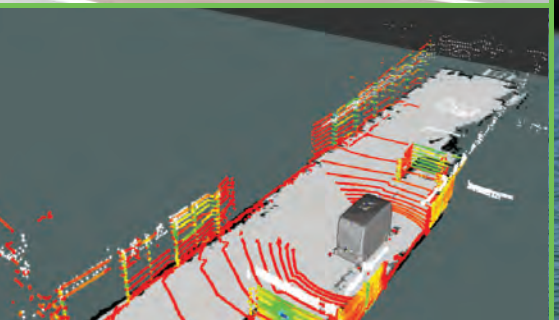
The Renewable Energy Vehicle Project (REV)

2008–2023

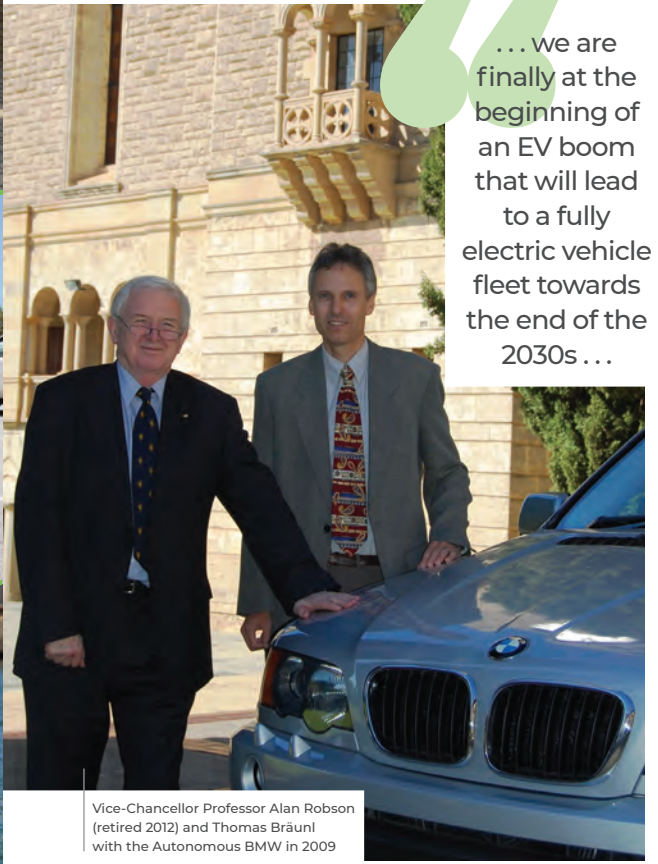
15 Years of Excellence



Foreword

The past fifteen years of the REV Project have seen the rise of electric cars. We did some of Australia's first road-legal electric vehicle conversions based on Lithium batteries in 2008—and we were surprised on how long it took the industry to adapt to this new technology. Fast forward to 2023 and we are finally at the beginning of an EV boom that will lead to a fully electric vehicle fleet towards the end of the 2030s.

With the advancement of the EV development and production by all major OEMs, our focus has changed as well. In recent years, REV has worked on electric watercraft, on EV charging networks and network software, but most prominently on autonomous driving. This involves four vehicles, from the advanced driver-assistance system we implemented in a BMW X5, over Australia's first fully autonomous Formula SAE race car, to the two autonomous shuttle buses that we are working on today.



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

> . . . we are finally at the beginning of an EV boom that will lead to a fully electric vehicle fleet towards the end of the 2030s . . .

Almost 300 students have participated in REV as team members, project leaders and student managers, winning the national and international IT awards WAITTA, iAwards and APICTA – and getting an excellent education for their future careers.

In 2022, we finally established the new degree program in Automation and Robotics as a major in the Bachelor of Engineering program. Students in this program will be even better equipped for a project in the REV Project, as well as for a career in Automation or the Automotive industry.

Enjoy this look back at 15 years of REV!

Professor Thomas Bräunl

Director, Renewable Energy Vehicle Project (REV)

http://REVproject.com

Electric Vehicles: **The Facts**

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.

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 105 years ago.

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.

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 50kWh EV, this would mean 21 hours for a full charge, but as the average daily driven distance is just 36km in WA, this will just take over two hours as a daily recharge.
- Level 2: Fast AC charging, either 7.7kW (32A single phase) or 23 kW (three-phase). This means 6.5 hours (single phase) or two hours (three phase) for a full charge.
- Level 3: Fast DC charging, 50kW up to 450kW, always charging up to 80% only, as charging slows down significantly above this level. So theoretically, if neither the car nor the station reduces the power level during charging up to 80% the sample EV would take 48 min. at a 50kW station, min. at 160kW, or 5 min. at 450kW. However, all curre EVs slow down charging a various levels of SoC (state of charge), so these times are not achievable in a rea scenario.

Stuart Speidel and Thomas Bräunl ready to 'fill up' an EV Ford Focus at the UWA Level 2 AC-Charging station

There are a number of different charging sockets in the market:

- 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 is limited to 50kW, therefore now outdated and no longer used for new vehicles in Australia.
- 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.
- MCS: Megawatt Charging Standard for trucks and buses – and potentially boats and planes. This system allows up to 3.75MW charging power (1,250V at 3,000A).

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.

Typical EV consumption is around 150Wh per km. At a standard electricity day-tariff of $0.30 per kWh this means a cost of 4.5ct/km. When charging at a night tariff, cost comes down to 2.3ct/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.

The UWA Level 3 DC-Charging station and the Combined Charging System (CSS) and CHAdeMO charging sockets

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.

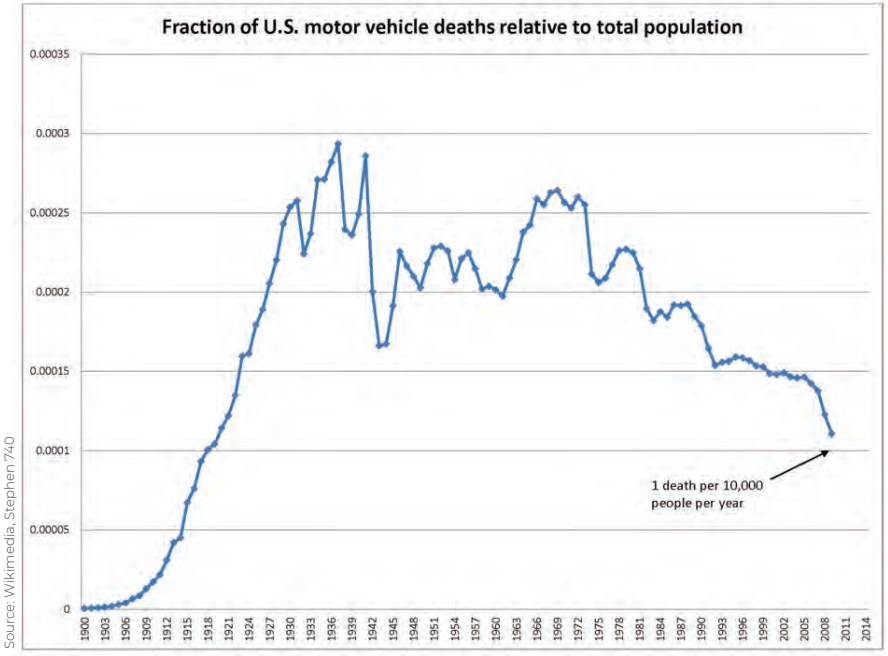
While electric vehicle technology is simple, autonomous driving is in fact rocket science. It requires building a robot in the shape of a car with still expensive high-performance onboard computer systems and even more expensive sensors, such as Lidars, cameras, IMUs (inertial measurement units) and 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, Stephen740

The REV Vehicles

Over the 15 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.

Formula SAE Electric car

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

REV Racer

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

Autonomous Electric Shuttle Buses—*n*UWA*y*

48V, 15.36kWh, 8 Lidars, 2 cameras, IMU, RTK-GNSS.

REVski

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

Autonomous BMW X5

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

Autonomous SAE Electric car

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

REV Waveflyer

Twin 5kW shrouded DC motors, 48V, 2kWh, 30min. drive-time.

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, Dyi Zen (Tan) Tan, Wilson Tay, Daksh Varma, Stephen Whitely

Chun Shing (Steve) Ip, Stephen Whitely and Dyi Zen Tan

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.

The REV Eco

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.

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.

Thomas Bräunl at the launch of the REV Project with the REV Eco

The Autonomous BMW

The REV Racer, a converted Lotus

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.

> . . . 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 . . .

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.

Photo credit: Australian, 10 Nov 2009, Page 31, IT Today. By: Jennifer Forestiere. E-car charge stations plan

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.

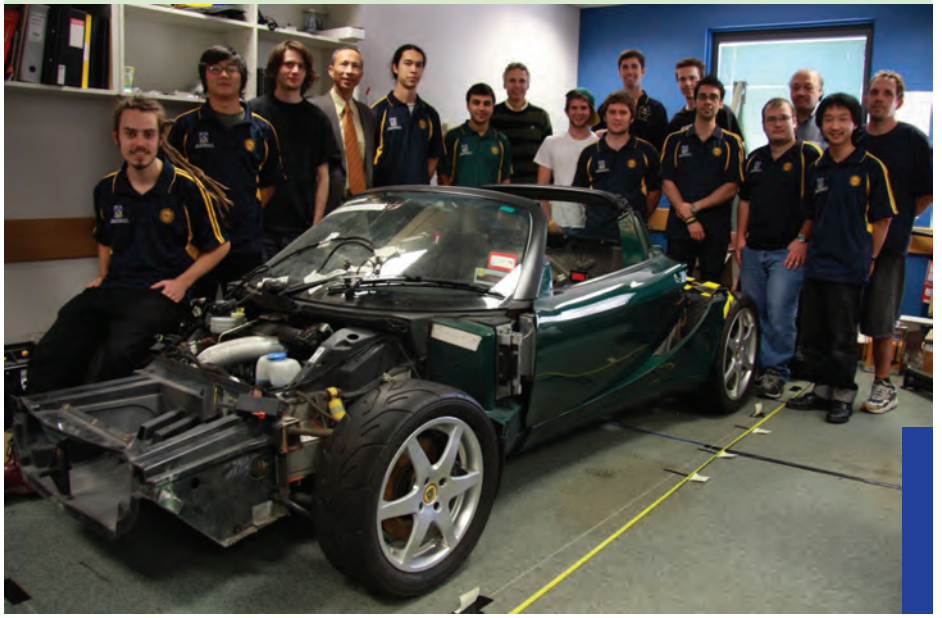
The 2009 Team

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 got 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.

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.

> "... 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. ..."

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 use it as my daily driver.

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.

Jonathan Wan, Ian Hooper and Thomas Bräunl 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.

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)

The BMW steer-by-wire in collision avoidance testing

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.

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

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)

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.

WA's first Level-2 charging station

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

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

Ivan Neubronner, Frank Yi Tan and Soo Siang Teoh

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

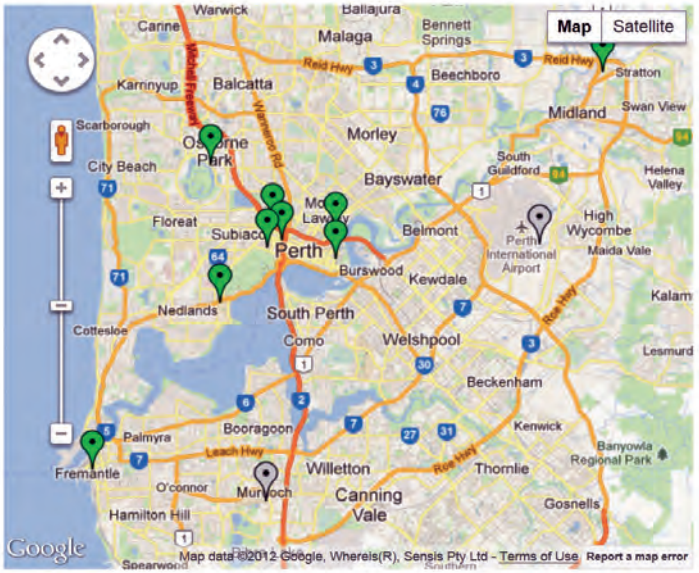
steering the car around the obstacle while also braking. For testing, a realistic looking inflatable copy of the REV Hyundai Getz is being used as the obstacle car.

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 conversions 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

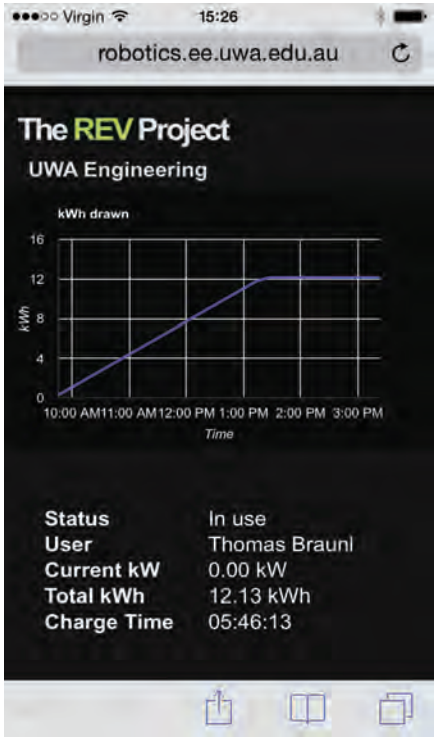
Team:

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

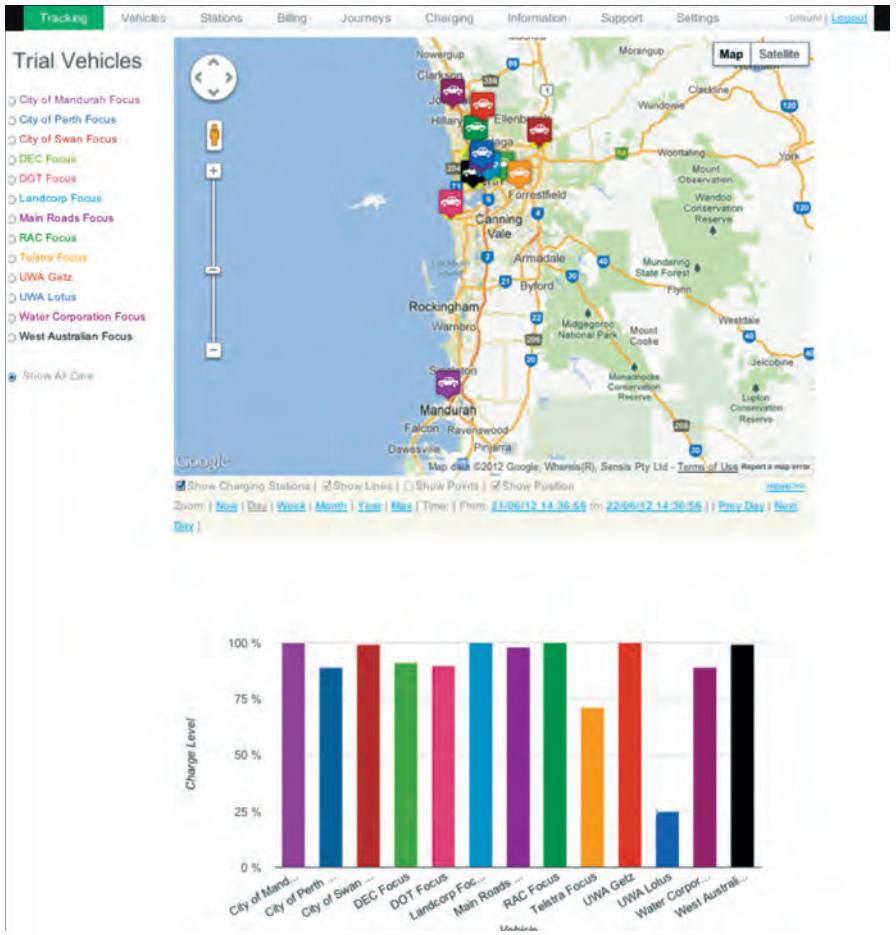
The Formula SAE–Electric is a new student competition category for single-seater electric race cars, designed and built by students. While our REV Formula SAE-E-2010 car was a conversion of an older vehicle from UWA Motorsport, we are now designing and building our 2012 car from scratch as a pure electric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

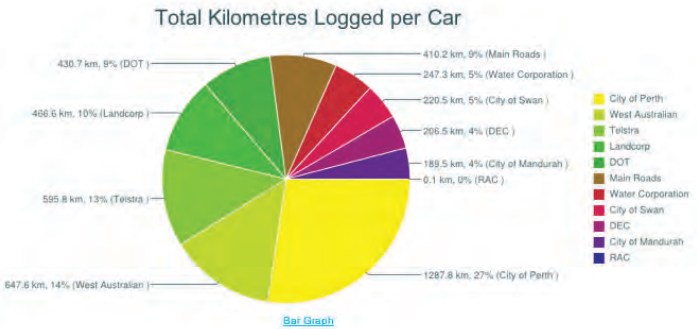


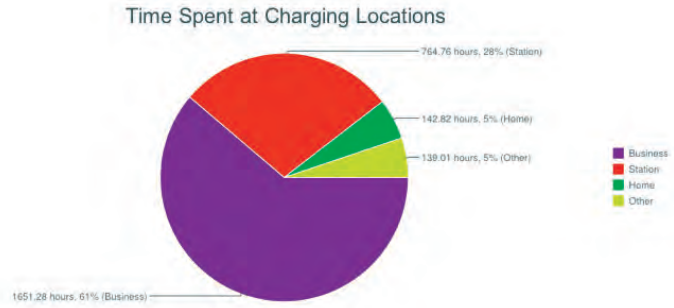
Stuart Speidel—Student Manager 2012–2014

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

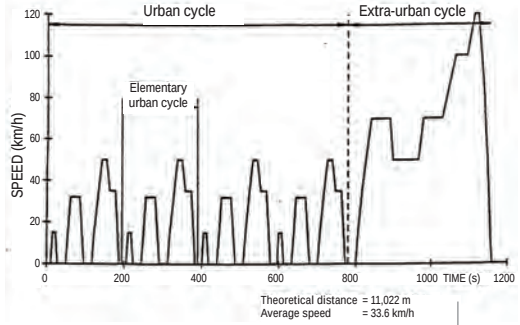
Student Manager:

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.



Australian Design Rules speed profile

The EV Lotus Elise is tested on Orbital Engines' dynamometer

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.

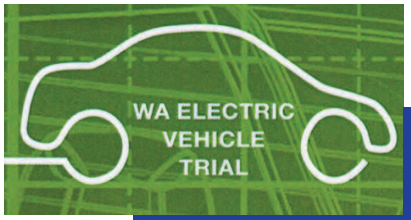
The 2014 Team

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



The WA Electric Vehicle Trial 2010–2013 was completed and the trial report made available for download from:

REVproject.com/trialreport.pdf

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.

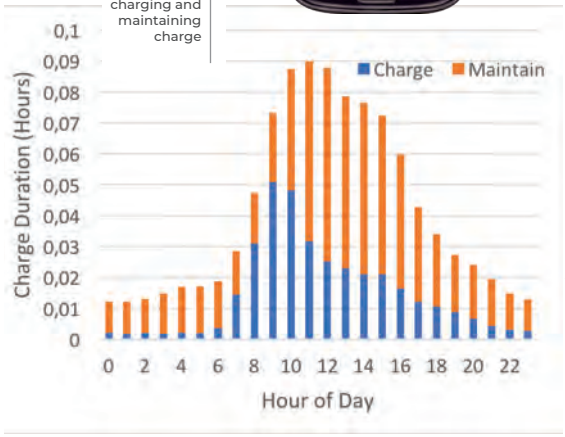
Professor Thomas Bräunl and Hon. Senator Christine Milne, Leader of the Australian Greens at the UWA charging station

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.

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 (blue–charging; orange–maintaining charge after completion of charging).

EV driving heat map

Smartphone app



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.

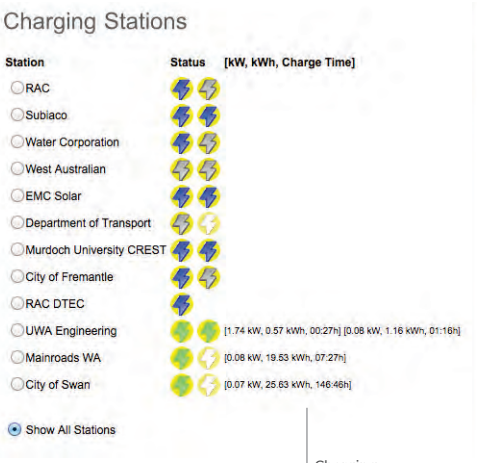
As a result of these outcomes, we do not propose further increase of the existing network of fast-AC chargers (7kW), but instead advocate to establish a smaller network of fast-DC chargers (50kW). On these systems a typical charge time is 20–30 minutes (for 80 per cent charge) and the driver is expected 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.

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-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 or the CHAdeMO standard, in order to cover almost all fast-charge capable EVs from the USA/Europe (CCS) and Japan (CHAdeMO).

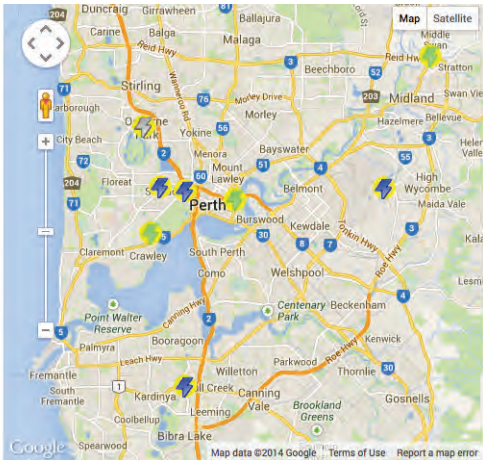
With 50kW DC charge power, the charger location had to be carefully considered. The selected bay next to the University Club has the advantage of sufficient power reserves of a large building and the driver can get a cup of coffee in one of the many cafes nearby while their car completes a fast charge.

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 commercial charging networks profitable, as they have a much higher customer throughput per day and



Charging station activity



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.

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.

Vehicle tracking and EV charging station locations in Perth

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

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

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

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

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.

Stuart Spiedal being presented with his prize at the 2014 iAwards in Melbourne

2014 iAWARDS

APICTA Asia Pacific ICT Alliance AWARDS

THE INCITE AWARDS

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

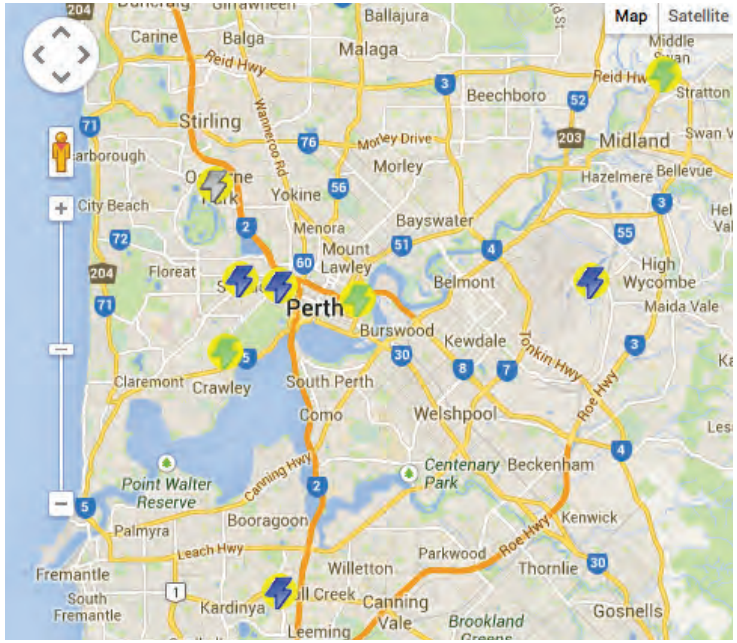
(SME) Perth, a Curtis controller, and high-current Headway Li-Ion battery cells. A total of 240 battery cells, organised in 30 sets in series of eight parallel battery strands each, enclosed in waterproof PVC tubes. This gives the jet ski an overall voltage of 96V and a total capacity of 7.6kWh. Larger 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 is shown 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.



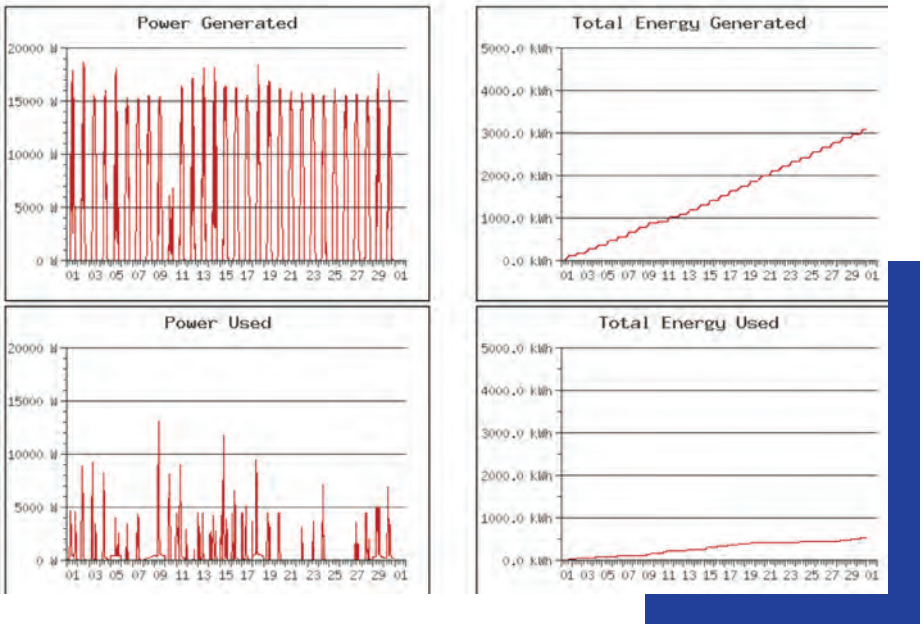
REV Project EV charging station locations are shown on this map.

- UWA University Club
- UWA Engineering
- Murdoch University CREST
- City of Subiaco
- City of Cockburn
- City of Swan
- City of Fremantle
- West Australian News-paper
- 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.

GUI of REV Racer Lotus Elise

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.

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 2015–2021

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. I had chosen to do a degree in Electrical and Electronic Engineering as I believed that I could learn something that could be useful for me in my career, as well as giving me the ability to tinker at home on my own electrical projects.

At the end of 2013, when it was time to choose my thesis project, I knew that this project 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 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.

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

Home Energy Management

Thomas Bräunl and Stuart Speidel

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

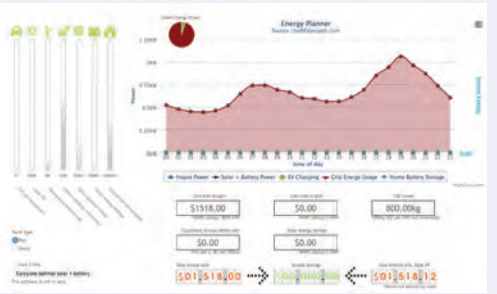
(1) The system starts with the typical daily energy usage distribution for Perth. The usage can be adjusted to match an individual home.

(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.

(1)



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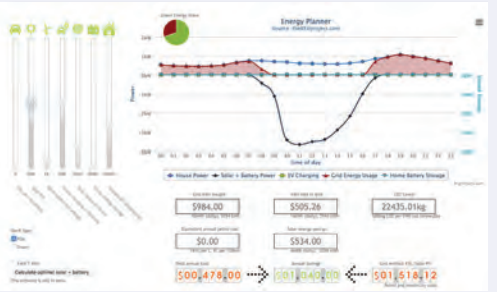

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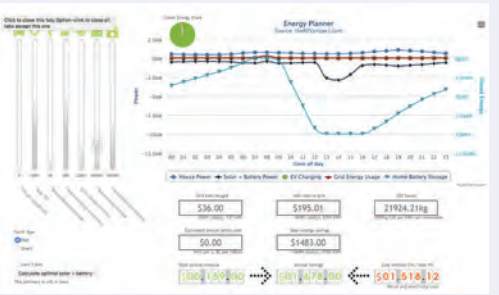

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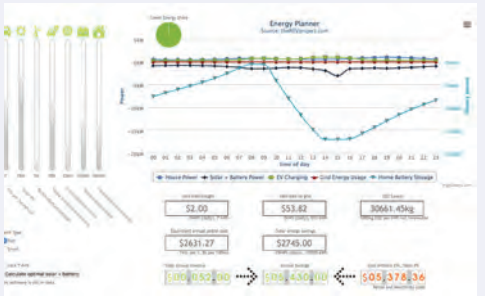


2018

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:

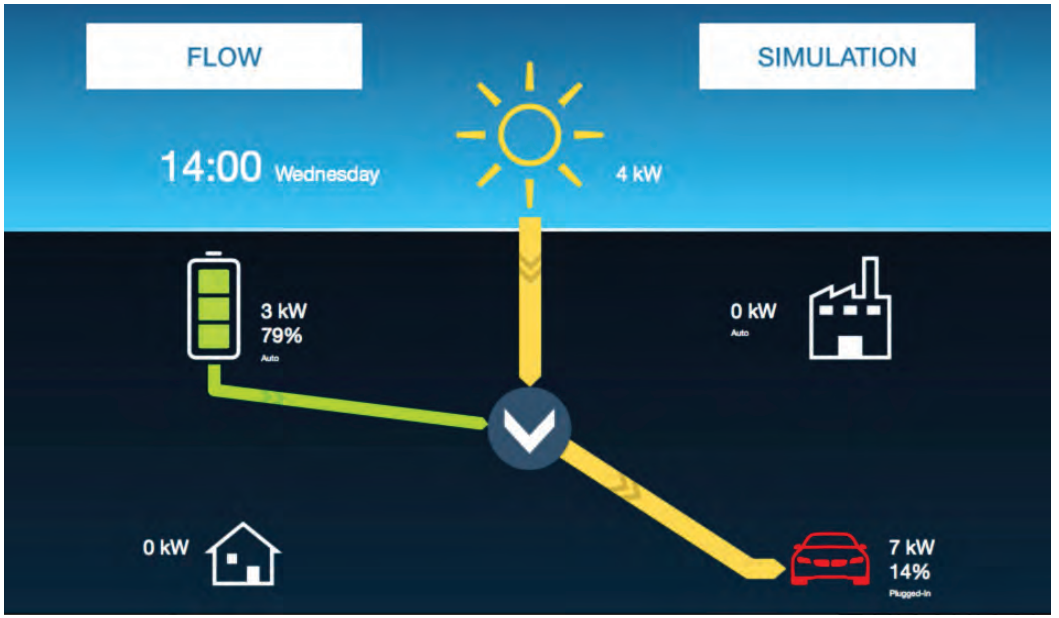
Marcus Pham

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.

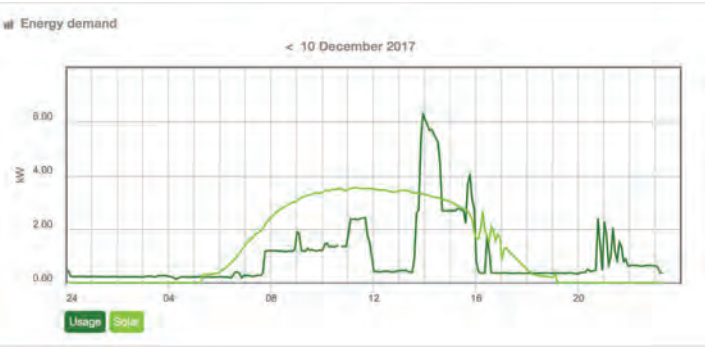


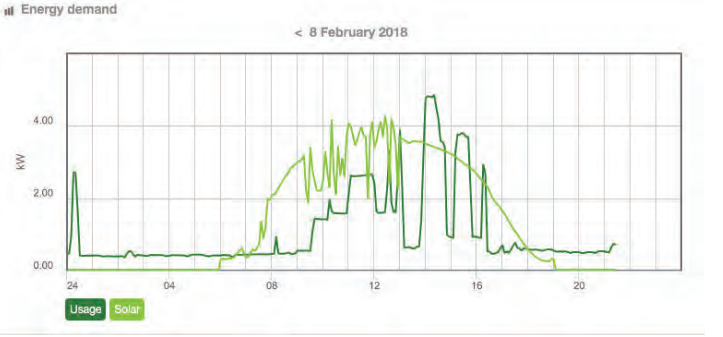
The other is the automatically detect and drive the internal roads of UWA by identifying lane markings with the camera and identifying the curb position with the Lidar sensor.

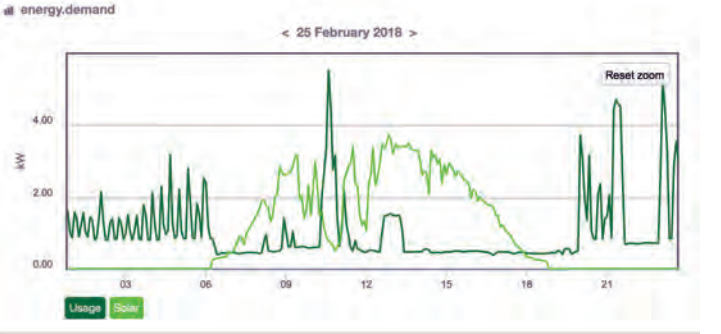
On the energy side we are looking at integrating electric vehicles into private homes as well as into company fleets, where concurrent charging of a larger number of EVs can be a real challenge.

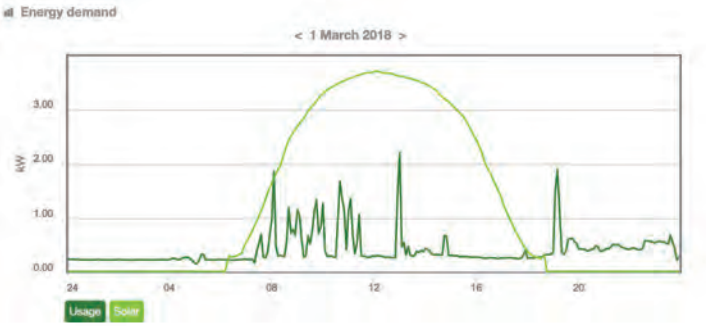
Together with the BMW Technology Center in Mountain View, California, we developed a Home Energy Management System (HEMS) which can control and visualise the power flow between solar PVs (renewable energy) and grid as inputs, plus household, EV charging and a battery-based home energy storage unit as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









The REV Project 10 Year Anniversary

REV celebrated its 10th Anniversary in March 2018.

Starting with a Homecoming event in the new REV lab for all students from the past 10 years, the evening continued with presentations from Professor Thomas Bräunl, reflecting on 10 years of REV achievements, and from Mr Colin Smith from energy retailer Synergy on the effect of EVs on the electricity grid.

Thomas Bräunl, Kai Lim and Marcus Pham display superhuman strength lifting the inflatable Getz

The advisory panel takes questions from the audience

Prof. John Dell, Executive Dean

Mr Colin Smith, Synergy

Colin Smith with the REV Jet Ski and REV 10 Year Anniversary Booklet

2019

The 2019 Team

Student Manager:
Marcus Pham

Team:

REView—Kai Li Lim

Autonomous SAE—Thomas Drage, Kai Li Lim, Chao Zhang, Craig Brogle, Eduardo Arteaga Guadarrama, Jia Yu, Jiajian Shao, Junwe Huang, Tuo Zhang, Hengyu Chen, Yi Zhang, Vihanga Silva, Yingjie Yao,

REVSki—Marti Leven, Dylan Leong, Maximilian Woloszyn, Alexander Morgan, Hjariz Mohd Jahis

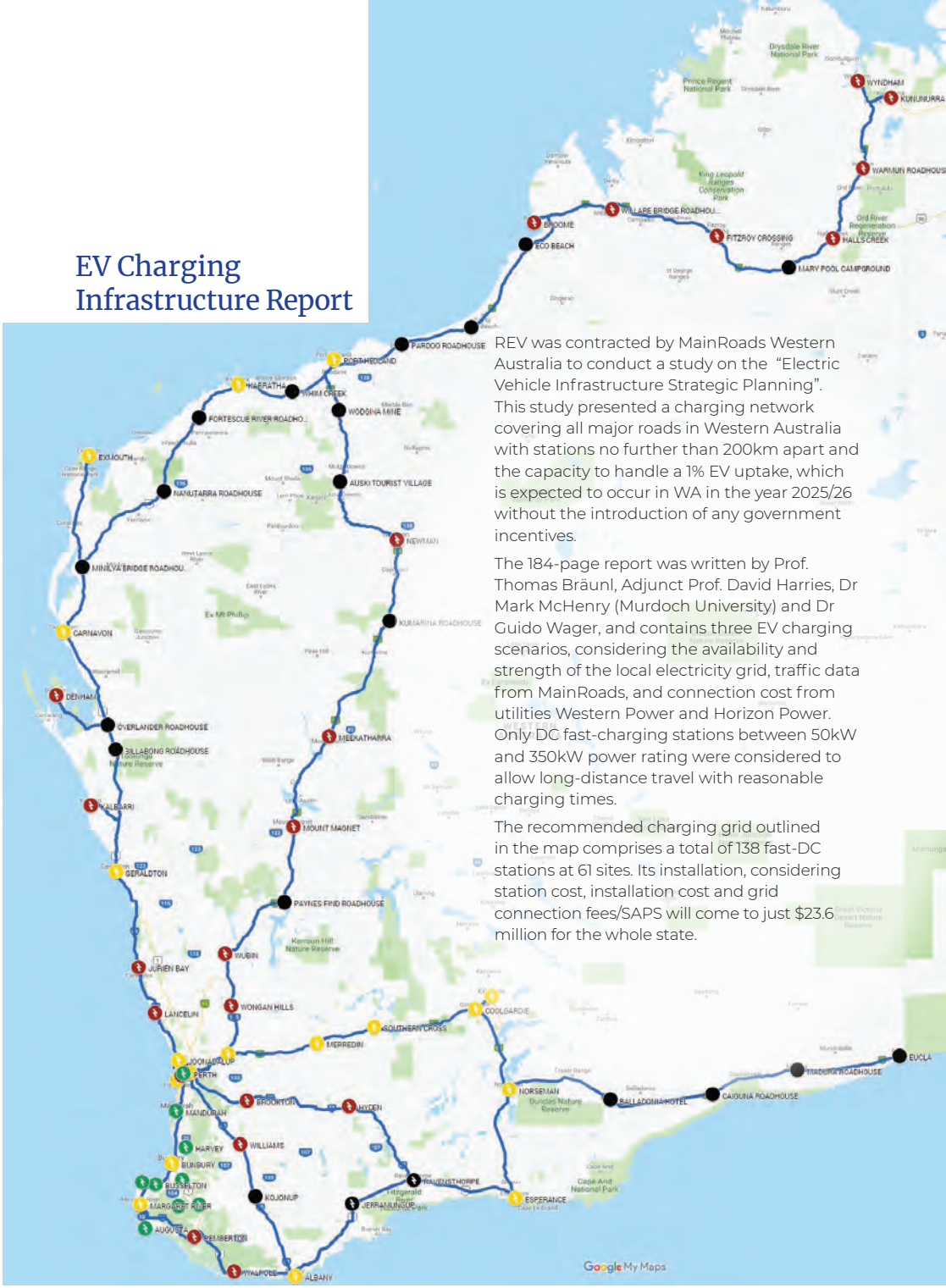
Electric Hydrofoil WaveFlyer

Together with Perth start-up company Electro.Aero, REV has completed the world's first electric hydrofoil personal watercraft. The WaveFlyer resembles a conventional jet ski, but when in motion, its two hydrofoils lift it out of the water for a completely new cruising experience, softly gliding above the waves. While this smoother ride makes the hydrofoil not necessarily faster than a conventional electric jet ski, it only uses about a quarter of the energy for driving the same distance. So an equivalent hydrofoil can travel four times longer or only requires one quarter of the batteries to cover the same distance.

A team of REV students is currently working on the second generation of the hydrofoil ski in the lead up to forming a new start-up company. The hardest challenge is to design a fly-by-wire system that achieves a sensor- based automatic stabilization for the ski. Because without it, the hydrofoil is very hard to control, especially for novice drivers.

The hydrofoil project has been funded by Galaxy Resources, the UWA School of Engineering and the UWA Innovation Quarter.

EV Charging Infrastructure Report

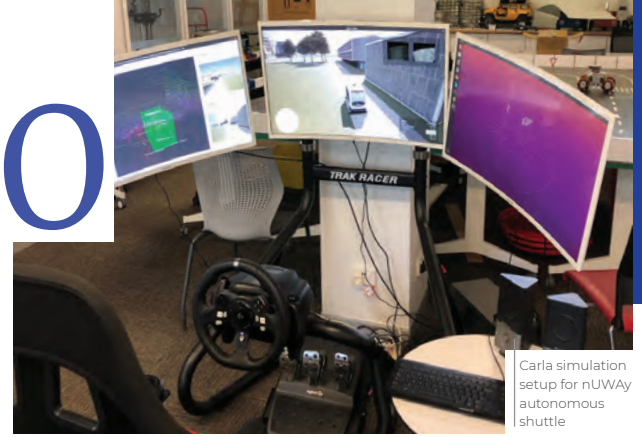


REV was contracted by MainRoads Western Australia to conduct a study on the "Electric Vehicle Infrastructure Strategic Planning". This study presented a charging network covering all major roads in Western Australia with stations no further than 200km apart and the capacity to handle a 1% EV uptake, which is expected to occur in WA in the year 2025/26 without the introduction of any government incentives.

The 184-page report was written by Prof. Thomas Bräunl, Adjunct Prof. David Harries, Dr Mark McHenry (Murdoch University) and Dr Guido Wager, and contains three EV charging scenarios, considering the availability and strength of the local electricity grid, traffic data from MainRoads, and connection cost from utilities Western Power and Horizon Power. Only DC fast-charging stations between 50kW and 350kW power rating were considered to allow long-distance travel with reasonable charging times.

The recommended charging grid outlined in the map comprises a total of 138 fast-DC stations at 61 sites. Its installation, considering station cost, installation cost and grid connection fees/SAPS will come to just $23.6 million for the whole state.

2020



Carla simulation setup for nUWAy autonomous shuttle

The 2020 Team

Student Manager:

Marcus Pham

Team:

REView—Kai Li Lim

nUWAy Autonomous Electric Shuttle Bus—Craig Brogle, Thomas Drage, Kai Li Lim, Farhad Ahmed, David Gregory, Kyle Crescencio, Joey Koh, Yuchen Du, Daniel Trang, Jason Chu.

eFoil Electric Hydrofoil—Layla Krishna, Alishan Aziz, Jeremy Guo, Liyang Leo Xu, Alexander Thatcher, Vladimir Pavkov, Benn Ness, Pierre-Louis Constant.

Autonomous Vehicle Driving Simulation

Zhihui (Eric) Lai

A simulation environment for the autonomous shuttle bus was designed based on Carla as a hardware-in-the-loop (HIL) system, which was later converted to a pure software simulation, as the HIL component did not improve the performance or accuracy of our system.

As part of the simulation environment, a digital version of the whole UWA university campus has been developed (see Figure 1). In addition, a 3D shuttle bus model was created as the main autonomous vehicle (see Figure 2).

The simulator has two control inputs: A steering wheel with accelerator and brake pedals (Logitech G920) and keyboard input. Users can conveniently set up and execute experiments with these controls and buttons. For simulator operation, we implemented six different modes;

1) Manual drive mode—Users can drive the simulated shuttle bus manually using the steering wheel and pedal or keyboard control. This mode is often used to collect lidar point cloud data (see Figure 3) to generate a pose-graph map and collect image data for the training of neural network models.

2) Lidar autonomous drive mode—Once a pose-graph map has been generated in manual drive mode, the simulated shuttle bus can drive autonomously from one place to another on an optimised path using the navigation module in ROS 2. This mode is identical to the driving operation implemented in the real shuttle bus.

Figure 1. Simulated UWA campus, facing north

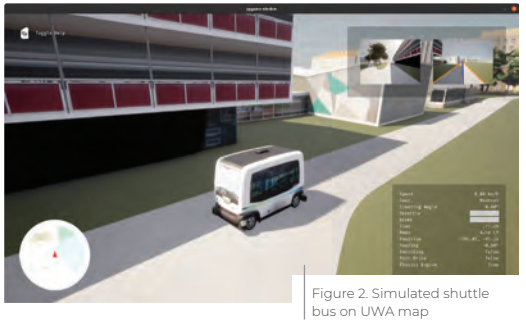


Figure 2. Simulated shuttle bus on UWA map

3) Computer vision autonomous drive mode—This autonomous driving mode uses OpenCV computer vision algorithms. By applying Canny edge detection and Hough line detection, the program can identify the lane's left and right boundaries (see camera image in Figure 3), determining the steering and throttle command. However, this approach has problems at intersections and has not yet been implemented in actual shuttle buses.

4) Neural network autonomous drive mode—This is an autonomous drive mode (see Figures 4 and 5) using deep learning neural network models. The currently employed model is a modified PilotNet that takes the front camera image as input and outputs steering angle and throttle control commands. This method can handle intersection with traffic lights and is planned to be implemented in the real shuttle bus.

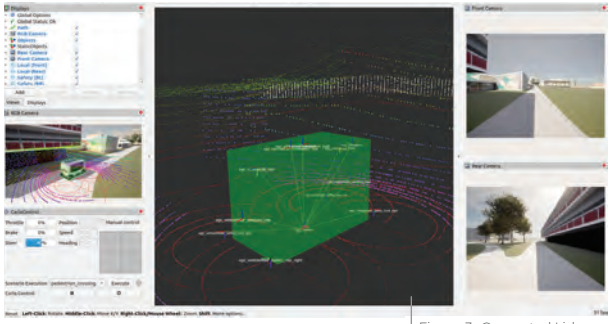


Figure 3. Generated Lidar point cloud

Figure 4. UWA neural network drive demo

5) Mirror drive mode—This mode connects simulation with reality. The real shuttle bus constantly publishes position, orientation and camera data to the web. The simulator accesses this data, converts the GNSS coordinates to the simulated vehicle's map position and replaces the simulation camera image displays with the actual camera images. Therefore, the simulated shuttle bus mimics the driving behaviour of the actual shuttle bus. This mode helps users monitor the actual shuttle bus remotely.

Figure 5. Carla Town01 neural network drive demo

6) Carla built-in autonomous drive mode—This mode extracts all the traffic information from the simulator program, including traffic light states, distance to other objects and current location. With these information, the algorithm is able to drive in the center of the road and randomly turn at intersections. This mode is often used to generate traffic and collect image data for the training of neural network models.

2021

Autonomous Shuttle Bus *n*UWAy

For a long time, REV has been trying to build a new autonomous vehicle. Finally, we had the chance in a cooperation with the UWA Business School and ST Engineering, Singapore, to purchase a used electric drive-by-wire shuttle bus built by Ligier in France. In its previous life, the shuttle transported visitors to the Singapore Gardens by the Bay as an EasyMile autonomous transporter, however, we only purchased the mechanics and electronics hardware, not EasyMile's software, as our goal always was to develop our own autonomous driving system.

The shuttle is equipped with identical sensor models like we had on our old autonomous Formula-SAE vehicle — only more of them. It has four Sick single-layer Lidar scanners as collision avoidance safety sensors (one at each corner), two Ibeo Lux automotive Lidar scanners on top for navigation (one facing forward and one facing backward) and two Velodyne puck sensors for traffic and pedestrian detection (one in front, one in back).

Our first large task was to identify all system components and get the shuttle driving again with our own software based on ROS (robot operating system) that we already used for our Formula-SAE car. We also updated the battery and charging system to comply with European charging and safety standard and added battery monitoring systems for the drive battery as well as the 12V utility system.

The shuttle can now be charged on any IEC Type-2 EV charging station and display its charging and battery status on an independent LCD.

Although we are not the first institution in Perth to operate an autonomous shuttle bus, we are the only one that actually develops their own self-driving system and is not just using some purchased foreign technology. As far as we know, we are the only Australian university developing autonomously driving passenger vehicles.

With the drive-by-wire system now attached to our own computer system and software, we are transferring our software solution from the Formula-SAE car to the shuttle bus and are implementing an intelligent autonomous driving mode. Unlike all commercial autonomous shuttle buses, our system will not just stop and give up if anything — even a parked bicycle or a piece of cardboard — is in its way. Our system will be able to deviate from a fixed preprogrammed path and safely drive a small detour around it.

Since 2022, REV is offering regular autonomous shuttle bus rides for staff and students along the North–South axis across the university campus. This work is conducted in cooperation with Doina Olaru and her team at the UWA Business School, who evaluate passenger experience and expectations for this technology.

The 2021 Team

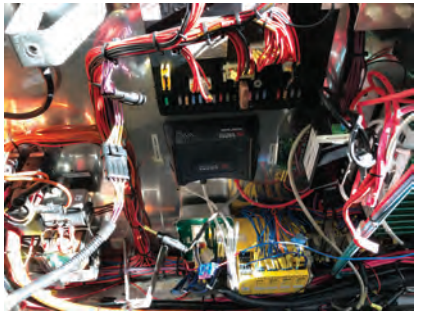
Student Manager:

Marcus Pham

Team:

Autonomous—Jai Castle, Zack Wong, Jason Chu, Daniel Trang, Xiaochen Bi, Yuchen Du, Kyle Crescencio

Nautic — Vladimir Pavkov, Benn Ness, Alishan Aziz



Top and centre: Shuttle bus controls before modifications
Below: Shuttle bus controls after modifications

Electric modifications on nUWAy shuttle bus:

- replacement of charging connector to IEC Type 2 "Mennekes"
- addition of ePro current and voltage meter for drive system
- addition of 12V gauge and charging points
- addition of Nvidia Xavier co-processor
- addition of a gigabit switch.

2022

The 2022 Team

Student Manager:
Kieran Quirke-Brown

Team:
Autonomous—Tim Tan, Thomas Copcutt, Zhihui Lai, Lemar Haddad.

Nautic—Pierre-Louis Constant, Yanke Cheng, Ben Daff, Hendrik Viljoen, Joshua Kirkham, Kai Han, Matthew Connell

Kieran Quirke-Brown—Student Manager 2022–current

When I first began working in the REV team, I was nervous as to what skills I could bring to the table as it was a relatively new field for me. While I had taken a number of different courses during my university life relating to the work we do in REV I had never had to combine the knowledge in such a way. The second challenge for me was coming back from the work force, having worked as an engineer for 4 years, and returning to the university lifestyle with students much younger than me. However, after working in the REV team for over a year now I have expanded my skill set enormously and had many great opportunities to interact with various businesses and students. As the current student manager of the REV team, I am excited to see what we have accomplished and what we will accomplish in the future. I feel that the future holds a lot of strong prospects for the team as autonomous and electric vehicles becomes a larger focus for the wider community making this the perfect time to be in the REV team. With the wider community rallying behind renewable energies, electric vehicles and vehicle automation we have seen the rise in various opportunities. In 2020 we acquired our first autonomous shuttle bus, where the team had to develop software and upgrade existing sensors so it could be driven on campus. This has been an exciting interactive project that is popular during demonstrations and for students studying at UWA. In 2022 we acquired our second shuttle bus and were approached by a developer with a request to drive the second autonomous shuttle bus on the roads in the northern parts of Perth in 2023. On top of this we have many other exciting projects and teaching opportunities for students starting the new Bachelor of Engineering in Automation and Robotics, and a growing Robotics club on campus. With the increasing number of students and projects I am excited to see what comes next for the REV team and excited to be at the head of that team.

Remote Northern WA High School Visits

Kieran Quirke-Brown

In 2022, UWA worked together with the Poly Farmer Foundation to demonstrate to students in remote communities some of the work we do at UWA. Three students were selected to represent UWA and take one of the autonomous shuttle buses to three high schools: Carnarvon Community College, St Luke's College (Karratha) and Newman Senior High School. At each school the UWA representatives gave a presentation on who we are and what we do and then demonstrated the autonomous shuttle bus's capabilities.

The students loved the experience of riding on the bus and were fascinated by the safety features on board. It was noted by some of the teachers that several students who have never shown any interest in anything, were highly inspired by the autonomous shuttle bus. In Newman many of the locals also came by to see what was happening.

On reflection, with the coordinating schools it was determine that the demonstration was considered a complete success with many students being inspired. There are now talks about what else UWA can bring to the remote communities for students to get more exposure to technology.

Presentation at Newman College

The *n*UWAy arrives at Carnarvon

Demonstration to Carnarvon Community College Students

Demonstration to students of St Luke's College, Karratha

Teaching

After offering 'Automation and Robotics' as a 3-year degree in 2021, UWA changed back to a standard 4-year Bachelor program and 'Automation and Robotics' became a Major in Engineering, alongside established degrees such as Electrical, Mechanical and Software Engineering. This new degree will produce students who are perfectly prepared not just for project work in the REV project, but they will have all necessary background to succeed in a career in the many application areas of Automation and Robotics.

The new degree program draws on units from the three pillars Electrical, Mechanical and Software Engineering, extended by a number of specialist units in Robotics and Automation.

Bachelor of Engineering – Automation and Robotics Engineering Major

Year 1 Semester 1 2023	**MATH1011*** Multivariable Calculus *Prereq: Math Specialist ATAR or MATH1722*	**CITS1401*** Comp. Thinking with Python *(or **CITS2401**** *Computer Analysis and Visualisation)*	**ENSC2004*** Engineering Mechanics *Prereq: (Physics ATAR or PHYS1030) & MATH1011 APS: PHYS1001*	**GENG1010*** Introduction to Engineering (If bridging: move this to year 2)
Year 1 Semester 2 2023	**MATH1012*** Mathematical Theory & Methods *Prereq: Math Specialist ATAR or MATH1722*	**CITS2002** Systems Programming *APS: CITS1001 or CITS1401 or CITS2401*	**ENSC1004** Engineering Materials *Prereq: (Chem ATAR or CHEM1003) & (Phys ATAR or PHYS1030)*	**ELEC1303** Digital Systems
Year 2 Semester 1 2024	Elective/Minor	**CITS2200** Data Structures & Algorithms *Prereq: CITS1001 APS: An additional programming unit*	**GENG2004** Solid Mechanics *Prereq: ENSC2004, MATH1011 & MATH1012*	**ENSC2003*** Eng. Electrical Fundamentals *Prereq: (Phys ATAR or PHYS1030) & MATH1011; Co-req: MATH1012 APS: PHYS1001*
Year 2 Semester 2 2024	**ELEC2311** Digital System Design	**CITS3001** Algorithms, Agents & AI *Prereq: CITS2200*	**MECH2004** Engineering Dynamics *Prereq: ENSC2004*	**ELEC3020** Embedded Systems *Prereq: CITS1001 or CITS2401*
Year 3 Semester 1 2025	Elective/Minor	**CITS4402** Computer Vision *Prereq: software unit*	**AUTO3002** Mechatronics *Prereq: ENSC3020*	**AUTO4508** Mobile Robots *Prereq: software unit*
Year 3 Semester 2 2025	**MECH3424** Measurement and Instrumentation *prereq CITS1001 & ENSC3001*	**GENG3402** Control Engineering *Prereq: ENSC2004, MATH1011 & MATH1012*	**MECH3001** Mechanisms and Machines *Prereq: (CITS1001 or CITS2401), ENSC2004, & MATH1011 APS: PHYS1001*	**ELEC3016** Power and Machines *Prereq: ENSC2003 & MATH1012 APS: PHYS1001*
Year 4 Semester 1 2026	**GENG4411*** Research Project 1	Elective/Minor	**AUTO4507** Robot Manipulators and Automation *Prereq: software unit*	**ELEC5506** Process Instrumentation & Control
Year 4 Semester 2 2026	**GENG4412*** Research Project 2	**GENG5507*** Risk, Reliability, Safety *Prereq: —, APS: IPE*	**GENG5505*** Project Management *Prereq: —, APS: IPE*	Elective/Minor

ATAR Prerequisites: Math Methods, Math Specialist, Physics, Chemistry (2 can be made up with bridging units)

* runs in both semesters

EV Charging – The Next Generation

First AC station in West Perth in 2010 and new AC station at UWA in 2022.

We installed Western Australia's first EV charging station in 2010 as part of our first network of some 20 AC chargers and one CCS-DC charger, the first of its kind in Australia.

The AC chargers had come to the end of their lifetime and needed replacement, as they could not sustain the continuous power draw of many modern EV brands. Also the manufacturer in the UK no longer existed, so we were also unable to get more RFID tokens for the growing number of users.

With the help of our REV charging station sponsors Allkem and Synergy we were able to purchase new AC stations from CirControl in Spain through local distributor e-Station and billing provider Smart-Charge in Brisbane.

The new AC stations are well engineered and will hopefully give us another 15 years of smooth worry-free operation.

While we continue to operate the 50kW Tritium Veefil station at the UWA University Club, we added a new 160kW dual-CCS Siemens station at the new EZONE building. This powerful station had been part of the planning of the building, to make sure that a sufficient power-level is available for EV charging.

Funding of the new DC charger was made possible by a crowd-funding campaign and matching funding from UWA. Prominent sponsors were David Lloyd, CD Dodd, Tesla Owners Club Australia Tesla Owners Club WA, Tesla Roadster Inc., Tesla WA Slack Forum, and many, many others.

DC stations at UWA with 50kW and 160kW

Photo credit: Plugshare

2023

Autonomous Road Trial

In 2023 we finally left the UWA campus with our autonomous shuttle bus and started a public road trial in the northern Perth suburb of Eglinton. The trial is being conducted as a partnership between REV and the UWA Business School with funding partner Stockland. The shuttle bus will provide a regular commute service for Eglinton residents to the beach and back. In this step of our autonomous driving research, we will be combining the three basic approaches to autonomous driving:

- GPS waypoint navigation
- Lidar based mapping (SLAM)
- Visual Navigation and Artificial Intelligence AI)

One of the hardest obstacles was getting the permit for this trial from the WA Department of Transport. Fortunately, Stockland was able to fund the required road safety inspection study and the feasibility study, which had to be completed by external consultants.

The 2023 Team

Student Manager:

Kieran Quirke-Brown

Team:

Autonomous—Tim Tan, Zhihui Lai, Xiangrui Kong.

Nautic—Pierre-Louis Constant, Edward Finnie, Yanke Cheng, Ben Daff, Hendrik Viljoen, Joshua Kirkham

PATREC

Doina Olariu
UWA Business School

The Planning and Transport Research Centre (PATREC) is conducting research in two distinct areas:

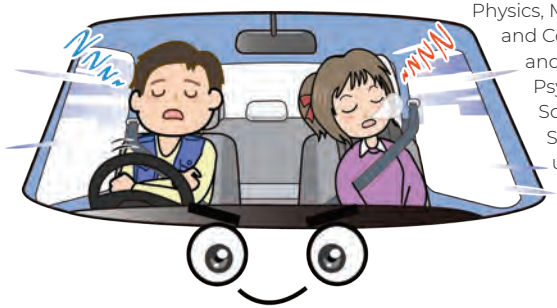
1. Understanding public attitudes towards autonomous vehicles and the role of various stakeholders in shaping the pathway for this technology in Australia.

This project involves a collaboration of PATREC core team (Brett Smith, Sharon Biermann, and Doina Olaru) with academics from the UWA Business School (Sharon Purchase, Sandra Kiffin-Petersen, Daniel Schepis). Findings to date indicate that trust is key for acceptance of the technology and researchers are conducting a series of study for clarifying its definition in the context of the AV technology. Also, qualitative research with experts from Australia and UK has highlighted the influential role of government and its potential evolution from a regulator to a facilitator and participator phase, with the aim to elevate the level of preparedness for the uptake of autonomous vehicles.

PATREC members are also co-supervising PhD students examining perceptions of public (Xiaolin Tang is submitting her dissertation before the end of the year) and WILG students on designing promotion campaigns for the nUWAy autonomous shuttle or participating as safety operators for our shuttle. The objective is to develop the nUWAy brand, recruit more students who can get the chance to learn about the technology and 'supervise' the bus, as well as disseminate research ideas on autonomous technologies.

2. Assessment of the implications of autonomous driving on the traffic conditions and urban landscape

This project is a collaboration of PATREC core team (Yuchao Sun, Brett Smith, Tristan Reed, Doina Olaru) with academics from the School of Physics, Mathematics and Computing and School of Psychology Science (Road Safety) on understanding the likely changes in the traffic conditions (delays, safety, emissions) at various degrees of penetration of autonomous vehicles in the current traffic. Traffic simulations (currently undertaken in AIMSUN) are indicating distinct patterns of interactions between AVs and non-AV vehicles, cyclists, pedestrians, and that a substantial percentage of AV-enabled traffic needs to occur to reap the benefits of the new technology. Also, communication with infrastructure and other vehicles is paramount. Further, the PATREC team is looking at the land-use implications of AVs and expected changes in the value of time and daily 'biographies'.



Similarly to project 1, WILG students are engaged, with the opportunity to learn first-hand about the technology on-campus, to observe interaction between the nUWAy bus and other traffic participants (pedestrians, cyclists) as well as examine human preferences to technology.

https://patrec.org/core-research-projects/

2024–2038

Outlook

The next 15 years will see the conversion of the whole private and commercial vehicle fleet to electric. Many countries have issued laws that disallow the registration of new petrol or diesel vehicles from 1. Jan. 2035. To cope with the increased energy demand, more renewable energy sources will have to be added to the grid and large-scale energy storage facilities will have to be built. Especially large-scale wind turbines are still a rarity in Australia.

Fully autonomous vehicles have been promised several times over in the past years but are still not a reality today. Finding that the last 0.01% in reliability has proven to be extremely hard to achieve. But as people's lives depend on it, autonomous driving can only succeed if safety and reliability can be guaranteed to earn the trust of the general public.

Media

Television Reports and Interviews

Channel 7, Seven News, Driverless Shuttle Bus at Amberton Beach, 17 Mar. 2023, 18:00

Channel 7, Seven News, Driverless Shuttle Bus at Amberton Beach, 17 Mar. 2023, 16:00

Channel 7, Sunrise, Driverless Shuttle Bus at Amberton Beach, 17 Mar. 2023, 5;30

ABC World News Australia, interview with Yvonne Yong, *Volvo stopping the import of petrol cars to Australia from 2026*, 8 Nov. 2022, 19:30

Channel 10, *Biofil EV charging station for the Nullarbor*, 22 Dec. 2021

Channel 7, co-broadcast

Channel 10, 10 NewsFirst, *UWA students have become the first in Australia to develop a driverless shuttle bus*, Narelda Jacobs, 18 June 2021, 18:15

West Digital Television (Albany), co-broadcast

WIN Television, Western Australia, co-broadcast

Channel 7, Seven News WA, *Students from the University of Western Australia Have become the first in the country to build the brains behind an autonomous shuttle bus*, Samantha Jolly, 18 June 2021, 16:13

The World ABC News, *Phasing out fossil fuel vehicles in New Zealand*, interview with Beverley O'Connor, live, 9 June 2021, 20:30

Network 10 Scope, National, *Electric Hydrofoil Jetski Explained*, Amanda Broomhall, episode 11, recorded 30. Aug. 2019, aired 12 Jan. 2020, 9:30

ABC News, Sydney, National, *Hydrofoil Jetski*, Michael Tetlow, 3. Aug. 2019, 0:19

ABC Nightly News, Sydney, National, *Hydrofoil Jetski*, Yvonne Yong, 2. Aug. 2019, 23:24

ABC Late Night News, Melbourne, National, *Hydrofoil Jetski*, Michael Tetlow, 2. Aug. 2019, 22:34

ABC News, Perth, *Hydrofoil Jetski*, James McHale, 2. Aug. 2019, 19:29

ABC News Hour, Sydney, National, *Hydrofoil Jetski*, Andrew Geoghegan, 2. Aug. 2019, 18:50

ABC News, Sydney, National, *Hydrofoil Jetski*, Kirsten Aiken, 2. Aug. 2019, 17:49

ABC News Afternoon Briefing, Sydney, National, *Hydrofoil Jetski*, Kirsten Aiken, 2. Aug. 2019, 16:29

Channel 10 News First, *Jetski Junkies*, Narelda Jacobs, 2. Aug. 2019, 17:26

Channel 9 News, *Electric Hydrofoil Jetski*, 2. Aug. 2019

Channel 7 News, *Electric Hydrofoil Jetski*, 2. Aug. 2019

Channel 7 News, *Augmented Reality Glasses in Dentistry*, 27. Apr. 2017

ABC News, *Electric jet ski gives silent, surreal ride*, 23. Oct. 2016

Channel 9, National Nine News, *The first electric jetski to hit Australian waters*, Tim McMillan and Emmy Kubainski, 23 Oct. 2015 18:46

ABC TV News, *WA's EV Charging Network*, Claire Moodie, 22 Jan. 2015, 17:17 and 19:21

SBS, *Electric cars are tipped to be the vehicles of the future*, filmed 24 Nov. 2014, aired 5. Jan. 2015

Channel 11, Scope, Student Science, *REV Autonomous SAE Car*, 23 Oct. 2014, 8:00

ABC Catalyst, *REV Racer Electric Lotus and EV Trial Ford Focus*, 7 Feb. 2013

Channel 10, *EV Charging Network*, Nick Way, 2 Sep. 2012

Channel 7, Today Tonight, *Clever Cars – Obstacle avoiding BMW X5*, report and interview, *Clever Country*, Monica Cos, 6 July 2011, 18:30

Channel 7, Today Tonight, *Electric Vehicle Trial and Acceleration Tests*, 10 June 2011, 18:30

Channel 10 TV News, *First Australian Electric Vehicle Trial*, 11 Mar. 2010

Channel 9 TV News, *First Australian Electric Vehicle Trial*, 11 Mar. 2010

ABC TV News, *First Australian Electric Vehicle Trial*, 11 Mar. 2010, 19:00

ABC Television, Stateline, *Interview and test drive with REV Eco Electric Vehicle*, 5 Mar. 2010, 19:30

Channel 10 News, Australian TV, *REV ECO Electric Car with WA Premier Colin Barnett at Galaxy Resources Ravensthorpe Lithium Mine Groundbreaking Ceremony*, 6 Nov. 2009

Channel 9 News, Australian TV, *REV ECO Launch at UWA*, 22. Nov. 2008

Channel 10 News, Australian TV, *Driver-Assistance Systems Research at UWA*, 11 Apr. 2008, 17:00

Film

IMAX Movie, *Dark*, by Peter Morse, Paul Bourke, Alan Duffy, Credits for electric Lotus Elise, http://darkthemovie.info, Aug. 2012

Radio Interviews

ABC Radio, Interview with Andrew Collins, *Election Programs for EV Charging*, 6 May 2022, 16:30

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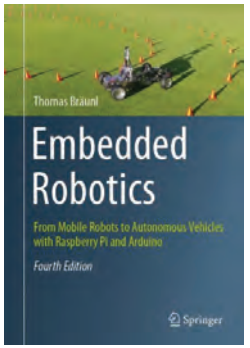

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The Lotus Elise 'REV Racer' in front of Winthrop Hall

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