# UNDERSTANDING RACE STRATEGY

WESTERN SYDNEY SOLAR TEAM | 2021

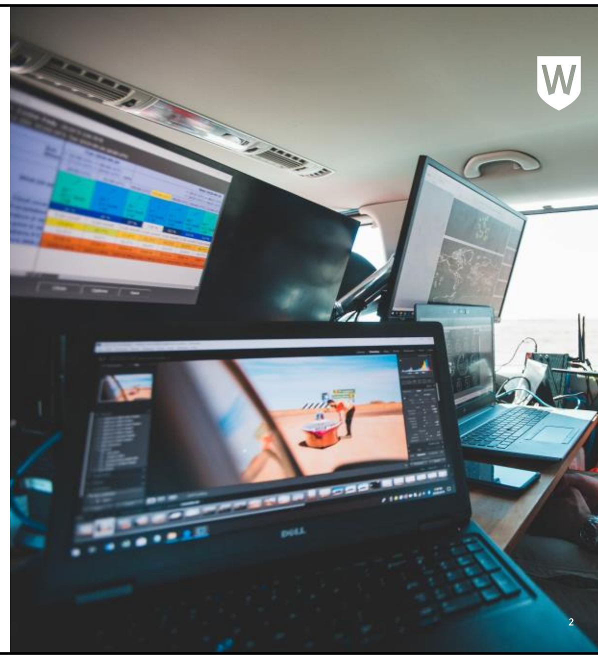
Andrew Smith & Jonathan Allen

Western Sydney University acknowledges the Darug, Eora, Dharawal (also referred to as Tharawal) and Wiradjuri peoples and thanks them for their support of its work on their lands (Greater Western Sydney and beyond).

## OVERVIEW

- Introduction to Race Strategy
- Approaches to Race Strategy
- Adjusting to track based racing





•First we will discuss the need for race strategy and some of the factors that come into play during the solar challenge

•Then we will discuss some established approaches to calculating a race strategy

•And finally we will talk about how we have had to change our approach for the upcoming Aussie Solar Challenge which is track based whereas the Bridgestone World Solar Challenge is a road based competition.


•The Bridgestone World Solar Challenge (BWSC for short) is a 3022km challenge from Darwin at the top of Australia all the way to Adelaide at the bottom. It runs every 2 years, but due to the COVID 19 pandemic was cancelled in 2021.

•The challenge takes place over a week and teams are only allowed to race between 8am and 5pm. There are 9 set ‘control stops’ along the challenge route which can be seen on this map, where the team must stop for 30 minutes and are not allowed to touch the car in that period.

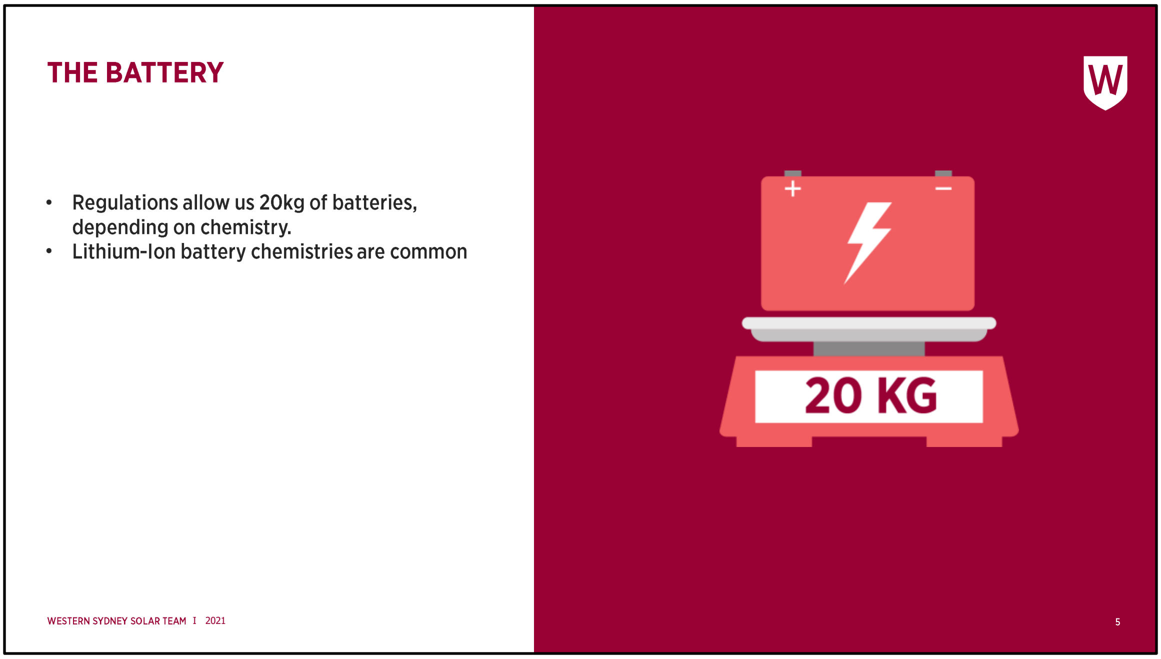
•We start the challenge with a fully charged battery pack and cannot use external sources of power, except the sun, to get us to Adelaide. This means no plugging in along the way.

•Our aim in the BWSC is to be the first team across the finish line in Adelaide.

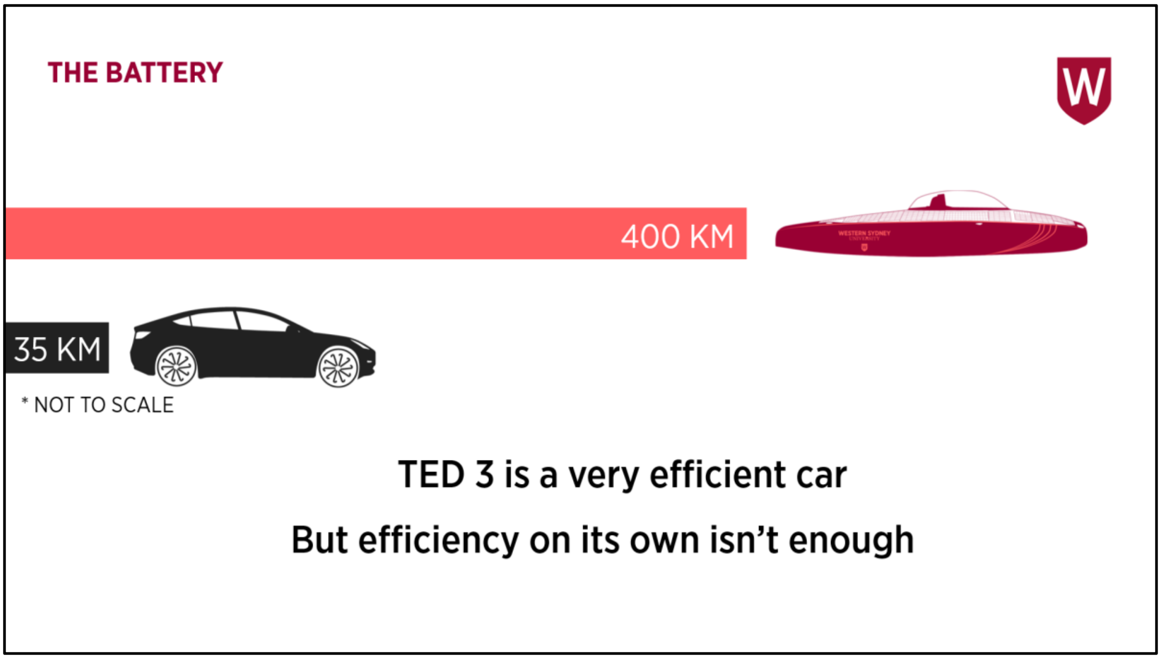
## THE CAR



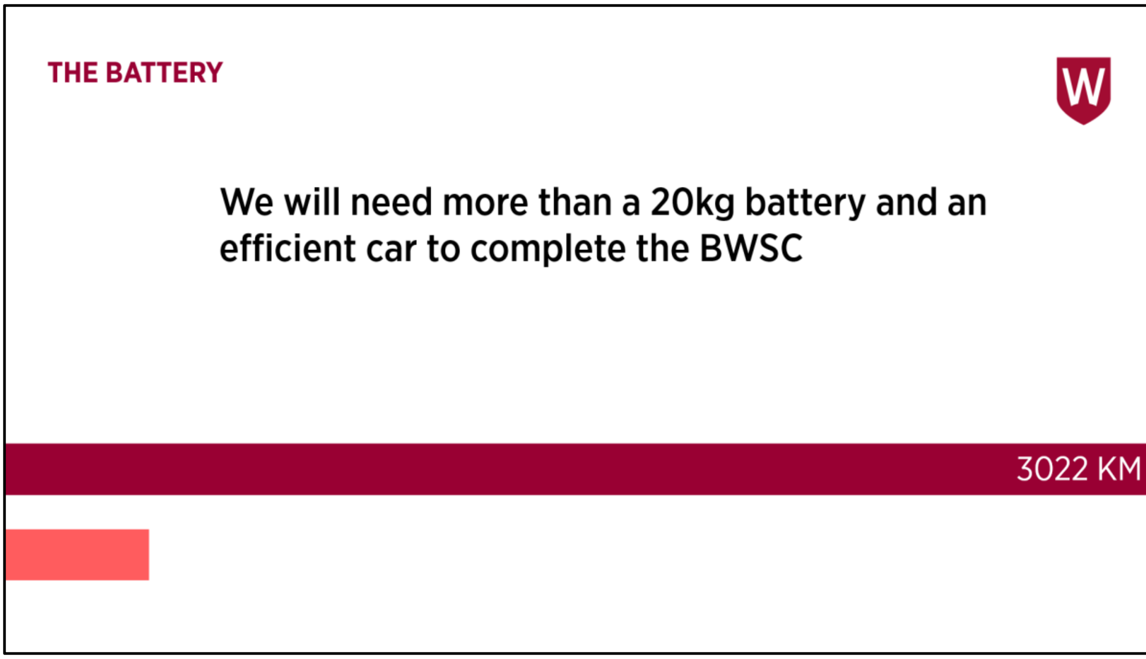

Let’s introduce our car for the BWSC, this is UNLIMITED 3.0 or ‘TED 3’ for short. This was the car we designed and manufactured for the 2019 BWSC and the team worked to optimise every aspect of the car for efficiency. This ranges from the aerodynamic design of the car, an almost completely carbon fibre construction, specifically chosen low rolling resistance tires and weight savings taken where possible. This led Ted 3 to be the lightest solar car to ever compete in the BWSC, coming in at only 116.8 kg. So we can see that we are bringing a very efficient car to the BWSC.



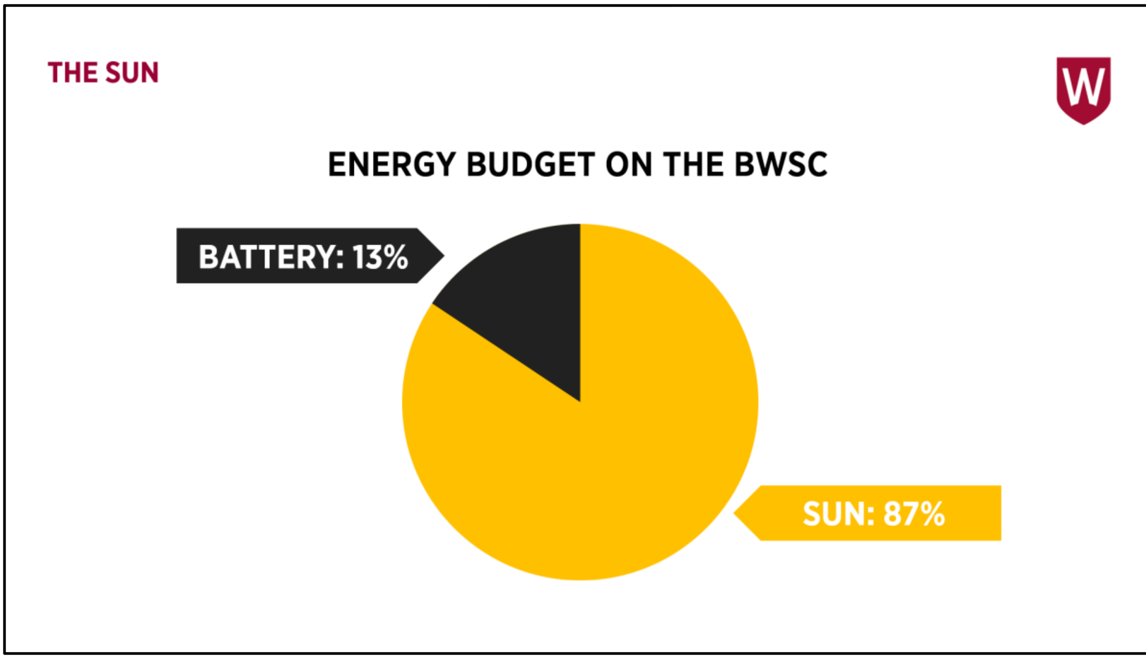

With the BWSC regulations, we are allowed 20kg of batteries, depending on the specific battery chemistry chosen.



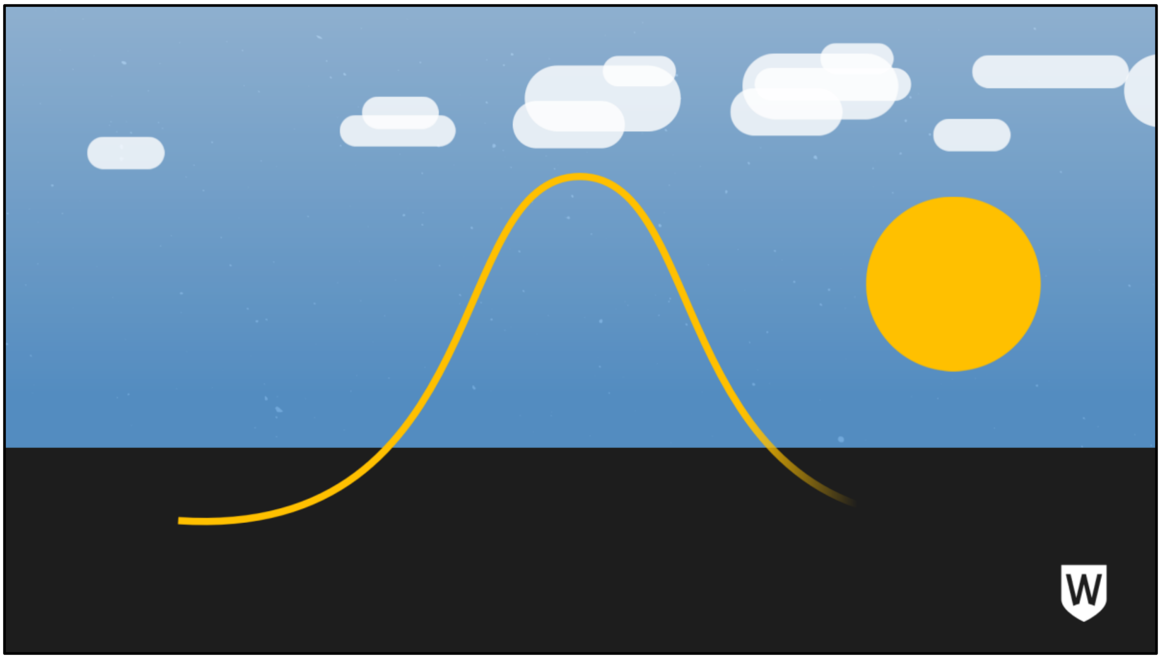

So lets see how far we get that 20kg battery pack gets us, because Ted 3 is so efficient we can travel around 400km on a single charge. For context a modern consumer electric vehicle will only travel around 35km on that same amount of energy. So we can conclude that Ted 3 is a very efficient car, but efficiency alone isn’t enough.



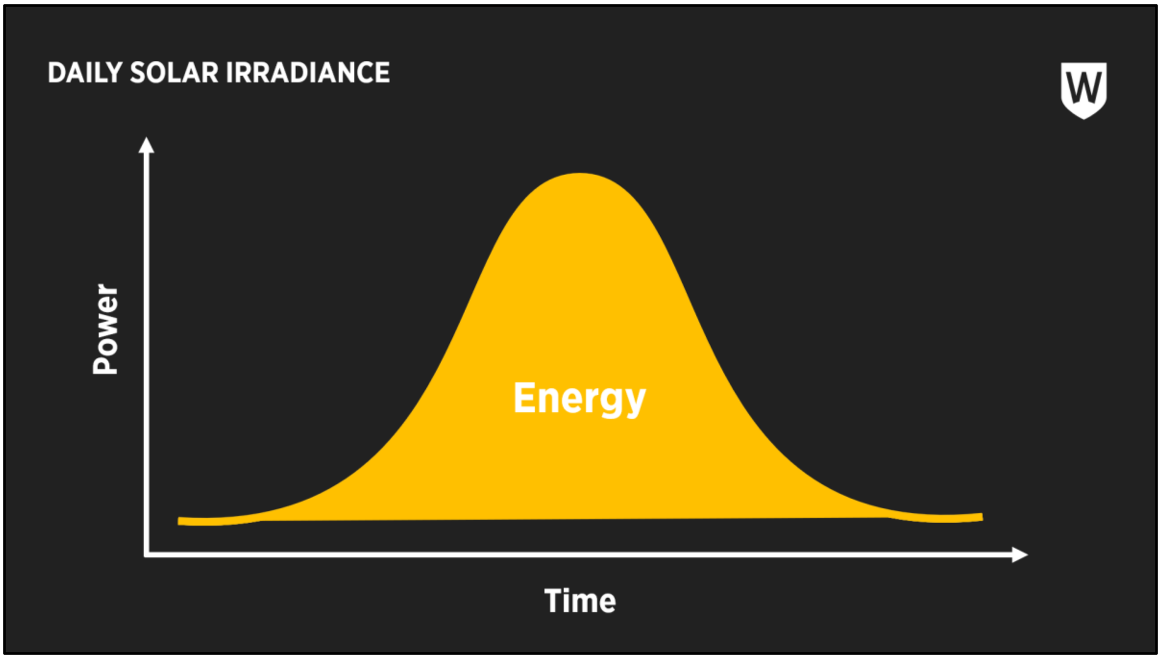

We run into an issue, and that is the fact that the BWSC is a 3022km challenge. Battery alone will only get us part of the way. So we are going to need more than our 20kg battery and a very efficient car if we want to complete the BWSC.



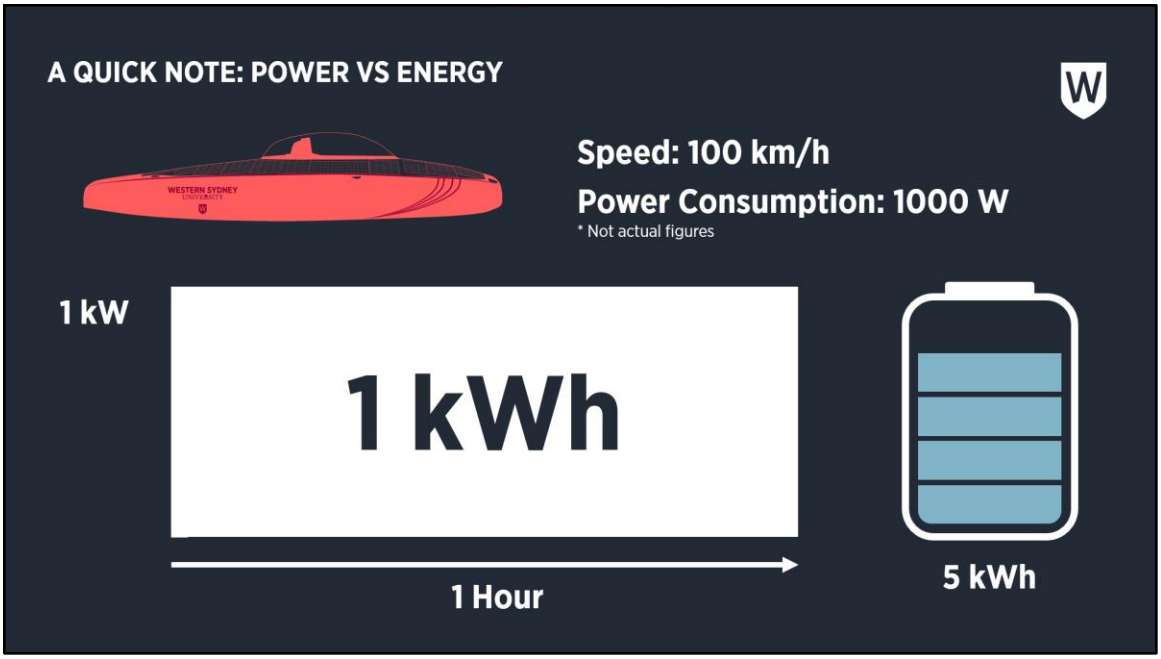

So the energy in our battery won't be enough for the BWSC, but we are a solar team after all. So we must rely on solar power to get us the rest of the way. Over the duration of the challenge we expect the battery to only provide 13% of the energy and the sun to provide 87% of the energy we will use on the challenge. So over the duration of the challenge we would expect to accumulate a certain amount of solar power and then we can add the energy in the battery at the start of the challenge, that makes this circle representative of all the energy we will have available to us on the challenge. So if our goal is to cross the finish line of the BWSC first, we will need to go as fast as possible, this would mean making the most effective use of all this energy. However, solar power isn't quite that simple. We can't really treat the energy we get from the sun like we do energy in the battery, as it isn't available to us in one go. Rather it is accumulated throughout the challenge.



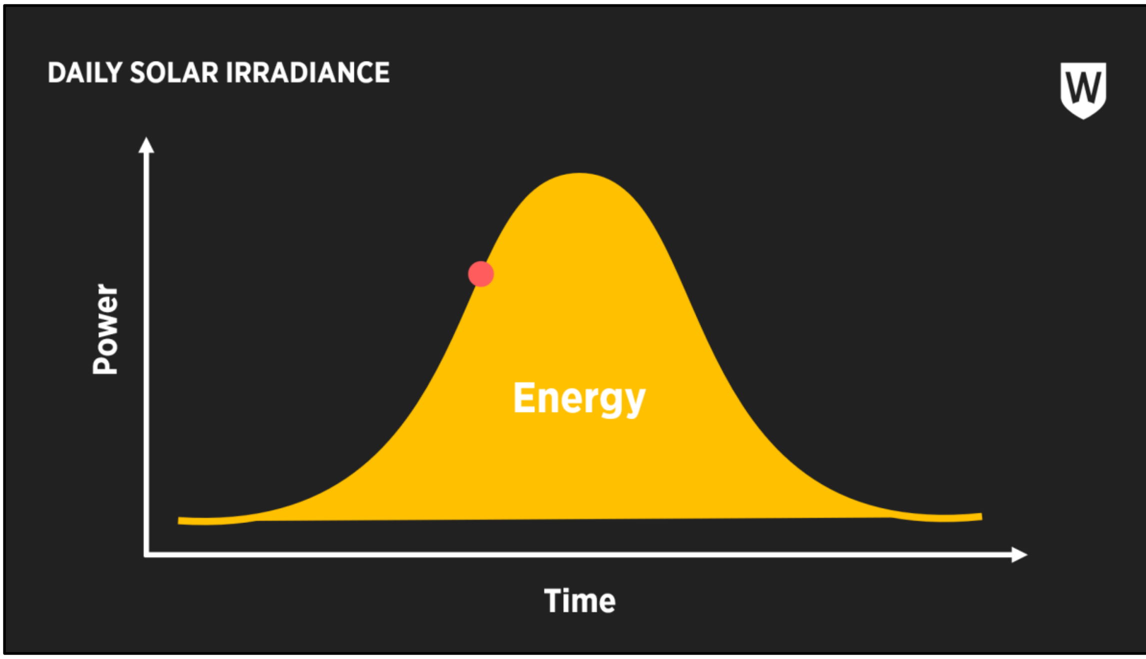

Solar power varies predictably throughout the day as the position of the sun changes. With the most solar power being at solar noon.



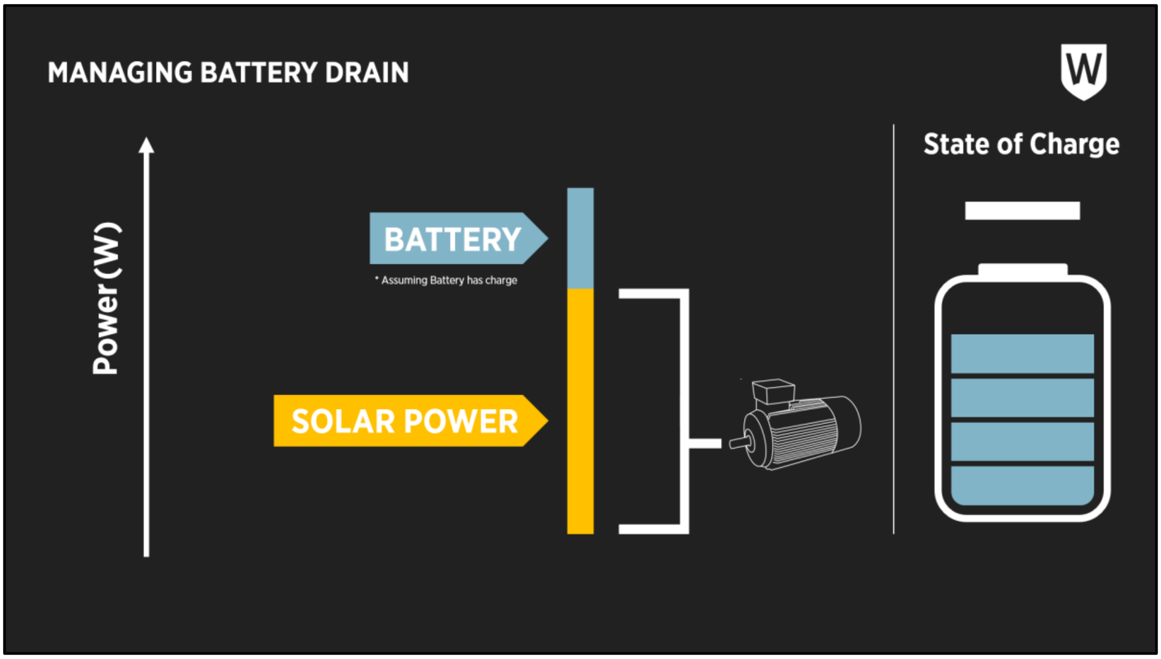

So on this plot, the Y axis represents the irradiance from the Sun measured in Watts per metre squared, but for simplicity we will discuss it in terms of it being 'Power' which is measured in Watts. The X axis represents time, in this case spanning a single day. The height of this yellow line is the power from the sun at a given point in time. Therefore, the area under this curve is the energy we will get from the sun over that day as energy = power multiplied by time



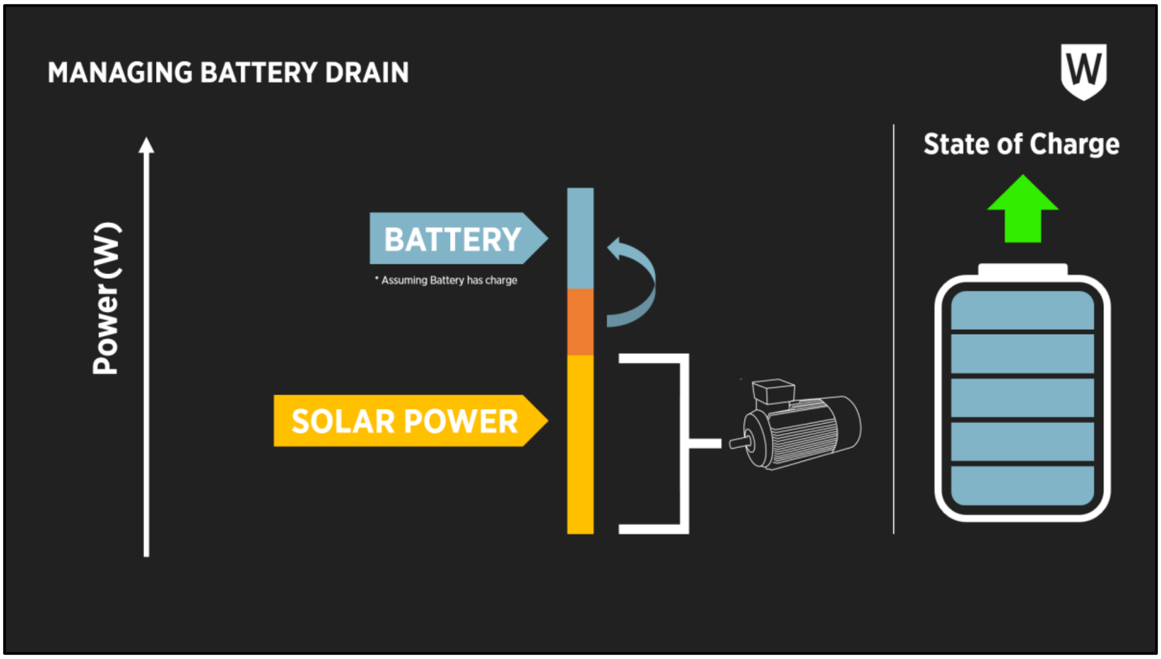

Just a quick note on the terms power and energy. Lets say we have our car travelling at 100 km/h which means it is consuming 1000 Watts of power, or 1 kW.  If we then ask the question of how much our battery will drain? Then we need a time component to answer that. So if we are travelling that speed for an hour, then we would have used 1 kWh of energy which would equate to 1/5th of a 5 kWh battery



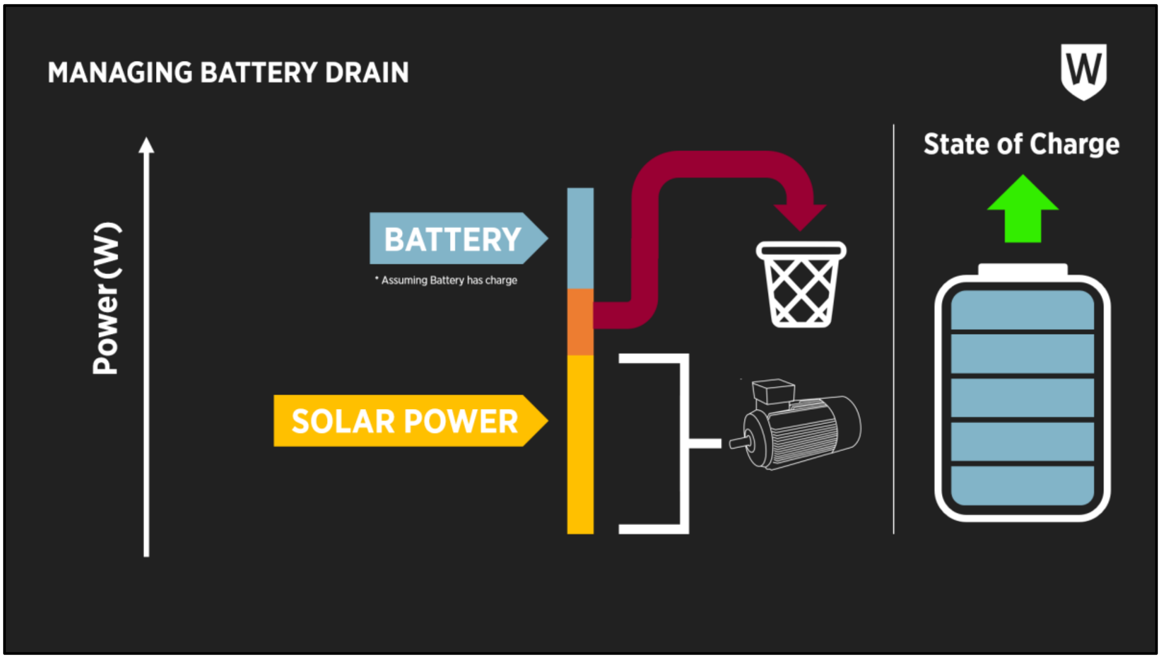

Lets pick a point along this line, at any given time we will have a certain amount of power coming in through our solar array.



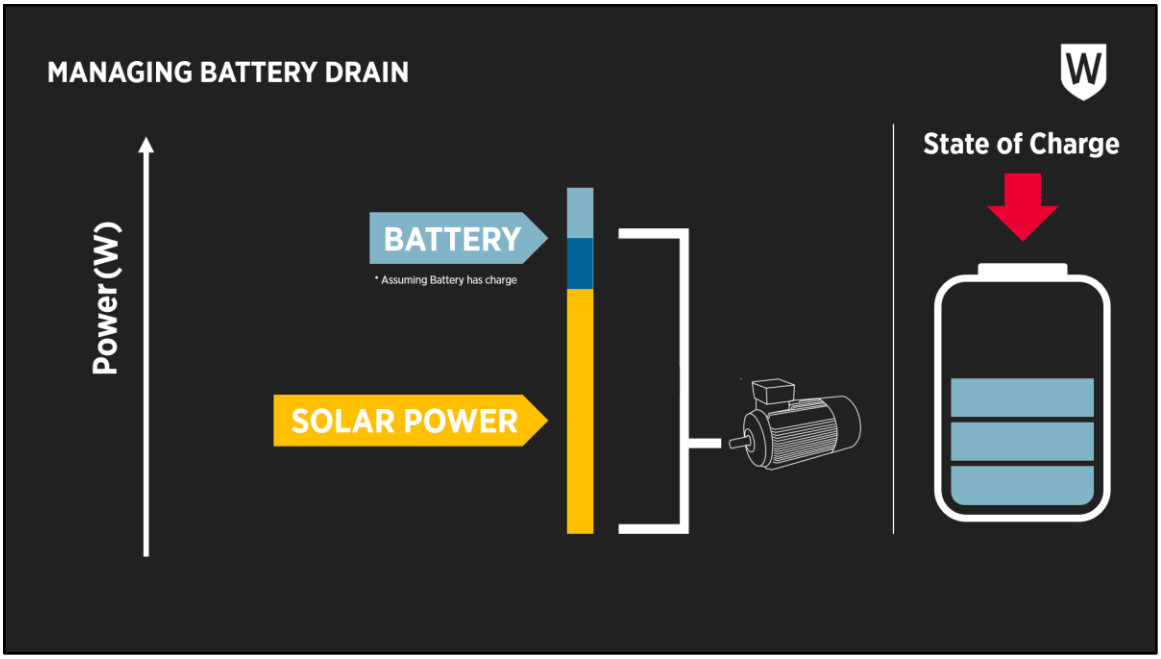

This solar power combined with the power we can draw from the battery becomes the power available to us at any given point. Of course we can only draw power from the battery if it has energy left in it. The main power consuming component of the solar car is the motor which drives the car. How much power this is consuming largely depends on the speed at which the car is travelling.
If we are using the same amount of power as the solar panels are providing then we are neither charging or draining the battery.



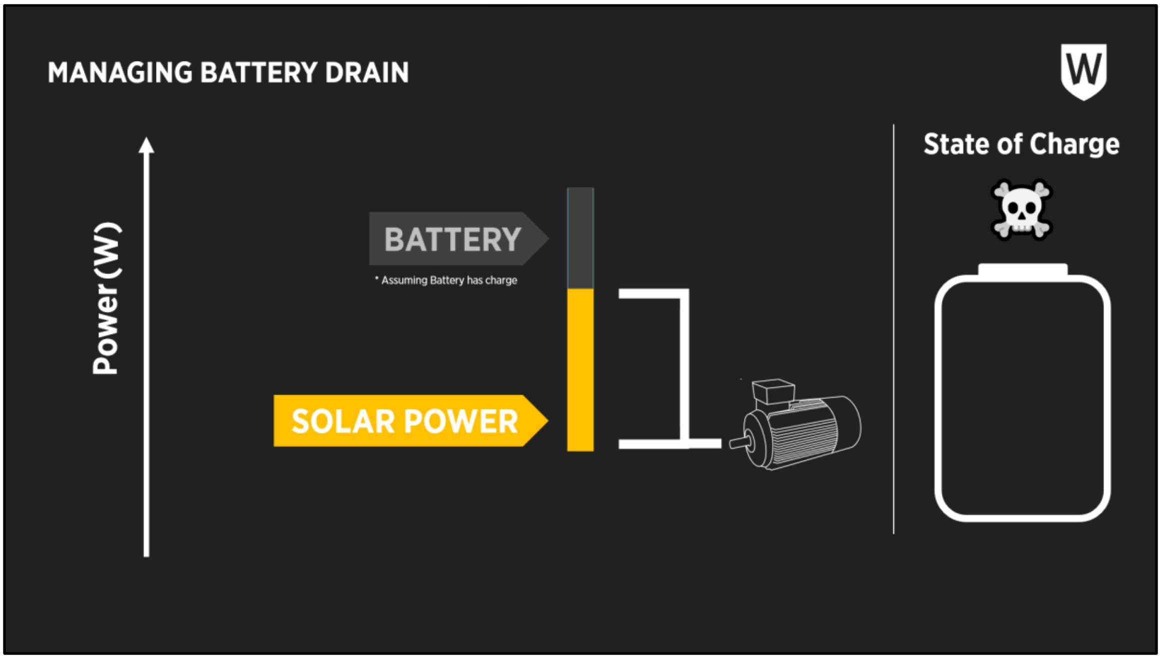

If we are using less than the solar panels are providing us then we can use the remaining solar power to charge the battery.



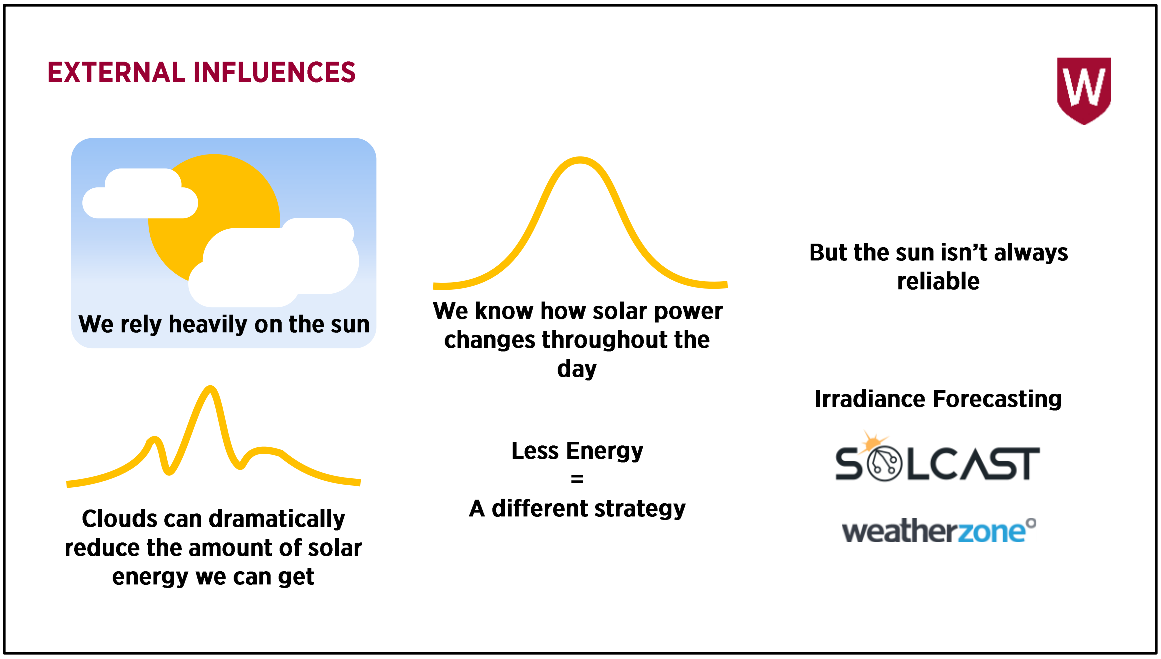

However, if the battery is full then this excess energy goes to waste. Therefore we don't want to have a completely charged battery for long during the challenge, as we want to use all the energy available to us, not discard it.




If we are using more power than the solar panels are providing then we are draining the battery. This isn't necessarily a bad thing as the battery provides us the flexibility to choose a speed not entirely dependent on solar power.

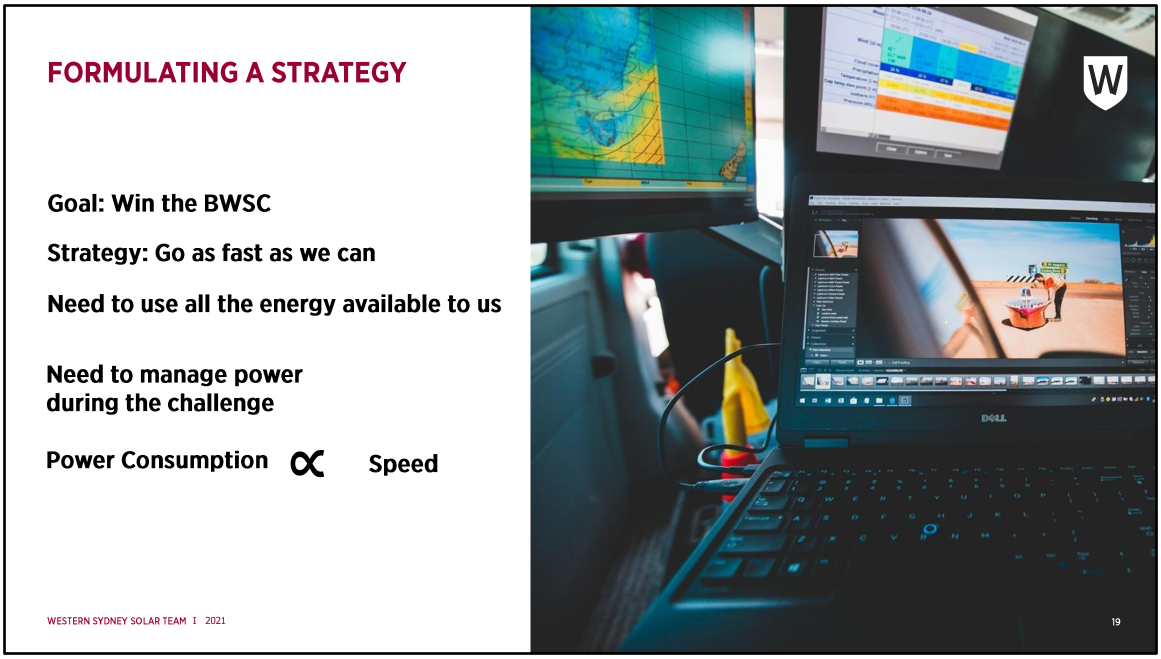



Now, if the battery is completely empty then we can only consume what the solar panels are providing us. This means our speed is dictated by the current conditions which severely limits our options.




So we have established that we rely heavily on solar power during the challenge and we know how the power in from the sun will vary throughout the day. While we rely on solar power, it isn't always reliable as it is subject to external influences. If there are clouds blocking the sun that can dramatically reduce the amount of solar power we can get at a given point.

If we are going to get less energy from the sun then we will make different decisions about the speed at which we travel. Less energy on the challenge will mean we will need to travel slower to still have enough energy to reach the finish line. If we have decided on a strategy and encounter clouds we weren't expecting, then we will need to rethink our strategy. But that is why we are partnered with Solcast and Weatherzone who provide best in class solar irradiance forecasting so we can plan our strategy around the expected conditions. However, these forecasts will never be 100% accurate so we will still require an adaptable strategy system.




So let’s quickly recap. Our goal is to win the BWSC, to do this our strategy is to go as fast as we possibly can. This means using all the energy available to us so we need to manage our power throughout the challenge. Power consumption is correlated with the speed we travel, so the goal of race strategy is to find the optimal speed to go to achieve this goal.

## CASE STUDY: 2017 BWSC

The 2017 was a year with uncharacteristic and severe weather. The team was faced with storm clouds ahead and had 3 options

1. Keep going the same speed knowing you will get less solar power
2. Slow down to account for less solar power
3. Speed up to ‘beat the clouds’



Lets look at a real world example, the 2017 Bridgestone World Solar Challenge. The 2017 challenge was plagued with uncharacteristic and severe weather including storms, which are atypical for the BWSC. Faced with dark storm clouds ahead, the 2017 team was presented with 3 options.

The first option is ‘do we go the same speed? Knowing we will drain the battery more since we will get less solar power while under cloud cover’.

The second option is to slow down to account for the loss in solar power, so you take a bit longer but your strategic position in terms of battery state of charge does not change.

The third option is to speed up to try and get ahead of the clouds, while you use more energy, you hope that by spending less time under the clouds you can get more overall solar power.

While it may sound counterintuitive, option 3 was shown to be the best option. Because as discussed earlier, solar power is the source of the majority of the energy on the challenge, therefore maximising that is more beneficial than preserving battery power in this scenario.

## MAKING INFORMED DECISIONS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21

So we’ve seen why we need race strategy. I'll now hand over to Andrew who will talk to you about how we can make these strategy decisions.

While the plan may sound simple, in that we need to go as fast as possible, it doesn’t necessarily mean we can sprint down the Stuart Highway at 130 km/h. We need to use the data available to us to choose when we could go fast and when we go slower.

## COMPUTER SIMULATION

With computer simulation we can look at how our decisions will play out to make the most informed decision. Allows us to ‘look ahead’.

Allows for an adaptable strategy system as we can reassess our decisions when we get new information.

Running a simulation requires computational power, this can be hard to come by in the middle of the desert. That is why we are collaborating with AWS as we can access more computing power in the cloud.

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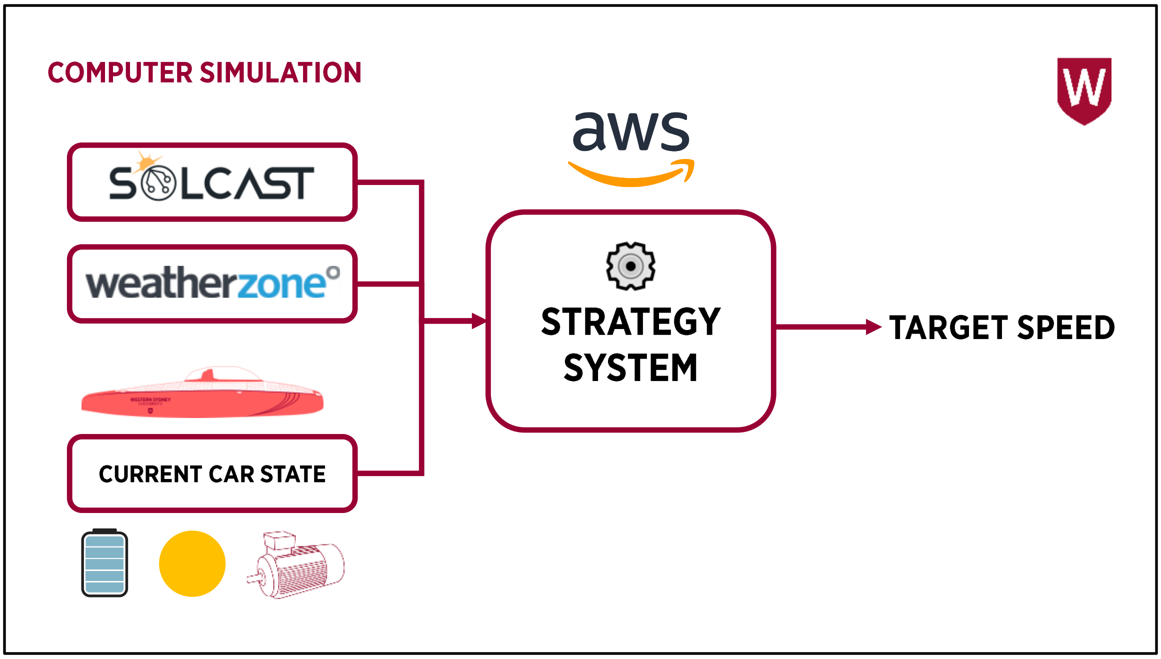
22

To make these decisions, we need to be able to simulate our solar car. We can look at how our decisions play out in future in order to make the best decision. With sufficient work, our system can be able to adapt to changes in conditions such as a sudden change in weather or anything. However it comes at a cost. The number of possible choices that can be made in the Bridgestone World Solar Challenge is potentially more than atoms in the universe depending on how you calculate it. As a result we need strong and capable compute power, a benefit of working with Amazon Web Services




So we've seen all the factors that we need to take into account, we then piece them together to form our system. Our current car state, consisting of battery state of charge, solar power in and power used in conjunction with the weather information we receive from Solcast and Weatherzone. These form inputs into our strategy system, powered by AWS, this system will give us the target speed we should travel for optimal performance.

## EXISTING APPROACHES


Optimal Energy Management for Solar Powered Cars
Peter Pudney, 2000

Solar Irradiance Forecasting by Machine Learning for Solar Car Races
Xiaoyan Shao et. al, 2016

World Solar Challenge: The Race Strategy Explained
Vincent de Geus, 2007

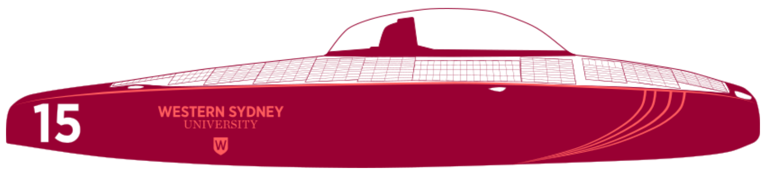


One of the unique elements of the Strategy team compared to the other technical sub-teams that make up solar car teams is that we are not necessarily bound by the regulations in what we do. As a result, you can find different examples where different teams have approached the Bridgestone World Solar Challenge in their own way to try and find the most optimal solution in completing the 3022 km.
A prime example of this is some of the work done by Peter Pudney with the University of South Australia and the Aurora Solar Team titled ‘Optimal Energy

Management for Solar-Powered Cars'. That details the entire 'solar car problem' and how to work to calculate an optimal strategy which helped to bring the team to victory at the 1999 World Solar Challenge.

In previous years, other teams across the world have published some details of elements of their strategy systems such as the University of Michigan publishing their work done in collaboration with IBM in creating a solar irradiance forecasting system along with a sky camera and the Vattenfall Solar Team using genetic algorithms. While these systems help achieve the goal of getting from Darwin to Adelaide as fast as possible, none of this work is required by regulations beyond ensuring that the minimum speed requirement is met.

## HERE'S A SOLAR CAR

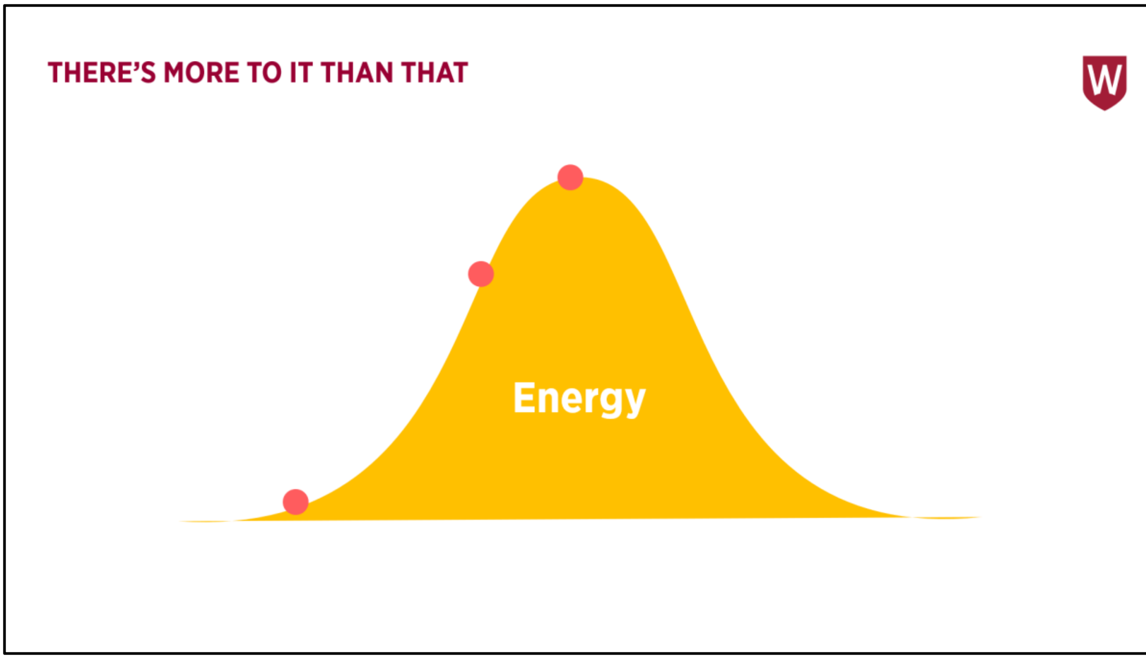



| | |
|---|---|
| Frontal Area: | 0.65m2 |
| Coefficient of drag: | 0.13 |
| Coefficient of rolling resistance: | 0.009 |
| Weight (without driver): | 139 kg |
| Solar panel: | 4m2 at 25% efficiency |

**Results:**

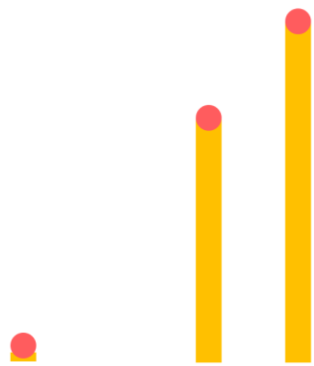
| | |
|---|---|
| **Target Speed:** | **89.16km/h** |
| **Duration:** | **34 hours** |

Here's an example of a solar car. Given the parameters on screen and expected values for battery power and the power intake during the Bridgestone World Solar Challenge, we can calculate the expected average speed during the entire challenge. While it is not completely accurate as it does not account for any incline/decline during the route, it can provide a general idea of expected performance that can be used to evaluate a design or provide an immediate strategy option.



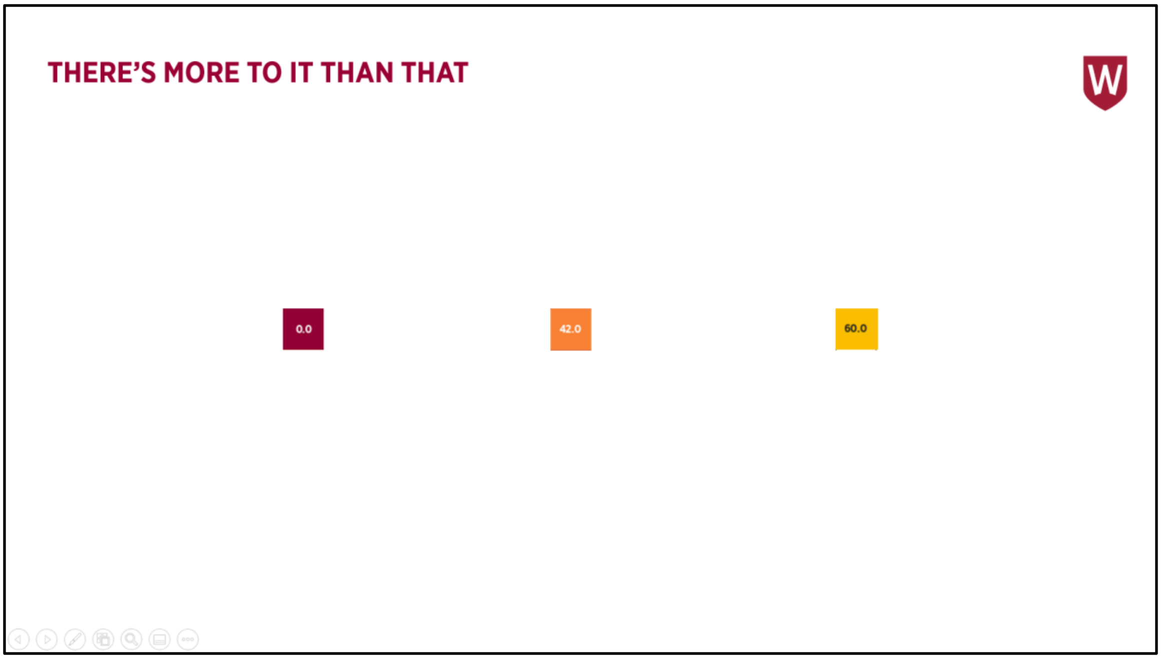

However there's more to it than that. The Bridgestone World Solar Challenge takes place over 8 hours per day for 7 days and the input solar irradiance can be represented as such.

## THERE'S MORE TO IT THAN THAT



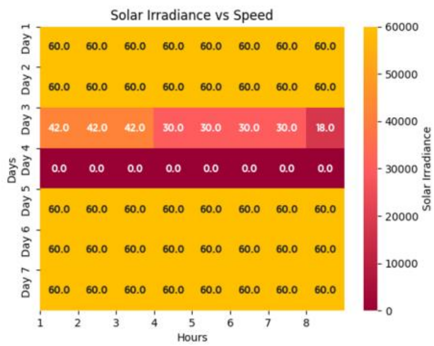
Bringing back the energy graph from before we can pick a few points along the curve to decide our energy input at any particular time.

## THERE'S MORE TO IT THAN THAT



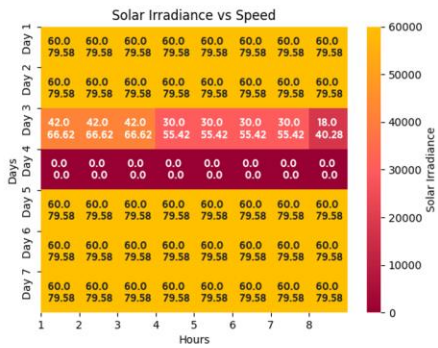

We can represent these as a number, where in this case it is the amount of kilowatts the car receives in an hour.

## THERE'S MORE TO IT THAN THAT

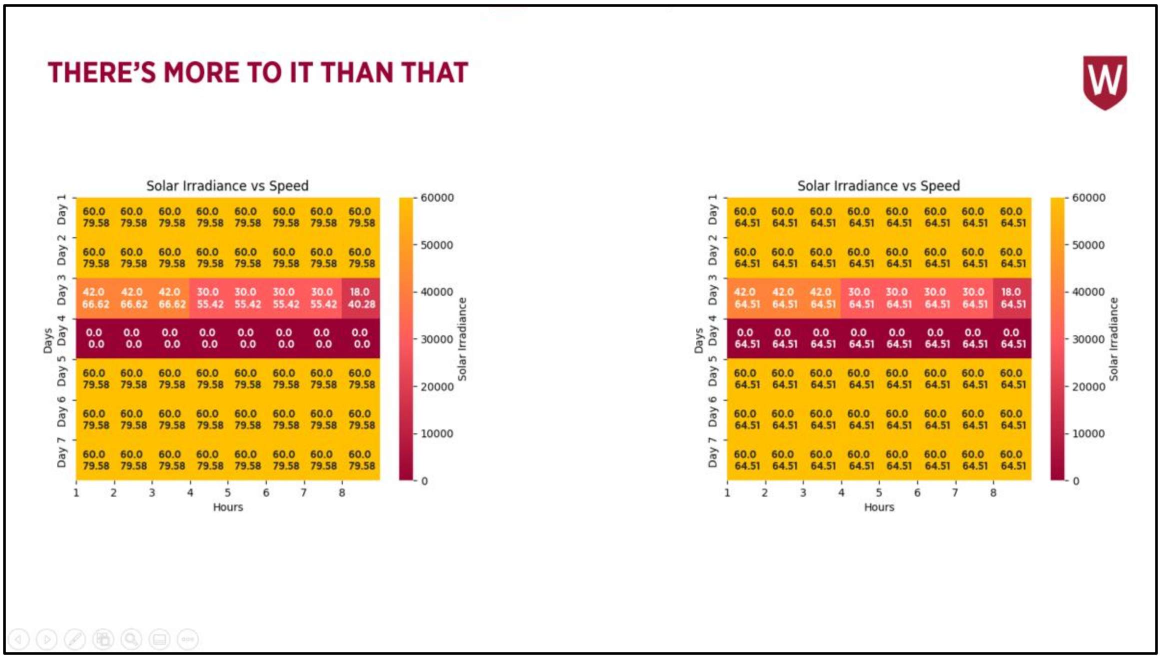



By arranging these numbers into a 7 by 8 grid where each row is a day and each column is an hour, we can create a basic representation of the Bridgestone World Solar Challenge. Here in this example a constant amount of solar irradiance is received on each hour of each day except for day 3 where it decreases during the day and day 4 where no solar power is available whatsoever. This exact scenario is extremely unlikely to occur during real life as the solar irradiance tends to follow a curve during the day where it tapers off at the start and end of each day. Having a full day of 0 solar irradiation is also not realistic but serves to demonstrate how irradiance can vary with differing conditions.

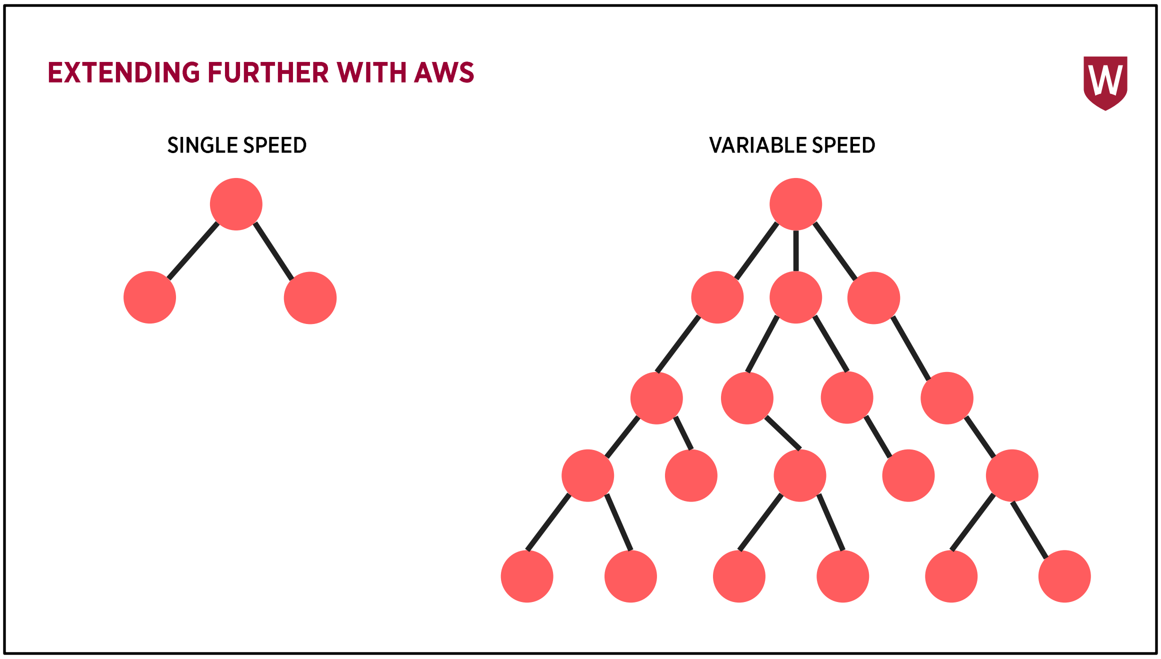
## THERE'S MORE TO IT THAN THAT




By knowing the parameters of the car we can model how much power the car will use when moving and construct a model based off of that. One approach we can take is to try and keep the car neutral in that the power into the car is equal to the power used as shown by the bottom number in each cell. However, as shown, that comes with a cost in that in times of low to no sunlight, the car significantly slows down and is at a stop when there is no sunlight as no power is running in the car.

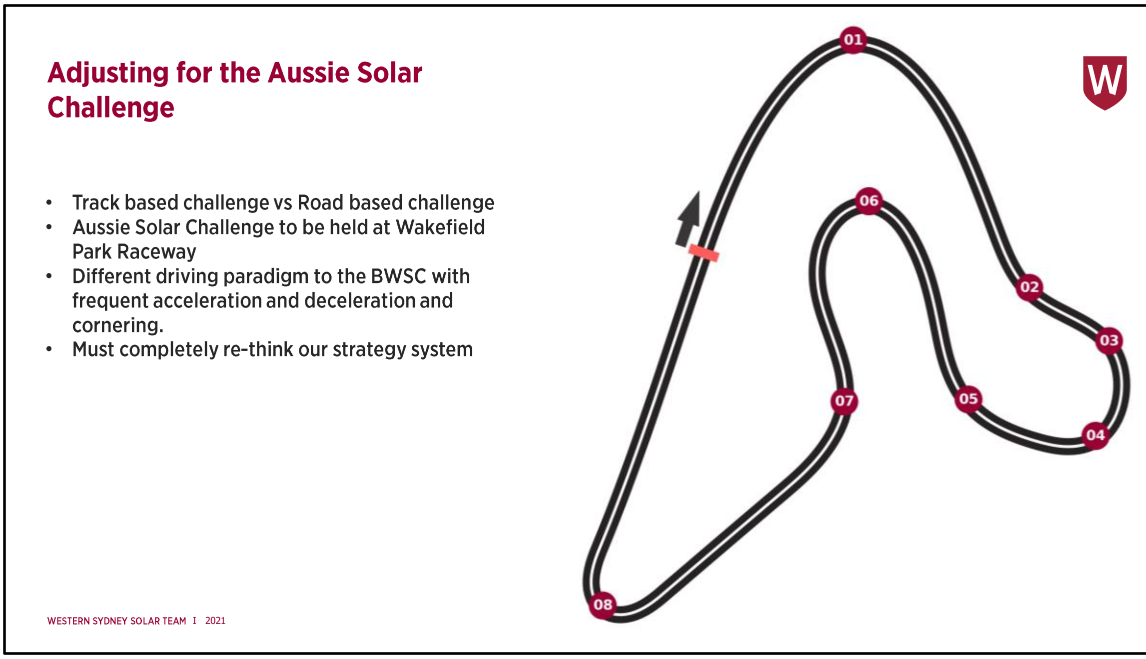



The advantage for us is that the car has a battery. So from this we can calculate a speed in which the car drives fastest without running out of charge before the finish. By running at a constant speed, we can quickly calculate a strategy in which the solar car completes the Bridgestone World Solar Challenge without running out of charge while going as fast as possible.




The previous approach only looks to calculate a singular speed to complete the entire challenge. While this approach may work, there are many more approaches that can be taken. This is where you may start to see a large amount of complexity, while in the previous model, there are less than 50,000 possibilities so calculating all possibilities is easy with a powerful computer, it can be adjusted where there would potentially be billions of possibilities. By analysing a greater number of possibilities we can hope to arrive at a better strategy than simply picking a single cruising speed. Imagine that each of these orange circles is a given 'state' that we could find ourselves in, each orange circle would represent being at a certain point along the route and with a certain battery state of charge and certain weather conditions and so on. Each of these orange circles is reached based on the decisions we make, represented by the black lines. So if we expand the decisions we make to include different speeds at different points along the route, then we massively increase the number of orange circles we need to consider.

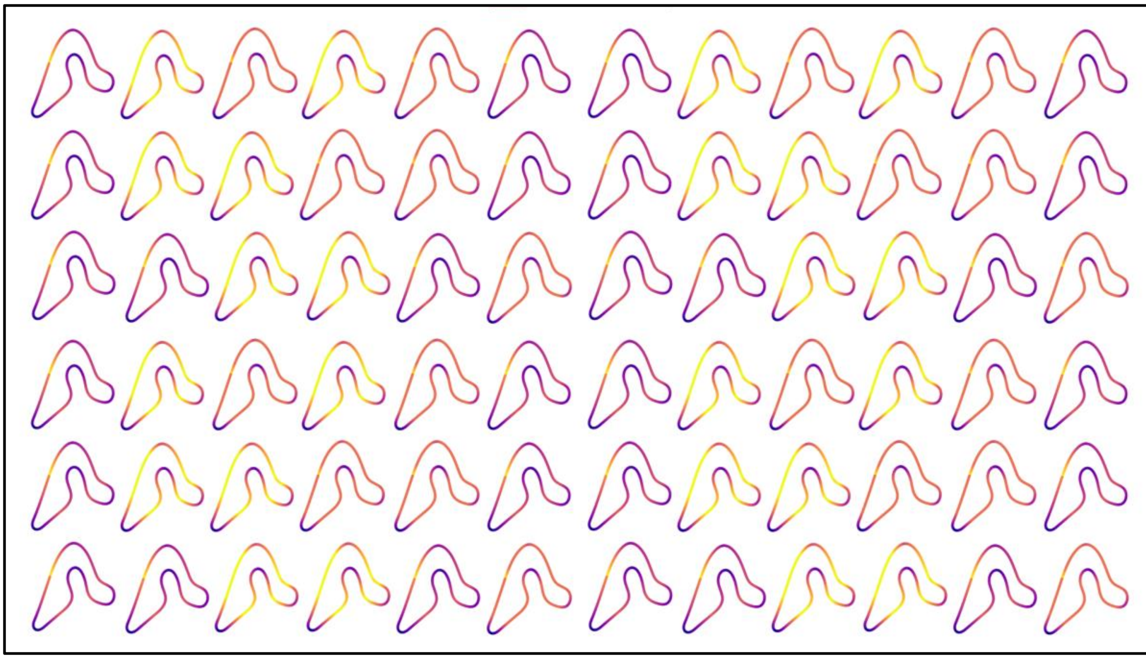
Calculating these possibilities requires a large amount of computing power. Having a large amount of computing power works to increase effectiveness and broaden our horizons on what is possible. Thankfully working with AWS we can transform ‘imagine if we could’ to ‘how do we’.



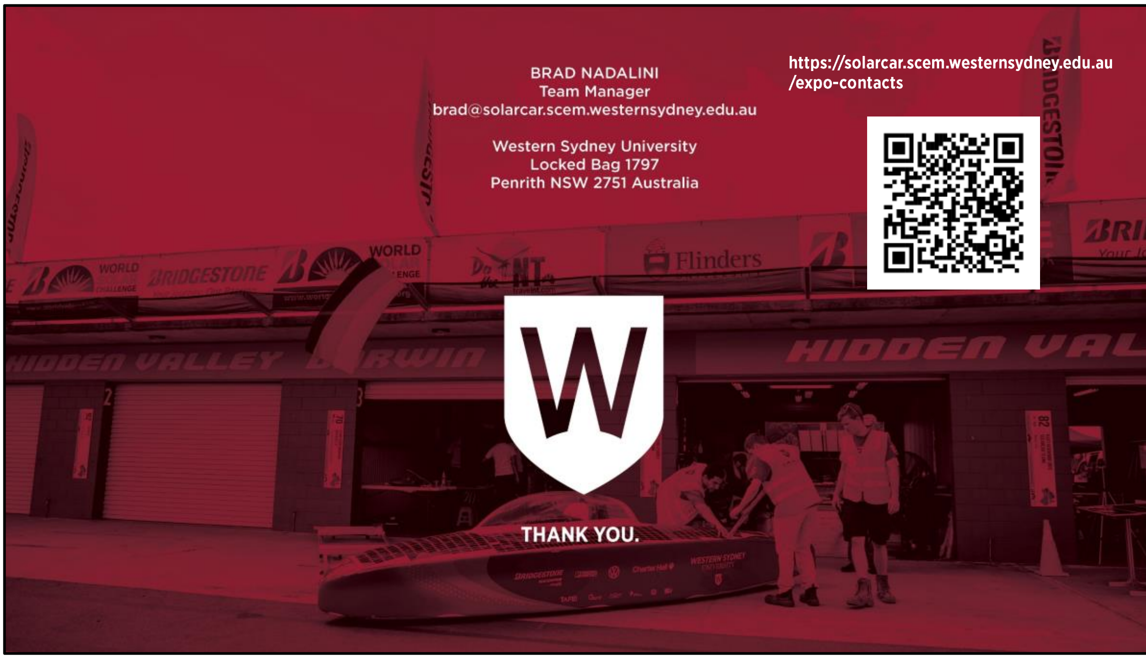

So we've seen how we can approach building a strategy system for the BWSC, but let's look at how a track based event changes things.

Following the cancellation of the 2021 Bridgestone World Solar Challenge, the Aussie Solar Challenge was created. While it was also postponed due to the recent Covid-19 lockdown, it presented a new challenge for us. The Bridgestone World Solar Challenge is a road based challenge whereas the Aussie Solar Challenge is track-based. Here we have to account for frequent acceleration and deceleration and cornering speeds unlike the Bridgestone World Solar Challenge where this is not necessarily a concern as it is largely cruising at a consistent speed on a motorway. As a result we have had to completely rethink our strategy system from the ground up.

Thankfully this is an area that has been worked on by other people in the area of Formula SAE, Roborace and more. With the known parameters of our car, we are able to simulate a single lap around a track



Which, if you piece many of these simulations together at varying speeds, to the level of possibly hundreds of laps you can create a simulation of the Aussie Solar Challenge to inform strategy decisions. With this we are able to face this new challenge with confidence




Thanks for listening, there is a QR code and a link to contact details that were referenced in this presentation. The rest of this session will be for questions and answers