THE UNIVERSITY OF WESTERN AUSTRALIA

The Renewable Energy Vehicle Project (REV)

10 Years of Excellence

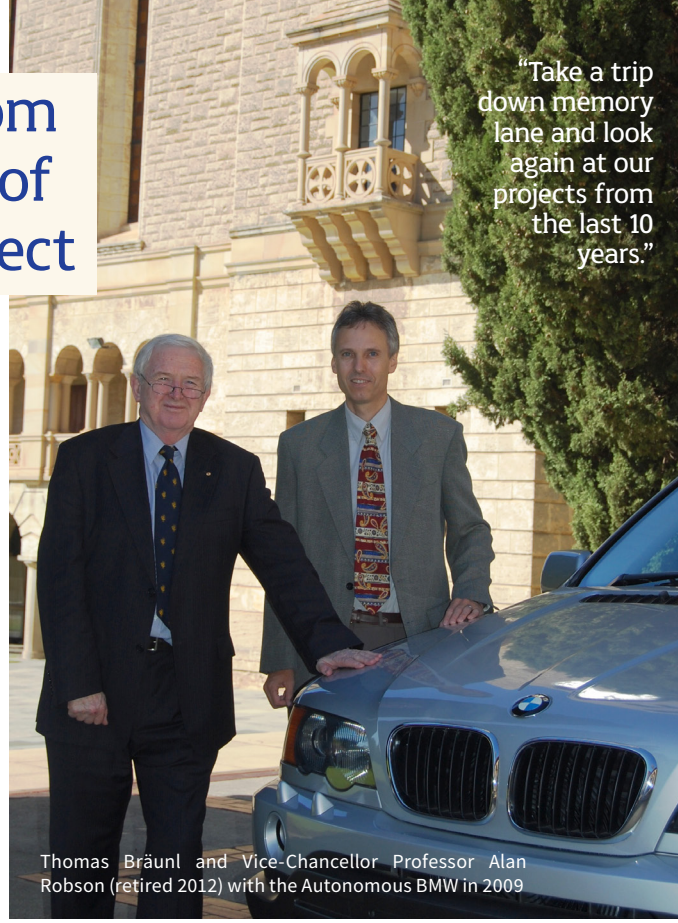
2008–2018

Foreword from the Director of the REV Project

Ten Years on the REV Project, one full decade packed with electric vehicle projects and autonomous driving endeavours. I have had a great time along this journey—and so have the almost 200 students involved over the years, be it as team members, project leaders, or my 'right hands'—the REV Student Managers.

We have a long list of achievements: the first road-registered electric car conversion of an Australian university (and one of the first officially registered EVs in all of Western Australia), the first Australian Electric Vehicle Trial, Australia's largest EV charging network, Australia's first CCS fast-DC charging station, Australia's first Electric Jet Ski (and the second in the world), Australia's first Formula-SAE Electric Race Car, Australia's first Autonomous Research Car (our BMW X5), Australia's first Formula-SAE Autonomous Race Car, and of course the innovative REView Software for EV and charging management, which won all national and international IT awards (WAITTA, iAwards, and APICTA).

Take a trip down memory lane and look again at our projects from the last 10 years.



"Take a trip down memory lane and look again at our projects from the last 10 years."

Thomas Bräunl and Vice-Chancellor Professor Alan Robson (retired 2012) with the Autonomous BMW in 2009

RENEWABLE ENERGY VEHICLE rev WWW.THEREVPROJECT.COM

Professor Thomas Bräunl

Director, Renewable Energy Vehicle Project (REV)

http://REVproject.com

Electric Vehicles—The Facts

Detroit Electric auto on promotional tour through mountains from Seattle to Mt. Rainier] / Cress-Dale Photo Co., Crary Bldg, Seattle [1919]. Courtesy Library of Congress: https://www.loc.gov/pictures/item/2003653829/

History

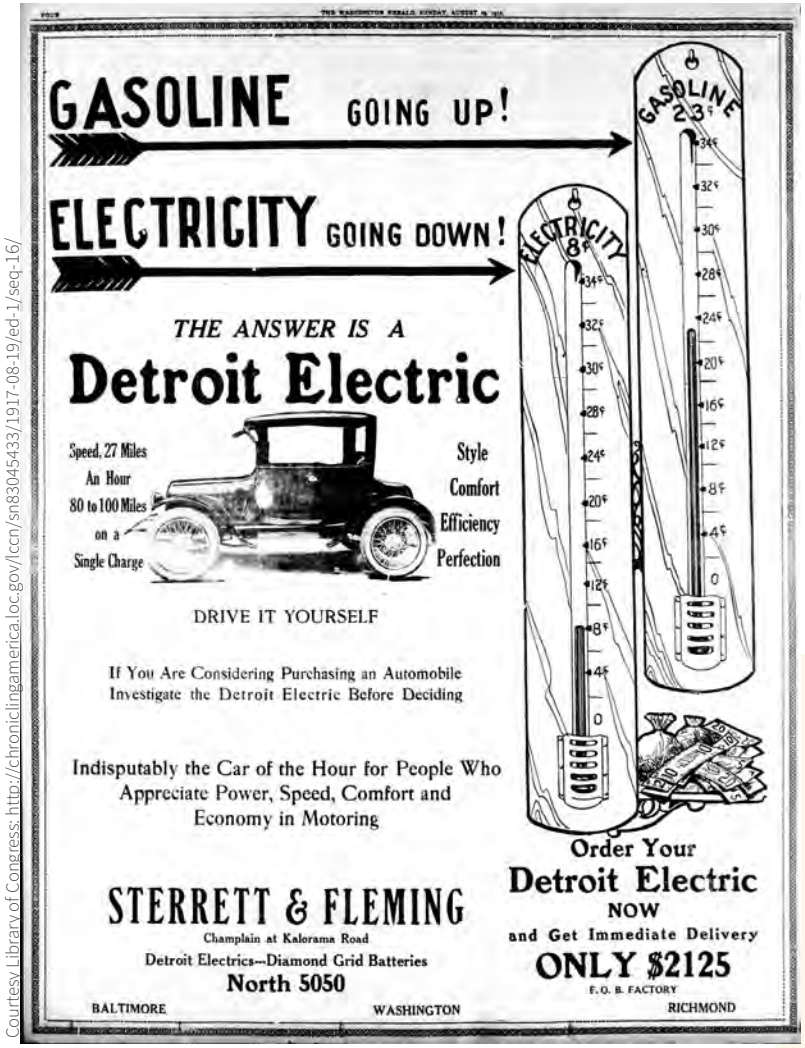
Electric vehicles (EVs) are not a new invention, in fact the very first cars around 1900 were electric before petrol cars took over. For many decades, we have had electric trains and electric forklifts, so the main components, electric motors, controllers and batteries are readily available. That's why building an electric vehicle is not rocket science, but rather common sense. It is not that hard to build an electric car in your shed if you have the right tools and skills, as there are plenty of components to choose from.

There have been several waves of electric cars over the last hundred years, the last one being the now infamous EV1 from General Motors. But every time, EVs did not have a break-through in the vehicle market. Despite all conspiracy theories, the reason behind this was the lack of battery capacity to ensure a suitable vehicle driving range.

This problem has now been solved with Lithium-Ion batteries. So in a very real sense, today's EVs owe their success to smartphones and laptop computers, which made this battery technology affordable.

EVs and PHEVs

We define purely electric vehicles (EVs—sometimes also called Battery Electric Vehicles, BEVs) and plug-in hybrid electric vehicles (PHEVs) as electric vehicles. Both types of cars can be charged via a power cord from the outside and have a certain electric driving range. PHEVs also have an auxiliary petrol motor on board (sometimes called 'range extender') that lets the PHEV drive a much larger distance on petrol once the battery range has been exhausted. The so-called 'mild hybrids' are not counted as EVs. While they use very similar technology to PHEVs, they do not have the ability to be charged with outside electricity and their electric range is typically very short (about one kilometre for a Toyota Prius). So they are basically petrol cars using some EV technology to reduce fuel consumption.



Courtesy Library of Congress: http://chroniclingamerica.loc.gov/lccn/sn83045433/1917-08-19/ed-1/seq-16/

A full-page ad from The Washington herald., August 19, 1917, p4, for the Detroit Electric Automobile claims an extraordinary 80 to 100 miles on a single charge. Notably the lower cost of electricity compared to fuel was a selling point even 100 years ago.

Emissions

EVs have zero tail-pipe emissions. But how much emissions are caused through power generation? This depends of course on the area you live in and the local power plants. Hydro is good, coal is bad. Still, anything is better than petrol or diesel cars, as they pollute the air in our cities, where most of the population lives, whereas power plants tend to be placed away from city centres in areas of low population density. Also, emissions from power plants can, in principle, be more effectively cleaned up than emissions from millions of cars.

Emissions are a serious health hazard and kill more people every year than road accidents (which is already a shocking number). Ten years from now, we might ask ourselves how we could have allowed petrol and diesel cars to destroy our air quality—maybe in the same way as we look back today at the times when smoking in restaurants was common.

Charging Standards and Cost

EVs need power and they can be charged either slowly from home (ideally from one's own solar panels) or fast at a public or private charging station.

The three main charging levels are:

- Level 1: Home charging, max. 2.4kW in Australia. For a 23kWh EV, this means 10 hours charging from empty to full
- Level 2: Fast AC charging, either 7.7kW (32A single phase) or 23 kW (three-phase). This means 3 hours (single phase) or 1 hour (three phase) charging from empty to full
- Level 3: Fast DC charging, 50kW up to 450kW, always charging up to 80% only, as charging slows down significantly above this level. This means for our sample EV 22 min. (at 50kW) or 2 min. (at 450kW) charging from empty to 80% full

There are a number of different charging sockets in the market. The most common ones are:

- Type 1: The AC connector/inlet pair used in the U.S and Japan, aka "SAE 1772" after the corresponding U.S. standard. As

the U.S. and Japan do not have a three-phase power grid, this standard is limited to single-phase and a lower power output than Type 2. For Type 1, the charging cable is permanently attached to the charging station.

- Type 2: The AC connector/inlet and plug/socket pairs used in Europe, aka "Mennekes" after the company first proposing this standard. Type 2 supports both single-phase and 3-phase charging at higher power rates than Type 1. Type 2 charging stations only have a socket, so users have to bring their own charging cable.
- CHAdeMO: The Japanese DC charging standard, limited to max. 50kW, therefore now outdated, but still in widespread use.
- CCS: The Combined Charging Standard (CCS) allows either AC (up to 23kW) or DC (up to 450kW) charging through the same vehicle inlet. There is CCS-Type-1 and CCS-Type-2 to match the U.S. (Type-1 single-phase) and European (Type-2 three-phase) standards.

Although Standards Australia has so far failed to recommend either EV charging standard, vehicle imports have now settled at Type-2 (AC) and CCS-Type-2 (DC) as the de-facto standard for Australia.

Cable-less inductive charging technology is already available and may become the future standard for AC charging.

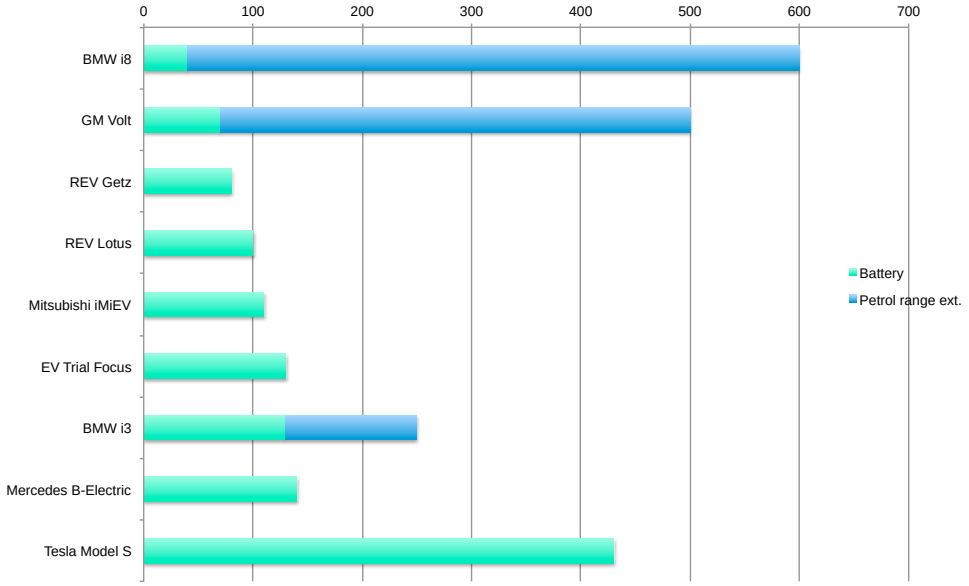
Typical EV consumption is around 150Wh per km. At a standard electricity day-tariff of $0.25 per kWh this means a cost of 3.8ct/km. When charging at a night tariff, cost comes down to 2ct/km and when using energy from your own solar panels, driving is practically free.

Also note that EVs have significantly reduced service costs, as no motor service will be required and brake pads and disks last a lot longer because EVs can reduce their speed through regenerative braking, which stores back energy into the batteries while at the same time reducing wear on the friction brakes.

Range and EV Adoption

Modern EVs have a range of 400km or more. So they last for almost two weeks of commuting without charging, considering Perth's current driving average of 36km/day, as well as for a longer business or holiday trip. Of course, charging infrastructure is essential for long distance travel, but can be ramped up with the increasing EV adoption over the next few years.

Next to the high purchase price, the limited range of early EV models had been identified as the most important hurdle in EV adoption. So while range is no longer an issue, the purchase price is still dominated by high battery cost. Government incentives can help to overcome the initial price gap between EVs and ICE (internal combustion engine) cars until EVs will eventually be cheaper than ICE cars



Range graph

Hydrogen

Hydrogen cars are expensive to build (all EV technology plus a hydrogen fuel cell), expensive to run (production, transport and storage of hydrogen consumes almost twice the amount of energy required to drive an EV) and require very expensive filling infrastructure. And hydrogen filling times have been all but equaled with current CCS charging technology.

So why are hydrogen vehicle projects still being pursued? They would allow oil companies to continue their business model by replacing one fuel with another.

Autonomous Vehicles—The Facts

Over 90% of vehicle accidents are due to driver error. We have about 1,200 fatalities in road accidents in Australia every year and a staggering 1.3 million worldwide. Clearly this horrible number must be reduced and autonomous vehicles (AV) will hopefully deliver this relief.

While electric vehicle technology is simple, autonomous driving is in fact rocket science. It requires building a robot in the shape of a car with still expensive high-performance onboard computer systems and even more expensive sensors, such as Lidars, cameras, IMUs (inertial measurement units) and GPS.

All automotive OEMs (original equipment manufacturers) as well as numerous start-ups in the U.S. and Europe work on autonomous driving today. It is probably the number one Engineering research topic of our times.

At the time of writing these lines, we have semi-autonomous systems or "advanced driver-assistance systems" on our roads. The driver is still in charge of the car (and liable in a legal sense). This will gradually change over the next decade until we will have fully autonomous cars that will not require a driver anymore.

While autonomous cars will significantly reduce accidents, they will not bring this number down to zero. There will still be (a low number of) accidents due to system failures, as well as collisions at high speeds, when the laws of physics do not allow stopping in time.

What AVs will not reduce is congestion. Although there will be a higher freeway and possibly city traffic throughput, AVs will drive less aggressively and leave a larger gap between vehicles than human drivers. And, of course, when it becomes cheaper to send your car back home after dropping you off to work and hailing it at the end of the day instead of paying for parking, then suddenly we will have twice the traffic that we have today.

Source: Wikimedia, Stephen 740

The REV Vehicles

Over the ten years that the REV Project has been running, the following vehicles have been built and/or modified by students.

REV Eco

Electric conversion of Hyundai Getz
DC drive system, 28kW, 144V, 13kWh,
80km range

REV Racer

Electric conversion of Lotus Elise S2
3-phase DC drive, 75kW, 266V, 16kWh,
100km range

Formula SAE Electric car

4-wheel drive system with wheel-hub
motors, torque vectoring, 60kW, 52V, 8kWh

Autonomous SAE Electric car

Twin DC drive motors, 13kW, 48V, 4.3kWh,
drive-by-wire, laser scanner, GPS, IMU,
camera

Scooter

36V, 750W, hub motor, top speed of 32km/h,
Battery—12cells of 10Ah 3.2V LiFePO4, total
of 38.4V, 15km range

REVski

Electric conversion of Jet Ski, Sea-Doo
4-TEC, 96V, 50kW, 7.6kWh, 30min. drive-time

Autonomous BMW X5

Drive-by-wire, laser scanner, GPS, IMU,
camera

2008

The idea of running an electric vehicle research project at UWA came as a suggestion from Hartmut Frigger to Thomas Bräunl. Although there was no initial start-up budget for this, Professor Bräunl had inherited a defunct Hydrogen Vehicle project, and after managing to convince the Dean was able to cancel that project's costly fuel cell order and sell its assets (including the light truck needed to carry it). This provided the budget to pay for the purchase of two cars and the equipment needed to convert them to EVs. The Renewable Energy Vehicle Project (REV) was reborn.

The 2008 Team

Student Manager:
Rohan Mathew

Team:
Nicole Artman, Carl Beyer, Nam Khuan Chua, Britney Dudley, Serajul Haque, Jeffrey Henkel, Chun Shing (Steve) Ip, Rob Jones, Kelsey Kennedy, Arthur Kinsey, Johnny (Shu) Lee, Jian Xian Lee , Leo (Li) Liang, Winston (Yehuan) Ma, Ewan Macleod, Alexander Meegan, Anthony Milton, Aron O'Connor, Michelle Ovens, Tim Pyper, Elizabeth Ruhl, Ross Sandrock, Amar Shah, Dyizen (Tan) Tan, Wilson Tay, Daksh Varma, Stephen Whitely

When it began in 2008 the REV Project immediately drew the largest number of students ever in a student project in the School of Electrical, Electronic and Computer Engineering, with 28 students from different Engineering backgrounds (Computer, Electrical, Electronic, Mechanical, Mechatronics and Software Engineering). Supervising the students were Professor Thomas Bräunl, directing the project and Dr Kami Cheng who was in charge of the Mechanical Engineering topics.

In its first year, REV purchased a new Hyundai Getz, a popular small commuter car, which would become the "REV Eco". After this "reasonable" EV choice, we were also looking for a sports car base, to show that EVs are not necessarily slow. After looking at a number of alternatives, we purchased a Lotus Elise in England, which was to become our "REV Racer". As it turned out, we were not the only ones having the idea of turning British sports cars into EVs. Elon Musk did exactly the same.

He imported Lotus Elise shells into the U.S. and turned them into his "Tesla Roadster".

We finished and officially launched our REV Eco in the same year.

After conversion the REV ECO was relicensed for roadworthiness by the DPI. Although using mostly existing technologies, this was a major undertaking. The conversion of the electric vehicle drive using 144V Lithium-Ion batteries with a gear-box-mounted DC electric motor was only about half the effort. A number of smaller projects had to be completed to ensure the roadworthiness of the car: electric power steering, electric vacuum brake assist, electric heating, electric air-conditioning. Also, an innovative in-car embedded computer control and instrumentation system has been developed, based on the Robotics and Automation Lab's EyeBot M6 embedded controller.

Thomas Bräunl launches the REV Project and the REV Eco

A further project that was started in 2008 was the conversion of the BMW X5 to drive-by-wire, in order to use it as a test vehicle for our driver-assistance systems.

Ro Matthew—Student Manager 2008

University teaches you a lot of things: but it never prepares you for how resistant the world is to change.

We've changed the world with technology but with our narrow mindsets and flawed economic model we've accelerated the path to our own extinction.

When I first saw the REV project it was nothing more than a set of futuristic sketches pinned to a booth. There were pieces of course, a fuel cell concept here and some part or another there.

You see at the time REV was a hydrogen fuel cell car. The world was so obsessed with our liquid fuels, even innovative projects like REV couldn't see past pumping something volatile into a car and blowing it up to create forward movement.

It had all but brought the project to a standstill and out of the hydrogen vapour a new, fresh approach was born.

In the first year of REV as we know it, a team of mutli-disciplinary student engineers coupled with engineering techs from UWA converted a petrol vehicle to electric and were well underway toward a second.

Perth stood up and took notice. Today, the idea of an electric car is driving auto manufacturers to compete, to do what should have been done decades ago. A movement away from fossil fuels is underway and even energy companies are looking for new ways to reinvent themselves.

But there are still problems to be solved. Problems that need fresh eyes:

- *How can the idea of transport be made easier, more efficient, more economical?*
- *Do I still need to own my car?*
- *Why do I still need to plug in my car to get it to charge?*
- *How can we charge cars faster?*
- *Could we do this faster/better mechanically instead of electrically?*
- *Can we make greener and more efficient batteries?*
- *What could we do if we could start again?*

In the next 10 years of REV let's ask ourselves what we take for granted and whether it's the only way of doing things.

As engineers it's our job to change people's minds. To create with technology not just improvements but a different idea of what's possible.

No candle 2.0 would have solved lighting the way a lightbulb does today—we don't even think about the infrastructure behind the flick of a switch. Let REV teach you to put aside everything people say can't be done and start to look at the world with fresh eyes.

2009

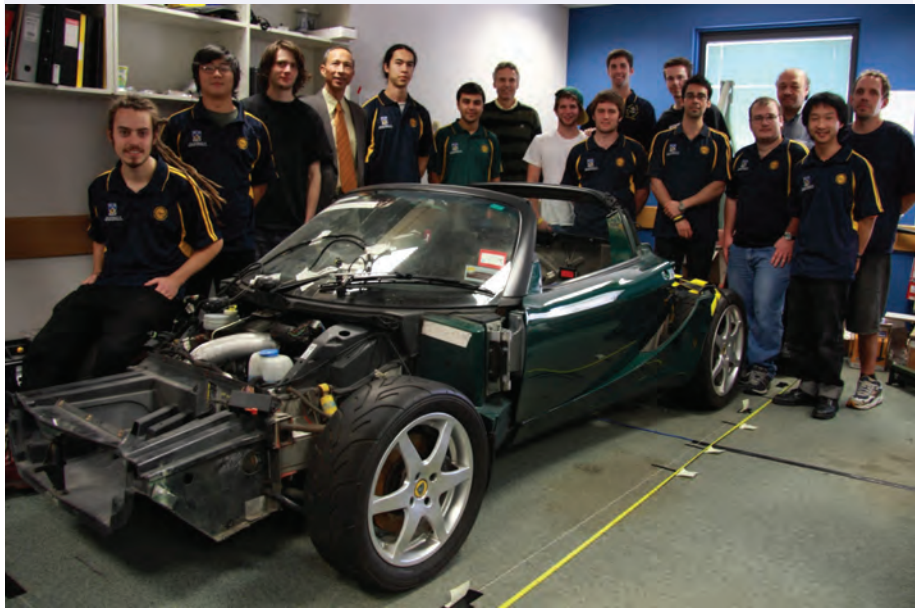
Work started on the conversion of the Lotus, which had been stuck for about six months in customs, as the import compliance company was not able to source a km-instrument panel from Lotus.

At the same time, work started on the BMW X5, which was donated to us by BMW Munich. We would leave this car as a petrol drive, but make it autonomous. The first step was to implement a drive-by-wire system.

The 2009 Team

Student Manager: Daniel Kingdom

Team: Tom Banasiak, Jennifer Berry, Calin Borceanu, Xin Cen, Peter Corke, William Crock, Colin Dickie, Adam Doster, Martin Duff, Jonathan Eng, Jason Fairclough, Anne Flinchbaugh, Zhi Guo, Karri Harper-Meredith, Daniel Harris, Chris Hellsten, Frans Ho, Ian Hooper, Marius Ivanescu, Jurek Malarecki, Andrew Morrigan, Jon Mullan, Jack Nay, Grace Ong, Tiong Kun Ooi, John Pearce, Bobby Powers, William Price, Nicholas Randell, Amar Shah, David Caleb Tang, Bryan Teague, Christian Tietzel, Daksh Varma, Ivo Vekemans, Franz Viertler, Tim Wallace, Jonathan Wan, Wesley Wang, Cameron Watts, Stephen Whitely



During 2009 the REV Eco, our first plug-in battery electric car conversion underwent a large number of evaluation and durability tests, as well as a number of improvements and modifications. The rear springs have been replaced by student-designed stronger custom springs and a new battery venting system has been designed and installed. The software implementation of the driver information on our own EyeBot M6 embedded controller has been constantly improved and extended with several functions. Using a 3G wireless broadband module, we are now able to transmit the car's GPS position and internal status in real-time over the internet. This allows us to log vehicle information over an indefinitely long time frame and also to investigate vehicle position and status from anywhere in the world. While our original REV Eco graphics designed by James Wong was held in green/yellow colours, one of our new REV sponsors requested a change in colour scheme, so the car was given new decals in red/blue.

Most of 2009's efforts went into the electric conversion of our Lotus Elise S2. The Lotus should have been a simpler project than the Getz, as it is conceptually a much simpler car: no power steering, no brake assist, no air-conditioning—so all these time consuming projects that we required for the Getz, we did not have to do for the Lotus. However, the small space available in this two-seater sports car and the large amount of batteries required, turned out

to be major problems. We solved this by providing three separate battery cages, before, over and behind the rear wheels. A completely new battery management system (BMS) was developed by our Senior Technician Ivan Neubronner and we are looking forward to seeing it in action.

The Lotus is being driven by a 75kW three phase DC motor and has a battery capacity of 16kWh (83 batteries of 60Ah each), which gives it a total nominal voltage of 266V. Due to the current reorganisation happening in the Faculty of Engineering, we were not able to get enough workshop hours in order to complete the Lotus in 2009, but we will get there in the first quarter of 2010.

Progress has been made in converting the BMW X5 to steer-by-wire and brake-by-wire, while maintaining its normal drivability. The car is being used as a test vehicle for evaluating vision-based driver assistance systems for lane keeping and collision avoidance. An inflatable copy of the REV Eco has been manufactured to be able to safely test collision (and collision avoidance) scenarios with the BMW.

Quite late in 2009 we finally received a race car chassis from UWA Motorsport, which will be the basis for UWA's first electric Formula SAE race car. The car is Motorsport's 2001 model and will be converted in two stages. In stage one, during 2010, we will equip the car with two drive motors, one for each rear wheel and an electronic differential. In stage two, during 2011, we will equip the car with four independent wheel-hub motors, developed at UWA.

During 2009, a total of 45 undergraduate and graduate students worked on the REV automotive projects and in addition to their project work donated uncounted hours of their time for the numerous exhibitions and project demonstrations we had over the year. Many thanks for this to all of you.

Daniel Kingdom—Student Manager 2009

Selecting a thesis that involved physical hardware and software in addition to theory was a priority for my final year selection. The REV project was a fantastic opportunity to work on a "real world" project with challenges and interactions similar to what we experience in our professional engineering career. Developing licenced road registered vehicles in a multi-discipline team (Electrical, Mechanical and Software) with our sponsors was a great introduction to our professional life after university.

I was fortunate enough to fill the role of REV manager for 2009 and worked with 40+ great students and UWA staff over multiple simultaneous projects including: the REV Sports Car (Lotus Elise), the SAE electric car, X5 Autonomous car project, upgrades to original Getz economy car, The engine sound emulation software development, automated feature identifier (image processing), tracking and navigation, BMS and safety systems, suspension upgrades, legal compliance and many more. I would like to again thank the 2009 team for your hard work and making the project a great success.

The REV project has formed some of my fondest memories of my time at UWA. I am still a fan of REV Electric Vehicles after been able to purchase one of the Ford Focus conversions by the 2010 team a few years ago at auction and still usw it as my daily driver.

E-car charge stations plan

JENNIFER FORESHEW

ELECTRIC vehicle charging stations will be trialled in Western Australia early next year in a joint research project.

A consortium, led by The University of Western Australia and Murdoch University, will install 10 charging stations in Perth to collect and evaluate data on user behaviour.

Project leader Thomas Braunl, from UWA School of Electrical and Electronic and Computer Engineering, said other cities in the US and Europe had some public charging infrastructure, but Australia was lagging.

"This will allow us to get a better idea of what is going to happen within 10 years, when we expect larger numbers of electric cars, and that can be used for forward planning for increased electricity and grid capacities required," he said.

The three-year project, to run until 2012, will involve UWA's two electric cars as well as the Australian Electric Vehicle Association, which has about 30 cars and 20 electric motorbikes and scooters in WA.

Additional electric vehicles are expected to become available in 2010 as part of a wider trial managed by Perth-based CO2Smart.

"We'll equip all the charging stations with wireless broadband so we will have over the internet the full record of who has been using which charging station, where and for how long," Professor Braunl said.

The cars will also be equipped with black boxes so researchers can get a picture of movement and charging patterns.

In the simplest case, Professor Braunl said, the charging stations would involve just a 240-volt wall outlet, but the team was looking at something more advanced to allow faster charging.

The project would raise awareness of electric vehicles and renewable energy in general, he said. An electric car, which has no emissions, can take about six hours to fully charge, but new technology could reduce that to two or three hours.

Electric vehicles, which currently cost more than a petrol-fuelled car to produce, were inexpensive to run, costing about one-tenth of a petrol-fuelled vehicle, Professor Braunl said.

"I think within two-and-a-half years you probably will have two or three different electric vehicle products from major car companies on the market that you can actually go to a dealership and have a choice to buy," he said.

The charging stations, which will cost from $3000 to $10,000 each, are expected to be installed by March next year. Only some locations have been finalised. Two will be at UWA, one at Murdoch University, and three at Gull service stations.

"The way it works, the charging station looks like a parking meter, for example, so you have to identify yourself with a smart card or credit card and select a full charge or a certain amount and there is a cable coming out similar to a power plug and you plug this into your car and leave it there for a couple of hours."

The team was hoping for some additional partners to add more charging stations and would target councils and shopping centres, he said.

"If this is going to be successful, we'd definitely look into doing this more on a commercial basis and doing it in other states as well," he said.

The project, recently awarded $229,000 by the Australian Research Councils Linkage grant scheme, involves UWA School of Electrical, Electronic and Computer Engineering, UWA Business School, Murdoch University CREST, AEVA, WA Department of Transport, Gull Petroleum and CO2Smart.

The Australian, 10-Nov-2009, P.31, IT Today by Jennifer Foreshew

2010

In mid-year we started Australia's first Electric Vehicle Trial with 11 external partners, each funding one converted Ford Focus. Trial management was conduct by CO2Smart, while all EV conversions were done by Perth company EV Works. The first converted EV was delivered to the WA Department of Transport for the acceptance test.

At the same time, we succeeded in getting ARC funding for establishing Western Australia's first EV charging network. The project would run until 2014 and besides scientific publications resulted in charging infrastructure and monitoring software that is still in use today.

On the vehicle side, we finally finished and launched our electric Lotus as the REV Racer together with the electric conversion of our first Formula-SAE race car.

The 2010 Team

Student Manager: Ian HOOPER

Team: Oscar Burke, Xin Cen, Nicholas Cockran, Karri Harper-Meredith, Daniel Harris, Paul Holmes, Ian Hooper, Alex Hukins, Brendan Keeler, Martin Kiszko, Markus Kohler, Yiwei Liu, John Moran, Jonathan Oakley, John Pearce, Nicholas Randell, Joey Rich, Teoh Soo, Frank Yi Tan, Thomas Walter, Jonathan Wan, Matthew Webster.

Ian Hooper and Jonathan Wan with the REV Electric Formula–SAE car

2010 was a great year for the REV project. The WA Electric Vehicle Trial started as the first of its kind in Australia and saw the conversionof 11 Ford Focus by local company EV Works in cooperation with UWA/REV and CO2Smart.

The project was launched at the UWA University Club by two ministers, the Hon. Simon O'Brien, Minister for Transportand the Hon. Donna Faragher, Minister for Youth.

The BMW steer-by-wire in collision avoidance testing

We also received funding under the ARC Linkage scheme for a research project on analyzing EV driving and charging behaviour with partners WA Dept. of Transport, Gull Petroleum, Australian Electric Vehicle Association (AEVA), Murdoch University and UWA.

Participating from Murdoch University was Prof. David Harries, who is now an Adjunct Professor at UWA. From UWA, Prof. John Taplin (Business School) and Prof. Thomas Braunl (Engineering) supervised two PhD students funded through the project, Ms Fakhra Jabeen and Mr Stuart Speidel.

The project also provided funds that together with additional outside partners led to the installation of a charging network of 24 Level-2 AC station in the Perth metro area—at that time, one of the largest charging networks in Australia.

In 2010 we finally completed the REV Racer, our electric conversion of a Lotus Elise S2. The vehicle was launched in the presence of the Hon. Bill Marmion, WA Minister for Environment.

REV Spec Sheet	REV Eco (2008)	REV Racer (2009/2010)
Base car	2008 Hyundai Getz	2002 Lotus Elise S2
Seats/doors	5 seats / 5 doors	2 seats / 2 doors
Original engine	1.4l, 4 cylinders, 70kW	1.8l, 4 cylinders, 116kW
Electric motor	Advanced DC FB 4001, DC	UQM Powerphase75, AC
Controller	Curtis 1231C, 500A	UQM DD45-400L, 400A
Power, Torque	28kW, 136Nm	75kW, 240Nm
Regenerative braking	No	Yes
Instrumentation	EyeBot M6	Automotive PC
Batteries	Lithium-Ion-Phosphate, 45 x 90Ah	Lithium-Ion-Phos.,83 x 60Ah
Battery weight	135kg	191kg
Voltage	144V	266V
Total capacity	13kWh	16kWh
Total weight (petrol, electric)	1160kg, 1160kg	780kg, 936kg
Top speed	125km/h	200km/h (estimate)
Range	80km road-tested	100km road-tested
Charging Time	6h (full charge)	6h (full charge)

Also launched in 2010 was REV's first version of a Formula SAE–Electric single seater race car. In this new international competition, students build an electric powered race car to compete in a driving and engineering challenge with other university teams. The REV 2010 SAE–Electric car is equipped with two drive motors, one for each rear wheel and uses an electronic differential.

November 2010 saw the first public Level–2 charging station in Australia installed at the RAC Headquarters in West Perth. This charging station is part of the ARC Linkage network of fast-charging stations.

The Lotus Elise charging-up at RAC Headquarters in West Perth

WA's first Level-2 charging station

Above: REV Student Manager Ian Hooper, REV Director Thomas Bräunl and WA Minister for Environment Bill Marmion

2011

Delivered all remaining EV conversions to the project partners, while at the same time setting up Perth's EV charging network, which grew to 23 AC stations and one fast-DC station.

On the autonomous driving side, we completed our autonomous BMW X5. We added steer-by-wire and brake-by-wire to the car, but left the accelerator as manual control for safety reasons. The X5 used camera sensors exclusively and demonstrated its performance for the TV cameras of Today Tonight on the RAC's DTEC Race Track.

BMW Germany in Munich awarded Thomas Bräunl's work on EV Home Integration with the BMW EI Innovation Award.

The 2011 Team

Student Manager: Ian Hooper

Team: Xin Cen, Alex Hukins, Martin Kiszko, Jonathan Oakley, John Pearce, Nicholas Randell, Teoh Soo, Frank Yi Tan

Our BMW X5, donated by BMW Group, was the star of a Channel Seven, Today Tonight report in the series 'The Clever Country'. The BMW has been converted to drive-by wire by UWA workshop staff and students, allowing it to steer and brake through digital signals from an embedded computer system. For this, an electric motor has been mounted to actuate the steering column, still giving the driver the ability to override the signal by moving the steering wheel manually. A powerful electric servo is being used to press down the brake pedal from behind, leaving enough room for the driver's foot to also operate the pedal. The accelerator pedal has not been actuated for safety reasons.

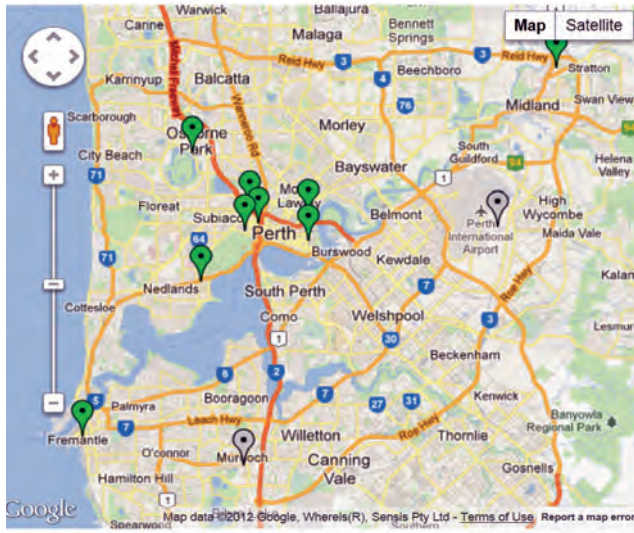
An EyeBot V6 advanced embedded controller is mounted with a suction cup on the BMW's windscreen combining a digital camera with the image processing hardware in one module. Software developed by students using the OpenCV image processing library uses a classifier system based on image symmetry to detect other cars as potential obstacles. If the system detects a possible collision with a car in front, it will warn the driver acoustically and then either conduct an emergency braking or alternatively take evasive action by actively steering the car around the obstacle while also braking. For testing, a realistic looking inflatable copy of the REV Hyundai Getz is being used as the obstacle car.

The final demonstration for this project was conducted in July 2011 at the RAC DTEC Driving Centre near Perth Airport and was broadcast by Channel Seven's Today Tonight, Australia.

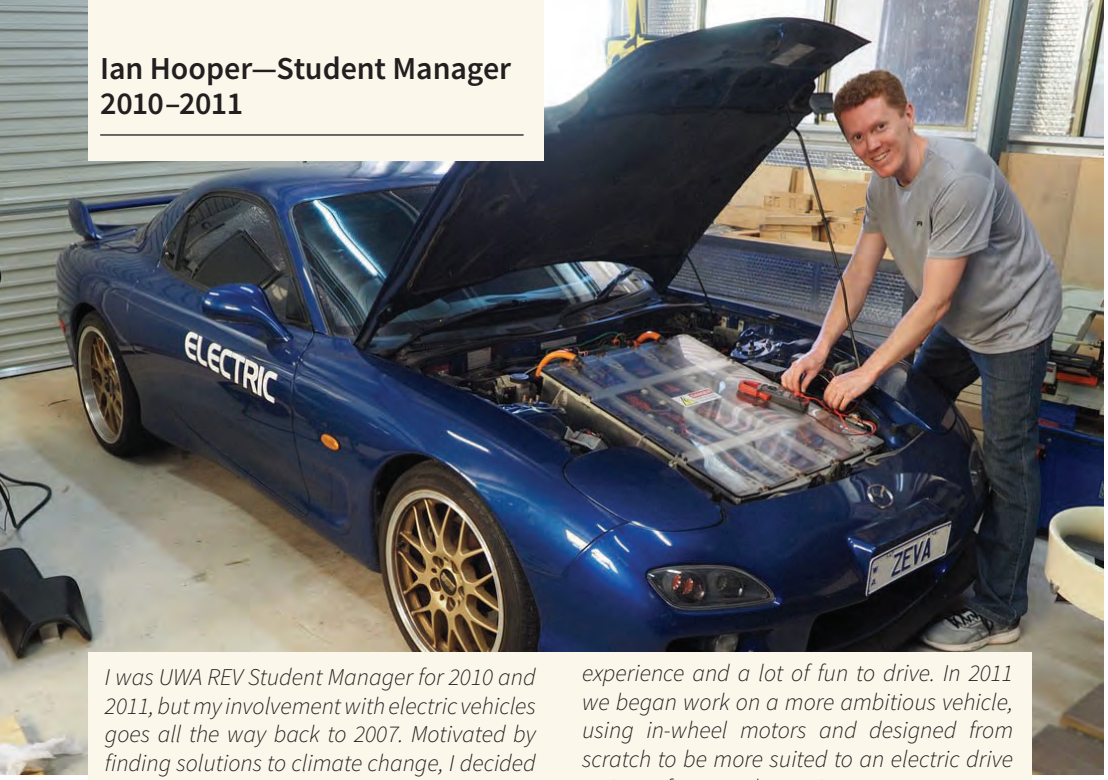
Also in the focus of a TV report from Channel Seven were our electric REV Eco (converted Hyundai Getz) and REV Racer (converted Lotus Elise), performing acceleration measurements at the RAC DTEC Driving Centre. Test results as well as an interview were recorded and broadcast in June 2011 by Channel Seven's Today Tonight, Australia.

2011 also saw the implementing of infra-structure for two Australia-first trials on EVs and on EV charging with converstions of 11 Ford Focus sedans to EVs by local company EV Works and installation of 23 charging stations in various locations in the Perth metro area.

The trials collect data on EV charging behaviour. Of special interest are *where* (home/office/station) and *when* (daytime/day-of-week) charging occurs. These questions can only be answered by collecting and evaluating relevant user data, as we are doing in this project.



Ian Hooper—Student Manager 2010–2011



I was UWA REV Student Manager for 2010 and 2011, but my involvement with electric vehicles goes all the way back to 2007. Motivated by finding solutions to climate change, I decided to try building my own electric car—or to be precise, converting a 1990 Mazda MX5 to electric. Soon after completing this I learned that UWA had also converted a car to electric, a 2008 Hyundai Getz, so from mutual interest I started to get involved with the REV group as a volunteer in 2009, including assisting with completion of the Lotus Elise project.

Towards the end of 2009 my involvement became official as I began a Masters by Research degree studying in-wheel motor design, and in 2010 I took over from Daniel Kingdom as REV Student Manager. The main projects during my tenure involved UWA's first forays into Formula SAE Electric, a global competition for teams of university students to build and race single-seater open-wheel electric race cars.

In 2010, the REV group inherited the chassis of an old Formula SAE vehicle from UWA Motorsport, and with a small team of students we proceeded to convert it to electric. Our performance goals for this prototype vehicle were modest, but it was a great learning experience and a lot of fun to drive. In 2011 we began work on a more ambitious vehicle, using in-wheel motors and designed from scratch to be more suited to an electric drive train. Unfortunately my time at UWA came to an end before this vehicle was completed!

Since finishing Masters and leaving UWA I have continued my involvement in the electric vehicle world, developing electronics for electric vehicles and supplying them to a global market of EV converters, hobbyists and startups through my personal business venture, Zero Emission Vehicles Australia. It has been gratifying to be a part of the exponential growth in electric vehicles over the past decade, and I feel confident that they are an essential piece of the puzzle to building a sustainable future.

2012

With all EVs delivered and all charging stations installed one by one in the previous year, we are now running the WA Electric Vehicle Trial in full capacity, logging and evaluating data from all cars and charging stations.

The 2012 Team

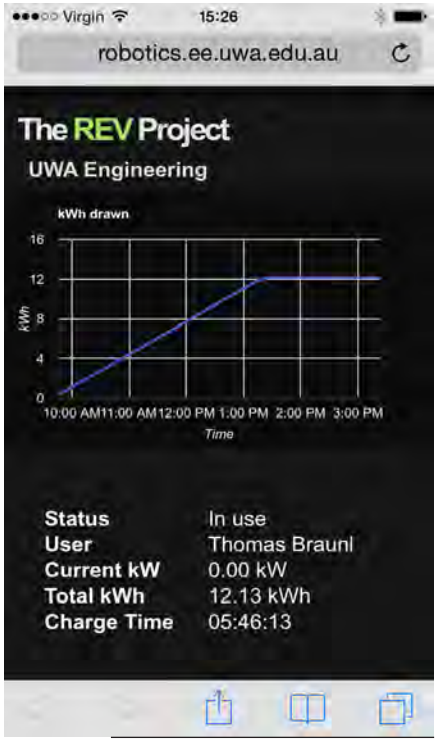
Student Manager: Stuart Speidel

Team: Naomi Altman, Elham Azadfar, Russel Bennett, Timothy Black, Lochlan Brown, James Cohen, Fakhra Jabeen, Timothy Jebakumbar, Sean Klimek, Nicholas Lee, Warren Lionnet, Matthew Michalek, Jon Mullanev, David Ogilvy, Alex Scherer, Adam Stephen, Davip Susanto, Brendan Waterman, Stephen Whitely

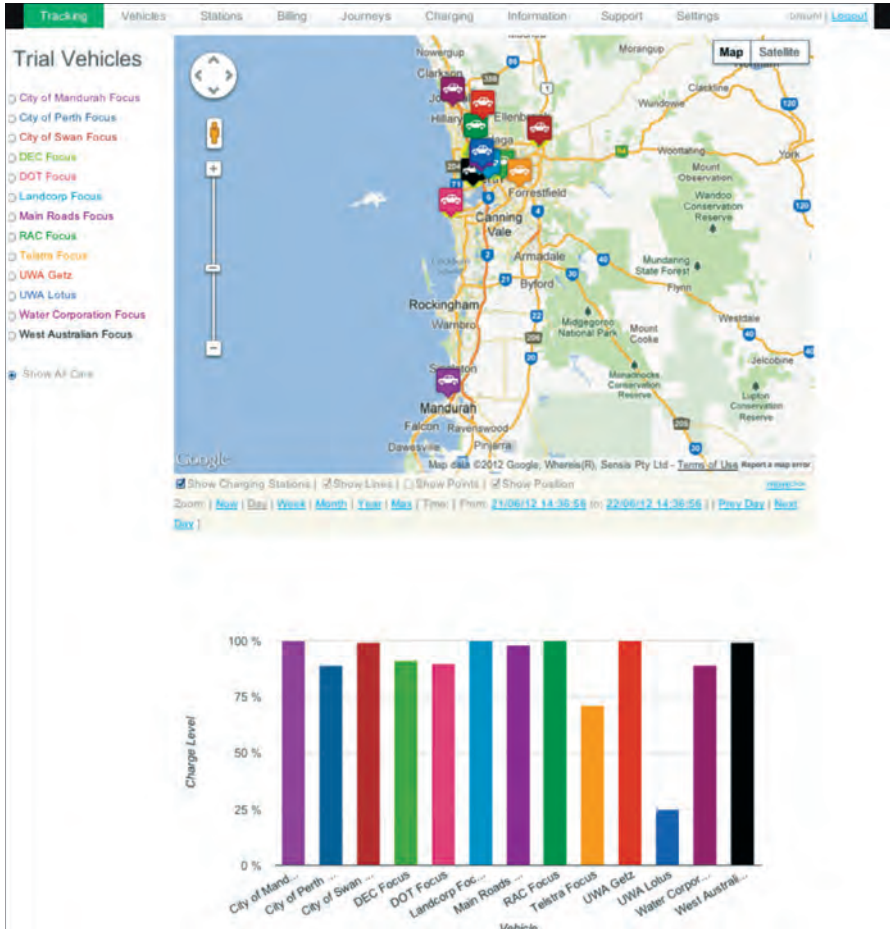
The Formula SAE–Electric is a new student competition category for single-seater electric race cars, designed and built by students. While our REV Formula SAE-E-2010 car was a conversion of an older vehicle from UWA Motorsport, we are now designing and building our 2012 car from scratch as a pure electric vehicle.

For the 2010 car, we used a twin rear engine design that let us experiment with multiple motor designs. For the 2012 car, we are now using four individual wheel hub motors, linked through an electronic control system. The challenges are in the mechanical design of packaging motor and gearing into the small available wheel hub space, as well as in the sensor-based electrical/computing control and coordination of the four motors in different driving situations.

Our two first Australian trials on EVs and on EV charging are now well underway with our 11 locally-converted Ford Focus EVs on the road and 23 charging stations in the ground.



All cars and all stations are equipped with GSM data loggers, plus GPS modules and additional sensors for the cars. With this, we are able to construct complete movement profiles of the electric fleet cars and we are able to collect comprehensive data on EV charging behaviour. As well as collecting data on where and when charging occurs, a follow-up question is—what effect can daytime dependent tariffs have in influencing people's charging behaviour, in order to avoid additional power demand peaks? This is a million-dollar question, which we are analysing very carefully.

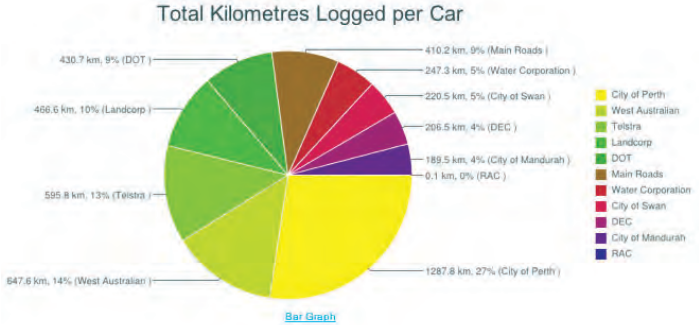


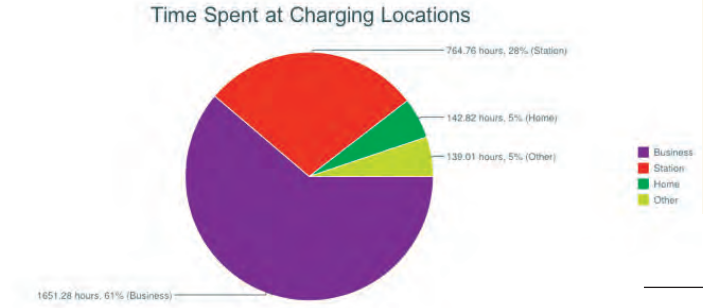
Stuart Speidel—Student Manager 2012–2014

I started working on the REV Project for the WA Electric Vehicle and Charging Station trial in 2012. We worked closely with many different West Australian businesses and government organisations installing and managing 13 electric vehicles and 23 charging stations with live data tracking. Over the course of my time at UWA, I managed hundreds of students over all engineering disciplines over my time as the REV Project manager. We built electric vehicles, charging infrastructure, electric SAE race cars, robotics (automated vehicles), simulators, and an electric jet ski.

Whilst I was manager of the REV Project, we represented UWA across multiple disciplines, with a large proportion of the students choosing the REV Project as their thesis or their final year project. We also represented UWA at the Melbourne SAE competition and the Australian Autonomous Ground Vehicle competition. We were featured many times in television and newspaper articles.

The REV Project is a hub for research, teaching, and collaboration, and a source of pride for the UWA EECE department as it is amongst the greatest university electric vehicle programs in Australia. Being the REV Project student manager is a challenging but thoroughly rewarding experience which has contributed immensely towards me developing skills in collaboration and teamwork. I am proud to see the REV Project continuing on and further providing these opportunities to current and future students.





2013

We completed our second Formula-SAE car, this time a purpose-built EV and took it to the national SAE competition in Melbourne.

To speed up progress on autonomous driving, we re-implemented our drive-by-wire technology (this time full drive-by-wire with steering, brakes and accelerator) on our first Formula-SAE car and added a full sensor suite including Lidar, camera, IMU (inertial measurement unit), GPS and wheel encoders to the vehicle. Using mainly GPS and Lidar data, the SAE car was able to drive along a pre-recorded path of waypoints.

The 2013 Team

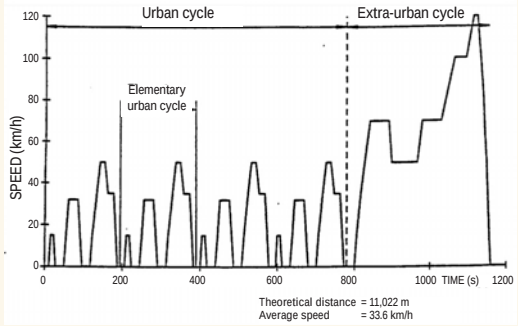
Student Manager: Stuart Speidel

Team: Yuxuan Bai, Alex Beckley, Lochlan Brown, Rowan Clark, Thomas Drage, Haydn Ford, Luke Frewer, Fakhra Jabeen, Rajinda Jayamanna, Jordan Kalinowski, Graham Lionnet, Don Madappuli, Rohan Mehra, Carl P-Conquilla, Andrew Pham, Dannis Savic, Jameson Wedge, Riley White, Calvin Yapp, Zare Zarev

We were finally able to confirm exact energy consumption for our REV Lotus and the electric Ford Focus. In a project in cooperation with Murdoch University, the electric Lotus and manual and automatic versions of the electric Focus were tested on a calibrated dynamometer at Orbital Engines. The cars were driven according to the speed profiles for urban and extra-urban cycles, required by the Australian Design Rules. Typically dynamometer testing gives more repeatable and comparable results, but also more favourable values (i.e. lower consumption and therefore longer range), as compared to real road testing, which we conducted previously.

The EV Lotus Elise is tested on Orbital Engines' dynamometer

Australian Design Rules speed profile



Formula SAE Competition

The UWA Formula REV Team represented Western Australian electric vehicle development, achieving Third Place in the Electric Vehicle category of the 2013 Formula SAE-Australasia competition in Melbourne. The annual competition, held in December, was an opportunity for 22 teams from Australian and international universities to showcase their technical achievements.

The students of The REV Project strive to explore electromechanical drivetrains like no other university racing team, thanks to our sponsors Swan Energy, and our new sponsor Tesla Forum WA. This was our first entry into the prestigious competition and it was great to see so much enthusiasm towards our concept. Our long awaited four-wheel-drive race car was praised for its innovation and ambition by design judges, and there was plenty of room for further innovations within the same concept.

We were very proud to represent UWA alongside the prestigious UWA Motorsport Team, and to produce two racecars in one year from UWA for the very first time.

REV '13 Technical Specifications:

- Propulsion: 4x 15kW (peak) Brushless Direct Current Motors, mounted in four symmetrical hub assemblies.
- Energy Storage: 2x 26V (52V total), 6.4kWh LiFePO4 Accumulators, mounted either side of driver.
- Wheels: Hoosier tyres, 13" wheel rim size.
- Chassis: Custom steel space-frame chassis.
- Mass: 275kg, 50-50 distributed.
- Range and endurance: To be determined.
- Safety features: Forward impact attenuator, side impact structure, Insulation Monitoring Device (IMD), Safety interlock circuit.

2014

Launch of Australia's first CCS fast-DC charging station. Stuart Speidel with supervisor Thomas Bräunl wins all national and international software awards (WAIITA, iAwards, APICTA) for the REView software suite for EV and charging station monitoring and evaluation.

The 2014 Team

Student Manager: Stuart Speidel

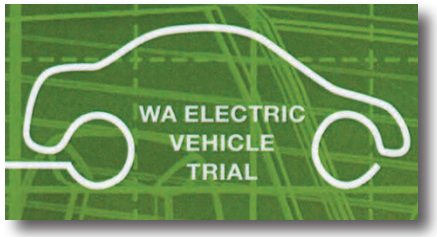
Team: Alex Beckley, Christopher Cork, Martin French, Jake Galiano, Samuel Gribble, Andrew Henson, Alexander Hildebrand, Fakhra Jabeen, Megat Megathsham, Ruvan Muthu-Krishna, Jonathon Oon, Carl P-Conquilla, Nick Ward

Eleven locally converted Ford Focus have been monitored via 3G-enabled black boxes. This allows us to monitor their driving, parking and charging behaviour.

Cumulating EV movements over two years allows us to highlight driving patterns and preferred charging locations.

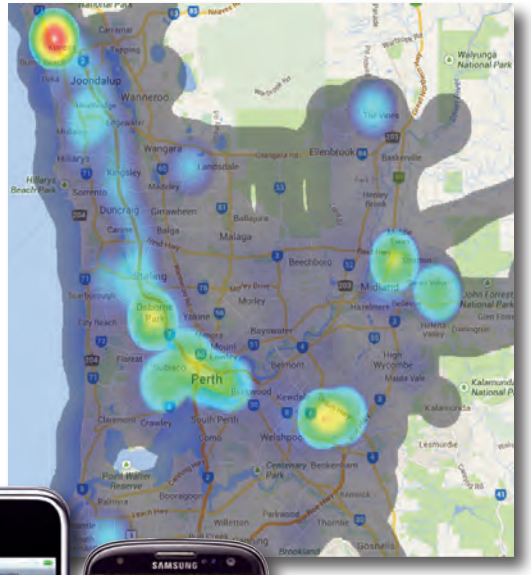
Having completed the REV Eco and REV Racer EV conversions in the previous years, our activities have now concentrated on monitoring and charging of EVs. As part of the ARC-funded Linkage project, we have established one of the largest EV charging networks in Australia with 23 charging outlets. We can monitor the live status of each station and we can give users feedback on their EV charging status via a smartphone app.

Professor Thomas Bräunl and Hon. Senator Christine Milne, Leader of the Australian Greens at the UWA charging station



The WA Electric Vehicle Trial 2010–2013 was completed and the trial report made available for download from: REVproject.com/trialreport.pdf

A significant finding of the two interwoven EV projects is customer behaviour at public charging stations. Most charging events are happening during daytime hours, so an EV charging station can be ideally offset or even directly fed by a rooftop solar PV system, as can be seen in the diagram (black–charging; grey–maintaining charge after completion of charging).



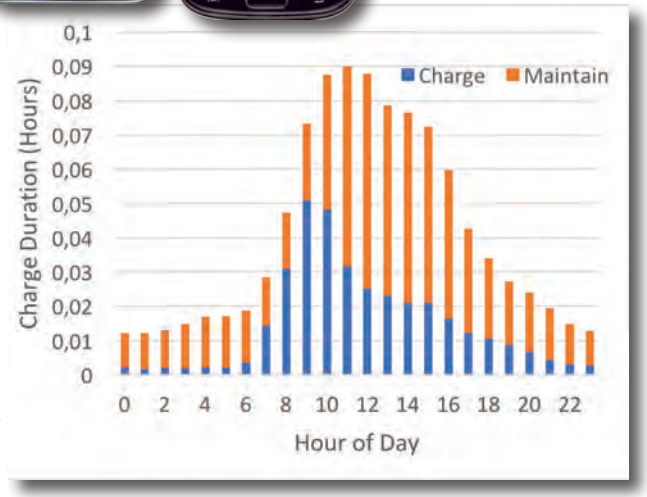
Above: EV driving heat map

Charging times do not match parking times: as the diagram demonstrates, cars occupy a charging bay much longer than actually required for charging. This is because a standard charging time of four hours is too long for staying with the car and in general, parking appears to be at a higher premium than charging.

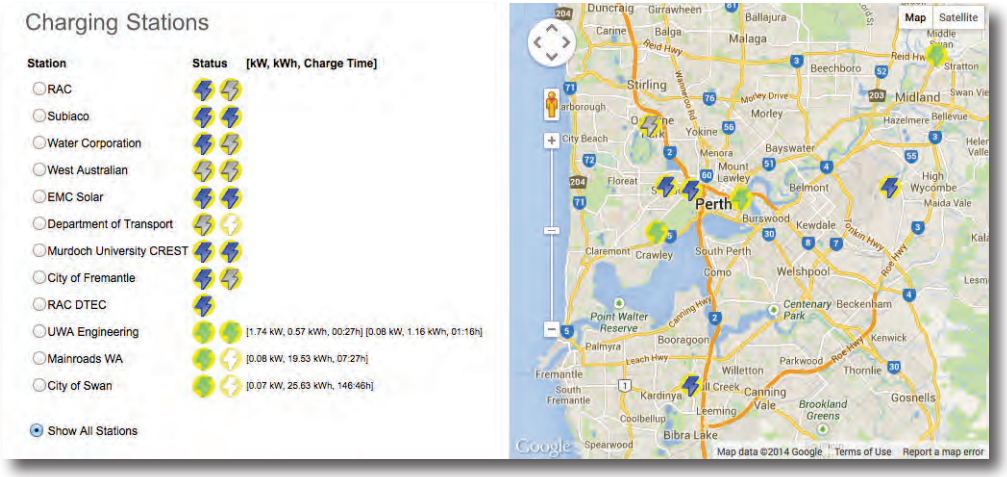
Left: Smartphone app

As a result of these outcomes, we do not propose further increase of the existing network of fast-AC chargers (7kW), but instead advocate to establish a smaller network of fast-DC chargers (50kW). On these systems a typical charge time is 20–30 minutes (for 80 per cent charge) and the driver is expected to stay with the vehicle and remove the vehicle after charging. This will effectively decouple charging from parking and allow a much more efficient use of charging stations.

Below: Time spent for charging and maintaining charge



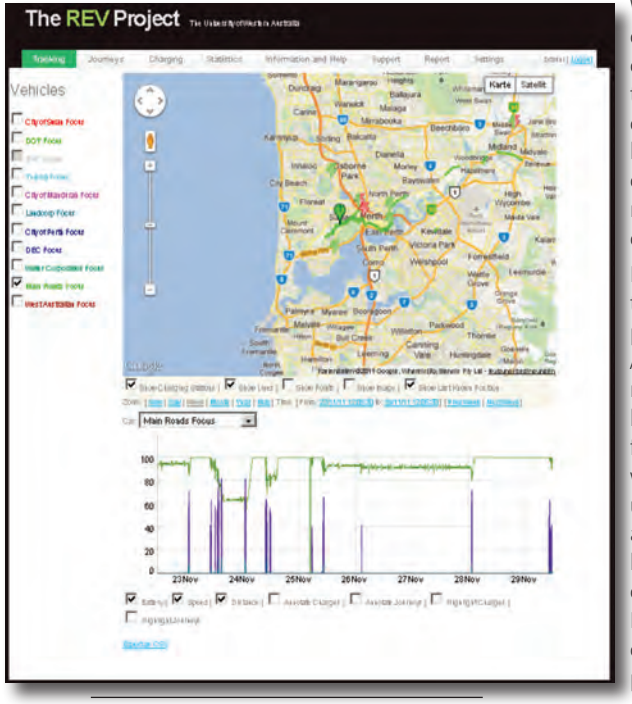
Indeed, one of the final achievements of the ARC Linkage project on Electric Vehicle (EV) charging was the installation in November 2014 of Australia's first commercial Combo-



Above: Charging station activity

CCS charging station. This station type can charge an EV in only 30 minutes from empty to an 80 per cent charge level, so it is about seven times faster than the medium–fast Level-2 charging station used in all other locations of this project and about 25 times faster than regular home charging. It can charge an EV with either the Combo CCS-1 or the CHAdeMO standard, in order to cover almost all fast-charge capable EVs from the USA/Europe (CCS) and Japan (CHAdeMO).

Below: Vehicle tracking and EV charging station locations in Perth



With 50kW DC charge power, the charger location had to be carefully considered. The selected bay next to the University Club has the advantage of sufficient power reserves of a large building and the driver can get a cup of coffee in one of the many cafes nearby while their car completes a fast charge.

Fast-charging stations will change the game for EVs, as they decouple parking from charging. During the ARC Linkage project we observed many cases of charging stations being used more for parking than for charging. This cannot happen with fast-DC stations, as the allowed usage time is limited to 30 minutes, after which the driver has to remove his/her EV and either drive it away or park it like a conventional vehicle. Fast-DC stations may also make com-mercial charging networks profitable, as they have a much higher customer throughput per day and offer a premium charging service for EV owners. From a research perspective, we are investigating the differences in energy efficiency between slow home charging, medium–fast AC charging, and fast-DC charging. We also plan to investigate the effect of repeated fast charging on battery life.

Above: Prof. Johnson, Prof. Thomas Braunl and Hon. Bill Marmion at the DC fast-charging station launch.

The new DC charging station is located off Hackett Drive in UWA's car park 3 next to the University Club and is open for use by the general public. For the time being, power is free and no parking fees apply.

The station was generously donated to the REV Project by a private Perth individual and was officially launched on 12 December 2014 by the Minister for Transport, Hon. Bill Marmion and by the Vice-Chancellor of UWA, Professor Paul Johnson

Mr Paul Eddington and Professor Thomas Bräunl promoting the Electric Highway Project to Local Government Minister Hon. Tony Simpson on 11 September 2014 at Parliament House

ARC Linkage Project Partners

- WA Department of Transport
- C02 Smart
- AEVA
- Murdoch University
- Gull Petroleum
- UWA Business School
- UWA Faculty of Engineering, Computing and Mathematics

Household Survey of EV Purchase and EV Charging

Dr Fakhra Jabeen

Supervised by Professor John Taplin, Professor Brett Smith, Dr Doina Olaru and Professor Thomas Bräunl

The household survey provided a total of 450 complete responses through a mail-out questionnaire, and 305 respondents through PureProfile panel data.

The mail-out sample showed an average of 1.85 vehicles per household, similar to an average of 1.8 vehicles per household for Perth residents. A comparison of the number of vehicles owned by mail-out and PureProfile samples was performed by using a t-test that is: t(8)=2.3; p=0.99, indicating that in this respect the two samples are not significantly different; approximately 60% of respondents had at least two or more cars in both the mail-out and PureProfile samples.

The mail-out survey showed a large variety of car brands. The most common was Toyota (18%) followed by Holden (11%). A small proportion (4%) of vehicles had an engine size greater than 4 litres, and 91% of vehicle fuel costs were paid by households. Another observation is that 33% of respondents indicated that it is 'somewhat likely'/'likely' that they will purchase an EV in the next five years. Looking at the fuels already used by households: petrol was the most common at 84%; 12% were Diesel, while 1% had EV/Hybrid vehicles. Comparing this with the Australia-wide data, petrol-powered vehicle registrations make 79.9% of the total vehicle fleet, while diesel-powered vehicle registration (including heavy vehicles) make 17.2%, and the rest are LPG, dual fuel and electric vehicles (ABS, 2013).

More than half of the respondents in both the mail-out and PureProfile samples expect to buy a new car in the next three years. When requested to indicate the amount that they were willing to spend to purchase their next car, 8.7% of the mail-out sample reported above $50K, 21.3% between $35K and $50K, 42.3% between $20K and $35K, with the remainder (27.7%) willing to spend less than $20K. The proportions in the PureProfile sample differed considerably; a larger part (39.7%) of the sample were willing to spend less than $20K, with 38.7% between $20K and $35K, 16.7% between $35K and $50K, and approximately 5% willing to spend above $50K for their next vehicle.

In terms of spatial coverage, the mail-out sample did not represent all suburbs of Perth. There were more respondents in the southern part of the city and they were more clustered along the main railway line compared to the north of the city. The online PureProfile sample uniformly covers metropolitan areas of Perth with almost an equal spread of respondents across the north and south of Swan River.

Findings from this study suggest that households from metropolitan areas of Perth are sensitive to purchase and running cost of vehicles. Households preferred short charging times for their vehicles, low noise and low emissions. A large number of respondents were concerned about environment. Another interesting finding from one of the household sample indicated that respondents had a strong preference for large number of charging stations. This reflects a requirement for establishment of charging infrastructure in Perth.

Range remains a barrier in the EV uptake. In the focus group conducted in November 2011 in the WA EV trial, drivers were concerned about the range of an EV and they clearly indicated in their discussions that they would pick EV if either the range is extended or there is availability of fast charging stations. This is confirmed through findings from the household study.

Prizes and Awards

PhD student Stuart Speidel with supervisor Thomas Bräunl won the Asia–Pacific ICT Alliance (APICTA) Awards for the entire Asia–Pacific region. He was awarded the prize in Jakarta on 30 November 2014. Stuart won this award in the Sustainability and Environmental Technology category for the REView project, a web-based portal software package that collects statistics from electronic vehicle trackers, vehicle charging stations, and on usage of renewable energy resources. REView will enable drivers, fleet managers and charging station operators to make more effective business decisions.

This win follows on the heels of Stuart winning the 2014 iAwards National Postgraduate Tertiary Student category on 29 August in Melbourne, recognising the most outstanding project or research undertaken by a postgraduate student or group of students during either coursework or research Masters, Doctoral or Post-Doctoral programs and also the 2014 WAiTTA Incite and Peter Fillery award in the Student Domain (WA IT Award) awarded on 30 June in Perth.

2015

We finally launched our electric jet ski to a huge media crowd. It became Australia's first and only the second electric jet ski in the world.

The 2015 Team

Student Manager: Marcus Pham

Team: Christopher Blignaut, Thomas Churack, Zisu Ding, Thomas Drage, Claye Jensen, Joshua Knight, Shu Low, James McCarthy, Sonia Miranda, Jeethan Rodrigues, Michael Stott

One of the highlights was the long awaited completion of the REV Electric Jet Ski, which received enormous media attention. The electric jet ski provides all the fun of riding a jet ski but without its negative aspects, which are excessive noise and substantial pollution of air and water. The jet ski is as easy to ride as a petrol-based version and all you hear is the splashing of water.

The electric jet ski was launched by UWA's Vice-Chancellor, Professor Paul Johnson in presence of all students and sponsors. Senator Linda Reynolds later visited REV to get first hand information on the electric jet ski as well as on the electric cars.

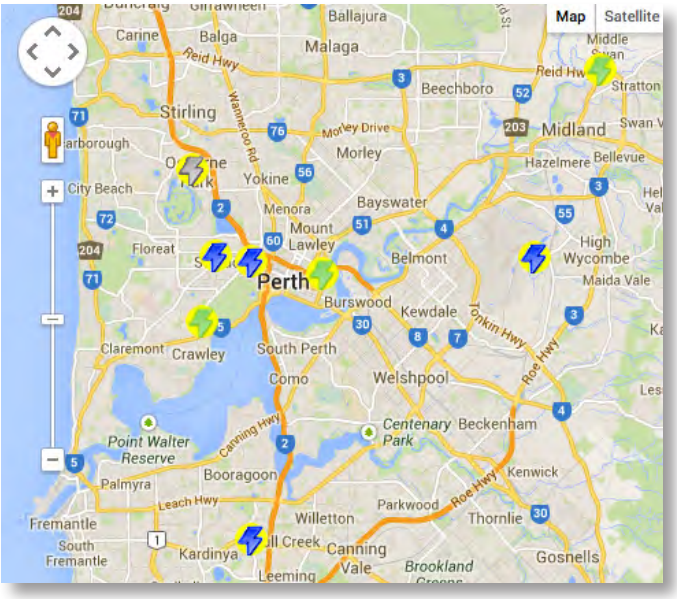
We based our system on a Sea Doo jet ski shell with a 50kW AC motor—developed and donated by Submersible Motor Engineering (SME) Perth, a Curtis controller, and high-current Headway Li-Ion battery cells. A total of 240 battery cells, organised in 30 sets in series of eight parallel battery strands each, enclosed in waterproof PVC tubes. This gives the jet ski an overall voltage of 96V and a total capacity of 7.6kWh. Larger battery packs are an option which we are looking to explore when conducting a first trial with several electric jet skis in a real application environment.

Members of the 2015 REV team

Senator Linda Reynolds examines the REV Electric Jet Ski

REV EV Charging Network

The REV Project continues to monitor electric vehicle charging behaviour as ongoing PhD research projects from its network of EV charging stations established for the WA Electric Vehicle Trial (2010–2014). Public participation in the charging trial is steadily being taken up by Perth locals who own converted or commercial electric vehicles.



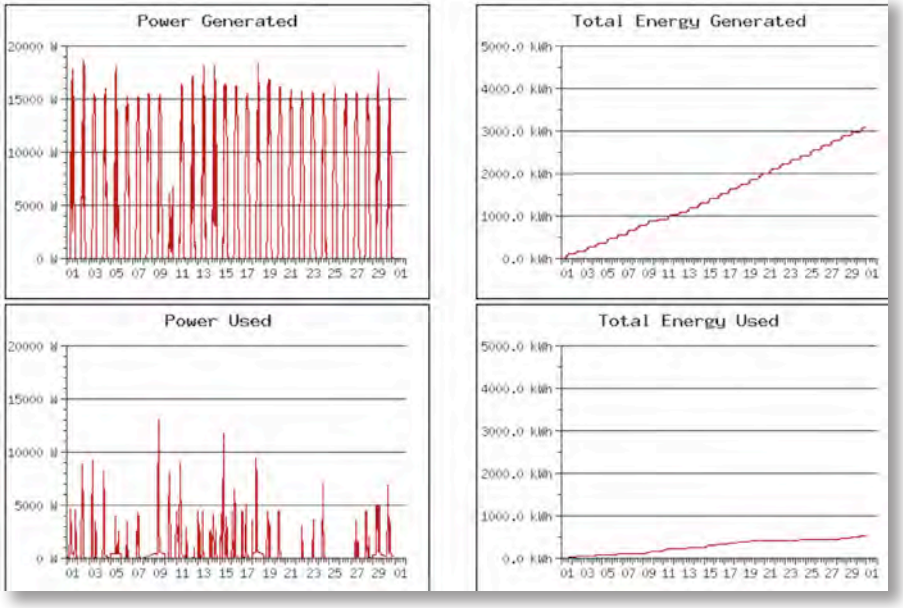
REV Project EV charging station locations are shown on this map.

- UWA University Club
- UWA Engineering
- Murdoch University CREST
- City of Subiaco
- City of Cockburn
- City of Swan
- City of Fremantle
- West Australian Newspaper
- RAC DTEC Centre, Airport
- Mainroads WA
- Perth Transport Authority

Perth's EV Community– gathering of Tesla drivers at Barbagallo Raceway, Wanneroo (Image courtesy of David Lloyd, WA Tesla Community Group).

Energy Monitoring

REV closely monitors the energy used for charging EVs as well as the energy created from on-campus rooftop solar PVs. As our studies have shown, most EV charging happens during sunshine hours, so the energy required for charging can almost directly come from our existing solar PV systems. Very little grid support is required.



REV Vehicle GUI and Instrumentation

Students in the Automotive Lab worked on the design of the Renewable Energy Vehicles' (REV) Graphical User Interface (GUI) and Instrumentation. The focus of the project is on creating a more robust and improved version of the Graphical User Interface (GUI) in the two Renewable Energy Vehicles—the REV Eco (Getz) and the REV Racer (Lotus). The new interface predominantly aims to give the user what is most likely to be the main reason behind their choice of an electric vehicle over an internal combustion vehicle—efficiency. Improvements will enable users to measure and see their driving efficiency and compare this with previous trips in real time. This will encourage drivers to more effectively reduce energy use, and thereby reduce costs and benefit the environment. This task will involve the addition of new features as well as removing redundant and unrequired features to maintain ease of use.

GUI of REV Racer Lotus Elise

UWA Endurance Vehicle Team

Shell Eco-Marathon, Manila

A team of 15 UWA undergraduate students represented Western Australia in the February 2015 Shell Eco-Marathon in Manila, The Philippines.

Over a period of six months the UWA Endurance Vehicle (EnVe) Team planned, designed and constructed the competition racer for the ultra-high-efficiency challenge. For most members, this was the first practical outlet for the skills they had learned in their classes, and was an opportunity to gain an intensive understanding of the design and manufacturing processes they will use throughout their careers. The team's Technical Director Rowan Heinrich, decided they would experiment with highly advanced technology such as vacuum-infused carbon fibre composites and in-house built electrical systems, as this expertise would better prepare members of the team for careers in engineering.

The UWA EnVe Team alongside the team from Deakin University were the first Australian teams ever to travel to the Shell Eco-Marathon, a series of endurance races designed to challenge vehicles of energy types including Hydrogen Fuel Cell, LPG, Petrol and Battery-Electric. The 10-day tour was also the first international competition for a UWA team since 2009.

Shell Global, who invited the team to participate, also hosted over 120 other international teams spanning a region from Egypt to Japan. The incredible scale of the event meant that even the racetrack and buildings for the event had to be planned for more than a year before the actual races.

The vehicle, featuring a full carbon fibre monocoque, 750W (1HP) electric motor, custom-built 48V LiFePO4 battery, adjustable gear system and hydraulic disk brakes managed to endure both a battery system malfunction and a transmission failure before being withdrawn from the race.

The team would like to thank sponsors for joining us on our competition journey.

The next competition for the team is anticipated to be the World Solar Challenge 2017 from Adelaide to Darwin.

Carl P-Conquilla

ITC Global EV Challenge

Following the Shell Eco-Marathon in February 2015, the UWA EnVe team was invited to participate in the 2015 ITC Global EV Challenge in Wundowie, Western Australia.

The competition is open to secondary and tertiary student teams, as well as privately entered teams with a focus on energy efficiency and cost-effectiveness. The entirely carbon-fibre monocoque construction of the 2015 EnVe racer, competed in the dynamic events.

Since the competition is aimed at significantly lower budget vehicles than the UWA entry, the team decided to experiment with some of the more advanced technologies such as heavier steering mechanism, overdriven motor controller, driver-selectable gear ratio and a stiffer rear brake assembly.

Carl P-Conquilla

EnVe 2015 Technical Specifications	
Weight:	62kg
Propulsion:	Rear wheel driven via chain and adjustable ratio sprocket, 750W brushed geared DC motor
Chassis:	Vacuum infused carbon fibre, with foam core, steel front and rear roll hoops, polycarbonate windows
Energy Storage:	12x LiFePO4 cells, 48Wh, 38.4V nominal
Suspension:	Carbon wing cantilever flexure beam, front only
Safety Features:	Five-point harness, fully encapsulating steel roll structure, carbon fibre impact structure front/sides/floor, firewall insulation between electrical systems and driver, rapid escape system (less than 3 seconds escape time), fire extinguisher and emergency shutdown interlock internal and external.

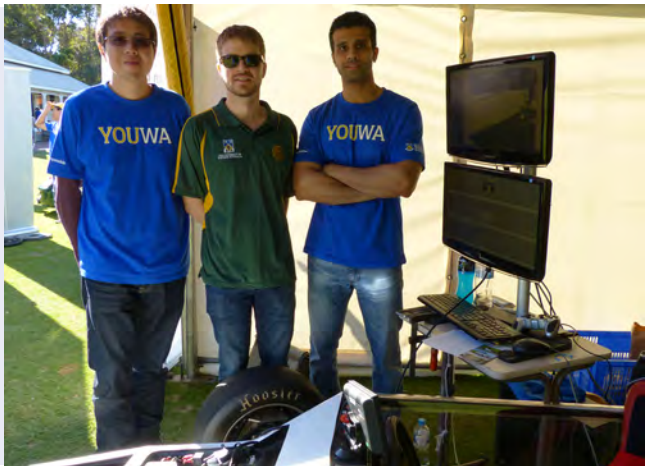
2016

Research work on EV charging for fleets and home owners, as well as on advanced demand response for energy providers was done in cooperation with BMW of North America and California energy provider PG&E (Pacific Gas & Electric) in Mountain View, California.

The 2016 Team

Student Manager:
Marcus Pham

Team:
Thomas Drage,
Kai Li Lim,
Sulaiman Mehfooz



Marcus Pham—Student Manager 2015-2018

From the beginning, I was always one who was interested in vehicles, and cars in particular. Up until 2014, I had only considered this to be a hobby that I enjoyed doing, working on my car on the weekend in between study at UWA. Initially, I had chosen to do a degree in Electrical and Electronic Engineering at UWA as I believed that throughout the degree, I could learn something that could be useful for me both in my career as well as giving me the ability to tinker at home and work on my own electrical projects.

At the end of 2013, when it was time for me to choose my thesis project, I saw the project and knew that this was what I wanted to do. Hence began my journey into electric vehicles, and the ability to join both of my interests. From there, I got myself more involved in the project, which sparked further motivation into using electric vehicles as a solution for climate change.

My thesis was focused predominantly on working with the already converted Getz and Lotus, with me working on the user interface and adding features to better suit electric vehicles. Additionally, along with working on the user interface came maintenance on the cars, which is where I began to really learn the ins and outs of an electric vehicle. And by 2015, I had been offered the role of Student Manager for the REV Project, taking over from Stuart. This lead to even more learning as I watched over students working on the REVSki, the Electric Scooter and the SAE Car. In particular, I learnt a lot about battery systems and battery management over the first few years.

This knowledge opened up many pathways for my future, starting with work at EVWorks, utilising my knowledge gained from the REV Project to do repairs and conversions of cars, lawnmowers and motorbikes (effectively anything that could be done) and leading to my current job at ElectroAero, where we are moving onto building sustainable electric aircraft for transport.

Throughout the 4 years as part of the REV Project, I have seen substantial improvements in movement away from fossil fuels and manufacturers looking for more sustainable methods of transport. I firmly believe that the REV Project has played a part in this positive change and will continue to pave the path to build a sustainable future.

Home Energy Management

We have developed a tool that allows planning and optimizing of solar PV and home energy storage systems, see: http://revproject.com/energy/energy.php

(1) The system starts with the typical daily energy usage distribution for Perth. The usage can be adjusted to match an individual home.

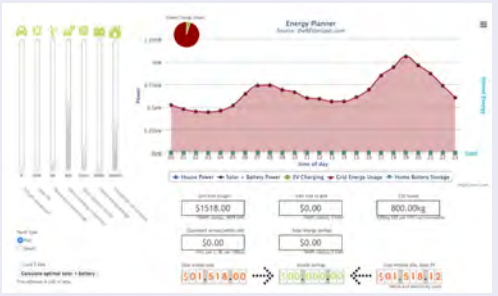
(2) The addition of solar PVs completely offset the energy usage during the daylight hours, but obviously cannot reduce energy consumption in the early morning hours or later afternoon/ evening hours. All excess energy goes back to the grid for a relatively low financial compensation. The figures at the bottom of the graph calculate the annual savings of the selected configuration.

(3) With the addition of home energy storage, we can store the excess energy produced by the solar PV during sunshine hours and use it for all other hours in the day. Pressing the “optimal” button will calculate the best setting for solar PC and energy storage sizing to not require any energy from the grid for the “average day”, bringing the annual energy cost close to zero. Unfortunately these settings are not sufficient to go completely “off the grid”, as a much larger energy storage would be required to overcome a few rainy/cloudy days in a row.

(4) Finally, EVs can be introduced into the household with their average daily driven distances and the effect on the solar/storage configuration be observed and again optimized.

Thomas Bräunl and Stuart Speidel

(1)



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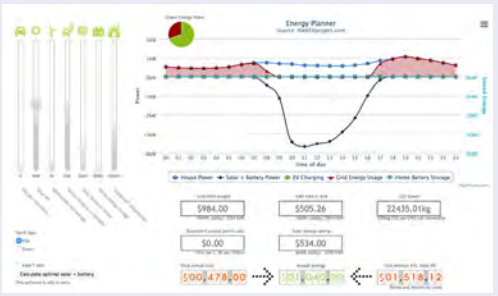

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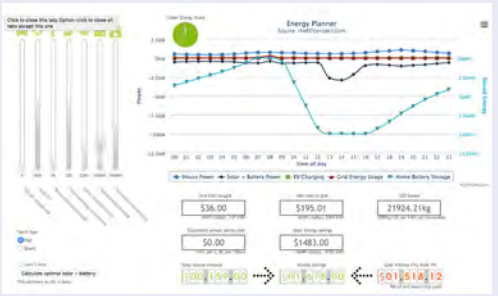


(4)

2017

The 2nd generation electric jet-ski with better weight distribution and advanced battery management and charging hardware was completed.

Also the 2nd generation of our Autonomous Formula-SAE car with an advanced embedded high-performance GPU controller from Nvidia was completed. The car has been invited for a demonstration event to the Melbourne Formula-SAE Competition, to lead into future Australian driverless vehicle competitions.

The 2017 Team

Student Manager: Marcus Pham

Team: Manuchekhr Adina-Zada, Geoffrey Channon, Jayden Dadleh, Logan Chau Zisu Ding, Thomas Drage, Samuel Evans-Thomson, Sara Fong, Anshul Goplani, Hjariz Mohd Jahis, Kai Li Lim, Jason Yao-Tsu Lin, "Rain" Yu Liu, Gabriel Meyer-Lee, Alexander Morgan, Roman Podolski, Mitchell Poole, Maximilian Woloszyn

Autonomous Driving

We are operating two autonomous research vehicles in REV. One is the semi-autonomous BMW X5 (donated by BMW Group), which we use for driver-assistance functions, the other one is the fully autonomous Formula-SAE-Electric car that was originally built and later modified at UWA.

Both cars use a similar sensor setup with GPS, Xsens IMU (Inertial Measurement Unit), IBEO-Lux Lidar, digital camera, and wheel odometry. The drive-by-wire actuation is also similar. Both cars use a DC motor to turn the steering wheel and a powerful servo to push down the brake pedal. The SAE car also has an electronic multiplexer for the accelerator, while the BMW always requires a human driver to push the accelerator.

We conduct research in autonomous driving in different scenarios, using “Deep Learning” approaches to classify sensor input and fuse information from different sensor types for generating a driving path. For on-board signal processing we are using an Nvidia Jetson processor board, for offline learning we are using an Nvidia Titan X GPU board (donated by Nvidia).

Above: The brake-pedal electric servo in the BMW

Above and below: The BMW steers autonomously around a stationery vehicle

Energy Efficiency of Electric Vehicles and Recharging Technologies

Dr Guido Wäger

Supervised by Professor Thomas Bräunl, Dr Jonathan Whale and Professor David Harries

Transportation in our developed world is a complex system and a major component of the world economy. However, the unsustainable use and air pollution caused by the use of conventional motor vehicles and their dependency on fossil fuels are a major concern. Although electric vehicles (EVs) are feasible solutions to reduce current transport issues EVs face market uptake barriers in particular due to limited range as well as efficiency and recharging issues. Although many major car manufacturers offer EVs there are knowledge gaps in efficient use and operation of these vehicles. This project will identify and analyse inefficiencies from the charging infrastructure to the vehicle operation and use and will offer potential solutions.

Firstly the project has investigated energy efficiency improvements by synchronising auxiliary air-conditioning (AC) with the vehicle drive train on a real road driving cycle pattern. The research findings are applicable to EVs, internal combustion engine (ICE) vehicles, and hybrids. An EV-converted Ford Focus was configured to operate the AC compressor solely from kinetic energy recovered from the drive train when coasting or slowing down. Test drives with the Ford Focus with standard AC operation increased the energy consumption by 11.6% compared to AC off, yet when the vehicle was synchronised with the drive train the energy consumption increased by only 5.8% compared to AC off, an energy saving of 8.1Wh km-1. The configuration maintained comfortable cabin conditions (temperature and humidity) similar to driving with a standard AC system configuration. In vehicles with an interconnected automatic AC and engine management system data-bus, this efficiency improvement may require a software update only. The second part of the project investigated driving of electric vehicles at highway speeds. Fast-DC charging significantly reduces the recharging time and can be used to make longer EV trips possible, e.g. on highways between cities. Although some EV and hybrid car studies have been conducted that separately address issues such as limited drivable ranges, charge stations, impact from auxiliary loads on vehicle energy consumption and emissions, there is currently limited research on the impact on drivable range from the combination of driving EVs at highway speeds, using auxiliary loads such as heating or air conditioning (AC), and reduced charge capacity from fast-DC charging and discharge safety margins. In this study we investigate these parameters and their impact on energy consumption and drivable range of EVs. Our results show a significantly reduced range under conditions relevant for highway driving and significant deviation from driving ranges published by EV manufacturers. The results and outcomes of this project are critical for the efficient design and implementation of so-called 'Electric Highways'. To prevent stranded cars and a possible negative perception of EVs, drivers and charging infrastructure planners need be aware of how EV energy and recharging demands can significantly change under different loads and driving patterns.

Further studies are planned for 2017 investigating efficient acceleration and decelerations (Smart Braking) of electric vehicles.

Autonomous Visual Navigation for Ground Robots and Vehicles

Kai Li Lim

Supervised by Professor Thomas Bräunl

Autonomous mobile robotics is a popular research field in recent times, as they are becoming increasingly indispensable for tasks that require the exploration of uncharted areas, reconnaissance and search-and-rescue operations. Likewise, the advent of visual and high-performance computing such as General-purpose computing on graphics processing units (GPGPU) is seeing the solving of computer vision problems at unprecedented speeds and accuracy. This research project works on a holistic visual navigation solution for autonomous ground robots and vehicles. This solution combines visual odometry and scene recognition to achieve navigation and localisation.

Visual odometry is an alternative to wheel odometry that is commonly used in mobile ground robots, its application is most beneficial for the solving of wheel slip—an odometric error that commonly occurs in varying terrains that accumulate during navigation. Using visual odometry also enables the robot to perform obstacle detection and avoidance, whereby the algorithm will be capable of estimating the distances between the robot and the obstacles through motion perception.

Visual scene recognition supplements visual odometry to achieve positioning and localisation using the camera, without the need for additional sensors or environmental fixtures. This is achieved by associating and recognising objects and features that are unique to a certain location. The recognition of these objects also enables obstacles to be tracked and classified, supplementing the results from optical flow on applications such as pedestrian detection and tracking. Additionally, using scene recognition enables the segmentation of ground areas into traversable and nontraversable areas; an example of this is the detection of kerbs and lane markers on roads. While visual odometry and place recognition is widely researched independently, works that combine both elements with optical flow are few. This project's execution will be done in two parts, where algorithms will first be tested on a Raspberry Pi-controlled mobile robot for prototyping before it is ported onto an electric vehicle for final testings. The finished product will incorporate state-of-the-art visual navigation techniques such as deep learning and classification on a dedicated hardware platform for autonomous driving.

2018

REV is focusing on an all-new approach for autonomous driving as well as completing the 2nd generation of our electric jet ski.

In addition, we are working on home energy management projects with EV integration.

The 2018 Team

Student Manager: Marcus Pham

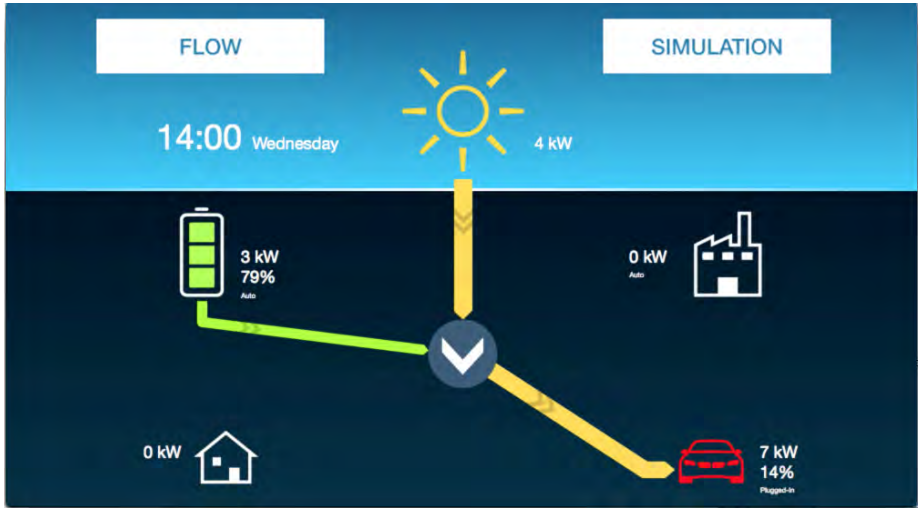
Team: Craig Brogle, Timothy Dan, Thomas Drage, Junho Jung, William Lei, Patrick Liddle. Kai Lim, Guido Wager, Chao Zhang.

We have completed the second generation electric jet ski, with an improved battery management system (BMS) and with a better weight balance than the original prototype, giving us a much better ride performance.

The software of the Autonomous SAE car is being completely rewritten, concentrating on two use-case scenarios. One is the Formula-SAE Autonomous competition, which uses a race track set by two rows of cones for the vehicle to drive through.

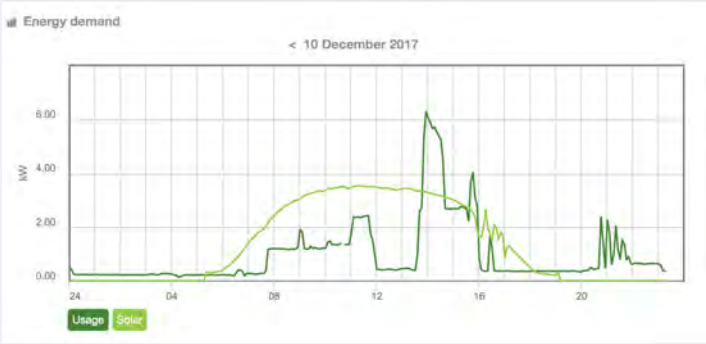
The other is the automatically detect and drive the internal roads of UWA by identifying lane markings with the camera and identifying the curb position with the Lidar sensor.

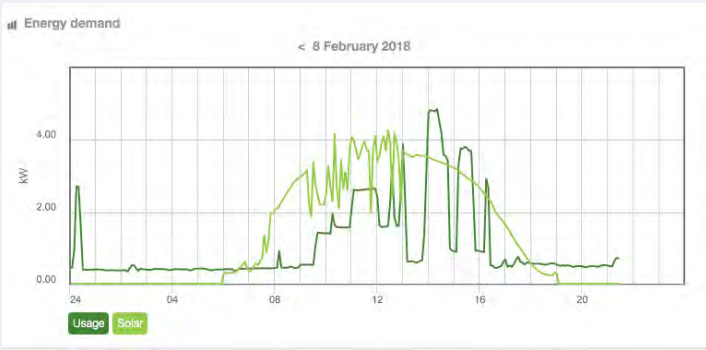
On the energy side we are looking at integrating electric vehicles into private homes as well as into company fleets, where concurrent charging of a larger number of EVs can be a real challenge.

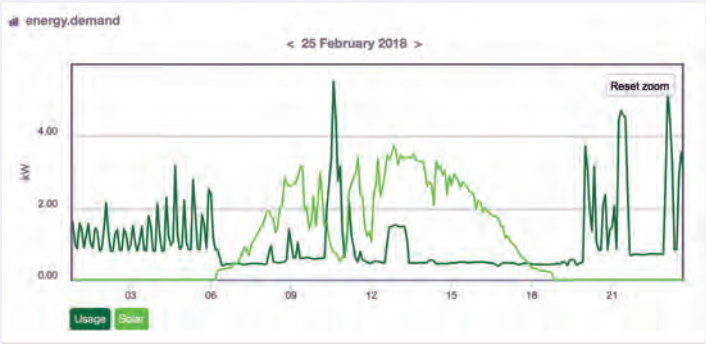


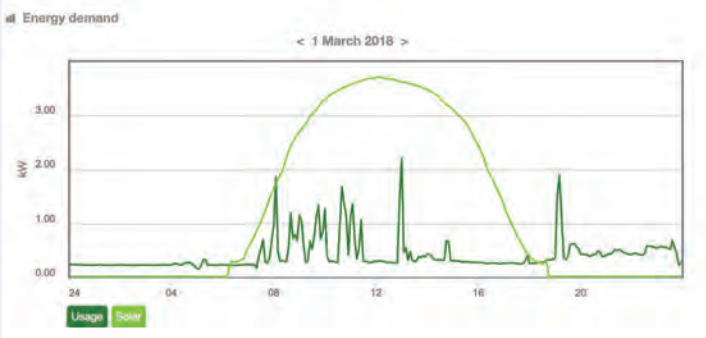
Together with the BMW Technology Center in Mountain View, California, we developed a Home Energy Management System (HEMS) which can control and visualise the power flow between solar PVs (renewable energy) and grid as inputs, plus household, EV charging and a battery-based home energy storage unit as outputs.

By analysing electric power demands of typical households, we are determining which home energy storage size will be cost-effective for private households. Solar energy is not always available when energy is needed, but also at times when there is usually sufficient solar energy, small disturbances such as clouds or a short temporary higher household demand can require energy import from the grid. Some smaller energy storage units may be sufficient to buffer these temporary demands and result in overall lower energy costs for private households.









2019 to 2029

We still have many goals for the next ten years of REV to come, making progress on both the EV sector as well as in autonomous driving.

Hopefully soon, EVs will be mainstream and thousands of them replacing petrol and diesel cars.

Recent studies have shown that significantly more people die prematurely from vehicle emissions than from road accidents. This must be the thought-provoking impulse to change our transport habits.

We now look back at the time 20 years ago and wonder how we could tolerate smoking in restaurants and other public places. In 20 years from today, our children will probably wonder how we could tolerate vehicle emissions in our cities today.

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Talks and Demonstrations

Invited Talks on REV (Professor Thomas Bräunl)

14 Dec. 2017	Invited Talk: Electric Vehicle Future, Rotary Club, Belmont
27 Nov. 2017	Invited Talk: Automotive Trends, Western Power, Perth
19 July 2017	Invited Keynote: Future Automotive Trends and How They Will Also Change Our Homes, IEEE Western Australia & Western Power
3 May 2017	Invited Talk: Building Robot Cars, Robotics Week, UWA Futures Observatory, Perth
20 Mar. 2017	Invited Talk: Silicon Valley Goes Automotive, Synergy, Perth
16 Feb. 2017	Invited Talk: Electric Vehicles, PACE Seminar Series, UWA
12 Dec. 2016	Invited Talk: From Autonomous Robots to Driverless Cars, Edge of Robotics Workshop, UWA
11 Nov. 2016	Invited Talk: Vision-Based Driver-Assistance Systems, Tongji University, Shanghai, China
23 Sep. 2016	Invited Talk: From Silicon Valley to Automotive Valley, Department of Transport, Perth Transit Authority, East Perth
22 July 2016	Automotive Valley, UWA/EECE Sabbatical Seminar Presentation
24 June 2016	ChargeForward and HEMS-EV Integration, BMW Group Technology Office, Mountain View CA
9 Feb. 2016	REV Lab Presentation at BMW Group Technology Office, Mountain View CA
20 Dec. 2015	Keynote Address together with Reinhard Klette (AUT, NZ) on Smart Vehicles for a Smart City, 2015 IEEE International Conference on Smart City, Chengdu, China
4 Dec. 2015	Invited Talk on Autonomous Vehicle Research, for Innovation Autonomous Vehicles Roundtable, PriceWaterhouseCoopers, Perth
3 Sep. 2015	Invited Talk: Electric Vehicle Research in Western Australia, AEVA Annual Meeting, Fremantle
11 Aug. 2015	Invited Talk: From Mobile Robots to Autonomous Vehicles, UWA Engineering Seminar, Perth
23 July 2015	Keynote Address: Autonomous Vehicles – The Future of Mobility, Australian Institute of Traffic Planning and Management (AITPM) - Self-Driving Vehicles Technical Forum, Perth
17 Feb. 2015	Keynote Address: From Electric Cars to Autonomous Vehicles, The 6th International Conference on Automation, Robotics and Applications (ICARA 2015), Queenstown, New Zealand
9 Dec. 2014	Invited Talk: Australia's First Combo-CCS Station at UWA, AEVA, Perth
10 Aug. 2014	Keynote Address: The Electric Vehicle Revolution - Lessons learned from the Western Australian EV Trial, TUM Expert Seminar on Electromobility in Tropical Megacities, Singapore
29 Nov. 2013	Invited Talk: Australia's First Electric Vehicle Trial, Sustainable Energy Association SEA, Perth
25 Oct. 2013	Invited Talk: Electric Vehicles, Building Better Schools Conference, Perth
17 Aug. 2013	Invited Talk: The Electric Car Revolution, University of the 3rd Age, Melville
26 Mar. 2013	Keynote Address: Electric Vehicle Trial in Western Australia, E-mobilia World, Kuala Lumpur
21 Mar. 2013	Keynote Address: Electric Vehicle Charging Future, MIECF Intl. Environmental Co-operation Forum, Macao
8 Oct. 2012	Invited Talk: Electric Vehicles, Public Works Training Week, Esplanade Hotel, Fremantle
31 July 2012	Keynote Address: From Robotics to Automotive Research, at: An Evening with Young Australian of the Year, Marita Cheng, Perth
20 Apr. 2012	Invited Talk: Electromobility meets Robotics, UWA Faculty of Engineering, Computing and Mathematics
16 Mar. 2012	Invited Talk: Safety Aspects of EV Charging, Steering Committee of WA Electric Vehicle Trial
13 Mar. 2012	Invited Talk: Future of EV Charging, Australian Electric Vehicle Association
29 Feb. 2012	Invited Talk: Electric Vehicle Charging Trends, ARC Linkage Meeting on EV Charging, UWA
8 Feb. 2012	Invited Talk: Electric Vehicle Charging, Solar Seminar, Peel Development Commission, Mandurah
19 May 2011	Invited Talk: The Electric Vehicle Revolution, WaterCorp, Perth
12 May 2011	Invited Talk: Electrification of Personal Transport in Western Australia, Western Power, Perth
14 Apr. 2011	Invited Talk: The Electric Vehicle Revolution, Centre for Water Research, Perth
25 Mar. 2011	Invited Talk: Is Western Australia ready for Electric Cars?, Energising South East Asia, Perth Convention Centre
17 Feb. 2011	Invited Talk: Electric Vehicles in Western Australia, Australian Fleet Managers Association, Perth
19 Nov. 2010	Keynote Address: Renewable Energy Vehicle Racer Lotus Elise Launch, UWA
5 Nov. 2010	Invited Talk: REV and WA Electric Vehicle Trial, 2010 AEVA National EV Festival Conference, Adelaide
22 Oct. 2010	Invited Talk: Electric Vehicles in Perth, Swan Rotary Club
21 Oct. 2010	Invited Talk: WA Electric Vehicle Trial, Electric Vehicles and Smartgrid Conference, Brisbane
21 Sep. 2010	Invited Talk: Electric Cars in Western Australia, MainRoads Australia
8 June 2010	Invited Talk: Electric Cars in Western Australia, The Society for Sustainability and Environmental Engineering (SSEE), Engineers Australia, Perth
12 May 2010	Invited Talk: Electric Vehicles, UWA Transport Workshop, Perth
11 Mar. 2010	Invited Talk: WA Electric Vehicle Trial Launch, University Club UWA with 100 guests from industry and government, including WA Minister for Transport, Simon O'Brian, WA Minister for Environment, Donna Faragher, UWA Vice-Chancellor Professor Alan Robson
8 Dec. 2009	Invited Talk: Electric Vehicle Charging, AEVA Perth Branch
15 Apr. 2009	Invited Talk: The Renewable Energy Vehicle Project at UWA, AEVA Perth Branch
20 Nov. 2008	Keynote Address: Renewable Energy Vehicle ECO Launch, UWA
23 June 2008	Invited Talk: Vision-Based Driver-Assistance Systems, Université Pierre et Marie Curie, Paris
20 Feb. 2008	Invited Talk: Electric Vehicle Projects at UWA, AEVA Perth Branch
21 Sep. 2007	Invited Talk: Automotive Image Processing, School of EECE, UWA
7 Feb. 2007	Invited Talk: Open Source Image Processing for Driver-Assistance Systems, Chair for Realtime Computer Systems, TU München, Germany

REV Project Demonstrations

16 Nov. 2017	REV Lab demonstrations for Woodside, Australia
14 Nov. 2017	REV Lab demonstrations for Geraldton Senior College
9 Sep. 2017	REV Presentation Research Week Teachers Inspiration Event
13 Aug. 2017	REV Presentation UWA Open Day
27 Apr. - 5 May 2017	EV Charging Demonstrations (AC and DC) and REV lab presentations for Synergy (over 4 days with 5 visitor groups each)
11 Feb. 2017	REV Vehicle Presentations at AEVA Elektrikhana, DTEC Perth Airport
8 Dec. 2016	REV Lab demonstration for Galaxy Resources
5 Dec. 2016	REV and Robotics&Automation Lab demonstration for Huawei
14 Aug. 2016	REV Jetski, EV, and Autonomous Vehicle exhibition at UWA Open Day
9–24 Apr. 2016	Electric Jetski Exhibition at Meet the Innovator event at SciTech, Perth
17–18 Mar. 2016	Electric Jetski Exhibition at Innovation Festival at SciTech, Perth
12 Mar. 2016	REV Electric Vehicle Exhibition at AEVA Elektrikhana, DTEC Driving Centre, Perth Airport
15 Jan. 2016	Automotive Demonstrations for visitors from Xiamen University of Technology XMUT, China
11 Dec. 2015	REV Electric Jet-Ski Demonstration for Senator Reynolds, UWA
20 Nov. 2015	REV Electric Jets-SKi Launch Event, UWA
4 Sep. 2015	REV Lotus Exhibition at AEVA Annual Meeting, Fremantle
28 Aug. 2015	REV Automotive Lab demonstrations for Ignite Program, Balga Senior High School
23 July 2015	Autonomous Vehicle Demonstratio for Australian Institute of Traffic Planning and Management (AITPM) - Self-Driving Vehicles Technical Forum, Perth
15 June 2015	REV Lotus demonstration for Byford Primary School
8 June 2015	REV Lotus demonstration for Dalkeith Primary School
3 June 2015	REV Demonstrations for Engineering Delegation from Coolbinia Primary School
2 June 2015	REV Demonstrations for Engineering Delegation from Universty Teknologi Malaysia (UTM)
7 Mar. 2015	REV Lotus, REV Getz and REV Autonomous SAE car presentation and demonstration at Electrikhana, RAC DTEC Race Course, Perth Airport
21–28 Nov 2014	REV Lotus Exhibition at Sustainability Week, Scitech, Perth
13 Oct. 2014	REV lab visit and demonstrations for Christ Church Grammar School
10 Oct. 2014	REV lab visit and demonstrations for University Teknologi, Mara, Malaysia
10 Aug. 2014	REV Autonomous EV Demonstrations, UWA Open Day
10 Apr. 2014	REV EV Demonstrations for Coolbinia Primary School
1 Apr. 2014	REV EV Demonstrations at Environfest, UWA, Perth
8 Mar. 2014	REV Racer Electric Lotus Demonstration at Elektrokhana, DTEC Driving Centre, Perth Airport
12–16 Dec. 2013	Formula SAE-Australasia Electric Competition, Victoria University, Melbourne
7 Nov. 2013	REV Electric Vehicle Demonstrations for Scotch College Highschool
6 Nov. 2013	REV Demonstrations for Engineering Delegation from Universty Teknologi Malaysia (UTM)
25 Oct. 2013	REV Electric Vehicle Exhibition at the Model Solar Car and Boat Challenge
16 Aug. 2013	REV Lotus Presentation at Lynwood High School
11 Aug. 2013	REV Demonstration of Electric Lotus and Electric Getz for UWA Open Day
11 Aug. 2013	Autonomous SAE Car Demonstration for UWA Open Day
31 July 2013	Autonomous SAE Car Demonstration for Japanese High School, Perth
1 May 2013	REV Project Demonstration for International Agents at UWA
10 Apr. 2013	REV Demonstrations for Leadership WA Meeting, Perth
23 March 2013	REV Demonstrations for Earth Hour, Perth
19 Mar. 2013	REV Demonstration at EnviroFest, Perth
10 Mar. 2013	REV Demonstrations of REV Racer, REV Eco, REV-SAE 201 and REV SAE-2013 at Electrokhana, RAC DTEC Driving Centre, Perth Airport
15 Jan. 2013	REV Demonstration for Scitech / CSIRO, Perth
11 Dec. 2012	REV Demonstration at Mount Lawley Senior High School
16 Nov. 2012	REV Demonstration for Bosch Investments, China
2 Nov. 2012	REV EV Trial Presentation at Kapinara Primary School
25–26 Oct. 2012	REV Exhibition for Model Solar Car Challenge, Perth
19 Sep. 2012	REV SAE-Electric Exhibition at the UWA Postgrad Expo
19 Sep. 2012	Representing REV and Perth's EV charging station network at the Sustainability Innovation Think Tank, Fremantle
7 Sep. 2012	Charging Station demonstration for Senator Christine Milne, Australian Greens Leader, UWA
17 Aug. 2012	REV Demonstration, Lynwood Senior High School, Parkwood
12 Aug. 2012	REV Demonstrations, UWA Open Day
3 Aug. 2012	REV Demonstration for representatives of University of Notre Dame, Illinois
17. July 2012	REV Demonstrations for "A Day in the Life of an Engineering Student", UWA
2 May 2012	REV Vehicle and Charging Station Demonstration for International Agents at UWA
26 Apr. 2012	REV Vehicle Exhibition and Demonstration, Elektrokhana, RAC-DTEC Driving Centre, Perth Airport
22 Apr. 2012	REV Vehicle Exhibition at Electric Fair, Northbridge
18 Apr. 2012	REV Student Project Demonstrations for UWA Media Unit
1 Apr. 2012	REV SAE-Electric car exhibition at Perth Sun Fair
26 Apr. 2012	REV Vehicle Demonstration for delegation from Anna University, India
23 Feb. 2012	REV Demonstration for Heilongjiang Province student delegation (China)
19. July 2011	REV Racer Lotus demo for "A day in the life of a uni student", UWA
19. July 2011	REV Racer Lotus demo for Yanchep Beach Development Project
30. June 2011	REV demonstration for IIT Kharagpur
11–18. July 2011	REV Eco Getz exhibition at Gravity Discovery Centre, Gingin
6 May 2011	REV Racer Lotus demonstration for Beilby, East Perth
13 Apr. 2011	REV Lotus and Getz demonstration for International Agents, UWA
10 Apr. 2011	REV Lotus exhibition at Perth Sun Fair
22–26 Mar. 2011	REV Lotus exhibition at Energising South East Asia Conference and Exhibition, Perth Convention Centre
28 Nov. 2010	REV Racer Lotus Elise presentation at Perth Festival of Speed
26 Nov. 2010	REV Formula SAE-Electric presentation at Opening of Monadelphous Integrated Learning Centre, UWA

25 Nov. 2010	WA Electric Vehicle Trial Presentation to RAC BusinessWise Day, RAC DTEC Driving Centre, Perth Airport
22 Nov. 2010	REV Project Presentation to UWA Indian Partners
19 Nov. 2010	REV Racer Lotus Elise Launch
10 Nov. 2010	REV Project Presentation for UWA New Courses Visitors
5 Nov. 2010	Launch of WA Electric Vehicle Trial prototype car and EV charging station at RAC, West-Perth
22 Oct. 2010	REV project presentation for Swan Rotary Club
5 Oct. 2010	Scitech Double Helix Science Club, REV Demonstrations
21 Sep. 2010	REV demonstration for MainRoads Australia
15 Sep. 2010	International Agents Showcase at UWA, REV Demonstrations
14 Sep. 2010	Kapinara Primary School, REV Demonstrations
11 Aug 2010	UWA Environmental Week, REV Demonstrations
29. July 2010	China University of Petroleum Visit, REV Demonstrations
2 July 2010	Electric Vehicle Demonstration of REV Eco for RAC WA
25 June 2010	Eng Quest, All Saints College, REV Demonstrations
10 May 2010	Electric Vehicle Demonstration of REV Eco at Carey College Thornlie
1–2 May 2010	Electric Vehicle Demonstration of REV Eco at Carmel Sustainability Exposition
30 April 2010	Electric Vehicle Demonstration of REV Eco at Days of Change Launch, Central Park Perth
22–24 Mar. 2010	Electric Vehicle Demonstration of REV Eco at Energising WA National Conference, Burswood Entertainment Complex, Perth
11 Mar. 2010	Electric Vehicle Demonstration of REV Eco, REV Racer, REV E-SAE at WA Electric Vehicle Trial Launch, University Club UWA with 100 guests from industry and government, including WA Minister for Transport, Simon O'Brian, WA Minister for Environment, Donna Faragher, UWA Vice-Chancellor Professor Alan Robson
15. Jan. 2010	Electric Vehicle Demonstration at Western Australian Parliament House
12 Dec. 2009	Electric Vehicle Demonstration at Elektrokhana, EV Works, RAC Driving Centre, Perth International Airport
6 Nov. 2009	Electric Vehicle Demonstration to WA Premier Colin Barnett: Ravensthorpe Galaxy Lithium Mine Ground Breaking, Ravensthorpe
25 Sep.–3 Oct. 2009	Electric Vehicle Demonstration: Perth Royal Show, Claremont Showgrounds, Perth
14–18 Sep. 2009	Electric Vehicle Demonstration: Kalgoorlie Races, Kalgoorlie
30 May –1 June 2009	Electric Vehicle Demonstration: Sustainable Energy Expo, Perth Convention Centre, Perth
12 May 2009	Electric Vehicle Demonstration: Science Show at St Hilda's School, Perth
5 Apr. 2009	Electric Vehicle Demonstration: Perth Sun Fair, UWA, Perth
28 Mar. 2009	Electric Vehicle Demonstration: Galaxy Resources Meeting, Burswood Convention Centre, Perth
22–26 Mar. 2009	Electric Vehicle Demonstration: Greenhouse 2009, Burswood Convention Centre, Perth
21 Nov. 2008	Automotive Demonstration: ResourCity, Central Park Foyer, Perth
20 Nov. 2008	Automotive Demonstration: Going Places - the Technology of Transport, Scitech, Perth
20 Nov. 2008	Automotive Demonstration: Renewable Energy Vehicle ECO Launch, UWA

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G. Wäger, Jonathan Whale, T. Bräunl, Smart Accelerating and Braking—Achieving Higher Energy Efficiencies in Electric Vehicles, International Journal of Electric and Hybrid Vehicles, Inderscience, Dec. 2017

G. Wäger, J. Whale, T. Bräunl, Performance Evaluation of Regenerative Braking Systems, Journal of Automobile Engineering, Part D, 1-14, Institute of Mechanical Engineers, 2017, pp. (14).

G. Wäger, J. Whale, T. Bräunl, Battery Cell Balance of Electric Vehicles under Fast-DC Charging, International Journal of Electric and Hybrid Vehicles (IJEHV), vol. 8, no. 4, pp. 351-361 (11), 2016

S. Speidel, T. Bräunl, Leaving the Grid - The Effect of Combining Home Energy Storage with Renewable Energy Generation, Renewable & Sustainable Energy Reviews, vol. 60, pp. 1213-1224 (12), July 2016

G. Wäger, J. Whale, T. Bräunl, Driving Electric Vehicles at Highway Speeds – The effect of higher driving speeds on energy consumption and driving range for electric vehicles in Australia, Renewable & Sustainable Energy Reviews, vol. 63, pp. 158-165 (8), 2016

J. Oakley, M. McHenry, T. Bräunl, Limitations of testing standards for battery electric vehicles: accessories, energy usage, and range, IET Electrical Systems in Transportation, pp. (17), 2016

T. Drage, J. Kalinowski, T. Bräunl, Integration of Drive-by-Wire with Navigation Control for a Driverless Electric Race Car, IEEE Intelligent Transportation Systems Magazine, pp. 23-33 (11), Oct. 2014

G. Wäger, M. McHenry, J. Whale, T. Bräunl, Enhanced EV and ICE vehicle energy efficiency through drive cycle synchronisation of deferred auxiliary loads, Intl. Journal of Electric and Hybrid Vehicles (IJEHV), pp. 179–194 (16), Oct. 2014

William Jacobs, Melinda Hodkiewicz, Thomas Bräunl, A cost-benefit analysis of electric loaders to reduce diesel emissions in underground hard rock mines, IEEE Transactions on Industry Applications, pp. (10), 2014

S. Speidel, T. Bräunl, Driving and charging patterns of electric vehicles for energy usage, Renewable and Sustainable Energy Reviews, vol. 40, Aug. 2014, pp. 97-110 (14)

William Jacobs, Thomas Bräunl, Melinda Hodkiewicz, The diesel-electric debate for underground mines – health and economic perspectives, Australian Resources & Investment Magazine, ARIM, vol. 8., no.1, Mar. 2014, pp. (3)

G. Wäger, M. McHenry, J. Whale, T. Bräunl, Testing energy efficiency and driving range of electric vehicles in relation to gear selection, Renewable Energy, Elsevier, no. 62, Feb. 2014, pp. 303-312 (10)

Soo Teoh, Thomas Bräunl, Symmetry-Based Monocular Vehicle Detection System, Journal of Machine Vision and Applications, Springer, vol. 23, no. 4, July 2012, pp. 831-842 (12)

Thomas Bräunl, Synthetic engine noise generation for improving electric vehicle safety, Intl. Journal on Vehicle Safety, vol. 6, no.1, 2012 pp. (8)

Jon Mullan, David Harries, Thomas Bräunl, Stephen Whitely, The technical, economic and commercial viability of the vehicle-to-grid concept, Journal of Energy Policy, vol. 40, issue 6, June 2012, pp. (13)

Jon Mullan, Stephen Whitely, David Harries, Thomas Bräunl, Modelling the Impacts of Electric Vehicle Recharging on the Western Australian Electricity Supply System, Journal of Energy Policy, vol. 39, issue 7, July 2011, pp. 4349-4359 (11)

Cheng Lim, Rosbi Mamat, Thomas Bräunl, Impact of Ambulance Dispatch Policies on Performance of Emergency Medical Services, IEEE Transactions on Intelligent Transportation Systems, 2011, pp. 624-632 (9)

International Conferences

Kai Li Lim, Thomas Drage, Thomas Bräunl, Implementation of Semantic Segmentation for Road and Lane Detection on an Autonomous Ground Vehicle with LIDAR, 2017 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems, Nov. 2017, Daegu, Korea

S. Teoh, T. Bräunl, Performance Evaluation of HOG and Gabor Features for Vision-based Vehicle Detection, 5th IEEE Intl. Conf. on Control System, Computing and Engineering (ICCSCE 2015), Penang Malaysia, 27.-29. Nov. 2015, pp. 72-77 (6) Best Paper Award

T. Drage, T. Churack, T. Bräunl, LIDAR Road Edge Detection by Heuristic Evaluation of Many Linear Regressions, 18th IEEE Intl. Conf. on Intelligent Transportation Systems, ITSC 2015, Gran Canaria, Sep. 15-18, 2015, pp. (6)

William Jacobs, Melinda Hodkiewicz, Thomas Bräunl, A cost-benefit analysis of electric loaders to reduce diesel emissions in underground hard rock mines, IEEE IAS 2014 Annual Meeting, 5.-9. Oct. 2014, Vancouver Canada

T. Drage, J. Kalinowski, T. Bräunl, Development of an Autonomous Formula SAE Car with Laser Scanner and GPS, The 19th World Congress of the International Federation of Automatic Control, IFAC'14, Aug. 2014, Cape Town, South Africa

J. Kalinowski, T. Drage, T. Bräunl, Drive-By-Wire for an Autonomous Formula SAE Car, The 19th World Congress of the International Federation of Automatic Control, IFAC'14, Aug. 2014, Cape Town, South Africa

F. Jabeen, D. Olaru, B. Smith, T. Bräunl, S. Speidel, Electric vehicle battery charging behaviour: Findings from a driver survey, Australasian Transport Research Forum ATRF, 2013, Brisbane, Australia, 2.-4. Oct. 2013, pp. (15)

S. Speidel, F. Jabeen, D. Olaru, D. Harries, T. Bräunl, Analysis of Western Australian Electric Vehicle and Charging Station Trials, 35th Australian Transport Research Forum (ATRF), Perth, Sep. 2012, pp. (12)

F. Jabeen, D. Olaru, B. Smith, T. Bräunl, S. Speidel, Acceptability of Electric Vehicles: Findings from a Driver Survey, 35th Australian Transport Research Forum (ATRF), Perth, Sep. 2012, pp. (14)

S. Teoh, T. Bräunl, A reliability point and Kalman filter-based vehicle tracking technique, Proceedings of the International Conference on Intelligent Systems (ICIS'2012), Penang, Malaysia, 2012, pp. 134-138 (5)

Adrian Boeing, Thomas Bräunl, ImprovCV: Open Component Based Automotive Vision, IEEE Intelligent Vehicles Symposium, IV 2008, Eindhoven, Netherlands, June 2008, pp. (6)

Azman Yusof, Thomas Bräunl, Using Xilinx ML310 Development Board as Testing and Development Platform for FPGA-based Embedded Vision System, International Conference on Robotics, Vision, Information and Signal Processing, ROVISP'07, Penang Malaysia, 28-30 Nov. 2007, pp. (4)

Magazines

T. Bräunl, Costly, toxic and slow to charge? Busting electric car myths, The Conversation, Melbourne Australia, article no. 21321, 20. Feb. 2014, pp. (5)

T. Bräunl, Trial complete: electric vehicles can work in Australia, The Conversation, Melbourne Australia, article no. 118843, 2. Dec. 2013, pp. (4)

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T. Bräunl, Setting the standard: Australia must choose an electric car charging norm, The Conversation, Melbourne Australia, article no. 16277, 16. Sep. 2013, Melbourne Australia, pp. (3)

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