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### Compression clamps for electrochemical stacks

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#### Abstract

The following disclosure relates to a compression tool for compressing a substack of electrochemical cells having a first plate, a second plate, and a plurality of electrochemical cells positioned between the first plate and the second plate. The compression tool is configured to be maintain on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

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**Background/Summary**

(1) This application claims the benefit of U.S. Provisional Patent Application No. 63/741,662, filed Jan. 3, 2025, which is hereby incorporated by reference in its entirety.

**FIELD**

(1) The following disclosure relates to electrochemical devices, systems, and components thereof. More specifically, the following disclosure relates to compression clamps for electrochemical stacks.

**BACKGROUND**

(2) Hydrogen has been considered as an ideal energy carrier to store renewable energy. Proton exchange membrane water electrolysis (PEMWE) as a means for hydrogen production offers high product purity, fast load response times, small footprints, high efficiencies, and low maintenance efforts. It is regarded as a promising technology, especially when coupled with renewable energy sources.

(3) An electrolysis cell or system uses electrical energy to drive a chemical reaction. For example, water is split to form hydrogen and oxygen. The products may be used as energy sources for later use. In recent years, improvements in operational efficiency have made electrochemical systems competitive market solutions for energy storage, generation, and/or transport. For example, the cost of generation may be below \$6 per kilogram of hydrogen in some cases. Increases in efficiency and/or improvements in operation will continue to drive the installation of electrochemical systems.

(4) An electrochemical stack may include a plurality of substacks, each including a plurality of individual electrochemical cells. Temporary clamps may be placed on an assembled substack to provide compression on the substack and a method for transporting the assembled substack to install the substack within the overall electrochemical stack. However, due to their cumbersome nature, the temporary clamps must be removed after the stack has been assembled. Therefore, there is no structure in place to keep the substacks aligned within the overall stack throughout the electrolysis reaction. Additionally, removal of each individual substack from the overall stack may be challenging as well.

(5) Therefore, there remains a desire for an improved compression tool for a substack to improve compressibility, maintain alignment throughout an electrolysis reaction, and provide improved installation and removal from the overall electrochemical stack.

#### SUMMARY

(6) In one embodiment, a compression tool is provided for compressing a substack of electrochemical cells having a first plate, a second plate, and a plurality of electrochemical cells positioned between the first plate and the second plate. The compression tool includes a first clamp component having a first cavity and a hole at a base of the first cavity. The first clamp component is configured to be positioned within a recess on an outer surface of the first plate of the substack such that the hole at the base of the first cavity is positioned toward a second clamp component of the compression tool. The compression tool also includes the second clamp component having a second cavity and a hole at a base on the second cavity. The depth of the second cavity is greater than a depth of the first cavity. The second clamp component is configured to be positioned within a recess on an outer surface of the second plate of the substack such that the hole at the base of the second cavity is positioned toward the first clamp component. The compression tool also includes a fastener having a head at a first end and a body, wherein the body is configured to be positioned through the hole of the first clamp component and the hole of the second clamp component, and wherein the head is positioned within the first cavity of the first clamp component. The compression tool also includes a retaining component configured to be attached to or threaded onto the fastener and positioned within the second cavity of the second clamp component such that the hole at the base of the second cavity is positioned between the first clamp component and the retaining component. The retaining component is configured to be adjusted on the fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks. The compression tool is configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

(7) In another embodiment, a substack for an electrochemical stack is provided. The substack includes a plurality of electrochemical cells, a first plate, a second plate, and a compression tool. The plurality of electrochemical cells is positioned between the first plate and the second plate. The compression tool includes a first clamp component having a first cavity and a hole at a base of the

first cavity. The first clamp component is positioned within a recess on an outer surface of the first plate of the substack such that the hole at the base of the first cavity is positioned toward a second clamp component of the compression tool. The compression tool also includes the second clamp component having a second cavity and a hole at a base on the second cavity. The depth of the second cavity is greater than a depth of the first cavity. The second clamp component is positioned within a recess on an outer surface of the second plate of the substack such that the hole at the base of the second cavity is positioned toward the first clamp component. The compression tool also includes a fastener having a head at a first end and a body, wherein the body is configured to be positioned through the hole of the first clamp component and the hole of the second clamp component, and wherein the head is positioned within the first cavity of the first clamp component. The compression tool also includes a retaining component configured to be attached to or threaded onto the fastener and positioned within the second cavity of the second clamp component such that the hole at the base of the second cavity is positioned between the first clamp component and the retaining component. The retaining component is configured to be adjusted on the fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks. The compression tool is configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

(8) In another embodiment, a method for forming a substack with a compression tool for an electrochemical stack is provided. The method includes providing a substack comprising a plurality of electrochemical cells, a first plate, and a second plate wherein the plurality of electrochemical cells is positioned between the first plate and the second plate. The method further includes positioning a first clamp component having a first cavity and a hole at a base of the first cavity, within a recess on an outer surface of the first plate of the substack and positioning the first cavity toward a second clamp component. The method further includes positioning the second clamp component, having a second cavity and a hole at a base on the second cavity wherein a depth of the second cavity is greater than a depth of the first cavity, within a recess on an outer surface of the second plate of the substack and positioning the hole at the base of the second cavity toward the first clamp component. The method further includes positioning a body of a threaded fastener having a head at a first end of the threaded fastener and thread extending along at least a portion of a body of the threaded fastener, through the hole of the first clamp component and the hole of the second clamp component and positioning the head of the threaded fastener within the first cavity of the first clamp component. The method further includes positioning a retaining component onto the thread of the threaded fastener within the second cavity of the second clamp component. The method further includes positioning the hole at the base of the second cavity between the first clamp component and the tightening nut. The method further includes adjusting the retaining component on the thread of the threaded fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks. The method further includes adding the substack to the electrochemical stack assembly, wherein the compression tool is maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

(9) This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

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## Description

## BRIEF DESCRIPTION OF THE DRAWINGS

- (1) Exemplary embodiments are described herein with reference to the following drawings.
- (2) FIG. 1 depicts an example of an electrochemical system including an electrochemical stack having a plurality of electrochemical cells.
- (3) FIG. 2 depicts an example of an electrochemical cell.
- (4) FIG. 3 depicts an additional example of an electrochemical cell.
- (5) FIG. 4 depicts, in an exploded view, an example of a substack of an electrochemical stack.
- (6) FIGS. 5A-5E depict examples of compression tools for compression of a substack.
- (7) FIG. 6 depicts an additional example of a compression tool.
- (8) FIGS. 7A-7D depict an additional example of a compression tool and compression tool components, such as a first clamp component and a second clamp component, each having a circular or oval-shaped portion configured to fit into a respective recess or pocket on the outer surface of a substack plate.
- (9) FIGS. 8A and 8B depict examples of plates of a substack having openings in the plates, wherein each opening has a recess or pocket within the outer edge of the plate.
- (10) FIGS. 9A-9D depict examples of clamp components positioned within the openings of the plates depicted in FIGS. 8A and 8B.
- (11) FIGS. 10A-10C depict an example of a substack coupled with a plurality of compression tools.
- (12) FIG. 11 depicts a flow chart describing a method for forming a substack with a compression tool.

## DETAILED DESCRIPTION

- (13) Compression tools may provide partial compression on a substack of electrochemical cells during manufacture and installation of the substack within an electrochemical stack. While conventional compression tools need to be removed from the substack following installation in the overall stack, the present disclosure provides an improved compression tool that may advantageously remain coupled to the substack after installation in the overall stack and throughout operation of the electrochemical stack to provide continuous compression throughout an electrolysis reaction, maintain alignment of the cells within the substack, and provide improved removal from the stack for maintenance.
- (14) The following disclosure provides such an improved compression tool for compressing a substack of electrochemical cells. Specifically, the following disclosure provides a compression tool for compressing a substack of electrochemical cells having a first plate, a second plate, and a plurality of electrochemical cells positioned between the first plate and the second plate.
- (15) Such compression tools may stay coupled to a substack after the substack is formed to ensure partial compression of the substack throughout the life of the substack. This allows the electrochemical cells inside a substack to not move during the various processes throughout the electrolysis reaction. This compression tool also provides that the substack stays aligned and also provides better full stack alignment when building an electrochemical stack. This can also result in lower manufacturing failures during the electrochemical stack assembly.
- (16) The compression tool allows the ability to measure the compression in a substack in terms of displacement of the substack. It also allows for the ability to measure the compression within each substack in a full stack and correlate that to performance of individual cells. This may also provide explanations as to which substacks are being more compressed than others.
- (17) Electrochemical Cells
- (18) FIG. 1 depicts an example of an electrochemical system including an electrochemical stack having a plurality of electrochemical cells. In certain examples, the electrochemical stack may contain 50-1000 cells, 50-100 cells, 500-700 cells, or more than 1000 cells. Any number of cells may make up a stack. The electrochemical cells within the electrochemical stack may be configured to operate with 200 mV or less of pure resistive loss when operating at a high current

density (e.g., at least 3 Amps/cm.<sup>2</sup>, at least 4 Amps/cm.<sup>2</sup>, at least 5 Amps/cm.<sup>2</sup>, at least 6 Amps/cm.<sup>2</sup>, at least 7 Amps/cm.<sup>2</sup>, at least 8 Amps/cm.<sup>2</sup>, at least 9 Amps/cm.<sup>2</sup>, at least 10 Amps/cm.<sup>2</sup>, at least 11 Amps/cm.<sup>2</sup>, at least 12 Amps/cm.<sup>2</sup>, at least 13 Amps/cm.<sup>2</sup>, at least 14 Amps/cm.<sup>2</sup>, at least 15 Amps/cm.<sup>2</sup>, at least 16 Amps/cm.<sup>2</sup>, at least 17 Amps/cm.<sup>2</sup>, at least 18 Amps/cm.<sup>2</sup>, at least 19 Amps/cm.<sup>2</sup>, at least 20 Amps/cm.<sup>2</sup>, at least 25 Amps/cm.<sup>2</sup>, at least 30 Amps/cm.<sup>2</sup>, in a range of 1-30 Amps/cm.<sup>2</sup>, in a range of 3-20 Amps/cm.<sup>2</sup>, in a range of 3-15 Amps/cm.<sup>2</sup>, in a range of 3-10 Amps/cm.<sup>2</sup>, or in a range of 10-20 Amps/cm.<sup>2</sup>). In additional examples, the amount of water (e.g., deionized (DI) water) transferred to or circulated through each cell of the stack may be in a range of 0.25-1 mL/Amp/cell/min, in a range of 0.25-5 mL/Amp/cell/min, or in a range of 0.5-1 mL/Amp/cell/min.

(19) As illustrated in the system of FIG. 1, water (H<sub>2</sub>O) may be supplied to the anodic inlet of an electrolytic cell stack 12. In some embodiments, only the anodic inlet of the cell stack 12 may receive water. In these embodiments, the cathode side of the cell stack 12 may not receive water (e.g., a dry cathode side may be used). In another embodiment, a cathode inlet may also receive water, wherein the water may be supplied to the cathode inlet to cool the cell stack 12 during electrolysis.

(20) The water supplied to the anodic inlet flows to an anodic inlet manifold that distributes the water to the anode side of the plurality of cells contained within the cell stack 12. In embodiments where water is supplied to the cathode inlet, water supplied to the cathode inlet flows to a cathodic inlet manifold that distributes the water to the cathode side of the plurality of cells in the cell stack 12. In certain examples, the amount of water (e.g., deionized (DI) water) transferred to or circulated through each cell of the stack may be in a range of 0.25-5 mL/Amp/cell/min.

(21) During electrolysis, oxygen (O<sub>2</sub>) is produced at the anode side of the electrolytic cells and hydrogen (H<sub>2</sub>) is produced at the cathode side of the electrolytic cells. Specifically, a water splitting electrolysis reaction is configured to take place within each individual cell in the cell stack 12. Each cell includes one interface (the anode side of the cell) configured to run an oxygen evolution reaction (OER) and another interface (the cathode side of the cell) configured to run a hydrogen evolution reaction (HER) (such as depicted in FIG. 2).

(22) During electrolysis, some of the water supplied to the anode side of an electrolytic cell may not be split into oxygen. Accordingly, a two-phase flow of oxygen and unreacted water is outlet from each of the anode sides of the cells into an anodic outlet manifold 13. The two-phase flow of oxygen and unreacted water flows from out of the cell stack 12 through the anodic outlet manifold 13. This stream within the anodic outlet manifold 13 may be configured to be transferred to a gas detection and conditioning system, such as described in greater detail below, for analysis of the composition within the stream. Specifically, this anodic stream may be analyzed to identify if any undesirable hydrogen gas has leaked (i.e., cross-leaked) across the membranes from the cathode sides of the cells to the anode sides of the cells within the cell stack.

(23) Additionally, in some embodiments, water may be supplied to the cathode side of the cell stack as a coolant. Accordingly, a two-phase flow of hydrogen and water is outlet from each of the cathode sides of the cells to a cathodic outlet manifold 14. The two-phase flow of hydrogen and water flows out of the cell stack 12 through the cathodic outlet manifold 14. Similarly, this particular stream within the cathodic outlet manifold 14 may be configured to be transferred to a gas detection and conditioning system (separate from the anodic gas detection and conditioning system) for analysis of the composition within the stream. Specifically, this cathodic stream may be analyzed to identify if any undesirable oxygen gas has leaked (i.e., cross-leaked) across the membranes from the anode sides of the cells to the cathode sides of the cells within the cell stack.

(24) FIG. 2 depicts an example of an electrochemical or electrolytic cell for hydrogen gas and oxygen gas production through the splitting of water. The electrochemical cell within FIG. 2 may be one of the plurality of cells within the electrochemical stack in FIG. 1. The electrochemical cell

includes a cathode, an anode, and a membrane positioned between the cathode and anode. The membrane may be a proton exchange membrane (PEM) that may have a catalyst coating on one or both surfaces of the PEM. In other examples, the membrane may be positioned within an electrochemical cell having a catalyst coating on an adjacent supporting layer within the cell (e.g., a gas diffusion layer or porous transport layer near or abutting the membrane).

(25) Proton Exchange Membrane (PEM) electrolysis involves the use of a solid electrolyte or ion exchange membrane. Within the water splitting electrolysis reaction, one interface runs an oxygen evolution reaction (OER) while the other interface runs a hydrogen evolution reaction (HER). For example, the anode reaction is  $\text{H}_2\text{O} \rightarrow 2\text{H}^{+} + \frac{1}{2}\text{O}_2 + 2\text{e}^{-}$  and the cathode reaction is  $2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2$ .

(26) FIG. 3 depicts an additional example of an electrochemical or electrolytic cell **300**.

Specifically, FIG. 3 depicts a portion of an electrochemical cell **300** having a cathode flow field **302**, an anode flow field **304**, and a membrane **306** positioned between the cathode flow field **302** and the anode flow field **304**. In certain examples, the membrane **306** may have an overall thickness that is less than 1000 microns, 500 microns, 100 microns, 50 microns, 10 microns, etc.

(27) In certain examples, additional layers may be present within the electrochemical cell **300**. For example, one or more additional layers **308** may be positioned between the cathode flow field **302** and membrane **306**. In certain examples, this may include a gas diffusion layer (GDL) **308** that may be positioned between the cathode flow field **302** and membrane **306**. This may be advantageous in providing a hydrogen diffusion barrier adjacent to the cathode on one side of the multi-layered membrane to mitigate hydrogen crossover to the anode side. In other words, the GDL is responsible for the transport of gaseous hydrogen to the cathode side flow field. For a wet cathode PEM operation, liquid water transport across the GDL is needed for heat removal in addition to heat removal from the anode side.

(28) Similarly, one or more additional layers **310** may be present in the electrochemical cell between the membrane **306** and the anode flow field **304**. In certain examples, this may include a porous transport layer (PTL) positioned between the membrane **306** (e.g., the anode catalyst layer **307** of the catalyst coated membrane **306**) and the anode flow field **304**.

(29) Similar to the GDL, the PTL is configured to allow the transportation of the reactant water to the anode catalyst layers, remove produced oxygen gas, and provide good electrical conductivity for effective electron conduction. In other words, liquid water flowing in the anode flow field is configured to permeate through the PTL to reach the CCM. Further, gaseous byproduct oxygen is configured to be removed from the PTL to the flow fields. In such an arrangement, liquid water functions as both reactant and coolant on the anode side of the cell.

(30) In some examples, an anode catalyst coating layer may be positioned between the anode flow field **304** and the PTL.

(31) The cathode flow field **302** and anode flow field **304** of the cell may individually include a flow field plate composed of metal, carbon, or a composite material having a set of channels machined, stamped, or etched into the plate to allow fluids to flow inward toward the membrane or out of the cell.

(32) In order to achieve desired system performance, multiple cells may be placed together to form a “stack” of cells, which may be referred to as an electrochemical stack, electrolytic stack, electrochemical stack, or simply just a stack. In one example, a stack may contain 50-1000 cells, 50-100 cells, 500-700 cells, or more than 1000 cells. Any number of cells may make up a stack.

(33) Further, as noted below, the electrochemical stack may include a plurality of substacks making up a portion less than all of the entire stack, wherein each substack includes a plurality of electrochemical cells bookended by a cathode (unipolar) plate and an anode (unipolar) plate such that the cathode and anode plates define the boundaries of each substack. In certain examples, a substack may include at least 2 cells, at least 3 cells, at least 4 cells, at least 5 cells, at least 10 cells, less than or equal to 100 cells, less than or equal to 50 cells, less than or equal to 30 cells, less than

or equal to 25 cells, less than or equal to 20 cells, in a range of 2-100 cells, in a range of 3-50 cells, in a range of 4 to 30 cells, in a range of 5-25 cells, or in a range of 10-20 cells stacked on top of one another in the electrochemical system to provide an electrochemical stack.

(34) Electrochemical Substack

(35) FIG. 4 depicts, in an exploded view, an example of a substack **400** of an electrochemical stack. The substack **400** includes four electrochemical cells stacked on top of one another (e.g., connecting, abutting, or the like): a first electrochemical cell **420**, a second electrochemical cell **440**, a third electrochemical cell **460**, and a fourth electrochemical cell **480**.

(36) In certain examples, the substack **400** is not limited to four electrochemical cells. Instead, the substack may include any plurality of electrochemical cells as defined above. For example, a substack may include at least 2 cells, at least 3 cells, at least 4 cells, at least 5 cells, at least 10 cells, less than or equal to 100 cells, less than or equal to 50 cells, less than or equal to 30 cells, less than or equal to 25 cells, less than or equal to 20 cells, in a range of 2-100 cells, in a range of 3-50 cells, in a range of 4 to 30 cells, in a range of 5-25 cells, or in a range of 10-20 cells stacked on top of one another in the electrochemical system to provide an electrochemical stack.

(37) Each electrochemical cell (i.e., electrochemical cells **420**, **440**, **460**, and **480**) of the substack **400** includes a cathode flow field **302**, an anode flow field **304**, and a membrane **306** positioned between the cathode flow field **302** and the anode flow field **304**. As noted above, the cathode flow field **302** and anode flow field **304** of each cell may individually include a flow field plate composed of metal, carbon, or a composite material having a set of channels machined, stamped, or etched into the plate to allow fluids to flow inward toward the membrane or out of the cell.

(38) In certain examples, each cell may include additional layers such as a gas diffusion layer (GDL) **308** and a porous transport layer (PTL) **310**, such as those layers described with reference to the electrochemical cell in FIG. 3. For instance, the GDL **308** may be positioned between the cathode flow field **302** and the membrane **306**. On the opposite side of the cell, the PTL **310** may be present in each electrochemical cell between the membrane **306** and the anode **304**.

Additionally, in certain examples, the membrane **306** may be a catalyst coated membrane (CCM) having a cathode catalyst layer **305** and/or an anode catalyst layer **307** positioned on respective surfaces of the membrane **306**. However, in terms of simplicity, these additional layers are not illustrated in FIG. 4.

(39) As mentioned above, the substack **400** includes multiple cells stacked on top of one another. More particularly, the first electrochemical cell **420** is stacked on top of a second electrochemical cell **440**. The second electrochemical cell **440** is stacked on top of the third electrochemical cell **460**, and the third electrochemical cell **460** is stacked on top of the fourth electrochemical cell **480**.

(40) As depicted in FIG. 4, the cathode flow field **302** of the first electrochemical cell **420** is positioned adjacent to the anode flow field **304** of the second electrochemical **440**. The cathode flow field **302** of the second electrochemical cell **440** is positioned adjacent to the anode flow field **304** of the third electrochemical cell **460**. Additionally, the cathode flow field **302** of the third electrochemical cell **460** is positioned adjacent to the anode flow field of the fourth electrochemical cell **480**.

(41) The substack **400** also includes two plates **402**, **404** positioned on opposite ends of the substack **400**, therein serving as the termination points for the electrical connection of the substack. The plates may be unipolar plates, i.e., a cathode unipolar plate **402** and an anode unipolar plate **404**, positioned on opposite ends of the substack **400**.

(42) In other words, the multiple cells (i.e., **420**, **440**, **460**, and **480**) are positioned between the anode unipolar plate **404** and the cathode unipolar plate **402**, such as to enclose the plurality of cells. For example, the anode flow field **304** of the first electrochemical cell **420** abuts the internal surface of the anode unipolar plate **404**. As noted above, the anode flow field **304** and the anode unipolar plate **404** may be a single structure (i.e., the flow fields or channels are etched, carved, or otherwise formed on one surface of the anode unipolar plate).



(43) Likewise, the cathode flow field **302** of the fourth electrochemical cell **480** abuts the internal surface of the cathode unipolar plate **402**. Again, in some examples, the cathode flow field **302** and the cathode unipolar plate **402** may be a single structure (i.e., the flow fields or channels are etched, carved, or otherwise formed on one surface of the anode unipolar plate).

(44) The unipolar plates may be made of any metal or metal alloy suitable to withstand an electrolysis environment. In one particular example, the unipolar plates include titanium or a titanium alloy, which may advantageously provide strength and durability at a small thickness, therein not unduly increasing the height of the substack and overall stack. Specifically, in some examples, the thickness or height of each unipolar plate may be at least 0.1 mm, at least 1 mm, less than or equal to 10 mm, less than or equal to 5 mm, less than or equal to 3 mm, in a range of 0.1-10 mm, in a range of 1-5 mm, or in a range of 1-3 mm. The unipolar plates advantageously enclose the plurality of cells to form the substack **400**.

(45) Compression Tool

(46) FIGS. 5A-5E depict an example of a compression tool **500** for compressing a substack of electrochemical cells having a first plate, a second plate, and a plurality of electrochemical cells positioned between the first plate and the second plate. In certain examples, the first plate and the second plate may be first and second unipolar plates as described above in FIG. 4.

(47) As noted above, the compression tool **500** is advantageous over the state of the art in that the compression tool may be configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction. This provides several advantages including providing a level of compression on the electrochemical cell layers of the substack following assembly prior to insertion into the overall stack, during inclusion within the overall stack, and following removal from the overall stack. This may allow the cell layers within the plurality of electrochemical cells in the substack to remain within alignment following assembly, as the compression tool is not removed following insertion into the overall stack. Additionally, by maintaining the compression tool on the substack following insertion into the overall stack, the substack may advantageously be more easily removed from the overall stack for maintenance.

(48) As depicted in FIG. 5A, the compression tool **500** may include a first clamp component **502** having a first cavity **504** and a hole **506** as a base **508** of the first cavity **504**. In certain examples, the first clamp component may be configured to be positioned within a recess or pocket on an outer surface of the first plate of the substack such that the hole **506** at the base **508** of the first cavity **504** may be positioned toward a second clamp component **510** of the compression tool. This may be advantageous in not adding any additional height to the substack when the first clamp component **502** is added to the substack. That is, by positioning the first clamp component **502** within a recess or pocket in the plate of the substack, the thickness of the portion of the first clamp component **502** abutting the first plate within the recess/pocket does not extend beyond the outer surface of the first plate.

(49) The compression tool **500** may include a second clamp component **510** having a second cavity **512** and a hole **514** at a base **516** on the second cavity **512**. In certain examples, a depth of the second cavity (as measured in a direction from the first plate to the second plate or a direction from the second clamp component to the first clamp component) may be greater than a depth of the first cavity. In certain examples, the second clamp component **510** may be configured to be positioned within a recess or pocket on an outer surface of the second plate of the substack such that the hole **514** at the base **516** of the second cavity **512** may be positioned toward the first clamp component **502**. Again, this may be advantageous in not adding any additional height to the substack when the second clamp component **510** is added to the substack. That is, by positioning the second clamp component **510** within a recess or pocket in the plate of the substack, the thickness of the portion of the second clamp component **510** abutting the second plate within the recess/pocket does not extend beyond the outer surface of the second plate.

(50) The compression tool may include a fastener (e.g., a threaded fastener) **518** configured to connect the first and second clamp components **502**, **510** with each other, therein assisting in securing or holding the substack positioned between the two clamp components. In certain examples, the fastener **518** may include a machined stud or a bolt **520** having a thread **522** extending along at least a portion of the body of the machined stud or bolt. In certain examples, the bolt is a carriage bolt, hex bolt, stove bolt, or machine bolt. In certain alternative examples, the fastener contains no thread extending along the body of the component.

(51) Further, the fastener **518** may include a retaining component **524** such as a ring, clip, or nut used in conjunction with the machined stud or bolt to fasten the parts together. In certain examples, the retaining ring or clip may be a c-clip. In other examples, the nut may be a dome nut, hex nut, or flange nut, for example.

(52) While FIGS. 5A-5E depict examples of bolt and nut combinations, these principles may extend to other fastener examples as well, such as machined stud and c-clip combinations.

(53) As depicted in FIG. 5A, the bolt **518** includes a head **520** at a first end of the bolt and a thread **522** extending along at least a portion of a body of the bolt. The body of the bolt **518** may be configured to be positioned through the hole **506** of the first clamp component **502** and the hole **514** of the second clamp component **510**, and wherein the head **520** of the bolt **518** may be positioned within the first cavity **504** of the first clamp component **502**.

(54) The compression tool may include a tightening nut **526** that may be configured to be threaded onto the thread of the bolt **518** and positioned within the second cavity **512** of the second clamp component **510** such that the hole **514** at the base **516** of the second cavity **512** may be positioned between the first clamp component **502** and the tightening nut **526**. The tightening nut **526** may be configured to be adjusted on the thread of the bolt **518** within the second cavity **512** to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks. In other words, the positioning of the tightening nut **526** on the threaded body **522** of the bolt **518** may be adjusted on the threaded body **522** to provide or modify a desired compression on the substack positioned between the two clamp components connected by the fastener/bolt **518**.

(55) In certain examples, the compression tool **500** may include a lock nut **524** that may be configured to be threaded onto the thread of the bolt **518** to secure the first clamp component **502** between the head **520** of the bolt **518** and the lock nut **524**. In practice, the lock nut **524** would be positioned on the threaded bolt prior to the inclusion of the second clamp component **510**. In other words, the body **522** of the threaded bolt **518** may be positioned through the hole **506** of the first clamp component **502**, and the lock nut **524** may then be fastened onto the body **522** of the bolt **518** to secure the first clamp component **502** between the head **520** of the bolt **518** and the lock nut **524**. Subsequent to securing the first clamp component **502** in place, the first clamp component **502** may be positioned within the recess or pocket of the first plate of the substack and further secured with the second clamp component **510** and tightening nut **526** as described above.

(56) In certain examples, the compression tool may include a spring mechanism, e.g., attached to at least one of the clamp components. Such a spring mechanism may be advantageous in providing a preload to the compression tool to assist in installation of the compression tool on the substack.

(57) As depicted in FIG. 5B, the compression tool **500** may include a tightening tool **530** configured to assist in securing the tightening nut **526** on the threaded bolt **518** within the recess **512** of the second clamp component **510**. In certain examples, after placing the tightening nut **526** on the threaded bolt **518**, the compression or tightening tool **530** may be aligned with the tightening nut **526** to move the tightening nut **526** down the threaded bolt **518** toward the first clamp component **502** to compress the substack between the two clamp components. In certain examples, the compression or tightening tool **530** may be configured to grip or clamp onto the tightening nut **526** to screw the tightening nut **526** and compress the substack. In some examples, the compression or tightening tool **530** may also be configured to grip or clamp onto the tightening nut **526** to

unscrew or loosen the compression on the substack. In one particular example, such as depicted in FIG. 5B, the compression or tightening tool **530** may be threaded onto the thread of the bolt **518** at a second end of the bolt opposite the first end or head **520** of the bolt **518** (after the tightening nut **526** has been attached to the thread of the bolt **518**). The tightening tool **530** may then be configured to be twisted or moved in a clockwise direction to abut the tightening nut **526** and move the tightening nut **526** in the same direction to tighten the tightening nut **526** to compress the substack.

(58) In certain examples, the tightening nut **526** may be tightened along the body **522** of the bolt **518** to a predetermined height. This may provide a desired or a first compression on the plurality of electrochemical cells of the substack. The tightening tool **530** may be configured to be removed from the compression tool **500** after the substack has been compressed to the predetermined height.

(59) In certain examples, the compression tool **530** may include a spacer configured to be inserted into an opening between the first clamp component **502** and the second clamp component **510** to set the predetermined height.

(60) FIG. 5C depicts an example of a spacer **532** being used with the compression tool **500**. In this example, the spacer **532** may be inserted prior to twisting or moving the tightening nut **526** down the body **522** of the bolt **518** toward the first clamp component **502**. After the first clamp component **502** and second clamp component **510** move towards each other a certain distance, the first and second clamp components may begin to abut the centrally positioned spacer **532**, therein identifying that the tightening nut **526** and abutting second clamp component **510** have reached the desired/predetermined height for compressing the substack.

(61) In certain examples, a plurality of different spacers with different sizes/heights may be provided. This may be advantageous for providing different substack heights for substacks having a different number of cells. In other words, a first spacer may be provided for a substack having four electrochemical cells such that the predetermined height for compression is appropriately scaled for four cells, while a second spacer may be provided for a substack of five electrochemical cells with a different associated predetermined height that provides a similar initial/first compression. As such, depending on the number of cells within the substack, a spacer **532** can be configured to provide and guide the tightening of the tightening nut **526** to a predetermined height associated with that number of cells in the substack for the initial/first compression of the stack. This is advantageous in limiting user/operator error in overly tightening the tightening nut **526** and either warping the first or second plates of the substack or overly compressing the substack prior to insertion into the overall stack. The spacer **532** is also advantageous in avoiding user/operator error in under tightening the tightening nut **526** and under compressing the substack, therein potentially leading to shifting of cell layers within the substack during movement/insertion of the substack into the overall stack.

(62) In certain examples, the spacer **532** may be configured to be removed from the compression tool **500** after the substack has been compressed to the predetermined height.

(63) FIG. 5D depicts an example of the compression tool **500** following removal of the tightening tool and the spacer, as depicted and described with reference to FIGS. 5B and 5C. As depicted in this example, the tightening nut **526** is attached to the threaded body of the bolt and positioned within the cavity **512** of the second clamp component **510**, therein providing a compression on the substack layers positioned between the two clamp components.

(64) In certain examples, the compression tool **500** may include a lifting mechanism configured to transport the substack.

(65) FIG. 5E depicts an example of such a lifting mechanism **534**. In this example, the lifting mechanism **534** may be configured to threaded onto the thread of the bolt **518** at a second end of the bolt opposite the first end/head **520**. In certain examples, the lifting mechanism **534** may include an eyelet, hook, or other latching element **536** configured to provide an attachment point for securing a separation lifting component to the compression tool **500** to assist moving or lifting

the substack and attached compression tool **500**, e.g., for loading or removing the substack from the overall stack. In certain examples, the lifting mechanism **534** may be configured to be removed from the compression tool **500** after the substack has been added to the electrochemical stack assembly.

(66) In certain alternative examples, the lifting mechanism **534** may be a fixed element attached to the first clamp component or the second clamp component.

(67) FIG. **6** depicts such an alternative embodiment of a compression tool having a fixed lifting mechanism. In this example, the compression tool includes a first clamp component, a second clamp component, and a bolt extending between the first and second clamp components. While not depicted in the figure, a lock nut and tightening nut may be present, as described above with FIGS. **5A-5E**.

(68) In this example, the lifting mechanism is fixed to the second clamp component. While not depicted, it is alternatively possible for the lifting mechanism to be fixed to the first clamp component instead.

(69) FIG. **6** depicts an alternative example of a compression tool **600** having a lifting mechanism **634** permanently fixed to the compression tool **600**. Similar to the example described in FIG. **5A**, the compression tool **600** may include a first clamp component **602** having a first cavity (not depicted) and a hole **606** as a base **608** of the first cavity. The compression tool **600** may also include a second clamp component **610** having a second cavity **612** and a hole (not depicted) at a base **616** on the second cavity **612**. In certain examples, a depth of the second cavity (as measured in a direction from the first plate to the second plate or a direction from the second clamp component to the first clamp component) may be greater than a depth of the first cavity.

(70) The compression tool may include a fastener **618** (e.g., bolt or machined stud) configured to connect the first and second clamp components **602**, **610** with each other, therein assisting in securing or holding the substack positioned between the two clamp components. In certain examples, the fastener **618** may include a thread **622** extending along at least a portion of the body of the machined stud or bolt.

(71) Further, the fastener **618** may include a retaining component such as a ring, clip, or nut used in conjunction with the machined stud or bolt to fasten the parts together. In certain examples, the retaining ring or clip may be a c-clip. In other examples, the nut may be a dome nut, hex nut, or flange nut, for example.

(72) As noted above, in this example of a compression tool **600**, the lifting mechanism **634** is permanently attached or fixed to the second clamp component **610**. In alternative examples, the lifting mechanism may be permanently fixed to the first clamp component **602**. As depicted in FIG. **6**, the lifting mechanism **634** may include a latching element **636** such as an eyelet. Alternatively, a hook or other latching element may be present to provide an attachment point for assisting in moving or lifting the substack and attached compression tool **600**, e.g., for loading or removing the substack from the overall stack. The lifting mechanism **634** may extend in a direction perpendicular to the bolt **618** (i.e., parallel with the electrochemical cell layers within the substack), extending outward from the plurality of electrochemical cells within the substack. This orientation is advantageous in allowing the lifting mechanism **634** to remain fixed or otherwise attached to the compression tool **600** without interfering in the operation of the substack. Further, the outward orientation provides an easy access or latch point to remove the substack from the overall stack.

(73) As depicted in FIG. **6**, the first clamp component **602** and the second clamp component **610** may each have a rectangular or square shaped portion **638**, **640** configured to fit within a similarly shaped rectangular or square shaped recess or pocket on an outer surface of the respective plate of the substack. Alternatively shaped configurations are also possible.

(74) FIGS. **7A-7D** depict an additional example of a compression tool **700**. For example, FIGS. **7A** and **7B** depict portions of a compression tool **700** that include a first clamp component **702** and a second clamp component **710**. The first clamp component **702** in FIG. **7B** includes a first cavity

(not depicted) and a hole **706** as a base **708** of the first cavity. FIG. 7A depicts the second clamp component **710** having a second cavity **712** and a hole (not depicted) at a base **716** on the second cavity **712**.

(75) In this example of a compression tool **700**, the first clamp component **702** and second clamp component **710** each includes a circular or oval-shaped portion **738**, **740** that is configured to fit into a respective recess or pocket on the outer surface of a substack plate. This may be advantageous in retaining the clamp component within the recess after compression, as the circular/oval shape prevents the clamp component from sliding out of the side of the stack after being compressed.

(76) As depicted in FIGS. 7A and 7B, the first and second clamp components **702**, **710** may have a truncated or flat portion **742**, **744** of the circular/oval shape of the clamp component. This flat or truncated section/portion **742**, **744** of the clamp component may be positioned on the outer edge of the substack when the clamp component **702**, **710** is added to the substack and compressed. This may be advantageous in arranging the clamp component in a specific orientation and additionally not having the clamp component extend beyond an outer edge of the substack.

(77) FIG. 7C depicts additional components forming the compression tool **700** that include the first and second clamp components **702**, **710** from FIGS. 7A and 7B. In this example, FIG. 7C further depicts a fastener **718** configured to connect the first and second clamp components **702**, **710** with each other, therein assisting in securing or holding the substack positioned between the two clamp components. In certain examples, the fastener **718** may include a machined stud or a bolt (e.g., having a thread extending along at least a portion of the body of the machined stud or bolt).

(78) Further, the fastener **718** may include a retaining component **724** such as a ring, clip, or nut used in conjunction with the machined stud or bolt to fasten the parts together. As depicted in this example in FIG. 7C, the retaining component is a c-clip.

(79) FIG. 7D depicts an additional cross-sectional view of the compression tool **700** of FIG. 7C. In this figure, the compression tool includes the first clamp component **702** having a first cavity **704** and a hole **706** as a base **708** of the first cavity **704**. The compression tool **700** further includes the second clamp component **710** having a second cavity **712** and a hole **714** at a base **716** on the second cavity **712**.

(80) The compression tool includes the fastener **718** configured to connect the first and second clamp components **702**, **710** with each other, therein assisting in securing or holding the substack positioned between the two clamp components. In certain examples, the fastener **718** may include a machined stud or a bolt (e.g., having a thread extending along at least a portion of the body of the machined stud or bolt). Further, the fastener **718** includes a c-clip retaining component **724**.

(81) As depicted in FIG. 7D, the bolt **718** includes a head **720** at a first end of the bolt and a thread extending along at least a portion of a body of the bolt. The body of the bolt **718** may be configured to be positioned through the hole **706** of the first clamp component **702** and the hole **714** of the second clamp component **710**, and the head **720** of the bolt **718** may be positioned within the first cavity **704** of the first clamp component **702**.

(82) In this example, near an opposite end of the head **720** of the fastener or bolt **718**, the fastener/bolt **718** includes a notch or cavity **746** in a surface of the threaded fastener **718**. In certain examples, the notch may be present and extend around or circumnavigate the entire diameter of the fastener **718**. In other alternative embodiments, the notch **746** may include one or more notches or cavities, each of which extends around only a portion of the diameter of the fastener **718**. The notch or notches present in the fastener may be advantageous providing a quick connect interface with a lifting mechanism, such as depicted in FIG. 5E.

(83) The compression tool may include a second retaining component (i.e., c-clip) **726** that may be configured to be attached to the bolt **718** and positioned within the second cavity **712** of the second clamp component **710** such that the hole **714** at the base **716** of the second cavity **712** may be positioned between the first clamp component **702** and the retaining component/c-clip **726**. The

positioning of the c-clip **726** may be configured to be adjusted on the bolt **718** within the second cavity **712** to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks. In other words, the positioning of the c-clip **726** on the body of the bolt **718** may be adjusted to provide or modify a desired compression on the substack positioned between the two clamp components connected by the fastener/bolt **718**.

(84) In certain examples, as noted above for FIG. 7C, the compression tool **700** may include a lock nut or c-clip **724** that may be configured to be attached to the bolt **718** to secure the first clamp component **702** between the head **720** of the bolt **718** and the c-clip **724**.

(85) In this example depicted in FIG. 7D, the compression tool further includes a spring or spring mechanism **748** that may be advantageous in providing a preload to the compression tool to assist in installation of the compression tool on the substack. In this example, the spring **748** is positioned around the outer circumference of the bolt **718** within the second cavity **712** of the second clamp component **710**, between the base **716** of the second cavity **712** and the c-clip/retaining component **726**.

(86) Compression Tool Coupled to a Substack

(87) As noted above, the first and second plates of the substack may each include an opening having a recess or pocket in the outer surface at an edge of the respective plate to receive and secure a clamp component of the compression tool.

(88) FIGS. **8A** and **8B** depict such examples of openings having recesses or pockets within the outer edges of the plates. Specifically, FIG. **8A** depicts a first plate **800** having a first opening **802** with a first recess or pocket **804** in an outer edge **806** of the first plate **800** that is configured to receive one of the clamp components, while FIG. **8B** depicts a second plate **810** having a second opening **812** with a second recess or pocket **814** in an outer edge **816** of the second plate **810** that is configured to receive the other of the two clamp components.

(89) In these examples, the opening **802**, **812** extends through the depth or height of the respective plate to receive the respective component. Further, the opening **802**, **812** includes a recess **804**, **814** positioned on an outer edge **806**, **816** of the plate **800**, **810** that is wider than the remaining portion of the opening. This may be advantageous in retaining or preventing the clamp component from sinking into the opening of the plate beyond its desirable location. Further, this recess **804**, **814** is configured to align with the shape of the portion of the clamp component to secure the clamp component within the plate. Additionally, and advantageously, the recess **804**, **814** is designed and configured such that no portion of the clamp component extends beyond an outer edge **806**, **816** of the plate **800**, **810**. This is advantageous for allowing the compression tool to remain fixed to the substack after installation in the overall stack of the electrochemical plant or system, as the compression tool does not add any height to the substack and does not restrict installation of further substacks within the overall stack.

(90) Furthermore, FIGS. **9A** and **9B** depict an example of a second clamp component **710** positioned within the opening of a second plate **800** depicted in FIG. **8A**. FIG. **9A** depicts a side view while FIG. **9B** depicts a top view of the clamp component **710** within the opening **802**. In this example, the second clamp component **710** has a rectangular or square shaped portion **740** configured to fit within a similarly shaped recess or pocket **804** of the opening **802** in the plate **800**. As noted above, other shapes are possible, and the clamp component may have a circular or oval portion that fits in a similarly shaped recess/pocket of the opening in the plate. As noted above, the clamp component **710** is configured to be positioned within the recess or pocket **804** of the plate **800** such that the outer surface of the clamp component **710** does not extend beyond the outer edge/surface **806** of the plate **800**.

(91) Additionally, FIGS. **9C** and **9D** depict an example of a first clamp component **702** positioned within the opening **812** of the first plate **810** depicted in FIG. **8B**. FIG. **9C** depicts a side view while FIG. **9D** depicts a top view of the clamp component **702** within the opening **812**. In this example,

the clamp component **702** has a rectangular or square shaped portion **738** configured to fit within a similarly shaped recess or pocket **814** of the opening **812** in the plate **810**. As noted above, other shapes are possible, and the clamp component may have a circular or oval portion that fits in a similarly shaped recess/pocket of the opening in the plate. Furthermore, the clamp component **702** is configured to be positioned within the recess or pocket **814** of the plate **810** such that the outer surface of the clamp component **702** does not extend beyond the outer edge/surface **816** of the plate **810**.

(92) FIGS. **10A-10C** depict an example **1000** of a substack **1002** for an electrochemical stack having a plurality of electrochemical cells, a first plate, and a second plate, wherein the electrochemical cells are positioned between the first plate and the second plate. Specifically, FIG. **10A** depicts an isometric view of a substack **1002** having a plurality of openings or cutouts **1004** (i.e., **4**) within the substack perimeter and a respective compression tool **1006** positioned within each respective opening. The compression tool may be an embodiment as identified and described above with reference to FIGS. **5A-9D** above.

(93) Each opening or cutout **1004** allows for portions of the first and second clamp components as well as the bolt extending between the two clamp components to be positioned within the respective opening. Additionally, as noted above, the first and second plates of the substack also include recesses or pockets within the outer surfaces of the plates allowing the respective clamp component to be secured within the recess/pocket and not protrude outward beyond the outer surface of the respective plate of the substack **1002**.

(94) FIG. **10B** depicts a top view of the substack of represented in FIG. **10A** and FIG. **10C** depicts a side view of the substack represented in FIG. **10A**.

(95) In this particular example in FIGS. **10A-10C**, there are four compression tools **1006** attached to and providing compression to the substack **1002**. More or fewer compression tools are possible.

(96) The location of each compression tool **1006** is also configurable. In one example, compression tools are provided only on the long sides of the rectangular shaped substack **1002**, such as depicted in FIGS. **10A-10C**. For example, a plurality of compression tools (e.g., at least two) are positioned on each long side of the substack. In certain examples, such as shown in FIGS. **10A-10C**, each compression tool on one long side of the substack is matched with a similarly positioned compression tool on the opposite long side of the substack. Alternatively, the positioning of each compression tool does not need to match or mirror the positioning of another compression tool's location.

(97) In an alternative example, compression tools may be positioned only on the short sides of the rectangular shaped substack. In further alternative examples, compression tools may be positioned on three or four sides of the substack.

(98) As noted above, these compression tools are advantageously configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

(99) Methods of Forming a Substack for an Electrochemical Stack

(100) FIG. **11** depicts a flowchart describing an example process of forming a substack of an electrochemical stack. In such an example, a substack is provided that includes a plurality of electrochemical cells, a first plate, and a second plate, wherein the plurality of electrochemical cells is positioned between the first and second plates.

(101) In act **S101**, the method includes positioning a first clamp component having a first cavity and a hole at a base of the first cavity, within a recess on an outer surface of the first plate of the substack and positioning the first cavity toward a second clamp component.

(102) In act **S103**, the method further includes positioning the second clamp component having a second cavity and a hole at a base on the second cavity wherein a depth of the second cavity is greater than a depth of the first cavity, within a recess on an outer surface of the second plate of the substack and positioning the hole at the base of the second cavity toward the first clamp

component.

(103) In act **S105**, the method further includes positioning a body of a threaded fastener (e.g., bolt or stud) having a head at a first end of the threaded fastener and thread extending along at least a portion of a body of the threaded fastener, through the hole of the first clamp component and the hole of the second clamp component and positioning the head of the threaded fastener within the first cavity of the first clamp component.

(104) In act **S107**, the method further includes positioning a retaining component (e.g., tightening nut or clip) onto the thread of the threaded fastener within the second cavity of the second clamp component. The method further includes positioning the hole at the base of the second cavity between the first clamp component and the retaining component.

(105) In act **S109**, the method further includes adjusting the retaining component in the thread of the threaded fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks.

(106) In act **S111**, the method further includes adding the substack to the electrochemical stack assembly, wherein the compression tool is maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

(107) In certain examples, the method may include threading a lock nut onto the thread of the threaded fastener and securing the first clamp component between the head of the threaded fastener and the lock nut.

(108) In certain examples, the method may include threading a tightening tool onto the thread of the threaded fastener at a second end of the threaded fastener opposite the first end, tightening the retaining component (e.g., tightening nut or clip) to a predetermined height, and providing the first compression of the plurality of electrochemical cells of the substack. The method may include removing the tightening tool after the substack has been compressed to the predetermined height.

(109) In certain examples, the method may include inserting a spacer into an opening between the first clamp component and the second clamp component to set the predetermined height. The method may include removing the spacer after the substack has been compressed to the predetermined height.

(110) In certain examples, the method may include transporting the substack using a lifting mechanism. The method may include threading the lifting mechanism onto the thread of the threaded fastener at a second end of the threaded fastener opposite the first end. The method may include attaching the lifting mechanism to the first clamp component or the second clamp component and extending the lifting mechanism in a direction perpendicular to the threaded fastener. The method may include removing the lifting mechanism after the substack has been added to the electrochemical stack assembly.

(111) In certain examples, the method may include maintaining alignment of cell layers within the plurality of electrochemical cells in the substack.

(112) One or more embodiments of the disclosure may be referred to herein, individually and/or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any particular invention or inventive concept. Moreover, although specific embodiments have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all subsequent adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, are apparent to those of skill in the art upon reviewing the description.

(113) As used herein, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise.



(114) As used herein, “for example,” “for instance,” “such as,” or “including” are meant to introduce examples that further clarify more general subject matter. Unless otherwise expressly indicated, such examples are provided only as an aid for understanding embodiments illustrated in the present disclosure and are not meant to be limiting in any fashion. Nor do these phrases indicate any kind of preference for the disclosed embodiment.

(115) The Abstract of the Disclosure is provided to comply with 37 C.F.R. § 1.72(b) and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all of the features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description, with each claim standing on its own as defining separately claimed subject matter.

(116) It is intended that the foregoing detailed description be regarded as illustrative rather than limiting and that it is understood that the following claims including all equivalents are intended to define the scope of the disclosure. The claims should not be read as limited to the described order or elements unless stated to that effect. Therefore, all embodiments that come within the scope and spirit of the following claims and equivalents thereto are claimed as the disclosure.

## Claims

1. A compression tool for compressing a substack of electrochemical cells having a first plate, a second plate, and a plurality of electrochemical cells positioned between the first plate and the second plate, the compression tool comprising: a first clamp component having a first cavity and a hole at a base of the first cavity, wherein the first clamp component is configured to be positioned within a recess on an outer surface of the first plate of the substack such that the hole at the base of the first cavity is positioned toward a second clamp component of the compression tool; the second clamp component having a second cavity and a hole at a base on the second cavity, wherein a depth of the second cavity is greater than a depth of the first cavity, wherein the second clamp component is configured to be positioned within a recess on an outer surface of the second plate of the substack such that the hole at the base of the second cavity is positioned toward the first clamp component; a fastener having a head at a first end and a body, wherein the body is configured to be positioned through the hole of the first clamp component and the hole of the second clamp component, and wherein the head is positioned within the first cavity of the first clamp component; and a retaining component configured to be attached to or threaded onto a thread of the fastener and positioned within the second cavity of the second clamp component such that the hole at the base of the second cavity is positioned between the first clamp component and the retaining component, wherein the retaining component is configured to be adjusted on the fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks; and wherein the compression tool is configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.
2. The compression tool of claim 1, further comprising: a lock nut or clip configured to be attached to or threaded onto the fastener to secure the first clamp component between the head of the fastener and the lock nut or the clip.
3. The compression tool of claim 1, wherein the retaining component is a tightening nut or clip.
4. The compression tool of claim 3, further comprising: a tightening tool configured to thread onto the fastener at a second end of the fastener opposite the first end and tighten the tightening nut to a

predetermined height to provide the first compression of the plurality of electrochemical cells of the substack, wherein the tightening tool is configured to be removed from the compression tool after the substack has been compressed to the predetermined height.

5. The compression tool of claim 4, further comprising: a spacer configured to be inserted into an opening between the first clamp component and the second clamp component to set the predetermined height, wherein the spacer is configured to be removed from the compression tool after the substack has been compressed to the predetermined height.

6. The compression tool of claim 1, further comprising: a lifting mechanism configured to transport the substack.

7. The compression tool of claim 6, wherein the lifting mechanism is configured to attach or thread onto the fastener at a second end of the fastener opposite the first end, and wherein the lifting mechanism is configured to be removed from the compression tool after the substack has been added to the electrochemical stack assembly.

8. The compression tool of claim 6, wherein the lifting mechanism is permanently attached to the first clamp component or the second clamp component and extends in a direction perpendicular to the fastener.

9. The compression tool of claim 6, wherein the fastener comprises a notch near an end of the fastener, wherein the notch provides a quick connect interface with the lifting mechanism.

10. The compression tool of claim 1, wherein the fastener is a bolt or a machined stud.

11. The compression tool of claim 1, further comprising: a spring positioned within the second cavity of the second clamp component around an outer circumference of the fastener between a base of the second cavity and the retaining component.

12. A substack for an electrochemical stack, the substack comprising: a plurality of electrochemical cells; a first plate; and a second plate, wherein the plurality of electrochemical cells is positioned between the first plate and the second plate; and a compression tool comprising: a first clamp component having a first cavity and a hole at a base of the first cavity, wherein the first clamp component is positioned within a recess on an outer surface of the first plate of the substack such that the hole at the base of the first cavity is positioned toward a second clamp component of the compression tool; the second clamp component having a second cavity and a hole at a base on the second cavity, wherein a depth of the second cavity is greater than a depth of the first cavity, wherein the second clamp component is positioned within a recess on an outer surface of the second plate of the substack such that the hole at the base of the second cavity is positioned toward the first clamp component; a fastener having a head at a first end and a body, wherein the body is configured to be positioned through the hole of the first clamp component and the hole of the second clamp component, and wherein the head is positioned within the first cavity of the first clamp component; and a retaining component configured to be attached to or threaded onto the fastener and positioned within the second cavity of the second clamp component such that the hole at the base of the second cavity is positioned between the first clamp component and the retaining component, wherein the retaining component is configured to be adjusted on the fastener within the second cavity to provide a first compression of the plurality of electrochemical cells within the substack outside of an electrochemical stack assembly having a plurality of substacks; and wherein the compression tool is configured to be maintained on the substack after the substack is added to the electrochemical stack assembly and the electrochemical stack assembly commences operation of an electrolysis reaction.

13. The substack of claim 12, further comprising: a lock nut or clip attached to or threaded onto the fastener to secure the first clamp component between the head of the fastener and the lock nut or the clip.

14. The substack of claim 12, wherein the retaining component is a tightening nut or clip.

15. The substack of claim 14, further comprising: a tightening tool configured to thread onto the fastener at a second end of the fastener opposite the first end and tighten the tightening nut to a

predetermined height to provide the first compression of the plurality of electrochemical cells of the substack, wherein the tightening tool is configured to be removed from the compression tool after the substack has been compressed to the predetermined height.

16. The substack of claim 15, further comprising: a spacer configured to be inserted into an opening between the first clamp component and the second clamp component to set the predetermined height, wherein the spacer is configured to be removed from the compression tool after the substack has been compressed to the predetermined height.

17. The substack of claim 12, further comprising: a lifting mechanism configured to transport the substack, wherein the lifting mechanism is configured to attach or thread onto the fastener at a second end of the fastener opposite the first end, and wherein the lifting mechanism is configured to be removed from the compression tool after the substack has been added to the electrochemical stack assembly.

18. The substack of claim 17, wherein the fastener comprises a notch near an end of the fastener, wherein the notch provides a quick connect interface with the lifting mechanism.

19. The substack of claim 12, further comprising: a spring positioned within the second cavity of the second clamp component around an outer circumference of the fastener between a base of the second cavity and the retaining component.

20. The substack of claim 12, wherein the compression tool maintains an alignment of cell layers within the plurality of electrochemical cells in the substack.

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