

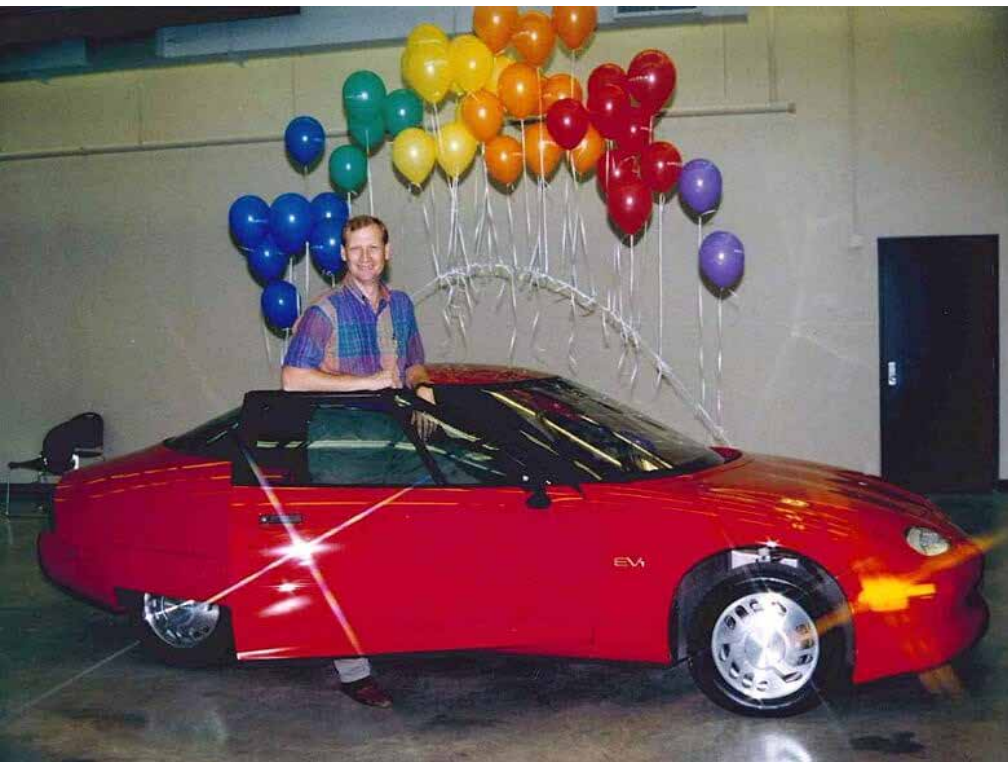


CTO Update: Applications for the Electrification Era

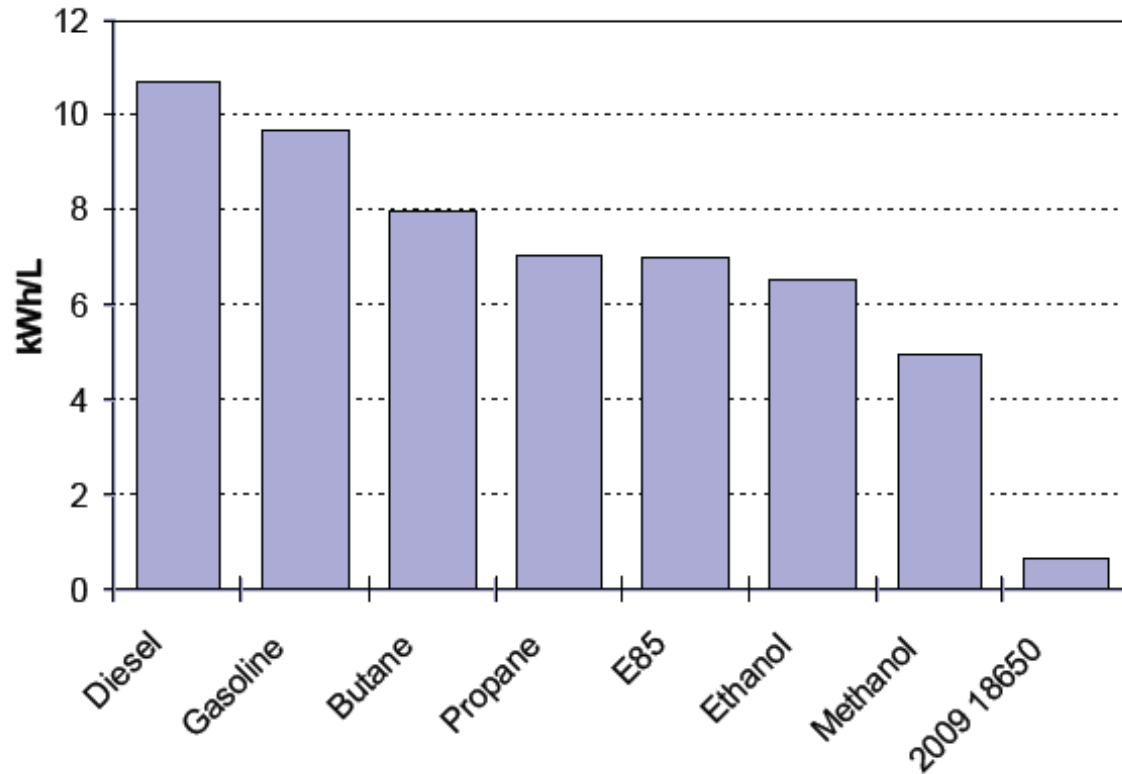
Robert L. Galyen

Retired CATL Chief Technology Officer – Senior Consultant
Chairman SAE Battery Standards Steering Committee
Chairman Emeritus NAATBatt International

TWO MILESTONES OF A CAREER....

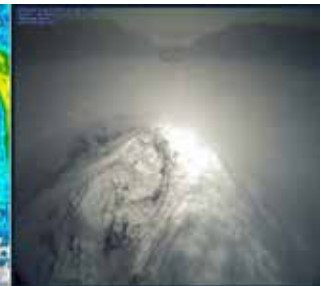
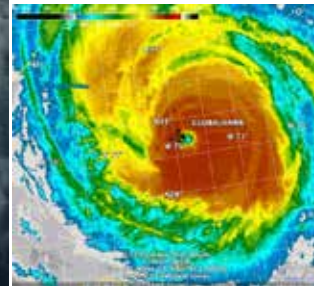


Comparison of Practical Energy Density



We must think differently about electrification due to energy density of fuel source.

IS ELECTRIFICATION THE PERFECT STORM?



GLOBAL MEGA TRENDS IMPACTING FUTURE MOBILITY



Urbanization



E-Mobility



Mega and Smart Cities



New Micro Mobility Products



Car Sharing/Car Pooling



Sustainable Public Transportation and BRT



Integrated Mobility Solutions



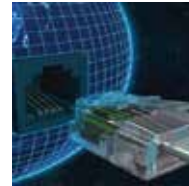
New Business Models (Value for Many)



High Speed Rail



Geo-Socialization And Social Media



Connected and Wireless Planet



Power to the Middle Class and Gen Y

EVOLUTIONARY/REVOLUTIONARY?



NEW ERA OF MOBILITY

Converging Technologies:

- Electrified Automobile
- Electric Smart Grid
- Connected/Autonomous Vehicle



Vehicle-to-Vehicle (V2V)



Vehicle-to-Devices



Vehicle-to-Infrastructure (V2I)



Vehicle-to-Grid (V2G)

ADOPTION SUCCESS FACTORS HAVE NOT CHANGED!

- Technology
- Consumer Acceptance
- Governmental Support
- New Infrastructures



5 GOLDEN RULES OF ELECTRIFICATION



Safety



Performance



Life



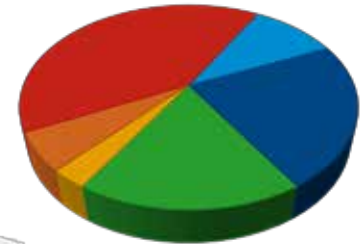
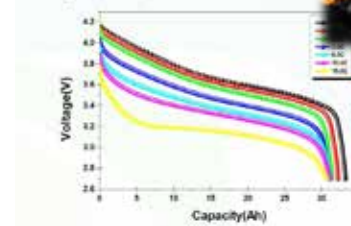
Cost



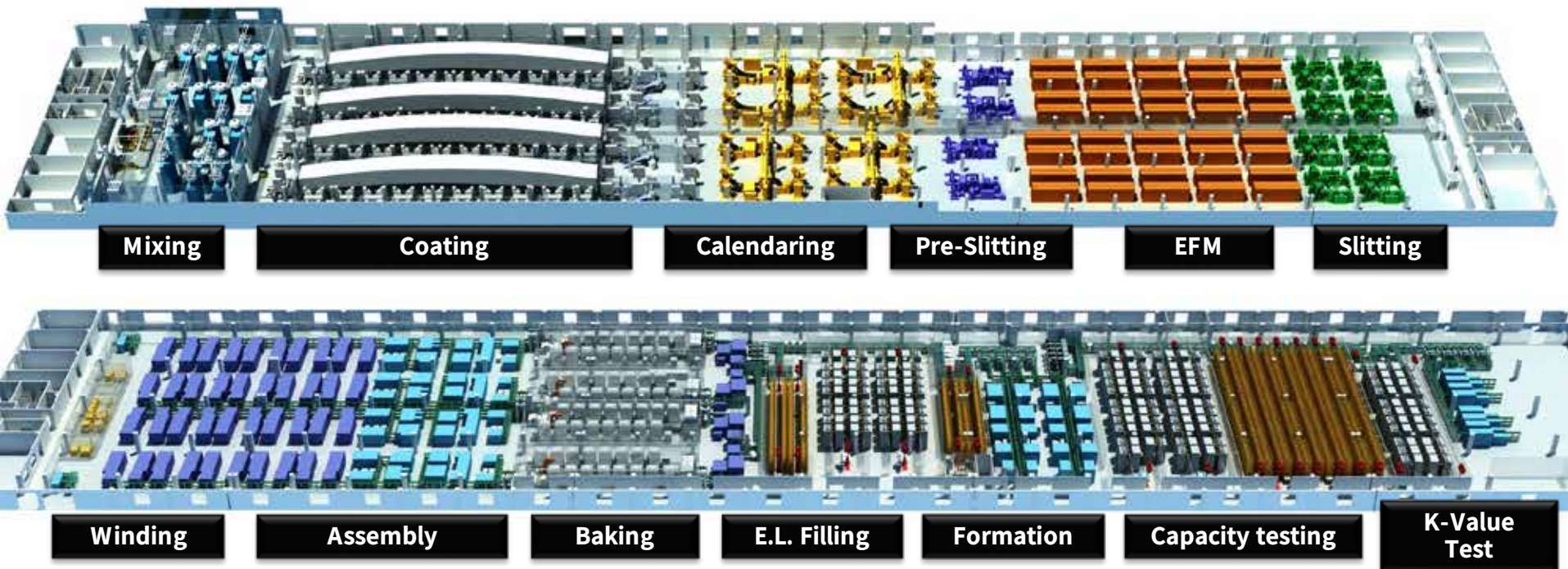
Environmental



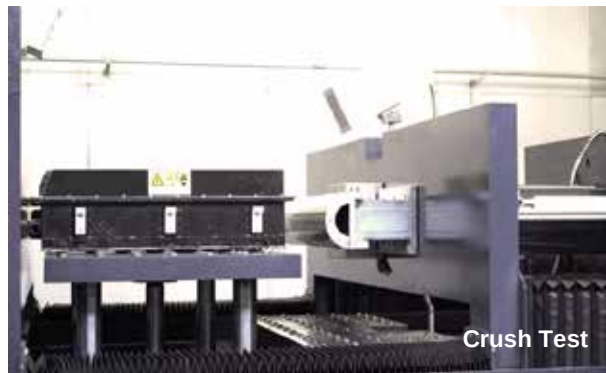
• Charge : CC-CV, 1.6C, 4.2V, 1080 cut off at 25± 5°C
• Discharge : CC, Each-rate, 2.7V cut off at 25± 5°C



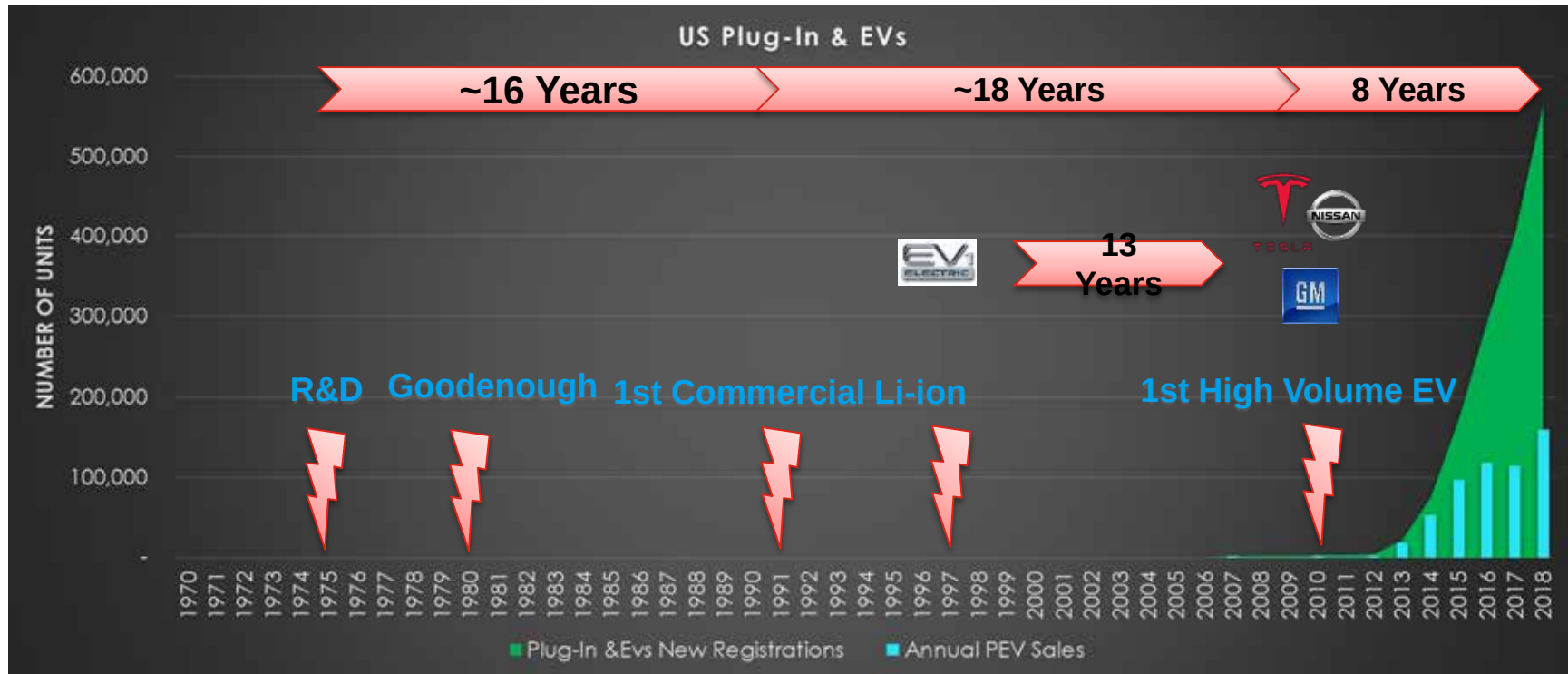
MANUFACTURABILITY IS KEY TO SUCCESS!



BATTERY TECHNOLOGY MUST BE VALIDATED!



ADOPTION OF LIB ENERGY STORAGE

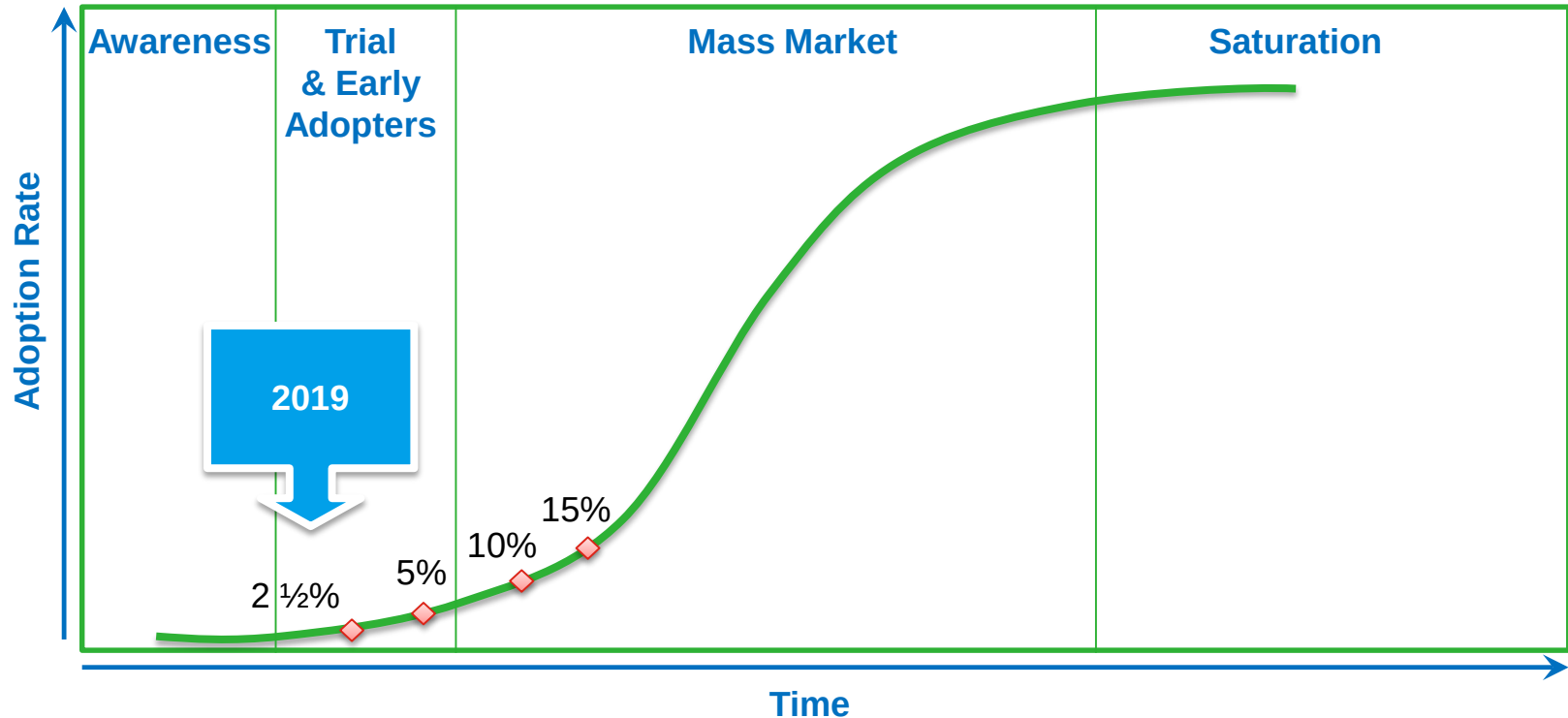


Electrification: Lab to Wide Spread Adoption

Source: Dr. John Warner

ADOPTION OF LIB ENERGY STORAGE

Electrification on the Technology Adoption Curve?



Source: Dr. John Warner

HEV ARCHITECTURE

- HIGHER COMPLEXITY
- MORE PARTS
- SERVICE MORE COMPLEX
- BATTERY COST REDUCTION
MAKING HEV ARCHITECTURE
OBSOLETE

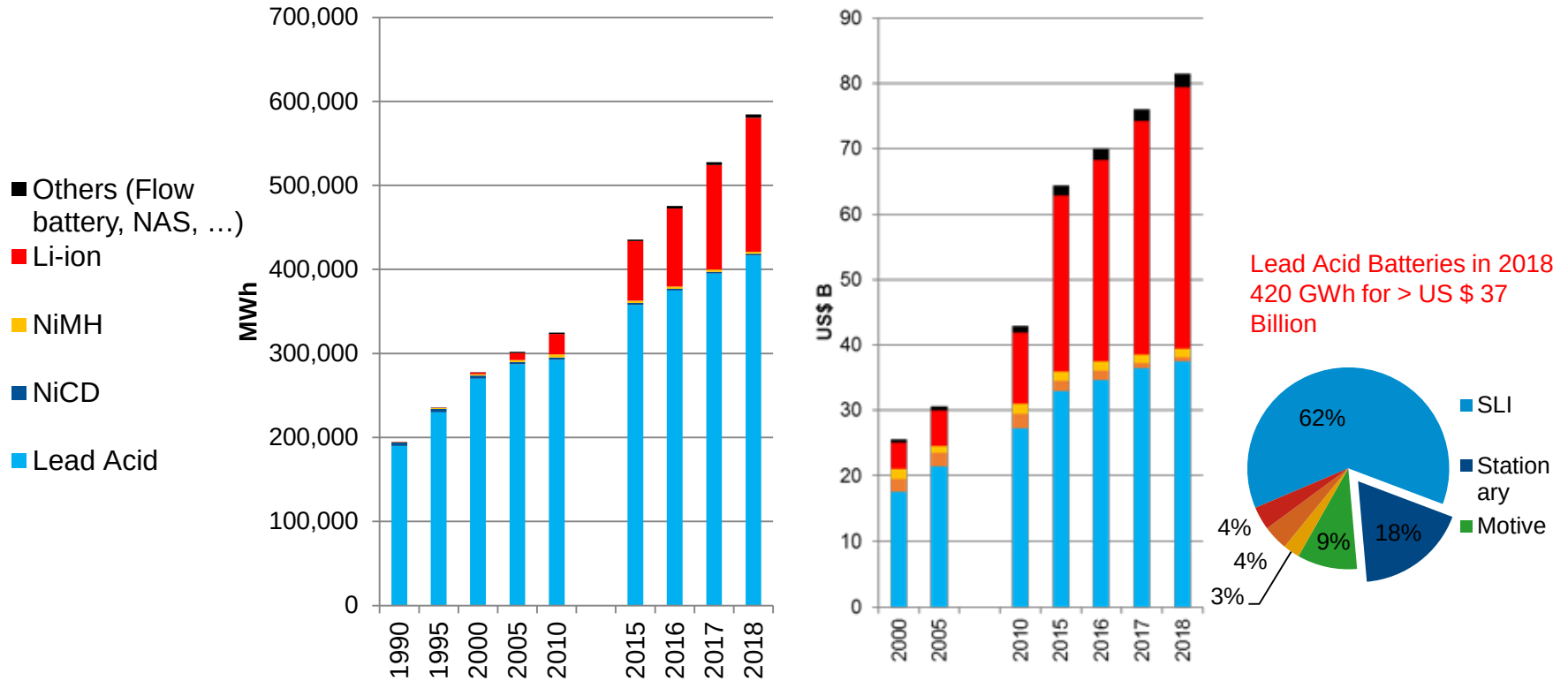


BEV ARCHITECTURE

- REDUCED COMPLEXITY
- LESS PARTS
- SIMPLER SERVICE
- BATTERY ENERGY STORAGE COST OF OWNERSHIP APPROACHING PARITY WITH PETROLEUM BASED FUELS



THE WORLDWIDE BATTERY MARKET

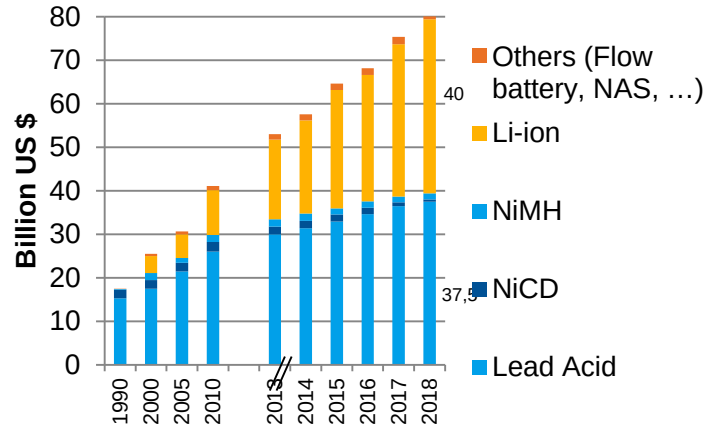


Source: AVICENNE ENERGY, 2019

THE WORLDWIDE BATTERY MARKET

80 BILLION US\$ in 2018 – Pack level¹

9% AVERAGE GROWTH PER YEAR (2010-2018)

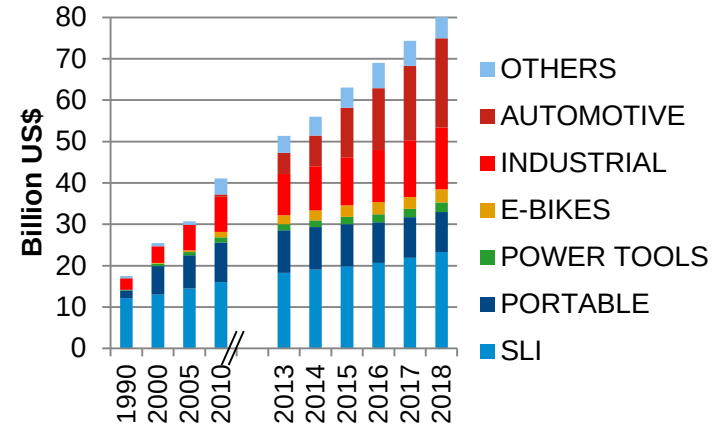


SLI: Start light and ignition batteries for cars, truck, moto, boat etc...

PORTABLE: consumer electronics (cellular, portable PCs, tablets, Camera, ...), data collection & handy terminals,

POWER Tools: power tools but also gardening tools

1- Pack: cell, cell assembly, BMS, connectors – Power electronics (DC DC converters, invertors...) not included



INDUSTRIAL

- MOTIVE: Forklift (95%), others
- STATIONARY: Telecom, UPS, Energy Storage System, Medical, Others (Emergency Lighting, Security, Railroad Signaling,, Diesel Generator Starting, Control & Switchgear,

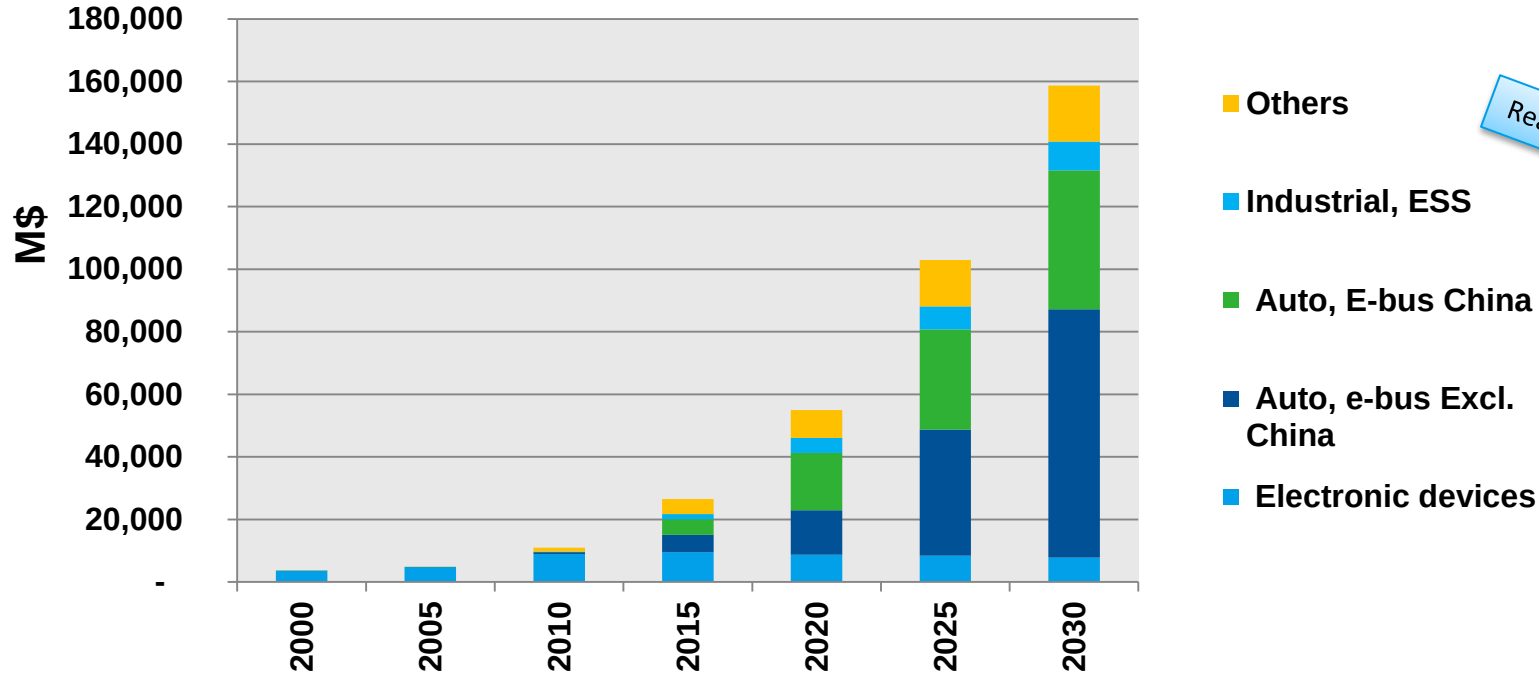
AUTOMOTIVE: HEV, P-HEV, EV

OTHERS: Medical: wheelchairs, medical carts, medical devices (surgical power tools, mobile instrumentation (x-ray, ultrasound, EKG/ECG, large oxygen concentrators, drones, Light Electric Vehicles, Hoverboard, ...

THE WORLDWIDE BATTERY MARKET

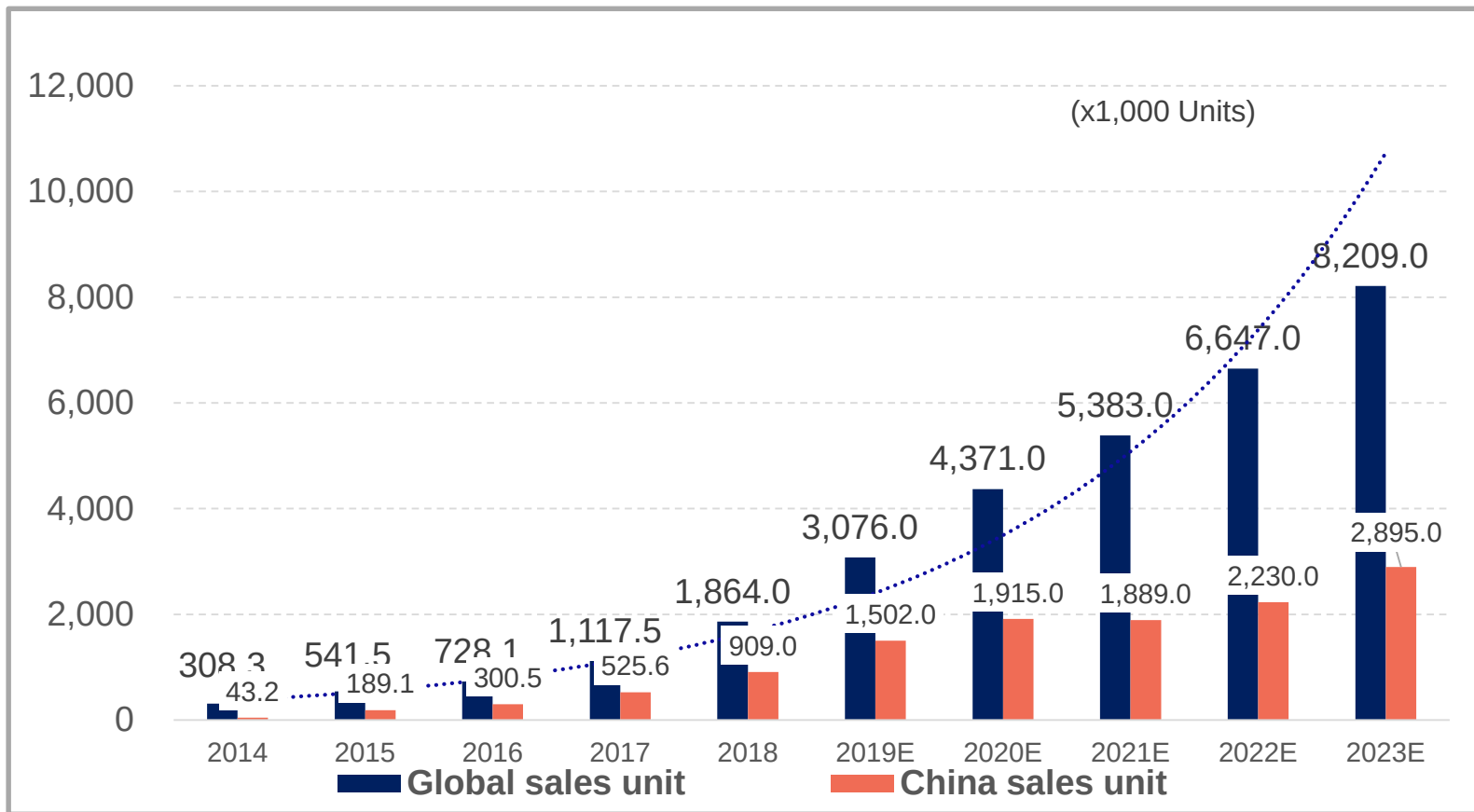
Li-ion Packs Worldwide 2000-2030

**CAGR 2015/2030: +24 % per year in Volume
Pack: +11% per year in value**



Source: AVICENNE Energy 2019

GLOBAL PASSENGER EV MARKET





DIVERSIFIED APPLICATIONS



Cell



Module



Pack

Energy Storage System



- PV & Wind Power Plant ESS
- Commercial & Industrial ESS
- Peak Shaving & Frequency Regulation ESS
- Residential ESS
- Telecom ESS

Electric Vehicle



- Battery Electric Car
- Plug-in Hybrid Car
- Range-extended Electric Car



- Battery Electric Bus & Coach
- Plug-in Hybrid Bus & Coach
- Range-extended Electric Bus & Coach



- Battery Electric Van
- Battery Electric Light Utility Truck
- Battery Electric Box Truck
- Battery Electric Self-trailer Truck
- Battery Electric Garbage Truck
- Battery Electric Refrigerated Truck

Other Applications

- Electric Boat/Ship
- Electric Forklift
- Electric Construction Machinery

.....

EARLY ADOPTERS IN CONSTRUCTION ELECTRIFICATION



ELECTRIC REGIONAL AIRCRAFT



Source clockwise from top left: 1. https://en.wikipedia.org/wiki/NASA_X-57_Maxwell, 2. <http://ampaire.com>, 3. <https://www.eviation.co/>, 4. <http://zunum.aero>,

MATERIAL HANDLING APPLICATIONS



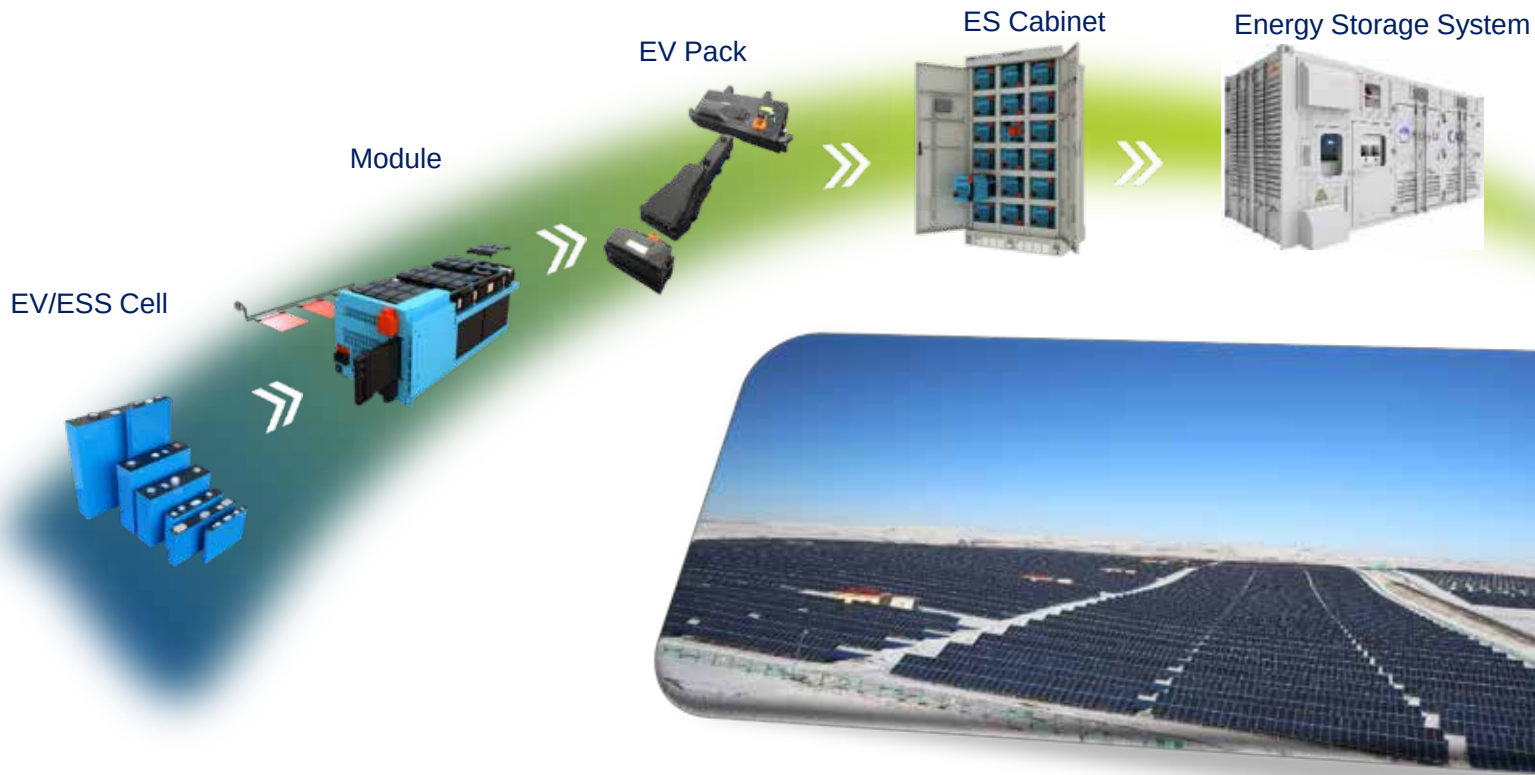
MARINE MARKET

Range from 100's of kWh to multi-MWh

- “Ellen” Largest electric ferry = 4.3 MWh
- “Yara Birkeland” – autonomous, container vessel launches in 2020 with 9 MWh battery



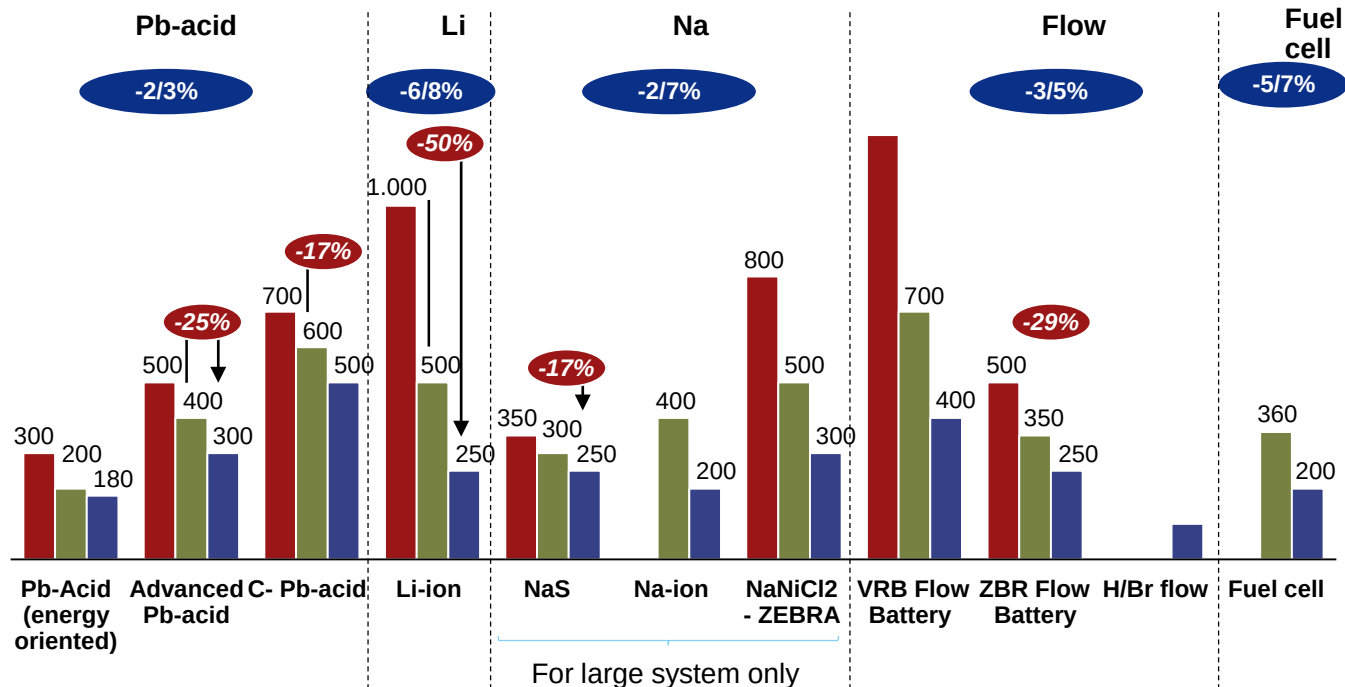
RENEWABLE ENERGY STORAGE IN ELECTRIFICATION



ESS COST IS DECREASING IN ALL CHEMISTRIES

Energy storage cost by technology
(\$/kWh, 2010-2025)

Estimates
Battery pack

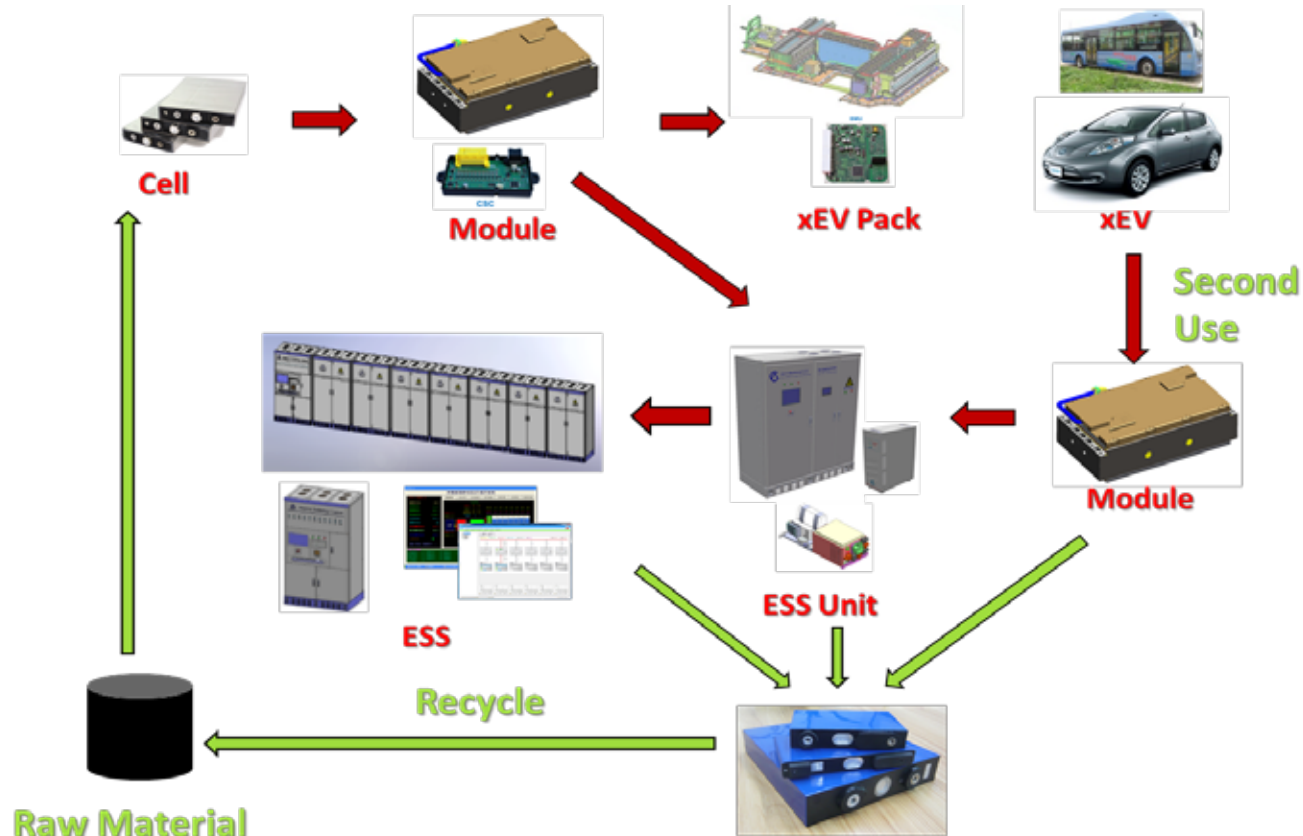


xx%

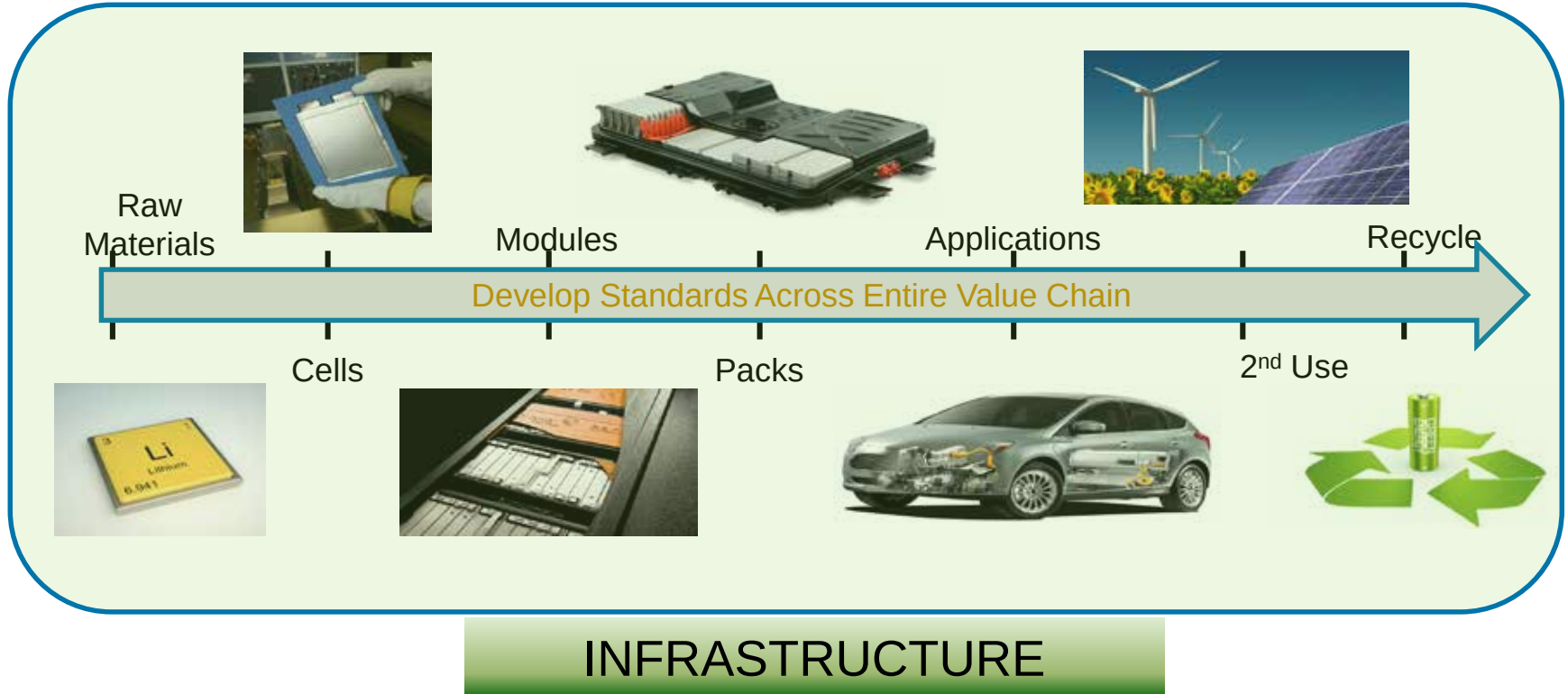
Cost reduction CAGR 2015-2025

Source: Avicenne,

TYPICAL BUSINESS MODEL



BATTERY VALUE CHAIN



BATTERY STANDARDS STEERING COMMITTEE

- Ø Started – 2009
- Ø Committee Membership
 - § >290 Individual Participants
 - § >160 Companies
 - OEM's
 - Suppliers
 - Government
 - Academia
- Ø 23 Subcommittees

NEW COMMITTEES

- 24) Electric Vehicle Battery Service
- 20) International Battery Interface

COMPONENTS & MATERIALS

- 23) Battery Systems Adhesives-Sealants-Heat Transfer Materials
- 21) Battery Thermal Management
- 19) Battery Systems Connectors
- 14) Battery Materials Testing

SUPPORT

- 4) Battery Transport
- 12) Battery Testing Equipment
- 13) Battery Terminology
- 3) Battery Labeling



LIFE MANAGEMENT

- 10) Battery Recycling
- 18) Battery Field Discharge & Disconnect
- 15) Secondary Use

PRODUCT SPECIFIC

- 2) Battery Standards Testing
- 1) Battery Safety
- 16) Start-Stop Battery
- 17) Capacitive Energy Storage
- 9) Battery Standards Future Energy Storage Systems
- 5) Battery Size Standardization
- 6) Starter Battery
- 8) Battery Standards Electronic Fuel Gauge

INDUSTRY SPECIFIC

- 11) Small Task Oriented Vehicle Batteries
- 7) Truck Batteries
- 22) Bus Battery

BATTERY STANDARDS COMMITTEE DOCUMENTS

Battery Life Assessment Testing:

J240, J2185, J2288, J2801

Sealing, Adhesives, Thermal Management:

J3073, JXXXX

Battery Testing Methodologies:

J537, J1495, J2758, J930

Battery Materials Testing:

J2983, J3021, J3042, J3159

Vibration:

J2380, J3060

Battery Recycling:

J3071, J2974, J2984

Battery Transport:

J2950

Battery Labeling:

J2936

Battery Safety:

J2929, J2464, J2946

Capacitive Energy & Start/Stop:

J3012, J3051

10 Active

15 Under

Revision

2 Stabilized

7 New in

Progress

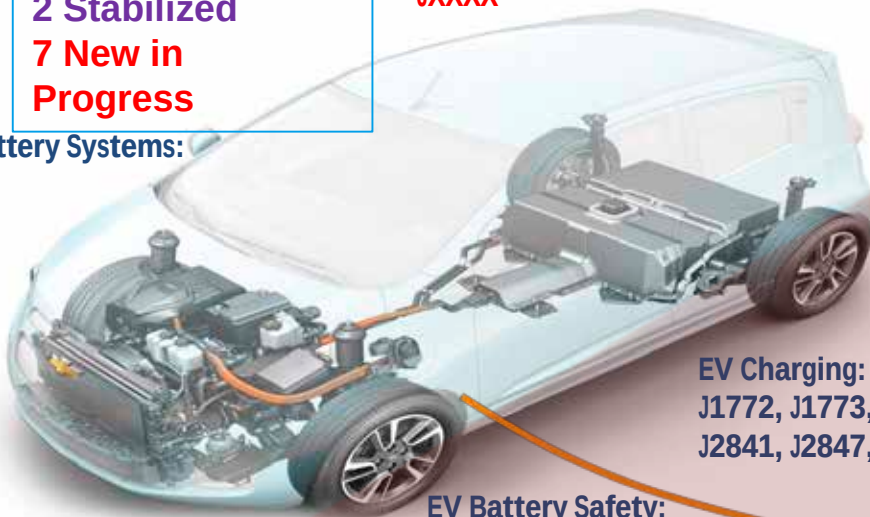
Future Battery Systems:

JXXXX

Functional

Guidelines:

J2289



Battery Testing

Equipment:

JXXXX

Battery

Performance

Rating: J1798

Battery Size,

Identification &

Packaging: J1797,

J3124, J2981

EV / Battery Fuel

Economy & Range:

J1634, J1711, J2711

EV Charging:

J1772, J1773, J2293, J2836, J2841, J2847, J2894, J2931

EV Battery Safety:

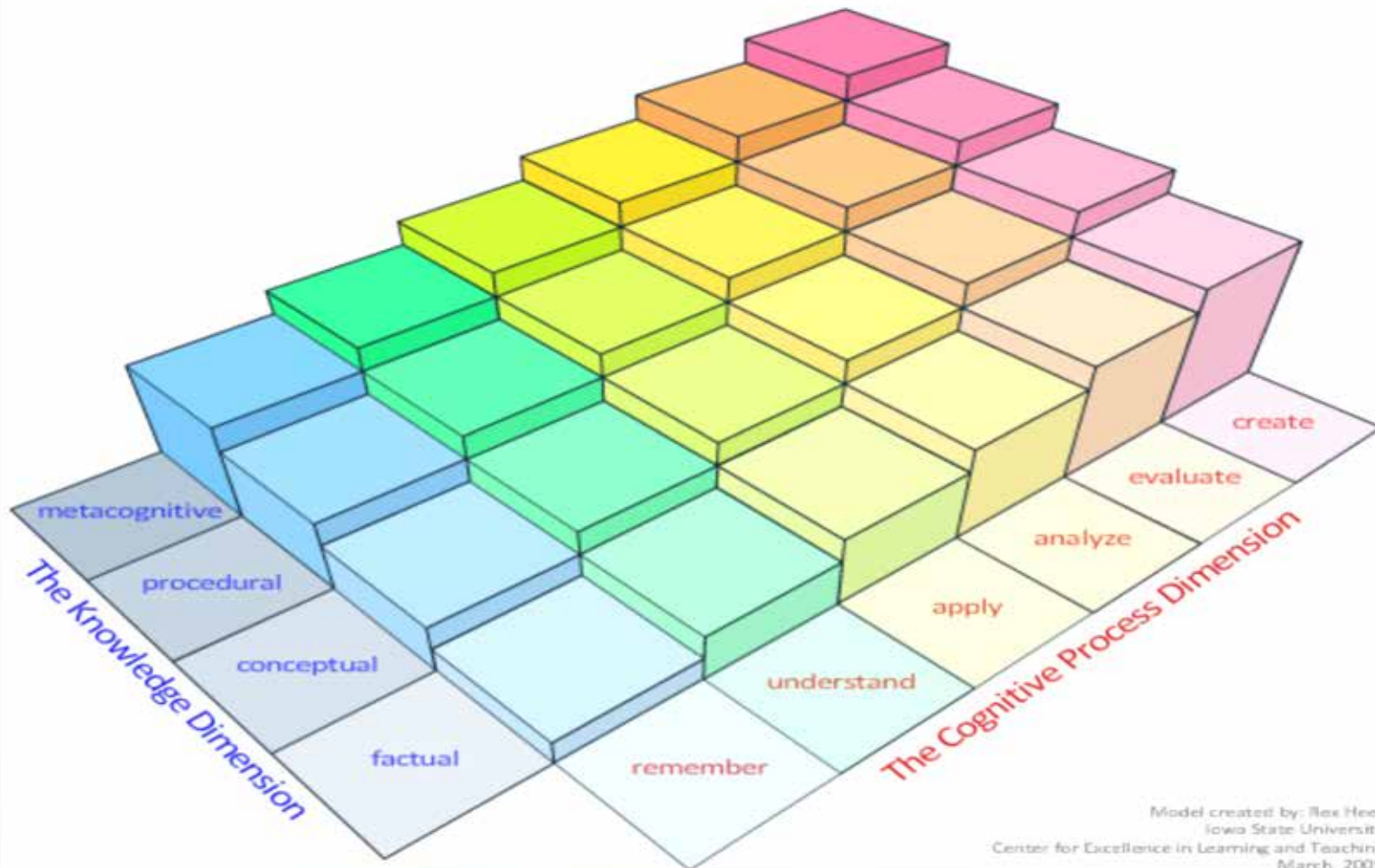
J1766, J2344, J2910, J2990

Battery Terminology:

J1715/2

EV Terminology:

J1715



BATTERY TECHNOLOGY



MAKING A BETTER WORLD FOR FUTURE GENERATIONS!