

CATALYST USE OPTIMISATION**FIELD OF THE INVENTION**

This invention relates to systems and methods for manufacturing catalysts for use in proton exchange membrane (PEM) electrolysis.

BACKGROUND TO THE INVENTION

The hydrogen industry is widely expected to be a key part of the drive towards decarbonisation and a net-zero emissions economy. Hydrogen can be combined with oxygen to release energy for power, either by burning the hydrogen directly, or within a fuel cell to produce electricity. In both cases, water is produced as a by-product. Hydrogen also has industrial applications, for example in the production of steel and glass, and as a component of many chemical processes. Hydrogen power has the advantages of using proven technology (hydrogen fuel cells were used as far back as the Apollo missions) and producing no greenhouse gases.

Despite being the most abundant element in the universe, hydrogen is not commonly found in commercial quantities on Earth, and must be manufactured. Hydrogen can be produced using PEM (proton exchange membrane) electrolysis. This method is in essence the reverse of a fuel cell. Water is passed through an electrically charged PEM electrode, which splits the water into hydrogen and oxygen. Unlike other methods of hydrogen production, PEM electrolysis does not produce carbon-dioxide or greenhouse gas as a by-product. Additionally, PEM electrolysis can be powered by renewable energy sources such as wind turbines. As a result, PEM electrolysis can be used to produce hydrogen with very low carbon emissions.

PEM electrolysis is typically performed by passing water through an electrochemical cell and applying a direct-current (DC) voltage at two electrodes: a negatively charged cathode and positively charged anode, separated by a gas-impermeable solid polymer proton exchange membrane. Water is oxidised giving protons and oxygen at the anode, the protons are transferred through the proton exchange membrane and are then reduced at the cathode with electrons, producing hydrogen. The protons (positively charged hydrogen ions) pass through the ion transport membrane (a solid polymer membrane) to the cathode, where they combine with electrons to form molecular hydrogen. The molecular hydrogen, in gaseous form, can then be collected at pressure.

Catalysts are typically used to accelerate the oxygen evolution reaction for PEM electrolysis. These catalysts are typically applied as a layer on one or both sides of the proton exchange membrane, anode, and/or cathode. The catalyst layer provides an optimised electrochemically active surface area, and has a high electrical conductivity to allow electrical charge to be transferred efficiently through the catalyst layer.

However, widespread adoption of electrolysis is constrained by the high cost and complexity of manufacturing and servicing electrochemical cells. The efficacy of the catalyst coating on the membrane is known to degrade over time, resulting in reduced efficiency of the electrolyser. This may be due to active surface area being lost via, for instance, gradual agglomeration. To mitigate the effects of degradation, it is common for the membranes to be manufactured with a higher loading of catalyst than is strictly necessary, typically between 0.5 – 2 mg per square centimetre. This ensures that the performance of the membrane and catalyst remain adequate throughout their intended operation, even at the end-of-life when the catalyst is degraded. The use of additional catalyst may further increase the cost of electrolyser systems, as the materials used for the catalyst may be expensive.

For these reasons, there is a need to provide more cost-effective PEM electrolyser systems, and methods for manufacturing and servicing thereof.

SUMMARY OF THE INVENTION

According to a first example, there comprises a method for manufacturing a catalyst coating for a recipient component of a PEM, comprising the steps of: processing a pre-used catalyst-coated donor component to recover a quantity of a catalyst; converting the catalyst recovered from the donor component into a powder, thereby producing a low-ECSA (ElectroChemically active Surface Area) recycled catalyst powder; and blending the recycled catalyst powder with a quantity of high-ECSA unrecycled catalyst powder to form a blended catalyst powder.

The recipient component of the PEM electrolyser (that is, the component which is being coated with the blended catalyst powder) may be a membrane, electrode, or another component. By contrast, the pre-used catalyst coated component is a donor component in the sense that catalyst is recovered from it.

The activity of a catalyst (that is, the increase in rate of reaction provided by the catalyst) is proportional to the ECSA of the catalyst. A higher ECSA means that a

greater active area is presented to the reactants. The ECSA of a powder is generally proportional to the specific surface area of the powder, which is the surface area per unit mass. The ECSA of a catalyst powder may also be influenced by the purity of the catalyst, as impurities can obscure the active surface area and prevent reactions from taking place.

One way to measure the ECSA of a powder is by means of cyclic voltammetry, with a higher current peak on the cyclic voltammogram indicating a greater rate of reaction and hence a higher ECSA. Alternatively or additionally, Brunauer–Emmett–Teller (BET) gas absorption may be used to measure a powder's ECSA.

The high-ECSA unrecycled catalyst powder may consist primarily of fresh catalyst, that is, catalyst which is not recycled and has never previously been used. In other examples, the high-ECSA unrecycled powder also comprises recovered and recycled catalyst, which has been through extensive conventional processing to return it to a low-impurity, fine-grade powder akin to fresh catalyst powder. Nevertheless, for the purpose of brevity, the high-ECSA unrecycled catalyst powder will simply be referred to herein as "unrecycled powder". The unrecycled powder may also known as UHSA (ultra-high surface area) powder, due to the high specific surface area resulting from its fine particle sizes.

The process for recovering powder results in the recycled powder having an ECSA which is lower than the unrecycled powder. While the ECSA of the recycled catalyst powder is lower than the unrecycled powder, it will be understood that it is not necessarily low in absolute terms. The recycled powder has a lower ECSA because it is not processed according to the extensive (but complex and expensive) conventional process for recovering and recycling catalyst. For example, the recycled catalyst powder may comprise larger and/or more irregular particles than an UHSA catalyst powder. In addition, the recycled catalyst powder may include more impurities than a highly refined unrecycled catalyst powder.

The donor component may be a solid polymer proton exchange membrane or electrode from a PEM electrolyser. In other words, a solid polymer proton exchange membrane or electrode could be recycled to make catalyst for a new polymer proton exchange membrane or electrode of the same type, or even the same design. The inventors have found that recovering catalyst from previously used PEM electrolyser donor components advantageously requires less intensive purification and refining. Due to the cleanliness of PEM water, catalyst poisoning in PEM electrolyzers is low. This means

that catalyst recovered from PEM electrolyser donor components is unlikely to contain high levels of impurities, even if the donor components have seen significant use. Catalyst is not generally eroded from within PEM electrolyzers, meaning that almost all of the catalyst from a coated polymer membrane or electrode could be recovered at the donor component's end of life.

This contrasts with more common applications of catalysts such as catalytic converters in the automotive industry, where catalyst poisoning is high. Recovering catalyst from catalytic converters, for example, requires intensive purification and chemical and/or thermal treatment cycles, in order to return the catalyst to an acceptably pure chemical state. In other words, there is an expectation in the technical field of the invention that extensive refining and processing is essential for recycling catalyst.

The recycled catalyst powder has a lower specific surface area and higher impurities than the unrecycled catalyst powder. This means that the catalytic activity of the recycled powder is diminished to some extent compared to the unused catalyst powder. However, the recycled catalyst powder still retains a high electronic conductivity. Hence, a fraction of the blended catalyst powder forming the catalyst layer in a new electrolyser can be replaced with used powder without significantly affecting the overall performance. The recycled catalyst powder acts as a filler, electrical conductor, and oxidation resistor within the blended powder, while the unused catalyst powder provides the requisite catalytic activity. It is advantageous to use recycled catalyst powder as the conductive filler because catalyst materials must be stable in the high-corrosion, high-temperature OER (Oxygen Evolution Reaction) environment inside an electrochemical cell. Other conductive metals and oxides are either known not to be stable, or have not been through the extensive testing and certification processes to permit use in OER environments. Re-using catalyst thus avoids the requirement for lengthy and expensive requalification and stress testing.

Preferably, the method further comprises the step of calcinating the recycled powder in a hydrogen atmosphere. Calcination involves heating, without melting, the recycled catalyst powder in a low-oxygen environment. The catalytic characteristics of recycled catalyst powder will vary depending on the history of the donor component it is recovered from, such as the donor component's active running hours. This poses difficulties when performing the method in bulk, combining quantities of recycled powder from many donor components. Calcination homogenises the ECSA of catalyst powder recovered from different donor components by regularising the amorphous crystalline structure of the powder particles, improving the consistency of the final

blended catalyst powder. In addition, impurities within the recycled catalyst (such as fragments of membrane or ionomer) may be oxidised (that is, burnt off), allowing them to be separated from the catalyst and further increasing the ECSA. Calcination may be combined, preceded or followed by mechanical processing such as ball milling, to further homogenise the powder. Unlike conventional thermal treatments, calcination does not fully chemically re-synthesise the catalyst. However, calcination is considerably less energy-intensive and complex to perform.

Optionally, processing the donor component comprises: dissolving the donor component into a solvent; and recovering and drying a layer of catalyst from the solvent. In some examples, the catalyst-coated donor component is disassembled or mechanically broken up before or after application of the solvent, so as to increase the exposed surface area of the component.

Preferably, the solvent is an alcohol-based solvent. Alcohol-based solvents are particularly effective at dissolving the polymer membranes, allowing the catalyst coating to be extracted.

Preferably, processing the donor component comprises mechanically separating the catalyst layer from the donor component. In some examples, mechanical separation is performed by means of scraping or grinding the catalyst powder. Mechanical separation may be more effective than solvent when the catalyst-coated donor component is made of metal, or another less soluble material. In other examples, a mechanical separation step may precede a solvent application step. The mechanical separation step separates the bulk of the donor component from the catalyst, but small fragments of the donor component may remain bonded to the catalyst, or may be mixed in with the catalyst during separation. The solvent is applied to the catalyst-component mixture, causing the remaining fragments of donor component to dissolve.

Optionally, the method further comprises the steps of: establishing the ECSA of the recycled catalyst powder; and determining, based on the effective activity, the quantity of unrecycled catalyst powder to be blended with the recycled catalyst powder. As previously discussed, the ECSA of the recycled catalyst can vary depending on the age and operating history of the donor component(s) from which the catalyst is recovered. To ensure that the blended catalyst powder is consistent, the ECSA of the catalyst may be measured following recovery. One way to estimate this is to determine the powder grade of the recycled catalyst powder. The specific surface area of a powder (which is proportional to the ECSA) is inversely proportional to the average diameter of particles

in the powder. Smaller particles have a higher surface area to volume ratio, which means a higher specific surface area and hence ECSA. The quantity of unrecycled to be blended with the recycled catalyst powder is adjusted based on the latter's exact ECSA. For example, if the ECSA of a batch of recycled catalyst powder is particularly low (e.g. because the catalyst is recovered from particularly well-used membranes), then the ratio of unrecycled powder may be increased to compensate.

Preferably, the recycled catalyst powder comprises between 10% and 90% of the catalyst coating by mass. The more recycled powder used, the less unrecycled powder is required, reducing the amount of catalyst which must be mined and processed (in the case of unused catalyst) or recovered and refined (in the case of recycled catalyst) into low-impurity UHSA catalyst powder. However, it is preferable that unrecycled powder comprises at least 10% by mass of the blended powder, to ensure that the catalytic activity of the blended powder is defined by the higher ECSA unused powder. The inventors have found that a small amount of unrecycled catalyst can significantly increase the ECSA of a blended powder. This is because the fine, small-diameter particles of the unrecycled powder fill the interstices between the irregular larger-diameter particles of the low-ECSA recycled powder, significantly increasing the overall specific surface area.

Optionally, the ECSA of the blended catalyst powder is between 10 and 50 meters squared per gram. This compares to a unrecycled ultra-high surface area (UHSA) catalyst powder made purely out of highly-refined, small-diameter particles, where the ECSA may be between 70 and 180 meters squared per gram. In other words, the ECSA of the blended catalyst may be between 5% and 75% of a purely unrecycled powder.

According to a further example, there comprises a PEM electrolyser membrane, comprising a catalyst coating manufactured using any previously described method. The catalyst coating may comprise an ink which can be applied or printed onto a solid polymer membrane. The ink comprises a liquid solvent in which the blended catalyst powder, and optionally other ionomers, are dispersed. In some examples, the unrecycled powder and recycled powder are first blended together to form a blended powder, and then the blended powder is dispersed into the ink. Alternatively, the unrecycled and recycled powders may be added to the ink separately, and then blended together while suspended in the ink.

According to a further example, there comprises a method for manufacturing a PEM electrolyser membrane, comprising: coating the membrane with a catalyst coating manufactured using any previously described method.

According to a further example, there comprises a blended catalyst powder for use in manufacturing a catalyst coating for a PEM electrolyser membrane, comprising a blend of: a first powder having a first ECSA; and a second powder having a second ECSA which is lower than the first ECSA, wherein the second powder comprises at least 10% by mass of the blended catalyst powder.

Preferably, an average size of particles of the second powder is greater than an average size of particles of the first powder. The specific surface area of the second powder is therefore lower than the specified surface area of the first powder.

Preferably, both the first and second powder primarily comprise iridium or ruthenium oxide. Iridium and ruthenium oxide provide the required catalytic effect, and additionally provide the catalyst layer with a high conductivity. This reduces electrical losses in the electrolyser. In some examples, the first and second powder are substantially chemically identical, that is, they primarily consist of the same material (e.g. iridium oxide) when ignoring any minor impurities. In other examples, the first and second powder consist of different materials, e.g. with one powder comprising iridium oxide and the other comprising ruthenium oxide.

Preferably the second powder comprises no more than 90% by mass of the blended catalyst powder. This ensures that the overall ECSA of the blended powder is determined by the unrecycled first powder.

Optionally, the second powder is a recovered catalyst powder manufactured by: processing a donor component to recover a quantity of a catalyst; and converting the catalyst recovered from the donor component into a powder, thereby producing a recycled catalyst powder.

BRIEF DESCRIPTION OF THE DRAWINGS

Examples of the present invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a known conventional method for recovering and recycling used catalyst.

Figure 2 shows a method for manufacturing a catalyst coating according to the invention.

Figure 3A schematically illustrates particles of an exemplary unrecycled powder. Figure 3B schematically illustrates particles of a recycled powder recovered using a method according to the invention.

Figure 4 schematically illustrates catalyst coatings applied to a recipient component. Figure 4A shows a prior-art catalyst comprising exclusively unrecycled powder. Figure 4B shows a catalyst coating comprising exclusively recycled powder. Figure 4C shows a catalyst coating according to the invention, comprising a blend of recycled and unrecycled powders.

DETAILED DESCRIPTION

Figure 1 shows a known conventional method 100 for recovering used catalyst from a donor component and recycling it into an unrecycled ultra-high surface area (UHSA) catalyst. This method is commonly used for recovering and recycling catalyst from the solid polymer membranes used in electrolyser systems, as well as in adjacent industries such as recycling automotive catalysts from catalytic converters.

In step 101, a donor component is provided. The donor component is a used catalyst-coated component, such as a solid polymer membrane.

In step 102, the donor component is mechanically scrapped or dismantled to break it up into smaller pieces. This increases the surface area of the donor component, facilitating the thermal treatment and chemical separation processes.

In step 103, the pieces of the donor component are then thermally treated. This may involve heating the donor components in a furnace to weaken the chemical bonds between the donor component and catalyst. Alternatively, the pieces of the donor component may be melted down into a slag, or burnt into ash. Further mechanical separation techniques may be applied to the slag to cause the catalyst to separate into a collectable layer.

Alternatively or additionally in step 104, a wet chemical separation process may be applied to collect and purify the catalyst. The chemical separation process is generally a complex, multistage process involving immersing the pieces in strong solvents. This causes the catalyst and/or donor component to dissolve into the solvent. Several successive stages of dissolution, separation and purification may be employed to minimise the amount of residue (such as small pieces of polymer from a dissolved solid polymer membrane) in the collected catalyst.

Once the catalyst solution has been filtered to a sufficient purity, it is generally converted 105 into an aqueous salt using strong acids. This can then be precipitated and refined 106 into an ultra-high surface area powder using conventional methods, such as the Adams method. Finally, the powder obtained is washed to eliminate additional unwanted products arising from the precipitating method. The powder may be further refined using sieving and milling methods to ensure a sufficiently fine powder grade.

The conventional method 100 is complex, expensive, slow and requires intensive use of chemicals and energy. However, the method 100 produces catalyst powder with a high specific surface area and purity, giving it a high ECSA. As a result, such methods 100 are common, established, and unavoidable in sectors where the spent or poisoned catalyst cannot be re-instated or is simply lost to the environment, such as in automotive catalyst.

A method 200 for manufacturing a catalyst coating for use in a PEM electrode, according to the invention, is described in relation to Figure 2.

In step 201, a donor component is provided. The donor component is a catalyst-coated component, from which catalyst will be recovered. While the method 200 is described in relation to a single donor component, it will be understood that the method 200 may be performed in bulk on multiple donor components at once. This provides improved economies of scale.

In step 202, the donor component is processed to separate the catalyst coating from the component. An exemplary processing method 202 for separating catalyst from a solid polymer membrane is shown in Figure 2B.

In step 2021, a catalyst-rich layer or section is mechanically separated from the rest of the donor component. In the case of a solid polymer membrane, this may involve

scraping or cutting off an outer catalyst-coated layer of the membrane. Alternatively, the catalyst may be ground off. The catalyst-rich section may contain fragments of the donor component, which may remain bonded to the catalyst after separation. The donor component may be dismantled or mechanically scrapped as described in the conventional method 100, in order to increase its surface area.

In step 2022, a solvent is applied to the catalyst-rich section. This causes the remaining fragments of the donor component to dissolve. Alcohol-based solvents such as 5% Butanol-Deionised Water, 10% Butanol-Deionised Water, or 25% IPA-Deionised Water may be particularly effective for dissolving the polymers of the solid-polymer membrane. Alcohol-based solvents are less expensive and easier to handle than the strong acids used to dissolve the catalyst metals in the conventional method 100. A pH change may be used to pre-sort the catalyst and donor component fragments prior to filtering, for example acidifying the solution to encourage phase separation.

In step 2023, the catalyst is dried, that is, the solvent is removed from the catalyst. Drying off the catalyst removes the dissolved donor component fragments, as well as any other impurities that may have been dissolved in the solvent. Once the catalyst dries, it can be collected 2024 in powder form.

In step 2025, the collected catalyst powder is calcinated in a low-oxygen environment, in order to homogenise the ECSA of powders recovered from different donor components. Calcination may be performed in a hydrogen atmosphere (that is, an atmosphere consisting primarily of hydrogen gas and minimal oxygen), to encourage impurities to burn off.

In step 2026, the ECSA of the collected catalyst powder is estimated. This may involve taking a sample of the recycled catalyst powder and performing cyclic voltammetry and/or Brunauer–Emmett–Teller (BET) gas absorption. The ECSA of the sample is given by the formula:

$$\text{ECSA} = C_{dl} / C_s$$

Where C_{dl} is the double-layer capacitance (e.g. as measured using cyclic voltammetry), and C_s is the specific capacitance, i.e. the expected capacitance per unit area if the catalyst were an idealised perfectly flat surface.

In step 2027, the quantity of unrecycled required for blending with the collected catalyst powder is determined based on the estimated ECSA.

In step 203, the collected, processed powder is used as the recycled catalyst powder, for blending with a quantity of unrecycled.

In step 204, the required quantity of unrecycled catalyst powder is provided. The unrecycled powder may fresh, that is, manufactured from never-previously used materials. Alternatively, the unrecycled catalyst powder may also be at least partially comprised of conventionally recycled catalyst, i.e. catalyst which has been recovered after use and then refined and re-synthesised into unrecycled UHSA powder.

The amount of unrecycled catalyst provided may depend on the amount of catalyst powder recovered, and the catalytic activity of the recycled catalyst powder. The ratio of unrecycled to recycled catalyst powder may depend on the estimated ECSA of the recycled catalyst powder. The lower the ECSA of the recycled catalyst powder, the more unrecycled catalyst powder is required to reach the desired catalytic activity in the blended catalyst powder.

In step 205, the unrecycled powder is blended together with the low-ECSA recycled powder. A V shaped powder blender may be used for blending the powders together. The powders may be blended until the resulting blended catalyst powder is substantially isotropic, with the ratio of the high and low ECSA powders being consistent across the blended powder. This ensures a homogenous ECSA when the catalyst is applied.

The blended catalyst powder may then used to formulate a homogenous ink or paste. This ink can then be applied to a donor component for use in a PEM electrolyser, such as a newly-manufactured solid polymer membrane.

Compared to the conventional method 100 for recycling catalyst, the method 200 is significantly less expensive and complex. The particularly intensive steps 103 – 106 of the conventional method are avoided. The blended powder typically has an ECSA of between 10 and 50 meters squared per gram, compared to an UHSA high catalyst powder which may have an ECSA of between 70 and 180 meters squared per gram. However, as previously discussed catalyst loadings in conventional catalyst coatings is generally higher than is strictly necessary. The lower overall ECSA of the blended powder therefore does not significantly reduce the rate of reaction.

Figure 3 compares particles 301 of an UHSA unrecycled powder (Figure 3A) against particles 302 of a recycled powder (Figure 3B). The unrecycled particles 301 are smaller on average. The average diameter of the particles 301 (given by the average of a characteristic length D1 for each particle) is smaller than the corresponding average diameter of the recycled catalyst powder particles 302 (which have a characteristic length D2 for each particle). In one example, 90% of the particles 302 in the recycled powder have a maximum diameter of 30 μm , while 90% of the particles 302 in the unrecycled powder have a maximum diameter of 20 μm . The average particle size in a powder may be measured using laser diffraction.

For the same mass (and assuming that the powders are made of the same base catalyst material), the unrecycled powder will have more particles 301 than the recycled catalyst powder. The intensive refining and purifying process for the unrecycled particles results in fewer and smaller surface impurities (represented diagrammatically as black regions 303), where catalytic activity on the particles' surface is impeded or blocked. By contrast, the particles 302 of the recycled powder have more and larger surface impurities 303. The lower specific surface area and purity of the recycled powder particles 302 leads to a lower ECSA compared to the unrecycled powder.

The blended powder comprises a blend of the unrecycled particles 301 and recycled particles 302.

Each of Figures 4A-C schematically illustrates a catalyst coating 400 applied on a substrate 403, the substrate 403 forming part of a recipient component such as a solid polymer membrane or electrode. The catalyst coating 400 is immersed in water to be electrolysed. The catalyst coatings 400 take the form of an ink 404 in which the catalyst particles 401, 402 are suspended. For the purposes of clarity, the particles 401, 402 are represented by circles, are not shown to scale relative to the thickness of the catalyst. In reality, the particles 401, 402 making up the catalyst coating 400 may be orders of magnitude smaller than the thickness of the coating 400, such that the coating is tens or hundreds of layers of particles thick. The ink 404 is porous, allowing water and ions to permeate through the catalyst coating 400 to and from the active sites on the catalyst particles 401, 402. In addition to providing a catalytic effect, the catalyst particles 401, 402 have a lower electrical resistance than the ink 404, increasing the overall electrical conductivity of the catalyst coating 400. This reduces electrical resistance to currents flowing through the catalyst coating 400, increasing operational efficiency of the electrolyser.

Figure 4A schematically illustrates a conventional catalyst coating 400A applied to the surface of a substrate 403. The catalyst coating 400A comprises exclusively UHSA catalyst particles 401, such as those manufactured from an unused catalyst material or recovered using the previously-described intensive processing method 100. Due to the high number of small-diameter powder particles 401, the coating 400A has a high total ECSA, facilitating a high rate of reaction.

Figure 4B illustrates a catalyst coating 400B consisting exclusively of recycled catalyst powder particles 402. The recycled catalyst powder particles 402 have a larger average diameter than the unused catalyst powder particles 401. For the same catalyst loading as the catalyst coating 400A of Figure 4A, in terms of catalyst mass per square centimetre of coating, the catalyst coating 400B will comprise fewer particles, each having a greater average diameter. As a result, the catalyst coating has a lower total ECSA, reducing the maximum achievable rate of reaction. With fewer catalyst particles, the average spacing between recycled particles 402 in the coating 400B is wider than the average spacing between more numerous unrecycled particles 401 in the coating 400A, resulting in a higher electrical resistance.

Figure 4C illustrates a catalyst coating 400C comprising a blended powder, that is, a blend of unrecycled particles 401 and recycled particles 402. The ratio of the of unrecycled particles 401 to recycled particles 402 is between 10% and 90%. The coating 400C is approximately homogenous in the sense that the ratio of unrecycled to recycled is maintained throughout the coating 400C, ensuring that there is uniform catalytic activity throughout the coating. The unrecycled powder particles 401 provide the catalyst coating with a high overall ECSA. In some examples, the overall ECSA of the blended catalyst powder, and thereby the catalyst coating 400C, is determined primarily by the unrecycled powder, even when the unrecycled makes only a minority of the blended catalyst powder by mass. That is, the overall ECSA of the blended powder is closer to the ECSA of the unrecycled powder than the recycled powder. In some examples, a plurality of small unrecycled particles can be arranged into a regular arrangement around a larger unrecycled particle using the Strong Metal Support Interaction (SMSI) principle, thereby further optimising the effective surface area of the catalyst. The recycled powder particles 402 act as a filler and provide electronic conductivity, allowing currents to pass efficiently within the catalyst coating 400C and between the catalyst coating 400C and substrate 403. As a result, the blended catalyst powder 400C provides a similarly low electrical resistance to the unrecycled catalyst powder 400A.

CLAIMS

1. A method for manufacturing a catalyst coating for a recipient component of a PEM electrolyser, comprising the steps of:
 - processing a pre-used catalyst-coated donor component to recover a quantity of a catalyst;
 - converting the catalyst recovered from the donor component into a powder, thereby producing a low-ECSA recycled catalyst powder; and
 - blending the recycled catalyst powder with a quantity of high-ECSA unrecycled catalyst powder to form a blended catalyst powder.
2. The method of claim 1, further comprising the step of calcinating the recycled powder in a hydrogen atmosphere.
3. The method of claim 1, wherein processing the donor component comprises:
 - dissolving the donor component into a solvent; and
 - recovering and drying a layer of catalyst from the solvent.
4. The method of claim 3, wherein the solvent is an alcohol-based solvent.
5. The method of any preceding claim, wherein processing the donor component comprises:
 - mechanically separating the catalyst layer from the donor component;
6. The method of any preceding claim, further comprising the steps of:
 - establishing the ECSA of the recycled catalyst powder;
 - determining, based on the ECSA of the recycled powder, the quantity of unrecycled catalyst powder to be blended with the recycled catalyst powder.
7. The method of any preceding claim, wherein the ECSA of the blended catalyst powder is between 10 and 50 meters squared per gram.
8. The method of any preceding claim, wherein the recycled catalyst powder comprises between 10% and 90% of the catalyst coating by mass.
9. The method of any preceding claim, wherein the donor component is a used solid polymer membrane.

10. A recipient component of a PEM electrolyser, comprising a catalyst coating manufactured using the method of any preceding claim.
11. A method for manufacturing a recipient component of a PEM electrolyser, comprising:
 - coating the component with a catalyst coating manufactured using the method of any of claims 1-9.
12. A blended catalyst powder for use in manufacturing a catalyst coating for a recipient component of a PEM electrolyser, comprising a blend of:
 - a first powder having a first ECSA; and
 - a second powder having a second ECSA which is lower than the first ECSA, wherein the second powder comprises at least 10% by mass of the blended catalyst powder.
13. The blended catalyst powder of claim 12, wherein an average size of particles of the second powder is greater than an average size of particles of the first powder.
14. The blended catalyst powder of claims 12 or 13, wherein both the first and second powder primarily comprise iridium or ruthenium oxide.
15. The blended catalyst powder of claims 12 to 14, wherein the second powder comprises no more than 90% by mass of the blended catalyst powder.
16. The blended catalyst powder of claims 12 to 15, wherein the second powder is a recycled catalyst powder manufactured by:
 - processing a pre-used catalyst-coated donor component to recover a quantity of a catalyst; and
 - converting the catalyst recovered from the donor component into a powder, thereby producing a recycled catalyst powder.