Cryogenic solutions to address net zero emissions targets

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Since 1st Jan 2022

Tuesday 11th July 2023

Honolulu, Hawaii, USA

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Outline

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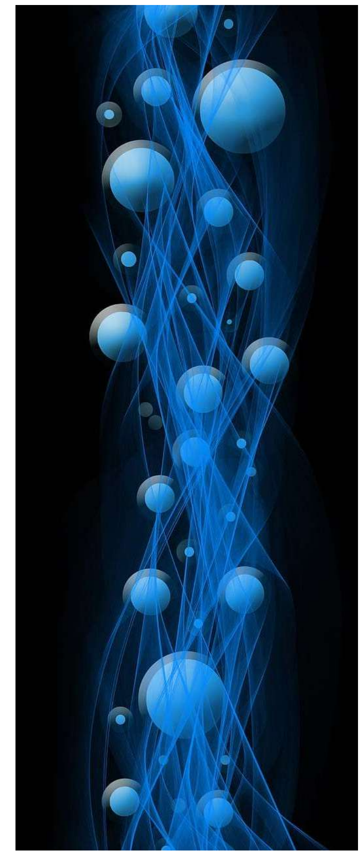
- The challenge
- Cryogenics overview
- UK activities on zero carbon emission targets by 2050
- Cryogenics for Electrifications and Electric Industry
  - Cryo-fuels for transport
  - Emergence of Hydrogen for transport and power
  - Cryogenic Rocket Engine
- Cryogenics for quantum
- Superconductivity Global Alliance (ScGA) for Zero Carbon Emission Targets by 2050
- Summary



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Zero Carbon Emission Targets by 2050

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Zero Carbon Emission targets

- Net-zero emissions, or carbon neutrality, is when the amount of greenhouse gases released into the atmosphere is offset by the amount removed.
- Achieving net zero requires a significant overhaul of our
  - **Energy systems, transportation, agriculture, and industrial practices.**
- There is an urgent global need to address climate change
  - Unprecedented changes are driven by
    - **Burning fossil fuels, deforestation & industrial processes**
  - Visible impacts of climate change
    - **Rising temperature & Extreme weather events**
    - **Melting ice caps & Sea level rise**
- **The scientific message is clear**
  - **To prevent catastrophic and irreversible consequences of climate change require serious effort to reduce greenhouse gas emissions**
  - **Achieving zero carbon emissions by 2050 is an ambitious but necessary target**
    - Leading us toward a sustainable and resilient future

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Zero Carbon Emission targets

Paris International Agreement on limiting global warming to 1.5 degrees by 2050 is a **legally binding international treaty on climate change**. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on **12 December 2015**. It entered into force on **4 November 2016**. https://unfccc.int/process-and-meetings/the-paris-agreement

- This ambitious yet feasible milestone encourages governments, businesses, and individuals to adopt cleaner and more sustainable practices.
- To limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and **decline 43% by 2030?**
- To achieve zero carbon emissions by 2050 requires a comprehensive & coordinated effort across multiple sectors
- Key strategies include:
  1. Renewable Energy Transition
  2. Electrification and Decentralisation
  3. Energy Efficiency
  4. Sustainable Land Use and Agriculture
  5. Circular Economy

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Strategies for Achieving Zero Emission Targets

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Policy and Regulation

- **Governments need to enact robust policies and regulations**
  - To incentivize emission reductions & penalize high-carbon activities.
- Implementing carbon pricing mechanisms,
- **Setting ambitious renewable energy targets**,
- Promoting sustainable practices across all sectors.

Innovation and Research

- **Continued investment in clean energy R&D**
- Advancements in
  - energy storage,
  - carbon capture,
  - sustainable agriculture.

International Cooperation

- **Between nations** is paramount to tackle climate change effectively.
- **Sharing knowledge, resources, and technologies**
- Platforms like the United Nations Framework Convention on Climate Change (UNFCCC) and international agreements, such as the Paris Agreement, provide frameworks for cooperation.

Financial Support

- **Mobilizing finance** at scale is necessary to support the transition to a zero-emission economy.
- **Public and private investment**
  - Renewable energy projects,
  - sustainable infrastructure,
  - R&D

The zero emission targets set for 2050 present a challenging yet imperative goal for the global community

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The challenge

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Global Environmental Challenges


Europe 15th July 2021


California 18th July 2021


UAE 17th July 2021

Greenland 2021 - melting
6 X times faster than 1990

Antarctica Icebergs
melting fast!

Key takeaway
Need new innovations!.... Superconducting materials and technologies can and will help

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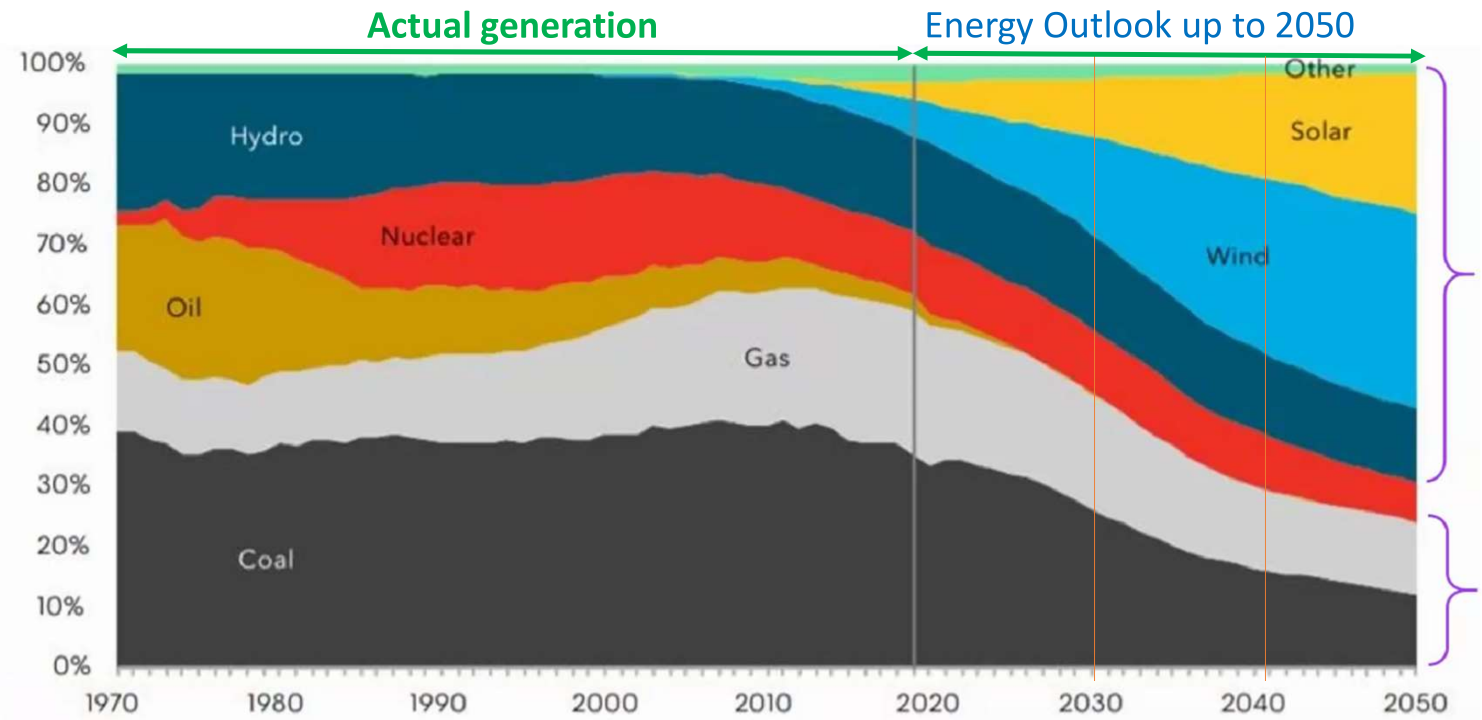
Estimated Global Electricity Generation Mix

New Energy Outlook 2020 report by Bloomberg (2020)



Renewables

- 2020: 38%
- 2030:53%
- 2040:60%
- 2050: 70%

Fossil (Target for Clean energy like Fusion)

- 2020: 62%
- 2030:47%
- 2040:40%
- 2050: 30%

Key takeaway

- Estimated investment in Electricity generation ~ $20 Trillion by 2050
- ~ 30% generation by Fossil fuels equivalent to $ 6.6 Trillion
  - Potential addressable market for Fusion VERY LARGE !

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Cryogenic solutions critical to achieve net zero emission targets

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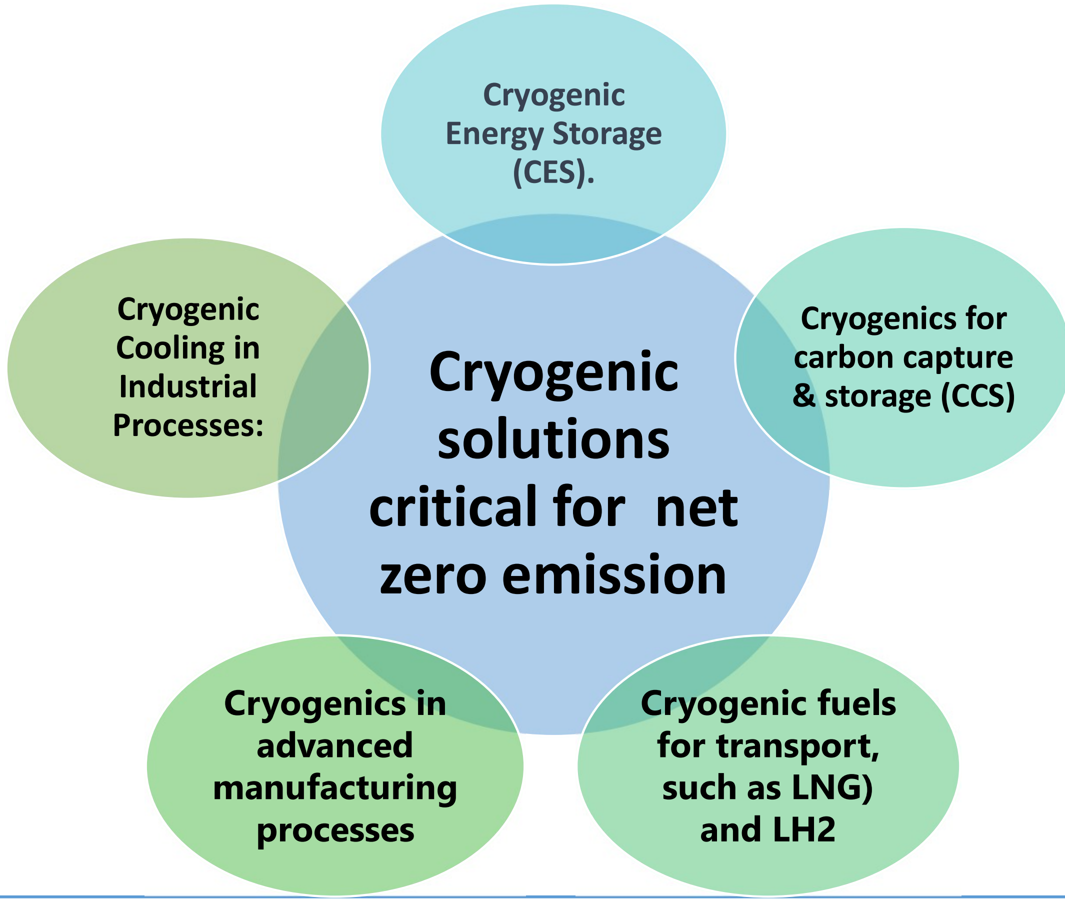

- Cryogenic solutions present promising opportunities for reaching net zero emission targets across various sectors.
- Energy storage, carbon capture, transportation, & advanced manufacturing, cryogenic colling in industrial processes offer innovative approaches to reducing greenhouse gas emissions & fostering sustainable development.
- To fully leverage the potential of cryogenics,
  - Continued research, development, & collaboration among industries, governments, and research institutions are crucial.
  - Embracing these cold technologies, will accelerate the transition toward a cleaner, greener, & more sustainable future

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Cryogenics Overview

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Cryogenics enable Diverse applications and End Markets with growing demand for “better” (time, quality, accurate) measurement/fabrication and now foe zero carbon emission management

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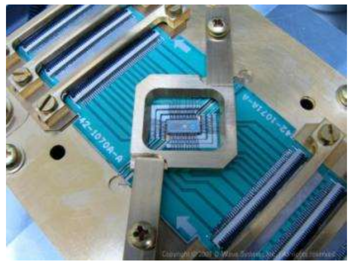
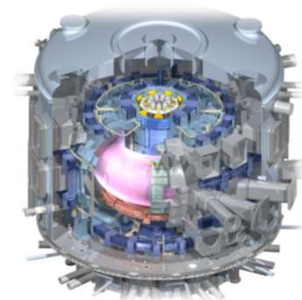
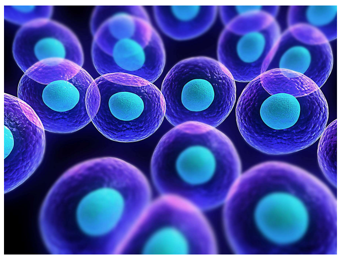
Digital/Quantum Computing

Image courtesy of D-Wave Systems Inc





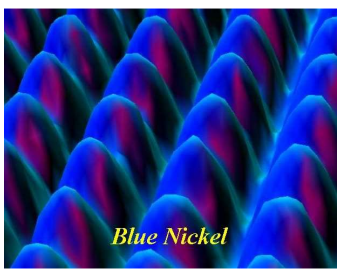
Energy Generation



Life Sciences

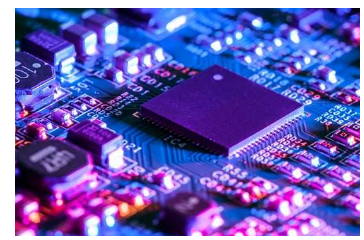
Cryogenics – a branch of physics that deals with the production of very low temperatures < 120 K and their effects on matter

Health Care



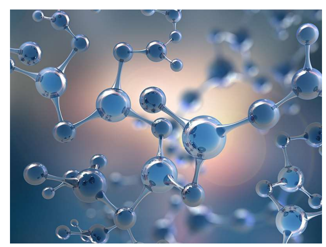
Materials Discovery/ Characterisation

Semiconductor Research



HEP/Particle Discoveries

LHC magnet (Courtesy of CERN)



Nanotechnology/ Mesoscience

The discovery of cryogenics over 170 years ago led to many discoveries and applications in physics & superconductivity

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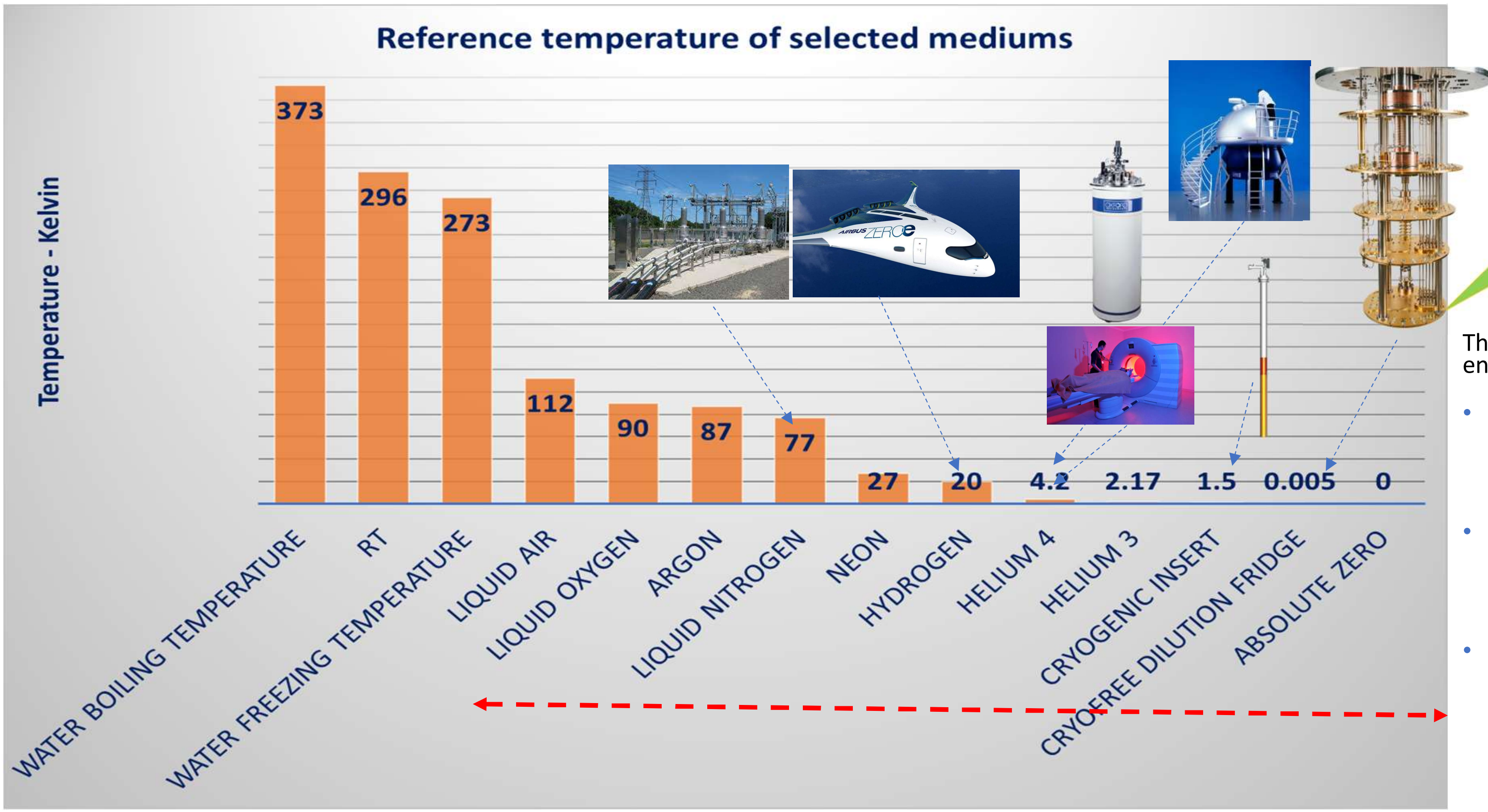
Cryogenics as a medium for applications



- Q Computing with SC Qubits @ <10 mK
- Material R&D @ 0.005K – 4.2 K

Three primary cooling environments

- Wet systems using Cryogens

- Dry Systems using mechanical coolers

- Hybrid using Wet + Dry
  - Re-condensed system

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Selection of Emerging Applications Enabled by Cryogenics In the 2nd Decade Of The 21st Century

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- Electrification and Electric Industry
- Cryo-fuels for Transport
- liquid hydrogen (LH2)
- Hydrogen Chemical Energy
- Fuel Cell for storage
- Cryogenic Rocket Engine
- Cryogenics for quantum applications

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UK activities on Zero Carbon emission targets by 2050

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U.K. plans for zero carbon emissions targets by 2050

U.K. plans for zero carbon emissions targets by 2050

Climate Change Act 2008

The act establishes a robust framework for emissions reduction, including the setting of carbon budgets and regular reporting on progress

Implemented various measures across multiple sectors of the economy.

- The primary focus is the energy sector, where the transition to renewable sources (wind, solar, and tidal power) plays a pivotal role.
- Plan to quadruple Offshore wind farms capacity by 2030

Phasing out unabated coal-fired power plants, replacing them with cleaner alternatives

- Renewable energy & nuclear power play a part in the UK's low-carbon energy mix.
  - The Hinkley Point C nuclear power station, is expected to make a substantial contribution to the UK's electricity generation while reducing carbon emissions.

Actively promoting the adoption of electric vehicles (EVs)

Providing financial incentives, expanding charging infrastructure, and supporting research and development in EV technology.

Plans to ban the sale of new petrol and diesel cars by 2030.

accelerating the shift towards cleaner transportation options.

The decarbonization efforts extend beyond the energy and transport sectors.

- Improving energy efficiency in buildings, reducing emissions from industry, and addressing the agricultural sector's environmental impact.
- New initiatives to incentivize energy-efficient renovations, promote sustainable manufacturing practices, and support sustainable farming techniques.

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U.K. initiative on Cryo fuels for zero emissions **"Project Laewest"**

The UK government announced in Sep 2021 a new initiative to explore the potential of using cryogenic fuels like liquid air & liquid hydrogen for transport & aviation as a way to achieve zero-emissions transportation. The government has committed £20 million in funding for the project, which will run until 2024.

Project leaders

Department for Transport (DfT)

Department for Business, Energy

Industrial Strategy (BEIS),

Industrial partners

BOC, a subsidiary of the Linde Group,

ITM Power

Objectives

Demonstrate the technical & economic feasibility of cryogenic fuels in applications,

- **liquid air** as a fuel for refrigeration trucks
- **Liquid hydrogen** as a fuel for buses & heavy-duty trucks.

potential for using cryogenic fuels in aviation, (a zero-emissions aircraft by 2030)

Key benefits

Produced using renewable energy sources.

Liquid hydrogen, produces only water as a byproduct when burned.

cryogenic fuels have a higher energy density than batteries, enabling longer ranges and faster refuelling times for vehicles.

If successful, the Project could provide a pathway for the UK to decarbonize its transportation sector and help achieve its goal of net-zero emissions by 2050

Hydrogen Market in the UK

There is a recognition that Hydrogen has the potential to play a significant role in decarbonizing the U.K. economy, particularly in **heavy industry, transport, and heating**.

UK Strategy

- investing in hydrogen production & distribution
- **Develop a hydrogen economy**
- **Producing 5GW of low-carbon hydrogen by 2030.**
- promoting the use of hydrogen in industry and transport,
- supporting R&D.

Industrial partners

- ITM Power
- Ceres Power
- Ryse Hydrogen.

Pilot projects

- hydrogen-powered **train** and **buses**,
- hydrogen heating trials.

UK ambition

- Address **domestic** demand
- Become a significant **exporter** of hydrogen,
- Plans to develop a hydrogen **trading hub** in the North Sea to facilitate the transport and storage of hydrogen across Europe..

The hydrogen market in the U.K. is still in its early stages, there is significant interest and investment in developing a hydrogen economy

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UK- ZeroAvia Project foe Zero-Emission Aviation

Primary objective

- Develop hydrogen-electric powertrain technology for commercial aircraft.
- Replace traditional fossil fuel engines with hydrogen fuel cells,

Stakeholders

- Investors, governments, & industry leaders.
- UK government provided substantial funding through its Aerospace Technology Institute (ATI) program.
  - The funding to accelerate R&D & Testing

Current achievements

- Conducted in In 2020, the world's first hydrogen-electric flight of a commercial-scale aircraft.
  - the 6-seater aircraft, powered by a hydrogen fuel cell system, completed a flight of over 250 miles,
- Since then, ZeroAvia has continued to refine its technology and expand its capabilities.

The project's ambitions

- Go beyond small-scale aircraft.
- Scale up its technology to enable hydrogen-electric powertrains for larger planes,
  - regional and transcontinental flights.
  - long-term vision is to create a fleet of zero-emission aircraft that can offer a sustainable alternative to conventional fossil fuel-powered planes.

ZeroAvia collaborators

- Aerospace manufacturers,
- Fuel suppliers,
- Research institutions,
- Government agencies.
- expanded its operations to the United States. In California to foster international collaboration

Total U.K. investment in projects towards addressing zero carbon emissions targets by 2050 ~ £ 22 Billion !

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£9.2 billion

Contracts for **Difference (CfD) scheme** for long-term contracts that support low-carbon electricity generation,

including offshore wind farms, tidal energy projects, and other renewable energy sources.

£4.7 billion

In **(R&D)** programs focused on clean technologies.

Through The Industrial Strategy Challenge Fund,

Green Growth Fund, provides £40 million to support clean growth projects in developing countries.

£1.3 billion

investment fund to encourage the adoption of electric vehicles **(EVs)**

expand the charging infrastructure

£1 billion

to support the development of ultra-low emission vehicles and their associated infrastructure through the **Automotive Transformation Fund..**

£5.8 billion

to the Energy **Company Obligation (ECO)** scheme. to improve the energy efficiency of homes and buildings,

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Cryogenics for Electrifications and Electric Industry

Transport, Power generation, Distribution, and Transmission

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Electric planes with SC – Selected examples

Fully electric aircraft that use cryogenic liquid hydrogen as an energy storage method and a coolant for SC components

Fully Turbo-electric plane: NASA N3-X

Fully distributed 50MW, Superconducting, 7500V, power system

Partial Turboelectric - NASA

solid oxide fuel cell topping cycle and driven by a **superconducting motor with a cryogenic power management system**

Empirical Systems Aerospace ECO–150R

SC electrical machines cooled with liquid hydrogen to conventional machines at various technology levels.

Potential Electric Plane components with SC

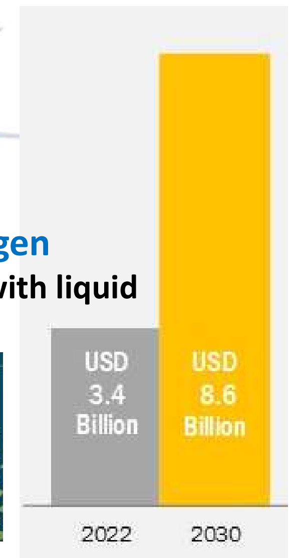
- SC cables
- Generators
- Motors
- Energy Storage
- Propulsion

Progress with Electric planes

- Right building blocks are in place to have a viable large-plane EAP configuration tested by 2025
- Entry into service in 2035
- LH2-based aircraft can, crucially, deliver a higher range.

ASCEND – Airbus SC+Hydrogen

SC electrical machines cooled with liquid hydrogen



Key takeaway – Serious effort to develop electric planes. Opportunities for National Facilities to Speed up risk retirement

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MAGLEV with SC – Serious in Japan

18 May 2011

- Japanese Government authorizes Central Japan Railway Co to proceed with high speed Maglev link from Tokyo to Osaka by 2045
- speed 580 kph

June 2015

- Chuo Shinkansen Maglev train Achieved 603 Kph (375 miles/hr) in Jun 2015
  - 1st phase complete by 2027 – Tokyo to Nagoya (40 min for 270 Km)
  - 2nd Phase by 2045 – Tokyo to Osaka (67 min hr for 500 Km)
  - Total cost ~ $55B
  - Using NbTi wire @4K

Key takeaway – Superconductors will have a significant impact on land transport and environment

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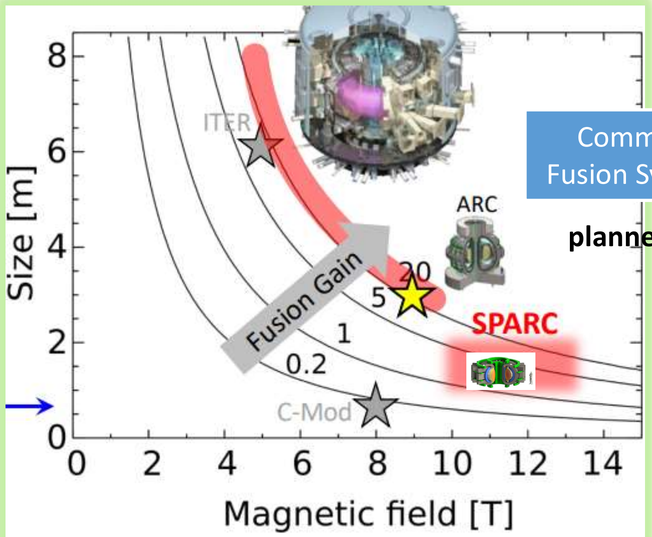
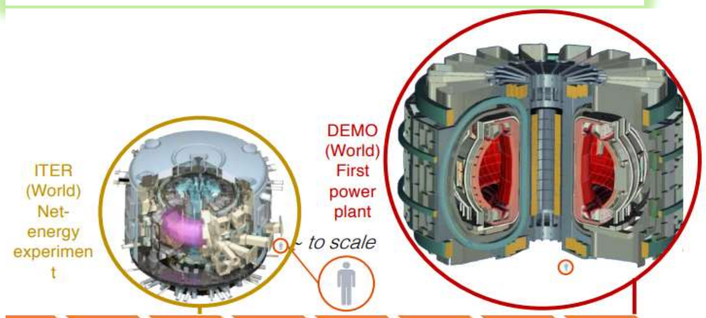
Future fusion devices using HTS – Led by private funds

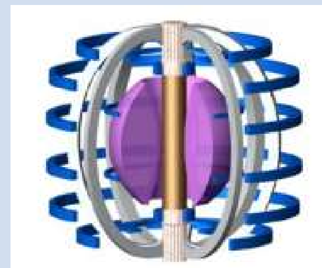
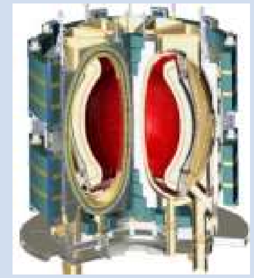


Commonwealth Fusion Systems , MIT

planned ~ 2025

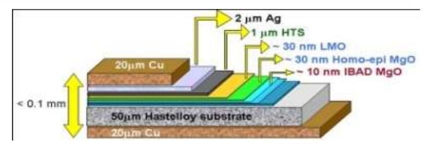


Source -Joseph V. Minervini Massachusetts Institute of Technology Plasma Science and Fusion Center Cambridge, MA USA

ST25 (2015) A World First: Tokamak with all HTS magnets Plasma pulse of >100s demonstrated in 2014 and for 29 hour plasma in 2015	**HTS magnet Demo planned ~ 2024**	**HTS magnet power generation planned ~ 2030**
		
OXFORD INSTRUMENTS; tokamak energy	tokamak energy	tokamak energy

Impact on Power Generation:

- Fast-tracking development of new power station
  - Clean energy and environmentally friendly
  - Safe power generation
  - Potential for smaller fusion power devices



https://indico.cern.ch/event/775529/contributions/3309887/attachments/1828600/2993908/Minervini_HTS-for-Fusion-WAMHTS-5.pdf

https://www.vtt.fi/sites/finnfusion2018/Documents/3-02%20Salmi%20Tokamak%20Energy.pdf

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ecoswing – SC wind power generation

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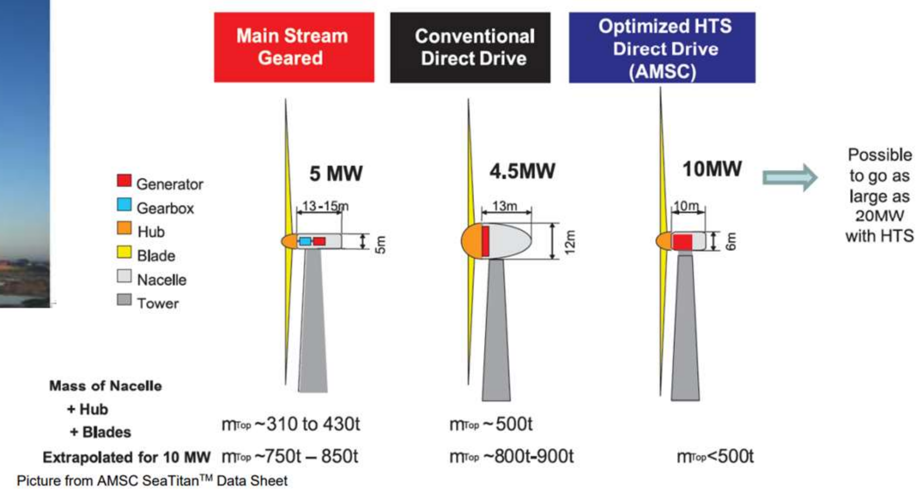
Horizon 2020
European Union Funding
for Research & Innovation

- HTS Conductor
- All roads capability
- Low-cost design
- Low-weight design
- Mainstream markets
  - 3.6 MW for onshore and offshore.
- Cryostat system integration
- Cryogen free for cooling



Source - Prof. M Noe- HTS Power Applications - _CERN [Microsoft PowerPoint - noe-hts power applications-2013-04-28 [Kompatibilitätsmodus] (cern.ch)]

HTS wire with thick copper stabilization for superior electrical stability and high mechanical robustness

- 9 Partners from 5 countries working for a common goal

ENVISION · ECO · JEUMONT Electric · DELTA · THEVA · SHI Cryogenics Group · Fraunhofer · UNIVERSITY OF TWENTE. · DNV·GL · SHI Cryogenics Group

Impact on Power Generation:
- More MW power per footprint
- Retrofitting existing infrastructure with enhanced generation

https://indico.cern.ch/event/445667/contributions/2558522/attachments/1521011/2376146/PI7-01_Kellers_EcoSwing_final_for_release.pdf

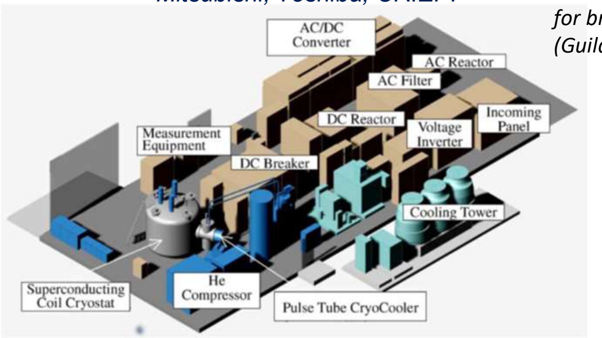
Energy storage and power transmission and distribution

2014

Ampacity ReBCO tape FCL 12kV 2.3kA

protecting superconducting cable in Essen city grid

Chubu Electric Power
Mitsubishi, Toshiba, CRIEPI



10 MVA/1 s SMES at Kameyama field test, in Japan.

S. Nagaya et al., "The state of the art of the development of SMES for bridging instantaneous voltage dips in Japan," Cryogenics (Guildf)., vol. 52, no. 12, pp. 708–712, Dec. 2012.

Impact on Power Applications:

- New technology
- Improved energy efficiency
- Higher power density
- Higher power quality
- Essential for decarbonisation & zero emission targets

Field test of 500m long HTS cable (Furukawa Electric CRIEPI (Central Research Institute of Electric Power Industry) & Super-GM (Engineering Research Association for Superconductive Generation Equipment & Materials) 2005

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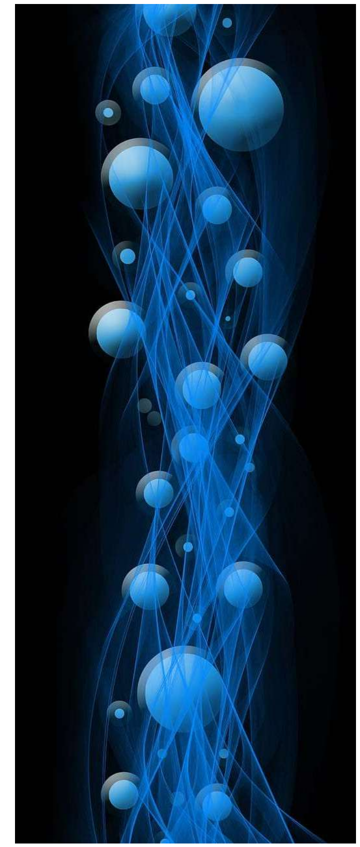
Cryo-fuels for Transport

Liquid natural gas (LNG) & Liquid Hydrogen for Transport



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Cryo-fuels for Transport

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- Liquid natural gas (LNG) is natural gas that has been cooled to a boiling temperature of -162°C (113 K).

- Have the potential to produce zero emissions when used as an energy source.

    - LNG is used as a fuel in heavy-duty large vehicles like trucks, buses, and ships, as it has a higher energy density than compressed natural gas (CNG), which means that it can provide more energy per unit of volume.

- Liquid hydrogen (LH2) that has been cooled to a temperature of -253°C (20 K
    - LH2 is used as a fuel in fuel cell vehicles, which convert hydrogen into electricity to power an electric motor.
        - The only emission from this process is water vapor.
    - Cryo-fuel advantages over traditional fuels,
        - lower emissions and greater efficiency.
    - Production of cryo-fuels can be challenging and expensive require significant energy inputs, which can impact their overall sustainability

Producing and storing cryo-fuels can be challenging and expensive, and the current infrastructure for distribution and transportation is limited.

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Emergence of Hydrogen for Transport and Power

Transport, Power generation, Distribution, and Transmission

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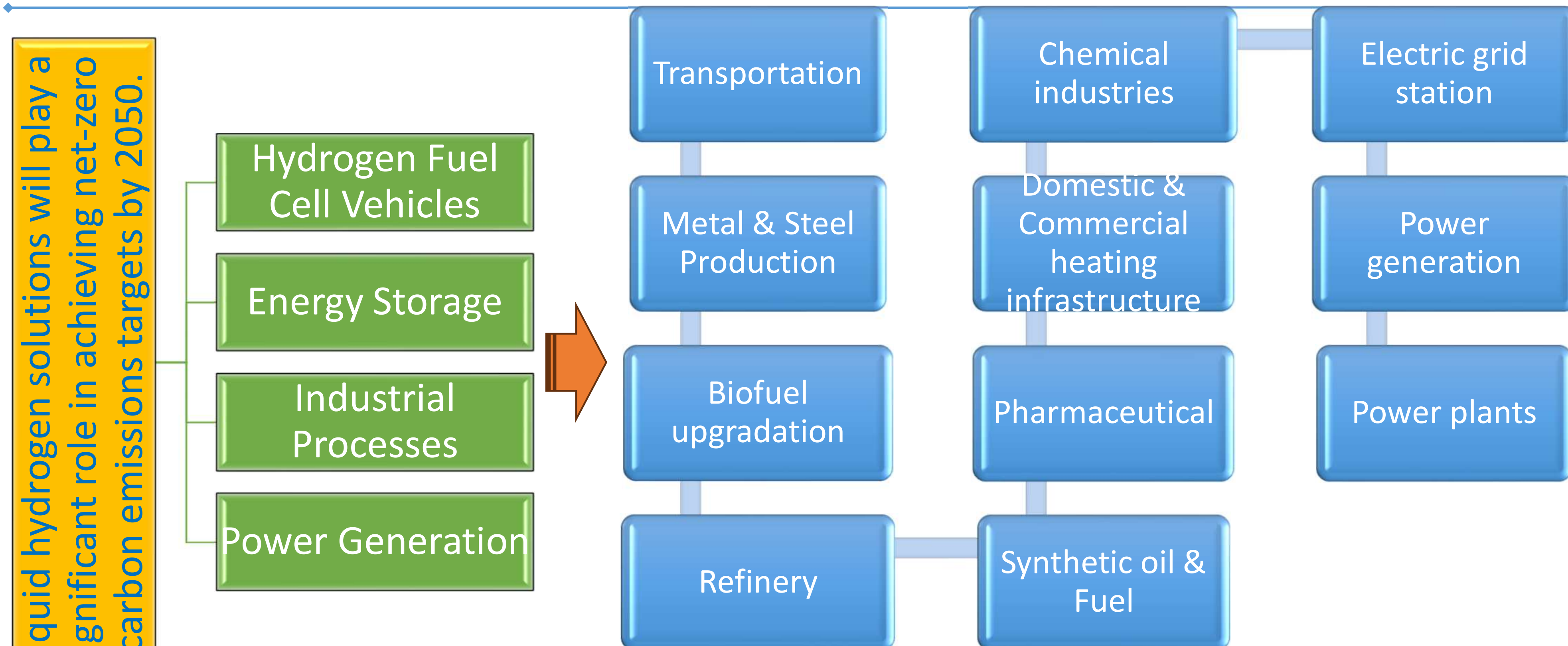
Current & Future H2 applications

Driven by Zero Emissions targets



Very promising impact of Hydrogen in achieving zero emission targets

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Challenges associated with liquid hydrogen solutions,

key areas of focus to unlock the full potential of liquid hydrogen in achieving net-zero carbon emissions targets by 2050. production costs,

- Storage requirements
- Infrastructure development
- Efficient production of hydrogen from renewable sources
- Advancements in hydrogen storage technologies
- Establishment of a comprehensive hydrogen infrastructure

Need serious investment in R&D and public and private partnerships to accelerate verification and introduction.

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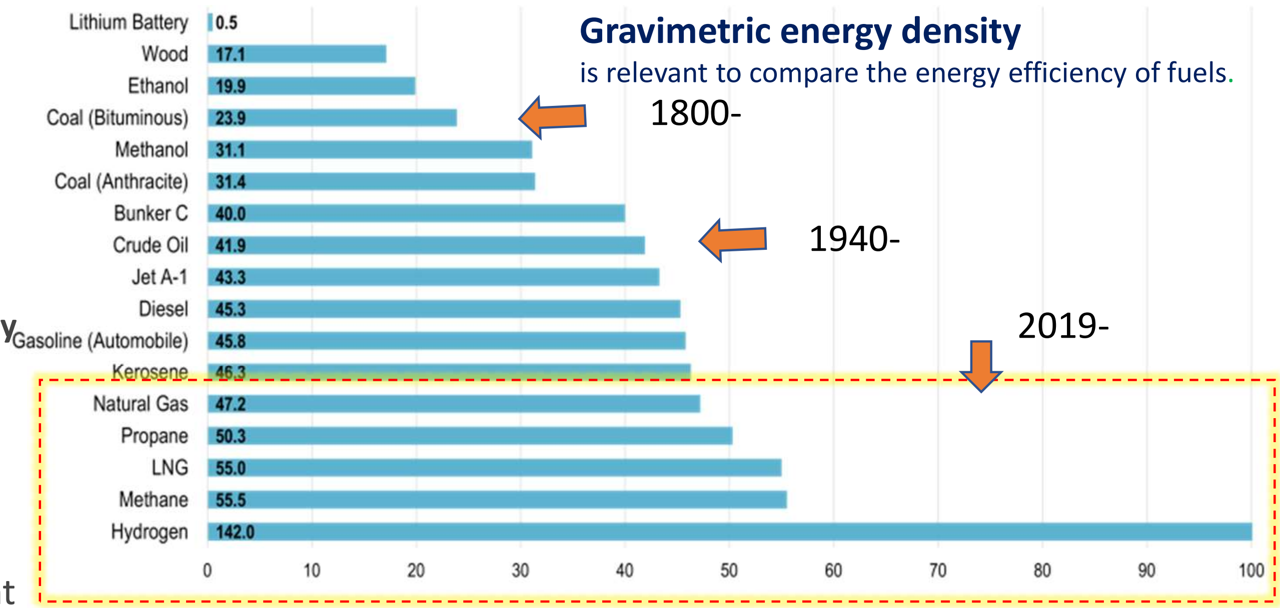
Energy Density of some Combustibles (MJ/kg) (gravimetric energy density)

- Different fuels have different energy density levels
  - Measured in terms of equivalent energy released through combustion.
  - Energy density is the amount of energy that can be released by a given mass or volume of fuel.
  - Measured in terms of **gravimetric energy density** (per unit of mass) or **volumetric energy density** (per unit of volume).
- Volumetric energy density is relevant to comparing transportation modes as storage space (fuel tank) must be present to carry the fuel propelling a vehicle.
- **The higher the energy density, the higher the fuel quality,**
  - inversely proportional to its chemical complexity.

Gravimetric energy density
is relevant to compare the energy efficiency of fuels.



- High-quality fuels are gases, while low-quality fuels are solids, with liquids in between.
- The highest energy density fuel is hydrogen, which is also the simplest chemical component in existence.

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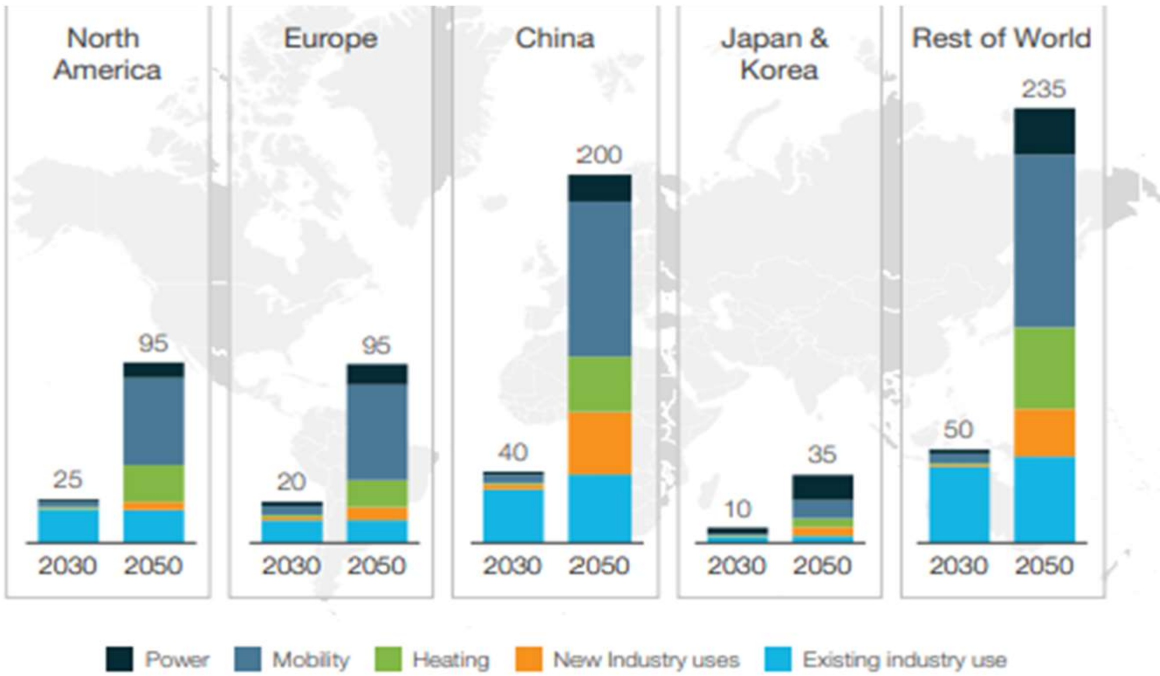
Hydrogen demand by region (MT) in 2030 and 2050 for Net Zero Emissions by 2050



- 660 MT hydrogen required p.a. in 2050 for net-zero
  - 22% of global final energy demand
- Prevent annual emissions of 7 gigatons (GT) of CO_2.
  - ~20% of the emissions if the world remains on its current global warming trajectory.
- By 2050, clean hydrogen could abate a cumulative total of 80 GT of CO_2 –
  - constitutes about 11% of the emissions reductions required to stay within the carbon budget of 420 GT needed to limit global warming to 1.5-1.8 degrees Celsius.

Estimated Global hydrogen investment requirement by 2030 (direct investment, by sector)

- 300 Billion Euros for Hydrogen production
- 200 Billion Euros for Hydrogen transmission & distribution
- 200 Billion Euros for Hydrogen end-use application

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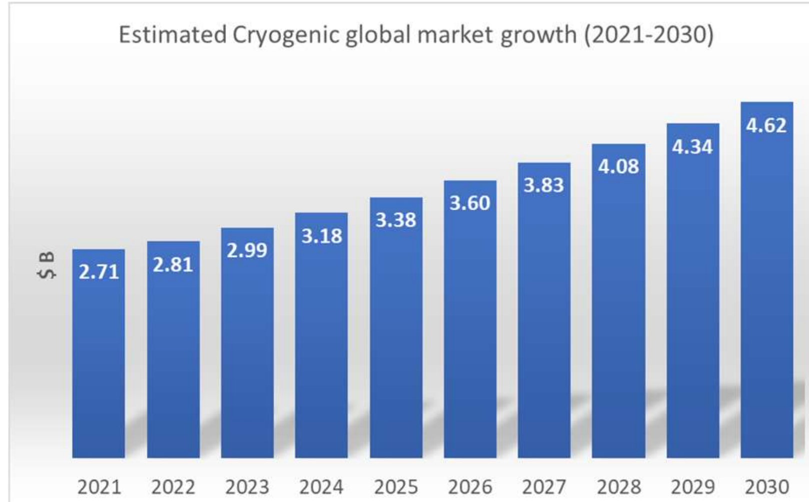
Cryogenic Rocket Engine

Cryogenic Rocket Engine – Essential for Space

- The development of today's space technology would have been impossible without cryogenics.
- Rocket engines boosters are comprised of a cryogenic fuel and oxidizer.
- The H_2-O_2 combination allows for specific impulses superior to the other pairs of propellants and is necessary for some specific applications such as in vehicles with a single step to orbit.
- A cryogenic rocket engine is more beneficial, and it delivers more thrust for every kg of propellant. It is ideal for solid and liquid engines.



1963 – RL 10 – USA in ATLAS V-Rocket

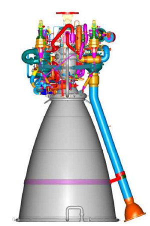
1977 – LE-5 – Japan

1979 – HM-7 – France

1984 – YF-73 China

1987 – KVD-1 Soviet Union

2017 – CE-20 -India



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Cryogenics for Quantum

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Quantum Computing –
Superconducting Qubits *> 10B $ commitment over the last 5 years*

Oxford Quantum Solutions

Superconducting Qubit Devices

Commercial Leaders:

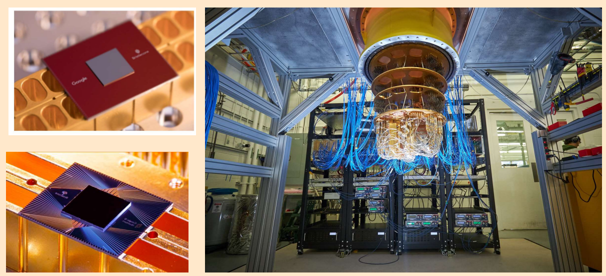
- D-Wave
- IBM
- Google
- Rigetti,
- Q Circuits Inc
- Intel

Academic Leaders:

- UCSB
- UC Berkley
- Yale
- ETH Zurich
- TU Delft
- MIT

Google unveiled the world's largest quantum computer processor to date

- Dubbed **Bristlecone**, it's a **72-qubit** gate-based superconducting system

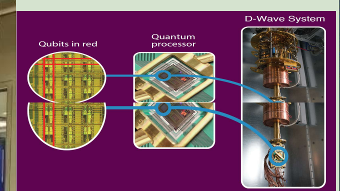


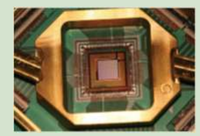
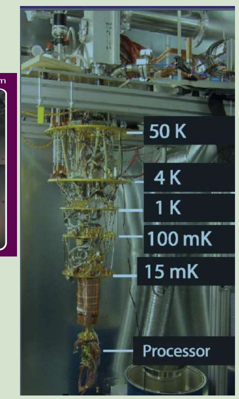
Google Research Blog

The D-Wave 2X system implements a quantum annealing algorithm

D:WAVE The Quantum Computing Company™

- D-Wave systems are being used, for example, by Lockheed Martin, Google, NASA, & the University of Southern California.

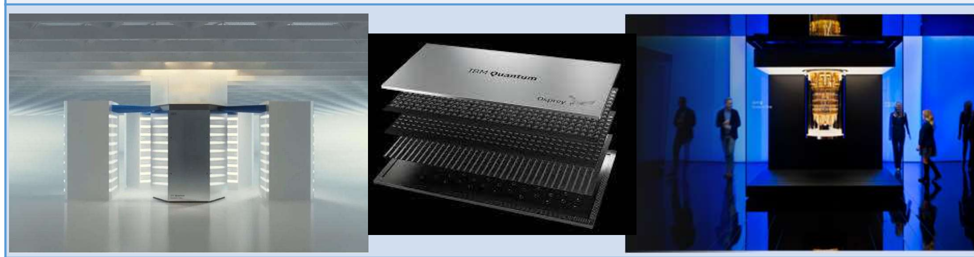



With 1000 qubits, the D-Wave 2X system can search through 2^{1000} possible solutions

IBM demonstrated a 433 SC Qubit Quantum Computer (Osprey)

- **Already providing users with > 20 Qubit QC**

Courtesy of IBM



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Superconductivity Global Alliance (ScGA) for Zero Carbon emission Targets by 2050

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UN Sustainable Development Goals – 17 in total

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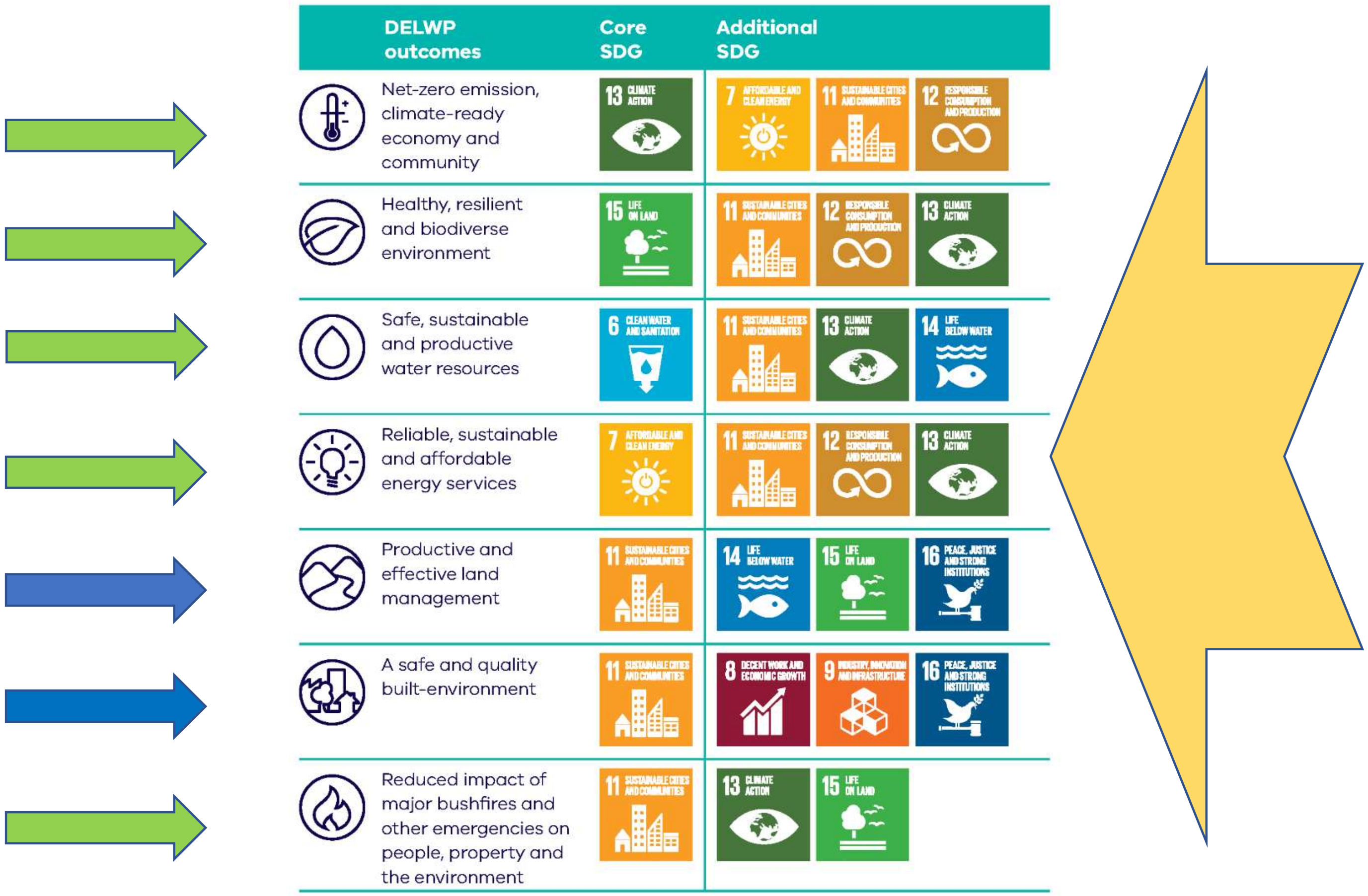
Superconducting Technologies and the SDG goals



SC for
Energy generation &
power management

SC for
Medical diagnostics,
medical treatment
And drug discovery

SC for
Digital age

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Superconductivity Global Alliance (ScGA) initiative
for a greener, healthier, prosperous, and sustainable future

- We wish to catalyse this process and fast-track development through **an "Initiative for Superconductivity" towards a greener, healthier, prosperous, and sustainable future.**

The Vision

Superconductivity has already enabled major advances and capabilities such as MRI, NMR, high magnetic field research, and high energy physics accelerators which otherwise would not be possible. In the future, superconductivity will provide a means towards zero-emission targets, for example by enabling fusion power, expanding usage of wind power, and facilitating zero-emission transportation, as well as enabling new technologies such as superconducting classical and quantum computing, water purification, new medical diagnosis and therapy tools, and new scientific breakthrough

↓

Superconductivity from the Frontier end to Mainstream technologies

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Superconductivity Global Alliance (ScGA) initiative
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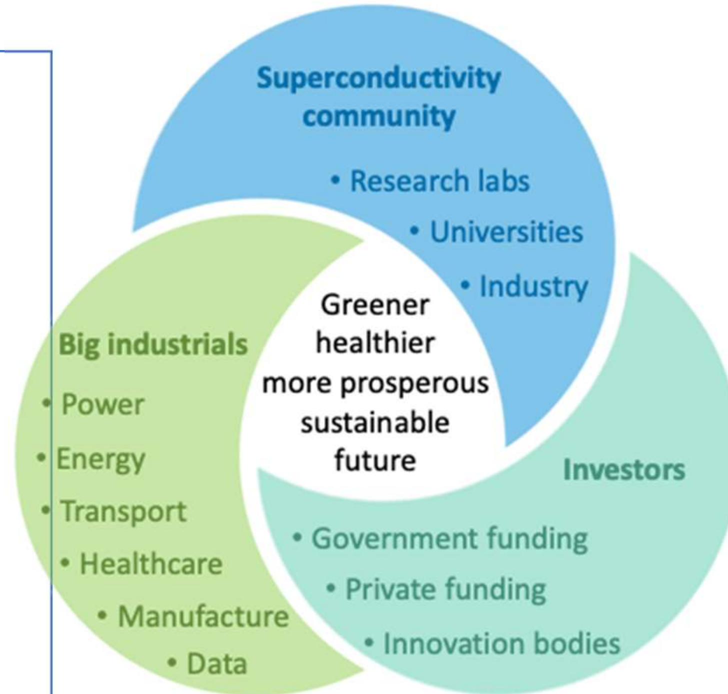
Oxford Quantum Solutions

ScGA Top Level Targets and Deliverables

- **Target 1-** Options for national and private funding of the proposed grand challenges (2024)
- **Target 2-** Develop consortia/partnerships between the SC Community, National and Private funding, and Big industrials to address grand challenges (2024)
- **Target 3-** Superconducting Global summit at the senior level to facilitate the proposed partnership (2024)
- **Target 4** – Adoption of identified options with public + private funding for grand challenges ~ > 1 B Euro over 10 years to deliver on the Strategic Roadmap and the promise from SC for the future



SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD

WORLD ECONOMIC FORUM

2023 UN Climate Change Conference (UNFCCC COP 28)

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Members ~100 (Research and Industry) of the ScGA initiative

Current members of the GSA

Industry (30) - Univ (25) - RI (39)

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Summary

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Summary

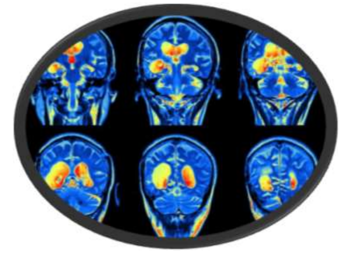
- Cryogenics has
  - ✓ Facilitated many new discoveries and development of innovative materials (e.g. Superconductors, Semiconductors, Graphene)
  - ✓ Enabled new R&D in diverse science & engineering applications

- Cryogenics will facilitate Superconducting Solutions that hold great potential for contributing to net-zero emissions targets by 2050.

- New advancements in cryogenics are & will enable new innovations in
  - Transport, Industry, energy storage, and power applications

- Cryogenics in the next decade will lead to significant improvements in electrification as well as in achieving the net zero emission targets and facilitating a greener future.

- The demand for cryogenic solutions will increase significantly in diverse industrial applications.



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