RENEWABLE ENERGY FROM HYDROGEN

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INTRODUCTION

- MOST OF US ARE FAMILIAR WITH HYDROGEN
- IT WAS DISCOVERED IN 1776 BY HENRY CAVENDISH
- I USED IT IN CHEMISTRY AT SCHOOL. IT BURNS WITH A PALE BLUE FLAME
- IMO MARPOL ANNEX VI PREVENTION OF AIR POLLUTION FROM SHIPS WAS INTRODUCED IN 1997 AND IMPLEMENTED IN 2005
- I THEN BECAME INTERESTED IN ALTERNATIVE NON-CARBON FUELS FOR SHIPS
- THE EU INTRODUCED SECA (SULPHUR EMISSION CONTROL AREAS) IN 2015 THAT COVERED THE BALTIC, NORTH SEA AND CHANNEL
- AFTER SOME RESEARCH I FOUND THAT HYDROGEN WAS ONE OF THE BEST FUELS TO SATISFY THESE REQUIREMENTS

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WHAT IS HYDROGEN?

- HYDROGEN IS THE MOST COMMON CHEMICAL ELEMENT IN THE UNIVERSE
- HYDROGEN MAKES UP ABOUT 2/3 OF THE MOLECULES FOUND ON THE EARTH
- THESE ARE MAINLY HELD IN THE FORM OF WATER (H_2O)
- HYDROGEN CONTAINS UP TO THREE TIMES MORE ENERGY PER UNIT MASS THAN DIESEL FUEL
- WHEN IT IS BURNED IT ONLY PRODUCES WATER AND NOT CO_2 SO_X OR FINE PARTICULATES

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UK HYDROGEN STRATEGY

- IN AUGUST 2021 THE UK GOVERNMENT PUBLISHED ITS **UK HYDROGEN STRATEGY**

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UK HYDROGEN STRATEGY

- THE **UK HYDROGEN STRATEGY** ENVISAGES HYDROGEN PROVIDING GREENER AND MORE FLEXIBLE ENERGY FOR POWER, HEAT AND TRANSPORT
- THE STRATEGY REFERS TO:
  - NET ZERO HYDROGEN FUND £240 MILLION
  - NET ZERO INNOVATION PORTFOLIO £1 BILLION (WITH HYDROGEN ONE OF THE KEY PRIORITY AREAS)
  - INDUSTRIAL ENERGY TRANSFORMATION FUND £315 MILLION
  - INDUSTRIAL FUEL SWITCHING COMPETITION £20 MILLION
- THIS IS A LARGE PROPOSED INVESTMENT AND SOME PROPOSED UK HYDROGEN PRODUCTION PROJECTS FOLLOW

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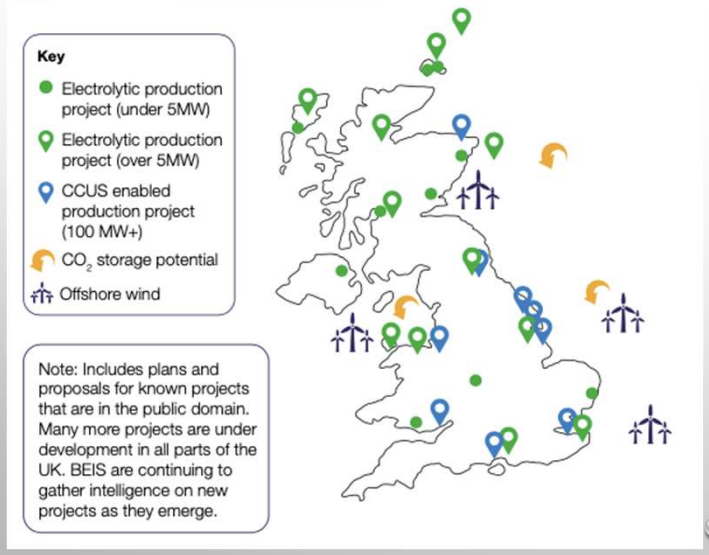
UK HYDROGEN STRATEGY



- CCUS = CARBON CAPTURE, UTILIZATION, AND STORAGE
- MANY PROJECTS UTILISE OFFSHORE WIND OR OTHER ENERGY SOURCE FOR SEA WATER ELECTROLYTIC PRODUCTION OF HYDROGEN

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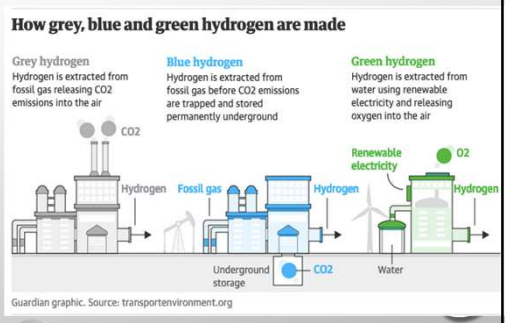
HYDROGEN PRODUCTION

- HYDROGEN WAS PRODUCED HISTORICALLY BY **STEAM METHANE REFORMATION** (NATURAL GAS REACTED WITH STEAM) IN CHEMICAL REFINERIES
- HYDROGEN CAN ALSO BE PRODUCED BY ELECTROLYSIS OF WATER BY DIFFERENT ENERGY SOURCES
- HYDROGEN IS COLOUR LABELLED RELATIVE TO THE SOURCE
  - GREEN (RENEWABLE ENERGY AND NO GHG EMISSIONS)
  - BLUE (MAINLY FROM NATURAL GAS WITH CCS)
  - GREY (WITHOUT CCS [CARBON CAPTURE AND STORAGE])
  - BROWN (USING LIGNITE)
  - BLACK (USING COAL)
  - PINK (USING NUCLEAR ENERGY)
  - YELLOW (USING SOLAR POWER
  - WHITE (GEOLOGICAL HYDROGEN RELEASED BY FRACKING)



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FUTURE HYDROGEN PRODUCTION

- THE GREENEST METHODS ARE GREEN, YELLOW AND PINK HYDROGEN
- HYDROGEN PRODUCED BY RENEWABLE ENERGY BY ELECTROLYSIS OF WATER ALLOWS SURPLUS ENERGY TO BE STORED AS HYDROGEN WHEN IT IS NOT NEEDED BY THE ELECTRICITY GRID AND PROVIDES GREATER GRID RESILIENCE
- THIS IS MORE ENVIRONMENTALLY FRIENDLY STORAGE METHOD THAN THE USE OF BATTERIES WHICH USE RARE METALS IN THEIR MANUFACTURE
- THE OFFSHORE WIND TURBINE INDUSTRY IS PROPOSING TO GENERATE HYDROGEN BY ELECTROLYSIS OF SEA WATER AT OFF-PEAK TIMES
- THE GREAT ADVANTAGE OF HYDROGEN IS THAT IT CAN BE STORED IN VERY LARGE QUANTITIES COMPARED WITH BATTERIES.
- THE ONLY OTHER STORAGE METHOD WITH SIMILAR CAPACITY IS PUMPED STORAGE
  - WHERE WATER IS PUMPED FROM A RIVER OR LAKE TO A HIGHER RESERVOIR

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ENERGY PRODUCTION FROM HYDROGEN

- HYDROGEN CAN BE USED IN SEVERAL WAYS:
  - DIRECTLY AS A FUEL FOR POWER PRODUCTION THROUGH HYDROGEN COMBUSTION IN TURBINES
  - DIRECTLY AS A FUEL FOR INDUSTRIAL GAS BOILERS
  - IN STATIONARY FUEL CELL POWER PLANTS
  - IN PORTABLE FUEL CELLS SIMILAR TO BATTERIES
- HYDROGEN CAN BE STORED CRYOGENICALLY (FROZEN TO -253^{O}C) OR IN COMPRESSED AIR CONTAINERS AS A GAS AT 350 - 700 BAR
- HYDROGEN IS A LIGHT GAS AND REQUIRES A LOT OF STORAGE SPACE
- IT CAN BE STORED IN CAVERNS UNDERGROUND OR IN HEAVY PRESSURISED STORAGE TANKS
- THERE ARE PROPOSALS FOR BUILDING GAS PIPELINES FOR HYDROGEN
  - FOR EXAMPLE FROM NORWAY TO GERMANY

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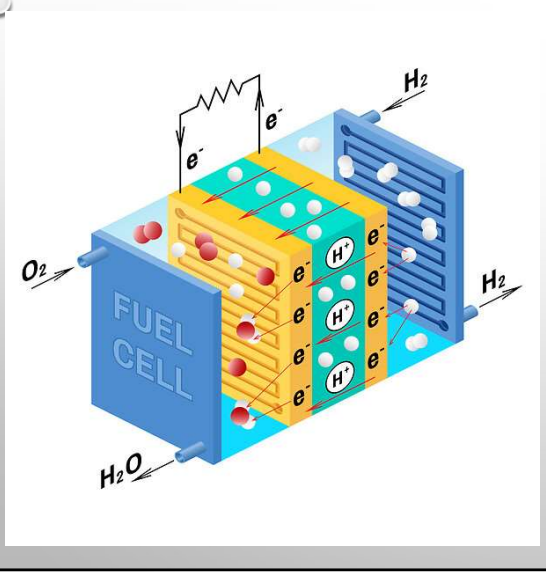
HYDROGEN FUEL CELLS



- FUEL CELLS WORK LIKE BATTERIES, BUT THEY DO NOT RUN DOWN OR NEED RECHARGING AS LONG AS FUEL IS SUPPLIED
- A TYPICAL FUEL CELL WORKS BY PASSING HYDROGEN THROUGH THE ANODE AND OXYGEN THROUGH THE CATHODE
- INDIVIDUAL FUEL CELLS ONLY PRODUCE A SMALL AMOUNT OF ELECTRICITY SO THEY ARE COMBINED INTO A FUEL CELL "STACK"
- A TYPICAL FUEL CELL STACK MAY CONSIST OF HUNDREDS OF FUEL CELLS

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HYDROGEN FUEL CELLS

- THERE ARE DIFFERENT TYPES OF FUEL CELLS BASED ON THE KIND OF ELECTROLYTE THEY USE
  - POLYMER ELECTROLYTE MEMBRANE FUEL CELLS (PEMFCS)
  - DIRECT METHANOL FUEL CELLS (DMFCS)
  - ALKALINE MEMBRANE FUEL CELLS (AMFCS)
  - PHOSPHORIC ACID FUEL CELLS (PAFCS)
  - MOLTEN CARBONATE FUEL CELLS (MCFCS)
  - SOLID OXIDE FUEL CELLS (SOFCS)
  - AND REVERSIBLE FUEL CELLS
- PLATINUM IS USED AS THE CATALYST
- RESEARCH IS UNDERWAY TO FIND NON-PLATINUM CATALYSTS

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DISADVANTAGES OF HYDROGEN

- HYDROGEN IS THE LIGHTEST ELEMENT AND IT IS VOLATILE
- THIS MAKES STORAGE AND TRANSPORT MORE DIFFICULT THAN OTHER GASEOUS PRODUCTS
  - VERY LARGE TANKS, HIGH PRESSURE
  - CRYOGENIC FREEZING
  - ABSOLUTELY LEAK PROOF PIPELINES
- IT REQUIRES A LOT OF ENERGY TO PRODUCE IT BY ELECTROLYSIS AND THIS MAKES IT EXPENSIVE AT PRESENT
- GENERALLY THE HYDROGEN PRODUCED GENERATES LESS ENERGY THAN THE ELECTROLYSIS PROCESS.
- THIS MAKES IT INEFFICIENT IF THERE ARE OTHER USES FOR THE ENERGY FOR ELECTROLYSIS
- IT CAN CAUSE EMBRITTLEMENT OF METALS SUCH AS STEEL, WHEN THEY ARE EXPOSED TO IT DURING MANUFACTURING OR WELDING.

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HYDROGEN AND THE ENVIRONMENT

- A STUDY, ATMOSPHERIC IMPLICATIONS OF INCREASED HYDROGEN USE, WAS PUBLISHED BY UNIVERSITY OF CAMBRIDGE, NCAS (NATIONAL CENTRE FOR ACADEMIC SCIENCE) AND UNIVERSITY OF READING IN APRIL 2022
- ANY LEAKAGE OF HYDROGEN WILL AFFECT ATMOSPHERIC COMPOSITION
  - IT WILL DECREASE HYDROXYL RADICALS, WHICH WILL INCREASE THE LIFETIME OF METHANE
  - IT WILL SLIGHTLY INCREASE OZONE
  - IT WILL INCREASE WATER VAPOUR IN THE ATMOSPHERE
- THESE EFFECTS MAY BE AN IMPROVEMENT ON THE CURRENT RELEASE OF GHG IN ENERGY PRODUCTION
- THE MESSAGE IS – PREVENT LEAKAGE OF HYDROGEN
- HYDROGEN IS ODOURLESS WHICH HAS IMPLICATIONS FOR DETECTING LEAKS

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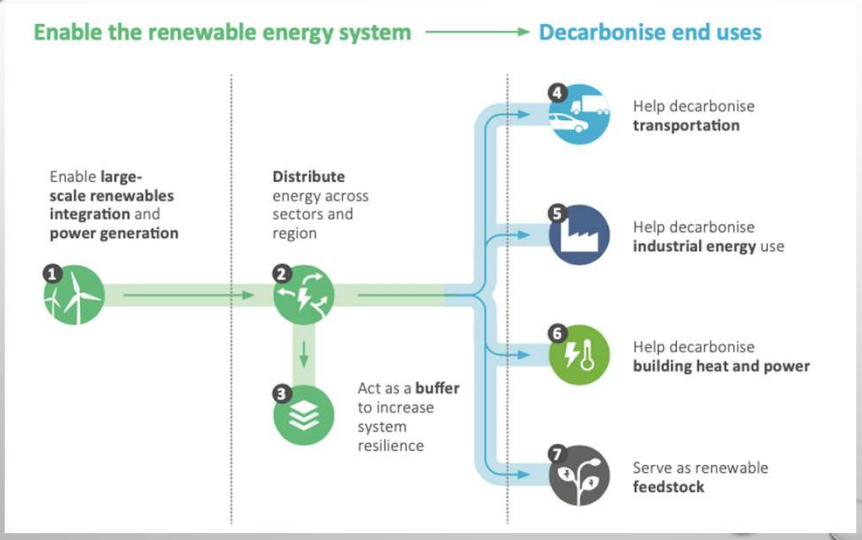
UK HYDROGEN FUTURE USES



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UK HYDROGEN PROJECTS

- HYDROGEN UK (TRADE ASSOCIATION) ENVISAGE VARIOUS USES FOR HYDROGEN
  - HEAT (I DISAGREE THAT THIS IS AN EFFICIENT USE IN BOILERS COMPARED WITH HEAT PUMPS)
  - HEAT IN CHP POWER STATIONS FROM HYDROGEN FUEL CELLS
  - TRANSPORT
    - CARS (BATTERIES OR NO PRIVATE CARS ARE BETTER SOLUTIONS)
    - VANS (BATTERY POWERED DELIVERY VANS SEEM TO BE THE CURRENT PREFERENCE)
    - BUSES (A FEW TRIALS BUT BATTERY POWERED SEEM TO BE PREFERRED)
    - HGV (THIS WOULD INCLUDE CARGO HANDLING EQUIPMENT) [GOOD FOR REFUELLING]
    - MARITIME (SOME SHIP ENGINES ALREADY CONFIGURED FOR HYDROGEN)
    - AVIATION (SEE AIRBUS)
    - RAIL (FUEL CELL POWERED LOCOMOTIVES WHERE ELECTRICITY NOT AVAILABLE)
  - INDUSTRY (STEEL, GLASS, CERAMICS, CHEMICALS, CEMENT, PULP AND PAPER, FOOD AND DRINK, AND TEXTILES PRODUCTION
  - POWER GENERATION (CCGT [COMBINED CYCLE GAS TURBINE])

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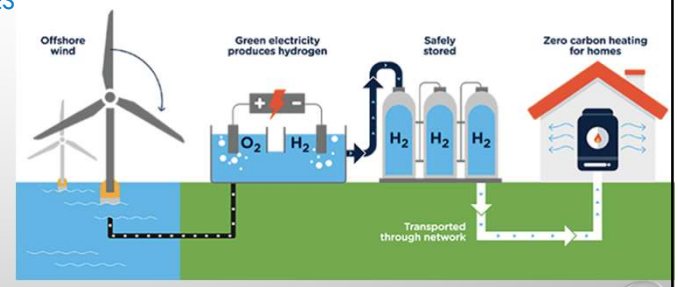
UK HYDROGEN PROJECTS

- RWE AND SGN HAVE TEAMED UP TO PROVIDE AN ALTERNATIVE TO LNG IN CAMPBELTOWN, STORNOWAY, OBAN, THURSO AND WICK
- SGN ARE PROVIDING HYDROGEN TO THE H100 FIFE PROJECT. THIS WILL PROVIDE HEAT FOR BOTH DOMESTIC AND BUSINESS PREMISES



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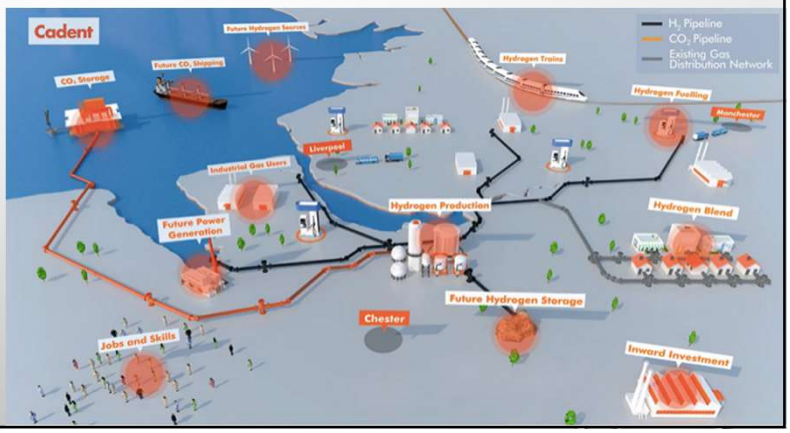
UK HYDROGEN PROJECTS

- TEES VALLEY HYDROGEN HUB
  - TRIAL OF VEHICLES AND REFUELLING ACROSS THE NORTH EAST
- HYDROGEN PRODUCTION PLANTS IN MERSEYSIDE AND ABERDEENSHIRE
- HYNET PROJECT IN CHESTER
  - BUT USES CCS!



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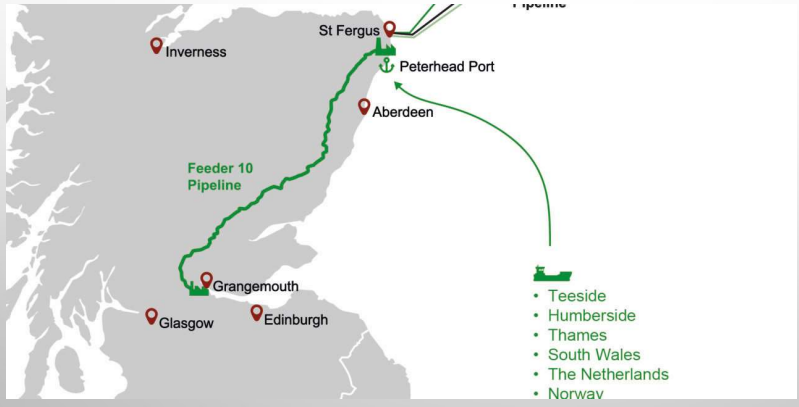
UK HYDROGEN PROJECTS

- FEEDER PIPELINE FROM PETERHEAD TO GRANGEMOUTH



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UK HYDROGEN PROJECTS

- ACORN HYDROGEN PROJECT IN PETERHEAD
  - PRODUCING HYDROGEN FROM NATURAL GAS WITH CCS
- DOLPHYN PROJECT (NORTH SEA AND ABERDEEN)
  - TWO-MEGAWATT (MW) PROTOTYPE OF THE TECHNOLOGY THAT COMBINES OFFSHORE WIND POWER WITH SEAWATER TO PRODUCE "GREEN" HYDROGEN
  - PRELIMINARY DESIGNS INCLUDE A 10MW FLOATING OFFSHORE WIND TURBINE, COMBINED WITH A WATER TREATMENT UNIT AND ELECTROLYSERS
- GIGASTACK PROJECT
  - TO PRODUCE GIGAWATT-SCALE POLYMER ELECTROLYTE MEMBRANE (PEM) ELECTROLYSERS
  - USING ENERGY FROM HORNSEA ONE OFFSHORE WIND FARM TO GENERATE RENEWABLE HYDROGEN FOR THE PHILLIPS 66 HUMBER REFINERY.

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UK HYDROGEN PROJECTS

- TRIAL OF HEATING SYSTEMS IN PEMBROKESHIRE

Smart hydrogen hybrid heating system successfully trialled in the UK

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UK HYDROGEN PROJECTS

- GREEN HYDROGEN SYSTEMS
  - TWO HYPROVIDE™ ELECTROLYSERS. FOR THE PRODUCTION OF GREEN HYDROGEN FOR POWERING CHARGING STATIONS AND OFF THE GRID CONSTRUCTION SITES.

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UK HYDROGEN PROJECTS

- IMMINGHAM HYDROGEN FUEL STATION
- HYDROGEN FUEL CELL POWERED PORT TRACTOR
- HYDROGEN POWERED MECHANICAL HANDLING EQUIPMENT

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UK HYDROGEN PROJECTS

- SIR KIER STARMER ON A HYDROGEN FUEL CELL POWERED BUS

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UK HYDROGEN PROJECTS

- AIRBUS PROPOSAL FOR HYDROGEN FUEL TURBINES

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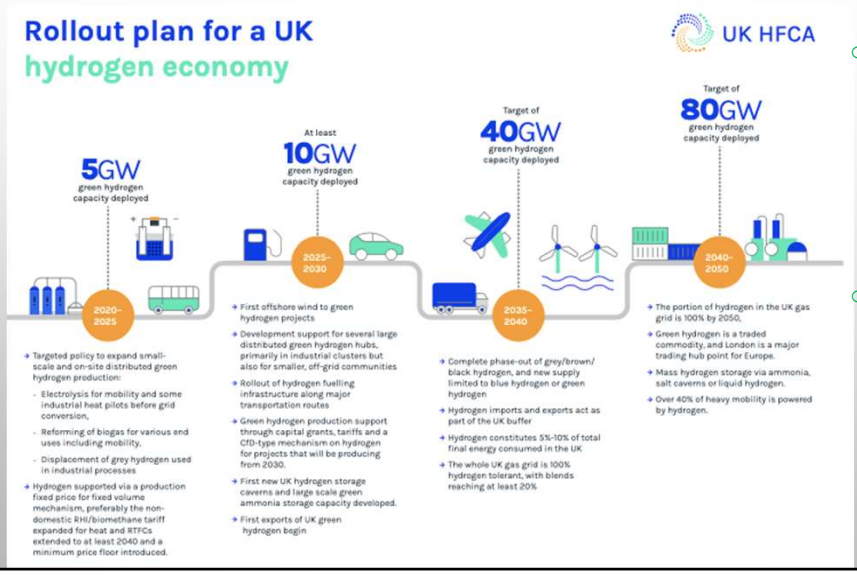
UK HYDROGEN ECONOMY TIMELINE



- THIS TIMELINE RUNS FROM 2020 TO 2050 IN 2 FIVE YEAR STEPS AND THEN 2 TEN 10 YEAR STEPS
- UK HYDROGEN AND FUEL CELL ASSOCIATION

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HYDROGEN COSTS

- GREEN HYDROGEN COSTS ARE DIRECTLY RELATED TO RENEWABLE ENERGY COSTS
- BY 2025 RENEWABLE ENERGY COSTS ARE LIKELY TO BE AROUND 2CENTS/KWH
- THIS EQUATES TO A COST OF $1.5/KG OF HYDROGEN
- CURRENTLY PORTUGAL PRODUCES THE CHEAPEST GREEN HYDROGEN AT €3.50/KG
- GLOBAL HYDROGEN DEMAND IN 2030 IS LIKELY TO BE 17 MILLION TONNES

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CONCLUSIONS

- THESE ARE MY PERSONAL CONCLUSIONS AND DO NOT ALIGN WITH UK POLICY
- HYDROGEN PRODUCED BY ELECTROLYSIS SHOULD ONLY USE RENEWABLE ENERGY FROM WIND TURBINES, SOLAR AND TIDAL STREAM ENERGY THAT IS SURPLUS TO REQUIREMENTS
- HYDROGEN GAS IS DIFFICULT TO STORE AND TRANSPORT BY PIPELINE
- DIRECT HYDROGEN GAS SHOULD ONLY BE USED IN POWER STATION TURBINES (INCLUDING DISTRICT HEATING) AND CHEMICAL INDUSTRY PROCESSES [AIRPLANES?]
- HYDROGEN FUEL CELLS IN MULTIPLES ARE BEST FOR HIGH POWER REQUIREMENTS SUCH AS IN SHIPS, LOCOMOTIVES AND HEAVY ROAD TRANSPORT (WITH FUELING STATIONS)
- BATTERIES ARE MORE ECONOMIC FOR CARS AND LIGHT VEHICLES (BUT REQUIRE RECHARGING)
- HYDROGEN SHOULD NOT BE USED FOR DOMESTIC HEATING (HEAT EXCHANGERS ARE BETTER)

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