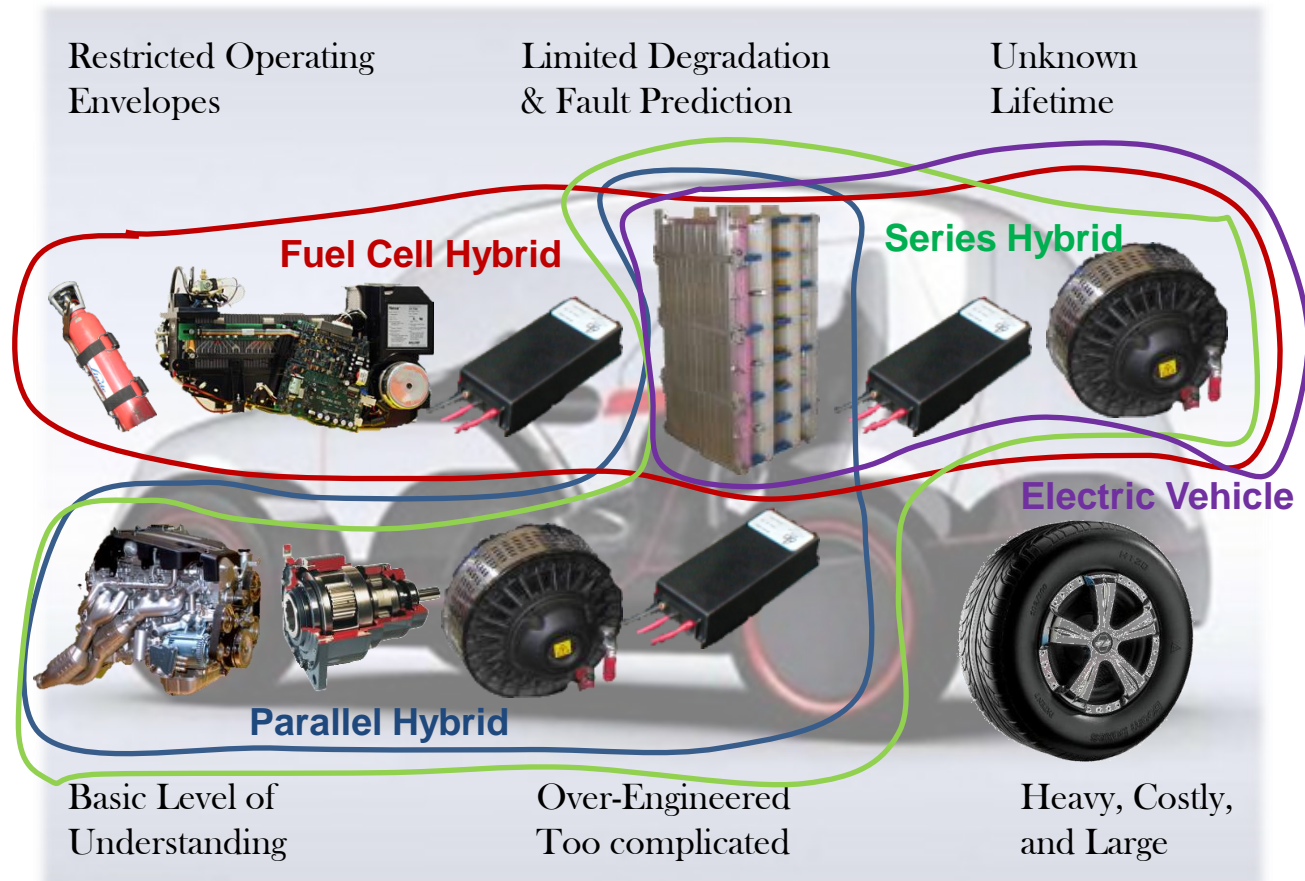


EPSRC Project “Developing
FUTURE Vehicles
(Fundamental Understanding
of Technologies for Ultra
Reduced Emission Vehicles)”

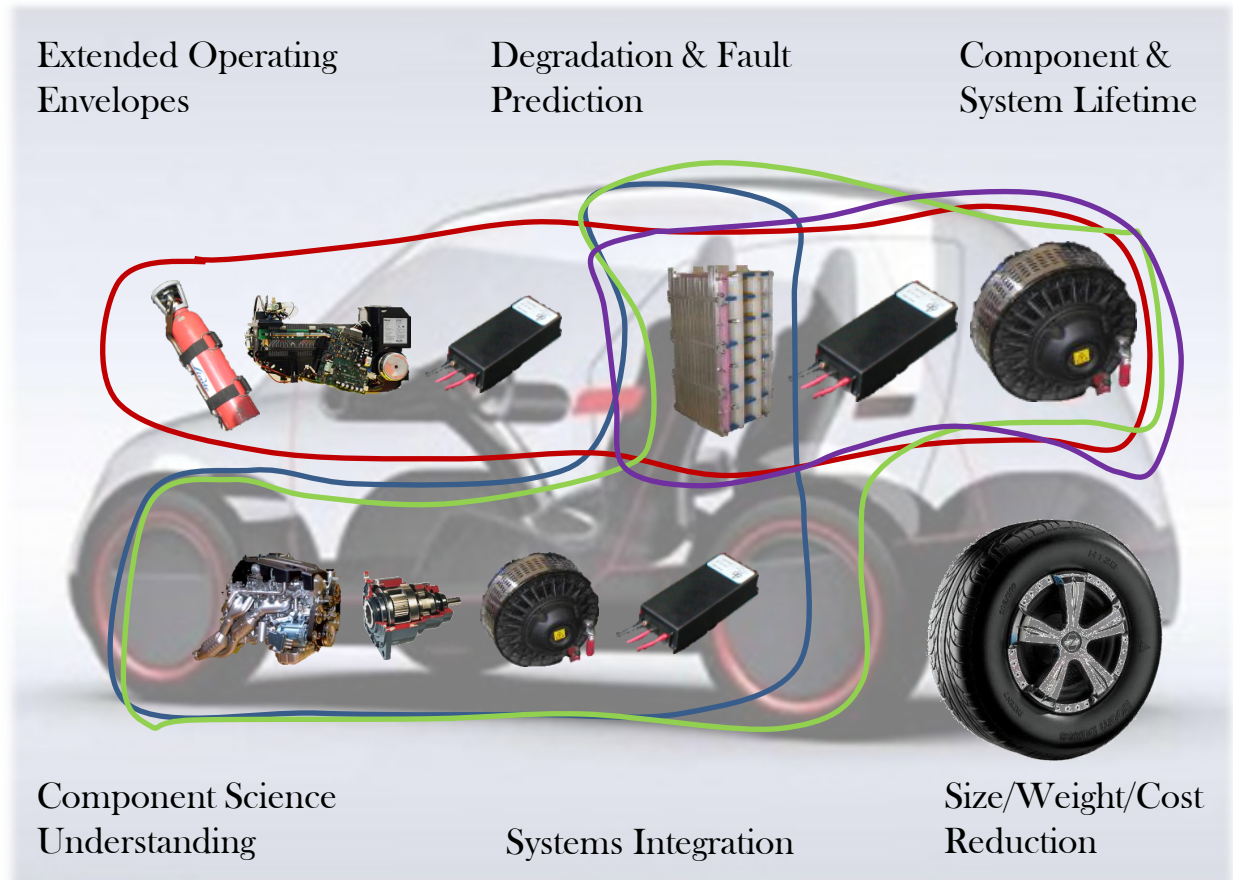
Developing FUTURE Vehicles

- Some of the challenges
- Ultra Low Carbon Vehicles are coming
- Britain wants to be a leader.
- The knowledge is not all there
- Coherent programme of inter-related projects
- Significant step change in knowledge and understanding
- Held together by systems integration



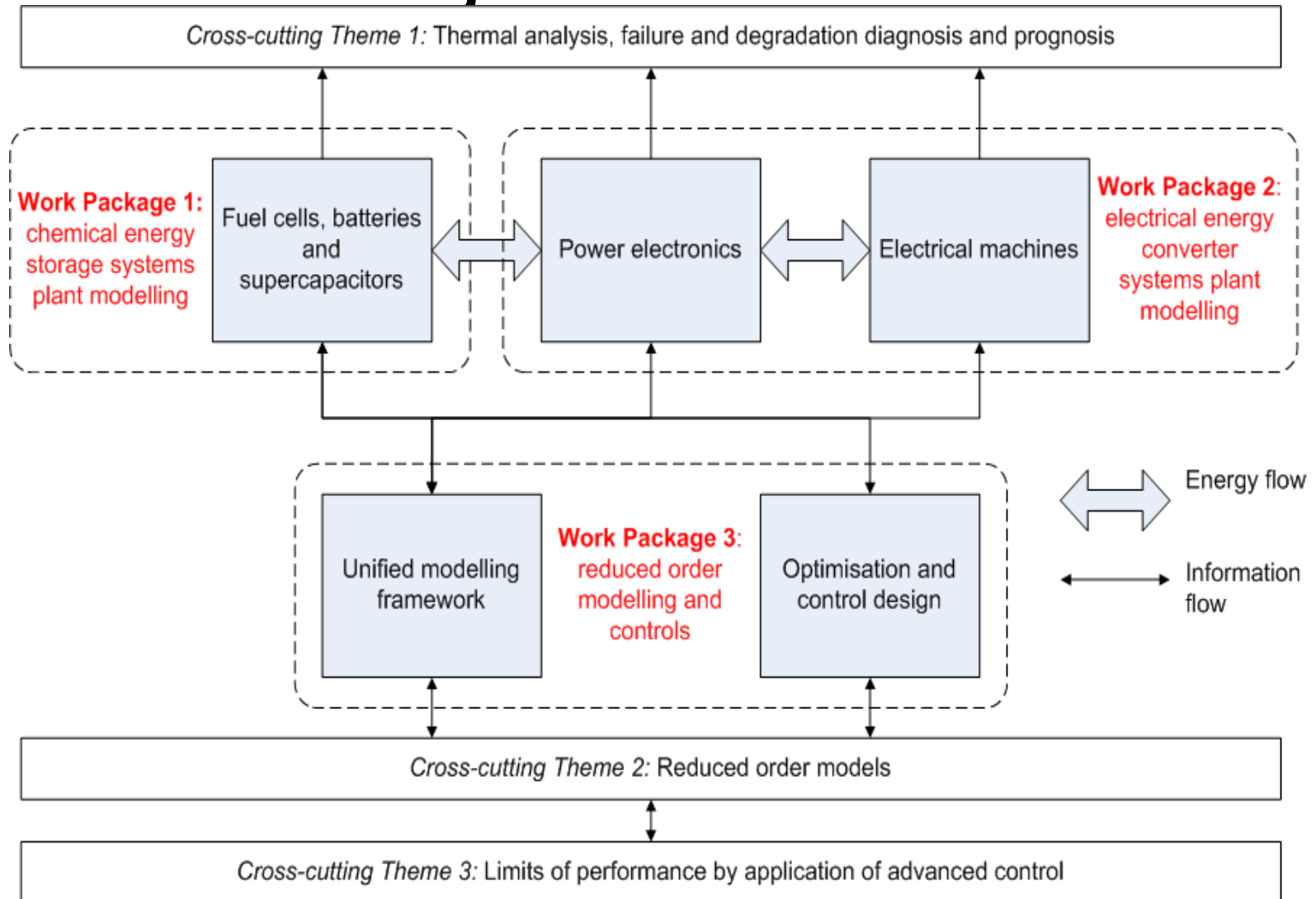
Impacts & Outputs

- **Lexicon of information**
 - To include...
- **Library models**
 - Control & reduced order
 - Detailed high fidelity
- **Unified open source approach/methodology**
 - Developing models
 - Parameterisation (exp)
- **Better understanding components**
 - Under extremes
 - Fault conditions
 - Lifetime/Degradation
- **Emergent behaviour**
 - Interactions
 - Systems optimisation



Unique to consortium, added value of interdisciplinary approach.
High impact, will aim to be a reference for systems engineers .

Project Structure



Objectives (1)

- Obtain an in-depth and better understanding of the Science behind:
 - Batteries
 - Supercapacitors
 - Fuel Cells
 - Power Electronics
 - Electric machines and electric machine drives

Objectives (2)

- Provide a systematic and unified approach to:
 - Failure modes
 - Prognostic indicators
 - Especially at the limits of performance
- Produce a “codified lexicon” of component models, including thermal and aging models

Objectives (3)

- Generate reduced order models of the components in Objectives (1)
- Demonstrate advanced control methodologies
- Diagnostics and Prognostics
- Failure modes and lifetime prediction
- HIL demonstrations

What is outside the scope?

- Vehicles – we will not be producing whole vehicles
- IC engines are specifically excluded – there are many existing projects in this area
- Specific configurations – this project is in TRLs 1,2,3

Project Partners

Academia

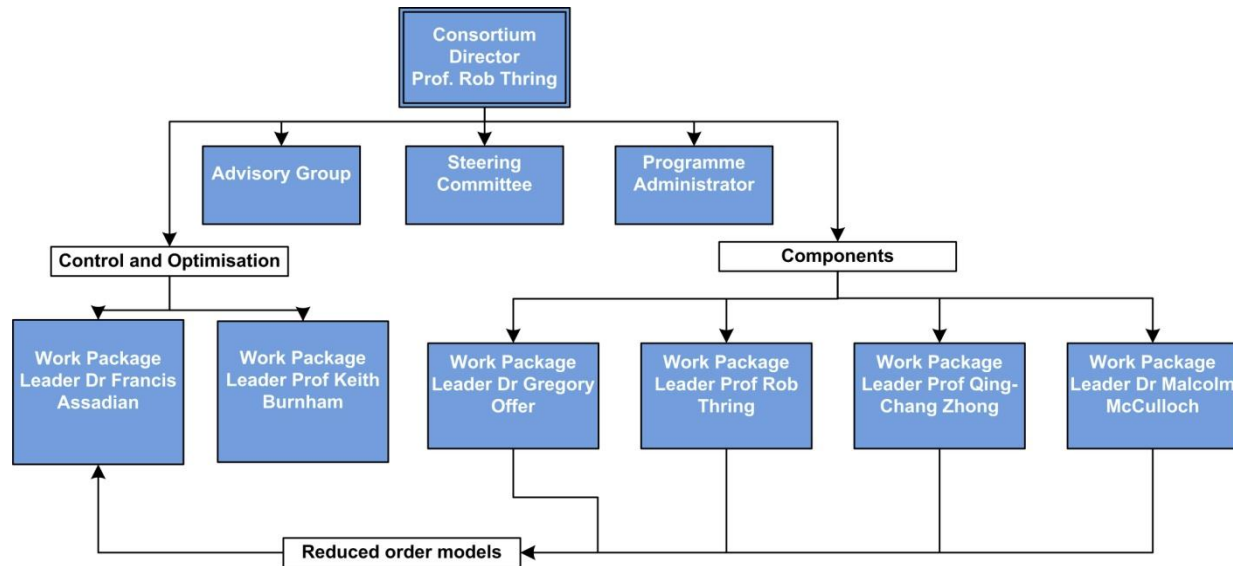
- Loughborough University (Lead)
- Imperial College, London
- University of Oxford
- Cranfield University
- Coventry University
- Sheffield University

Industry

- AVL Powertrain UK Ltd
- Cenex
- Dennis Eagle Ltd
- Intelligent Energy Ltd
- MIRA Ltd
- SAIC Motor UK Ltd
- TUV Nord Mobilitat
- Jaguar Land Rover
- Lotus
- Axeon
- Vector Fields, Cobham Tech Serv
- Hirst Magnetic Instruments
- Nidec SR Drives

Project Funded, thanks to EPSRC

- £3.1M
- Start date; 1st December, 2011
- Duration: 4½ years



Management Strategy

Outputs so far...

- Journal papers:

Journals				
No.	Title	Authors	Journal	Publication Date (done or planned)
1	Module Design and Fault Diagnosis in Electric Vehicle Batteries	Offer, G. J., Yufit, V., Howey, D. A., Wu, B., Brandon, N. P.	Journal of Power Sources, Volume 206, May 2012, pp.383-392. DOI:10.1016/j.jpowsour.2012.01.087. ISSN: 0378-7753	May-12
2	A Novel Method for the Parameterization of a Li-Ion Cell Model for EV/HEV Control Applications	Antaloe, C. AVL Powertrain UK Ltd., Basildon, UK, Marco, J., Assadian, F.	Vehicular Technology, IEEE Transactions on (Volume:61, Issue:9) Nov 2012, pp. 3881-3982 DOI: 10.1109/TVT.2012.2212474. ISSN 0018-9545	Nov-12
3	An Optimization Framework for Comparative Analysis of Multiple Vehicle Powertrains.	Mohan, G., Assadian, F., Longo, S	Energies 2013, 6, p5507-5537. DOI:10.3390/en6105507	Oct-13
4	Coupled Thermal–electrochemical Modelling of Uneven Heat Generation in Lithium-ion Battery Packs	Wu, B., Yufit, V., Marinescu, M., Offer, G. J., Martinez-Botas, R., F., Brandon, N., P.	Journal of Power Sources, Volume 243, December 2013, pp. 544-554. DOI:10.1016/j.jpowsour.2013.05.164. ISSN: 0378-7753.	Dec-13
5	The Effect of Thermal Gradients on the Performance of Lithium-ion Batteries	Troxler, Y., Wu, B., Marinescu, M., Yufit, V., Patel, Y., Marquis, A. J., Brandon, N.P., Offer G. J.	Journal of Power Sources, Volume 247, February 2014 , pp.1018-1025. DOI:10.1016/j.jpowsour.2013.06.084. ISSN: 0378-7753	Feb-14
6	Mechatronics in Sustainable Mobility: Two Electric Vehicle Applications	Longo, S., Auger, DJ & Assadian, F	The Journal of Sustainable Mobility, Volume 1, Number 1, May 2014, pp. 19-36(18) DOI: http://dx.doi.org/10.9774/GLEAF.2350.2014.00004	May-14
7	Battery Internal Temperature Estimation by Combined Impedance and Surface Temperature Measurement	Richardson RR, Ireland PT, Howey DA	Journal of Power Sources, Volume 265, 1 November 2014, Pages 254–261 DOI:10.1016/j.jpowsour.2014.04.129	Nov-14
8	Impact of Battery Ageing on an Electric Vehicle Powertrain Optimisation	Auger, Daniel J. Maxime, F. Groff Mohan, Ganesh Longo, Stefano Assadian, Francis	Journal of Sustainable Development of Energy, Water and Environment Systems Volume 2, Issue 4, pp 350-361. DOI: http://dx.doi.org/10.13044/j.sdewes.2014.02.0028	Dec-14
9	Nonlinear filtering techniques comparison for battery state estimation	Papazoglou, Aspasia Longo, Stefano Auger, Daniel Assadian, Francis	Journal of Sustainable Development of Energy, Water and Environment Systems Volume 2, Issue 3, pp 259-269 DOI:http://dx.doi.org/10.13044/j.sdewes.2014.02.0021	2014
10	Minimizing degradation of motors in electric vehicles using optimal control	Lilantha Samaranyake, Stefano Longo		Under preparation
11	Model predictive control for degradation control of electric machines in electric vehicles	Lilantha Samaranyake, Stefano Longo		

Outputs so far...

- Conference papers

Conference #	No.	Title	Authors	Conference	Publication Date (done or planned)
		1 A Comparison Of Real World Measured Performance Of Various Energy And Best-In-Class Electric, Hybrid And Conventional Powertrain Types For Light Duty Vehicles In Europe: Battery Electric Vehicles, Hydrogen Fuel Cells And Biofuels: Which Will Be The Winner?	Howey, D., and Offer, G. J.	World Electric Vehicle Summit 2012, 12-14 June, Copenhagen Denmark	Jun-12
		2 Influence of Cost Function on EV Powertrain Sizing	Mohan, G., Assadian, F. and Marco, J.	Powertrain Modelling and Control 2012, September 4, Bradford UK	Sep-12
		3 Reduction of DC-Bus Voltage Ripples and Capacitors for Single-Phase PWM-Controlled Rectifiers	Zhong, Q.-C., Ming, W.-L., Cao, X. and Krstic, M.	IECON 2012 - 38th Annual Conf. IEEE Industrial Electronics Society, Oct 25-28, Montreal, QC, pp. 708-713. DOI: 10.1109/IECON.2012.6388665, ISSN:1553-572X	Oct-12
		4 The Effect of Temperature Gradients on the Performance of Li-Ion Batteries	Marinescu, M., Tzolek, Y., Wu, B., Yufit, V., Patel, Y., Marquis, A. J., Brandon, N. P., Offer, G. J.	10th Symposium for Fuel Cell and Battery Modelling and Experimental Validation 2013 (ModVal 2013), March 19-20, Bad Boll/Suttgart, Germany	Mar-13
		5 Improving the Power Quality of Traction Power Systems with a Single-Feeding Wire	Zhong, Q.-C., Ming, W.-L., and Krstic, M.	IEEE Green Technologies Conference, 2013 April 4-5, pp. 233-238. DOI:10.1109/GreenTech.2013.43. ISSN 2166-646X	Apr-13
		6 System Thermal and Water Balance in an Evaporatively Cooled PEM Fuel Cell Vehicle	Fly, A. and Thring, R.H.	IMEchE conference on Vehicle Thermal Management Systems 2013 (VTMS11), May 15-16, Coventry Technocentre, UK, pp.267 - 277. ISBN: 978-0-85709-472-8 DOI:10.1533/9780857094728.6.267	May-13
		7 Electric Vehicles	Gregory Offer	Renault/Nissan Alliance Conference 2013, June 25, Brussels	Jun-13
		8 The Effect of Temperature Gradients on the Performance of Li-Ion Batteries	Marinescu, M., Tzolek, Y., Wu, B., Yufit, V., Patel, Y., Marquis, A. J., Brandon, N. P., Offer, G. J.	6th International Conference on Polymer Batteries and Fuel Cells 2013 (PBFC 2013), June 3-7, Ulm, Germany	Jun-13
		9 Future of Transport in 20 Years Time	Gregory Offer	Tech Foresight Conference 2013, July 5, Imperial College London	Jul-13
		10 An Applied Laboratory Characterisation Approach for Electric Machine Insulation	Kavanagh, K., Howey, D., McCulloch, M.	9th IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives 2013 (SDEMPED13) Valencia, Spain, August 27-30, pp.391-395, DOI: 10.1109/SDEMPED.2013.6646745	Aug-13
		11 The Impact of Battery Ageing on an Electric Vehicle Powertrain Optimisation	Auger DJ, Groll MF, Mohan G, Longo S & Assadian F	The 8th Conference on Sustainable Development of Energy, Water and Environment Systems 2013 (SDEWES 2013), September 22-27, Dubrovnik, Croatia (SDEWES2013.088)	Sep-13
		12 Computational Aspects of Estimation Algorithms for Battery-Management Systems	Papazoglou, A, Longo S, Auger DJ & Assadian F	The 8th Conference on Sustainable Development of Energy, Water and Environment Systems 2013 (SDEWES 2013), September 22-27, Dubrovnik, Croatia (SDEWES2013.088)	Sep-13
		13 Investigation of Model Order Reduction techniques: A Supercapacitor case study	Aizad, T., Sumislawska, M., Maganga, O., Agbaje, O., Phillip, N., Burnham, K. J.	International Conference on Systems Science 2013, September 10-12, Wroclaw, Poland. DOI:10.1007/978-3-319-01857-7_76	Sep-13
		14 Comparative Analysis of Forward-Facing Models vs Backward-Facing Models in Powertrain Component Sizing	Mohan, G., Assadian, F. and Longo, S.	IEE 4th Hybrid and Electric Vehicles Conference 2013 (HEVC13), November 6-7, London. DOI:10.1049/cp.2013.1880	Nov-13
		15 Reduction of High Fidelity Lithium-Ion Battery Model Via Data-driven System Identification	Sumislawska, M., Phillip, N., Marinescu, M. M., Burnham, K. J.	IEE 4th Hybrid and Electric Vehicles Conference 2013 (HEVC13), November 6-7, London. DOI:10.1049/cp.2013.1887	Nov-13
		16 Estimation of Temperature Dependent Equivalent Circuit Parameters for Traction-based Electric Machines	Agbaje, O., Kavanagh, D. F., Sumislawska, M., Howey, D. A., McCulloch, M. D., Burnham, K. J.	IEE 4th Hybrid and Electric Vehicles Conference 2013 (HEVC13), November 6-7, London. DOI:10.1049/cp.2013.1888	Nov-13
		17 The Effect of Thermal Gradients on the Performance of Battery Packs in Automotive Applications	M M Marinescu, M., Wu, B., Yufit, V., Offer, G. J., Von Sbrink, M. T.	IEE 4th Hybrid and Electric Vehicles Conference 2013 (HEVC13), November 6-7, London. DOI:10.1049/cp.2013.1888	Nov-13

Outputs so far...

- Conference papers, continued:

18	FUTURE Powertrain	Howey, D., Marinescu, M., Martinez-Botas, R., F. Offer, G. J. Assadian, F.	Future Powertrain Conference (FPC2014), February 19-20, National Motorcycle Museum, Solihull	Feb-14
19	Next-Generation Smart Grids: Completely Autonomous Power Systems (CAPS)	Zhong, Q-C.	The Sixth Annual IEEE Green Technologies Conference (IEEE GREENTECH 2014), 3-4 April 2014, Texas	Apr-14
20	Analysis and Control of Ripple Eliminators in DC Systems	Cao, X, Zhong, Q-C, Ming W-L	The Sixth Annual IEEE Green Technologies Conference (IEEE GREENTECH 2014), 3-4 April 2014, Texas. DOI:10.1109/GREENTECH.2014.23	Apr-14
21	Comparative Analysis of Multiple Powertrain Architectures based on a Novel Optimization Framework	Mohan, G., Assadian, A., and Longo, S	SAE World Congress 2014, SAE Technical Paper 2014-01-1105, 2014. DOI:10.4271/2014-01-1105	Apr-14
22	Temperature Regulation of an Evaporatively Cooled PEMFC stack	Fly, A. and Thring, R.H.	20th World Hydrogen Energy Conference (WHEC 2014), Gwangju, Korea	Jun-14
23	Compact Bidirectional DC-DC Converters with Two Input Sources	Cai J., Zhong, Q-C.	Power Electronics for Distributed Generation Systems (PEDG), 2014 IEEE 5th International Symposium on, 24-27 June 2014, Galway, Ireland. DOI:10.1109/PEDG.2014.6878668	Jun-14
24	A Gamma-Z Source Based Hybrid Power Converter for Battery-Fuel Cell Hybrid Electric Vehicle	Cai J., Zhong, Q-C., Stone, D	CONTROL 2014: UKACC International Conference on Control (Control 2014) 9-11 July 2014, Loughborough University DOI:10.1109/CONTROL.2014.6915176	Jul-14
25	Equivalent Circuit Model Estimation of Induction Machines under Elevated Temperature Conditions	Agbaje, O., Sumislawska, M., Kavanagh, D. F., Burnham, K. J	CONTROL 2014: UKACC International Conference on Control (Control 2014) 9-11 July 2014, Loughborough University DOI:10.1109/CONTROL.2014.6915176	Jul-14
26	Condensation of Water From Saturated Air in a Compact Plate Condenser With Application to Water balance in Proton Exchange Membrane Fuel Cell Systems	Fly, A. and Thring, R.H.	15th International heat transfer conference (IHTC-15), Kyoto, Japan ISBN:978-1-56700-421-2	Aug-14
27	A Comparative Study of Model-Based and Data-Based Model Order Reduction Techniques for Nonlinear Systems	Aizad, T., Sumislawska, M., Maganga, O., Burnham, K. J	23rd International Conference on Systems Engineering (ICSEng 2014), August 2014, University of Nevada, Las Vegas, USA DOI:10.1007/978-3-319-08422-0_12	Aug-14
28	An Asymmetrical Gamma-Z source Hybrid Power Converter with Space Vector Pulse-width Modulation	Cai J., Zhong, Q-C., Stone, D, Ming, WL.	The Energy Conversion Congress and Exposition (ECCE) 2014, September 14 - 18, Pittsburgh, PA, USA.	Sep-14
29	A Compact Power Converter for Hybrid Energy Systems	Cai J., Zhong, Q-C., Stone, D	IECON 2014. The 40th Annual Conference of the IEEE Industrial Electronics Society, Sheraton Hotel Dallas - Dallas, TX - USA. October 29 - November 1, 2014	Nov-14
30	Sensors-models trade-offs in battery state estimation	Feig, P., Billitteri, F., Longo, S., Auger, D. J.	5th Hybrid and Electric Vehicle Conference	Nov-14
31	Energy Saving Driver Model using Fuzzy Logic Control for Autonomous Electric Vehicles	L.Samaranayake, A. O. Al-Jazeera, S. Longo, D. Auger	Accepted to IEEE International Electric Vehicles Conference (IEVC) 2014	Dec-14
32	Differential thermal voltammetry for tracking of degradation in lithium-ion batteries	Billy Wu, Vladimir Yufit, Yu Merla, Ricardo F. Martinez-Botas, Nigel P. Brandon and Gregory J. Offer		Under preparation
33	Real-time degradation index for motors in electric vehicles	Lilantha Samaranayake, Stefano Longo		Under preparation
34	Reduction of battery degradation using battery-supercapacitor hybrid control in electric vehicles	Lilantha Samaranayake, Stefano Longo		Under preparation

Outputs so far...

- Workshops/presentations:

No.	Title	Authors	Workshops/Presentations	Publication Date (done or planned)
1	Developing FUTURE Vehicles Project	Thring, R	Atlanta Workshop, March 2012	Mar-12
2	Resource 2012	McCulloch, M and Howey, D	Resource 2012, 12-13 July, Oxford University	Jul-12
3	Developing FUTURE Vehicles Project	Thring, R.	Cenex LCV 2012, September 5-6, Bedfordshire	Sep-12
4	Developing FUTURE Vehicles Project	Thring, R., Offer, G. J., Marinescu, M., Kavanagh, D., Assadian, F., Phillip, N.	FUTURE & VESI Dissemination Seminar 2013, January 15, Warwick	Jan-13
5	Developing FUTURE Vehicles Project	Burnham, K., Phillip, N	FUTURE Vehicles Reduced Order Modelling Workshop 2013, April 22, Coventry University	Apr-13
6	Developing FUTURE Vehicles Project	Thring, R	Low Carbon Vehicle Partnership Innovation Working Group (IWG-A-13-10), October 10, 2013, Loughborough University	Oct-13
7	Developing FUTURE Vehicles Project	Assadian, F., Longo, S., Auger, D	FUTURE Vehicles Controls Workshop 2013, November 28, Cranfield University	Nov-13
8	Lithium Ion Battery Degradation Workshop	Brandon, N., Offer, G. J,	Lithium Ion Battery Degradation Workshop 2013, November 22, Institute of Physics, London	Nov-13
9	Developing FUTURE Vehicles Project	Thring, R., Marinescu, M., McCarthy, N., Zhong, QC, Cai, J., Kavanagh, D., Sumislawska, M., Longo, S.	FUTURE & VESI Dissemination Seminar 2014, January 14, Loughborough	Jan-14
10	Developing FUTURE Vehicles Project	Thring, R	Cenex LCV 2014, September 10-11, Milbrook, Bedfordshire	Sep-14

Outputs so far...

- All outputs are posted on the FUTURE Vehicles project website, URL: <http://www.futurevehicles.ac.uk/>

An Aspiration

- We want the results to feed into future industry work in TRLs 4,5,6.
 - Dissemination events (January, 2013, January, 2014, January, 2015)
 - Should lead to benefits for UK PLC

Acknowledge EPSRC