R O B O T I C S

# ENERGY FREEDOM SOLAR ELECTRIC VEHICLE PILOT PROJECT
# MID-PROJECT REPORT

Prepared by Shane Ambry, CFO
August 2020

*This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.*

# Contents

## INTRODUCTION

This report summarises progress and key learnings from the first fifteen months of the Energy Freedom Solar Electric Vehicle project, including testing outcomes for the first vehicle prototype.

### Project context:

As the way we live changes, there is a pressing need to reimagine the way we move people and goods, with a sharp focus on sustainability. Electrification of our global vehicle fleet is important to improving sustainability, but to get the best results we must address two issues:

- **Energy efficiency:** Today's Electric Vehicles (EV's) are large and heavy, because they are designed to perform a range of tasks. This makes them inherently inefficient in the amount of energy they consume for most of their day to day uses; and
- **EV adoption:** Adoption of EV's is slow globally but especially in Australia, because of vehicle cost and limited availability of high-speed charging.

### Project background and objectives:

AEV aims to produce lightweight, energy efficient, autonomous electric vehicles that will incorporate a solar photovoltaic roof and lithium battery. Designed to be a modular and allow for many applications, the system is focussed on short trips and low speed.

This project makes a significant contribution on two fronts, by driving accelerated development of our technology and also supporting the rapid team and business growth that is pivotal for an early stage business such as AEV, in order to commercialise our product.

The objective of this project is to explore ways to improve EV efficiency and sustainability, so that we can reduce the cost and improve adoption. We are focussed on four (interconnected) areas that contribute to EV efficiency, each of which is a project workstream:

1. Solar gain: Can solar charging contribute a meaningful portion of the EV's energy budget?
2. Low mass: How can using new materials make the vehicle lighter and improve efficiency?
3. Energy Systems: What is the best energy system for the kind of EV we are designing?
4. Driveline efficiency: How can we ensure that our EV design uses energy very efficiently?

### Learnings to date:

In July 2020, after a long period of research and development, we conducted a comprehensive set of tests to establish baseline data that we can use for comparison as we deliver our new EV systems. Our focus was primarily on solar gain, energy efficiency and range, although analysis of the early assessment of structural performance of the solar roof array was also conducted. The results from this preliminary testing are very promising. They suggest some key learnings and we will confirm these over the coming months through further testing:

- Solar charging has potential to provide a significant portion of a high-efficiency vehicle's energy needs, but the actual contribution varies based on conditions and solar system design.

- Early assessments indicate that we can reduce vehicle mass and retain structural performance using new materials and manufacturing methods.
- Our energy models have highlighted four key areas where energy efficiency must be addressed to optimise efficiency - road losses, drivetrain, heating / cooling and compute / control systems.

Based on our early results we believe we are within reach of our targets for energy efficiency and use of renewables.

## SOLAR GAIN

A key objective of our project is to use solar charging to significantly reduce the energy that must be sourced from non-renewable sources. We have sought to address a number of questions:

- How much of the vehicle energy budget can be derived from the roof array?
- How does shading and vehicle movement impact solar gain and circuit design?
- How does the manufacturing method and curved surface impact solar efficiency?
- What are the charging systems and components required to manage the energy generated?

Over the project to date, we have:

- Conducted research and feasibility studies on the best approach for a solar charging system;
- Produced a range of sample solar arrays to test materials and manufacturing methods; and
- Established two working designs for the system that provide options on performance vs cost (V1 is focussed on lower cost and V2 is focussed on higher performance).

**Learning: Solar charging for a high efficiency vehicle has real potential to provide a significant portion of the vehicle's energy budget:**

In July 2020 we tested our first (V1) full-size solar array on the Prototype 1 vehicle. We tested in the lab and also real-world conditions. In general, results from our first round of comprehensive testing were very encouraging and in line with our expectations:

- The manufacturing methods and materials we have chosen do not have a significant impact on solar gains, but there are some opportunities to improve performance.
- The curved shape of the roof and the fact that the vehicle moves mean that real world solar gain varies as the solar roof changes its position relative to the sun. The design of the solar roof and charging systems can be revised to minimise this impact.
- The shading impact on the solar roof was significant due to its lower cost circuit design, causing a reduction in solar charging when a shadow lowered or blocked sunlight from parts of the roof. The design of the solar roof and charging systems can be revised to minimise this impact.
- Solar gain is significant - the V1 solar roof provided a very significant portion of vehicle needs under optimal conditions and a significant proportion of vehicle needs under real world (winter sun) conditions. But it can be challenging to establish a single measure of performance because it varies widely based on conditions.

## LOW MASS

Vehicle weight (or mass) has a significant impact on the energy required to move it. The heavier the vehicle, the larger the motors required and consequently the batteries required to drive it. This creates a 'vicious circle' where mass and cost keep increasing. Our aim is to reverse this

paradigm and seek the lightest possible vehicle. By achieving this we will reduce the battery required and the cost of the vehicle.
To achieve low mass, we are exploring how new designs, materials and manufacturing methods can reduce mass for a low speed vehicle. Over the project to date, we have:

- Conducted research and feasibility studies on the best vehicle design, materials and manufacturing methods to reduce mass;
- Completed the computer-based engineering of key parts of the vehicle, based on our selected materials;
- Run computer simulations of the vehicle design to assess it likely structural performance in the real world; and
- Commenced construction of a prototype using this new design, in preparation for testing in Prototype 2.

**Learning: Early assessments indicate that we can reduce vehicle mass and retain structural performance using new materials and manufacturing methods:**

After extensive assessment we are confident our modular approach to design and engineering is feasible. We have established a standard ‘toolkit’ of materials, engineering approaches and manufacturing methods that allow us to produce a range of body structures quickly and economically.

Computer simulations show good structural performance at target mass, and testing of Prototypes 2 and 3 over the period from September to December 2020 is expected to confirm this view.

## ENERGY SYSTEMS

The energy system is central to the performance, energy efficiency and cost of the vehicle. To arrive at the optimum energy system, we have sought to address a number of technical questions:

- What system voltage should we choose?
- What storage capacity is required?
- What battery chemistry is best for our use?
- What is the best battery management system for our needs?
- How should we fit the battery system within the vehicle?
- What is the best approach to managing heat within the battery system?
- How can we optimise regenerative braking benefits?

Over the project to date, we have:

- Conducted research and feasibility studies on the best battery system design; and
- Tested different system specifications (voltage, battery chemistry, cell type, battery management systems and thermal management methods) to assess how they might meet our requirements.

**Status: We have reached a working specification for our Energy system and will test it in Prototype 2:**

After trialling a range of system specifications in prototype form, we have arrived at a new working specification for the energy system. The system specifications are significantly different to our first design, with adjustments to system voltage, battery chemistry, cell type and configuration, battery management system and thermal management design. We are now constructing a prototype system for testing in our Prototype 2 vehicle.

Two rounds of testing are scheduled between now and December 2020 – Prototype 2 and Prototype 3. Based on test results we will continue our research and development with the aim of optimising the system over time.

## DRIVELINE EFFICIENCY

Energy efficiency is central to our philosophy. Once we have captured and stored as much renewable energy as possible, we need to ensure that the energy we have is used as efficiently as possible. The cost to acquire and run an EV, together with its impact on our environment, are fundamentally influenced by this efficiency. With this in mind, AEV is striving to deliver the most energy efficient systems possible. We are trying to answer several questions:

- System Consumption: What systems in a vehicle consume the most energy?
- System Losses: Where in the driveline and ancillary systems is energy lost and how can we prevent or minimise these losses?
- Cost-effective improvement: What are the best areas to focus if we wish to optimise energy efficiency and cost to manufacture?

Over the project to date, we have:

- Developed an energy model that simulates the consumption characteristics of the vehicle and its systems, then updated it over time;
- Run a range of simulations based on possible vehicle specifications and use cases; and
- Compared the results of the model against real world testing to assess its accuracy.

**Learning: Our energy modelling has highlighted four key areas where energy efficiency must be addressed to optimise efficiency:**

The models suggest that there are four key areas of focus for energy efficiency. Addressing these four categories accounts for the bulk of energy consumed and represents the main areas where efficiency can be improved. They include:

- Road losses (such as tyre rolling resistance and aerodynamics)
- Drivetrain
- Heating and cooling
- Computing and control systems

Recent physical testing of consumption in the Prototype 1 has proven that our modelling is quite accurate, which allows us to have a high level of confidence in the conclusions drawn from the model.

With these areas in mind we are working our way through the vehicle systems looking for the 'low-hanging fruit' – areas where we can make a design change and gain maximum improvement in efficiency. A number of these design changes will be reflected in our P2 and P3 vehicle prototypes and subject to testing in the next six months.

**Learning: We are within reach of our energy consumption targets:**
As part of our recent Prototype 1 testing, we created a set of consumption data. The Prototype 1 vehicle does not represent all our latest design elements, but it was useful in establishing a baseline set of performance metrics to compare with our new systems in Prototypes 2 and 3.
In summary, we were very pleased with the results of testing:

- Based on specification, Prototype 1 meets consumption targets (Wh/km).
- A number of areas were identified where vehicle efficiency can be improved, so we will explore these in subsequent testing.

While there are some areas where improvements can be made, the overall efficiency metrics delivered by Prototype 1 are in line with our expectations and put us in a good position to achieve target performance with our new design.

## NEXT STEPS

We are now in the late stages of the project, requiring us to build and test our prototype systems in a series of prototype vehicles. Overall, we will test three prototypes, each more sophisticated than the last.

As discussed in this report, Prototype 1 was built in July 2020 and testing is complete. Two further prototypes will be built and tested between now and December 2020. Using our latest (Generation 5) vehicle base, each prototype will be more mature than the last, with testing being more comprehensive:

| Vehicle | Prototype 1 | Prototype 2 | Prototype 3 |
|---|---|---|---|
| **Timing** | Jul 2020 (Completed) | Sep-Oct 20 | Oct-Nov 20 |
| **Objectives** | Test baseline Solar charging & energy consumption | Test key prototype systems & components | Full test of prototype vehicle systems |
| **Vehicle Systems** | Existing vehicle base with V1 Solar roof & charging system | Generation 5 vehicle base with V2 Solar roof & charging systems | Generation 5 vehicle base + passenger pod + V2/3 solar roof & charging systems |
| **Testing Scope** | • Solar Gain<br>• Energy Efficiency & Range<br>• Structural Performance<br>• Attachment Methods | • Solar Gain<br>• Energy Efficiency & Range<br>• Structural Performance<br>• Attachment Methods<br>• Mass | • Solar Gain<br>• Energy Efficiency & Range<br>• Structural Performance<br>• Attachment Methods<br>• Mass<br>• Thermal Performance<br>• Design for Assembly<br>• Durability |

*Table 1 - Prototype Testing Program*