



Configurazioni di macchine elettriche
e sistemi di accumulo per applicazioni automotive.

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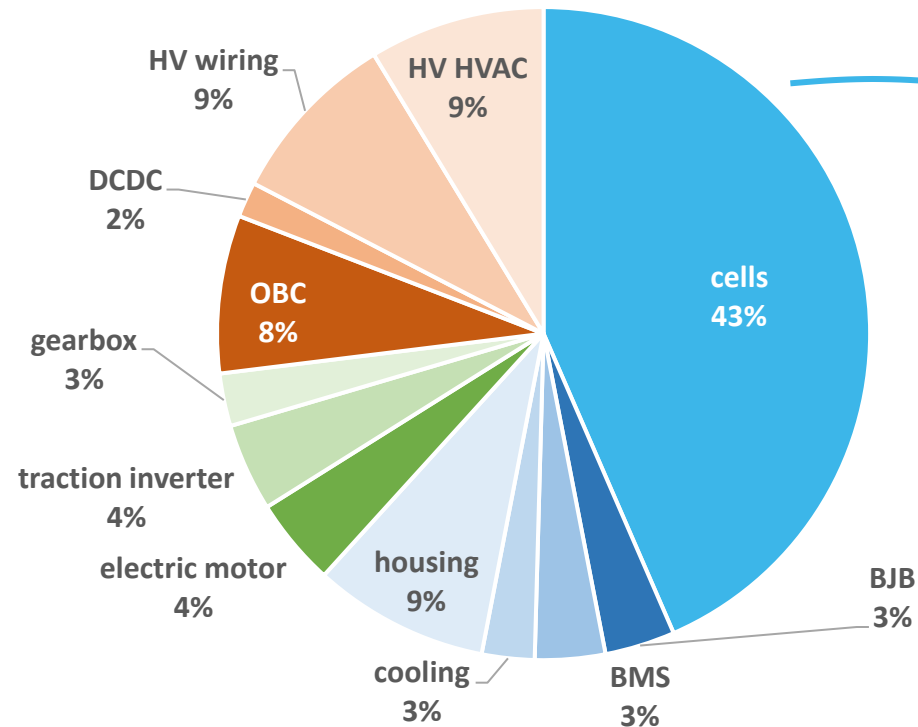
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
930 YEARS AND COUNTING



Lavorazioni Laser nel Settore E-Mobility: Stato dell'Arte e Prospettive Future

Configurazioni di macchine elettriche e sistemi di accumulo per applicazioni automotive.

electric driveline - cost breakdown
BEV-SUV 60kWh-150kW



Lithium-ion battery price survey results: Volume-weighted average

Battery pack price (real 2019 \$/kWh)



Source: BloombergNEF

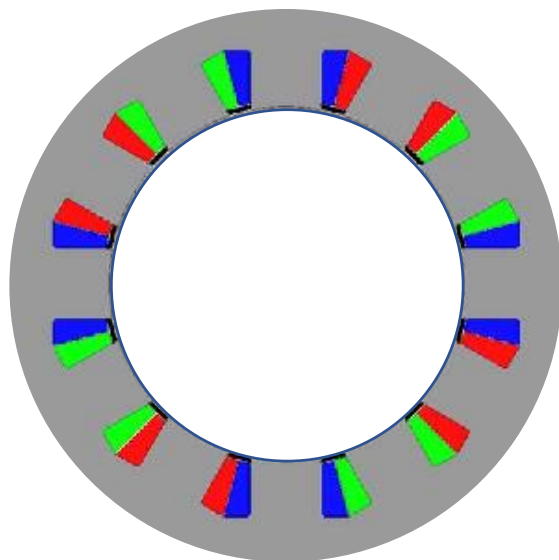
MACCHINE ELETTRICHE



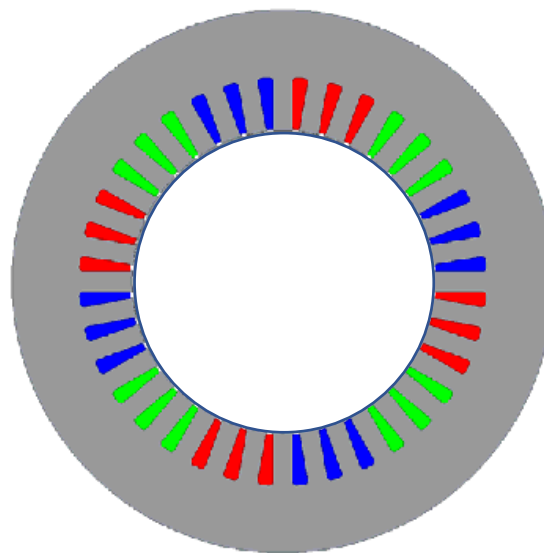
BATTERIE



AVVOLGIMENTI CONCENTRATI



Per macchine con elevato numero di poli elevato rapporto D/L

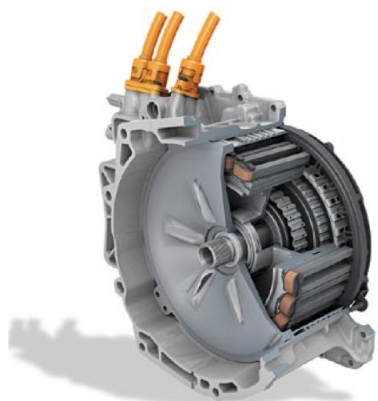


Per macchine di grande potenza, o con basso rapporto D/L

AVVOLGIMENTI DISTRIBUITI



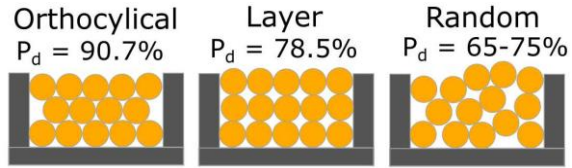
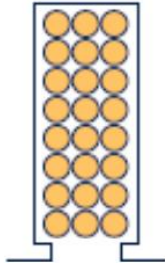
VW APP310 for ID3.0



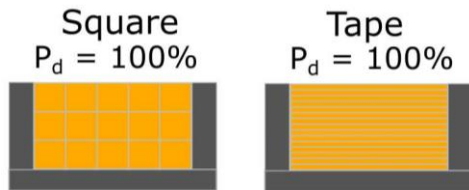
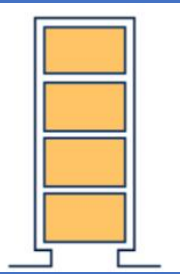
VW GOLF GTE

ELECTRIC MOTOR WINDINGS

WIRE WINDING



COPPER BAR WINDING



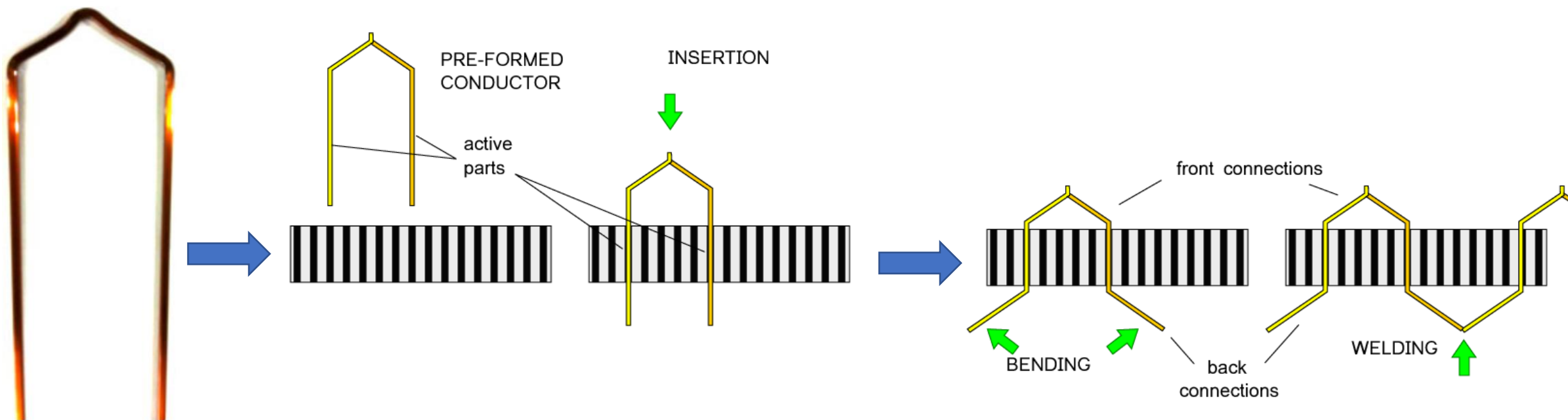
Technical features

- high slot fill factor
- good heat dissipation
- strong rigidity
- short end-windings

Impacts

- enhance torque and power density
- improve efficiency
- decrease vibration
- enhance power density
- compact structure
- low cost
- dedicated automation
- increase AC copper losses for proximity and skin effect

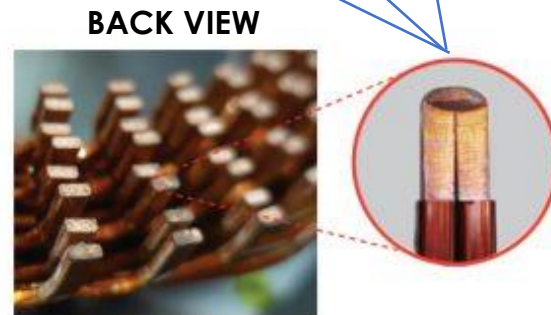
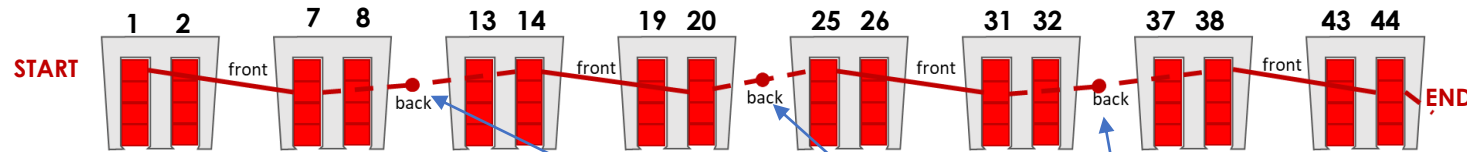
COPPER BAR WINDING



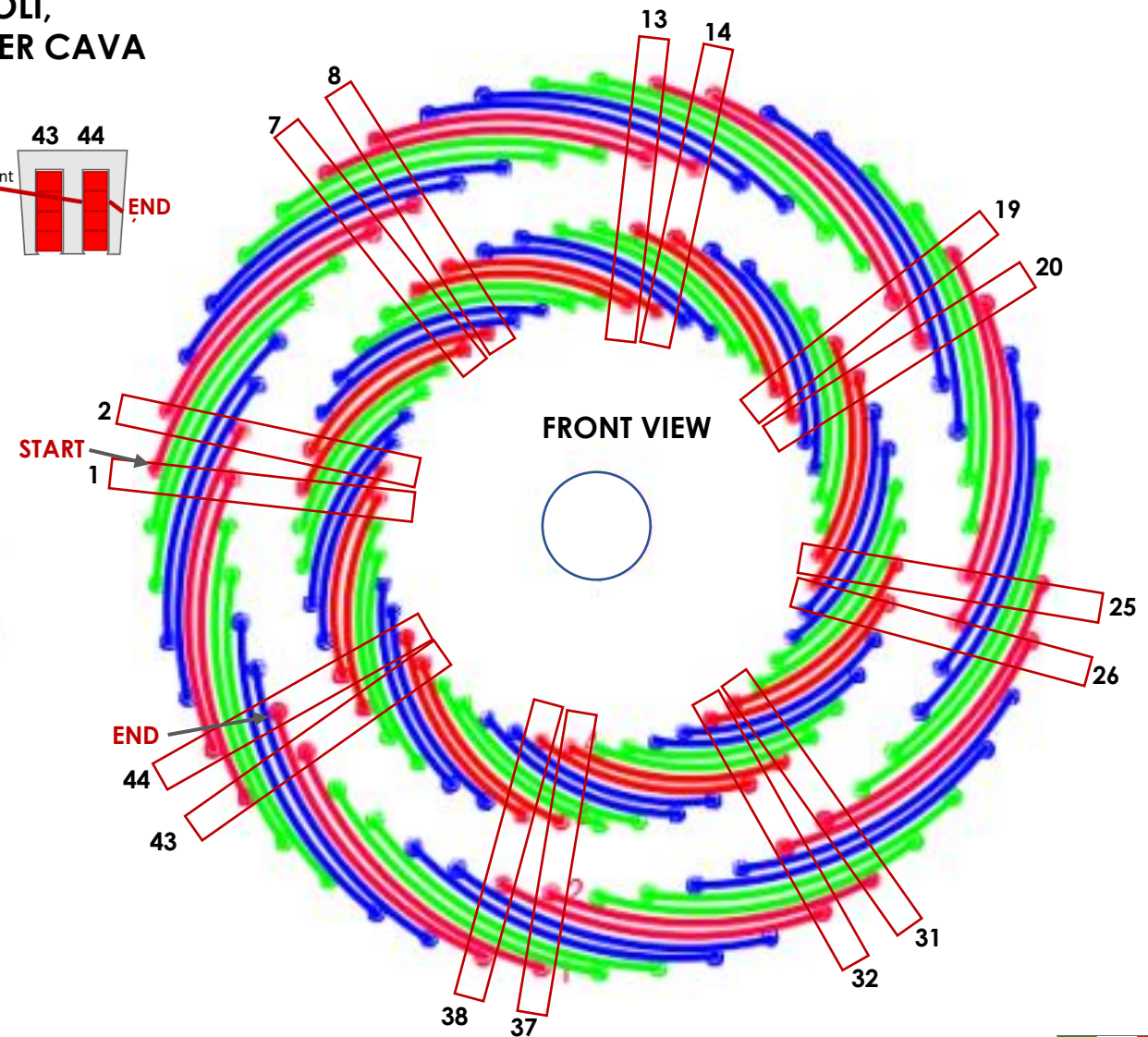
ELECTRIC MOTOR WINDINGS

COPPER BAR WINDING

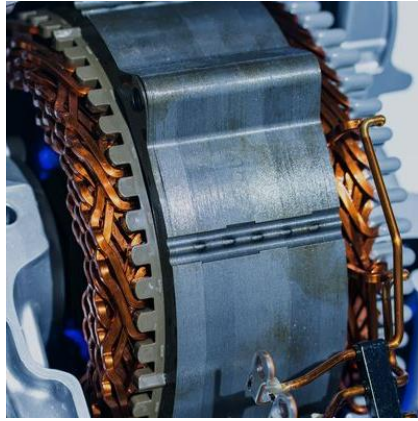
ES. 48 CAVE, 8 POLI,
4 CONDUTTORI PER CAVA



192 WELDING SPOTS



COPPER BAR WINDING TOYOTA IV (P610)



ZF HYBRID AUTOMATIC GEARSHIFT

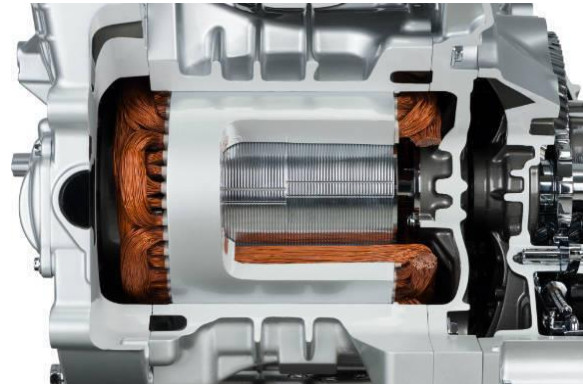


RICARDO 25KW, 48V

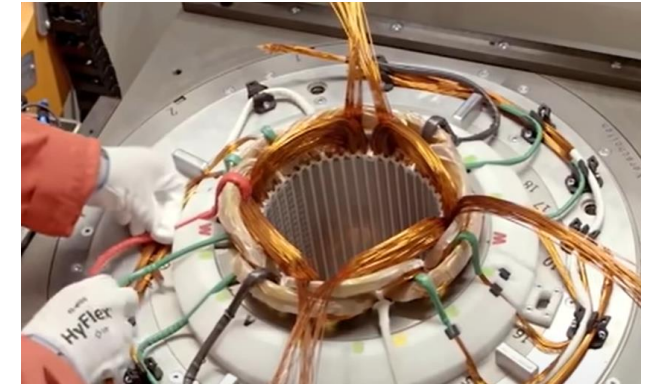


WIRE WINDINGS

NISSAN LEAF 2018



AUDI E-TRON



TESLA Model 3 front motor

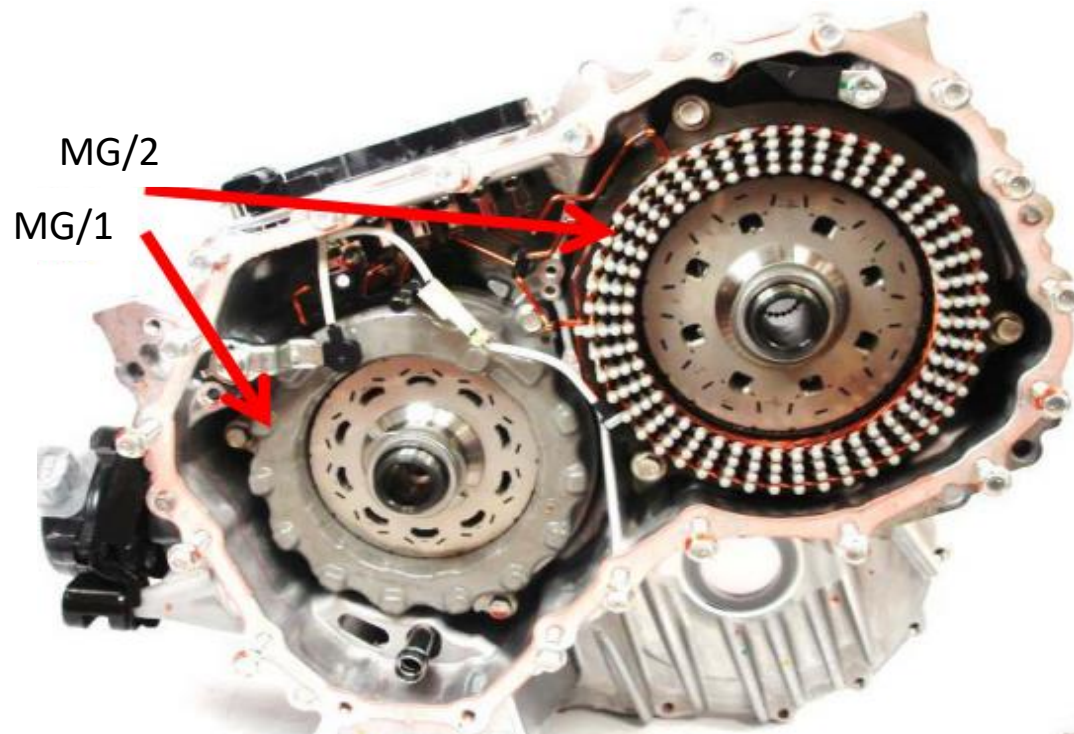


BMW i8



COPPER BAR WINDING

Toyota Hybrid IV GEN (P610)



WIRE WINDINGS

Chrysler Pacifica Si-EVT Hybrid Transaxle



ELECTRIC MOTOR WINDINGS

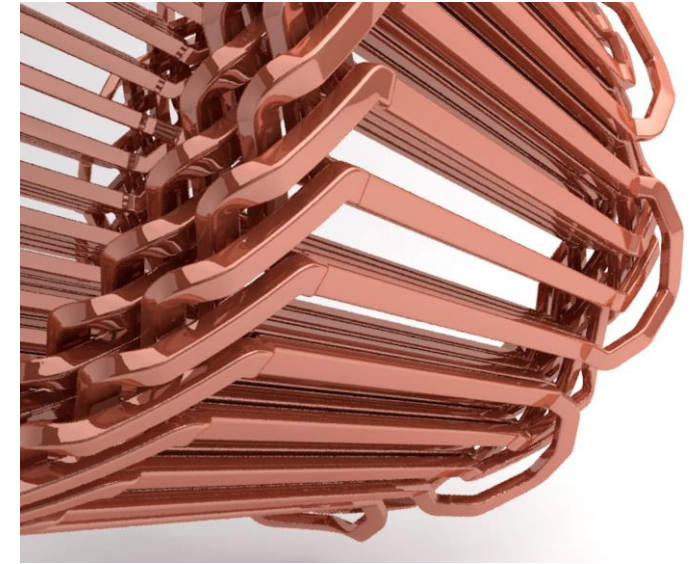
COPPER BAR WINDING

New technologies

Assembled copper induction rotor
of the front motor of Tesla model 3



Copper 3D printing



Hollow copper



BATTERY INTEGRATION

CELL FORMAT



	Cylinder	Pouch	Prismatic
Energy density	very high	high	medium
Power density	very high	high	medium
Thermal performance	high	very high	medium
Energy cost ratio	very high	high	medium
Ease of integration	low	medium	high
Passive safety	very high	low	high
Thermal runaway protection	high	low	medium
Cell size	low	High	Very high

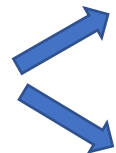
BATTERY INTEGRATION

CELL-TO-PACK INTEGRATION POUCH CELLS – NISSAN LEAF 2019

CELLS



56.3Ah



module



2S2P

MODULES

Stack of modules



48 modules in three different stack configurations



3 different module configurations

PACK

41kWh pack



192 cell (96s2p)

62kWh pack



288 cell (96s3p)

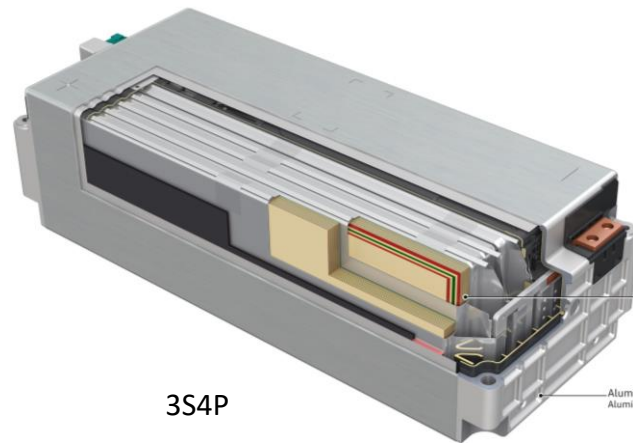
BATTERY INTEGRATION

CELL-TO-PACK INTEGRATION POUCH CELLS: AUDI e-tron 5S QUATTRO

CELLS



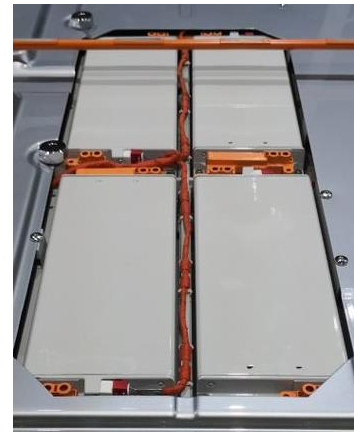
60Ah



3S4P

Alumi
Alumir

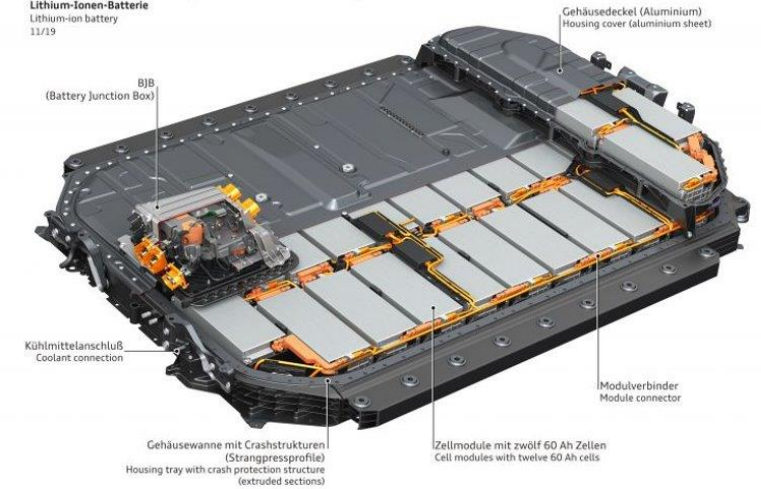
MODULES



PACK

Audi e-tron Sportback 55 quattro

Lithium-Ionen-Batterie
Lithium-ion battery
11/19



432 cells; 36 modules (108S4P)

BATTERY INTEGRATION

CELL-TO-PACK INTEGRATION POUCH CELLS: TESLA Model 3

CELL



21700
4.8Ah

MODULES



2 modules 25S46P
2modules 23S46P

PACK

75kWh pack



4 modules, 4416 cells (96S46P)

BATTERY INTEGRATION – TERMINAL WELDING

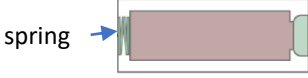
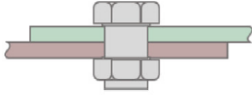
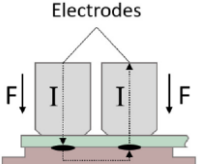
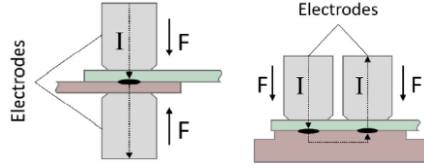
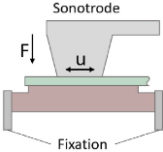
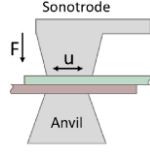

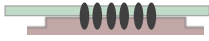

CELL welding

terminal	Cylinder	Pouch
Positive tab	Nickel-plated steel, hilumin	Copper, nickel plated copper
Negative tab	Nickel-plated steel, hilumin	Aluminium
Joint position	<p>Interconnector Cell Interconnector ● Joint</p>	<p>Interconnector Interconnector Tab Cell Single Tab Multiple Tabs ● Joint</p>
Joint example	<p>Resistive spot welding ultrasonic Laser beam</p>	

GENERAL REQUIREMENTS
ELECTRICAL AND THERMAL
Low electrical resistance with a narrow scattering range
Small thermal input during manufacturing
High thermal fatigue resistance of created joints
MATERIAL AND METALLURGICAL
Low corrosion risk
Joining of different materials
Adaptability to a variety of surface conditions
MECHANICAL
Strong interconnections
Good fatigue and creep resistance
Low stress level during welding
Avoid mechanical or vibrational damage during joining
PROCESS
Automatable for mass production
High quality and possibility to control quality

[Zwicker et al. Automotive battery pack manufacturing –a review of battery to tab joining](#)

BATTERY INTEGRATION – TERMINAL WELDING

technology	Cylinder	Pouch	Advantages	Disadvantages
mechanical			<ul style="list-style-type: none"> • Easy dismantling and recycling • Easy repair 	<ul style="list-style-type: none"> • Additional weight due to additional parts • High connection resistance • Expensive • Contact with active part
resistive spot welding			<ul style="list-style-type: none"> • Low cost • Fully automatable • Mature technology 	<ul style="list-style-type: none"> • Difficult to produce large joints • Difficult for joining more than two layers • Electrode sticking/wear • Difficult to control quality • Contact with active part
ultrasonic			<ul style="list-style-type: none"> • Joining of dissimilar materials • Good for thin sheet or multi-layer sheets 	<ul style="list-style-type: none"> • Need for clamping • Expensive consumables • Sonotrode sticking • Sensitive to surface conditions • Contact with active part
wire bonding (ultrasonic)		/	<ul style="list-style-type: none"> • Joining of dissimilar materials • Widely applied in electronics industry • Mature process 	<ul style="list-style-type: none"> • Only suitable for thin wires • Low joint strength • Contact with active part • Slow process
Laser beam welding			<ul style="list-style-type: none"> • Easy automatable and high speed • Low thermal input • Non-contact process • High precision • Large contact surface 	<ul style="list-style-type: none"> • Needs good joint adherence • Difficult to control quality • High initial cost
<ul style="list-style-type: none"> • Friction stir welding • TIG welding • Forming • Solder-Reinforced Adhesive 	/	under development	<ul style="list-style-type: none"> • Low cost • Automatable 	<ul style="list-style-type: none"> • TBD

BATTERY INTEGRATION – TERMINAL WELDING

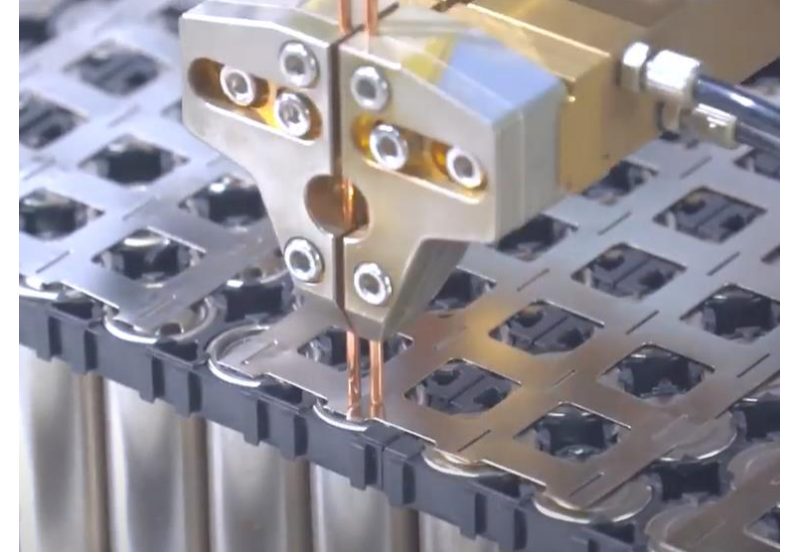
Cylindrical cell welding



Wire bonding



Laser welding on large bus bar



Spot welding



TESLA S, X, Y, model3



PROTERRA



VOLVO 7900



EURABUS 3.0



Dongfeng



RIMAC C-two



Dandong Huanghai

BATTERY INTEGRATION – TERMINAL WELDING

CELL-TO-PACK INTEGRATION POUCH CELLS: TESLA Model 3

CELL CONNECTION

CELL



Wire bonding on the same side



MODULES



BATTERY INTEGRATION – TERMINAL WELDING

JOINT DEGRADATION

Thermal stress

Mechanical stress

Chemical degradation

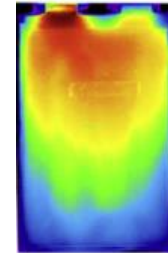
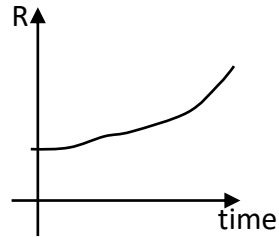
Reduction of contact surface

Increase of contact resistance

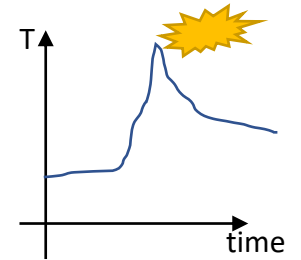
Localized heat generation

Cell degradation

Trigger of Thermal runaway



SEI decomposition
Separator degradation
ISC – Internal Short Circuit



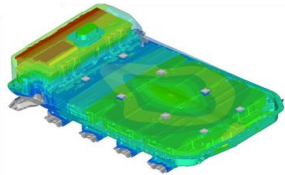
50 BEV buses caught fire in Beijing – June 2017



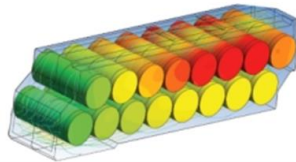
Porsche Taycan caught fire in Florida, Feb. 2020



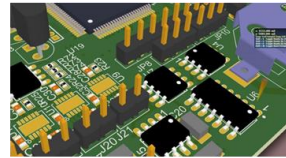
Tecnologie per integrazione di pacco per celle cilindriche



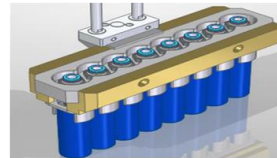
Materials and structural mechanics



Thermal fluid dynamics



Electrical engineering



Process automation



Process technology



V2I



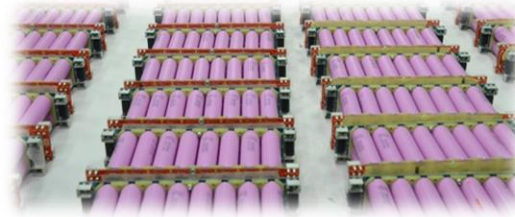
Edge and cloud computing



Product quality

Principali risultati attesi

1. Soluzioni cell-to-brick, brick-to-module, module-to pack, pack-to-vehicle
2. Prototipi validati su applicazioni automotive
3. Modello produttivo distribuito
4. Gestione remota della flotta di pacchi
5. Elevata sicurezza attiva e passiva



Asse 1, Azione 1.2.2 - Contributi per raggruppamento di laboratori



Partenariato LiBER



CIRI

MECCANICA AVANZATA E MATERIALI

CIRI

ICT - TECNOLOGIE DELL'INFORMAZIONE E DELLA COMUNICAZIONE

TOYOTA

MATERIAL HANDLING



N:ER
INGEGNERIA



romagnatech
INNOVATION VALUE



Regione Emilia-Romagna

MUNER – Motor vehicle UNiversity Emilia Romagna 3 master degrees - 4 semesters

AEE - Advanced Automotive Engineering

- MANUFACTURING TECHNOLOGIES
- MECHANICAL VIBRATIONS –
- INTERNAL COMBUSTION ENGINES -
- POWERTRAIN DESIGN
- BATTERY TECHNOLOGY
- TESTING AND HOMOLOGATION
- ELECTRIC DRIVELINES

AAEE – Advanced Automotive Electronic Engineering

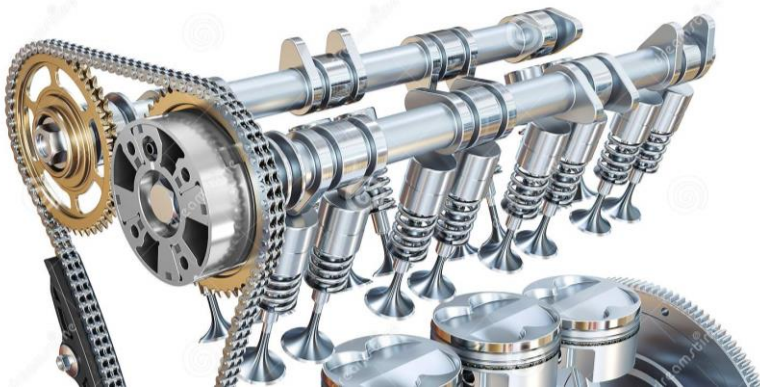
- VEHICULAR COMMUNICATIONS
- AUTOMOTIVE EMBEDDED SYSTEM
- AUTOMOTIVE LIGHTING
- AUTOMOTIVE ELECTRONICS
- AUTOMOTIVE SENSORS
- AUTONOMOUS DRIVING
- AUTOMOTIVE CYBER SECURITY
- INFOTAINMENT

EVE - Electric Vehicle Engineering

NEW

NEW

- ELECTRICAL MACHINES -
- POWER ELECTRONICS
- ELECTRIC DRIVES
- ELECTRIC DRIVELINES
- ELECTROMAGNETIC COMPATIBILITY
- ON BOARD POWER SYSTEMS
- BATTERY TECHNOLOGY
- HVAC SYSTEMS



dallara



MAGNETI
MARELLI

HPE COXA



8. SUSTAINABLE MOBILITY LIVING LAB: EMILIA 4 – SOLAR CAR

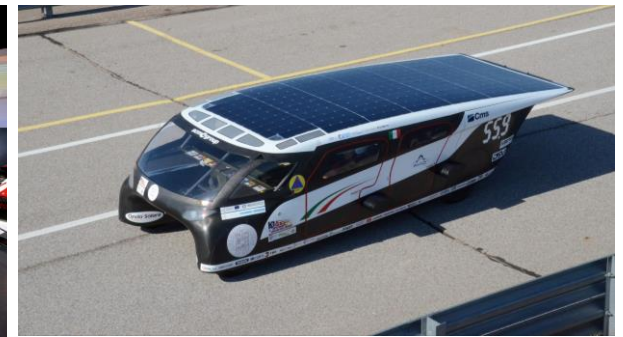
The first four-seater car of all times crossing USA from Midwest to Pacific on a 2900km race using only SOLAR ENERGY.

The winner of the American Solar Challenge 2018



Bend, Oregon – USA July, 22nd 2018

- 105 km/h top speed
- 5 m² photovoltaic panels
- 1.1. kW peak PV power
- Unlimited range at 55 km/h in sunny day
- 320 kg weight with no passengers
- Up to 320 kg weight of passengers
- 17kWh LiBER battery pack
- 700 km range with no sun





ALMA MATER STUDIORUM
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Dept. of Electrical Electronic and Information Engineering (DEI)

LEMAD Lab. of power electronic and electric drives for sustainable mobility

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