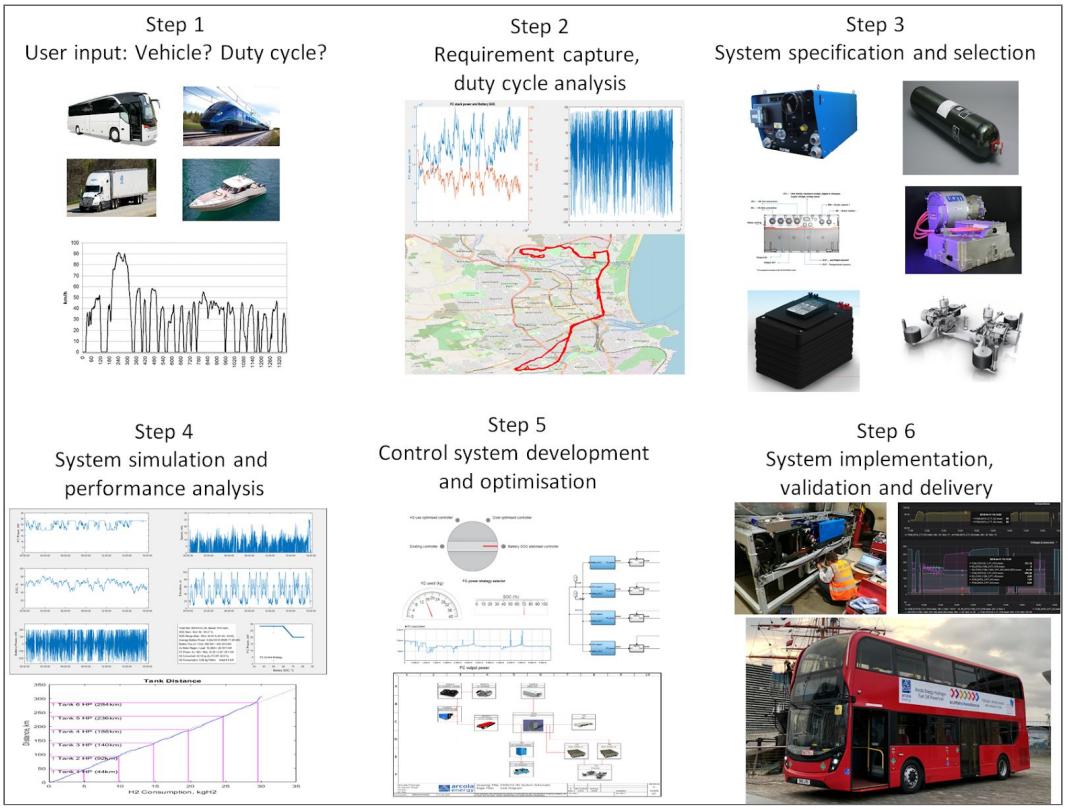
Powertrain modelling at Arcola Energy

Our modelling capability is at the heart of our powertrain design and development, enabling us to build systems that meet requirements for performance, efficiency, system cost and lifetime. Our models include a deep understanding of the science of individual devices combined with vehicle-derived validation. We are at the leading edge of hydrogen and fuel cell powertrain design with the ability to save time and money in design and development of zero-emission vehicles, and to create best-in-class vehicles

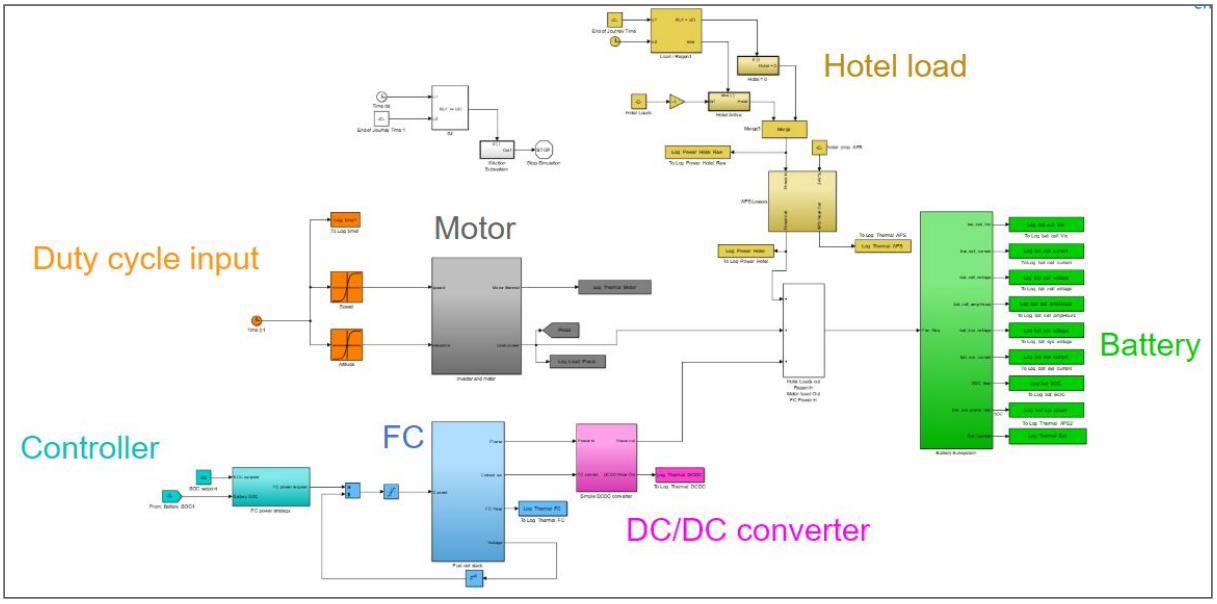


Our powertrain models calculate power and energy needed for a given vehicle on a given route by taking recorded speed and elevation data from vehicles and using this to define performance requirements. We can also build up requirements from route data and a physics-based model of the vehicle in question. The modelling results are much better than estimations based on peak and average power requirements or other less sophisticated approaches.

Our powertrain modelling can accommodate different configurations between the main power source (e.g. fuel cell) and energy storage (e.g. batteries). Dependent on duty cycles, power requirements and available space we can simulate and optimise a variety of battery and range extender sizing options. We optimise fuel cell and battery lifetimes through estimation of component life and developed models of mean time between failures and likely warranty costs across a 10-year vehicle lifetime.

We model powertrain designs with varying specifications of traction motor, fuel cell, battery and hydrogen storage. We compare designs for power delivery, operating efficiency and component lifetime for understanding bill of material (BoM) costs and total cost of system ownership. The powertrain model can assist with sizing battery, fuel cells, motors and other components to support

mechanical considerations of fitting into available space, and financial considerations of budget or preferred suppliers.



For example, our current bus powertrain design uses a smaller fuel cell than comparable vehicles leading to lower BoM cost, better performance and reduced lifetime costs. In test, the double-deck bus, developed with Alexander Dennis, is the most efficient in its class with 28% greater efficiency than the equivalent hydrogen single deck buses currently operating across Europe and using about half the energy of an equivalent hybrid double-deck. Modelling meant we could design the system right first time and then use the developed model to validate which would enable potential further optimisations.

Importantly, the model has been validated against the actual performance of vehicles in operation. Our remote monitoring systems capture data from across the integrated system, reporting on aspects of system performance. This data is used continually by our team to refine the model and characteristics of individual devices and the complete system. The bus powertrain, designed for the Alexander Dennis double-deck project, has been validated in a number of different duty cycles in cities including London, Liverpool and Aberdeen.

Thermal modelling is a key part of our powertrain model, enabling thorough investigation of thermal characteristics of the system in design. Clients can use the model to understand the effects of various heat inputs and variable controls to support cooling system specification and heat recovery design.

The model can be used to design, test and evaluate different power management strategies which can help optimise fuel economy and contribute to specification of fuel cell and battery size. Depending on requirements, the power management strategy can be optimised for a range of outcomes, for example fuel economy, system cost, system performance, or individual component lifetime. Control algorithms developed and validated in the powertrain model can be directly exported to the vehicle powertrain controller

Underpinning our models is research from leading research groups at Imperial College London and Warwick Manufacturing Group. These groups have analysed the fundamental processes underlying efficiency and degradation in batteries and fuel cells and have tested specific technologies and

devices. We bring this knowledge into our models so we can design systems for maximum performance and lifetime and minimise total cost of ownership.