



## **Advanced Automotive Energy Storage and Delivery Report - 2011 Edition**

The 2011 edition of this report discusses the key issues currently facing the advanced automotive energy storage sector. The report looks at the evolution of energy storage technologies and analyses major advanced battery suppliers.

Furthermore, the report considers targets for ESS performance, market drivers, market development issues, strategic issues and a market forecast along with profiles of 47 key suppliers active in this industry.

### **Background to this Research**

Since the first version of this report was published in late 2009 the global automotive industry has been busy preparing a mass of new environmentally friendly models, all requiring advanced energy storage, at the same time going through the severest economic crisis in living memory. During this period battery technology has progressed, perhaps not quite as fast as many would have wanted, but significantly nonetheless and the pace of investment doesn't appear to have slowed. The vehicle and energy storage manufacturers have been focused on developing cost effective packages and addressing issues related to vehicle fitment, battery life and many commercial aspects of the market.

At the time of the original report the Nissan Leaf was still being touted as the first major volume application of Lithium-ion batteries, and the Toyota Prius the leading hybrid car, with a NiMh battery. This is still the case. New models with Lithium-ion batteries are starting to enter the market and will make up the majority of new models in the future. In total during 2010/11 over 30 new hybrid and electric vehicle models or trials have been introduced with another 50 almost certain over the next 2-3 years.

### **Table of Contents**

**Foreword 8**

**Glossary 9**

**Introduction 10**

**Methodology and scope 11**

Forecast Horizon 11

Advanced Energy Storage - definition 11

## **Executive Summary 12**

Technology Developments 16

## **Discussion of Key Issues 16**

Market Drivers 16

Short term and long term CO<sub>2</sub> goals 18

## **Evolution of Energy Storage Technologies 24**

Energy Storage Performance Requirements 24

Energy and Power Density 26

Drive Cycles 28

Cycle life 28

Technology Costs 30

Other measures 34

Safety 34

Charge-discharge efficiency 35

Charge Time 36

Thermal Operating Characteristics 37

Durability and Reliability 38

Packaging 38

Recycling and Environmental Issues 41

Self-Discharge 41

Weight 42

Batteries 43

Advanced lead acid (VRLA/AGM/VFB) 44

Other Advanced Lead Acid Batteries 46

Nickel Metal Hydride (NiMH) 46

Advanced batteries - Lithium 47

Cathodes 48

Anodes 49

Separators 50

Electrolyte 50

Cell Packaging 50

Safety Circuits 50

Packaging 50

Lithium Chemistries 52

Lithium Nickel Cobalt Aluminium – (NCA)  $\text{Li}(\text{NiCoAl})\text{O}_2$  52

Lithium Cobalt Oxide (LCO) –  $\text{LiCoO}_2$  52

Lithium Iron Phosphate (LFP) –  $\text{LiFePO}_4$  52

Lithium Magnesium Iron Phosphate (LFMP) 53

Lithium Manganese Spinel (LMO/LMS)-  $\text{LiMn}_2\text{O}_4$  53

Lithium Nickel Cobalt Manganese (NCM)-  $\text{Li}(\text{NiCoMn})\text{O}_2$  53

Lithium Iron Sulphide (LFS) –  $\text{LiFeS}$  53

Lithium Polymer (Li-Po) 54

Lithium Nickel  $\text{LiNiO}_2$  54

Lithium Titanate Oxide (LTO) -  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  54  
Lithium Metal Polymer (LMP) 55  
Lithium Vanadium Phosphate (LVP) –  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  55  
Lithium Sulphur 55  
Lithium Manganese Titanium (MNS) 56  
Other battery chemistries 57  
Metal-air 57  
Zinc-Air 58  
Lithium-Air (Li-Air) 58  
Nickel Sodium 58  
Zinc-Nickel 59

### **Major Advanced Battery Suppliers 60**

A123 61  
Advanced Lithium 62  
AESC 62  
Axeon 64  
Bolloré-Batscap 64  
Boston Power 65  
Chinese Manufacturers 65  
Dow Kokam 66  
EIG 66  
Electrovaya 66  
Enerdel 67  
European Batteries OY 67  
Evonik 67  
FZ SoNick (Formerly MesDea) 67  
GS Yuasa 68  
Hitachi EV 68  
Johnson Controls-Saft (JCS) 69  
LG Chem 71  
Lithium Technology 71  
Magna 72  
Mitsubishi Electric 72  
NEC 72  
Primearth (Formerly Panasonic EV Energy (PEVE)) 72  
Panasonic-Sanyo 74  
SB Limotive 75  
SK Energy 75  
Toshiba 76  
Valence 77  
Niche suppliers 77  
Super-Capacitors 78  
Major Super-capacitor Suppliers 81  
Maxwell 81  
Others 81  
Flywheel energy storage 81

Hydraulic energy storage 85

## **Targets for ESS performance 87**

### **Market Drivers 92**

'Green' vehicle power requirements 92  
Conventional Vehicles 92  
Micro Hybrids 92  
Mild Hybrids 94  
Full hybrids 94  
Plug-in Range Hybrids (PHEV) 94  
Extended Range Electric Vehicles (EREV) 94  
Electric Vehicles (EV) 95  
Energy Management Strategies 100

### **Market Development Issues 103**

The OEMs position 103  
BMW 105  
Chrysler 105  
Daimler 105  
FHI 106  
Fiat 106  
Ford 106  
General Motors 107  
Honda 108  
Hyundai 108  
Mitsubishi 108  
PSA Peugeot Citroen 110  
Renault-Nissan 111  
Tata 113  
Toyota 113  
Volkswagen Group 113  
Volvo 114  
Other manufacturers 114  
Chinese Manufacturers 114  
The System Suppliers position 116  
The Cost – Benefit Relationship 117  
Range 119  
Taxes and incentives 120  
Penalty avoidance may help the economic case 122  
Charging 123  
Charging Infrastructure Costs 123  
Other System Requirements 124

### **Market Forecast 124**

Vehicle Segmentation and Market Demand Patterns on Adoption Rates for Advanced Power Storages 128

**Strategic Issues 128**

Risks Sharing 129

Investment Requirements and R&D Costs 132

Production Investment 133

Supply Limitations 135

Standardisation 136

Intellectual Property Rights 137

Warranty 137

Material Cost Fluctuation 137

Disruptive Technology 137

Supply Chain Development 138

Risk and Liability 138

Safety 139

The Value Chain 139

Rationalisation and Consolidation 140

Appendix 1 – CURRENT AVAILABILITY OF HEV, BEV SYSTEMS IN EUROPE, NORTH AMERICA, JAPAN AND KOREA 2011 141

Appendix 2 - Technology Road map 143

Appendix 3 - Announced national EV and PHEV sales targets 2009 144

**Company Profiles**

A123 Systems

Advanced Battery Technologies

AESC

Aleees

Altair Nanotechnologies

Amberjac

Amperex

Atraverda

Axeon

Axion Power

Blue Energy Japan

Bolloré

Boston Power

BYD

Cobasys

Continental

Deutsche Accumotive

Dow Kokam

E-oneMoli

EIG

Electrovaya

ENAX

Ener1

Energy Conversion Devices  
Envia  
European Batteries  
Exide Technologies  
FZ SoNick  
GS Yuasa  
Hitachi  
Johnson Controls  
K2 Energy  
LG Chem  
Li-Tec  
Lithium Energy Japan  
Lithium Technology Corporation  
Maxwell Technologies  
NEC  
NessCap  
Nichicon  
Panasonic  
Primearth EV Energy  
Saft  
SB LiMotive  
SK Innovation  
Valence  
Winston Battery

## **List of Figures**

Figure 1 Scenario for 2015 EV HEV Market Penetration 14  
Figure 2 Energy Storage Market Forecast 15  
Figure 3 AEA 'Blue Map' Scenario 16  
Figure 4: Major industry drivers and stakeholders 18  
Figure 5: Global Short Term CO<sub>2</sub> and Fuel Economy targets 20  
Figure 6: Tank/Well to wheels analysis (TTW/WTW) 20  
Figure 7: Well to Wheels CO<sub>2</sub> on the Japanese 10-15 mode cycle (Total CO<sub>2</sub> per km driving) 21  
Figure 8: Energy requirement kWh per km for various test cycles 21  
Figure 9: Overall efficiency of conventional powertrain vs electric 22  
Figure 10: Fuel specific and gravimetric energy density 23  
Figure 11: Contribution of Alternative Technologies to meet EU CO<sub>2</sub> targets 2015/2020 (%) 24  
Figure 12: Simple comparison of ESS 25  
Figure 13: Summary of Alternative ESS (1 – Very Poor 10 Very Good) 26  
Figure 14: Ragone chart 26  
Figure 15: Detailed Ragone chart 27  
Figure 16: Trends in Energy Density of Batteries (Wh/kg) (Based on raw material specific energy density) 29  
Figure 17: Number of cycles needed by application 30  
Figure: 18: Cycles by chemistry (Deep Discharge) 30  
Figure 19: Forecast energy density and estimated costs (pack) per kWh for Lithium-ion 33  
Figure 20: Battery Cell Cost (Lithium-Ion) 33

Figure 21: Battery Cell Cost Reduction (Lithium-ion) 34  
Figure 22: Potential Evolution of Battery Costs per kWh (Pack) 35  
Figure 23: Charge-discharge energy efficiency % of rechargeable batteries 36  
Figure 24: Potential Charge and Discharge Rates 37  
Figure 25: ESS Operating Temperatures 39  
Figure 26: Toyota Prius III Battery Packaging (NiMH HEV) 41  
Figure 27: GM Volt Battery Pack (Lithium-ion EREV) 41  
Figure 28: Nissan Leaf Battery Pack (Lithium-ion - EV) 41  
Figure 29: Comparison of Alternative ESS Self Discharge Rates 43  
Figure 30: Battery Weight for current applications 44  
Figure 31: EFB battery components 46  
Figure 32: VRLA battery components 46  
Figure 33 Summary of Japanese battery technology developments 2009 49  
Figure 34: Lithium-ion Battery Construction Cylindrical/Spiral Design 52  
Figure 35: Lithium-ion Battery Construction Prismatic Design 52  
Figure 36 Theoretical metal air battery energy densities. 58  
Figure 37: Major Battery Suppliers OEM Relationships 61  
Figure 38 Major Battery Suppliers Chemistries 62  
Figure 39: A123 Cell Performance Improvement 63  
Figure 40 Characteristics of the L3-10 and L3-3 Cells 64  
Figure 41: Batscap LMP Battery Characteristics 65  
Figure 42 Hitachi cells Specifications 70  
Figure 43: Johnson Controls Saft Battery Specifications 71  
Figure 44 Lithium Technology's Battery Chemistry comparison 73  
Figure 45: PEVE Hybrid Vehicle NiMH modules 74  
Figure 46: PEVE Hybrid Vehicle NiMH modules 74  
Figure 47 Panasonic HEV Cells 76  
Figure 48 SK Energy Cells 77  
Figure 49 SK PHEV Packs 77  
Figure 50 Toshiba cell specification 78  
Figure 51: Super-capacitor components 80  
Figure 52: Super-capacitor applications requirements 80  
Figure 53: Typical Super-capacitor Capacity/Voltage configurations 82  
Figure 54 Flybrid's Flywheel 84  
Figure 55: Eaton Heavy Duty Hydraulic Launch Assist 88  
Figure 56: METI & NEDO Battery R&D Targets 89  
Figure 57: EUCAR Battery Targets 89  
Figure 58: USABC Goals for Advanced Batteries for PHEVs 90  
Figure 59: USABC Goals for Advanced Batteries for HEVs 91  
Figure 60: Examples of vehicles with stop-start 2011 in Europe 94  
Figure 61 Energy Storage for Current and Near Future Hybrids and EVs 97  
Figure 62: Functions of Various Drivelines 98  
Figure 63: Energy Storage for Current and Near Future Hybrids and EVs 2009-2010 models 99  
Figure 64: Energy Storage for Current and Near Future Hybrids and EVs 2010- models 100  
Figure 65 Energy Management Strategies by vehicle type 101  
Figure 66: Energy Management for Driveline Types 102  
Figure 67: OEM ESS relationships and programmes 104  
Figure 68: Current and Future Micro Hybrids, HEV, PHEV, BEV 2008-2010/11 105

Figure 69: Miev Cell Specifications 110  
Figure 70 Maxwell Super-capacitors Supplied to PSA 112  
Figure 71: Supplier Battery Relationships 117  
Figure 72: Cost vs savings 2010 Europe (Based on 5 Years (€)) 119  
Figure 73: Cost vs savings 2010 US (Based on 5 Years (€)) 119  
Figure 74: Cost-benefit estimates EU 2025 Over 5 Years (€) 120  
Figure 75: Distances travelled by region 121  
Figure 76: Incentives for Hybrids and EV purchase 2011 121  
Figure 77: Impact of Incentives on Economics 123  
Figure 78: European CO2 penalties 123  
Figure 79: Charging time vs power (Nissan) 125  
Figure 80 Market penetration scenarios 2015 127  
Figure 81: Market penetration scenarios 2025 128  
Figure 82: Energy Storage System Market Forecast 129  
Figure 83: Examples of Battery Alliances (Non-Exhaustive) 132  
Figure 84: Selected Battery investments 2008-2012 133  
Figure 85: Government Funding and Support Programmes 135  
Figure 86: Risks for OEMs 136  
Figure 87 Cobalt Supply Forecast 137  
Figure 88 Lithium Supply Forecast 137  
Figure 89: Value chain 140  
Figure 90: Key model availability in Europe, North America, Japan and Korea 142  
Figure 91: Power Storage Technology Roadmap 144  
Figure 92: Announced national EV and PHEV sales targets 2009 145