

Battery Tower

TECHNICAL FIELD

- 5 The present invention relates to a battery tower comprising a stack of cell housings and a connector that fluidly couples cooling ducts of adjacently stacked cell housings, and to a battery pack comprising a plurality of such battery towers.

BACKGROUND

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An increasing focus on using renewable energy instead of fossil fuels has led to the development of many new electrical products. For example, cars, trains, heating systems and domestic products may all be powered by electricity. In some cases it may be advantageous for an electrical product to be powered, at least in part, by an electro-chemical battery. A
15 battery typically includes a plurality of cells that are electrically connected to one another in some way. Whilst batteries have many advantages, some technical challenges remain.

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For example, charging and discharging a battery cell can cause the temperature of the respective cell to vary. Such fluctuations in cell temperature may, over time, cause a change in resistance, loss of charging or discharging performance, and mechanical stresses, and may therefore be detrimental to the longevity of the cell. Accordingly, managing the temperature of the cells in use is an important consideration.

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Further, battery cells typically contain chemicals and therefore require protection from damage for safe use. Finally, batteries may be used in applications where space is limited, and a space-efficient battery cell arrangement and temperature management solution may therefore be advantageous in many situations.

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It is against this background that the present invention has been developed.

SUMMARY OF THE INVENTION

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According to an aspect of the invention there is provided a battery tower comprising a plurality of cell housings stacked on top of one another. Each cell housing defines at least one cell compartment and a cooling duct thermally coupled to the at least one cell compartment. The

battery tower further comprises a cooling duct connector attached to two adjacently stacked cell housings to fluidly couple the cooling ducts of the two adjacently stacked cell housings.

5 In use, the cooling duct preferably comprises a cooling fluid. Accordingly, the battery tower may be referred to as a fluid-cooled battery tower. The cooling fluid may comprise a cooling liquid. For example, the cooling fluid may comprise water or a water-based cooling liquid. The battery tower is therefore advantageously configured to both retain, i.e. hold, one or more battery cells and to also provide cooling to the battery cells retained by the cell housing, in use. As such, the battery tower facilitates effective cooling and space efficient means for support and organisation of multiple cells. Additionally, the cell housings, and in particular the cell compartments, may help to protect cells in the battery tower.

15 The battery tower facilitates management of the temperature of cells retained within cell compartments of the respective cell housings. In particular, in advantageous examples the battery tower comprises cell housings featuring cell compartments and an integrated cooling duct. Cooling is therefore provided at least in part by the same components that retain the cells in position. The battery tower may therefore be referred to as an integrally-cooled battery tower in some examples.

20 Whilst reference is made herein primarily to cooling cells in the cell housings, it will be appreciated that the apparatus described herein is primarily configured to facilitate heat transfer between the cells and the cooling duct (i.e. a cooling fluid in the cooling duct, in use) of a respective cell housing. Accordingly, the battery tower described herein facilitates temperature management of cells in the cell compartments, i.e. both cooling and heating such cells. Cooling the cells is described in more detail throughout, but by way of a further example, cells retained in the cell compartments may also be heated, in use, by providing a fluid in the cooling ducts which is at a higher temperature than the cells in the cell compartments. In such an example, a heating fluid in the cooling ducts may supply heat to the cell housing, and in particular to the cell compartments via conduction through the cell housing, thereby supplying heat to a respective cell in the cell compartment. References herein to a cooling duct may therefore be understood to also refer more generally to a fluid duct, and references herein to a cooling fluid may be understood to also refer more generally to a fluid and not just a cooling fluid. The facility to both heat and cool the cells may be advantageous for maintaining the temperature of the cells in a safe and/or optimal temperature range, thereby increasing performance of the cells and/or increasing their longevity.

Thermally coupling the cell compartment(s) and cooling duct of a cell housing facilitates the transfer of thermal energy, i.e. heat, between the cell compartment(s) and the cooling duct of the respective cell housing. A cell compartment of a cell housing may be directly thermally coupled to the cooling duct, e.g. if the cell compartment and cooling duct are defined by a single, monolithic component, or indirectly thermally coupled via a separate conductive component. The term "thermally coupled" should therefore be understood to refer to the facility for transferring heat between the cell compartment(s) and the cooling duct of a cell housing. Conversely, for context, if a component is thermally insulated it is not thermally coupled to another component. For example, such a thermally insulated component may be separated from another component by a thermally insulating material.

As used herein, the terms "stacked" and "adjacently stacked" refer to the relative position of components above one another. As such, in some examples a stacked arrangement of cell housings may include adjacently stacked cell housings in direct contact with one another. In some preferred examples, the battery tower may include one or more other components or materials between adjacently stacked cell housings, i.e. between cell housing that are stacked on top of one another. For example, the battery tower may include an adhesive or a filler material between adjacently stacked cell housings. Advantageously, such an adhesive or filler material may compensate for manufacturing tolerances when assembling the battery tower, such as dimensional tolerances of the cell housings which could affect alignment of the cell housings relative to one another. For example, a thixotropic adhesive may be particularly advantageous for filling gaps between adjacent cell housings during assembly of the tower. Additionally, in some examples the adhesive or filler material may be thermally conductive, and may thereby facilitate heat transfer between adjacently stacked cell housings.

In some examples, the battery tower may comprise a gasket arranged between the cooling duct connector and the respective cell housing to which the cooling duct connector is attached. In some examples, the or each gasket may comprise rubber. For example, the gasket may comprise nitrile rubber. In some examples, the or each gasket may comprise silicone. In some examples, the or each gasket may comprise a fibre-reinforced gasket, i.e. the gasket may comprise fibrous material impregnated with rubber or silicone, for example. In some preferred examples, the or each gasket may comprise an elastomeric polymer, such as thermoplastic polyurethane (TPU) for example. Accordingly, the or each sealing gasket may be an overmoulded thermoplastic polyurethane sealing gasket. A sealing gasket may improve the seal between the cooling duct connector and the adjacently stacked cell housings to which it is connected. In particular, a sealing gasket may compensate for minor expansions or

contractions of the cell housing and/or connector resulting from temperature fluctuations in use to thereby ensure that a seal is maintained between the respective parts. In some preferred examples, the battery tower may comprise a plurality of sealing gaskets, and each cell housing may be sealed to the cooling duct connector with a respective individual gasket.

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In some preferred examples, the cooling duct of each cell housing may extend substantially horizontally within the respective cell housing. Stacking the cell housings comprising horizontally-extending cooling ducts vertically on top of one another is particularly advantageous. In examples wherein the cooling ducts comprise a cooling liquid, such as water
10 for example, horizontally oriented cooling ducts may be advantageous for minimising the risk of trapping air, i.e. air bubbles, in the cooling ducts, which could reduce the efficiency with which heat is transferred away from the cell compartment(s), in use. Additionally, configuring the battery tower with vertically stacked cell housings having a plurality of interconnected horizontally-extending cooling ducts may facilitate bleeding all of the cooling ducts of air in a
15 single action when they are first filled, in use, because this arrangement avoids air being trapped within the cooling ducts. Further, in some examples, the cell housing and cell compartment(s) defined by the cell housing may be elongated in the horizontal direction. In particular, in some examples the cell compartment(s) may extend longitudinally in a compartment direction, along a cell compartment axis. Accordingly, the cell housing may be
20 configured such that the cell compartment axis is substantially horizontal, in use. As such, a cooling duct extending horizontally in the cell housing along a cell compartment may advantageously present a large surface area for transferring heat from the respective cell compartment to a cooling fluid in the cooling duct, in use.

25 In some preferred examples, a "substantially horizontally" extending cooling duct may be inclined at less than +/- 2 degrees from horizontal (0 degrees), or more preferably still at less than +/- 1 degrees from horizontal, in use. Orienting the cooling ducts in this range and/or orienting the battery tower such that the cooling ducts extend in this range is particularly advantageous for minimising the risk of trapping air in the cooling ducts. It will be appreciated
30 that inclination of a cooling duct preferably refers to an angle defined between a horizontal line (i.e. 0 degrees) and a longitudinal axis of the cooling duct. Most preferably the cooling duct may not be inclined relative to horizontal, i.e. the cooling duct may be inclined at 0 degrees from horizontal, in use.

35 In some examples, each cooling duct may be a substantially u-shaped cooling duct. Accordingly, each cooling duct may comprise a first portion configured to flow fluid in a first

direction and a second portion configured to flow fluid in a second direction that is substantially opposite to the first direction. A u-shaped cooling duct may be particularly advantageous for transferring heat away from the cell compartment(s) in use because a u-shaped cooling duct presents a large surface area for conducting heat from the respective cell compartment to a cooling fluid in the cooling duct, and may help to distribute the cooling effect more evenly along the cell compartment.

Further, as described later in more detail, in some examples the battery tower may comprise more than two cell housings stacked on top of one another. If each cooling duct is substantially u-shaped, and each cell housing is oriented the same way, then the cooling ducts of each cell housing in the stack may each start and end on the same side of the battery tower. Accordingly, the cooling ducts of the adjacently stacked cell housings may all be fluidly coupled at the same side of the battery tower. This may be beneficial for assembly and maintenance of the battery tower. Each cell housing may therefore comprise a connection end at which the cooling duct connector is attached, and each cell housing may be arranged with its respective connection end on the same side of the battery tower.

In some examples, the first portion of the cooling duct may be a lower portion and the second portion may be an upper portion. The first and second portions of each cooling duct may extend substantially horizontally in the cell housing. As described previously, a horizontally-extending cooling duct may be particularly advantageous for heat transfer in examples wherein the cell housing and cell compartment(s) defined by the cell housing are elongated in the horizontal direction, and may help to minimise the risk of air bubbles being trapped in the cooling duct. Additionally, a u-shaped cooling duct may distribute the cooling effect achieved by cooling fluid in the cooling duct in use, in an advantageous way. For example, a horizontally-extending u-shaped cooling duct may help to reduce temperature variations and/or minimise a temperature gradient along the horizontal length of the or each cell compartment.

In some examples, the u-shaped cooling duct of each cell housing may be defined at least in part by a channel extending through the entire length of the cell housing and by an end cap blocking one end of the channel. It will be appreciated that in some such examples, the end cap preferably blocks the opposing end of the channel to that at which the cooling duct connector is fluidly coupled to the cooling duct, i.e. the end cap may block an end of the channel that is opposite to the connection end of the cell housing. Forming the cell housing with a u-shaped cooling duct defined at least in part by a channel extending through the entire

length of the cell housing may be advantageous for simple and cost-effective manufacture of the cell housing.

In some examples, the u-shaped cooling duct may be defined at least in part by two channels
5 extending through the entire length of the cell housing. For example, the first portion may be defined by a first channel and the second portion may be defined by a second channel. The first and second channels may be separated by a web starting at the connection end of the cell housing and extending towards the end cap. Preferably such a web either does not extend up to the end cap, or comprises an opening near to the end cap, to thereby define a gap
10 facilitating fluid communication between the first and second portions to form the u-shaped cooling duct. In some examples, the cell housing may be manufactured by extrusion, and the web and the first and second channels extending through the cell housing may be formed simultaneously in the extrusion process. The gap connecting the first and second portions of the cooling duct may be formed by removing, for example machining, a portion of the web
15 following the extrusion process, in such an example.

In some examples the end cap may comprise a sealing plug, such as a plastic or rubber plug or a plastic plug comprising a rubber seal such as a nitrile rubber O-ring. In some other examples, the end cap may comprise a sealing plate attached to a front face of the cell
20 housing. For example, such a sealing plate may be bolted to the front face of the cell housing. In examples comprising a sealing plate, the end cap may further include a sealing gasket arranged between the sealing plate and the cell housing. In some preferred examples the battery tower may comprise a similar or equivalent sealing gasket on both sides of the cell housing, i.e. between the cell housing and each of the cooling duct connector and sealing
25 plate attached to the cell housing. This may be advantageous for reducing manufacturing complexity and cost. In some other preferred examples, the end cap may comprise a sealing plate attached to the front face of the cell housing by means of an adhesive. As such, the sealing plate may be bonded to the cell housing. Bonding the sealing plate to the cell housing may provide a dual benefit in that the adhesive both attaches and seals the sealing plate to
30 the cell housing.

In some examples, the cooling duct connector and the end cap may be attached to the respective cell housing with a shared bolted connection. For example, the cell housing may be sandwiched between the cooling duct connector and the end cap. Accordingly, the cooling
35 duct connector, cell housing and end cap may be clamped together using the same connection means. In some preferred examples, each cell housing may be clamped between the cooling

duct connector and a respective end cap by two or more bolts clamping the various components together.

5 In some examples, the battery tower may comprise a complex end plug arranged with each cell housing to define the respective end cap, at least part of the separating web between the first and second portions of the cooling duct, and the gap facilitating fluid communication between the first and second portions. For example, the cooling duct may be defined in part by a single channel extending through the cell housing. In such an example, the complex end plug may be arranged to block an end of the channel, thereby forming an end cap, and the
10 first and second portions of the cooling duct may be defined at least in part by a separating web portion of the complex end plug. In such an example the complex end plug may comprise a hole or gap through the separating web portion of the complex end plug, or between the web portion and an end cap portion, to facilitate fluid communication through the separating web and thereby form a u-shaped cooling duct.

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In some examples, the cooling duct of a cell housing may be U-shaped. A U-shaped cooling duct may be defined by one or more channels formed in the cell housing. The U-shaped cooling duct may be formed by blocking an end of the one or more channels. For example, the battery tower may comprise an end cap arranged to block an end of the or each channel, as described previously, to thereby direct fluid flowing in a first portion of the cooling duct into an opposite direction to flow in a second portion of the cooling duct.

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The or each channel in the cell housing may extend longitudinally in the same direction as the or each cell compartment of the respective cell housing. As previously described, in some
25 examples the cell compartment may extend substantially horizontally. The or each channel forming the U-shaped cooling duct may therefore also extend substantially horizontally. In some preferred examples, the or each channel formed in the cell housing may extend at for at least the same length as the or each cell located in the or each cell compartment of the cell housing. Further, in some examples the or each channel in the cell housing may extend for at
30 least the same length as the or each cell compartment. As described previously, in some preferred examples the or each channel formed in the cell housing may extend through the entire length of the cell housing.

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In some examples, the cooling duct connector may fluidly couple the first portion of the cooling
35 duct of a cell housing to the second portion of a cooling duct of an adjacently stacked cell housing. For example, the cooling duct connector may fluidly couple the upper portion of a

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cooling duct of a cell housing to the lower portion of a cooling duct of an adjacently stacked cell housing. The upper portion of a cooling duct may define an outlet of the cooling duct, and the lower portion of a cooling duct may define an inlet of the cooling duct. Accordingly, the cooling duct connector may fluidly couple an outlet of a cooling duct of a cell housing to an inlet of a cooling duct of an adjacently stacked cell housing. It will be appreciated that in some preferred examples the cooling duct connector may therefore fluidly couple adjacent cooling duct portions of different, adjacently stacked cell housings. Such a configuration may advantageously simplify manufacture of the battery tower.

10 In some examples, the cooling ducts and the cooling duct connector may together define a serpentine flow path through a plurality of the adjacently stacked cell housings. Accordingly, the battery tower may be configured such that the flow path defined by the cooling ducts of the adjacently stacked cell housings and the cooling duct connector is an in-series flow path flowing through a cell housing, through the cooling duct connector and subsequently through an adjacent stacked cell housing, after one another in series. Such a configuration may be advantageous for cooling performance in use, and for ease of manufacture.

In some examples, the cooling duct of the cell housing may extend along substantially the full length of the or each respective cell compartment. Such a configuration may help to provide a large surface area for effectively transferring heat between the cell compartment and fluid in the cooling duct, in use. It will be appreciated that in some examples, the first and second portions of the cooling duct of each cell housing may therefore extend along substantially the full length of the respective cell compartment. Further, in some examples, the cooling duct of each cell housing may extend across substantially the full height of the respective cell compartment. Again, such a configuration may be advantageous for heat transfer between the cell compartment and the cooling fluid in the cooling duct, in use.

In some examples, the cell housing may define a plurality of cell compartments. A cell housing defining a plurality of cell compartments may advantageously facilitate thermal management of a plurality of cells in a compact, space-efficient configuration. For example, the same cooling duct of a cell housing may be thermally coupled to a plurality of cell compartments to thereby facilitate an effective transfer of heat between the duct and a plurality of cell compartments, in use.

35 In some examples, the plurality of cell compartments of the cell housing may be defined in a stacked configuration on top of one another. In other words, each cell compartment of a given

cell housing may be adjacent to (on top of or below) at least one other cell compartment of the respective cell housing. A stacked configuration may be space-efficient whilst still facilitating effective heat transfer between the cell compartments and the cooling duct. Additionally, such a configuration may simplify the manufacture and assembly of the battery tower.

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In some examples, the battery tower may further comprise a plurality of cells. Each cell may be located in a cell compartment of a cell housing. In some examples, a cell compartment may comprise a plurality of cells, such an arrangement may be cost-effective and relatively fast to assemble. In some other examples described later in more detail, each cell may be individually located in its own cell compartment.

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In some examples, the respective cell may be bonded into the cell compartment in which it is located. Accordingly, each cell compartment may comprise adhesive for bonding a cell to the cell housing. Each cell compartment may comprise one or more internal surfaces. In some preferred examples, each cell may be bonded to each internal surface of the cell compartment in which the cell is located. For example, the battery tower may comprise a layer of adhesive between each cell and the respective cell compartment in which the cell is located. In some preferred examples, the adhesive layer may be substantially continuous, i.e. unbroken and free of voids, between the cell and a respective internal surface of the cell compartment. More preferably still, in some examples the cell may be surrounded by a substantially continuous layer of adhesive. A substantially continuous layer of adhesive provides an advantageous thermal bridge between the cell and the cell housing for transferring heat in use.

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In some examples, one or more other components may be present with a cell in a respective cell compartment, as described later in more detail. In such examples, it may still be preferable to provide a substantially continuous layer of adhesive between the cell and the cell compartment for advantageous heat transfer. In some examples, the one or more other components may therefore also be surrounded by a layer of adhesive. Alternatively, a layer of adhesive may be present between the cell and the at least one other component in the cell compartment. Additionally or alternatively a layer of adhesive may be present between the at least one other component and the cell compartment, particularly if an adhesive layer is not present between cell and the at least one other component. Such configurations help to ensure that a layer of adhesive is preferably present between the cell and the cell compartment on all sides, which may be advantageous for heat transfer to and from the respective cell.

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In some preferred examples, the adhesive may have a thermal conductivity greater than 0.2 W/mK, more preferably greater than 0.3 W/mK, and more preferably still greater than 0.4 W/mK. As such, the adhesive is preferably thermally conductive to facilitate heat transfer from the or each cell to the respective cell compartment and cooling duct. Further, in some preferred
5 examples, the adhesive may be electrically insulating. The adhesive may be an epoxy-based, or silicone-based adhesive, in some examples. An example of a suitable adhesive may be Mumentive® RTV627, which has a thermal conductivity of 0.31W/mk.

The adhesive may be referred to as a potting compound in some examples. The adhesive
10 may advantageously accommodate production tolerances in both the cell and the cell housing, in particular tolerances in the cell compartment of the cell housing. For example, during manufacture of the battery tower, when bonding the or each cell into a respective cell compartment, the adhesive introduced to the cell compartment may have a viscosity of less than 25 pascals seconds (Pa.s). Such an adhesive may advantageously spread thoroughly
15 throughout the cell compartment, forming a continuous layer that provides a thermal bridge which is advantageous for heat transfer. In some particularly preferred examples, the adhesive introduced to a respective cell compartment for bonding a cell in the cell compartment may have a viscosity of less than 5 pascals seconds (Pa.s) to ensure that the adhesive flows throughout the cell compartment during assembly. This helps to ensure that a substantially
20 continuous thermal bridge between the cell and cell housing is provided by the adhesive. By way of example, a particularly advantageous adhesive, such as Mumentive® RTV627, may have a viscosity of less than 1.5 pascals seconds (Pa.s). In some preferred examples, the adhesive, when set to bond a respective cell in a cell compartment, may be somewhat flexible or compliant, i.e. not rigid, such that the adhesive layer may accommodate minor fluctuations
25 in cell volume in use, for example as a result of thermal expansion and contraction of the cell in use and out-gassing as the cell ages.

In some examples, in addition to a cell, a pad of compliant material may be located within a respective cell compartment. A pad of compliant material may be a compressible material
30 configured to deform and mould in response to compressive forces. For example, the pad may be located between the cell and a cell wall, i.e. between the cell and an internal surface of the cell compartment. Advantageously, the pad may therefore provide a degree of flexibility within the cell compartment to allow for thermal expansion and contraction of the or each cell in use, in particular during charging and discharging of the or each cell. The pad may also provide
35 flexibility to allow for expansion of the or each cell resulting from gas in the cell which may increase in volume throughout the lifetime of the cell. The pad of compliant material may

comprise a pad of foam. For example, the pad may be formed of HT800 flame retardant silicone foam, in some examples. The combination of the pad of compliant material and the adhesive layer arranged between the cell and the cell compartment provides a hybrid solution which offers both compliance i.e. flexibility (via the pad), to allow for variations in cell volume and dimensional tolerance of the compartment, and thermal conductivity (via the adhesive layer), to facilitate advantageous temperature management of the cell.

As previously described, a substantially continuous layer of adhesive between the cell and the cell compartment may provide a substantially continuous thermal bridge between the cell and cell housing for advantageous heat transfer. In examples comprising a pad of compliant material, such as foam, in the cell compartment, the adhesive in the cell compartment may preferably still be arranged to form a thermal bridge between the cell and the cell compartment walls of the cell housing. For example, the pad of compliant material may be surrounded by the adhesive in some examples. Alternatively, a layer of adhesive may be present between the cell and the pad of compliant material. Additionally or alternatively a layer of adhesive may be present between the pad of compliant material and the cell compartment, particularly if an adhesive layer is not present between cell and the pad. Such configurations help to ensure that a layer of adhesive is preferably present between the cell and the cell compartment on all sides, which increases surface area of the adhesive in contact with the cell and the cell compartment to thereby facilitate particularly effective heat transfer between the cell and cell housing.

In some examples, the cells may be pouch cells comprising a flexible outer skin and two electrically conductive cell terminals. The cells may therefore be somewhat compliant, which may simplify arrangement of the cells in the respective cell compartment. Accordingly, the cells may not have a rigid container or exterior structure. Instead, in some examples the cells may be supported in the respective cell compartment by an adhesive as described previously.

The two cell terminals, i.e. a positive cell terminal and a negative cell terminal, may extend from opposite ends of the respective cell in some examples. In some other examples, the positive and negative cell terminals of a respective cell may extend from the same end of the cell. The cells, and in particular the cell terminals, are preferably configured to facilitate electrical connection of each cell terminal to a cell terminal of another cell in the battery tower. Accordingly, when assembled, in some preferable examples the cell terminals may project out of the cell compartment housing the respective cell to facilitate simple electrical connection of the cells. In some examples, the battery tower may comprise a plurality of cells connected in

series, i.e. a positive cell terminal of each cell may be connected to a negative cell terminal of a different cell. Alternatively, in some examples, the battery tower may comprise a plurality of cells connected in parallel, i.e. a positive cell terminal of each cell may be connected to a positive cell terminal of a different cell. The cell compartments defined by the respective cell housings may be advantageous for organising and aligning the cells facilitating a faster and more efficient process for connecting the cell terminals during manufacture of the battery tower.

In some examples, each cell may be individually located in its own respective cell compartment. As such, in some examples, each cell compartment may comprise a single cell. Advantageously, individually locating a cell in its own cell compartment may be particularly effective for transferring heat away from the cell, in use. For example, with such a configuration each cell may be close to a plurality of cell walls defining the respective cell compartment. Additionally, such a configuration may aid manufacture of the battery tower by facilitating more repeatable and accurate arrangement of each cell in the battery tower. Accordingly, this may simplify electrical connection of the terminals of each cell.

In some examples, each cell compartment may comprise a substantially rectangular cross-sectional profile defined at least in part by three cell compartment walls. Accordingly, the cell located in a respective cell compartment may be surrounded by the cell compartment on at least three sides. Further, in some examples, each cell compartment may comprise a substantially rectangular cross-sectional profile defined by four cell compartment walls. The cell located in a respective cell compartment may therefore be surrounded by the cell compartment on at least four sides. Surrounding the cell on three or more sides advantageously provides a substantial surface area to capture heat from the cell and transfer heat away from the cell, in use, and also protects the cells from damage in use.

In some preferred examples the cross-sectional profile of a cell may be substantially the same shape as the cell compartment in which the cell is located. For example, in some preferred examples each cell may comprise a substantially rectangular cross-sectional profile. Further, in some examples, an aspect ratio of the cell may be substantially the same as the corresponding aspect ratio of the cell compartment in which the cell is located. It will be appreciated that in this context the aspect ratio of a cell or cell compartment refers to the ratio of cell or cell compartment width to cell or cell compartment height. Substantially matching the shape and/or size of the cell and cell compartment means that, when assembled, the cell may be in close proximity to the cell walls, thereby aiding heat transfer and cooling of the cell.

Additionally, in examples also comprising an adhesive layer between the cell and respective cell compartment, the substantially equivalent aspect ratios may result in an adhesive layer of substantially uniform thickness between the cell and any cell compartment walls.

- 5 In some examples, each cell compartment wall may be thermally coupled to the cooling duct of the respective cell housing. This further improves heat transfer away from the cells in use because heat transferred to the cell compartment walls from the respective cell may then be further conducted to the cooling duct and a cooling fluid in the cooling duct. As such, this configuration facilitates very effective cooling of the cells in the battery tower, in use. Thermally
10 coupling the cell compartment walls and the cooling duct, i.e. fluid duct, facilitates heat transfer between the duct and compartment walls, and therefore may also facilitate the delivery of heat from the duct to the cell compartment, in some examples, as previously described.

- In some examples, the cooling duct of each cell housing may be defined at least in part by
15 one or more duct walls. Each cell compartment defined by the respective cell housing may be defined at least in part by a duct wall. Accordingly, in some examples each cell compartment may share a wall with the cooling duct of the respective cell housing. In other words, in some examples each cell housing may comprise a cell compartment wall that is also a duct wall. In preferred examples, the duct wall may be formed of a heat-conductive material. As such, the
20 duct wall may be referred to as a heat-conductive wall. For example, the or each duct wall may comprise a heat-conductive material having a thermal conductivity of at least 150 W/mK, preferably at least 200 W/mK. A cell housing comprising a duct wall that also defines at least part of a cell compartment may provide a particularly direct route for conducting heat away from the cell and to a cooling fluid in the cooling duct, in use.

- 25 In some examples, each cell compartment defined by a respective cell housing may be defined at least in part by the same duct wall. Such a configuration may be advantageous for packaging the various features of the cell housing in a space-efficient manner, and also for ease of manufacturing the cell housing. Additionally, this facilitates efficient transfer of heat
30 between adjacent cells for the purpose of controlling thermal runaway of a single cell without triggering those nearby.

- In some examples, each cell may extend longitudinally in a respective cell compartment. Accordingly, a longitudinal axis of each cell may be substantially parallel to the respective cell
35 compartment axis. The longitudinal axis of each cell may also be substantially parallel to the longitudinal axis of the cooling duct of the respective cell housing. The cooling duct thermally

coupled to the respective cell compartment may extend along a length of the cell compartment that is at least equivalent to the length of the cell in the respective cell compartment, in some preferred examples. This may help to provide effective cooling along the full length of the respective cell in use, to avoid temperature gradients and/or hot spots in the cell in use. It will
5 be appreciated that the length of a cell as used herein may not include the extent of the or each cell terminal of the respective cell.

In some examples, the cell housings may comprise an assembly of separate components that are thermally coupled to one another. For example, the cooling duct of a cell housing may be
10 defined by one component, and the or each cell compartment of the respective cell housing may be defined by a different component. The components may be attached to one another to form the cell housing, for example permanently attached such as by welding or bonding, or removably attached such as via a bolted or clamped connection. In particular, the different components in such an example are thermally coupled to one another to ensure that heat can
15 be transferred between the cell compartment(s) and the cooling duct. For example, both the cooling duct and the cell compartment may be defined by thermally conductive components such that attaching the components together thermally couples the cell compartment(s) and the cooling duct. It should therefore be understood that references herein to a cell housing may refer to a cell housing comprising an assembly of separate thermally coupled
20 components, in some examples.

In some other examples, the cell housing may comprise a single monolithic component defining each of the cell compartments and the cooling duct. In particular, in examples where the cooling duct is a U-shaped cooling duct, the U-shaped cooling duct may be formed
25 integrally with the cell housing. In particular, the first and second portions of the U-shaped cooling duct may be formed integrally with the cell housing. Further, means for providing fluid communication between the first and second portions of the U-shaped cooling duct, i.e. a fluid coupling such as the gap in the web described previously, may be formed integrally with the cell housing. Accordingly, in some examples the cell compartment(s) and cooling duct may be
30 integrally formed with the respective cell housing. Such a configuration may be advantageous for conducting heat from the cell compartment(s) to the cooling duct. Additionally, such a configuration may facilitate simple and cost-effective manufacture of the cell housing.

It follows that in some examples, the entire cell housing may be formed of the same material,
35 i.e. the entire cell housing may be homogenous. Aluminium may be a preferred material for the cell housing due to its thermal conductivity and relative ease of manufacture, in particular

its suitability for extrusion, allowing for efficient manufacture of long tubular sections. It follows that in some examples, the cell housing may be an extruded component. In some other examples, the cell housing may be a cast component. In some examples, a cast or extruded cell-housing may be post-machined to form the upper and lower portions of the cooling duct, and/or to form a gap connecting the upper and lower portions, and/or to form through holes and threaded holes for receiving bolts when assembling the battery tower.

In some examples, the battery tower may comprise three or more cell housings stacked on top of one another. The cooling duct connector may be attached to each of the stacked cell housings to fluidly couple the cooling ducts of adjacently stacked cell housings. For example, the cooling duct connector may define a plurality of separate conduits. Each conduit may fluidly couple the cooling ducts of two adjacent stacked cell housings. A single cooling duct connector that fluidly couples the cooling ducts of three or more, and preferably of all, cell housings of the battery stack is particularly advantageous because the various cooling ducts can all be fluidly connected in a single assembly operation by attaching the single cooling duct connector to the respective cell housings.

In some preferred examples, the cooling duct connector may be configured such that when it is not yet connected to a cell housing, each conduit defined by the cooling duct connector may be fluidly isolated from the other conduits defined by the connector. Accordingly, fluid communication between the conduits may only be facilitated via the cooling ducts of the stacked cell housings. Accordingly, the cooling duct connector may be configured to fluidly couple the cooling ducts of three or more, and preferably of all, cell housings of the battery stack in series. Notably, the single cooling duct connector may therefore facilitate in-series fluid communication between all of the cooling ducts of the battery tower. As such, the cooling duct connector may be configured to form an in-series flow path through a cell housing, through the cooling duct connector, through an adjacent stacked cell housing and through the cooling duct connector and so on through each of the stacked cell housings in the battery tower. In some preferred examples the cooling ducts and the plurality of conduits defined by the cooling duct connector may together define a serpentine fluid flow path through the cell housings and the cooling duct connector.

This configuration provides a multitude of exchanges of fluid between cell housing and duct connector whilst minimising the number of individual components because a single cooling duct connector connects multiple pairs of adjacent cooling ducts. Such a configuration also facilitates the use of relatively simple cast components, for example for the cooling duct

connector, and the use of gaskets to seal between the housings and the cooling duct connector. Such gaskets may be clamped with the use of simple fasteners. Accordingly, this configuration results in a relatively simple assembly that facilitates effective heat transfer, is cost effective, and is easy to assemble.

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According to another aspect of the invention there is provided a battery pack comprising at least two battery towers in accordance with any of the examples described herein. The at least two battery towers are arranged side by side.

- 10 In some examples of a battery pack, the cooling ducts and cooling duct connector of a first battery tower may define a first flow path and the cooling ducts and cooling duct connector of an adjacent second battery tower may define a second flow path. The battery pack may further comprise a lower transverse pipe and an upper transverse pipe connected to the cooling duct connectors of each battery tower to fluidly couple the first and second flow paths. Accordingly,
- 15 the first and second flow paths may be parallel to one another. In use, cooling fluid may therefore flow through the first and second flow paths in parallel, and the cooling fluid in the first and second flow paths may flow in series through the respective cell housings and cooling duct connectors of the first and second battery towers. Flowing cooling fluid through the flow paths of the first and second battery towers in parallel may be advantageous for cooling
- 20 performance, to ensure that cells in both battery towers are cooled evenly.

- In some examples the upper and/or lower transverse pipe may be integral with the cooling duct connector of the first and/or second battery tower. It follows that in some preferred examples, the cooling duct connector of the first battery tower and the cooling duct connector
- 25 of the second battery tower may be defined by a single component. For example, the cooling duct connectors of the first and second battery towers may be defined by a single cast component which defines a plurality of separate conduits configured for fluidly coupling the cooling ducts of adjacently stacked cell housings of the first battery tower, and defines a plurality of separate conduits configured for fluidly coupling the cooling ducts of adjacently
- 30 stacked cell housings of the second battery tower. In such an example, upper and lower transverse pipes may also be part of the single cast component, or in some examples may be defined by cast or machined channels facilitating fluid communication between the first and second flow paths as described previously. Alternatively, in some examples the upper and/or lower transverse pipe may be a separate component that is connected to the respective
- 35 cooling duct connector, for example via a threaded connection.

In some examples, the battery pack may further comprise a cooling fluid inlet upstream of the first cooling duct defining the first flow path in the first battery tower. Further, the battery pack may comprise a cooling fluid outlet downstream of the last cooling duct defining the second flow path in the second battery tower. In some examples, the cooling fluid inlet may be defined by the lower transverse pipe. Alternatively, in some preferred examples, the cooling fluid inlet may be defined by a lower end of the cooling duct connector of the first battery tower. In some examples, the cooling fluid outlet may be defined by the upper transverse pipe. Alternatively, in some preferred examples, the cooling fluid outlet may be defined by an upper end of the cooling duct connector of the second battery tower.

In some examples, the lower transverse pipe may be fluidly coupled to the first and second flow paths upstream of the respective first cooling duct defining the first and second flow paths in the respective first and second battery towers. Further, in some examples, the upper transverse pipe may be fluidly coupled to the first and second flow paths downstream of the respective last cooling duct defining the first and second flow paths in the respective first and second battery towers. Accordingly, substantially the entire first flow path may be parallel with substantially the entire second flow path.

In use, any cooling fluid entering the battery pack may therefore be distributed between the first and second battery towers for cooling the cells therein, before the cooling fluid from both flow paths is merged together again in the outlet to facilitate treatment of the cooling fluid downstream of the battery pack in an effective and space-efficient manner. For example, a heat exchanger may be arranged downstream of the cooling fluid outlet to remove heat from the cooling fluid before said cooling fluid is recirculated to back to the cooling fluid inlet, for example using a circulation pump. In some preferred examples, the heat exchanger may be a cross-flow heat exchanger. Combining the fluid from the first and second flow paths to a single flow for delivery to such a heat exchanger and/or circulation pump may simplify the piping required.

In some examples, the battery pack may further comprise an expansion element to accommodate variations in cooling fluid volume resulting from fluctuations in cooling fluid temperature, in use. The expansion element may comprise a pocket of gas contained in one of the fluid flow paths at a fixed location such that the pressure of the pocket of gas is directly related to the pressure of cooling fluid in the first and second flow paths. For example the pocket of gas may be defined by a flexible diaphragm, or in some other examples, the pocket of gas may be an air bubble deliberately trapped at a specific location such that it is fixed in

position and doesn't flow through the battery pack with the cooling fluid, in use. In some examples, the expansion element may be provided at an upper or lower end of the cooling duct connector of one of the first or second battery towers. Notably, with such an arrangement, no further elements, such as fluid inlets or outlets, should be connected downstream of the expansion element, in some preferred examples. In examples where the expansion element comprises a pocket of gas, such as an air bubble, deliberately trapped at a specific location, no further elements should be connected above the expansion element as this may otherwise remove the deliberately trapped pocket of gas.

10 In some examples, the battery pack may comprise a top-up valve fluidly coupled to the first and second flow paths. For example, the top up valve may be connected to an upper or lower end of the cooling duct connector of one of the first or second battery towers. In examples where the battery pack comprises both an expansion element and a top-up valve, these should preferably be connected to different cooling duct connectors or at least different ends of a cooling duct connector. The top-up valve may facilitate the addition of cooling fluid to the first and/or second flow path.

In some examples, the battery pack may further comprise a coolant pump upstream of, and fluidly coupled to, the cooling fluid inlet. The coolant pump may be configured to motivate a cooling fluid into and through the flow paths of the first and second battery towers, in use.

In another aspect of the invention there is provided an alternative battery pack. For ease of reference, the alternative battery pack will be referred to herein as a second battery pack. It should be appreciated that all aspects of the previously-described battery pack, the battery towers forming the battery pack, and components such as the cells and cell housings, may be equally applicable to the second battery pack in the absence of any contrary description detailing a specific feature of the second battery pack.

Notably, in some examples, the second battery pack may comprise a connection manifold instead of the previously described individual cooling duct connectors of the first and second battery towers. The connection manifold may serve substantially the same function as the previously described cooling duct connectors of the first and second battery towers, namely, to fluidly couple the cooling ducts of adjacently stacked cell housings. However, the connection manifold may provide a simplified means for providing all of the fluid communication between the cooling ducts of the cell housings of the first and second battery towers, in a single component. Further, the connection manifold may also optionally facilitate a different flow of

fluid through the cooling ducts of the first and second battery towers, compared to the previously described separate cooling duct connectors, as will be described below in more detail.

- 5 In some preferred examples of the second battery pack, the cell housings of a respective battery tower may all be arranged in the same orientation, such that the connection end of each cell housing is substantially aligned on the same side of the battery pack, such as a back side of the battery pack. Further, in some preferred examples, each cell housing of a respective battery tower may be arranged such that the cooling duct of each respective cell
- 10 housing is on the same side of the battery tower, such as a left side or a right side of the respective tower. Accordingly, the respective cooling ducts of the cell housings of a respective battery tower may be considered to be stacked on top of one another, or arranged in a stacked configuration.
- 15 Further still, the first and second battery towers, i.e. the stacks of cell housings comprising cells, may be arranged side by side and oriented such that the cooling ducts of the respective cell housings of the first and second battery towers are arranged side by side. That is to say, in preferred examples, the cooling duct of a cell housing of the first battery tower may be sideways adjacent to, i.e. neighbouring, the cooling duct of a corresponding cell housing of
- 20 the second battery tower. Accordingly, the cooling ducts of all of the cell housings in the second battery pack may be arranged together in a central portion of the second battery pack. Advantageously this simplifies connection and sealing of the connection manifold.

- It should be appreciated that “sideways adjacent to” and “neighbouring” may include one or
- 25 more other components or materials between the neighbouring cooling ducts of the corresponding neighbouring cell housings. For example, the second battery pack may comprise an adhesive or a filler material between neighbouring cooling ducts of corresponding neighbouring cell housings. Advantageously, such an adhesive or filler material may compensate for manufacturing tolerances when assembling the second battery pack, such as
- 30 dimensional tolerances of the cell housings which could affect alignment of the cell housings relative to one another. For example, a thixotropic adhesive may be particularly advantageous for filling gaps between neighbouring cell housings during assembly of the second battery pack. Additionally, in some examples the adhesive or filler material may be thermally conductive. The adhesive or filler may thereby facilitate heat transfer between the
- 35 neighbouring cell housings, and in particular between the neighbouring cooling ducts of the

cell housings. In some preferred examples, the adhesive or filler material may be sandwiched directly between the neighbouring cooling ducts, with no other components between.

5 In some examples, the connection manifold may be attached to, and sealed to, the connection end of each cell housing. For example, the second battery pack may comprise a seal or a gasket between the connection manifold and the cell housings.

10 Alternatively, in some examples the second battery pack may comprise one or more back plates arranged between the cell housings and the connection manifold. For example, as described in more detail below, a backplate may be sealed, for example adhesively sealed, to the connection end of a cell housing. In particular, the back plate may comprise apertures corresponding to the cooling ducts, in particular to the inlet and outlet of each cooling duct, of the cell housing attached to the back plate. The apertures may also correspond to respective conduits of the connection manifold. Accordingly, fluid communication between the connection
15 manifold and the respective cooling duct of the cell housing may be provided via the back plate, i.e. via one or more apertures in the back plate. The back plate may therefore provide an interface between the connection manifold and the cell housing. Such a configuration may advantageously simplify sealing the connection manifold to the cell housing, and to the cooling duct of the cell housing in particular.

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In some examples, a back plate may be attached to a plurality of cell housings. For example, a single back plate may be attached to, and sealed to, a plurality of adjacently stacked cell housings in a respective battery tower. It follows that the back plate may therefore also provide an interface between the connection manifold and the plurality of adjacently stacked cell
25 housings. In some examples, a single back plate may be attached to, and sealed to, a corresponding pair of side by side adjacent, i.e. neighbouring, cell housings of the first and second battery towers. It follows that the back plate may therefore also provide an interface between the connection manifold and the corresponding pair of side by side adjacent, i.e. neighbouring, cell housings. In some preferred examples, a single back plate may be attached to, and sealed to, a plurality of adjacently stacked cell housings in the first battery tower, and to the corresponding side by side adjacent, i.e. neighbouring, cell housings of the second battery tower. For example a back plate may be attached to, and sealed to two adjacently stacked cell housings of the first battery tower and to the two corresponding side by side adjacent cell housings of the second battery tower. It should be understood that the back plate
30 may therefore provide an interface between the connection manifold the respective cell housings, and their respective cooling ducts, attached to the back plate. Such a configuration

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provides an advantageously simple interface for fluidly coupling the connection manifold to the respective cooling ducts. In some examples, sealing the connection manifold to the back plate may be significantly simpler than sealing the connection manifold to each individual cell housing and/or cooling duct.

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It follows that in some examples the second battery pack may comprise one or more sealing members arranged between the connection manifold and the or each back plate. For example, the or each sealing member may comprise a sealing gasket as described previously, such as an overmoulded elastomeric polymer sealing gasket comprising thermoplastic polyurethane.

10 In some examples the or each sealing member may comprise an overmoulded rope seal. In some preferred examples, the one or more sealing member may be integrated with one or more back plates. For example, the or each back plate may comprise an integrated sealing member in accordance with the examples described herein, wherein the integrated sealing member extends around the or each aperture in the back plate. An integrated sealing member
15 may further simplify assembly of the second battery pack.

Notably, in some examples the or each cell compartment of a cell housing may extend through the entire cell housing, i.e. the cell compartment may have a tubular or duct-like form. As such, the or each cell compartment may be substantially open-ended. Such a configuration may be
20 resultant of a manufacturing method, such as extrusion, used for forming the cell housing. Such a configuration may also facilitate simple arrangement of the or each cell in the cell compartment during manufacture. A back plate may be attached to the cell housing to block off an end of the or each cell compartment. The back plate may therefore help to retain the or each cell in the or each cell compartment during manufacture. As described in more detail
25 later, in some examples an internal surface of the back plate may be spaced apart from the connection end of the cell housing to define a gap via which fluid communication may be facilitated between a plurality of cell compartments defined by the cell housing, during assembly.

30 Notably, in examples comprising a back plate, the back plate may preferably be sealed to the cooling duct of the or each respective cell housing attached to the back plate, and in particular to the inlet and outlet of the cooling duct. In particular, such sealing may fluidly isolate the cooling ducts from the cell compartments. In turn, this may help to ensure that cooling fluid flowing between the cooling ducts and the connection manifold, via the apertures in the back
35 plate, flows in a simple flow path in use and does not leak to areas comprising electrical components, such as the cells.

The connection manifold may define a cooling fluid inlet for receiving a combined flow of cooling fluid. The connection manifold may define a cooling fluid outlet for discharging a flow of cooling fluid. In preferred examples the cooling fluid outlet may be configured to discharge
5 the combined flow of cooling fluid. The connection manifold may define a plurality of separate first conduits configured to fluidly couple the cooling ducts of adjacently stacked cell housings of the first battery tower. The connection manifold may define a plurality of separate second conduits configured to fluidly couple the cooling ducts of adjacently stacked cell housings of the second battery tower.

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In some examples, the plurality of first conduits and the plurality of second conduits may be separate from one another. Accordingly, the second battery pack may comprise a first flow path to direct cooling fluid in series through the cooling ducts of the first battery tower and the first conduits of the connection manifold, and a second flow path to direct cooling fluid in series
15 through the cooling ducts of the second battery tower and the second conduits of the connection manifold. For example, after receiving the combined flow of cooling fluid at the cooling fluid inlet, the connection manifold may be configured to split the combined flow into the first and second flow paths such that portions of the cooling fluid flow in series through the respective cooling ducts of the respective first and second battery towers. The connection manifold may be configured to receive the portions of the cooling fluid from the first and second
20 flow paths after each portion of the cooling fluid has flowed in series through the cooling ducts of a respective battery tower. The connection manifold may be configured to recombine the portions of the cooling fluid flow to subsequently discharge the combined flow from the cooling fluid outlet downstream of the cooling ducts. Similar to the previously described battery pack, the first and second flow paths may therefore be respective in-series flows, which are
25 configured in parallel.

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Alternatively, in some examples the connection manifold may be configured to encourage mixing and temperature balancing between fluid flowing through the first battery tower and fluid flowing through the second battery tower. For example, in some preferred examples, each first conduit of the connection manifold may be fluidly coupled to a corresponding second conduit of the connection manifold. Accordingly, the connection manifold may be configured to facilitate fluid communication between corresponding cooling ducts of corresponding cell housings in the first and second battery towers. In some examples each corresponding pair of
35 first and second conduits may be defined by a respective channel in the connection manifold. Notably, each first conduit is preferably separate from each other first conduit, and each

second conduit is preferably separate from each other second conduit. Accordingly, the connection manifold may comprise a plurality of separate channels, where each separate channel defines a first conduit and a corresponding second conduit. Accordingly, the connection manifold may be configured to provide fluid communication between
5 corresponding cooling ducts of cell housings in the first and second battery towers in parallel via a respective channel, whilst ensuring that fluid communication between cooling ducts of cell housings in the same battery tower is only provided in an in-series or consecutive manner.

It follows that the connection manifold may be configured such that when it is not yet attached
10 to and sealed to a cell housing, for example via a back plate, each channel defined by the connection manifold may be fluidly isolated from other channels defined by the connection manifold. Accordingly, fluid communication between the channels may only be facilitated via the cooling ducts of the cell housings.

By way of an example, the connection manifold may be configured to receive a combined flow
15 of cooling fluid at the cooling fluid inlet. The connection manifold may be configured to split the combined flow into a first portion flowing through the cooling duct of a first cell housing of the first battery tower, and a second portion flowing through the cooling duct of a corresponding cell housing of the second battery tower. The connection manifold may be
20 configured to receive the first and second portions of the flow of cooling fluid via respective first and second conduits after the portions have flowed through the respective cooling ducts. For example, the connection manifold may be configured to recombine the portions of the flow into the combined flow in a channel defining the respective first and second conduits. It follows
25 that the connection manifold may be configured to then split the combined flow into another first portion flowing through the cooling duct of a cell housing of the first battery tower, and another second portion flowing through the cooling duct of a corresponding cell housing of the second battery tower. The connection manifold may be configured to fluidly couple all of the cooling ducts of the first and second battery towers in this way to promote enhanced mixing and temperature balancing between the fluid flowing through the connection ducts of the
30 respective first and second battery towers.

The connection manifold may therefore define a plurality of pairs of parallel fluid flow paths. It follows that each pair of parallel fluid flow paths may comprise a first flow path directing a portion of the cooling fluid through the cooling duct of a cell housing of the first battery tower
35 and a second flow path directing a portion of the cooling fluid through the cooling duct of a cell housing of the second battery tower. It should be understood that the connection manifold

may be configured to recombine the portions of the cooling fluid into the combined flow at the cooling fluid outlet downstream of all of the cooling ducts.

5 The cooling ducts of the cell housings in the second battery pack may be u-shaped cooling ducts in some preferred examples, as described previously. As previously described, in examples where each cell housing is oriented the same way, each U-shaped cooling duct of each cell housing in a respective battery tower starts and ends on the same side of the battery tower. In other words, each cooling duct may comprise an inlet and an outlet, and in examples where the cooling duct is U-shaped, the inlet and outlet of the respective cooling duct may be provided on the same side of the cell housing, such as at the connection end of the respective cell housing. With the cell housings oriented and arranged as previously described, the inlets and outlets of all of the cooling ducts in the second battery pack may be provided in the central portion of the second battery pack. Such an arrangement is advantageous for ease of assembly and sealing.

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It follows that in examples where the cooling ducts are U-shaped cooling ducts, the respective conduits defined by the connection manifold may be configured and arranged to fluidly couple the outlet of a cooling duct of a respective cell housing to the inlet of a cooling duct of respective adjacently stacked cell housing. In other words, each first conduit of the connection manifold may fluidly couple the outlet of the cooling duct of a cell housing of the first battery tower to an inlet of the cooling duct of an adjacently stacked cell housing of the first battery tower. Similarly, each second conduit of the connection manifold may fluidly couple the outlet of the cooling duct of a cell housing of the second battery tower to an inlet of the cooling duct of an adjacently stacked cell housing of the second battery tower. It should be understood that the description provided previously in relation to corresponding pairs of first and second conduits being defined by a respective channel of the connection manifold is equally applicable to examples where the conduits (and therefore the respective channel) fluidly couple the outlet of a cooling duct to the inlet of a cooling duct of an adjacently stacked cell housing.

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In another aspect of the invention there is provided an electrical water heating system comprising a battery tower or a battery pack as described in any of the examples herein, including the second battery pack. The electrical water heating system may be an electrical boiler suitable for supplying heated water to outlets and/or a water-based heating system in a building. As described previously, in some examples a heat exchanger, such as a cross-flow heat exchanger, may be arranged downstream of the cooling fluid outlet of the battery pack,

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or second battery pack. In such examples, the heat from the cooling fluid flowing through the heat exchanger in use may be used to heat or pre-heat water in the electric boiler.

According to another aspect of the invention there is provided a battery module. The battery
5 module comprises a cell housing in accordance with any of the examples described herein. Accordingly, the cell housing defines at least one cell compartment and a cooling duct thermally coupled to the at least one cell compartment. The battery module further comprises at least one cell in accordance with any of the examples described herein. The or each cell is located in a cell compartment defined by the cell housing.

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In some preferred examples, the battery module may comprise a plurality of cell. The cell housing may comprise a plurality of cell compartments. Each cell may be individually located in its own respective cell compartment.

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As described previously, in some examples, the or each cell may be bonded into a cell compartment. Accordingly, the battery module may comprise a layer of adhesive between the cell and the cell compartment. For example, the battery module may comprise a layer of adhesive between the cell and at least three internal surfaces of the cell compartment. Accordingly each cell may be substantially surrounded on at least three sides, preferably at
20 least four sides, by adhesive between the cell and the cell compartment walls. In some examples a pad of compliant material may be located in the or each cell compartment as previously described. The battery module may comprise a layer of adhesive between the pad of compliant material and a cell wall.

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In some preferred examples, the battery module may further comprise a back plate. Notably, where included, the back plate is preferably sealed to the cell housing. For example, sealing may include adhesive bonding. In particular, the back plate may be sealed to the cell housing such that the cooling duct of the cell housing is fluidly isolated from the cell compartment(s) of the cell housing.

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The battery module may comprise a plurality of cell housings attached to and sealed to a back plate. Various examples of a back plate have been described previously and will not be described in detail again for conciseness. However, for reference, the battery module may comprise a plurality of adjacently stacked cell housings attached and sealed to the same back
35 plate. Additionally or alternatively, the battery module may comprise a plurality of side-by side adjacent, i.e. neighbouring cell housings attached and sealed to the same back plate. In

examples where the battery module comprises a plurality of cell housings, an adhesive or filler material may be arranged between the cell housings. This may help to conduct heat between the cell housings.

- 5 It should be appreciated that the second battery pack may comprise a plurality of battery modules. The battery modules may be arranged in a stacked configuration, in some examples. In some other examples, the battery modules may be arranged in a side by side adjacent configuration. In examples where the second battery pack comprises a plurality of battery modules, adjacently stacked cell housings, or side by side neighbouring cell housings, of
10 different battery modules may be bonded together with adhesive. Further, it should be appreciated that in some examples the second battery pack may comprise a connection manifold attached and sealed to the plurality of battery modules to fluidly couple the cooling ducts of the cell housings of the battery modules, as described previously. The implementation of battery modules may facilitate a simple and efficient method of manufacturing the second
15 battery pack, wherein each battery module may be manufactured separately, before the plurality of battery modules are attached and sealed to the connection manifold.

- According to another aspect of the invention there is provided a method of manufacturing a battery module in accordance with some of the examples described herein. The method
20 comprises providing a cell housing in accordance with any of the examples described herein. The method further comprises providing adhesive in the or each cell compartment defined by the cell housing. The method further comprises arranging at least one cell in the or each cell compartment.

- 25 In some preferred examples, the method may comprise arranging the cell housing in an upright orientation prior to providing adhesive in the or each cell compartment. For example, the or each cell compartment may extend longitudinally in a compartment direction, along a respective compartment axis. The cell housing may be arranged in an upright orientation in which the or each compartment axis extends substantially vertically. Accordingly, an opening
30 of the cell compartment may face upwards, with the cell compartment extending downwards from the opening, when the cell housing is arranged in the upright orientation. In some such examples, the or each cell may be arranged in the or each cell compartment by lowering the cell to the cell compartment through the opening.

- 35 In some examples, the method may comprise providing adhesive in the or each cell compartment prior to arranging the or each cell in the or each cell compartment. Accordingly,

the method may comprise arranging the or each cell in the or each cell compartment comprising adhesive. In some examples the cell may settle or sink into the adhesive in the cell compartment such that a layer of adhesive is formed between the cell and the cell compartment walls. As previously described, the cell housing may comprise a plurality of cell compartments. The battery module may comprise a plurality of cells each located in an individual cell compartment. Accordingly the method may comprise providing adhesive in each cell compartment and subsequently arranging each cell in an individual cell compartment.

In some other examples, the method may comprise arranging the or each cell in the or each cell compartment prior to the introduction of adhesive to the cell compartment. For example, the cell compartment may be flooded with adhesive following arrangement of the cell in the cell compartment. Such a method may facilitate faster assembly of the battery module. As previously described, the cell housing may comprise a plurality of cell compartments. The battery module may comprise a plurality of cells each located in an individual cell compartment. Accordingly, the method may comprise arranging each cell in its respective cell compartment, and subsequently flooding each cell compartment with adhesive.

As previously described, the battery module may comprise a back plate. The back plate may comprise an internal surface. The method may therefore comprise sealing, for example adhesively sealing, the internal surface of the back plate to the connection end of the cell housing. Notably, the internal surface of the back plate may be sealed to the connection end of the cell housing such that the cooling duct of the cell housing is fluidly isolated from the or each cell compartment.

The back plate may comprise at least one adhesive inlet. The method may comprise providing, i.e. introducing, adhesive to the or each cell compartment of the cell housing via the adhesive inlet in the associated back plate. In some examples, the back plate may comprise a plurality of adhesive inlets to facilitate faster supply of adhesive to the or each cell compartment.

As previously described, the internal surface of the back plate may be sealed to the connection end of the cell housing such that the cooling duct of the cell housing is fluidly isolated from the or each cell compartment. Accordingly, the back plate may comprise one or more apertures in a first portion of the back plate to facilitate fluid communication with the cooling duct of the cell housing, through the back plate. The back plate may comprise one or more adhesive inlets in a second portion of the back plate to facilitate fluid communication between a source of adhesive and the or each cell compartment.

In some examples, the back plate may comprise one or more protrusions or steps extending from the internal surface of the back plate. The or each protrusion or step may be configured to engage the connection end of the cell housing such that, when attached the cell housing, the internal surface of the back plate is spaced apart from the cell housing to form a gap between the cell housing the internal surface. As previously described, in some examples the cell housing may define a plurality of cell compartments. It follows that the back plate may be configured to facilitate fluid communication between the plurality of cell compartments, via the gap defined between the cell housing and the internal surface of the back plate. In some examples, each cell compartment may be fluidly coupled to the at least one adhesive inlet via the gap defined between the cell housing and the internal surface of the back plate.

Accordingly, the method may comprise providing adhesive in the or each cell compartment via the adhesive inlet and the gap defined between the cell housing and the internal surface of the back plate. Adhesive may be provided in the or each cell compartment in this way irrespective of whether the adhesive is provided prior to or after arrangement of the cell in the cell compartment. In either example, adhesive provided to the cell compartment in this way may advantageously spread through and around the or each cell compartment such that a substantially continuous adhesive layer is formed between the at least one cell and the cell compartment walls.

As previously described, in some examples, in addition to a cell, a pad of compliant material may be located within a respective cell compartment. Accordingly, the method may comprise arranging a pad of compliant material in the or each cell compartment. In some preferred examples, the method may comprise attaching the pad of compliant material to a respective cell prior to arranging the cell in the cell compartment. For example, the pad of compliant material may comprise a pad of self-adhesive foam which is attached, i.e. bonded, to the cell before the cell is arranged in the cell compartment.

In an additional example of the battery pack or second battery pack comprising a plurality of adjacently stacked cell housings, each cell housing may comprise a substantially unidirectional cooling duct. In other words, the cooling duct may be configured to direct and flow cooling fluid in a single direction, in use. For example, each unidirectional cooling duct may comprise a first end and an opposing second end. Each cooling duct may be configured to flow cooling fluid in a single direction, either from the first end to the second, or from the

second end to the first end depending on the orientation of the respective cell housing and the configuration of the battery tower.

In some examples, the unidirectional cooling duct may be defined, at least in part by a channel
5 extending through the cell housing, as described previously. For example, the cooling duct may be defined, at least in part by a single channel extending through the cell housing. In some preferred examples the channel may extend through the entire length of the cell housing. For example, the channel, and thereby the unidirectional cooling duct, may extend longitudinally from the connection end of the cell housing to the front face of the cell housing.
10 As such, the first end of a unidirectional cooling duct may be defined by one of the connection end or front face of a respective cell housing, and the second end of the unidirectional cooling duct may be defined by the other of the connection end or front face of the respective cell housing. Further, a unidirectional cooling duct may be formed integrally with cell housing such that the cell housing may comprise a single monolithic component defining each of the cell
15 compartments and the unidirectional cooling duct.

In some preferred examples, each cell housing of a respective battery tower of the battery pack or second battery pack may be arranged such that the unidirectional cooling duct of each respective cell housing is on the same side of the battery tower, such as a left side or a right
20 side of the respective tower. Accordingly, the respective unidirectional cooling ducts of the cell housings of a respective battery tower may be considered to be stacked on top of one another, or arranged in a stacked configuration.

Notably, in an example comprising substantially unidirectional cooling ducts, the battery tower,
25 battery pack or second battery pack may comprise one or more front duct connectors. Notably, the or each front duct connector may be arranged instead of the previously-described end cap. Accordingly, the or each front duct connector may be configured to provide fluid communication between unidirectional cooling ducts of a pair of adjacently stacked cell housings. In other words, the or each front duct connector may define a conduit fluidly coupling
30 the unidirectional cooling ducts of a pair of adjacently stacked cell housings.

Further, in an example comprising substantially unidirectional cooling ducts, the battery tower, battery pack or second battery pack may comprise a cooling duct connector or connection manifold configured to provide fluid communication between unidirectional cooling ducts of a
35 pair of adjacently stacked cell housings. For example, the cooling duct connector or connection manifold may define a conduit fluidly coupling the unidirectional cooling ducts of a

pair of adjacently stacked cell housings. Notably, the battery tower may be configured such that the first end of each unidirectional cooling duct is connected to a cooling duct connector or connection manifold, and such that the second end of each unidirectional cooling duct is connected to a front duct connector. Notably, in preferred examples the battery tower may be
5 configured such that fluid communication is provided between the cooling duct of a respective cell housing and the cooling duct of an adjacently stacked cell housing by either the cooling duct connector or connection manifold, or by the or each front duct connector, on an alternating basis throughout the battery tower.

10 It follows that , in some preferred examples, the cooling duct connector or connection manifold, and the or each front duct connector, together with the unidirectional cooling ducts of the adjacently stacked cell housings, may be configured to define a serpentine flow path through a plurality of the adjacently stacked cell housings. For example, the respective battery tower may be configured such that the flow path defined by the unidirectional cooling ducts of the
15 adjacently stacked cell housings, the cooling duct connector or connection manifold, and the or each front duct connector, is an in-series flow path. By way of an example, the flow path may be defined to direct a flow of cooling fluid through a unidirectional cooling duct of a cell housing, subsequently through a conduit of a cooling duct connector or connection manifold, subsequently through a unidirectional cooling duct of an adjacently stacked cell housing, and
20 subsequently through a conduit of a front duct connector and into a unidirectional cooling duct of an adjacently stacked cell housing, after one another in series, through all of the cell housings in a respective battery tower.

As such, in some examples the battery tower may be configured such that, in use, cooling
25 fluid flows through the unidirectional cooling duct of each cell housing in an opposite direction in comparison to the direction of flow through the cooling duct of the or each immediately adjacently stacked cell housing. Accordingly, the battery tower may be configured such that in use, cooling fluid flows from the first end of a respective cooling duct to the second end, or from the second end of a respective cooling duct to the first end, in an alternating manner
30 through the unidirectional cooling ducts of the adjacently stacked cell housings. Such a configuration may be advantageous for cooling performance in use.

It follows that the cooling duct connector or connection manifold may be arranged on a first side of a respective battery tower, and the or each front duct connector may be arranged on
35 an opposing second side of the battery tower. For example the cooling duct connector or connection manifold may be connected to the connection end of a plurality of cell housings,

for example via one or more back plates, and the or each front duct connector may be connected to the front face of a plurality of cell housings. The or each front duct connector may be sealed to the front face of a cell housing using any example of a seal or gasket described herein. Alternatively, in some other examples, the or each front duct connector may
5 be adhesively bonded, and thereby sealed, to the front face of a respective cell housing.

In some examples, the battery tower, battery pack or second battery pack may comprise a single front coupling component defining a plurality of front duct connectors. Such a front coupling component may define a plurality of separate conduits in a similar manner as
10 described previously with reference to the cooling duct connector and connection conduit. In some examples of the second battery pack, a single front coupling component may define conduits coupling cooling ducts of side by side adjacent, i.e. neighbouring pairs of adjacently stacked cell housings. Such conduits may be fluidly coupled, for example such pairs of corresponding conduits may be defined by a respective channel in the front coupling
15 component, in a similar manner as described previously with reference to the channels and conduits in the connection manifold.

It should be appreciated that all other aspects of the battery tower, battery pack and second battery pack may be equally applicable to, and combined with, this additional example of a
20 battery pack or second battery pack.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

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Figure 1 shows a schematic perspective view of a cell housing defining a plurality of cell compartments and a cooling duct;

Figure 2 shows a schematic perspective view of a battery tower comprising a plurality of cell
30 housings stacked on top of one another;

Figure 3 shows a schematic cross-sectional view of a portion of the battery tower showing the cell compartments and cooling ducts of the cell housings in more detail;

35 Figure 4 shows a schematic cross-sectional side view of a portion of the battery tower showing a flow path through the stacked cell housings;

Figure 5a shows a schematic perspective front view of a battery pack comprising two battery towers arranged side by side;

5 Figure 5b shows a schematic perspective rear view of the battery pack;

Figure 6 shows a schematic perspective view of a second battery pack;

Figure 7a shows a schematic cross-sectional view of the second battery pack;

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Figure 7b shows a schematic cross-sectional view of a connection manifold of the second battery pack;

Figure 8 shows a schematic cross-sectional perspective view of the second battery pack;

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Figure 9 shows a schematic diagram of fluid flow through the second battery pack;

Figure 10a shows a schematic perspective view of a battery module; and

20 Figure 10b shows schematic cross-sectional views of the battery module.

DETAILED DESCRIPTION

Figure 1 is a schematic perspective view of a cell housing 10. As will be described in more
25 detail later with reference to the subsequent figures, the cell housing 10 is configured to retain, i.e. hold, and cool one or more battery cells 12 (shown in Figures 2 and 3). Accordingly, the cell housing 10 defines one or more cell compartments 14 for holding one or more cells 12. As shown in Figure 1, in some examples the cell housing 10 may define a plurality of cell compartments 14 for retaining and cooling a plurality of cells 12. To retain cells 12 in an
30 organised and space-efficient manner, the cell compartments 14 may be defined in a stacked configuration on top of one another, as shown in Figure 1.

Each cell housing 10 also defines a cooling duct 16. The cooling duct 16 is thermally coupled to the cell compartments 14 defined by the cell housing 10. As such, heat from the cell
35 compartments 14 may be conducted to the cooling duct 16, and vice versa. It will be appreciated that the cooling duct 16 is preferably configured to receive and direct a flow of

cooling fluid, in use. Examples of a flow path defined by the cooling duct 16 will be described in more detail later, however, as a brief overview, Figure 1 provides an initial indication of how the cell housing 10 is configured to transfer heat between cells 12 retained in the cell compartments 14 and a cooling fluid in the cooling duct 16 in use.

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A plurality of cell housings 10 may be stacked on top of one another to form a battery tower 18, as shown in the schematic perspective view of Figure 2. Whilst not shown in the accompanying figures, in some examples the stacked cell housings 10 may be attached to a frame to maintain the position of the cell housings 10 relative to one another. Additionally or
10 alternatively, in some examples the stacked cell housings 10 may be bonded together with an adhesive. With brief reference to Figure 3, in some examples the battery tower 18 may therefore comprise a layer of adhesive 20 between adjacently stacked cell housings 10.

Referring again to Figure 2, the cooling ducts 16 of adjacently stacked cell housings 10 are
15 fluidly coupled by a cooling duct connector 22 that is attached to the adjacently stacked cell housings 10. As shown in the example of Figure 2, the battery tower 18 may include three or more cell housings 10 stacked on top of one another, and the cooling duct connector 22 may be attached to each of the stacked cell housings 10 to fluidly couple their respective cooling ducts 16.

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Referring still to Figure 2, the battery tower 18 preferably comprises a plurality of cells 12. Each cell 12 preferably includes a positive electrically conductive cell terminal 24a and a negative electrically conductive cell terminal 24b. The terminals 24 of each cell may be connected (not shown) to terminals 24 of other cells 12 to form a battery suitable for providing
25 electrical power to electrical apparatus. Whilst not shown in the accompanying figures, the cells 12 may be connected in series or in parallel, dependent on the requirements of a given application for the battery tower 18.

As previously noted, the cell housing 10 is configured to retain, i.e. hold, the cells 12 whilst
30 also facilitating heat transfer to manage the temperature of the cells 12, for example to cool the cells 12. As such, each cell 12 is preferably located in a cell compartment 14 of a cell housing 10. For example, as shown in Figure 2, each cell 12 may be individually located in its own respective cell compartment 14. This helps to hold the cells 12 in position, and also facilitates effective cooling of the cells 12 as will be described in more detail below with
35 reference to Figures 3 and 4.

Referring initially to Figure 3, which shows a schematic cross-sectional view of the battery tower 18 through line A-A indicated in Figure 2, each cell compartment 14 may be at least partly defined by a plurality of cell compartment walls 26. Each cell compartment wall 26 is preferably thermally coupled to the cooling duct 16 of the respective cell housing 10. As such,
5 the cell compartment walls 26 may facilitate an effective and efficient transfer of heat from the cell compartment 14 to the cooling duct 16, thereby cooling the cell 12 in the respective cell compartment 14. In some examples, the cell housing 10 may comprise a single monolithic component defining each of the cell compartments 14 and the cooling duct 16. This may be particularly effective for conducting heat from the cell compartment 14 to the cooling duct 16,
10 or vice versa, without interruption.

In the example shown in Figure 3, each cell compartment 14 comprises a substantially rectangular cross-sectional profile and is defined at least in part by a plurality of cell compartment walls 26. In some preferred examples, the cell 12 located in a respective cell
15 compartment 14 may be surrounded by the cell compartment 14 on at least three sides. Surrounding the cell 12 in a cell compartment 14 in this way provides a substantial surface area to receive heat from the cells 12 and to conduct such heat away from the cells 12 in use. In the example shown in Figure 3 the cells 12 are surrounded by the cell compartment 14 on four sides, providing additional surface area via which to transfer heat away from the cells 12,
20 and providing a closed boundary to help retain the cells 12 in the compartments 14 during manufacture and use.

Referring still to Figure 3, in some preferred examples the cell compartments 14 may share a wall 26i with the cooling duct 16 to provide a particularly effective route for transferring cell
25 heat to a cooling fluid in the cooling duct 16 in use. For example, the cooling duct 16 may be defined at least in part by a duct wall 28. As shown in Figure 3, the duct wall 28 may also define at least part of each cell compartment 14 of the respective cell housing 10, i.e. at least part of a cell compartment wall 26i. In the example shown in Figure 3, each of the cell compartments 14 of each respective cell housing 10 is defined in part by the same duct wall
30 28 of the respective cell housing 10. In preferred examples the duct wall 28 may be formed of a heat-conductive material having a thermal conductivity of at least 150 W/mK. Sharing a wall 26i, 28 between the cooling duct 16 and the cell compartment 14 minimises the distance between the cell compartment 14 and the cooling duct 16 and is therefore particularly advantageous for transferring heat away from the cell compartment 14 in use.

In some examples, each cell 12 may be bonded into the cell compartment 14 in which it is located. For example, an epoxy or silicone based adhesive 30 or potting compound may be used to bond the cell 12 in the respective cell compartment 14, as shown in Figure 3. Momentive ® RTV627, which has a thermal conductivity of 0.31W/mk, may be an
5 advantageous adhesive 30 for bonding the cell 12 in the respective cell compartment 14. The adhesive 30 provides a thermal bridge to conduct heat directly from the cell 12 to the respective cell compartment walls 26, and may therefore be particularly effective for transferring heat from the cells 12 to the compartment walls 26 in use.

10 In some particularly preferred examples, the adhesive 30 may form a substantially continuous layer containing no gaps or air pockets between the cell 12 and the respective cell wall 26. For example, during manufacture of the battery tower 18, adhesive 30 may be arranged in the cell compartment 14 and, with the adhesive 30 still in a substantially liquid state, a battery cell
15 12 may be subsequently introduced to the cell compartment 14 such that the cell 12 is at least partially submerged in the adhesive 30. This may cause the adhesive 30 to be squeezed into any free space within the cell compartment 14 between the cell 12 and the cell compartment walls 26, thereby forming a substantially continuous thermal bridge between the cell 12 and the respective cell compartment walls 26. Examples of a method of manufacturing a battery module comprising cells 12 bonded into respective cell compartments 14 of a cell housing 10
20 will be described in more detail later with reference to Figures 10a and 10b.

With reference still to Figure 3, in some examples the cells 12 may be pouch cells, comprising a flexible outer skin 32. This may be advantageous for assembling the battery tower 18, because the cells 12 may be somewhat compliant and therefore easier to fit into the respective
25 cell compartments 14. A protective structure surrounding each cell 12 may be provided by the adhesive 30 bonding the cells 12 into the respective cell compartment 14, as described previously.

Figure 4 shows a schematic cross-sectional view of the battery tower 18 through line *B-B*
30 indicated in Figure 2. It will be appreciated that the four uppermost cell housings 10 of the battery tower 18 are not shown in Figure 4 in order to show the configuration of the cooling duct connector 22 more clearly. In particular, the cross-sectional view in Figure 4 shows an example of a flow path configuration defined by the cooling ducts 16 and the cooling duct connector 22 of the battery tower 18. The cooling duct 16 of a respective cell housing 10
35 preferably extends along substantially the full length of the cell compartments 14 defined by

the cell housing 10. In particular, the cooling duct 16 preferably extends along at least the full length of the cell 12 located in a cell compartment 14 of the respective cell housing 10.

As shown in Figure 4, in some examples the cooling duct 16 of each cell housing 10 may be a substantially u-shaped cooling duct 16. As such, the cooling ducts 16 may each include a first portion 16a, for example a lower portion, configured to flow fluid in a first direction and a second portion 16b, for example an upper portion, configured to flow fluid in a second direction that is substantially opposite to the first direction. This configuration helps to distribute the cooling effect of cooling fluid in the cooling duct 16 more evenly along the length of the cell compartments 14 in use. In examples where the cooling duct 16 comprises an upper and a lower portion 16a, 16b, these may extend substantially horizontally in the cell housing 10. This may help to reduce the risk of trapping air or gas bubbles in the cooling duct 16 in use, which could reduce the cooling performance.

As previously described, the cooling duct connector 22 fluidly couples the cooling ducts 16 of adjacently stacked cell housings 10. In examples where the cooling ducts 16 are substantially u-shaped, and each cell housing 10 is oriented the same way, the cooling duct connector 22 may fluidly couple the first portion 16a of a cooling duct 16 of a cell housing 10 to the second portion 16b of a cooling duct 16 of an adjacently stacked cell housing 10. For example, the first portion 16a of a cooling duct 16 may define an inlet 33a of the cooling duct 16, and second portion 16b of the cooling duct 16 may define an outlet 33b of the cooling duct 16. Accordingly, the cooling duct connector 22 may fluidly couple an outlet 33b of a cooling duct 16 of a cell housing 10 to an inlet 33a of a cooling duct 16 of an adjacently stacked cell housing 10. Accordingly, the cooling ducts 16 and the cooling duct connector 22 may together define a serpentine flow path through a plurality of the adjacently stacked cell housings 10.

As shown in Figure 4, the same cooling duct connector 22 may be configured to fluidly couple the cooling ducts 16 of three or more adjacently stacked cell housings 10. For example, the cooling duct connector 22 may define a plurality of separate conduits 34, where each conduit 34 is configured to fluidly couple the cooling ducts 16 of two adjacently stacked cell housings 10. Notably, in some such examples, the separate conduits 34 of the cooling duct connector 22 may not be directly fluidly coupled to one another. Accordingly, the conduits 34 may be fluidly isolated from one another, with fluid communication between the separate conduits 34 facilitated only via the cooling ducts 16 of the stacked cell housings 10. As such, the cooling ducts 16 and the cooling duct connector 22 may define an in-series flow path directing the cooling fluid through the cell housings 10 and the cooling duct connector 22 in series, in use.

With reference still to Figure 4, but with reference also to Figure 1, in some examples the u-shaped cooling ducts 16 may be defined, at least partly, by a channel 36 extending through the entire length of the cell housing 10. As shown in the accompanying figures, in some examples the cell housing 10 may comprise two channels 36 extending longitudinally through the cell housing 10. The channels 36 may be separated by a web 38, and a gap 40 may be provided in the web 38 to fluidly couple the two channels 36 and thereby at least partly define the u-shaped cooling duct 16. Further, an end cap 42 may block one end of the or each channel 36 to change the direction of flow of the cooling fluid in the cooling duct 16 in use. In some examples, such as that shown in Figure 4, the end cap 42 may comprise a sealing plate attached to the cell housing 10.

Figures 5a and 5b show a battery pack 44 including two of the previously described battery towers 18 arranged side by side. As previously described, the cooling ducts 16 and cooling duct connector 22 of a respective battery tower 18 define a flow path through the battery tower 18. As such, the first battery tower 18a comprises a first flow path and the second battery tower 18b comprises a second flow path. The cooling ducts 16 of different cell housings 10 in the respective battery towers 18 may be referred to in relation to their relative position along the respective flow path. For example, each battery tower 18 comprises a first cooling duct which is the furthest upstream cooling duct 16 defining the respective first or second flow path. Similarly, each battery tower 18 comprises a last cooling duct which is the furthest downstream cooling duct 16 defining the respective first or second flow path. It will be appreciated that any other cooling ducts 16 of a respective battery tower 18 are located between the first and last cooling ducts, i.e. downstream of the first cooling duct, and upstream of the last cooling duct.

In some examples, as shown in Figure 5b, the battery pack 44 may include a lower transverse pipe 48 and an upper transverse pipe 50. These transverse pipes 48, 50 may be connected to the cooling duct connectors 22 of each battery tower 18 to fluidly couple the first and second flow paths. As such, the first and second flow paths may be parallel flow paths, i.e. parallel to one another. In some examples the lower transverse pipe 48 may be fluidly coupled to the first and second flow paths upstream of the respective first cooling ducts of each battery tower 18. The upper transverse pipe 50 may be fluidly coupled to the first and second flow paths downstream of the respective last cooling ducts of each battery tower 18. Accordingly, substantially the entire portion of each flow path that is defined by the cooling ducts 16 of the cell housings 10 in the first and second battery towers 18a, 18b may be parallel with one another. This may help to ensure an even distribution of cooling fluid between the first and

second battery tower 18a, 18b in use, and also to help substantially equalise the fluid pressure and flow rate in the first and second flow paths.

With reference still to Figures 5a and 5b, the battery pack 44 may include a cooling fluid inlet 52 fluidly coupled to the first flow path and upstream of the first cooling duct. In examples comprising a lower transverse pipe 48, the cooling fluid inlet 52 may be fluidly coupled to the first flow path upstream of the lower transverse pipe 48, in some preferred examples. Accordingly, in such examples the first and second flow paths may be substantially parallel downstream of the cooling fluid inlet 52.

The battery pack 44 may also include a cooling fluid outlet 54 fluidly coupled to the second flow path and downstream of the last cooling duct. In examples comprising an upper transverse pipe 50, a cooling fluid outlet 54 may be fluidly coupled to the second flow path downstream of the upper transverse pipe 50, in some preferred examples. It follows that in some examples comprising upper and lower transverse pipes 48, 50 and a cooling fluid inlet 52 and outlet 54, the first and second flow paths between the cooling fluid inlet 52 and the cooling fluid outlet 54 may be parallel to one another.

As shown in Figures 5a and 5b, in some examples the inlet and outlet 52, 54 may be defined by an end portion of a respective cooling duct connector 22. For example, the inlet 52 may be defined by a lower end portion 56a of a cooling duct connector 22a of the first battery tower 18a, i.e. a lower end 56a of a first cooling duct connector 22a. The outlet 54 may be defined by an upper end 58b of a cooling duct connector 22b of the second battery tower 18, i.e. an upper end 58b of a second cooling duct connector 22b. Preferably, the inlet and outlet 52, 54 may be provided in substantially opposite locations in relation to the first and second flow paths. Accordingly, the length of each flow path between the inlet and outlet 52, 54 is preferably substantially the same, and this may also help to maintain substantially the same fluid pressure in each flow path.

Whilst Figures 5a and 5b show an inlet 52 at the lower end 56a of the first cooling duct connector 22a and an outlet 54 at the upper end 58b of the second cooling duct connector 22b, it will be appreciated that the location of the inlet and outlet 52, 54 may be interchangeable. Indeed, in some examples the inlet 52 may be located at the upper end 58a of the first cooling duct connector 22a and the outlet 54 may be located at the lower end 56b of the second cooling duct connector 22b, or vice versa.

In some examples, the battery pack 44 may comprise one or more additional components, such as a top-up valve (not shown) for introducing additional cooling fluid to the first and second flow paths, and/or an expansion element (not shown) to compensate for variations in cooling fluid pressure in use. Such additional components may be connected to ends 56, 58 of the first or second cooling duct connectors 22a, 22b that do not comprise an inlet 52 or an outlet 54, in some examples. For each of these components the location may be substantially interchangeable, as long as they are fluidly coupled to the flow paths to perform the desired function. Additionally, whilst not shown in the accompanying figures, the battery pack 44 may include a coolant pump, i.e. a circulation pump, configured to motivate cooling fluid into and through each flow path in the battery pack 44. In some preferred examples such a coolant pump may be provided upstream of, and fluidly coupled to, the cooling fluid inlet 52.

Reference is now made to Figures 6 to 9, which show an alternative battery pack 60. For ease of reference, the alternative battery pack 60 may be referred to herein as a second battery pack 60. The second battery pack 60 is similar to the battery pack 44 described previously, and includes many of the same features as the battery pack 44. Accordingly, it should be appreciated that equivalent features will not be described again in detail. Further, equivalent features maintain the same reference numerals throughout all of the examples described herein. For the avoidance of doubt, any of the features described previously with reference to the battery pack 44 may be equally applicable to the second battery pack 60.

The second battery pack 60 comprises a plurality of cell housings 10 in accordance with examples described previously. The cell housings 10 each comprise at least one cell compartment 14, and at least one cell 12 is located in each cell compartment 14. In the examples shown in Figures 6 to 9, the cell housings 10 each define three separate cell compartments 14, and each cell 12 is individually located in its own cell compartment 14. Further, the cooling ducts 16 of the cell housings 10 may be substantially U-shaped, as described previously, such that an inlet 33a and an outlet 33b of each cooling duct 16 may be located on a connection end of the respective cell housing 10. In some preferred examples, the cell housings 10 may all be arranged and oriented such that the cooling ducts 16, and in particular inlets and outlets 33a, 33b of the cooling ducts 16 are located in a substantially central portion of the second battery tower 60.

The plurality of cell housings 10 are arranged in a stacked configuration, and the second battery pack 60 comprises a plurality of cell housings 10 arranged side by side. Accordingly, the second battery pack 60 may be considered to comprise a plurality of battery towers 118

arranged side by side, similar to the battery towers 18 described previously with reference to the battery pack 44. However, as described previously the cell housings 10 of the battery towers 118 of the second battery pack 60 may be oriented such that the respective cooling ducts 16 are arranged centrally, and notably, the battery towers 118 of the second battery pack 60 do not include the same cooling duct connector 22 as described previously.

Instead, the second battery pack 60 comprises a connection manifold 62. The connection manifold 62 serves to fluidly couple the cooling ducts 16 of the cell housings 10 in each battery tower 118 in a substantially similar way to the cooling duct connector 22. However, the connection manifold 62 provides fluid communication both between the cooling ducts 16 of a first battery tower 118a and between the cooling ducts 16 of a second battery tower 118b, in a single component. Accordingly, with reference particularly to the cross-sectional views in Figures 7b and 8, and the schematic diagram in Figure 9, the connection manifold 62 defines a plurality of first conduits 34a configured to fluidly couple the cooling ducts 16 of the cell housings 10 of the first battery tower 118a. The connection manifold 62 further defines a plurality of second conduits 34b configured to fluidly couple the cooling ducts 16 of the cell housings 10 of the second battery tower 118b. As shown in Figures 7b and 8, the respective first conduits 34a are preferably isolated from one another in the connection manifold 62, and only fluidly coupled via the cooling ducts 16 of the respective cell housings 10. The same applies to the plurality of second conduits 34b.

Notably, pairs of first and second conduits 34a, 34b may be defined by a respective channel 64 in the connection manifold 62. For example, a respective channel 64 in the connection manifold 62 may define a first conduit 34a fluidly coupling the cooling ducts 16 of two adjacently stacked cell housings 10 of the first battery tower 118a, and the same channel 64 may define a corresponding second conduit 34b fluidly coupling the cooling ducts 16 of two corresponding, neighbouring cell housings 10 of the second battery tower 118b. With reference in particular to the diagram in Figure 9, the connection manifold 62 may therefore be configured to receive a combined flow of cooling fluid at a cooling fluid inlet 52, to split the flow into two portions where each portion of the cooling fluid flows through a cooling duct 16 of a cell housing 10 of one of the first or second battery towers 118a, 118b, and to subsequently recombine the portions of the cooling fluid in a channel 64. The channel 64 may define a corresponding pair of first and second conduits 34a, 34b such that the combined flow of cooling fluid may then be split again into two portions which each flow through a respective cooling duct 16 of a cell housing 10 of one of the first or second battery towers 118a, 118b,

before the portions of the cooling fluid are again recombined in a channel 64 of the connection manifold 62.

5 The cooling ducts 16 of all of the cell housings 10 in the second battery pack 60 may be fluidly coupled in this way. Accordingly, the cooling ducts 16 of a respective battery tower 118a, 118b may all be fluidly coupled in series, and the cooling ducts 16 of corresponding pairs of neighbouring cell housings 10 may be fluidly coupled in parallel. This configuration promotes mixing between the cooling ducts 16 of the first and second battery towers 118a, 118b in use, thereby improving temperature balancing.

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The connection manifold 62 may also define a cooling fluid outlet 54 downstream of all of the cooling ducts 16 such that, after flowing through the respective cooling ducts 16 of each battery tower 118a, 118b, a combined flow of cooling fluid may be discharged from the connection manifold 62. As described in more detail later, the cooling fluid outlet 54 may be
15 fluidly coupled to a heat exchanger (not shown) to recycle the heat from the cooling fluid for a functional purpose.

With reference now to the schematic perspective view in Figure 10a and the cross-sectional views in Figure 10b, in some examples the second battery pack 60 may comprise a back plate
20 66. For example, the back plate 66 may be attached to a cell housing 10 and the connection manifold 62 may be fluidly coupled to the respective cooling duct 16 via a respective aperture 68 in the back plate 66. In some examples, as shown in Figures 10a and 10b, a single back plate 66 may be attached to a plurality of stacked and/or neighbouring cell housings 10. The inclusion of a back plate 66 may simplify connection and sealing of the connection manifold
25 62 to the respective cell housings 10, and in particular to the cooling ducts 16 of the cell housings 10.

Advantageously, the configuration of the second battery pack 60 may facilitate modular manufacture, in some examples. For example, the second battery pack 60 may comprise a
30 plurality of battery modules 70 which may each be manufactured separately, i.e. offline, before being assembled together and fluidly coupled with the connection manifold 62 to form the second battery pack 60. As such, a method of manufacturing a battery module 70 will now be described with reference primarily to Figure 10b, but with continued reference also to the previously-described figures.

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For reference, a battery module 70 may comprise at least one cell housing 10 defining at least one cell compartment 14, and at least one cell 12 may be adhesively bonded into the at least one cell compartment 14. In the example shown in Figures 10 and 10b, the battery module 70 may comprise a plurality of cell housings 10 each defining a plurality of separate cell compartments 14. Each cell compartment 14 may house an individual cell 12 as described previously.

The method includes providing a cell housing 10 and providing adhesive 30 in the or each cell compartment 14 defined by the cell housing 10. For example, the adhesive 30 may be a potting compound, such as Momenite ® RTV627 which has a low viscosity and high thermal conductivity. The method also include arranging a cell 12 in the respective cell compartment 14.

In some examples, the cell 12 may be arranged in the cell compartment 14 after the provision of adhesive 30 in the cell compartment 14. As such, the cell 12 may be lowered into adhesive 30 in the cell compartment 14 and substantially submerged therein such that a layer of adhesive 30 is formed between the cell 12 and the cell compartment walls 26. It should be noted that the adhesive 30 is not shown in Figure 10b for clarity, i.e. Figure 10b shows a module prior to the provision of adhesive 30 in the cell compartments 14.

In some preferred examples, the cell 12 may be arranged in the cell compartment 14 prior to the introduction of adhesive 30 to the cell compartment 14. For example, with reference to Figure 10b, in some examples the cell housing 10 may be arranged in an upright configuration, and the cell 12 may be located in a respective cell compartment 14. The cell compartment 14 may subsequently be flooded with adhesive 30 to surround the cell 12 and thereby form a layer of adhesive 30 bonding the cell 12 to the cell compartment walls 26.

Notably, in some preferred examples the battery module 70 may comprise a back plate 66 as previously described. As shown in Figures 10a and 10b, the battery module 70 may comprise a plurality of cell housings 10 attached to the back plate 66. Whilst the benefits of the back plate 66 for providing simplified sealing mechanisms has been described previously, in some examples the back plate 66 may also be advantageous for manufacturing the battery module 70.

For example, a back plate 66 attached to a plurality of cell housings 10 may provide stability when supplying adhesive 30 to the cell compartments 14 and arranging the or each cell 12 in

the cell compartments 14. In addition, the back plate 66 may be configured to supply the adhesive 30 to the cell compartments 14, in some examples. For example, the back plate 66 may comprise one or more adhesive inlets 72 through which adhesive 30 may be supplied to the cell compartments 14. With the or each cell housing 10 arranged in an upright orientation, i.e. such that the cell compartments 14 extend substantially vertically from the back plate 66, supplying adhesive 30 to the cell compartments 14 via the back plate 66 may result in filling the cell compartments 14 from the bottom up. Flooding the cell compartments 14 with adhesive 30, i.e. potting compound, in this way may be advantageous for simplifying the manufacturing process and ensuring accurate delivery of adhesive 30 to the cell compartments 14.

Notably, in some examples the back plate 66 may comprise one or more protrusions, steps, or shoulders 74 configured to engage the cell housing 10. Such protrusions may maintain a gap 76 between an internal surface 78 of the back plate 66 and the cell housing 10. Advantageously such a configuration may facilitate fluid communication between the cell compartments 14. This in turn may mean that adhesive 30 can be supplied to all of the cell compartments 14 from a single adhesive inlet 72, or from a reduced number of adhesive inlets 72, via the gap 76 which may be in fluid communication with each of the cell compartments 14. Advantageously this may facilitate substantially simultaneous provision of adhesive 30 to each cell compartment 14. Accordingly, the method may comprise providing adhesive 30 to each cell compartment 14 via an adhesive inlet 72 and via the gap 76 between the back plate 66 and the cell housing 10.

With reference more generally to all of the accompanying figures, it will be appreciated that the illustrated examples are provided by way of example only and that many different configurations and combinations of features remain within the scope of the invention as defined by the appended claims.

For example, as previously described, whilst the description provided herein primarily refers to cooling the cells 12 in use, the battery towers 18, 118 and cell housings 10 of the battery towers 18, 118 are configured to facilitate both heating and cooling the cells 12 in use. Accordingly, the battery towers 18, 118 and cell housings 10 are configured to help maintain the temperature of the cells within a desired range for optimal performance and/or longevity, for example by facilitating increasing the temperature of the cells 12 or cooling the cells 12 in dependence on the cell temperature.

Further, whilst each example of a cell housing 10 shown in the accompanying figures comprises a plurality of cell compartments 14, it will be appreciated that in some examples a cell housing 10 may have only one cell compartment 14, and such a cell housing 10 may still achieve the benefit of simultaneously retaining and cooling one or more cells 12 located in said cell compartment 14. Similarly, whilst the cell compartments 14 in each illustrated example described herein comprise four cell compartment walls 26, it will be appreciated that in some examples three compartment walls 26 may be sufficient to help retain a cell 12 and conduct heat away from said cell 12.

Further, the examples shown in the accompanying figures each comprise cell compartments 14 defined in part by the same duct wall 28 in a respective cell housing 10, i.e. the same duct wall 28 is shared with each cell compartment 14 of a given cell housing 10. However, it will be appreciated that in some examples, a cell housing 10 may comprise cell compartments 14 that do not share the same duct wall 28. For example, the cooling duct 16 may be defined by two or more duct walls 28, including a first duct wall and a second duct wall 28. In some examples the cell housing 10 may include one or more cell compartments 14 defined in part by the first duct wall and one or more cell compartments 14 defined in part by the second duct wall. For example the cooling duct 16 may be a central cooling duct 16 configured to flow a cooling fluid between different cell compartments 14 of the same cell housing 10.

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Battery towers 18, 118 or battery packs 44, 60 as described herein may be suitable for many different applications. For example, a battery tower 18, 118 or battery pack 44, 60 may be used as a main power source for drive elements on vehicles such as boats or trains, or as an auxiliary power source on such vehicles. However, in preferred example the battery tower 18, 118 or battery pack 44, 60 described herein may be implemented in a stationary application. For example, the battery tower 18, 118 or battery pack 44, 60 may be used as power source for a domestic electrical system or for a commercial electrical system, or as a back-up power source instead of a fossil-fuelled power generator, to name some possible examples.

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In some particularly advantageous examples, the battery tower 18, 118 or battery pack 44, 60 may form part of an electrical water heating system (not shown). For example, such a water heating system may include an electrical heating element that is powered at least partly by power from cells 12 in the battery tower 18, 118 or battery pack 44, 60. Some examples of the battery tower 18, 118 or battery pack 44, 60 may include a heat exchanger for removing heat from the cooling fluid flowing through the cooling ducts 16 of the various cell housings 10 in use. For example, the cooling fluid outlet of the battery pack 44, 60 may be fluidly coupled to

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- the heat exchanger such that cooling fluid may flow to the heat exchanger after flowing through the cooling ducts 16 of the cell housings 10 of the battery pack 44, 60. Such a heat exchanger may be configured to pre-heat water in the electrical water heating system such that water may be initially heated by heat removed from the cells 12 in a battery tower 18, 118 prior to
- 5 being heated by the heating element. This may provide a more efficient water heating system because less power may be required to heat the water to a desired temperature using the main heating element. In some examples, the heat exchanger (not shown) may be a cross flow heat exchanger.
- 10 It will be appreciated that any features described in relation to the various examples above may be readily combined with any other features described with reference to different examples without departing from the scope of the invention as defined in the appended claims. Further, it will be appreciated that the above description and accompanying figures are provided merely as an example. Many alternatives to the specific examples provided above
- 15 are therefore possible without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A battery tower (18) comprising:
 - a plurality of cell housings (10) stacked on top of one another, each cell housing
 - 5 defining at least one cell compartment (14) and a cooling duct (16) thermally coupled to the at least one cell compartment; and
 - a cooling duct connector (22) attached to two adjacently stacked cell housings to fluidly couple the cooling ducts of the two adjacently stacked cell housings.
- 10 2. The battery tower (18) of Claim 1, wherein each cooling duct (16) is a substantially u-shaped cooling duct comprising a first portion (16a) configured to flow fluid in a first direction and a second portion (16b) configured to flow fluid in a second direction that is substantially opposite to the first direction.
- 15 3. The battery tower (18) of Claim 2, wherein the first portion (16a) is a lower portion and the second portion (16b) is an upper portion, and wherein the first and second portions of each cooling duct (16) extend substantially horizontally in the cell housing (10).
4. The battery tower (18) of Claim 3, wherein the u-shaped cooling duct (16) of each
- 20 cell housing (10) is defined at least in part by a channel (36) extending through the entire length of the cell housing and by an end cap (42) blocking one end of the channel.
5. The battery tower (18) of any of Claims 2 to 4, wherein the cooling duct connector (22) fluidly couples the first portion of the cooling duct (16a) of a cell housing (10) to the
- 25 second portion of a cooling duct (16b) of an adjacently stacked cell housing.
6. The battery tower (18) of Claim 5, wherein the cooling ducts (16) and the cooling duct connector (22) together define a serpentine flow path through a plurality of the adjacently stacked cell housings (10).
- 30 7. The battery tower (18) of any preceding claim, wherein the cooling duct (16) of the cell housing (10) extends along substantially the full length of the or each cell compartment (14) of the respective cell housing.
- 35 8. The battery tower (18) of any preceding claim, wherein the cell housing (10) defines a plurality of cell compartments (14).

9. The battery tower (18) of Claim 8, wherein the plurality of cell compartments (14) of the cell housing (10) are defined in a stacked configuration on top of one another.
- 5 10. The battery tower (18) of any preceding claim, further comprising a plurality of cells (12), wherein each cell is located in a cell compartment (14) of a cell housing (10).
11. The battery tower (18) of Claim 10, wherein the respective cell (12) is bonded into the cell compartment (14) in which it is located.
- 10 12. The battery tower (18) of Claim 10 or Claim 11, wherein the cells (12) are pouch cells comprising a flexible outer skin (32) and two electrically conductive cell terminals (24).
13. The battery tower (18) of any of Claims 10 to 12, wherein each cell (12) is individually
- 15 located in its own respective cell compartment (14).
14. The battery tower (18) of Claim 13, wherein each cell compartment (14) comprises a substantially rectangular cross-sectional profile defined at least in part by three cell compartment walls (26), and wherein the cell (12) located in a respective cell compartment is
- 20 surrounded by the cell compartment on at least three sides.
15. The battery tower (18) of Claim 14 wherein each cell compartment wall (26) is thermally coupled to the cooling duct (16) of the respective cell housing (10).
- 25 16. The battery tower (18) of any preceding claim, wherein the cooling duct (16) of each cell housing (10) is defined at least in part by one or more duct walls (28), and wherein each cell compartment (14) defined by the respective cell housing is defined at least in part by a duct wall.
- 30 17. The battery tower (18) of Claim 16, wherein each cell compartment (14) defined by a respective cell housing (10) is defined at least in part by the same duct wall (28).
18. The battery tower (18) of Claim 16 or Claim 17, wherein the or each duct wall (28) comprises a heat-conductive material having a thermal conductivity of at least 150 W/(mK).

19. The battery tower (18) of any preceding claim, wherein the cell housing (10) comprises a single monolithic component defining each of the cell compartments (14) and the cooling duct (16).
- 5 20. The battery tower (18) of any preceding claim, wherein the battery tower comprises three or more cell housings (10) stacked on top of one another, and wherein the cooling duct connector (22) is attached to each of the stacked cell housings to fluidly couple the cooling ducts (16) of adjacently stacked cell housings.
- 10 21. A battery pack (44) comprising at least two battery towers (18) as claimed in any preceding claim, wherein the at least two battery towers are arranged side by side.
22. The battery pack (44) of Claim 21, wherein the cooling ducts (16) and cooling duct connector (22) of a first battery tower (18a) define a first flow path and the cooling ducts and
15 cooling duct connector of an adjacent second battery tower (18b) define a second flow path, and wherein the battery pack (44) further comprises a lower transverse pipe (48) and an upper transverse pipe (50) connected to the cooling duct connectors of each battery tower to fluidly couple the first and second flow paths.
- 20 23. The battery pack (44) of Claim 22, further comprising a cooling fluid inlet (52) upstream of the first cooling duct defining the first flow path in the first battery tower (18a), and a cooling fluid outlet (54) downstream of the last cooling duct defining the second flow path in the second battery tower (18b).
- 25 24. The battery pack (44) of Claim 23, wherein the lower transverse pipe (48) is fluidly coupled to the first and second flow paths upstream of the respective first cooling ducts defining the first and second flow paths in the respective first and second battery towers (18a, 18b),
and wherein the upper transverse pipe (50) is fluidly coupled to the first and second
30 flow paths downstream of the respective last cooling ducts defining the first and second flow paths in the respective first and second battery towers.
25. The battery pack (44) of Claim 23 or Claim 24, further comprising a coolant pump upstream of, and fluidly coupled to, the cooling fluid inlet (52).

26. An electrical water heating system comprising a battery tower (18) as claimed in any of Claims 1 to 20 and/or a battery pack (44) as claimed in any of Claims 21 to 25.