



Hydrogen Train Capabilities

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Hydrogen trains – what's the point?

- We all know that electrification is the most efficient means of providing energy to power trains
- Charging batteries is more energy efficient than creating hydrogen
- We understand batteries, we understand electrification, we've never used hydrogen
- So why are we talking about hydrogen, and building hydrogen trains..?



Storing energy – why we love liquid hydrocarbons...

- ~25% of the network in Scotland is electrified
- ~40% across the UK
- Zero emission self powered trains are needed
- “Self powered” means carrying stored energy
- Compared to diesel, energy density is key:
- Diesel = 35.8MJ/l
- Hydrogen = 4.6MJ/l @ 350bar
- Li-Ion = 2.3MJ/l
- So, hydrogen takes 8x the space of diesel
- Batteries, 16x
- (and batteries are 50x lower density per kg)



But diesel is **not** the comparator

- Diesel is dead – by 2035 here in Scotland
- A rolling programme of electrification can address the high priority routes
- Continuous electrification programmes will reduce the costs of electrifying these routes
- But, we can't and won't electrify everywhere for reasons of cost, disruption and environmental issues/embedded carbon
- These factors are the comparators, hydrogen is a “competitor” with electrification for longer, trickier regional routes
- In reality, the technologies are complimentary and need to be pursued in parallel



What are the capabilities of hydrogen trains?

- Zero emissions from the train
- Range >1,000km
- Speeds up to 160km/h (Cat A & B)
- Battery hybrid drive uses regen braking energy
- Performance to match DMUs replaced
- Refill times & process similar to diesel
- All weather capability
- System introduction without service impact



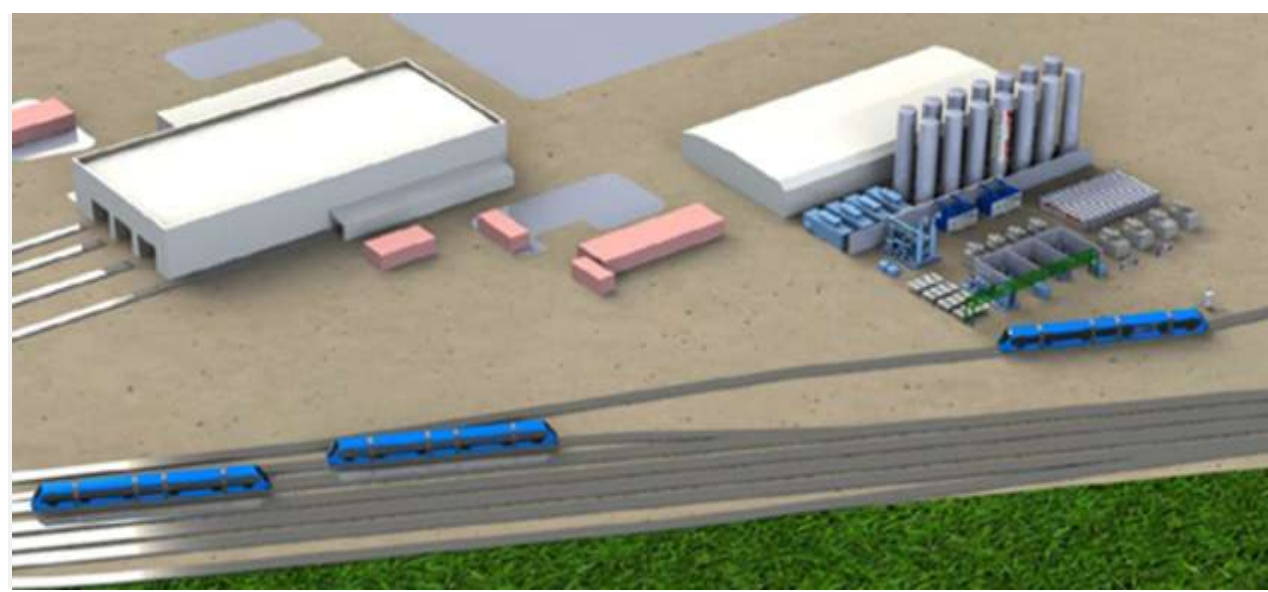
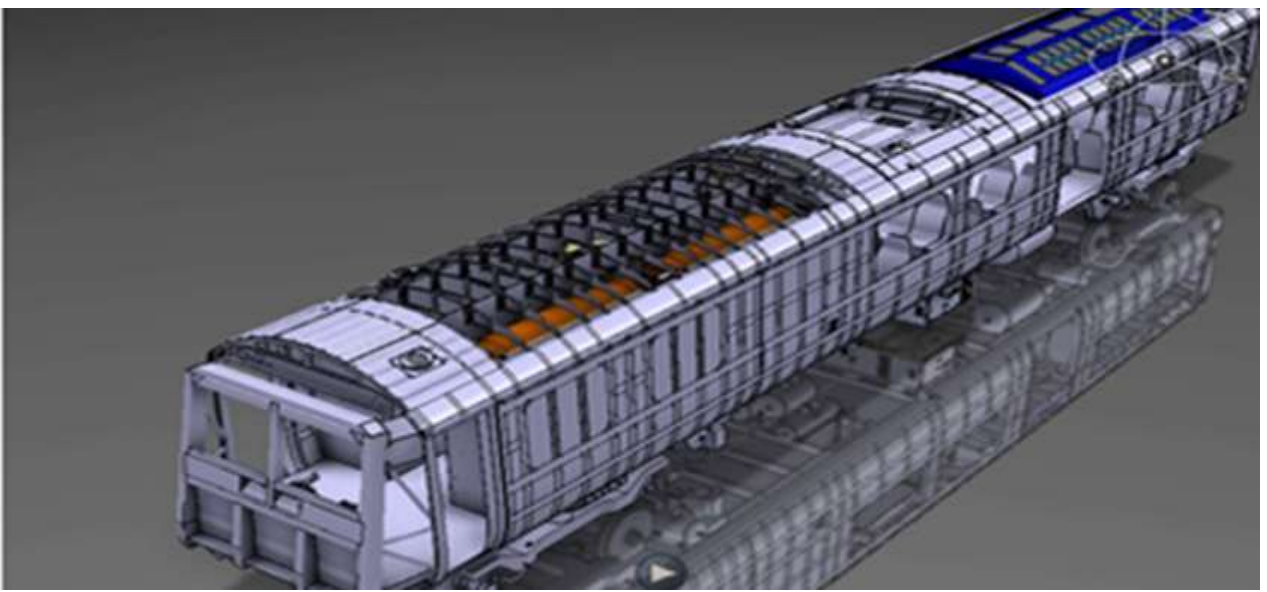
What might it solve in Scotland?

- There are a number of routes that may not suit electrification here in Scotland
- Even if they do, it may be decades before they are all completed
- As a final solution, or a transition technology to bridge the 2035 objective, hydrogen fits perfectly in the mix
- Hydrogen infrastructure is also multi-modal, the output of a hydrogen facility can power buses, cars, buildings or industry as well as, or after, powering trains

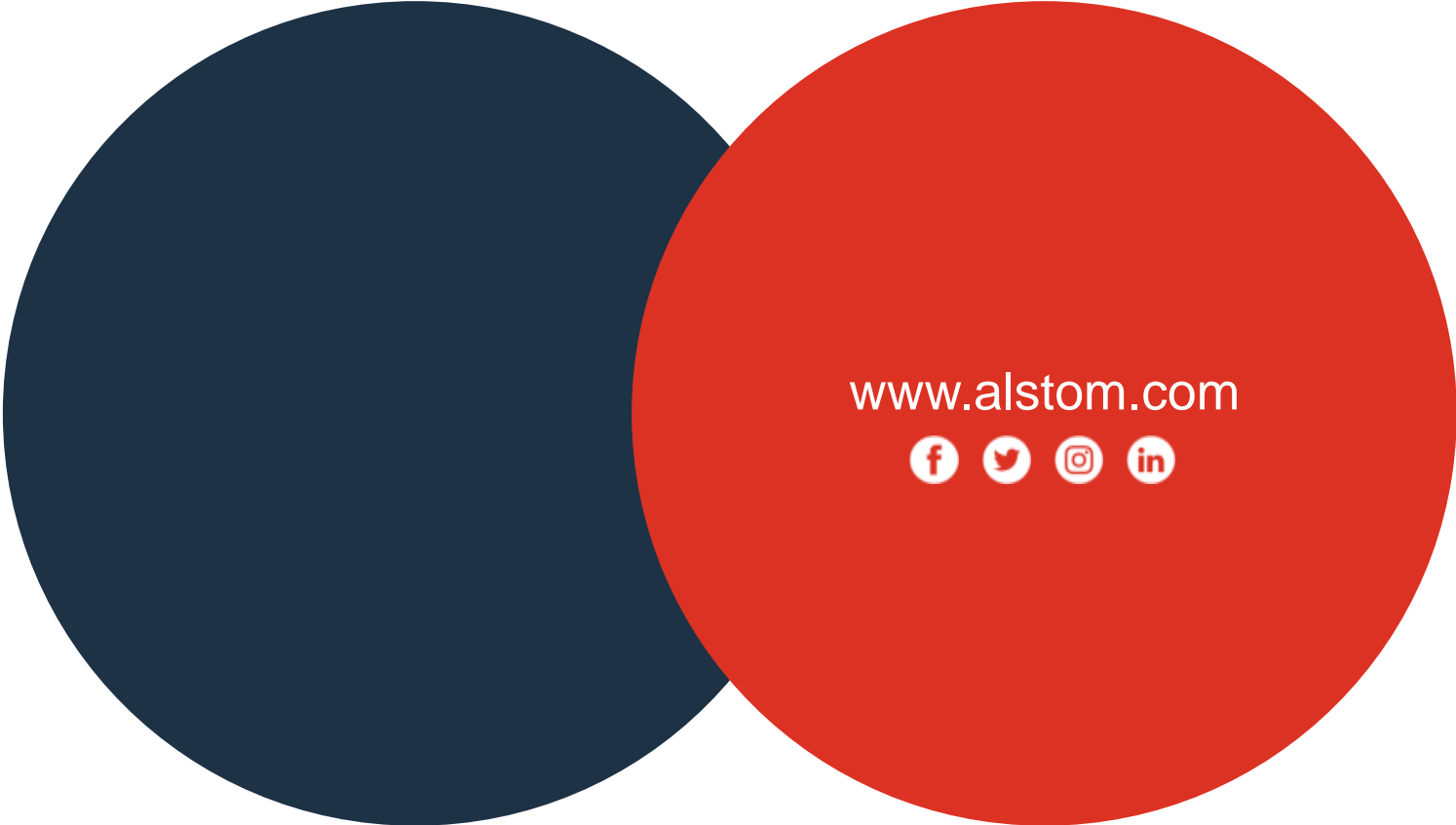


New technology, new challenges, better outcomes

- Hydrogen trains will require dedicated fuel facilities, just like diesel did or batteries need chargers
- With green hydrogen, these trains would be the cleanest on the network, any network
- Scotland's world leading renewable energy potential lends itself to green hydrogen production
- Conventional business cases, residual values and homologation are challenging
- The technology exists. With leadership and a vision to decarbonise it can play its part...







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