CLAIMS

[Claim 1] An external cooling system for individualized cooling of a plurality of segmented battery modules, the system comprising an electric vehicle comprising one of a locomotive having at least one traction motor and a power car for the locomotive; and paired with a power source paired with and externally disposed relative to the locomotive or the power car, wherein the system further comprises:

(a) a plurality of energy storage devices housed in the electric vehicle, each individual energy storage device including a heat exchanger and one of the segmented battery modules in thermal conductivity with each other,

(i) wherein the heat exchanger of each individual energy storage device includes:

(1) an HE flow controller comprising a variable speed drive (VSD) coolant pump for controlling flow of coolant through the heat exchanger;

(2) an HE inlet for receiving the coolant into a plurality of HE passages within the heat exchanger; and

(3) an HE outlet for discharging coolant from the HE passages of the heat exchanger; and

(ii) wherein the segmented battery module of each energy storage device includes:

(1) a plurality of battery cells in electrical connection with an electrical connection connector;

(2) a battery management module (BMU) in data communication with a plurality of sensors, the sensors including at least one temperature sensor located within the segmented battery module and the BMU configured to collect sensor information from the sensors; and

(3) a BMU connector in wired or wireless data communication with the BMU;

(b) an electrical connection housed in the electric vehicle,

(i) wherein the electrical connection is in electrical connection to the battery connector of each of the energy storage devices;

(ii) wherein the electrical connection is in electrical connection with one or more electrical connection connectors; and

(iii) wherein each of the one or more electrical connection connectors are connectable to one of one or more power supplies of the power source during each of a plurality of charging sessions for one or more of the energy storage devices during each charging session;

(c) a master battery management system (MBMS) housed in the electric vehicle, wherein the MBMS is in wired or wireless data communication with the BMU of each energy storage device via the BMU connector of the energy storage device;

(d) an external cooling unit housed in the power source, the external cooling unit including an ECU inlet and an ECU outlet;

(e) a pair of coolant trunks housed in the electric vehicle,

(i) wherein the pair of coolant trunks includes:

(1) a cool trunk for receiving cooled coolant; and

(2) a warm trunk for discharging warmed coolant;

(ii) wherein the cool trunk is in fluid connection with ~~each of~~ the HE inlet~~s~~ of ~~the~~ each individual energy storage device~~s~~;

(iii) wherein the warm trunk is in fluid connection with ~~each of~~ the HE outlet~~s~~ of ~~the~~ each individual energy storage device~~s~~;

~~(iv) wherein a segmented coolant pathway between the external cooling unit and each heat exchanger is established for each energy storage device,~~

~~(1) the segmented coolant pathway passing through the HE flow controller of the energy storage device; and~~

~~(2) the segmented coolant pathway having an HE flow rate through the HE flow controller of the energy storage device; and~~

~~(v) wherein the segmented coolant pathway established for each energy storage device has an HE flow rate regulated by the HE flow controller; and~~

(f) an internal cooling unit housed in the electric vehicle and having an ICU inlet and an ICU outlet;

(g) a charging segmented cooling controller (SCC), the charging SCC including a set of parameters,

(i) wherein during each charging session the charging SCC is in direct or indirect data communication by wire or wirelessly with:

(1) the external cooling unit;

(2) the HE flow controller of each energy storage device;

(3) the MBMS; and

(4) the BMU of the segmented battery module of each energy storage device via the MBMS and the BMU connector of the energy storage device;

(ii) wherein during each charging session the charging SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information including at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device;

(iii) wherein the set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage device;

(iv) wherein during each charging session the charging SCC is configured to periodically:

(1) calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each individual energy storage device, the optimal range a function of:

(a) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and

(b) the preferred temperature range for the energy storage device; and

(2) control by wire or wirelessly the HE flow rate of each individual energy storage device, via the direct or indirect data communication with the HE flow controller of the energy storage device, to maintain the HE flow rate within the optimal range; and

(v) wherein the charging SCC is housed in the power source and, for each energy storage device, data communication between the charging SCC and the HE flow controller of the energy storage device does not pass through either:

(1) the MBMS of the motorized electric vehicle; or

(2) the BMU of the energy storage device

(h) wherein during each charging session:

(i) a segmented coolant pathway exists that provides a flow of coolant between each individual energy storage device of the motorized electric vehicle and the external cooling unit, whereby coolant is transferred between the external cooling unit and the heat exchanger of each individual energy storage device by way of the VSD coolant pump of the HE flow controller of the energy storage device, and further wherein:

(1) for each individual energy storage device, the segmented coolant pathway includes the HE flow controller of the energy storage device, and the HE flow controller of the energy storage device has an HE flow rate therethrough; and

(2) for each individual energy storage device, the segmented coolant pathway exits from the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage

device, through the HE outlet of the energy storage device, through the warm trunk, into the ICU inlet, through the internal cooling unit, out of the ICU outlet, into the ECU inlet, and back into and through the external cooling unit; and

(ii) the charging SCC is configured to prioritize individual cooling needs of the segmented battery modules by way of increasing or decreasing coolant flow through the HE flow controller of each individual energy storage device to establish an individualized flow of coolant to each energy storage device.

~~[Claim 2] The system of claim 1,~~

~~(a) wherein the cool trunk receives cooled coolant from the external cooling unit via the ECU outlet;~~

~~(b) wherein the warm trunk discharges warmed coolant into the external cooling unit via the ECU inlet; and~~

~~(c) wherein the segmented coolant pathway for each energy storage device exits from the external cooling unit via the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, and back into the external cooling unit via the ECU inlet.~~

~~[Claim 3] The system of claim 1, the system further comprising an external-to-internal heat exchanger and an internal cooling unit,~~

~~(a) wherein the internal cooling unit includes an ICU inlet and an ICU outlet;~~

~~(b) wherein the cool trunk receives cooled coolant from the internal cooling unit via the ICU outlet after the coolant passes through the external-to-internal heat exchanger;~~

~~(c) wherein the warm trunk discharges warmed coolant into the internal cooling unit via the ICU inlet;~~

~~(d) wherein the segmented coolant pathway for each energy storage device exits from the internal cooling unit via the ICU outlet, through the external-to-internal heat exchanger, through the cool trunk of the pair of coolant trunks, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, and back into the internal cooling unit via the ICU inlet; and~~

~~(e) wherein a second coolant pathway exits from the external cooling unit via the ECU outlet, passes through the external-to-internal heat exchanger, and returns to the external cooling unit via the ECU inlet.~~

~~[Claim 4] The system of claim 1, the system further comprising an internal cooling unit,~~

~~(a) wherein the cool trunk receives cooled coolant from the external cooling unit via the ECU outlet;~~

~~(b) wherein the warm trunk discharges warmed coolant into the internal cooling unit via the ICU inlet; and~~

~~(c) wherein the segmented coolant pathway for each energy storage device exits from the external cooling unit via the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, into the internal cooling unit via the ICU inlet, out of the internal cooling unit via the ICU outlet, and back into the external cooling unit via the ECU inlet.~~

~~[~~Claim ~~5~~2~~]~~ The system of claim 1, wherein the charging SCC employs a control loop to:

(a) adjust a power rating delivered to the external cooling unit;

(b) according to the temperature information from the temperature sensor of the segmented battery module of each of the energy storage devices, prioritize delivery of coolant to at least one of the energy storage devices; and

(c) adjust the HE flow rate of coolant through one or more of the HE flow controllers.

[Claim 6] The system of claim 1,

(a) wherein the plurality of sensors in the segmented battery module of each energy storage device further include a current sensor configured to measure and transmit current information of the battery cells of the segmented battery module to the charging SCC via the BMU of the energy storage device;

(b) wherein the set of parameters includes a thermal model for each energy storage device; and

(c) wherein calculation or recalculation by the charging SCC of the optimal range for each energy storage device includes calculation or recalculation of:

(i) a heat generation estimate for the energy storage device from:

(1) the thermal model of the energy storage device;

(2) the current information for the energy storage device; and

(3) the preferred temperature range for the energy storage device; and

(ii) the optimal range for the HE flow rate of the energy storage device to counteract the heat generation estimate for the energy storage device.

~~[Claim 7] The system of claim 1, wherein the coolant is a fluid, water, a gas, or air.~~

[Claim ~~8~~]4 The system of claim 1,

(a) wherein the heat exchanger and the segmented battery module of each energy storage device are paired in thermal conductivity via a thermal interface;

(b) wherein the heat exchanger for each energy storage device includes a plurality of heat sinks conforming to ~~at least one~~ outer surface areas of the segmented battery module of the energy storage device; and

(c) wherein the thermal interface between ~~the~~ each heat sink and the segmented battery module of each energy storage device is a compressible thermally conductive material or a thermally conductive paste.

[Claim ~~9~~]5 The system of claim ~~8~~4, wherein ~~the~~ at least one heat sink of each energy storage device comprises an aluminium shell enclosing the HE passages of the energy storage device.

~~[Claim 10] The system of claim 1,~~

~~(a) wherein the electric vehicle is a motorized electric vehicle including a vehicle control system and at least one traction motor in electrical connection with the electrical connection; and~~

~~(b) wherein operation of the at least one traction motor is controlled by the vehicle control system.~~

~~[~~Claim ~~11]~~6 The system of claim 1,

~~(a)~~ wherein the ~~electric vehicle is a~~ power car includ~~es~~ing one or more power outlets ~~in electrical connection to the electrical connection; and~~

~~(b) wherein the one or more power outlets are~~ connectable to one or more power inlets of ~~a motorized electric vehicle~~the locomotive.

~~[~~Claim ~~12]~~7 A computer-implemented ~~external cooling~~ method for individualized cooling of a plurality of segmented battery modules of an electric vehicle comprising one of a locomotive having at least one traction motor and a power car for the locomotive; and a power source paired with and externally disposed relative to the locomotive or the power car, the method comprising:

(a) maintaining a plurality of energy storage devices in an electric vehicle, each individual energy storage device including a heat exchanger and one of the segmented battery modules in thermal conductivity with each other,

(i) wherein the heat exchanger of each individual energy storage device includes:

(1) an HE flow controller comprising a variable speed drive (VSD) coolant pump for controlling flow of coolant through the heat exchanger;

(2) an HE inlet for receiving the coolant into a plurality of HE passages within the heat exchanger; and

(3) an HE outlet for discharging coolant from the HE passages of the heat exchanger; and

(ii) wherein the segmented battery module of each energy storage device includes:

(1) a plurality of battery cells in electrical connection with an electrical connection connector;

(2) a battery management module (BMU) in data communication with a plurality of sensors, the sensors including at least one temperature sensor located within the segmented battery module and the BMU configured to collect sensor information from the sensors; and

(3) a BMU connector in wired or wireless data communication with the BMU;

(b) maintaining an electrical connection in the electric vehicle,

(i) wherein the electrical connection is in electrical connection to the battery connector of each of the energy storage devices;

(ii) wherein the electrical connection is in electrical connection with one or more electrical connection connectors; and

(iii) wherein each of the one or more electrical connection connectors are connectable to one of one or more power supplies of the power source during a charging session for ~~one or more~~plurality of ~~the~~ energy storage devices;

(c) maintaining a master battery management system (MBMS) in the electric vehicle, wherein the MBMS is in data communication with the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device; and

(d) maintaining an external cooling unit in a power source, the external cooling unit including an ECU inlet and an ECU outlet;

(e) maintaining a pair of coolant trunks in the electric vehicle,

(i) wherein the pair of coolant trunks includes:

(1) a cool trunk for receiving cooled coolant; and

(2) a warm trunk for discharging warmed coolant;

(ii) wherein the cool trunk is in fluid connection with ~~each of~~ the HE inlet~~s~~ of ~~the~~ each individual energy storage device~~s~~;

(iii) wherein the warm trunk is in fluid connection with ~~each of~~ the HE outlet~~s~~ of ~~the~~ each individual energy storage device~~s~~;

~~(iv) wherein a segmented coolant pathway between the external cooling unit and each heat exchanger is established for each energy storage device,~~

~~(1) the segmented coolant pathway passing through the HE flow controller of the energy storage device; and~~

~~(2) the segmented coolant pathway having an HE flow rate through the HE flow controller of the energy storage device; and~~

~~(v) wherein the segmented coolant pathway established for each energy storage device has an HE flow rate regulated by the HE flow controller; and~~

(f) maintaining an internal cooling unit housed in the electric vehicle and having an ICU inlet and an ICU outlet;

(g) maintaining a charging segmented cooling controller (SCC), the charging SCC including a set of parameters,

(i) wherein during ~~each~~ the charging session the charging SCC is in direct or indirect data communication by wire or wirelessly with:

(1) the external cooling unit;

(2) the HE flow controller of each energy storage device;

(3) the MBMS; and

(4) the BMU of the segmented battery module of each energy storage device via the MBMS and the BMU connector of the energy storage device;

(ii) wherein during ~~each~~ the charging session the charging SCC is configured to directly or indirectly receive the sensor information collected by the BMU of each energy storage device wirelessly or by wire via the BMU connector of the energy storage device, the sensor information including at least temperature information measured by the at least one temperature sensor located within the segmented battery module of the energy storage device;

(iii) wherein the set of parameters include at least a preferred temperature range for the segmented battery module of each energy storage device; and

(iv) wherein the charging SCC is maintained in the power source and, for each energy storage device, data communication between the charging SCC and the HE flow controller of the energy storage device does not pass through either:

(1) the MBMS of the motorized electric vehicle; or

(2) the BMU of the energy storage device;

(h) establishing for the charging session a segmented coolant pathway that provides a flow of coolant between each individual energy storage device of the motorized electric vehicle and the external cooling unit, whereby coolant is transferred between the external cooling unit and the heat exchanger of each individual energy storage device during each charging session by way of the VSD coolant pump of the HE flow controller of the energy storage device, and further wherein:

(1) for each individual energy storage device, the segmented coolant pathway includes the HE flow controller of the energy storage device, and the HE flow controller of the energy storage device has an HE flow rate therethrough; and

(2) for each individual energy storage device, the segmented coolant pathway exits from the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, into the ICU inlet, through the internal cooling unit, out of the ICU outlet, into the ECU inlet, and back into and through the external cooling unit;

(~~g~~i) commencing the charging session for ~~one or more~~the plurality of energy storage devices, the step of commencing the charging session including:

(i) connecting the MBMS to the charging SCC; and

(ii) connecting the electrical connection to one or more power supplies via one or more electrical connection connectors;

(~~h~~j) during the charging session, periodically employing the charging SCC to calculate or recalculate an optimal range for the HE flow rate of the heat exchanger of each individual energy storage device, the optimal range a function of:

(i) the sensor information received by the charging SCC from the sensors of the energy storage device via the BMU of the energy storage device; and

(ii) the preferred temperature range for the energy storage device; and

(~~i~~k) during the charging session, prioritizing individual cooling needs of the segmented battery modules by way of increasing or decreasing coolant flow through the HE flow controller~~ing by wire or wirelessly the HE flow rate~~ of each individual energy storage device under charging SCC control to establish an individualized flow of coolant to each ~~, via the direct or indirect data communication with the HE flow controller of the~~ energy storage device~~, to maintain the HE flow rate within the optimal range~~.

~~[Claim 13] The method of claim 12,~~

~~(a) wherein the cool trunk receives cooled coolant from the external cooling unit via the ECU outlet;~~

~~(b) wherein the warm trunk discharges warmed coolant into the external cooling unit via the ECU inlet; and~~

~~(c) wherein the segmented coolant pathway for each energy storage device exits from the external cooling unit via the ECU outlet, through the cool trunk, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, and back into the external cooling unit via the ECU inlet.~~

~~[Claim 14] The method of claim 12, the method further comprising maintaining an external-to-internal heat exchanger and an internal cooling unit,~~

~~(a) wherein the internal cooling unit includes an ICU inlet and an ICU outlet;~~

~~(b) wherein the cool trunk receives cooled coolant from the internal cooling unit via the ICU outlet after the coolant passes through the external-to-internal heat exchanger;~~

~~(c) wherein the warm trunk discharges warmed coolant into the internal cooling unit via the ICU inlet;~~

~~(d) wherein the segmented coolant pathway for each energy storage device exits from the internal cooling unit via the ICU outlet, through the external-to-internal heat exchanger, through the cool trunk of the pair of coolant trunks, through the HE inlet of the energy storage device, through the HE passages of the energy storage device, through the HE outlet of the energy storage device, through the warm trunk, and back into the internal cooling unit via the ICU inlet; and~~

~~(e) wherein a second coolant pathway exits from the external cooling unit via the ECU outlet, passes through the external-to-internal heat exchanger, and returns to the external cooling unit via the ECU inlet.~~

~~[~~Claim ~~15]~~8 The method of claim ~~12~~7, wherein the charging SCC employs a control loop to:

(a) adjust a power rating delivered to the external cooling unit;

(b) according to the temperature information from the temperature sensor of the segmented battery module of each of the energy storage devices, prioritize delivery of coolant to at least one of the energy storage devices; and

(c) adjust the HE flow rate of coolant through one or more of the HE flow controllers.

[Claim 16]9 The method of claim 127,

(a) wherein the plurality of sensors in the segmented battery module of each energy storage device further include a current sensor configured to measure and transmit current information of the battery cells of the segmented battery module to the charging SCC via the BMU of the energy storage device;

(b) wherein the set of parameters includes a thermal model for each energy storage device; and

(c) wherein the step of periodically employing the charging SCC to calculate or recalculate the optimal range includes calculating or recalculating for each energy storage device:

(i) a heat generation estimate for the energy storage device from:

(1) the thermal model of the energy storage device;

(2) the current information for the energy storage device; and

(3) the preferred temperature range for the energy storage device; and

(ii) the optimal range for the HE flow rate of the energy storage device to counteract the heat generation estimate for the energy storage device.

[Claim 17] The method of claim 12, wherein the coolant is a fluid, water, a gas, or air.

[Claim 18]10 The method of claim 127,

(a) wherein the heat exchanger and the segmented battery module of each energy storage device are paired in thermal conductivity via a thermal interface;

(b) wherein the heat exchanger for each energy storage device includes a plurality of heat sinks conforming to at least one outer surface areas of the segmented battery module of the energy storage device; and

(c) wherein the thermal interface between the at least one heat sink and the segmented battery module of each energy storage device is a compressible thermally conductive material or a thermally conductive paste.

[Claim 19]11 The method of claim 1810, wherein the heat sink of each at least one energy storage device comprises an aluminium shell enclosing the HE passages of the energy storage device.

~~[Claim 20] The method of claim 12,~~

~~(a) wherein the electric vehicle is a motorized electric vehicle including a vehicle control system and at least one traction motor in electrical connection with the electrical connection; and~~

~~(b) wherein operation of the at least one traction motor is controlled by the vehicle control system.~~

~~[~~Claim ~~21]~~12 The method of claim ~~12~~7,

~~(a)~~ wherein the ~~electric vehicle is a~~ power car includ~~es~~~~ing~~ one or more power outlets ~~in electrical connection to the electrical connection; and~~

~~(b) wherein the one or more power outlets are~~ connectable to one or more power inlets of ~~a motorized electric vehicle~~the locomotive.