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## INTEGRATED FRAME AND BATTERY PACK STRUCTURE FOR ELECTRIC VEHICLES

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### Abstract

Integrated frame and battery pack structure for electric vehicles are disclosed. An example apparatus disclosed herein includes a battery pack structure including a flange to be coupled to a surface of a longitudinal rail of a frame of a vehicle, a first wall, and a second wall, the first wall and the second wall defining an interior, a battery disposed within the interior, a cross member disposed within the interior.

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## Background/Summary

RELATED APPLICATION [0001] This application arises from a continuation of U.S. patent application Ser. No. 18/363,482, filed on Aug. 1, 2023 and entitled “INTEGRATED FRAME AND BATTERY PACK STRUCTURE FOR ELECTRIC VEHICLES,” which is a continuation of U.S. patent application Ser. No. 17/077,765, filed on Oct. 22, 2020, entitled “INTEGRATED FRAME AND BATTERY PACK STRUCTURE FOR ELECTRIC VEHICLES,” both of which are incorporated herein by reference in their entireties.

### FIELD OF THE DISCLOSURE

[0002] This disclosure relates generally to electric vehicles and, more particularly, to an integrated frame and battery pack structure for electric vehicles.

### BACKGROUND

[0003] Known electric vehicles include an electric motor that is powered by rechargeable batteries. The rechargeable batteries are typically located in a battery pack that is placed inside the electric vehicle near the electric motor. The battery pack is typically large in size and weight to provide enough power to the electric motor over a desired travel range. The placement of the battery pack in the electric vehicle must account for the size of the battery pack while also maintaining the electric vehicle stiffness for vehicle support and crash safety loads.

### SUMMARY

[0004] An example electric vehicle comprising a frame of the electric vehicle to which a body of the electric vehicle is coupled, the frame including longitudinal frame rails, a mid-section of the frame not including frame cross-members, and a battery pack mounted in the mid-section of the frame, the battery pack including battery pack cross-members, each of the battery pack cross-members connected to a top surface of the longitudinal frame rails and a bottom surface of the longitudinal frame rails.

[0005] An example electric vehicle comprising a frame of the electric vehicle isolated from a body of the electric vehicle, the frame including longitudinal frame rails and frame cross-members fixed to the frame, and a battery pack including battery pack cross-members, the battery pack cross-members connected to respective bottom surfaces of the frame cross-members and the longitudinal frame rails.

[0006] An example apparatus comprising an electric vehicle assembly having a body and a frame, the frame isolated from the body, a mid-section of the frame not including frame cross-members, and a battery pack removably coupled to the frame via bolts, the battery pack including battery pack cross-members between longitudinal frame rails in a mid-section of the frame.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates an example frame for a body on frame vehicle.

[0008] FIG. 2 illustrates an example first integrated battery pack and frame structure in accordance with the teachings of this disclosure.

[0009] FIGS. 3A, 3B and 3C illustrate a cross-sectional view of an example first assembly of the example first integrated battery pack and frame structure of FIG. 2. discrepancy

[0010] FIGS. 4A, 4B and 4C illustrate a cross-sectional view of an example second assembly of the

example first integrated battery pack and frame structure of FIG. 2.

[0011] FIG. 5 illustrates an example placement of the example first integrated battery pack and frame structure of FIG. 2 in an example electric vehicle in accordance with the teachings of this disclosure.

[0012] FIGS. 6A, 6B and 6C illustrate a cross-sectional view of example torsional loading, example vertical loading, and example side loading applied to the example first assembly of FIGS. 3A, 3B and 3C.

[0013] FIG. 7 illustrates an example second integrated battery pack and frame structure in accordance with the teachings of this disclosure.

[0014] FIGS. 8A, 8B and 8C illustrate example cross-sectional views of the battery pack included in the example second integrated battery pack and frame structure of FIG. 7.

[0015] FIGS. 9A and 9B illustrate example top views of the battery pack included in the example second integrated battery pack and frame structure of FIG. 7.

[0016] FIGS. 10A, 10B and 10C illustrate example cross-sectional views of an example first assembly of the example second integrated battery pack and frame structure of FIG. 7.

[0017] FIGS. 11A, 11B and 11C illustrate a first assembly of the example first assembly of FIGS. 10A, 10B and 10C connected to a body structure in accordance with the teachings of this disclosure.

[0018] FIGS. 12A, 12B and 12C illustrate example cross-sectional views of a second assembly of the example second integrated battery pack and frame structure of FIG. 7.

[0019] FIGS. 13A and 13B illustrate a second assembly of the example second assembly of FIGS. 12A, 12B and 12C connected to a body structure in accordance with the teachings of this disclosure.

[0020] The figures are not to scale. Instead, the thicknesses of the layers or regions may be enlarged in the drawings. Although the figures show layers and regions with clean lines and boundaries, some or all of these lines and/or boundaries may be idealized. In reality, the boundaries and/or lines may be unobservable, blended, and/or irregular. In general, the same reference numbers will be used throughout the drawing(s) and accompanying written description to refer to the same or like parts. As used herein, unless otherwise stated, the term “above” describes the relationship of two parts relative to Earth. A first part is above a second part, if the second part has at least one part between Earth and the first part. Likewise, as used herein, a first part is “below” a second part when the first part is closer to the Earth than the second part. As noted above, a first part can be above or below a second part with one or more of: other parts therebetween, without other parts therebetween, with the first and second parts touching, or without the first and second parts being in direct contact with one another. As used in this patent, stating that any part (e.g., a layer, film, area, region, or plate) is in any way on (e.g., positioned on, located on, disposed on, or formed on, etc.) another part, indicates that the referenced part is either in contact with the other part, or that the referenced part is above the other part with one or more intermediate part(s) located therebetween. As used herein, connection references (e.g., attached, coupled, connected, and joined) may include intermediate members between the elements referenced by the connection reference and/or relative movement between those elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and/or in fixed relation to each other. As used herein, stating that any part is in “contact” with another part is defined to mean that there is no intermediate part between the two parts.

[0021] Unless specifically stated otherwise, descriptors such as “first,” “second,” “third,” etc. are used herein without imputing or otherwise indicating any meaning of priority, physical order, arrangement in a list, and/or ordering in any way, but are merely used as labels and/or arbitrary names to distinguish elements for ease of understanding the disclosed examples. In some examples, the descriptor “first” may be used to refer to an element in the detailed description, while the same element may be referred to in a claim with a different descriptor such as “second” or “third.” In

such instances, it should be understood that such descriptors are used merely for identifying those elements distinctly that might, for example, otherwise share a same name. As used herein, “approximately” and “about” refer to dimensions that may not be exact due to manufacturing tolerances and/or other real world imperfections.

#### DETAILED DESCRIPTION

[0022] Some vehicles such as, for example, automobiles, are equipped with electric motors rather than traditional combustion engines. The electric motors are typically powered by rechargeable batteries that are located in a battery pack. The battery pack is typically large in size and weight to provide enough power to the electric motor over a desired travel range. The placement of the battery pack in the electric vehicle must account for the size of the battery pack while also maintaining the electric vehicle stiffness for vehicle support and crash safety loads.

[0023] In a unibody vehicle where the body and frame of the vehicle are integrated (e.g., a standard passenger vehicle), the body of the vehicle provides added stiffness and durability for the vehicle. However, in body on frame vehicles, the bodies and frames of the vehicles are separate (e.g., trucks, pickups, etc.), and the frame of the vehicle provides the stiffness and durability for the vehicle. For an electric body on frame vehicle, the placement of the battery pack on the frame of the vehicle is more challenging than in a unibody vehicle. In particular, if the battery pack of the body on frame vehicle decreases the stiffness and durability of the frame of the vehicle, then the overall stiffness and safety of the body on frame vehicle is decreased.

[0024] Current frame designs of body on frame vehicles and battery pack designs for electric vehicles pose packaging challenges for a large battery pack to power an all-electric body on frame vehicle. The packaging challenges include integrating a large volume of heavy batteries into the frame of the body on frame vehicle while meeting structural performance (e.g., stiffness, durability, safety, etc.), weight, serviceability, and occupant package requirements for the body on frame vehicle. However, the placement of the battery pack in the frame of the body on frame vehicle is not the only challenge. Controlling the added weight from the battery pack is another challenge for the body on frame vehicle. The battery pack design and placement should retain the stiffness of the body on frame vehicle to meet the structural performance requirements without a large increase in weight of the vehicle. The battery pack in a body on frame vehicle should minimize the amount of added weight to efficiently be able to use the power of the batteries to move the vehicle.

[0025] Current battery pack designs for body on frame vehicles do not contribute to overall stiffness of the frame or work in conjunction with the frame to mitigate intrusions. Typical frames for a body on frame vehicle include frame cross-members that provides the stiffness and durability for the vehicle for any loads that might act on the vehicle. However, in an example battery pack design, a majority of the frame cross-members were removed to make room for the battery pack, which resulted in a decrease in the structural stiffness of the vehicle. In this example design, the battery pack contained battery pack cross-members within the battery pack. However, these battery pack cross-members only acted to support the weight of the battery modules and did not provide stiffness to the vehicle. To increase the structural stiffness of the vehicle, an exoskeleton with cross-members was added below the battery pack on the frame. However, the exoskeleton added significant mass to the vehicle (e.g., greater than 100 kg of added mass), consumed substantial volume in the frame of the vehicle, and degraded the ground clearance of the vehicle. The added exoskeleton caused more challenges for the vehicle in that it increased the weight of the vehicle, which increased the load on the vehicle and decreased the efficiency of power usage.

[0026] A preferred location of the battery pack for a body on frame vehicle is between the frame rails in the mid-rail section of the frame below the body of the vehicle. However, as mentioned above, this space is occupied by frame cross-members that add stiffness to the vehicle to support noise, vibration, and harshness (NVH) and manage crash safety loads. Removing the frame cross-members would pose a challenge to meet sub-system frame stiffness targets and crash safety assessments. Placing the battery pack in the midrail section of the frame results in the midrails

being pushed outward (i.e., widening the frame), which again poses a challenge to meet side pole impact requirements, and results in a large offset between the front and mid-rails of the frame.

[0027] Examples disclosed herein include a first battery pack design that is an integrated assembly with the frame of the body on frame vehicle to improve load paths and reduce redundant structural members. In examples disclosed herein, the battery pack is an integrated assembly that, when installed, adds stiffness to the frame structure. In examples disclosed herein, the first battery pack design eliminates frame cross-members in the midrail section to provide room for the battery pack. In examples disclosed herein, the battery pack includes battery pack cross-members. In examples disclosed herein, the battery pack cross-members of the first battery pack design function as cross-members of the chassis (frame) of the body on frame vehicle. In examples disclosed herein, the battery pack cross-members provide support for the battery modules in the battery pack and increase the frame stiffness for different load paths (e.g., lateral, torsional, and vertical). In examples disclosed herein, the first battery pack design eliminates the frame cross-members in the midrail section, and the battery pack cross-members are connected to the frame structure to provide support and stiffness while not duplicating structures.

[0028] Examples disclosed herein include a second battery pack design that structurally integrates a battery pack with a conventional frame of body on frame vehicles. In examples disclosed herein, the second battery pack design includes a new frame structure that has a pre-sealed battery pack that is hard mounted to the frame via the frame rails and frame cross-members. In examples disclosed herein, the second battery pack design includes battery pack cross-members within the battery pack that are bolted or otherwise fixed to the frame cross-members as well as the frame rails. In examples disclosed herein, the battery pack cross-members are connected to the frame cross-members at multiple mounting points between the battery pack and the frame structure. In examples disclosed herein, the multiple mounting points increase the number of packages for battery modules in the battery pack and improve the load paths for stiffness and side pole impact performance. In examples disclosed herein, the second battery pack design reduces the twisting of the frame where the battery pack is placed, which improves the durability of the battery modules. In examples disclosed herein, the improved connections between the battery pack structure and the frame structure using the cross-members also support the mass of the battery pack. In examples disclosed herein, the second battery pack design also allows for the top hat of the body to be either hard mounted (to provide additional vehicle stiffness and crashworthiness) or bolted (via conventional isolated mounts) to the connected battery pack and frame structures.

[0029] In examples disclosed herein, both the first battery pack design the second battery pack design improve battery pack integration into the frame structure of electric, body on frame vehicles. In examples disclosed herein, the first battery pack design and the second battery pack design include battery pack cross-members that improve stiffness for load paths from side impact events. However, in examples disclosed herein, the first battery pack design is removable and mounted to the frame using the battery pack cross-members and frame rails. In examples disclosed herein, the battery pack of the second battery pack design is an integral member of the frame through connecting the battery pack cross-members to the frame cross-members for increased load paths and stiffness. In examples disclosed herein, both the first battery pack design and second battery pack design use existing structures of the vehicle frame to minimize the amount of space consumed by the battery pack and to minimize any added weight of integrating the battery pack (to increase energy usage efficiency for the electric vehicle).

[0030] As used herein, singular references (e.g., “a”, “an”, “first”, “second”, etc.) do not exclude a plurality. The term “a” or “an” entity, as used herein, refers to one or more of that entity. The terms “a” (or “an”), “one or more”, and “at least one” can be used interchangeably herein. Furthermore, although individually listed, a plurality of means, elements or method actions may be implemented by, e.g., a single unit or processor. Additionally, although individual features may be included in different examples or claims, these may possibly be combined, and the inclusion in different

examples or claims does not imply that a combination of features is not feasible and/or advantageous.

[0031] FIG. 1 illustrates an example frame **100** for a body on frame vehicle. The frame **100** of FIG. 1 includes example longitudinal frame rails **105A**, **105B**, an example front cross-member **110**, an example suspension cross-member **115**, an example cross-member **120**, an example midrail cross-member **125**, an example midrail cross-member **130**, an example rear suspension cross-member **135**, an example rear cross-member **140**, an example rear cross-member **145**, and an example mid-section **150**.

[0032] In the illustrated example FIG. 1, the frame **100** is isolated from the body of the body on frame vehicle. The longitudinal frame rails **105A**, **105B** run parallel along the length of the frame **100** to provide support for the body on frame vehicle. In some examples, the front cross-member **110**, the suspension cross-member **115**, and the cross-member **120** are included in the front end of the frame **100**. The front cross-member **110**, the suspension cross-member **115**, and the cross-member **120** provide structural support and stiffness for the frame **100** in response to frontal loads. The midrail cross-member **125** and the midrail cross-member **130** are included in the mid-section **150** (e.g., the midrail section) of the frame **100**. In some examples, the midrail cross-member **125** and the midrail cross-member **130** provide stiffness to the frame **100** to support noise, vibration, and harshness (NVH) for the vehicle and supports crash safety loads from impact events. In some examples, the rear suspension cross-member **135**, the rear cross-member **140**, and the rear cross-member **145** are included in the rear (e.g., backend) of the frame **100**. The rear suspension cross-member **135**, the rear cross-member **140**, and the rear cross-member **145** provide structural support and stiffness to the rear of the vehicle during rear-end impact events.

[0033] In the illustrated example of FIG. 1, an advantageous location for the placement of a battery pack in an electric, body on frame vehicle is between the longitudinal frame rails **105A**, **105B** in the mid-section **150** of the frame **100** below the body of the vehicle. In the illustrated example of FIG. 1, this space is occupied by the midrail cross-member **125** and the midrail cross-member **130**. If the midrail cross-member **125** and the midrail cross-member **130** are eliminated from the frame **100**, the frame **100** would not meet frame stiffness targets or crash safety assessments for the vehicle. Examples disclosed herein include an example first integrated battery pack and frame structure and an example second integrated battery pack and frame structure for the electric, body on frame vehicle while maintaining/improving the frame stiffness targets and crash safety assessments of the frame.

[0034] FIG. 2 illustrates an example first integrated battery pack and frame structure **200** in accordance with the teachings of this disclosure. The first integrated battery pack and frame structure **200** includes an example longitudinal frame rail **205**, an example longitudinal frame rail **210**, example battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E**, example bolts **220A**, **220B**, **220C**, **220D**, **220E**, **220F**, **220G**, **220H**, **220I**, **220J**, **220K**, **220L**, **220M**, **220N**, example battery modules **225A**, **225B**, **225C**, **225D**, and an example top cover **230**.

[0035] In the illustrated example of FIG. 2, the longitudinal frame rail **205** and the longitudinal frame rail **210** are similar to the longitudinal frame rails **105A**, **105B** of FIG. 1. The longitudinal frame rail **205** and the longitudinal frame rail **210** are connected to the battery pack cross-members **215A-E** via the bolts **220A-N**. In the illustrated example of FIG. 2, the battery pack cross-members **215A-E** are connected to top surfaces of the longitudinal frame rail **205** and the longitudinal frame rail **210** using the bolts **220A-N**. In some examples, the battery pack cross-members **215A-E** are connected to the longitudinal frame rail **205** and the longitudinal frame rail **210** in the midrail section (e.g., the mid-section **150** of FIG. 1) of the frame of the vehicle. In some examples, battery pack cross-members **215A-E** increase the stiffness of the frame structure for different load paths (e.g., lateral, torsional, and vertical).

[0036] In the illustrated example of FIG. 2, the battery modules **225A-D** are positioned between the battery pack cross-members **215A-E**. In some examples, the battery pack cross-members **215A-E**

provide support for the battery modules **225A-D** and secure the positions of the battery modules **225A-D** within the battery pack structure included in the first integrated battery pack and frame structure **200**. The battery modules **225A-D** provide power for an electric vehicle that includes the first integrated battery pack and frame structure **200**. In some examples, the battery modules **225A-D** include lithium-ion batteries. However, other types of batteries may additionally and/or alternatively be used. In the illustrated example of FIG. 2, the top cover **230** is positioned on the top surfaces of the battery pack cross-members **215A-E** and the battery modules **225A-D**. In some examples, after the battery modules **225A-D** are positioned between the battery pack cross-members **215A-E**, the top cover **230** is positioned on the top surfaces of the battery pack cross-members **215A-E** and the battery modules **225A-D** to secure the battery modules **225A-D** in the positions. In some examples, the top cover **230** is connected to the top surface of the battery pack cross-members **215A-E** using bolts. However, other fasteners, such as nuts and screws, may additionally and/or alternatively be used.

[0037] FIGS. 3A, 3B and 3C illustrate a cross-sectional view of an example first assembly of the example first integrated battery pack and frame structure **200** of FIG. 2. The first assembly of FIG. 3A includes an example battery pack structure **305**, example battery pack internals **310**, an example top cover **315**, example longitudinal frame rails **320A**, **320B**, example flanges **325A**, **325B**, example bottom surfaces **340**, and example flanges **345A**, **345B**.

[0038] In the illustrated example of FIG. 3A, the battery pack structure **305** is a plate (e.g., a skid plate) that is connected to a bottom surface of the battery pack internals **310**. In some examples, the battery pack internals **310** include the battery pack cross-members (e.g., the battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E** of FIG. 2) and the battery modules (e.g., the battery modules **225A**, **225B**, **225C** of FIG. 2). In some examples, the battery pack structure **305** protects the battery pack internals **310** and underside of the vehicle from the ground. In some examples, the battery pack structure **305** includes an abrasion-resistant material, such as aluminum and steel, however, other materials may additionally and/or alternatively be used. In some examples, the battery pack structure **305** includes the flanges **345A**, **345B**. In some examples, the flanges **345A**, **345B** connect the battery pack structure **305** to the longitudinal frame rails **320A**, **320B**, which is described in further detail below in connection with FIG. 3B. In the illustrated example of FIG. 3A, the top cover **315** (e.g., similar to the top cover **230** of FIG. 2) is connected to a top surface of the battery pack internals **310**. In some examples, the top cover **315** is connected to the top surface of the battery pack internals **310** to secure the battery pack internals **310** in position and to protect the battery pack internals **310** from other components inside the electric vehicle. In some examples, the top cover **315** is connected to the top surface of the battery pack internals **310** using bolts.

However, other fasteners, such as nuts and screws, may additionally and/or alternatively be used.

[0039] In the illustrated example of FIG. 3A, the longitudinal frame rails **320A**, **320B** (e.g., similar to the longitudinal frame rails **105A**, **105B** of FIG. 1 and the longitudinal frame rails **205**, **210** of FIG. 2) are the supporting structures of the frame of the vehicle. In the illustrated example, the longitudinal frame rails **320A**, **320B** are connected to the flanges **325A**, **325B**. In some examples, the flanges **325A**, **325B** are connected to bottom surfaces **340** of the longitudinal frame rails **320A**, **320B** using bolts. However, other fasteners, such as nuts and screws, may additionally and/or alternatively be used. In some examples, the flanges **325A**, **325B** provide a connection point between the longitudinal frame rails **320A**, **320B** and the battery pack structure **305**. The illustrated example of FIG. 3A illustrates the battery pack (e.g., the battery pack structure **305**, the battery pack internals **310**, and the top cover **315**) and the frame (e.g., the longitudinal frame rails **320A**, **320B** and the flanges **325A**, **325B**) before connecting these components to be the first integrated battery pack and frame structure **200** of FIG. 2.

[0040] The first assembly of FIG. 3B includes the battery pack structure **305**, the battery pack internals **310**, the top cover **315**, the longitudinal frame rails **320A**, **320B**, the flanges **325A**, **325B**, the bottom surfaces **340**, and the flanges **345A**, **345B** of FIG. 3A. The first assembly of FIG. 3B

further includes example top bolts **330A**, **330B**. The illustrated example of FIG. 3B illustrates the battery pack (e.g., the battery pack structure **305**, the battery pack internals **310**, and the top cover **315**) and the frame (e.g., the longitudinal frame rails **320A**, **320B** and the flanges **325A**, **325B**) of FIG. 3A after the battery pack has been lowered into the frame.

[0041] In the illustrated example of FIG. 3B, the battery pack structure **305**, the battery pack internals **310**, and the top cover **315** are installed between the longitudinal frame rails **320A**, **320B**. In the illustrated example, the battery pack structure **305**, the battery pack internals **310**, and the top cover **315** are installed from above the longitudinal frame rails **320A**, **320B**. In some examples, the battery pack structure **305** is positioned on the top surfaces of the flanges **325A**, **325B**. In some examples, the battery pack structure **305** is in contact with the internal, side surfaces of the longitudinal frame rails **320A**, **320B**. In the illustrated example of FIG. 3B, the flanges **345A**, **345B** included in the battery pack structure **305** are connected to the top surfaces of the longitudinal frame rails **320A**, **320B** using the top bolts **330A**, **330B**. In some examples, the top bolts **330A**, **330B** can alternatively be other fasteners, such as nuts, screws, etc.

[0042] The first assembly of FIG. 3C includes the battery pack structure **305**, the battery pack internals **310**, the top cover **315**, the longitudinal frame rails **320A**, **320B**, the flanges **325A**, **325B**, the bottom surfaces **340**, and the flanges **345A**, **345B** of FIG. 3A and the top bolts **330A**, **330B** of FIG. 3B. The first assembly of FIG. 3C further includes example bottom bolts **335A**, **335B**. The illustrated example of FIG. 3C illustrates the final connected battery pack (e.g., the battery pack structure **305**, the battery pack internals **310**, and the top cover **315**) and frame (e.g., the longitudinal frame rails **320A**, **320B** and the flanges **325A**, **325B**) to assemble the first integrated battery pack and frame structure **200** of FIG. 2.

[0043] In the illustrated example of FIG. 3C, the battery pack structure **305** is positioned on the top surfaces of the flanges **325A**, **325B** as described above in connection with FIG. 3B. In the illustrated example, the battery pack structure **305** is connected to the top surfaces of the flanges **325A**, **325B** using the bottom bolts **335A**, **335B**. In some examples, the bottom bolts **335A**, **335B** can alternatively be other fasteners, such as nuts, screws, etc. In the illustrated example of FIG. 3C, the battery pack structure **305** (including the battery pack internals **310** and the top cover **315**) is connected to the longitudinal frame rails **320A**, **320B** from the top and bottom (e.g., through the top bolts **330A**, **330B** and the bottom bolts **335A**, **335B**). In some examples, battery pack structure **305** is connected to the top of the longitudinal frame rails **320A**, **320B** using the flanges **345A**, **345B**, which are included in the battery pack structure **305**. In some examples, the battery pack structure **305** is connected to the bottom of the longitudinal frame rails **320A**, **320B** using the flanges **325A**, **325B**, which are connected to the bottom surface of the battery pack structure **305** and the bottom surfaces **340** of the longitudinal frame rails **320A**, **320B**.

[0044] FIGS. 4A, 4B and 4C illustrate a cross-sectional view of an example second assembly of the example first integrated battery pack and frame structure **200** of FIG. 2. The second assembly of FIG. 4A includes an example battery pack structure **405**, example battery pack internals **410**, an example top cover **415**, example longitudinal frame rails **420A**, **420B**, example flanges **425A**, **425B**, example top surfaces **440**, and example flanges **445A**, **445B**.

[0045] In the illustrated example of FIG. 4A, the battery pack structure **405** is a plate (e.g., a skid plate) that is connected to a bottom surface of the battery pack internals **410**. In some examples, the battery pack internals **410** include the battery pack cross-members (e.g., the battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E** of FIG. 2) and the battery modules (e.g., the battery modules **225A**, **225B**, **225C** of FIG. 2). In some examples, the battery pack structure **405** protects the battery pack internals **410** and underside of the vehicle from the ground. In some examples, the battery pack structure **405** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In the illustrated example of FIG. 4A, the top cover **415** (e.g., similar to the top cover **230** of FIG. 2) is connected to a top surface of the battery pack internals **410**. In some examples, the battery pack structure **405** includes



the flanges **445A**, **445B**. In some examples, the flanges **445A**, **445B** connect the battery pack structure **405** to the longitudinal frame rails **420A**, **420B**, which is described in further detail below in connection with FIG. **4B**. In some examples, the top cover **415** is connected to the top surface of the battery pack internals **410** to secure the battery pack internals **410** in position and to protect the battery pack internals **410** from other components inside the electric vehicle. In some examples, the top cover **415** is connected to the top surface of the battery pack internals **410** using bolts.

However, other fasteners, such as nuts and screws, may additionally and/or alternatively be used. [0046] In the illustrated example of FIG. **4A**, the longitudinal frame rails **420A**, **420B** (e.g., similar to the longitudinal frame rails **105A**, **105B** of FIG. **1** and the longitudinal frame rail **205** and the longitudinal frame rail **210** of FIG. **2**) are the supporting structures of the frame of the vehicle. In the illustrated examples, the longitudinal frame rails **420A**, **420B** are connected to the flanges **425A**, **425B**. In some examples, the flanges **425A**, **425B** are connected to a top surface of the longitudinal frame rails **420A**, **420B** using bolts. However, other fasteners, such as nuts and screws, may additionally and/or alternatively be used. In some examples, the flanges **425A**, **425B** provide a connection point between the longitudinal frame rails **420A**, **420B** and the battery pack structure **405**. The example of FIG. **4A** illustrates the battery pack (e.g., the battery pack structure **405**, the battery pack internals **410**, and the top cover **415**) and the frame (e.g., the longitudinal frame rails **420A**, **420B** and the flanges **425A**, **425B**) before connecting these components to be the first integrated battery pack and frame structure **200** of FIG. **2**.

[0047] The second assembly of FIG. **4B** includes the battery pack structure **405**, the battery pack internals **410**, the top cover **415**, the longitudinal frame rails **420A**, **420B**, the flanges **425A**, **425B**, the top surfaces **440**, and the flanges **445A**, **445B** of FIG. **4A**. The second assembly of FIG. **4B** further includes example bottom bolts **430A**, **430B**. The illustrated example of FIG. **4B** illustrates the battery pack (e.g., the battery pack structure **405**, the battery pack internals **410**, and the top cover **415**) and the frame (e.g., the longitudinal frame rails **420A**, **420B** and the flanges **425A**, **425B**) of FIG. **4A** after the battery pack has been raised into the frame.

[0048] In the illustrated example of FIG. **4B**, the battery pack structure **405**, the battery pack internals **410**, and the top cover **415** are installed between the longitudinal frame rails **420A**, **420B**. In the illustrated example, the battery pack structure **405**, the battery pack internals **410**, and the top cover **415** are installed from below the longitudinal frame rails **420A**, **420B**. In some examples, the battery pack structure **405** is positioned on the bottom surfaces of the flanges **425A**, **425B**. In some examples, the battery pack structure **405** is in contact with the internal, side surfaces of the longitudinal frame rails **420A**, **420B**. In the illustrated example of FIG. **4B**, the flanges **445A**, **445B** included in battery pack structure **405** are connected to the bottom surfaces of the longitudinal frame rails **420A**, **420B** using the bottom bolts **430A**, **430B**. In some examples, the bottom bolts **430A**, **430B** can alternatively be other fasteners, such as nuts, screws, etc.

[0049] The second assembly of FIG. **4C** includes the battery pack structure **405**, the battery pack internals **410**, the top cover **415**, the longitudinal frame rails **420A**, **420B**, the flanges **425A**, **425B**, the top surfaces **440**, and the flanges **445A**, **445B** of FIG. **4A** and the bottom bolts **430A**, **430B** of FIG. **4B**. The second assembly of FIG. **4C** further includes example top bolts **435A**, **435B**. The illustrated example of FIG. **4C** illustrates the final connected battery pack (e.g., the battery pack structure **405**, the battery pack internals **410**, and the top cover **415**) and frame (e.g., the longitudinal frame rails **420A**, **420B** and the flanges **425A**, **425B**) to assemble the first integrated battery pack and frame structure **200** of FIG. **2**.

[0050] In the illustrated example of FIG. **4C**, the battery pack structure **405** is positioned on the bottom surfaces of the flanges **425A**, **425B** as described above in connection with FIG. **4B**. In the illustrated example, the battery pack structure **405** is connected to the bottom surfaces of the flanges **425A**, **425B** using the top bolts **435A**, **435B**. In some examples, the top bolts **435A**, **435B** can alternatively be other fasteners, such as nuts, screws, etc. In the illustrated example of FIG. **4C**, the battery pack structure **405** (including the battery pack internals **410** and the top cover **415**) is

connected to the longitudinal frame rails **420A**, **420B** from the top and bottom (e.g., through the bottom bolts **430A**, **430B** and the top bolts **435A**, **435B**). In some examples, the battery pack structure **405** is connected to the top of the longitudinal frame rails **420A**, **420B** using the flanges **425A**, **425B**, which are connected to the top surface of the battery pack structure **405** and the top surfaces **440** of the longitudinal frame rails **420A**, **420B**. In some examples, battery pack structure **405** is connected to the bottom of the longitudinal frame rails **420A**, **420B** using the flanges **445A**, **445B**, which are included in the battery pack structure **405**.

[0051] FIG. 5 illustrates an example placement of the example first integrated battery pack and frame structure **200** of FIG. 2 in an example electric vehicle **500** in accordance with the teachings of this disclosure. The electric vehicle **500** of FIG. 5 includes an example body **505**, an example frame **510**, and the first integrated battery pack and frame structure **200** of FIG. 2.

[0052] In the illustrated example of FIG. 5, the electric vehicle **500** is representative of a body on frame vehicle because the body **505** is separate from the frame **510**. The first integrated battery pack and frame structure **200** is positioned in a midrail section of the frame **510** (e.g., the mid-section **150** of FIG. 1). To make space for the first integrated battery pack and frame structure **200** in the electric vehicle **500**, the midrail section of the frame **510** does not include any cross-members (e.g., the midrail cross-member **125** and the midrail cross-member **130** of FIG. 1). The first integrated battery pack and frame structure **200** includes the battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E** that provide stiffness and structural support for the midrail section of the frame **510**. In the illustrated example of FIG. 5, the battery pack included in the first integrated battery pack and frame structure **200** is separate from the frame **510**. In the illustrated example of FIG. 5, the longitudinal frame rail **205** and the longitudinal frame rail **210** of FIG. 2 are included in the frame **510** while the battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E**, the battery modules **225A**, **225B**, **225C**, **225D**, and the top cover **230** included in the first integrated battery pack and frame structure **200** of FIG. 2 are installed similarly to the first assembly of FIGS. 3A, 3B and 3C and/or the second assembly of FIGS. 4A, 4B and 4C. In some examples, the first integrated battery pack and frame structure **200** can be installed from the top or the bottom of the frame **510**, as seen above in connection with FIGS. 3A, 3B and 3C, and FIGS. 4A, 4B and 4C, respectively.

[0053] In the illustrated example of FIG. 5, the battery pack included in the first integrated battery pack and frame structure **200** (e.g., the battery pack cross-members **215A**, **215B**, **215C**, **215D**, **215E**, the battery modules **225A**, **225B**, **225C**, **225D**, and the top cover **230**) is separate from the frame **510** to allow for serviceability. The battery pack included in the first integrated battery pack and frame structure **200** can be removed in one piece from the frame **510** as needed for service. In some examples, the body **505** can be removed from the electric vehicle **500** to provide access to the battery pack included in the first integrated battery pack and frame structure **200** for service.

[0054] FIGS. 6A, 6B and 6C illustrate a cross-sectional view of example torsional loading **600**, example vertical loading **620**, and example side loading **640** applied to the example first assembly of FIGS. 3A, 3B and 3C. In some examples, the torsional loading **600**, the vertical loading **620**, and the side loading **640** of FIG. 6 can also be applied to the example second assembly of FIGS. 4A, 4B and 4C. The illustrated examples of FIGS. 6A, 6B and 6C are illustrative of body on frame vehicle load paths (e.g., the example electric vehicle **500** of FIG. 5). In some examples, the body (e.g., the body **505**) of a body on frame vehicle is isolated from the frame (e.g., the frame **510**) by rubber isolators. In such examples, the stiffness provided by the body is not applied to the top of the battery pack because of the isolation. The examples of FIGS. 6A, 6B and 6C illustrate how the first assembly of FIGS. 3A, 3B and 3C provides the necessary stiffness for the vehicle, which reduces any stress concentrations in the bottom of the frame and battery typical for body on frame vehicles.

[0055] The illustrated example of FIG. 6A includes the battery pack structure **305**, the top cover **315**, the longitudinal frame rails **320A**, **320B**, and the flanges **325A**, **325B** of FIG. 3A, the top bolts

330A, 330B of FIG. 3B, and the bottom bolts 335A, 335B of FIG. 3C. The torsional loading 600 of FIG. 6A further includes an example battery pack cross-member 605, example top load paths 610A, 610B, 610C, 610D, and example bottom load paths 615A, 615B, 615C, 615D. In the illustrated example of FIG. 6A, the battery pack cross-member 605 is included in the battery pack internals 310 of FIGS. 3A, 3B and 3C. The battery pack cross-member 605 is connected to the battery pack structure 305 similar to the battery pack internals 310 in FIGS. 3A, 3B and 3C. [0056] In the illustrated example of FIG. 6A, the top load paths 610A-D illustrate the torsional load paths generated from the connection of the top surface of the battery pack structure 305 to the top surface of the longitudinal frame rails 320A, 320B. The bottom load paths 615A-D illustrate the torsional load paths generated from the connection of the bottom surface of the battery pack structure 305 and the bottom surface of the longitudinal frame rails 320A, 320B through the use of the flanges 325A, 325B as described above in connection with FIG. 3C. In the illustrated example of FIG. 6A, the top load paths 610A-D and the bottom load paths 615A-D illustrate the dispersion of stress throughout the battery pack in response to the torsional loading 600. The top connections and bottom connections present in the first assembly of FIGS. 3A, 3B and 3C allow for an even distribution of the torsional stress throughout the entire height of the battery pack cross-member 605.

[0057] In the illustrated example of FIG. 6A, the top connections between the battery pack structure 305 and the longitudinal frame rails 320A, 320B disperse the stress from the torsional loading 600 throughout the entire height of the battery pack cross-member 605, as seen in the top load paths 610A-D. The bottom connections between the battery pack structure 305 and the longitudinal frame rails 320A, 320B concentrate the stress from the torsional loading 600 at the bottom of the battery pack cross-member 605, as seen in the bottom load paths 615A-D. In the illustrated example, the top connections between the battery pack structure 305 and the longitudinal frame rails 320A, 320B work together with the bottom connections between the battery pack structure 305 and the longitudinal frame rails 320A, 320B to uniformly distribute the torsional loading 600 across the entire height of the battery pack cross-member 605, as seen in the top load path 610A-D and the bottom load path 615A-D. In some examples, the distribution of the torsional loading 600 across the entire height of the battery pack cross-member 605 allows for the entire battery pack cross-member 605 to be engaged in response to the torsional loading 600, instead of the stress from the torsional loading 600 being concentrated in a part of the battery pack cross-member 605. The top connections and bottom connections increase the stiffness of the battery pack cross-member 605, and the increased stiffness allows for minimizing any bending and/or twisting of the battery pack due to the torsional loading 600.

[0058] The illustrated example of FIG. 6B includes the battery pack structure 305, the top cover 315, the longitudinal frame rails 320A, 320B, and the flanges 325A, 325B of FIG. 3A, the top bolts 330A, 330B of FIG. 3B, the bottom bolts 335A, 335B of FIG. 3C, and the battery pack cross-member 605 of FIG. 6A. The vertical loading 620 of FIG. 6B further includes the top load paths 625A, 625B and the bottom load paths 630A, 630B, 630C.

[0059] In the illustrated example of FIG. 6B, the top load paths 625A, 625B illustrate the vertical load paths generated from the connection of the top surface of the battery pack structure 305 to the top surface of the longitudinal frame rails 320A, 320B. The bottom load paths 630A-C illustrate the vertical load paths generated from the connection of the bottom surface of the battery pack structure 305 and the bottom surface of the longitudinal frame rails 320A, 320B through the use of the flanges 325A, 325B as described above in connection with FIG. 3C. In the illustrated example of FIG. 6B, the top load paths 625A, 625B and the bottom load paths 630A-C illustrate the dispersion of stress throughout the battery pack in response to the vertical loading 620. The top connections and bottom connections present in the first assembly of FIGS. 3A, 3B and 3C work together to uniformly distribute the vertical loading 620 across the entire height of the battery pack cross-member 605, as seen in the top load path 625A, 625B and the bottom load paths 630A-C. In

some examples, the distribution of the vertical loading **620** across the entire height of the battery pack cross-member **605** allows for the entire battery pack cross-member **605** to be engaged in response to the vertical loading **620**, instead of the stress from the vertical loading **620** being concentrated in a part of the battery pack cross-member **605**.

[0060] In the illustrated example of FIG. **6B**, the top connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** concentrate the stress from the vertical loading **620** at the top of the battery pack cross-member **605**, as seen in the top load paths **625A**, **625B**. The bottom connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** concentrate the stress from the vertical loading **620** at the bottom of the battery pack cross-member **605**, as seen in the bottom load paths **630A-C**. In the illustrated example, the top connections and bottom connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** work together to uniformly disperse the stress from the vertical loading **620** between the top and bottom of the battery pack cross-member **605**, which allows for the entire battery pack cross-member **605** to be engaged in response to the vertical loading **620** to provide more uniform vertical loading **620**, as seen in the top load paths **625A**, **625B** and the bottom load paths **630A-C**. The top connections and bottom connections increase the stiffness (e.g., highway hop resonance stiffness) of the battery pack cross-member **605**, and the increased stiffness allows for supporting the battery pack against the vertical loading **620** from the weight of the batteries in the battery pack.

[0061] The illustrated example of FIG. **6C** includes the battery pack structure **305**, the battery pack internals **310**, the top cover **315**, the longitudinal frame rails **320A**, **320B**, and the flanges **325A**, **325B** of FIG. **3A**, the top bolts **330A**, **330B** of FIG. **3B**, the bottom bolts **335A**, **335B** of FIG. **3C**, and the battery pack cross-member **605** of FIG. **6A**. The side loading **640** of FIG. **6C** further includes the top load paths **645A**, **645B**, **645C**, **645D** and the bottom load paths **650A**, **650B**, **650C**, **650D**.

[0062] In the illustrated example of FIG. **6C**, the top load paths **645A-D** illustrate the side load paths generated from the connection of the top surface of the battery pack structure **305** to the top surface of the longitudinal frame rails **320A**, **320B**. The bottom load paths **650A-D** illustrate the side load paths generated from the connection of the bottom surface of the battery pack structure **305** and the bottom surface of the longitudinal frame rails **320A**, **320B** through the use of the flanges **325A**, **325B** as described above in connection with FIG. **3C**. In the illustrated example of FIG. **6C**, the top load paths **645A-D** and the bottom load paths **650A-D** illustrate the dispersion of stress throughout the battery pack in response to the side loading **640**. The top connections and bottom connections present in the first assembly of FIGS. **3A**, **3B** and **3C** work together to uniformly distribute the vertical loading across the entire height of the battery pack cross-member **605**, as seen in the top load paths **645A-D** and bottom load paths **650A-D**. In some examples, the distribution of the side loading **640** across the entire height of the battery pack cross-member **605** allows for the entire battery pack cross-member **605** to be engaged in response to the side loading **640**, instead of the stress from the side loading **640** being concentrated in a part of the battery pack cross-member **605**.

[0063] In the illustrated example of FIG. **6C**, the top connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** concentrate the stress from the side loading **640** at the top and center of the battery pack cross-member **605**, as seen in the top load paths **645A-D**. The bottom connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** concentrate the stress from the side loading **640** at the bottom of the battery pack cross-member **605**, as seen in the bottom load paths **650A-D**. In the illustrated example, the top connections and bottom connections between the battery pack structure **305** and the longitudinal frame rails **320A**, **320B** work together to uniformly disperse the stress from the side loading **640** between the top, center, and bottom of the battery pack cross-member **605**, which allows for the entire battery pack cross-member **605** to be engaged in response to the side loading

**640** to provide more uniform side loading **640**, as seen in the top load paths **640A-D** and the bottom load paths **650A-D**. The top connections and bottom connections provide an even load transfer through the battery pack cross-member **605**, which helps to reduce the amount of deformation of the battery pack during side loading events.

[0064] FIG. 7 illustrates an example second integrated battery pack and frame structure **700** in accordance with the teachings of this disclosure. second integrated battery pack and frame structure **700** includes an example body **705**, example rockers **710A**, **710B**, an example underbody cross-member **715**, example bolts **720A**, **720B**, **720C**, **720D**, **720E**, **720F**, **720G**, **720H**, example longitudinal frame rails **725A**, **725B**, example frame cross-members **730A**, **730B**, **730C**, **730D**, example bolts **735A**, **735B**, **735C**, **735D**, **735E**, **735F**, **735G**, **735H**, an example battery pack structure **740**, example battery pack cross-members **745A**, **745B**, **745C**, **745D**, example battery modules **750A**, **750B**, **750C**, **750D**, example bolts **755A**, **755B**, **755C**, **755D**, **755E**, and an example bolt **760**.

[0065] In the illustrated example of FIG. 7, the body **705** is separate from the frame structure due to the design of the body on frame vehicle. The body **705** is connected to the rockers **710A**, **710B**, which run longitudinally along the sides of the body **705** to provide structural support for the body **705**. The underbody cross-member **715** are connected to the bottom surface of the body **705** to provide structural support and stiffness for the body **705**. In some examples, there are a plurality of underbody cross-members (e.g., the underbody cross-member **715**) connected to the bottom surface of the body **705**. In some examples, the number of underbody cross-members is equal to the number of frame cross-members. For example, if there a four frame cross-members (the frame cross-members **730A-D**), then there are four underbody cross-members. The body **705** and the underbody cross-members (e.g., including the underbody cross-member **715**) are connected to the frame cross-members **730A-D** using the bolts **720A-E**. In some examples, the bolts **720A-E** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the body **705** and the underbody cross-members are hard mounted to the frame cross-members **730A-D** instead of using the bolts **720A-E** via conventional isolated mounts. In some examples, hard mounting the body **705** and the underbody cross-members to the frame cross-members **730A-D** provides additional vehicle stiffness and increases the crashworthiness of the vehicle in response to loads.

[0066] In the illustrated example of FIG. 7, the longitudinal frame rails **725A**, **725B** are similar to the longitudinal frame rails **105A**, **105B** of FIG. 1. The longitudinal frame rails **725A**, **725B** are connected to the frame cross-members **730A-D**. In some examples, the frame cross-members **730A-D** are inserted through the longitudinal frame rails **725A**, **725B** (e.g., parts of the frame cross-members **730A-D** are extended through the longitudinal frame rails **725A**, **725B** and welded on both the inboard and outboard faces of the longitudinal frame rails **725A**, **725B**). In some examples, the underbody cross-members are connected to the frame cross-members **730A-D** using the bolts **720A-E**. For example, the underbody cross-member **715** is connected to the frame cross-member **730D** using the bolts **720D** and **720H**. In some examples, the extensions of the frame cross-members **730A-D** are connected to the rockers **710A**, **710B** using the bolts **735A-H**. In some examples, the bolts **735A-H** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the bolts **735A-H** are bolted from the bottom of the extensions of the frame cross-members **730A-D** up through the rockers **710A**, **710B**.

[0067] In the illustrated example of FIG. 7, the battery pack structure **740** is a plate (e.g., a skid plate) that is connected to bottom surfaces of the battery pack cross-members **745A-D** and the battery modules **750A-D**. In some examples, the battery pack structure **740** protects the undersides of the battery pack cross-members **745A-D** and the battery modules **750A-D** from the ground. In some examples, the battery pack structure **740** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In some examples, the battery pack cross-members **745A-D** are connected to the top surface of the battery pack structure **740**. In some examples, the battery modules **750A-D** are positioned between

the battery pack cross-members **745A-D**. In some examples, the battery pack cross-members **745A-D** provide support for the battery modules **750A-D** and secure the positions of the battery modules **750A-D** on the battery pack structure **740**. The battery modules **750A-D** provide power for the electric vehicle. In some examples, the battery modules **750A-D** include lithium-ion batteries. However, other types of batteries may additionally and/or alternatively be used.

[0068] In the illustrated example of FIG. 7, the battery pack structure **740** is connected to the longitudinal frame rails **725A**, **725B** using the bolts **755A-E**. In some examples, there are more bolts than the bolts **755A-E** that are not visible in the view of the second integrated battery pack and frame structure **700** of FIG. 7. In some examples, the bolts **755A-E** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the bolts **755A-E** are bolted from the bottom of the battery pack structure **740** up through the longitudinal frame rails **725A**, **725B**. In some examples, the frame structure (e.g., the longitudinal frame rails **725A**, **725B** and the frame cross-members **730A-D**) are lowered onto the battery pack structure **740**, the battery pack cross-members **745A-D**, and the battery modules **750A-D**. The longitudinal frame rails **725A**, **725B** are positioned on the top surface of the battery pack structure **740** to use the bolts **755A-E** to connect the longitudinal frame rails **725A**, **725B** and the battery pack structure **740**. The frame cross-members **730A-D** are positioned on the top surface of the battery pack cross-members **745A-D**.

[0069] In the illustrated example of FIG. 7, the battery pack cross-members **745A-D** are connected to the frame cross-members **730A-D** using bolts (e.g., bolt **760**) in the center of the battery pack cross-members **745A-D** and the frame cross-members **730A-D**. For example, the battery pack cross-member **745A** is connected to the frame cross-member **730D** using the bolt **760**. In some examples, there are a plurality of bolts (e.g., bolt **760**) to connect the battery pack cross-members **745A-D** and the frame cross-members **730A-D**. In some examples, the number of bolts is equal to the number of battery pack cross-members. For example, if there are four battery pack cross-members (the battery pack cross-members **745A-D**), then there are four bolts. In some examples, the plurality of bolts (including the bolt **760**) can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the bolts (including the bolt **760**) are bolted from the bottom of the battery pack cross-members **745A-D** up through the frame cross-members **730A-D**. In some examples, the battery modules **750A-D** are positioned between the connected battery pack cross-members **745A-D** and frame cross-members **730A-D**. The connected battery pack cross-members **745A-D** and frame cross-members **730A-D** extend the full height of the battery modules **750A-D** to provide support for the battery modules **750A-D** and secure the positions of the battery modules **750A-D**. In some examples, the battery modules **750A-D** are positioned between the longitudinal frame rails **725A**, **725B** after the longitudinal frame rails **725A**, **725B** and the battery pack structure **740** are connected.

[0070] In the illustrated example of FIG. 7, the battery pack cross-members **745A-D** are connected to the frame cross-members **730A-D** and the battery pack structure **740** is connected to the longitudinal frame rails **725A**, **725B** to provide increased stiffness and impact strength for the second integrated battery pack and frame structure **700** in an electric vehicle. In some examples, the plurality of mounting points between the battery pack cross-members **745A-D**, the frame cross-members **730A-D**, the battery pack structure **740**, and the longitudinal frame rails **725A**, **725B** via the bolts **755A-E** and the bolt **760** increase the number of spaces available for the battery modules **750A-D** to be installed on the battery pack structure **740** and improve the load paths for stiffness and side pole impact performance for the second integrated battery pack and frame structure **700**. In some examples, the plurality of mounting points also reduces twisting (e.g., due to torsional loading) of the frame structure (e.g., the longitudinal frame rails **725A**, **725B** and the frame cross-members **730A-D**) where the battery modules **750A-D** are located, which improves the durability of the battery modules **750A-D**. In the illustrated example of FIG. 7, the battery modules **750A-D** are serviceable from the bottom of the battery pack structure **740**, which makes service needs easier because the body **705** and the frame structure (e.g., the longitudinal frame rails **725A**, **725B** and the

frame cross-members **730A-D**) do not need to be removed to access the battery modules **750A-D**. [0071] FIGS. **8A**, **8B** and **8C** illustrate example cross-sectional views of the battery pack included in the example second integrated battery pack and frame structure **700** of FIG. **7**. The illustrated example of FIG. **8A** includes an example battery pack structure **805**, an example battery pack cross-member **810**, and an example battery module **815**.

[0072] In the illustrated example of FIG. **8A**, the battery pack structure **805** is a plate (e.g., a skid plate) that is connected to bottom surfaces of the battery pack cross-member **810**. In some examples, the battery pack structure **805** protects the underside of the battery pack cross-member **810** from the ground. In some examples, the battery pack structure **805** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In some examples, the battery pack structure **805** is the same as the battery pack structure **740** of FIG. **7**. In some examples, the battery pack cross-member **810** is connected to the top surface of the battery pack structure **805**. The battery pack cross-member **810** provides stiffness and improves load paths for the battery pack. In the illustrated example of FIG. **8A**, the battery module **815** provides power for the battery pack. In some examples, the battery module **815** includes lithium-ion batteries. However, other types of batteries may additionally and/or alternatively be used. In some examples, the battery module **815** is the same as the battery modules **750A-D** of FIG. **7**. In the illustrated example of FIG. **8A**, the battery module **815** is lowered onto the top surface of the battery pack structure **805**, which is described in further detail below in connection with FIG. **8B**.

[0073] The illustrated example of FIG. **8B** includes the battery pack structure **805**, the battery pack cross-member **810**, and the battery module **815** of FIG. **8A**. The illustrated example of FIG. **8B** further includes an example sealant layer **820**.

[0074] In the illustrated example of FIG. **8B**, the battery module **815** is connected to the top surface of the battery pack structure **805**. In some examples, the battery module **815** is positioned behind the battery pack cross-member **810**. In some examples, the battery module **815** is positioned between two battery pack cross-members (e.g., the battery pack cross-member **810** and an additional battery pack cross-member not visible in FIG. **8B**). In some examples, the battery pack cross-member **810** provides support and stiffness for the battery module **815** and secures the position of the battery module **815** on the battery pack structure **805**. In the illustrated example of FIG. **8B**, the battery pack cross-member **810** includes cut-outs to include space for the wiring/bus bar for electrical connections and the coolant hose for the coolant connections that are needed for the battery module **815**. In the illustrated example of FIG. **8B**, the sealant layer **820** is positioned on the top surfaces of the battery pack structure **805**, the battery pack cross-member **810**, and the battery module **815**. In some examples, after the battery module **815** is positioned on the top surface of the battery pack structure **805**, the sealant layer **820** is positioned on the top surfaces of the battery pack structure **805**, the battery pack cross-member **810**, and the battery module **815** to secure the battery module **815** in position.

[0075] The illustrated example of FIG. **8C** illustrates a side view of the battery pack illustrated in FIG. **8B**. The illustrated example of FIG. **8C** includes the battery pack structure **805** of FIG. **8A** and the sealant layer **820** of FIG. **8B**. The illustrated example of FIG. **8C** further includes example battery pack cross-members **810A**, **810B**, **810C**, **810D** and example battery modules **815A**, **815B**, **815C**, **815D** in accordance with the battery pack cross-member **810** and the battery module **815** of FIG. **8A**, respectively.

[0076] In the illustrated example of FIG. **8C**, the battery pack cross-members **810A-D** are the same as the battery pack cross-member **810** of FIGS. **8A** and **8B**. The battery modules **815A-D** are the same as the battery module **815** of FIGS. **8A** and **8B**. The illustrated example of FIG. **8C** illustrates the plurality of battery pack cross-members (e.g., battery pack cross-members **810A-D**) and the plurality of battery modules (e.g., battery modules **815A-D**) that connected to the top surface of the battery pack structure **805** that are not illustrated in the front cross-sectional views of FIGS. **8A** and

**8B.** In the illustrated example, the battery modules **815A-D** are positioned between the battery pack cross-members **810A-D**, as described above in connection with FIG. **8B**.

[0077] FIGS. **9A** and **9B** illustrate example top views of the battery pack included in the example second integrated battery pack and frame structure **700** of FIG. **7**. The example top view of FIG. **9A** includes an example battery pack structure **905**, example battery pack cross-members **910A**, **910B**, **910C**, **910D**, and example battery modules **915A**, **915B**, **915C**, **915D**.

[0078] In the illustrated example of FIG. **9A**, the battery pack structure **905** is a plate (e.g., a skid plate) that is connected to bottom surfaces of the battery pack cross-members **910A-D**. In some examples, the battery pack structure **905** protects the underside of the battery pack cross-members **910A-D** from the ground. In some examples, the battery pack structure **905** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In some examples, the battery pack structure **905** is the same as the battery pack structure **740** of FIG. **7**. In some examples, the battery pack cross-members **910A-D** are connected to the top surface of the battery pack structure **905**. The battery pack cross-members **910A-D** provide stiffness and improve the load paths for the battery pack.

[0079] In the illustrated example of FIG. **9A**, the battery modules **915A-D** are connected to the top surface of the battery pack structure **905**. In some examples, the battery modules **915A-D** provide power for the battery pack. In some examples, the battery modules **915A-D** include lithium-ion batteries. However, other types of batteries may additionally and/or alternatively be used. In some examples, the battery modules **915A-D** are the same as the battery modules **750A-D** of FIG. **7**. In some examples, the battery modules **915A-D** are positioned between the battery pack cross-members **910A-D**. In some examples, the battery pack cross-members **910A-D** provide support and stiffness for the battery modules **915A-D** and secure the positions of the battery modules **915A-D** on the battery pack structure **905**.

[0080] The example top view of FIG. **9B** includes the battery pack structure **905**, the battery pack cross-members **910A**, **910B**, **910C**, **910D**, and the battery modules **915A**, **915B**, **915C**, **915D** of FIG. **9A**. The top view of FIG. **9B** further includes example battery pack longitudinal cross-members **920A**, **920B**.

[0081] In the illustrated example of FIG. **9B**, the battery pack includes the battery pack longitudinal cross-members **920A**, **920B** in addition to the lateral battery pack cross-members **910A-D** to improve front impact performance for the electric vehicle. The battery pack longitudinal cross-members **920A**, **920B** are perpendicular to the battery pack cross-members **910A-D**. In some examples, the battery pack longitudinal cross-members **920A**, **920B** are positioned above the battery pack cross-member **910A**. The battery pack longitudinal cross-members **920A**, **920B** are connected to the battery pack longitudinal cross-member **920B** and the battery pack structure **905**. In some examples, the battery pack longitudinal cross-members **920A**, **920B** provide additional stiffness to the battery pack for frontal loads.

[0082] FIGS. **10A**, **10B** and **10C** illustrate example cross-sectional views of an example first assembly of the example second integrated battery pack and frame structure **700** of FIG. **7**. The cross-sectional view of the first assembly of FIG. **10A** includes an example longitudinal frame rail **1005**, example frame cross-members **1010A**, **1010B**, **1010C**, **1010D**, and example inserts **1040A**, **1040B**, **1040C**, **1040D**.

[0083] In the illustrated example of FIG. **10A**, the longitudinal frame rail **1005** is the same as the longitudinal frame rails **725A**, **725B** of FIG. **7**. The longitudinal frame rail **1005** includes inserts **1040A-D** in the midrail section of the longitudinal frame rails for the frame cross-members **1010A-D**. In some examples, the frame cross-members **1010A-D** are inserted through the longitudinal frame rail **1005** using the inserts **1040A-D**. In some examples, the frame cross-members **1010A-D** extend through the longitudinal frame rail **1005** to create extensions of the frame cross-members **1010A-D** on the outer side of the longitudinal frame rail, which is described in further detail below in connection with FIG. **10B**.



[0084] The cross-sectional view of the first assembly of FIG. **10B** includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A**. The cross-sectional view of the first assembly of FIG. **10B** further includes an example longitudinal frame rail **1015**, an example battery pack structure **1020**, an example battery pack cross-member **1025**, an example battery module **1030**, and example extensions **1045A**, **1045B**.

[0085] In the illustrated example of FIG. **10B**, the longitudinal frame rail **1015** is the same as the longitudinal frame rail **1005** of FIG. **10A**. In some examples, the longitudinal frame rail **1015** is parallel to the longitudinal frame rail **1005**, similar to the longitudinal frame rails **725A**, **725B** of FIG. **7**. In some examples, the frame cross-member **1010A** is inserted through the longitudinal frame rail **1005** and the longitudinal frame rail **1015**. In the illustrated example of FIG. **10B**, the frame cross-member **1010A** is extended through the longitudinal frame rail **1005** and the longitudinal frame rail **1015**. In some examples, the extensions **1045A**, **1045B** are the parts of the frame cross-member **1010A** that are extended through the longitudinal frame rail **1005** and the longitudinal frame rail **1015**. In some examples, the frame cross-member **1010A** is on the internal (inboard) sides of the longitudinal frame rail **1005** and the longitudinal frame rails **1015**. In some examples, the extensions **1045A**, **1045B** are on the external (outboard) sides of the longitudinal frame rail **1005** and the longitudinal frame rails **1015**. In some examples, the external sides of the longitudinal frame rail **1005** and the longitudinal frame rails **1015** are opposite to the internal sides of the longitudinal frame rail **1005** and the longitudinal frame rails **1015**. In some examples, the frame cross-member **1010A** is inserted through the longitudinal frame rail **1005** and the longitudinal frame rail **1015** and welded at the inboard and outboard faces of the longitudinal frame rail **1005** and the longitudinal frame rail **1015**.

[0086] In the illustrated example of FIG. **10B**, the battery pack structure **1020** is a plate (e.g., a skid plate) that is connected to bottom surfaces of the battery pack cross-member **1025**. In some examples, the battery pack structure **1020** protects the underside of the battery pack cross-member **1025** from the ground. In some examples, the battery pack structure **1020** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In some examples, the battery pack structure **1020** is the same as the battery pack structure **740** of FIG. **7** and the battery pack structure **805** of FIGS. **8A**, **8B** and **8C**. In some examples, the battery pack cross-member **1025** is connected to the top surface of the battery pack structure **1020**. The battery pack cross-member **1025** provides stiffness and improves load paths for the battery pack.

[0087] In the illustrated example of FIG. **10B**, the battery module **1030** provides power for the battery pack. In some examples, the battery module **1030** includes lithium-ion batteries, however, other types of batteries may additionally and/or alternatively be used. In some examples, the battery module **1030** is the same as the battery modules **750A-D** of FIG. **7** and the battery module **815** of FIGS. **8A**, **8B** and **8C**. In some examples, the battery module **1030** is connected to the top surface of the battery pack structure **1020**. In some examples, the battery module **1030** is positioned behind the battery pack cross-member **1025**. In some examples, the battery module **1030** is positioned between two battery pack cross-members (e.g., the battery pack cross-member **1025** and an additional battery pack cross-member not visible in FIG. **10B**). In some examples, the battery pack cross-member **1025** provides support and stiffness for the battery module **1030** and secures the position of the battery module **1030** on the battery pack structure **1020**. In the illustrated example of FIG. **10B**, the frame cross-members **1010A**, the longitudinal frame rail **1005**, and the longitudinal frame rail **1015** are lowered onto the top surface of the battery pack structure **1020**, which is described in further detail below in connection with FIG. **10C**.

[0088] The cross-sectional view of the first assembly of FIG. **10C** includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A** and the longitudinal frame rail **1015**, the battery pack structure **1020**, the battery pack cross-member **1025**, the battery module **1030**, and the extensions **1045A**, **1045B** of FIG. **10B**. The cross-sectional view of the first assembly of FIG. **10C**

further includes example bolts **1035A**, **1035B**, **1035C**.

[0089] In the illustrated example of FIG. **10C**, the frame cross-members **1010A**, the longitudinal frame rail **1005**, the longitudinal frame rail **1015**, and the extensions **1045A**, **1045B** are lowered onto the top surface of the battery pack structure **1020**. In some examples, the longitudinal frame rail **1005** and the longitudinal frame rail **1015** are connected to the top surface of the battery pack structure **1020** using the bolts **1035A** and **1035C**. In some examples, the frame cross-member **1010A** is connected to the top surface of the battery pack cross-member **1025** using the bolt **1035B**. In some examples, the bolts **1035A-C** can alternatively be other fasteners, such as nuts, screws, etc.

[0090] In the illustrated example of FIG. **10C**, the battery pack cross-member **1025** and the frame cross-member **1010A** are layered and connected to reach the height of the battery module **1030**. In some examples, the battery module **1030** is positioned between the connected battery pack cross-member **1025** and frame cross-member **1010A** and an additional connected battery pack cross-member and frame cross-member not illustrated in the FIG. **10C**. In some examples, the battery pack cross-member **1025** and the frame cross-member **1010A** work together to increase stiffness for side impact loads early on in the impact to effectively protect the battery module **1030**.

[0091] FIGS. **11A**, **11B** and **11C** illustrate an example first assembly of the example first assembly of FIGS. **10A**, **10B** and **10C** connected to a body structure in accordance with the teachings of this disclosure. The illustrated example of FIG. **11A** includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A**, the longitudinal frame rail **1015**, the battery pack structure **1020**, the battery pack cross-member **1025**, the battery module **1030**, and the extensions **1045A**, **1045B** of FIG. **10B**, and the bolts **1035A**, **1035B**, **1035C** of FIG. **10C**. The illustrated example of FIG. **11A** further includes an example underbody cross-member **1105** and example rockers **1110A**, **1110B**.

[0092] In the illustrated example of **11A**, the underbody cross-member **1105** is connected to the bottom surface of the body of the electric vehicle to provide structural support and stiffness for the body. The underbody cross-member **1105** is connected to the rockers **1110A**, **1110B**, which run longitudinally along the sides of the body to provide structural support for the body. In the illustrated example of FIG. **11A**, the underbody cross-member **1105** and the rockers **1110A**, **1110B** are lowered onto the top surface of the frame cross-member **1010A**, the top surface of the longitudinal frame rail **1005**, the top surface of the longitudinal frame rail **1015**, and the top surfaces of the extensions **1045A**, **1045B**, which is described in further detail below in connection with FIG. **11B**.

[0093] The illustrated example of FIG. **11B** includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A**, the longitudinal frame rail **1015**, the battery pack structure **1020**, the battery pack cross-member **1025**, the battery module **1030**, and the extensions **1045A**, **1045B** of FIG. **10B**, the bolts **1035A**, **1035B**, **1035C** of FIG. **10C**, and the underbody cross-member **1105** and the rockers **1110A**, **1110B** of FIG. **11A**. The illustrated example of FIG. **11B** further includes example bolts **1115A**, **1115B** and example bolts **1120A**, **1120B**.

[0094] In the illustrated example of FIG. **11B**, the underbody cross-member **1105** is connected to the frame cross-member **1010A** using the bolts **1115A**, **1115B**. In some examples, the bolts **1115A**, **1115B** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the underbody cross-member **1105** is not connected to the frame cross-member **1010A** (e.g., the bolts **1115A**, **1115B** are not included), which keeps the body isolated from the frame of the electric vehicle. In some examples, the extensions **1045A**, **1045B** of the frame cross-member **1010A** are connected to the rockers **1110A**, **1110B** using the bolts **1120A**, **1120B**. In some examples, the bolts **1120A**, **1120B** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the bolts **1120A**, **1120B** are bolted from the bottom of the extensions **1045A**, **1045B** up through the rockers **1110A**, **1110B**.

[0095] The illustrated example of FIG. **11C** includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A**, the longitudinal frame rail **1015**, the battery pack structure

**1020**, the battery pack cross-member **1025**, the battery module **1030**, and the extensions **1045A**, **1045B** of FIG. **10B**, the bolts **1035A**, **1035B**, **1035C** of FIG. **10C**, the underbody cross-member **1105** and the rockers **1110A**, **1110B** of FIG. **11A**, and the bolts **1115A**, **1115B** and the bolts **1120A**, **1120B** of FIG. **11B**. The illustrated example of FIG. **11C** further includes an example side impact **1125**, and example side load paths **1130A**, **1130B**, **1130C**.

[0096] In the illustrated example of FIG. **11C**, the side load paths **1130A-C** illustrate the side load paths generated from the connection of the underbody cross-member **1105** to the frame cross-member **1010A**, the connection of the rockers **1110A**, **1110B** to the extensions **1045A**, **1045B**, the connection of the frame cross-member **1010A** and the battery pack cross-member **1025**, and the connection of the battery pack structure **1020** and the longitudinal frame rail **1005** and longitudinal frame rail **1015**. In the illustrated example of FIG. **11C**, the side load paths **1130A-C** illustrate the dispersion of stress throughout the battery pack cross-member **1025**, the frame cross-member **1010A**, and the underbody cross-member **1105** in response to the side impact **1125**. The connections between the underbody cross-member **1105**, the rockers **1110A**, **1110B**, the frame cross-member **1010A**, the extensions **1045A**, **1045B**, the battery pack cross-member **1025**, the battery pack structure **1020**, the longitudinal frame rail **1005**, and longitudinal frame rail **1015** allow for an even distribution of the side stress across the entire height of the battery module **1030**.

[0097] In the illustrated example of FIG. **11C**, the connection of the underbody cross-member **1105** to the frame cross-member **1010A** and the connection of the rockers **1110A**, **1110B** to the extensions **1045A**, **1045B** disperse a portion of the side stress from the side impact **1125** to the underbody cross-member **1105** (e.g., the side load path **1130A**). The connection of the rockers **1110A**, **1110B** to the extensions **1045A**, **1045B** and the connection of the frame cross-member **1010A** and the battery pack cross-member **1025** disperse a portion of the side stress from the side impact **1125** to the frame cross-member **1010A** (e.g., the side load path **1130B**). The connection of the frame cross-member **1010A** and the battery pack cross-member **1025** and the connection of the battery pack structure **1020** and the longitudinal frame rail **1005** and longitudinal frame rail **1015** disperse a portion of the side stress from the side impact **1125** to the battery pack cross-member **1025** (e.g., the side load path **1130C**). In the illustrated example, the battery pack cross-member **1025**, the frame cross-member **1010A**, and the underbody cross-member **1105** work together to disperse the stress between the top, center, and bottom of the total height of the battery module **1030** to provide more uniform side loading, as seen in the side load paths **1130A**, **1130B**, **1130C**.

[0098] FIGS. **12A**, **12B** and **12C** illustrate example cross-sectional views of a second assembly of the example second integrated battery pack and frame structure **700** of FIG. **7**. The cross-sectional view of the second assembly of FIG. **12A** includes an example longitudinal frame rail **1205**, example frame cross-members **1210A**, **1210B**, **1210C**, **1210D**, and example inserts **1245A**, **1245B**, **1245C**, **1245D**.

[0099] In the illustrated example of FIG. **12A**, the longitudinal frame rail **1205** is the same as the longitudinal frame rails **725A**, **725B** of FIG. **7**. The longitudinal frame rail **1205** includes inserts **1245A-D** in the midrail section of the longitudinal frame rails for the frame cross-members **1210A-D**. In some examples, the frame cross-members **1210A-D** are inserted through the longitudinal frame rail **1205** using the inserts **1245A-D**. In the illustrated example of FIG. **12A**, the inserts **1245A-D** are located lower on the longitudinal frame rail **1205**, which causes the frame cross-members **1210A-D** to be inserted lower on the longitudinal frame rail **1205** compared to the illustrated example of the first assembly of FIG. **10A**. In some examples, the frame cross-members **1210A-D** extend through the longitudinal frame rail **1205** to create extensions of the frame cross-members **1210A-D** on the outer side of the longitudinal frame rail, which is described in further detail below in connection with FIG. **12B**.

[0100] The cross-sectional view of the second assembly of FIG. **12B** includes the longitudinal frame rail **1205** and the frame cross-members **1210A** of FIG. **12A**. The cross-sectional view of the second assembly of FIG. **12B** further includes an example longitudinal frame rail **1215**, an example

position change **1220**, an example battery pack structure **1225**, an example battery pack cross-member **1230**, an example battery module **1235**, and example extensions **1250A**, **1250B**.

[0101] In the illustrated example of FIG. **12B**, the longitudinal frame rail **1215** is the same as the longitudinal frame rail **1205** of FIG. **12A**. In some examples, the longitudinal frame rail **1215** is parallel to the longitudinal frame rail **1205**, similar to the longitudinal frame rails **725A**, **725B** of FIG. **7**. In some examples, the frame cross-member **1210A** is inserted through the longitudinal frame rail **1205** and the longitudinal frame rail **1215**. In the illustrated example of FIG. **12B**, the frame cross-member **1210A** is extended through the longitudinal frame rail **1205** and the longitudinal frame rail **1215**. In some examples, the extensions **1250A**, **1250B** are the parts of the frame cross-member **1210A** that are extended through the longitudinal frame rail **1205** and the longitudinal frame rail **1215**. In some examples, the frame cross-member **1210A** is on the internal (inboard) sides of the longitudinal frame rail **1205** and the longitudinal frame rails **1215**. In some examples, the extensions **1250A**, **1250B** are on the external (outboard) side of the longitudinal frame rail **1205** and the longitudinal frame rail **1215**. In some examples, the external sides of the longitudinal frame rail **1205** and the longitudinal frame rails **1215** are opposite to the internal sides of the longitudinal frame rail **1205** and the longitudinal frame rails **1215**. In some examples, the frame cross-member **1210A** is inserted through the longitudinal frame rail **1205** and the longitudinal frame rail **1215** and welded at the inboard and outboard faces of the longitudinal frame rail **1205** and the longitudinal frame rail **1215**. In the illustrated example of FIG. **12B**, the position change **1220** illustrates the difference where the frame cross-member **1210A** is inserted through the longitudinal frame rail **1205** and the longitudinal frame rail **1215** compared to where the frame cross-member **1010A** is inserted through longitudinal frame rail **1005** and the longitudinal frame rail **1015** in FIGS. **10A**, **10B** and **10C**. The position change **1220** illustrates that the frame cross-member **1210A** is inserted lower on the longitudinal frame rail **1205** and the longitudinal frame rail **1215** compared to the illustrated example of the first assembly of FIGS. **10A**, **10B** and **10C**. In some examples, the position change **1220** allows an example underbody cross-member to be inserted further down in the vertical direction to improve the packaging of the battery pack by decreasing the size of the battery pack.

[0102] In the illustrated example of FIG. **12B**, the battery pack structure **1225** is a plate (e.g., a skid plate) that is connected to bottom surfaces of the battery pack cross-member **1230**. In some examples, the battery pack structure **1225** protects the underside of the battery pack cross-member **1230** from the ground. In some examples, the battery pack structure **1225** includes an abrasion-resistant material, such as aluminum and steel. However, other materials may additionally and/or alternatively be used. In some examples, the battery pack structure **1225** is the same as the battery pack structure **740** of FIG. **7** and the battery pack structure **805** of FIGS. **8A**, **8B** and **8C**. In some examples, the battery pack cross-member **1230** is connected to the top surface of the battery pack structure **1225**. The battery pack cross-member **1230** provides stiffness and improves load paths for the battery pack. In the illustrated example of FIG. **12B**, the battery pack cross-member **1230** is shallow in height compared to the battery pack cross-member **1025** of FIGS. **10B** and **10C**. In some examples, the battery pack cross-member **1230** is shallow in height to make room for the position change **1220** associated with the frame cross-member **1210A**.

[0103] In the illustrated example of FIG. **12B**, the battery module **1235** provides power for the battery pack. In some examples, the battery module **1235** includes lithium-ion batteries, however, other types of batteries may additionally and/or alternatively be used. In some examples, the battery module **1030** is the same as the battery modules **750A-D** of FIG. **7** and the battery module **815** of FIGS. **8A**, **8B** and **8C**. In some examples, the battery module **1235** is connected to the top surface of the battery pack structure **1225**. In some examples, the battery module **1235** is positioned behind the battery pack cross-member **1230**. In some examples, the battery module **1235** is positioned between two battery pack cross-members (e.g., the battery pack cross-member **1230** and an additional battery pack cross-member not visible in FIG. **12B**). In some examples, the battery pack

cross-member **1230** provides support and stiffness for the battery module **1235** and secures the position of the battery module **1235** on the battery pack structure **1225**. In the illustrated example of FIG. **12B**, the frame cross-member **1210A**, the longitudinal frame rail **1205**, and the longitudinal frame rail **1215** are lowered onto the top surface of the battery pack structure **1225**, which is described in further detail below in connection with FIG. **12C**.

[0104] The cross-sectional view of the second assembly of FIG. **12C** includes the longitudinal frame rail **1205** and the frame cross-members **1210A** of FIG. **12A** and the longitudinal frame rail **1215**, the battery pack structure **1225**, the battery pack cross-member **1230**, the battery module **1235**, and the extensions **1250A**, **1250B** of FIG. **12B**. The cross-sectional view of the second assembly of FIG. **12C** further includes example bolts **1240A**, **1240B**, **1240C**.

[0105] In the illustrated example of FIG. **12C**, the frame cross-member **1210A**, the longitudinal frame rail **1205**, the longitudinal frame rail **1215**, and the extensions **1250A**, **1250B** are lowered onto the top surface of the battery pack structure **1225**. In some examples, the longitudinal frame rail **1205** and the longitudinal frame rail **1215** are connected to the top surface of the battery pack structure **1225** using the bolts **1240A** and **1240C**. In some examples, the frame cross-member **1210A** is connected to the top surface of the battery pack cross-member **1230** using the bolt **1240B**. In some examples, the bolts **1240A-C** can alternatively be other fasteners, such as nuts, screws, etc.

[0106] In the illustrated example of FIG. **12C**, the battery module **1235** is positioned between the connected battery pack cross-member **1230** and frame cross-member **1210A** and an additional connected battery pack cross-member and frame cross-member not illustrated in the FIG. **12C**. In some examples, the battery pack cross-member **1230** and the frame cross-member **1210A** work together to increase stiffness for side impact loads early on in the impact to effectively protect the battery module **1235**. In the illustrated example of FIG. **12C**, the connected battery pack cross-member **1230** and frame cross-member **1210A** do not extend to the full height of the battery module **1235**, unlike the connected battery pack cross-member **1025** and frame cross-member **1010A** of FIG. **10C**.

[0107] FIGS. **13A** and **13B** illustrate a second assembly of the example second assembly of FIGS. **12A**, **12B** and **12C** connected to a body structure in accordance with the teachings of this disclosure. The illustrated example of FIG. **13A** includes the longitudinal frame rail **1205** and the frame cross-member **1210A** of FIG. **12A**, the longitudinal frame rail **1215**, the battery pack structure **1225**, the battery pack cross-member **1230**, the battery module **1235**, and the extensions **1250A**, **1250B** of FIG. **12B**, and the bolts **1240A**, **1240B**, **1240C** of FIG. **12C**. The illustrated example of FIG. **13A** further includes an example underbody cross-member **1305** and example rockers **1310A**, **1310B**.

[0108] In the illustrated example of FIG. **13A**, the underbody cross-member **1305** is connected to the bottom surface of the body of the electric vehicle to provide structural support and stiffness for the body. The underbody cross-member **1305** is connected to the rockers **1310A**, **1310B**, which run longitudinally along the sides of the body to provide structural support for the body. In the illustrated example of FIG. **13A**, the underbody cross-member **1305** and the rockers **1310A**, **1310B** are lowered onto the top surface of the frame cross-member **1210A**, the top surface of the longitudinal frame rail **1205**, the top surface of the longitudinal frame rail **1215**, and the top surfaces of the extensions **1250A**, **1250B**, which is described in further detail below in connection with FIG. **13B**.

[0109] The illustrated example of FIG. **13B** includes the longitudinal frame rail **1205** and the frame cross-members **1210A** of FIG. **12A**, the longitudinal frame rail **1215**, the battery pack structure **1225**, the battery pack cross-member **1230**, the battery module **1235**, and the extensions **1250A**, **1250B** of FIG. **12B**, the bolts **1240A**, **1240B**, **1240C** of FIG. **12C**, and the underbody cross-member **1305** and the rockers **1310A**, **1310B** of FIG. **13A**. The illustrated example of FIG. **13B** further includes the longitudinal frame rail **1005** and the frame cross-member **1010A** of FIG. **10A**, the longitudinal frame rail **1015**, the battery pack structure **1020**, the battery pack cross-member

**1025**, the battery module **1030**, and the extensions **1045A**, **1045B** of FIG. **10B**, the bolts **1035A**, **1035B**, **1035C** of FIG. **10C**, the underbody cross-member **1105** and the rockers **1110A**, **1110B** of FIG. **11A**, and the bolts **1115A**, **1115B** and the bolts **1120A**, **1120B** of FIG. **11B**.

[0110] In the illustrated example of FIG. **13B**, the extensions **1250A**, **1250B** of the frame cross-member **1210A** are connected to the rockers **1310A**, **1310B** using the bolts **1315A**, **1315B**. In some examples, the bolts **1315A**, **1315B** can alternatively be other fasteners, such as nuts, screws, etc. In some examples, the bolts **1315A**, **1315B** are bolted from the bottom of the extensions **1250A**, **1250B** up through the rockers **1110A**, **1110B**. In the illustrated example of FIG. **13B**, the second assembly of FIG. **13B** is more compact than the first assembly of FIG. **11B**. The battery pack cross-member **1230** is smaller in height than the battery pack cross-member **1025**. In the illustrated example, the frame cross-member **1210A** is inserted lower on the longitudinal frame rail **1205** and the longitudinal frame rail **1215** compared to where the frame cross-member **1010A** is inserted on the longitudinal frame rail **1005** and the longitudinal frame rail **1015**. In some examples, the example, the lower insertion of the frame cross-member **1210A** lower on the longitudinal frame rail **1205** and the longitudinal frame rail **1215** allows for the underbody cross-member **1305** to be inserted further down in the vertical direction compared to where the underbody cross-member **1105** is inserted. In some examples, the lower insertions of the frame cross-member **1210A** and the underbody cross-member **1305** improve the packaging of the battery pack by decreasing the size of the battery pack. In some examples, the second assembly of FIG. **13B** is an alternative example of the first assembly of FIG. **11B** that includes modifications for a smaller design of the second integrated battery pack and frame structure **700** of FIG. **7**.

[0111] From the foregoing, it will be appreciated that example methods, apparatus and articles of manufacture have been disclosed that integrates a battery pack into the frame of an electric vehicle to improve structural performance and packaging of the battery modules in the battery pack. The example methods, apparatus and articles of manufacture improve battery pack integration into the frame structure of electric, body on frame vehicles. The example methods, apparatus and articles of manufacture include battery pack cross-members that improve stiffness for load paths from side impact events. The example methods, apparatus and articles of manufacture use existing structures of the vehicle frame to minimize the amount of space consumed by the battery pack and to minimize any added weight of integrating the battery pack (to increase energy usage efficiency for the electric vehicle).

[0112] Example methods, apparatus, systems, and articles of manufacture for an integrated frame and battery pack structure for electric vehicles are disclosed herein. Further examples and combinations thereof include the following:

[0113] Example 1 includes an electric vehicle comprising a frame of the electric vehicle to which a body of the electric vehicle is coupled, the frame including longitudinal frame rails, a mid-section of the frame not including frame cross-members, and a battery pack mounted in the mid-section of the frame, the battery pack including battery pack cross-members, each of the battery pack cross-members connected to a top surface of the longitudinal frame rails and a bottom surface of the longitudinal frame rails.

[0114] Example 2 includes the electric vehicle of example 1, wherein the battery pack includes battery modules positioned between the battery pack cross-members and between the longitudinal frame rails.

[0115] Example 3 includes the electric vehicle of example 1, wherein the longitudinal frame rails include flanges on at least one of the top surface or the bottom surface.

[0116] Example 4 includes the electric vehicle of example 3, wherein the battery pack cross-members are connected to the flanges on the at least one of the top surface or the bottom surface.

[0117] Example 5 includes the electric vehicle of example 1, wherein the battery pack cross-members are connected to the top surface of the longitudinal frame rails and the bottom surface of the longitudinal frame rails via bolts.

[0118] Example 6 includes the electric vehicle of example 1, wherein the battery pack is to be installed and removed in one piece from the frame.

[0119] Example 7 includes an electric vehicle comprising a frame of the electric vehicle isolated from a body of the electric vehicle, the frame including longitudinal frame rails and frame cross-members fixed to the frame, and a battery pack including battery pack cross-members, the battery pack cross-members connected to respective bottom surfaces of the frame cross-members and the longitudinal frame rails.

[0120] Example 8 includes the electric vehicle of example 7, wherein the battery pack includes battery modules positioned between the battery pack cross-members, the frame cross-members, and the longitudinal frame rails.

[0121] Example 9 includes the electric vehicle of example 7, wherein the frame cross-members extend through the longitudinal frame rails.

[0122] Example 10 includes the electric vehicle of example 9, wherein a first part of each frame cross-member is connected to a respective battery pack cross-member on a first side of the longitudinal frame rails.

[0123] Example 11 includes the electric vehicle of example 10, wherein the body includes rockers, and wherein a second part of each frame cross-member is connected to a rocker on a second side of the longitudinal frame rails opposite the first side of the longitudinal frame rails.

[0124] Example 12 includes the electric vehicle of example 7, wherein the battery pack cross-members are connected to the respective bottom surfaces of the frame cross-members and the longitudinal frame rails via bolts.

[0125] Example 13 includes the electric vehicle of example 7, wherein the battery pack further includes longitudinal cross-members between at least two of the battery pack cross-members to increase stiffness of the frame in response to frontal loads.

[0126] Example 14 includes the electric vehicle of example 7, wherein each of the battery pack cross-members is connected to the respective bottom surfaces of the frame cross-members and the longitudinal frame rails to at least increase stiffness of the frame, support a weight of the battery pack, and reduce twisting of the frame.

[0127] Example 15 includes an apparatus comprising an electric vehicle assembly having a body and a frame, the frame isolated from the body, a mid-section of the frame not including frame cross-members, and a battery pack removably coupled to the frame via bolts, the battery pack including battery pack cross-members between longitudinal frame rails in a mid-section of the frame.

[0128] Example 16 includes the apparatus of example 15, wherein the battery pack includes battery modules positioned between the battery pack cross-members and between the longitudinal frame rails.

[0129] Example 17 includes the apparatus of example 15, wherein each of the battery pack cross-members are connected to a top surface of the longitudinal frame rails and a bottom surface of the longitudinal frame rails.

[0130] Example 18 includes the apparatus of example 17, wherein the longitudinal frame rails include flanges on at least one of the top surface or the bottom surface.

[0131] Example 19 includes the apparatus of example 18, wherein the battery pack cross-members are connected to the flanges on the at least one of the top surface or the bottom surface.

[0132] Example 20 includes the apparatus of example 15, wherein the battery pack is to be removed from the frame in one piece.

[0133] Although certain example methods, apparatus and articles of manufacture have been disclosed herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus and articles of manufacture fairly falling within the scope of the claims of this patent.

[0134] The following claims are hereby incorporated into this Detailed Description by this reference, with each claim standing on its own as a separate embodiment of the present disclosure.

## Claims

1. (canceled)
2. An apparatus comprising: a battery pack structure including: a skid plate including a first end and a second end; a first flange extending laterally from the first end, the first flange to be coupled to a first bottom surface of a first longitudinal rail of a frame of a vehicle; a second flange extending laterally from the second end, the second flange to be coupled to a second bottom surface of a second longitudinal rail of the frame; a first wall extending vertically from the first end; and a second wall extending vertically from the second end, the first wall and the second wall defining an interior; a battery disposed within the interior; and a cross member disposed within the interior.
3. The apparatus of claim 2, wherein a third bottom surface of the first flange is flush with a fourth bottom surface of the skid plate.
4. The apparatus of claim 2, wherein the battery is a first battery and the apparatus further includes a second battery separated from the first battery by the cross member.
5. The apparatus of claim 2, wherein the battery pack structure further includes a top plate, the top plate and the skid plate further defining the interior.
6. The apparatus of claim 5, wherein the top plate is coupled to the cross member.
7. The apparatus of claim 5 wherein the first flange, the second flange, the top plate, and the skid plate are parallel.
8. The apparatus of claim 2, wherein the battery pack structure is to be in contact with a side surface of the first longitudinal rail.
9. The apparatus of claim 2, further including at least five cross members including the cross member.
10. The apparatus of claim 2, further including a third flange coupled to the first wall the third flange to be coupled to a top surface of the first longitudinal rail.
11. An assembly comprising: a frame including: a first longitudinal rail; and a second longitudinal rail; a battery pack structure including: a skid plate including a first end and a second end; a first flange extending laterally from the first end, the first flange to be coupled to a first bottom surface of the first longitudinal rail; a second flange extending laterally from the second end, the second flange to be coupled to a second bottom surface of the second longitudinal rail; a first wall extending vertically from the first end; and a second wall extending vertically from the second end, the first wall and the second wall defining an interior; a battery disposed within the interior; and a cross member disposed within the interior.
12. The assembly of claim 11, wherein the first longitudinal rail has a first vertical length, the first wall has a second vertical length equal to the first vertical length.
13. The assembly of claim 11, wherein the battery pack structure is in contact with a side surface of the first longitudinal rail.
14. The assembly of claim 11, wherein a third bottom surface of the first flange is flush with a fourth bottom surface of the skid plate.
15. The assembly of claim 14, further including a bolt on the third bottom surface, the bolt extending through the first flange and the first bottom surface.
16. The assembly of claim 11, wherein the battery pack structure further includes a top plate, the top plate and the skid plate further defining the interior.
17. The assembly of claim 16, wherein the top plate is coupled to the cross member.
18. The assembly of claim 16, wherein the first flange, the second flange, the top plate, and the skid plate are parallel.



- 19.** The assembly of claim 11, wherein the battery pack structure is to be in contact with a side surface of the first longitudinal rail.
- 20.** The assembly of claim 11, further including at least five cross members including the cross member.
- 21.** The assembly of claim 11, further including a third flange coupled to the first wall the third flange to be coupled to a top surface of the first longitudinal rail.
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