CuCl_2$, or a combination thereof, wherein the inorganic oxidizing agent optionally has a concentration of from about 0.01 M to about 0.1 M in the acetic acid solvent, preferably a concentration from about 0.01 to about 0.05 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.5 M;

the carboxylic acid stabilizer comprises citric acid, acetic acid, or a combination thereof; preferably citric acid, wherein carboxylic acid stabilizer optionally has a concentration of from about 0.1 M to about 1 M in the acetic acid solvent, preferably a concentration from about 0.1 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach the palladium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 20 min, at a temperature of about 20 °C to about 30 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 15 min, or about 1 min to about 10 min, or about 1 min to about 8 min, or about 1 min to about 5 min; and the temperature is about 20 °C to about 25 °C, and optionally the conditions to leach the palladium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach the palladium are tolerant of up to about 10 wt% water.

18. The process of any one of claims 15 to 17, wherein the spent catalyst further comprises oxidized palladium, and the process further comprises contacting the spent catalyst with a reductant under conditions to at least partially reduce the oxidized palladium; and at least partially reducing the oxidized palladium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium of the spent catalyst comprises a contaminant, the process further comprising contacting the spent catalyst with a chelating agent under conditions to at least partially remove the contaminant; and at least partially decontaminating the palladium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof, and/or

the conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

19. The process of any one of claims 15 to 18, wherein the process selectively leaches about 40% to about 100%, or about 50% to about 99.9%, or about 60% to about 99.9%, or

about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9% of the palladium in the spent catalyst.

20. The process of any one of claims 15 to 19, further comprising:

adding an oxidant and a polyatomic salt to the leach solution under conditions to precipitate the leached palladium, and precipitating the leached palladium;

wherein preferably

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof, and/or

the conditions to precipitate the leached palladium comprise contacting the spent catalyst with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the process optionally further comprising

contacting the leached palladium with a reducing agent under conditions to reduce the leached palladium to palladium metal; and reducing the leached palladium to palladium metal, wherein

contacting the leached palladium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium to palladium metal optionally comprises contacting the leached palladium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the process optionally further comprising

contacting the palladium metal with a refining mixture under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

the palladium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

21. The process of any one of claims 15 to 20, wherein the spent catalyst:

further comprises platinum and/or rhodium, and the process selectively leaches the palladium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit form.

22. A method of leaching about 40% or more, or about 50% or more of at least two of palladium, platinum, and rhodium from a spent catalyst in about 30 min or less, the method comprising: contacting the spent catalyst with a leach mixture comprising

an metal chloride ligand source,
an inorganic oxidizing agent,
an acid catalyst, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst;

leaching of at least two of the palladium, platinum, and rhodium from the spent catalyst; and

forming a leach solution comprising at least two of leached palladium, platinum, and rhodium.

23. A method of leaching at least two of palladium, platinum, and rhodium from a spent catalyst at a leaching rate at least 1 time, or at least 5 times, or at least 15 times, or at least 20 times faster than aqua regia, the method comprising:

contacting the spent catalyst with a leach mixture comprising

an metal chloride ligand source,

an inorganic oxidizing agent,

an acid catalyst, and

acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst;

leaching at least two of the palladium, platinum, and rhodium from the spent catalyst; and

forming a leach solution comprising at least two of leached palladium, platinum, and rhodium.

24. The method of claim 22 or 23, wherein:

the chloride ligand source comprises $CaCl_2$, HCl, or a combination thereof, wherein the chloride ligand source optionally has a concentration of about 0.1 M to about 0.5 M, or about 0.1 to about 0.4 M, or from about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M, in the acetic acid solvent;

the oxidizing agent comprises MnO_2, $FeCl_3$, $CuCl_2$, H_2O_2, HNO_3, or a combination thereof, wherein the oxidizing agent optionally has a concentration of from about 0.01 M to about 0.2 M in the acetic acid solvent, preferably between about 0.01 to about 0.1 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.2 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach at least two of palladium, platinum, and rhodium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 25 min, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 20 min, or about 1 min to about 15 min, about 1 min to about 10 min, about 1 min to about 5 min; and the temperature is about 80 °C to about 90 °Cand optionally the conditions to leach at least two of palladium, platinum, and

rhodium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach at least two of palladium, platinum, and rhodium are tolerant of up to about 10 wt% water, or between about 10 wt% to less than 50 wt% water, such as 30 wt% water.

25. The method of any one of claims 22 to 24, wherein the spent catalyst comprises oxidized palladium, platinum, and/or rhodium, and the method further comprises contacting the spent catalyst with a reductant under conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium; and at least partially reducing the oxidized palladium, platinum, and/or rhodium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium, platinum, and/or rhodium of the spent catalyst comprise a contaminant, the method further comprising contacting the spent catalyst with a chelating agent under conditions to at least partially remove the contaminant; and at least partially decontaminating the palladium, platinum, and/or rhodium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof; and/or

the conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

26. The method of any one of claims 22 to 25, wherein the method leaches about 40% to about 99.9%, or about 50% to about 99.9%, or about 60% to about 99.9%, or about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9% of at least one of

the palladium, platinum, and rhodium in the spent catalyst, preferably at least two of the palladium, platinum, and rhodium.

27. The method of any one of claims 22 to 26, further comprising:

adding an oxidant and a polyatomic salt to the leach solution under conditions to precipitate the leached palladium, platinum, and/or rhodium; and precipitating the leached palladium, platinum, and/or rhodium;

wherein preferably

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof, and/or

the conditions to precipitate the leached palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the method optionally further comprising

contacting the leached palladium, platinum, and/or rhodium with a reducing agent under conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal; and reducing the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal, wherein

contacting the leached palladium, platinum, and/or rhodium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, platinum, and/or rhodium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal optionally comprises contacting the leached palladium, platinum, and/or rhodium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the method optionally further comprsing

contacting the palladium, platinum, and/or rhodium metal, wherein the palladium, platinum, and/or rhodium metal at least comprises palladium metal, with a refining mixture under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium, platinum, and/or rhodium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

at least one of the palladium, platinum, and/or rhodium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

28. The method of any one of claims 22 to 27, wherein the spent catalyst:

further comprises aluminium oxide, and the method selectively leaches the at least two of palladium, platinum, and rhodium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit or powder form.

29. Use of a leach mixture for leaching about 40% or more, or about 50% or more of at least two of palladium, platinum, and rhodium from a spent catalyst in about 30 min or less,

under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst and form a leach solution comprising at least two of leached palladium, platinum, and rhodium, the leach mixture comprising

an metal chloride ligand source,
an inorganic oxidizing agent,
an acid catalyst, and
acetic acid as a water-miscible organic solvent, preferably glacial acetic acid.

30. Use of a leach mixture for leaching at least two of palladium, platinum, and rhodium from a spent catalyst at a leaching rate at least 1 time, or at least 5 times, or at least 15 times, or at least 20 times faster than aqua regia, under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst and form a leach solution comprising at least two of leached palladium, platinum, and rhodium, the leach mixture comprising

an metal chloride ligand source,
an inorganic oxidizing agent,
an acid catalyst, and
acid as a water-miscible organic solvent, preferably glacial acetic acid.

31. The use of claim 29 or 30, wherein:

the chloride ligand source comprises $CaCl_2$, HCl, or a combination thereof, wherein the chloride ligand source optionally has a concentration of about 0.1 M to about 0.5 M, or about 0.1 to about 0.4 M, or from about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M, in the acetic acid solvent;

the oxidizing agent comprises MnO_2, $FeCl_3$, $CuCl_2$, H_2O_2, HNO_3, or a combination thereof, wherein the oxidizing agent optionally has a concentration of from about 0.01 M to about 0.2 M in the acetic acid solvent, preferably between about 0.01 to about 0.1 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.2 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach at least two of palladium, platinum, and rhodium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 25 min, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 20 min, or about 1 min to about 15 min, about 1 min to about 10 min, about 1 min to about 5 min; and the temperature is about 80 °C to about 90 °Cand optionally the conditions to leach at least two of palladium, platinum, and rhodium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach at least two of palladium, platinum, and rhodium are tolerant of up to about 10 wt% water, or between about 10 wt% to less than 50 wt% water, such as 30 wt% water.

32. The use of any one of claims 29 to 31, wherein the spent catalyst comprises oxidized palladium, platinum, and/or rhodium, and the use further comprises use of a reductant for contacting the spent catalyst under conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium; and at least partially reducing the oxidized palladium, platinum, and/or rhodium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium, platinum, and/or rhodium of the spent catalyst comprise a contaminant, the use further comprising use of a chelating agent for contacting the spent catalyst under conditions to at least partially remove the contaminant, and at least partially decontaminating the palladium, platinum, and/or rhodium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof; preferably citric acid and/or salt thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof, and/or

the conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

33. The use of any one of claims 29 to 32, wherein the leach mixture leaches about 40% to about 99.9%, or about 50% to about 99.9%, or about 60% to about 99.9%, or about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9%, of at least one of the palladium, platinum, and rhodium in the spent catalyst, preferably at least two of the palladium, platinum, and rhodium.

34. The use of any one of claims 29 to 33, further comprising:

use of an oxidant and a polyatomic salt for precipitating the leached palladium, platinum, and/or rhodium by adding the oxidant and the polyatomic salt to the leach solution under conditions to precipitate the leached palladium, platinum, and/or rhodium, and precipitating the leached palladium, platinum, and/or rhodium;

wherein preferably

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof; and/or

the conditions to precipitate the leached palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the use optionally further comprising

contacting the leached palladium, platinum, and/or rhodium with a reducing agent under conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal; and reducing the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal, wherein

contacting the leached palladium, platinum, and/or rhodium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, platinum, and/or rhodium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal optionally comprises contacting the leached palladium, platinum, and/or rhodium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the use optionally further comprising

use of a refining mixture for refining the palladium metal of the palladium, platinum, and/or rhodium metal, wherein the palladium, platinum, and/or rhodium metal at least comprises palladium metal, under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium, platinum, and/or rhodium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

at least one of the palladium, platinum, and/or rhodium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

35. The use of any one of claims 29 to 34, wherein the spent catalyst:

further comprises aluminium oxide, and the leach mixture selectively leaches the at least two of palladium, platinum, and rhodium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit or powder form.

36. A process of recycling at least two of palladium, platinum, and rhodium from a spent catalyst, the process comprising:

contacting the spent catalyst with a leach mixture comprising

an metal chloride ligand source,

an inorganic oxidizing agent,

an acid catalyst, and

acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst;

leaching about 40% or more, or about 50% or more of at least two of the palladium, platinum, and rhodium from the spent catalyst in about 30 min or less to form a leach solution comprising leached palladium, platinum, and/or rhodium and a leached spent catalyst;

separating the leach solution from the leached spent catalyst; and

treating the leach solution comprising leached palladium, platinum, and/or rhodium under conditions to form palladium, platinum, and/or rhodium metal.

37. A process of recycling at least two of palladium, platinum, and rhodium from a spent catalyst, the process comprising:

contacting the spent catalyst with a leach mixture comprising

an metal chloride ligand source,

an inorganic oxidizing agent,

an acid catalyst, and

acetic acid as a water-miscible organic solvent, preferably glacial acetic acid,

under conditions to leach at least two of the palladium, platinum, and rhodium from the spent catalyst;

leaching at least two of the palladium, platinum, and rhodium from the spent catalyst at a leaching rate at least 1 time, or at least 5 times, or at least 15 times, or at least 20 times faster than aqua regia to form a leach solution comprising leached palladium, platinum, and/or rhodium and a leached spent catalyst;

separating the leach solution from the leached spent catalyst; and

treating the leach solution comprising leached palladium, platinum, and/or rhodium under conditions to form palladium, platinum, and/or rhodium metal.

38. The process of claim 36 or 37, wherein:

the chloride ligand source comprises $CaCl_2$, HCl, or a combination thereof, wherein the chloride ligand source optionally has a concentration of about 0.1 M to about 0.5 M, or about 0.1 to about 0.4 M, or from about 0.1 M to about 0.3 M, or about 0.1 to about 0.2 M, in the acetic acid solvent;

the oxidizing agent comprises MnO_2, $FeCl_3$, $CuCl_2$, H_2O_2, HNO_3, or a combination thereof, wherein the oxidizing agent optionally has a concentration of from about 0.01 M to about 0.2 M in the acetic acid solvent, preferably between about 0.01 to about 0.1 M;

the acid catalyst comprises a hydrogen halide, preferably HCl, wherein the acid catalyst optionally has a concentration of from about 0.01 M to about 1 M in the acetic acid solvent; or preferably has a concentration of from about 0.1 M to about 0.2 M;

the acetic acid as the water-miscible organic solvent makes up at least 50 wt% of the liquid phase of the leach mixture;

the conditions to leach at least two of palladium, platinum, and rhodium from the spent catalyst comprises contacting the spent catalyst with the leach mixture for a time of about 0.1 min to about 25 min, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 20 min, or about 1 min to about 15 min, about 1 min to about 10 min, about 1 min to about 5 min; and the temperature is about 80 °C to about 90 °C, and optionally the conditions to leach at least two of palladium, platinum, and rhodium further comprise contacting the spent catalyst with the leach mixture at a solid to liquid phase ratio of 1:10; and/or

the conditions to leach at least two of palladium, platinum, and rhodium are tolerant of up to about 10 wt% water, or between about 10 wt% to less than 50 wt% water, such as 30 wt% water.

39. The process of any one of claims 36 to 38, wherein the spent catalyst comprises oxidized palladium, platinum, and/or rhodium, and the process further comprises contacting the spent catalyst with a reductant under conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium; and at least partially reducing the oxidized palladium, platinum, and/or rhodium;

wherein preferably

the reductant comprises organic reductants, such as ascorbic acid, formic acid, oxalic acid, or salts thereof, or a combination thereof; inorganic reductants, such as H_2, $NaBH_4$, $FeCl_2$, hydrazine hydrochloride, hydroxylamine hydrochloride, or a combination thereof; or a combination thereof; and/or

the conditions to at least partially reduce the oxidized palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the reductant for a time of about 1 hour to about 6 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure;663 wherein preferably, the time is about 2 to 4 hours; and the temperature is about 70 °C to about 90 °C;

wherein optionally

the palladium, platinum, and/or rhodium of the spent catalyst comprise a contaminant, the process further comprising contacting the spent catalyst with a chelating agent under conditions to at least partially remove the contaminant; and at least partially decontaminating the palladium, platinum, and/or rhodium, wherein

the chelating agent optionally comprises citric acid, oxalic acid, or salts thereof, or a combination thereof,

the contaminant optionally comprises carbon deposits, hydrocarbons, sulfur-based compounds, phosphorous-based compounds, silicon-based compound, and metals such as Pb, Ca, Zn, Fe, Cu, Ni, or a combination thereof, and/or

The conditions to at least partially remove the contaminant optionally comprise contacting the spent catalyst with the chelating agent for a time of about 1 hour to about 12 hours, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 2 to 8 hours; and the temperature is about 70 °C to about 90 °C.

40. The process of any one of claims 36 to 39, wherein the process leaches about 40% to about 99.9%, or about 50% to about 99.9%, or about 60% to about 99.9%, or about 70% to about 99.9%, or about 80% to about 99.9%, or about 90% to about 99.9% of at least one of the palladium, platinum, and rhodium in the spent catalyst, preferably at least two of the palladium, platinum, and rhodium.

41. The process of any one of claims 36 to 40, further comprising:

adding an oxidant and a polyatomic salt to the leach solution under conditions to precipitate the leached palladium, platinum, and/or rhodium, and precipitating the leached palladium, platinum, and/or rhodium;

wherein preferably

the oxidant comprises H_2O_2, CaO_2, Cl_2, I_2, HNO_3, CaO_2, MnO_2, $NaIO_3$, $CuCl_2$, $FeCl_3$, $HClO_4$, $NaClO_2$, $NaClO_3$, NaClO, $K_2Cr_2O_7$, $KMnO_4$, $Ca(ClO)_2$, O_2 from air, or combinations thereof; preferably H_2O_2, CaO_2, $NaClO_2$, $NaClO_3$, NaClO, or combinations thereof,

the polyatomic salt comprises an ammonium salt, such as ammonium chloride, ammonium sulfate, ammonium nitrate, or combinations thereof, and/or

the conditions to precipitate the leached palladium, platinum, and/or rhodium comprise contacting the spent catalyst with the oxidant and polyatomic salt for a time of about 0.1 min to about 1 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 5 min; and the temperature is about 20 °C to about 25 °C;

the process optionally further comprising

contacting the leached palladium, platinum, and/or rhodium with a reducing agent under conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal; and reducing the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal, wherein

contacting the leached palladium, platinum, and/or rhodium with the reducing agent optionally comprises forming an aqueous mixture comprising the leached palladium, platinum, and/or rhodium, and adding the reducing agent to the aqueous mixture,

the reducing agent optionally comprises H_2, metal powder, metal strips, or a combination thereof, the metal comprising Al, Cu, Fe, Zn, or a combination thereof, and/or

the conditions to reduce the leached palladium, platinum, and/or rhodium to palladium, platinum, and/or rhodium metal optionally comprises contacting the leached palladium, platinum, and/or rhodium with the reducing agent for a time of about 0.1 min to about 2 hour, at a temperature of about 20 °C to about 90 °C, under ambient pressure; wherein preferably, the time is about 0.1 min to about 20 min; and the temperature is about 20 °C to about 25 °C; and

the process optionally further comprising

contacting the palladium, platinum, and/or rhodium metal with a refining mixture, wherein the palladium, platinum, and/or rhodium metal at least comprises palladium metal, under conditions to refine the palladium metal, the refining mixture comprising (i) an iodide ligand source, (ii) an oxidant, (iii) an optional acid catalyst, (iv) an optional carboxylic acid stabilizer, and acetic acid as a water-miscible organic solvent, preferably glacial acetic acid, wherein optionally

(i) the iodide ligand source comprises NaI, KI, HI, or a combination thereof, preferably at a concentration in the acetic acid solvent between about 0.1 M to about 4 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(ii) the oxidant comprises H_2O_2, I_2, $NaIO_3$, $FeCl_3$, O_2, $CuCl_2$, bubbled air, or a combination thereof, preferably at a concentration in the acetic acid solvent from about 0.01 to about 2.5 M, or about 0.1 M to about 2 M, or about 0.1 to about 1 M, or from about 0.1 M to about 0.5M, or about 0.1 to about 0.2 M;

(iii) the acid catalyst comprises a hydrogen halide, such as HCl or HI, sulfuric acid, or a combination thereof, preferably has a concentration in the acetic acid solvent of from about 0.1 M to about 4 M, or from about 0.1 M to about 2 M, or from about 0.1 M to about 1 M, or from about 0.1 M to about 0.5 M, or from about 0.1 M to about 0.2 M;

(iv) the carboxylic acid stabilizer comprises acetic acid, citric acid, or a combination thereof, preferably at a concentration in the acetic acid solvent of from about 0.1 M to about 2.5 M, or about 0.1 M to about 1 M, or about 0.2 M to about 0.8 M, or about 0.3 to about 0.7 M, or about 0.4 M to about 0.6 M;

the conditions to refine the palladium metal comprises contacting the palladium, platinum, and/or rhodium metal with the refining mixture for a time of about 0.1 min to about 18 hours, at a temperature of about 20 °C to about 120 °C, under ambient pressure; wherein preferably, the time is about 1 min to about 9 hours, or about 15 min to about 5 hours, or about 30 min to about 2 hours; and the temperature is about 20 °C to about 90 °C, or about 20 °C to about 50 °C, or about 20 °C to about 25 °C; and/or

at least one of the palladium, platinum, and/or rhodium metal has a purity of about 90% to about 100%, or about 95% to about 99.9%, or about 98% to about 99.9%.

42. The process of any one of claims 36 to 41, wherein the spent catalyst:

further comprises aluminium oxide, and the process selectively leaches the at least two of palladium, platinum, and rhodium from the spent catalyst; and/or

the spent catalyst is a catalytic converter; preferably a gasoline-based or diesel-based catalytic converter in biscuit or powder form.