Sustainable, low-cost composites for net-zero infrastructure: Green hydrogen pressure vessels for self-sufficient rural and off gas grid detached homes

Hanisa Hasrin[a], Colin Robert[a], Conchúr Ó Brádaigh[a],
Alex Baidak[b], Benjamin Wood[b], Paul Mackenzie[b]

[a] Institute for Materials and Processes, The University of Edinburgh, Edinburgh, UK
[b] Hexcel Composites Limited, Duxford, UK

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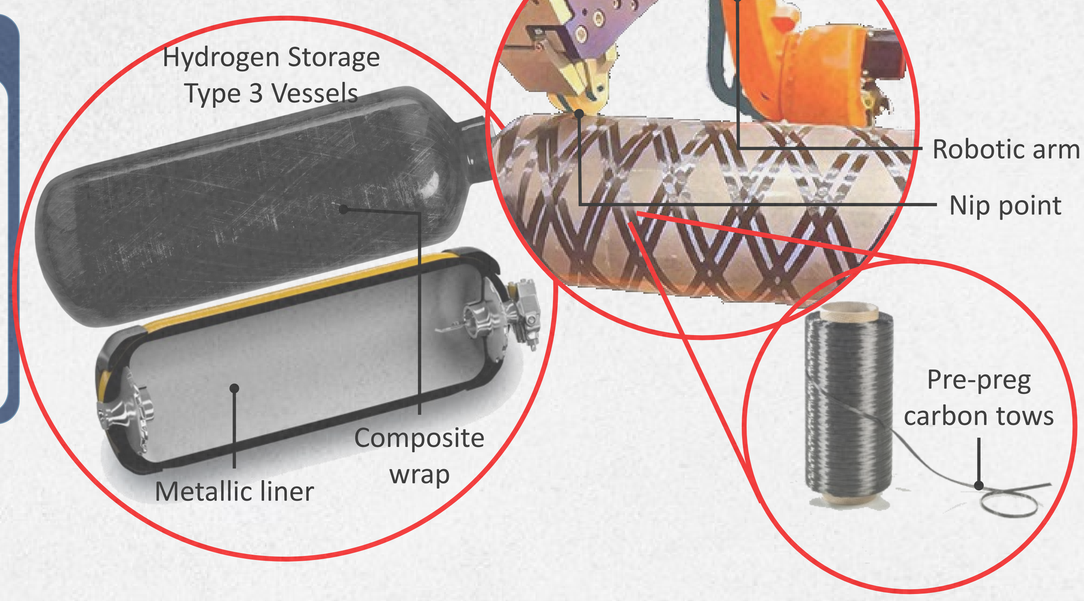
Research Summary

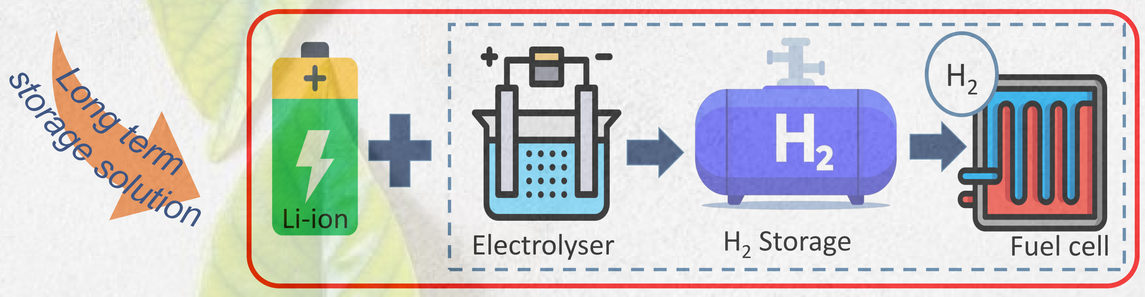
1. Self-sufficient, off gas-grid homes

- Residential sector is the 2nd largest CO_2 emitter in the UK (68.1 $MtCO_2$ in 2021), thus **pushing their dependency on RES** for energy production
- Sustainable home reliance on RES is limited by its variability and intermittency
- Produced energy need **efficient storage system** to allow self-sufficiency and detachment from gas-grid



2. Typical Energy Storage for Homes

- Currently, most homes store energy electrochemically with **rechargeable batteries (Li-ion)**
- Batteries **lifetime is influenced by operating condition**
- Only suitable for **short-term storage** due to its limited capacity & self-discharge



3. Hybrid Energy Storage System (Ba-H_2)

- Hydrogen has high energy density (142 MJ/kg), favourable for **long term energy storage**
- However, hydrogen has **poor round trip conversion efficiency**, thus not suitable as a stand alone system
- The most efficient way to **convert hydrogen to electricity** is through **fuel cell**
- Hybrid storage configuration (Ba-H_2) **lowers LCOE**, allowing battery not to be oversized[1]

4. Hydrogen High-Pressure Vessels

- **Pressurised gas** is the most matured hydrogen storage technology
- Storage dimension & capacity depends on climate
- Pressure vessels of **Type 3 or 4** allows for high volumetric storage density at **high pressure**
- Type 3 or 4 has **composite wrapping** as load bearing structure, therefore a more lightweight vessel

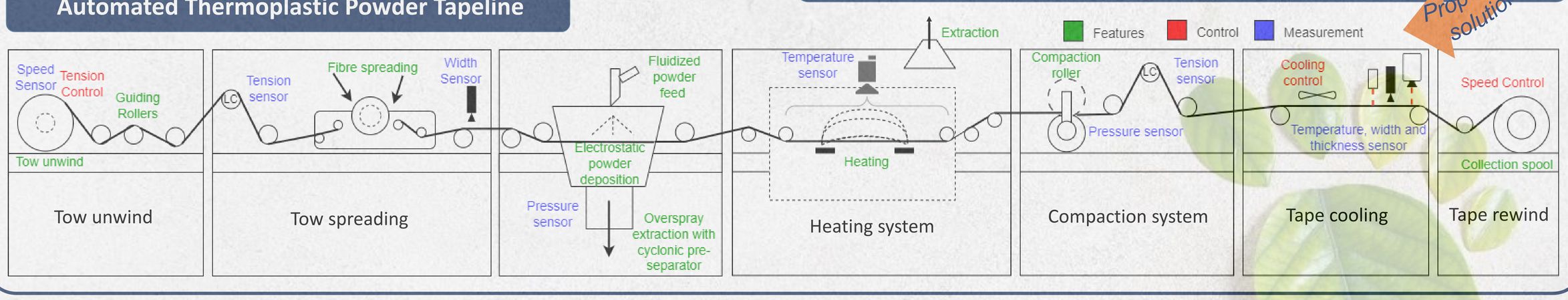
5. Vessel Manufacturing and Material

- Vessels composite wrap is manufactured via **automated fibre placement (AFP) or filament winding (FW)**
- Feed material is composite tape of **long continuous fibre** with width typically of ½ -inch or ¼ -inch
- Long continuous fibre provides **mechanical strength**
- **High cost - more than 50%** of production cost is from **material cost**[2]

6. Problem Statement

- To lower material cost for hydrogen vessels production by:
  - ✓ **Automation** of tape production
  - ✓ Utilize **dry powder process** to eliminate high cost of solvent needed for liquid processing
- Push towards decarbonising and sustainability of composite manufacturing
  - ✓ In line with industry driven needs, use of **thermoplastic** as matrix
  - ✓ Thermoplastic has **higher impact resistance,** ability to be **reshaped** at elevated temperature and **recyclable**
  - ✓ Thermoplastic composite **enables faster production** by eliminating curing stage

Automated Thermoplastic Powder Tapeline



Research Development

7. Research Aim and Objectives

- **Design and construction** of a high performance **thermoplastic powder tapeline**
- Manufacturing and **optimization** of thermoplastic tape **to meet industry standard** – assessed by using tape with industrial ready equipment (AFP and/or FW)
- Perform **mechanical, physical and optical characterization** of the high-performance thermoplastic tape.
- Look for collaborators for **production of hydrogen vessels**
- Potentially deliver a low-cost high-performance thermoplastic hydrogen pressure vessel (**Type 3 or 4**) suitable for use in individual housing

8. Thermoplastic Tapeline Concept Design

- Modular system
  - Increase **adaptability** – ability to operate with wide range of thermoplastic powder
  - Ease module optimisation
- **Low energy** by adapting low power heating technology with RF heating[3]
- **Low waste** by recycling over-sprayed powder
- System controlled by **custom built HMI** on LabVIEW
- **Monitoring** of line speed, tension, temperature, consolidation pressure and tape width
- **Control** over line speed, tension, heating temperature, consolidation roller temperature, cooling rate

9. Research Challenges

- **High melt viscosity** of thermoplastic
  - Limits full fibre wet out and consolidation
  - **Compaction roller system** on tapeline to improves consolidation
- **Adaptability** to wide range of powder
  - Tapeline capability for heating up to **400 °C** with RF heating, adapt to wide range of powder
- Quality of tape produced should be **industrial ready** (targeted FVF, low void, targeted crystallinity, tape width control)

References

[1] P. Marocco, D. Ferrero, A. Lanzini, and M. Santarelli, "The role of hydrogen in the optimal design of off-grid hybrid renewable energy systems," *J Energy Storage*, vol. 4 6, 2022, doi: 10.1016/j.est.2021.103893
[2] A. Elberry, J. Thakur, and A. Santasalo-Aarnio, "Large-scale compressed hydrogen storage as part of renewable electricity storage systems, doi: 10.1016/j.ijhydene.2021.02.080
[3] A. Vashisth, R.E. Healey, M. Pospisil, J. Oh and M. Green, "Continuous processing of pre-pregs using radio frequency heating," Composites Science and Technology, vol. 195, 2020, doi: 108211/j.est.2021.103893.