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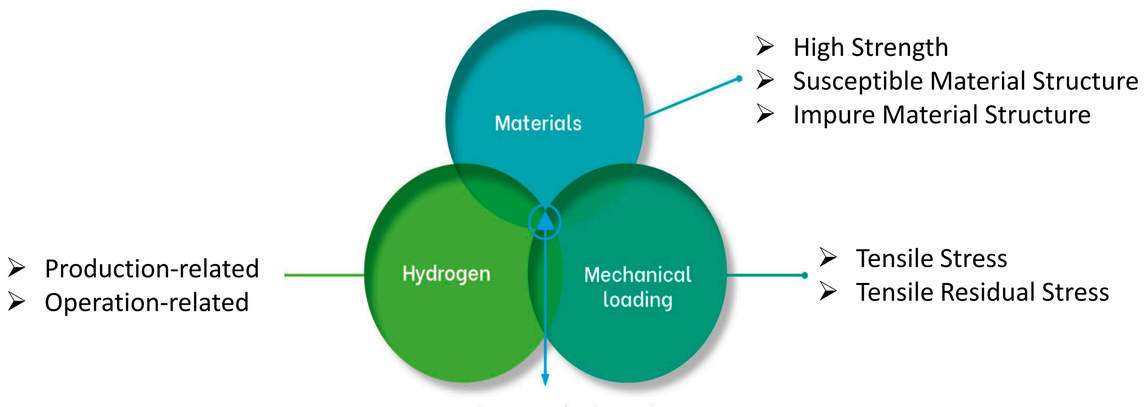
Coating network and barrier property design strategies for protection against hydrogen embrittlement

INTRODUCTION

Hydrogen gas represents a viable energy vector in the shift towards a net zero society, facilitated by the cost-effective utilization of current pipeline infrastructure for the storage and transportation of H_2. Nonetheless, it is recognized that atomic hydrogen can diminish the material toughness and promote cracking phenomena in steel alloys.

Hydrogen embrittlement (HE) is a complex phenomenon that affects the integrity and performance of metals and alloys in environments where hydrogen is present. It occurs when hydrogen atoms diffuse into the metal, leading to a reduction in ductility and toughness, ultimately causing premature failure under stress. This problem is particularly critical in high-stress environments such as aerospace, automotive, and energy sectors, where the reliability and safety of materials are paramount.

The causes of this form of failure, as illustrated, involve the existence of a vulnerable material, conditions favorable for degradation, and stress (whether inherent or externally applied). When any two out of these three elements coexist, failure becomes unavoidable [1].



Hydrogen Embrittlement

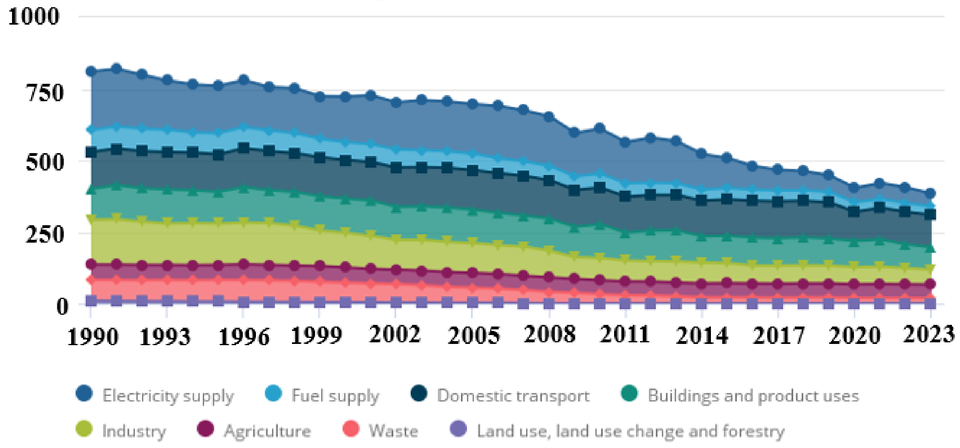
Goals

The UK Greenhouse Gas Emissions and Net-Zero Goals

According to UK Climate Change Act 2008 — Net Zero by 2050

In 2023, total UK emissions were estimated at **384** million tonnes of carbon dioxide equivalent (Mt CO_2e)

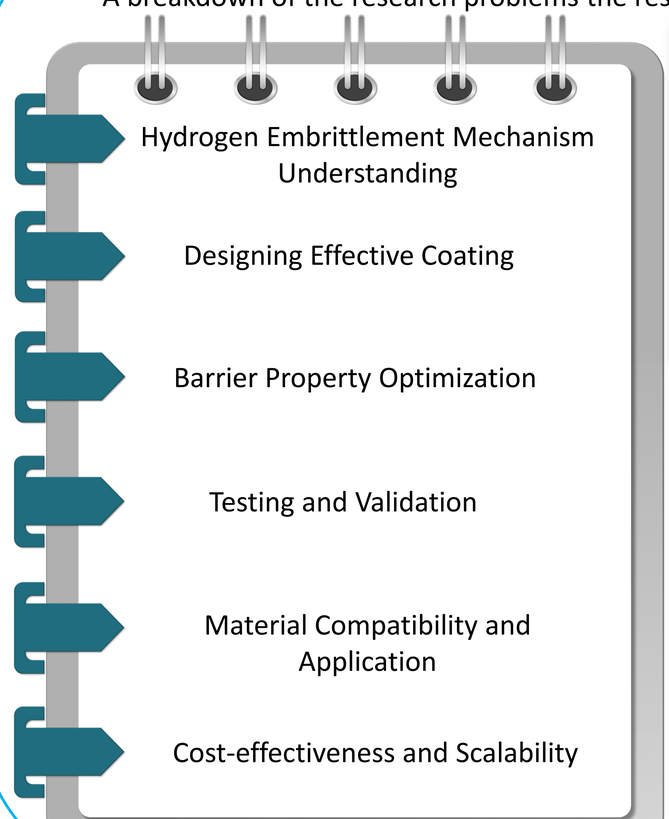
UK greenhouse gas emissions, 1990-2023 (National Statics) [2]



Hydrogen is key to achieving a net zero society and hydrogen economy, crucial for heating, transport, and industry, relying on current and new infrastructure

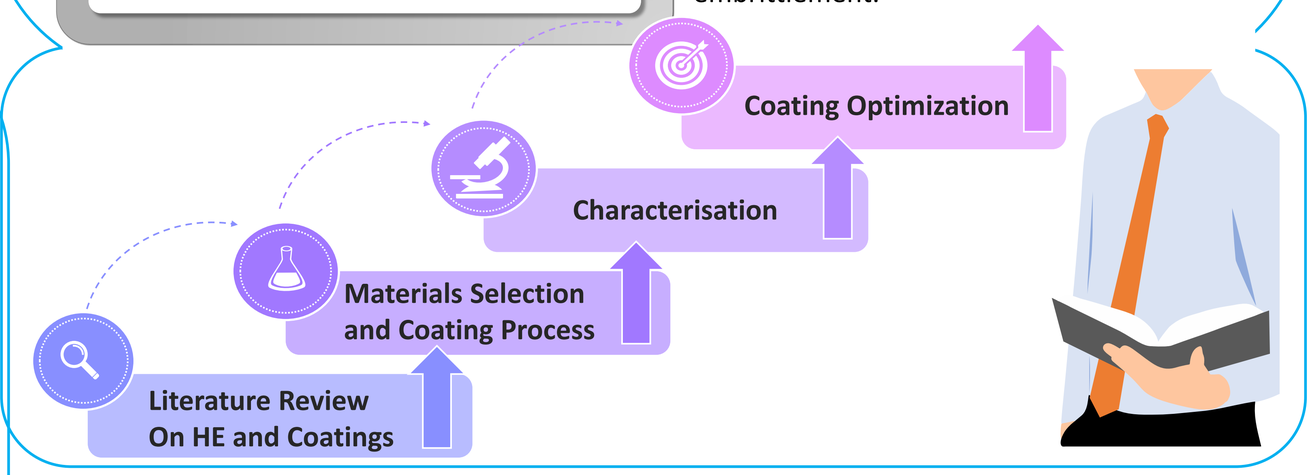
RESEARCH PROBLEM

A breakdown of the research problems the research seeks to solve is as follow:



Hydrogen Atom Permeation into Metal Lattice H

Addressing these research problems requires a multidisciplinary approach, combining materials science, chemistry, mechanical engineering, and industry-specific knowledge to develop innovative solutions that can be widely adopted to mitigate the risks associated with hydrogen embrittlement.



Impact of Hydrogen barrier Coatings (HBCs)

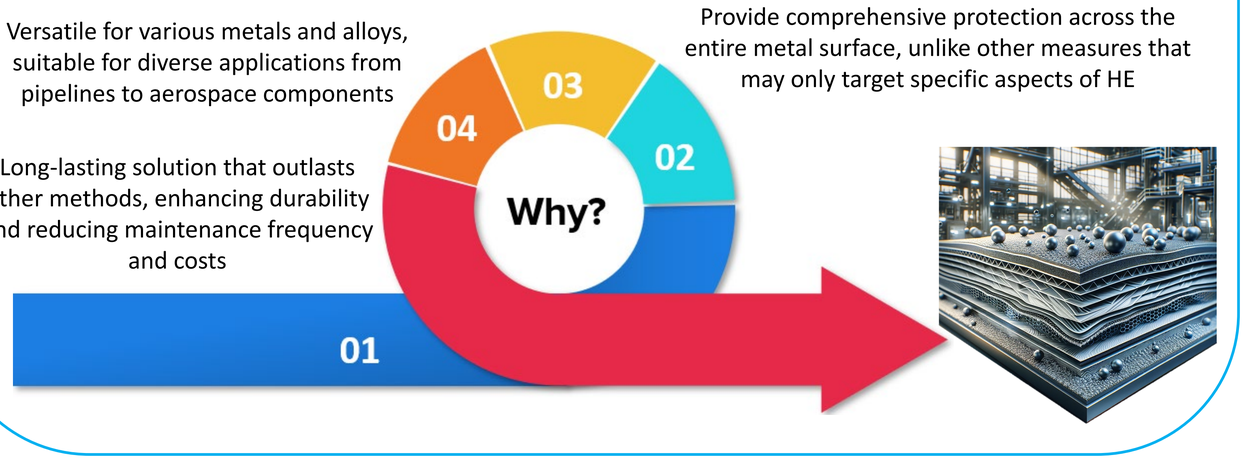
Direct Prevention at the Source
"Prevent hydrogen atoms from penetrating the metal surface, addressing the root cause of hydrogen embrittlement proactively"

Cost-effective compared to other measures, with reduced maintenance, extended component lifetimes, and fewer failures leading to significant long-term savings [3,4]

Versatile for various metals and alloys, suitable for diverse applications from pipelines to aerospace components

Provide comprehensive protection across the entire metal surface, unlike other measures that may only target specific aspects of HE

Long-lasting solution that outlasts other methods, enhancing durability and reducing maintenance frequency and costs



DESIRED OUTCOMES

1. **Hydrogen Barrier Coatings (HBCs):** The project aims to develop coating design criteria and understand factors which influence hydrogen embrittlement
2. **Advanced Application Techniques:** A goal is to innovate in the application of these coatings to ensure uniform coverage and optimal performance across diverse metal substrate types specially for pipes.
3. **Safety and Reliability Improvement:** Ultimately, the project seeks to safeguard the safety and extend the lifespan of metal components in critical applications, contributing significantly to the fields of materials science and engineering.

REFERENCES

[1] Hydrogen Gas Embrittlement: Mechanisms, Mechanics, and Design, Elsevier, 2024.
[2] Department for Energy Security and Net Zero (DESNZ), www.ons.gov.uk
[3] Recent Advances and Prospects in Design of Hydrogen Permeation Barrier Materials for Energy Applications—A Review, Molecules, 27 (2022) 6528.
[4] Preventing Hydrogen Embrittlement: The Role of Barrier Coatings for the Hydrogen Economy, Hydrogen, 4 (2023) 307-322.

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