

Innovations in green hydrogen technologies for the low carbon energy transition

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www.imperial.ac.uk/electrochem-sci-eng/



RFC POWER



Contents

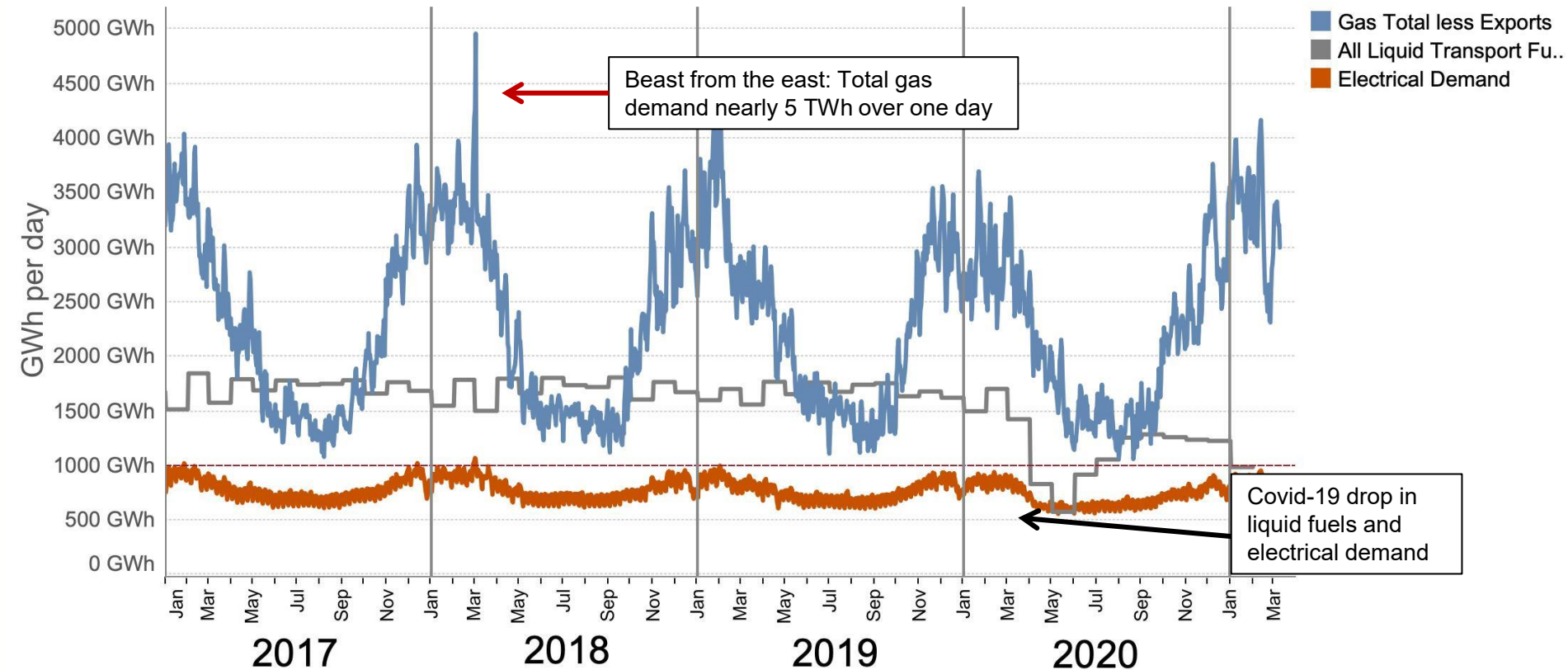
- Why electrochemical technologies for the energy transition?
- Innovation in Solid Oxide Electrolysis and Fuel Cells.
- Innovation in flow batteries - using hydrogen.
- Innovation in the manufacture of high surface materials for electrolysers and batteries (and thermal management).
- Innovation in distributed hydrogen systems.

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Daily UK total gas, all liquid transport fuels, and electrical demand

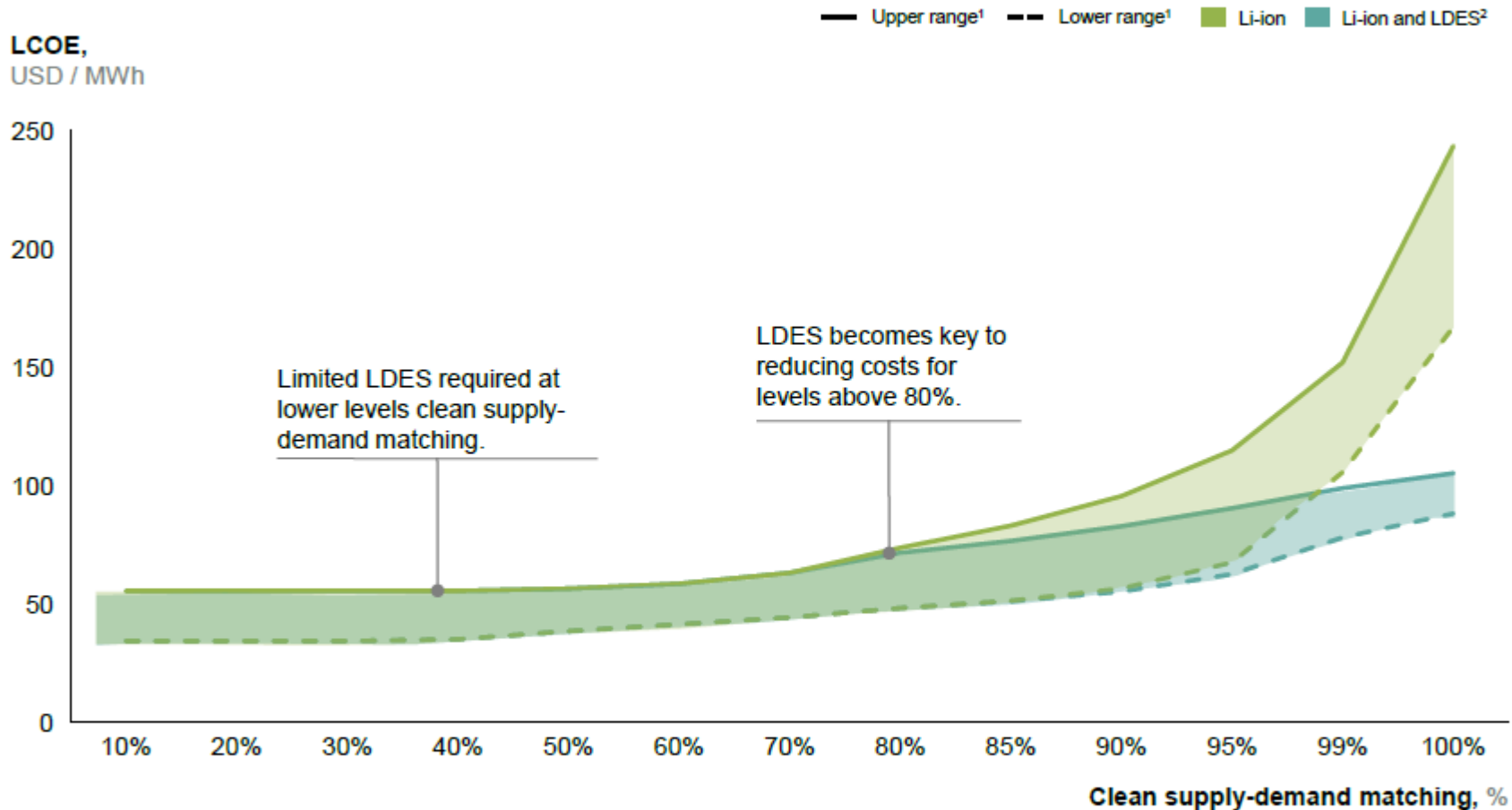
Multi-vector Energy Diagram for Great Britain GWh per day



A growing need for longer term energy storage

RES + Storage LCOE for different levels of clean supply-demand matching

2025



1. Based on modelling a baseload in locations with average (UK) and optimal (Australia) LCOE.

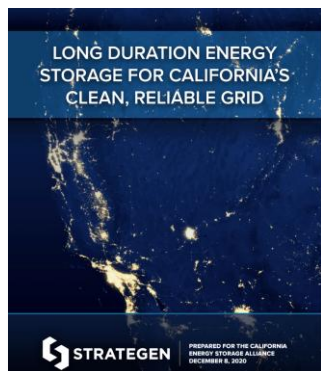
2. LDES 8-24h and 24h+ technologies.

Source: LDES Council 2021 technology benchmark and report, McKinsey Power Model.

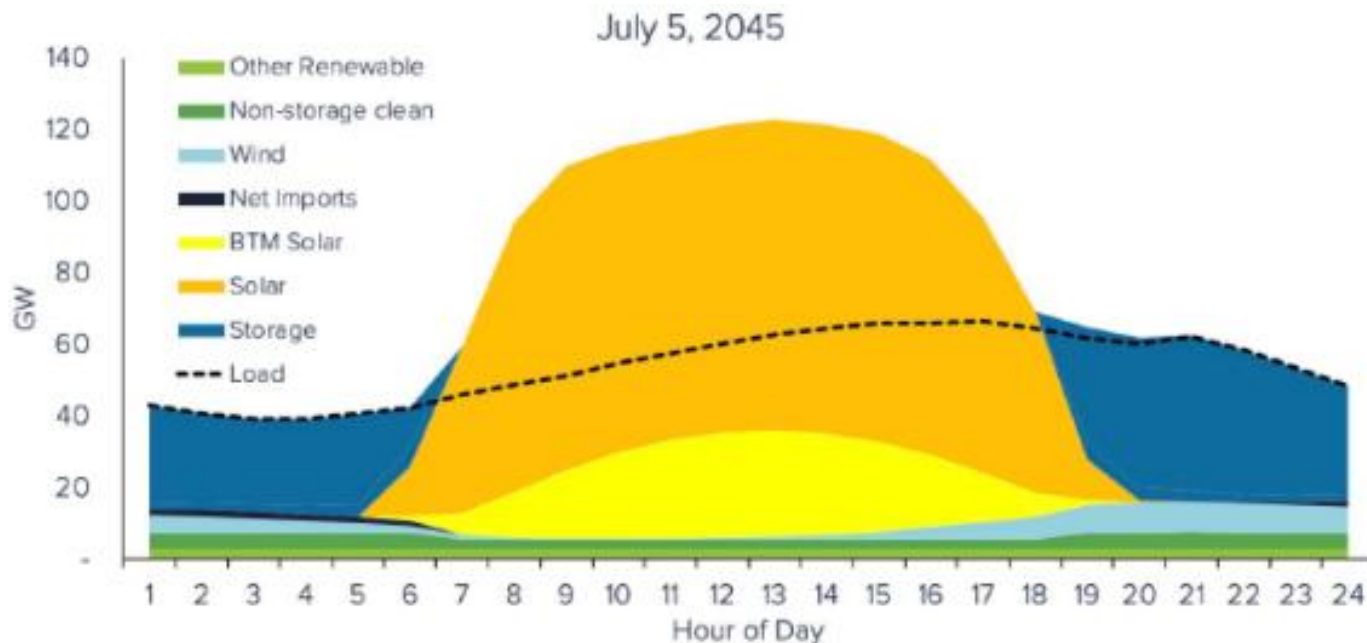


A growing market for longer term energy storage

Daily Dispatch in Sample Summer Day, 2045



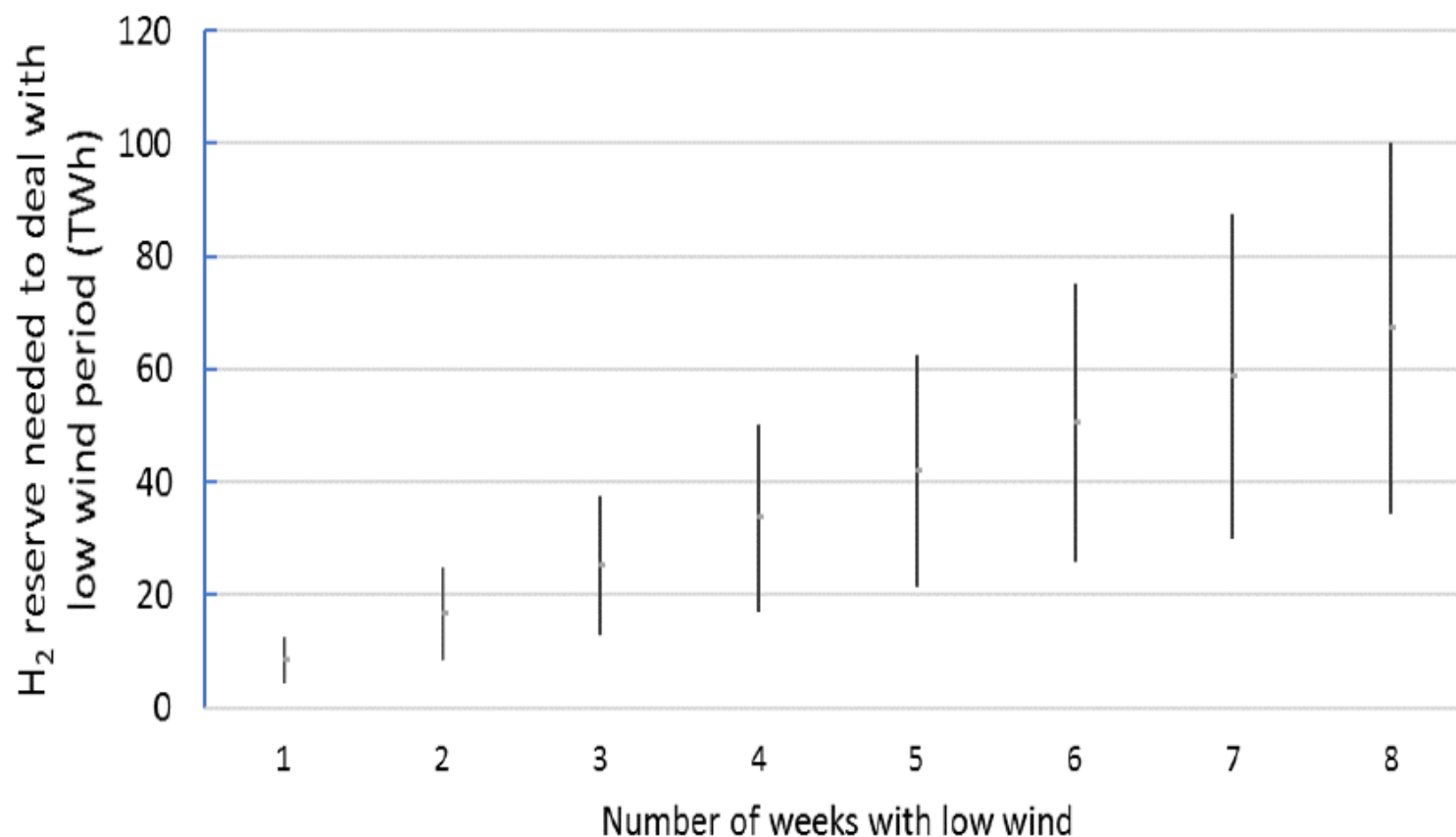
44-55 GW of 10 hour storage by 2045 in California



“Diurnal cycling is the largest application of energy storage (44-55 GW by 2045) from 2030-2045, primarily met by 10-hour storage” California Energy Storage Alliance (CESA), Dec 2020.

Storage technologies that offer a good fit to this application are flow batteries, liquid air, compressed air, and potentially reversible electrolyser/fuel cells.

Additional H₂ storage to deal with a prolonged low/no wind periods – *H₂ enhances the resilience effectively*

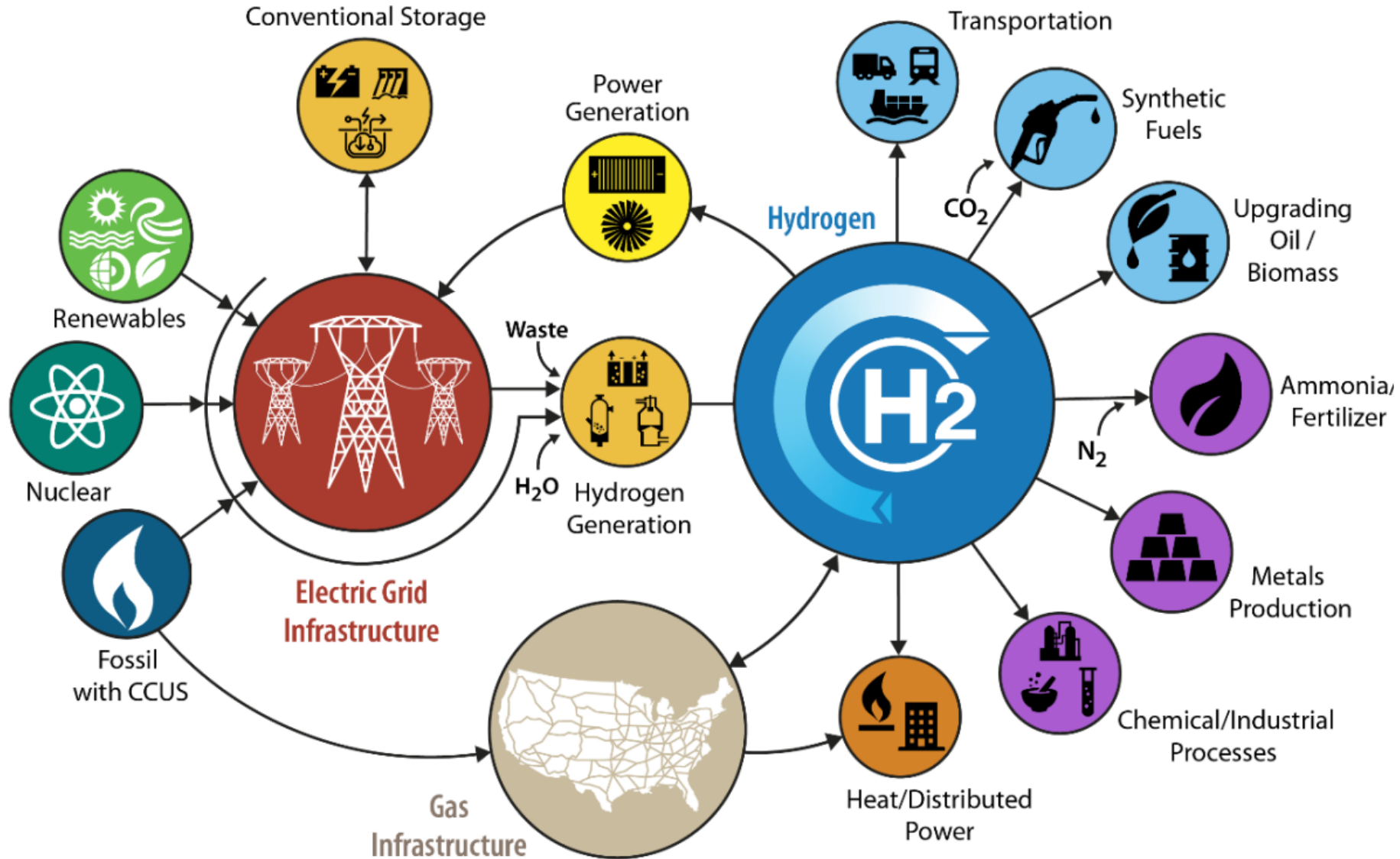


UK Pumped Hydro @ Dinorwig – 9.1 GWh

1 million tonnes of hydrogen stored = 33 TWh or > 3600
pumped hydro facilities such as Dinorwig in the UK



Hydrogen and Electricity working together



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Reversible Solid Oxide Cell (rSOC)

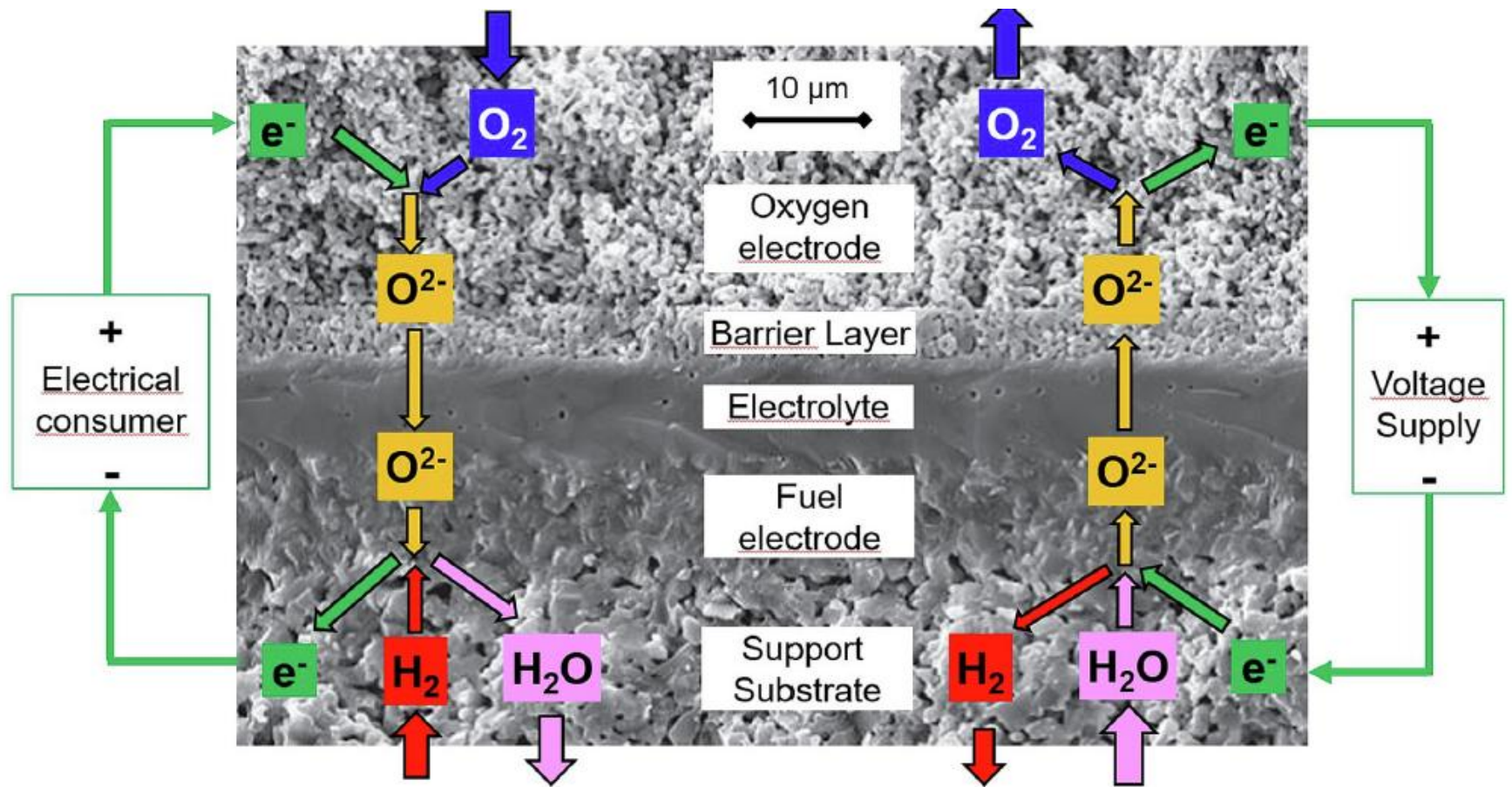
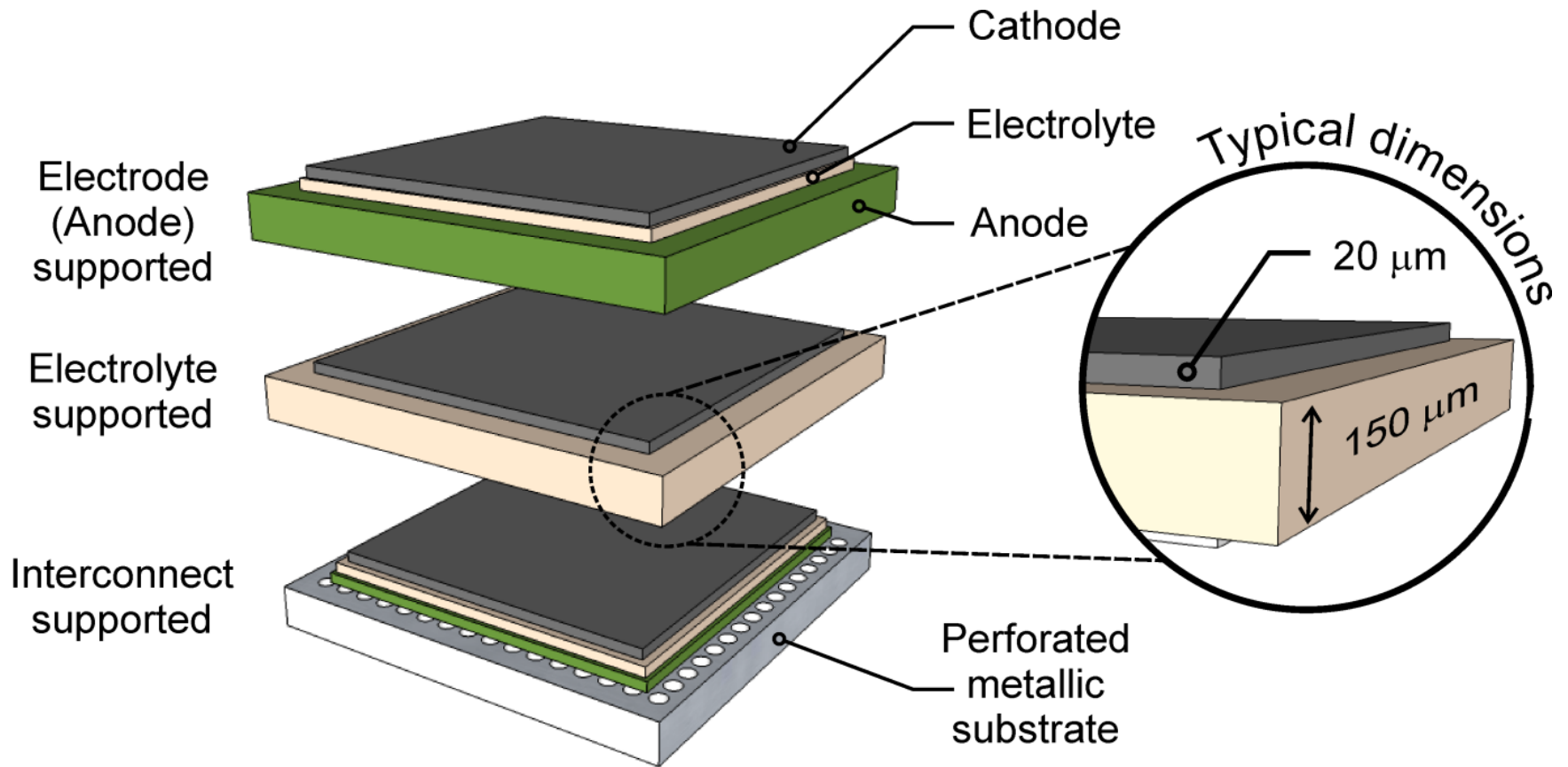


Fig. 1. Cross section of a high temperature solid oxide cell with $\text{H}_2/\text{H}_2\text{O}$ redox reaction paths at the electrodes (left SOFC, right SOEC).

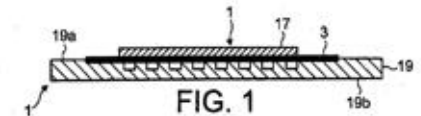
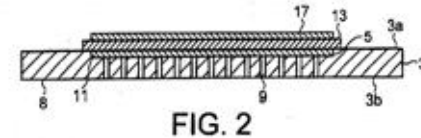
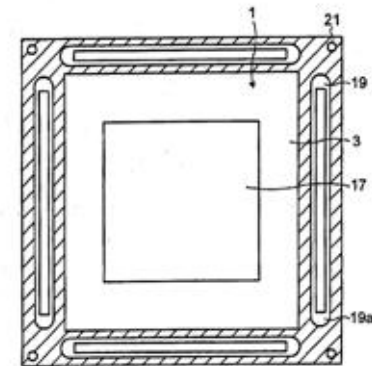
Typical planar SOFC geometries



Innovative metal supported Solid Oxide Cells



U.S. Patent Sep. 21, 2004 Sheet 1 of 3 US 6,794,075 B2

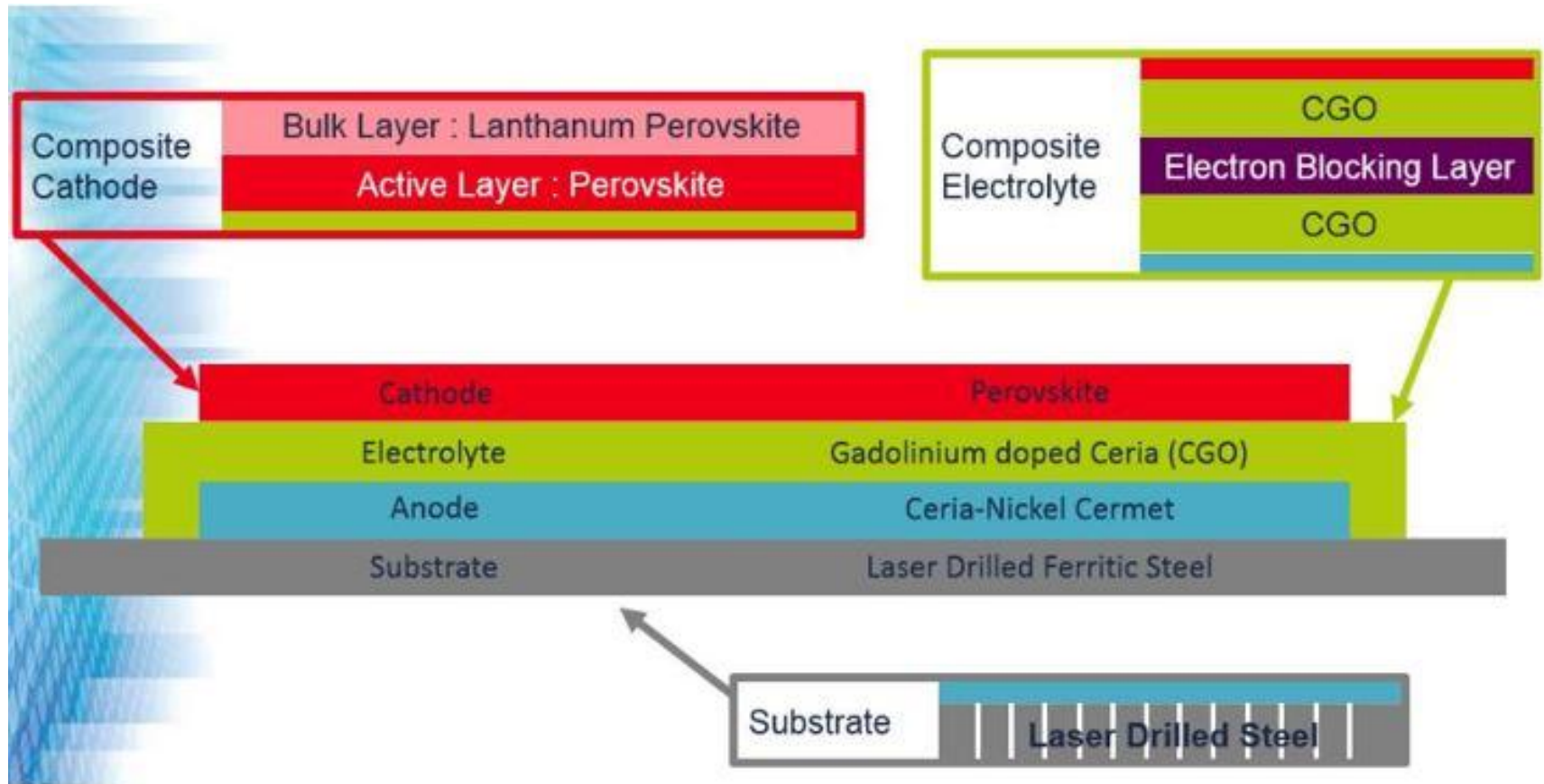
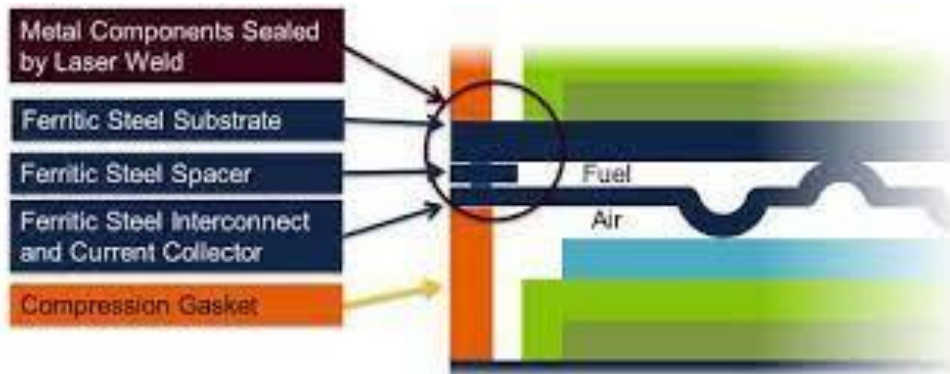
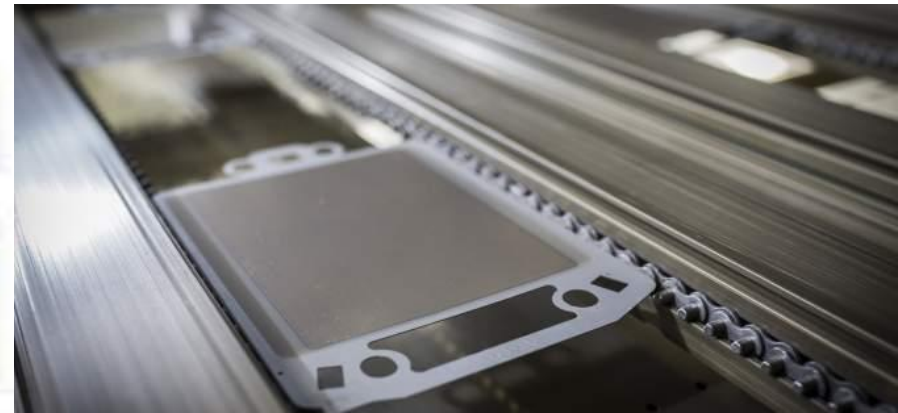


Catalysed by EPSRC proposal “OPTIMISATION AND EVALUATION OF INTERMEDIATE-TEMP (500 C) SOLID OXIDE FUEL CELL (IT-SOFC) STACKS” £260k, GR/N04638/01, Oct 2000 to Jan 2004.

B C H Steele, A Atkinson, J A Kilner, N P Brandon, R A Rudkin, Oct 25th (2000). Assignee Ceres Power Ltd., US 6,794,075 B2, Sep 21 (2004).

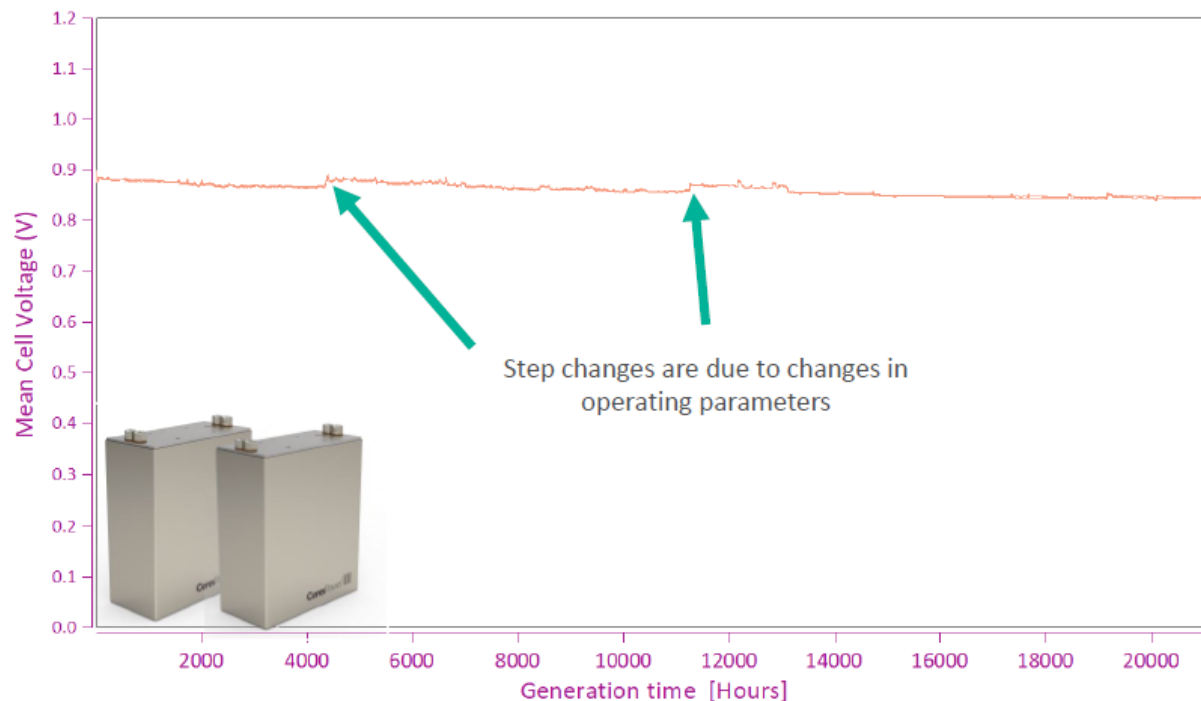


Ceres Power metal supported SOC



Data from a field trial system demonstrates unparalleled real-world robustness of Ceres stacks

- **10kW system** (2 stacks) has operated for **over 22kh** (>4y) without stack replacement
- Degradation rate of **0.2%/kh**
- **34 thermal cycles**
- **2 E-stops**
- Providing **heat and power** to an electronics manufacturing plant
- System is still running



Ceres stacks have undergone significant testing hours in the lab and in field trials, proving efficiency, durability, and robustness of the technology



>5 million
Accumulated test
hours

ceres

Commercialization of Ceres' unique technology for green hydrogen and power generation

Dr Robert Leah Research Fellow

CLEAN ENERGY STARTS WITH CERES

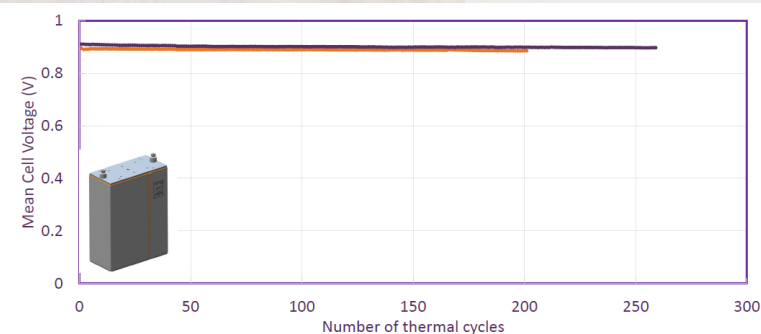
14th July 2025

SOFC XIX Stockholm

Our 1 MW demonstrator with Shell in Bangalore, India continues to produce H₂



<https://www.ceres.tech/news/ceres-mw-scale-electrolyser-project-produces-first-hydrogen/>



Metal supported technology is inherently robust to on/off temperature gradients

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A novel liquid-gas flow battery

RFC Power – an Imperial College spin out



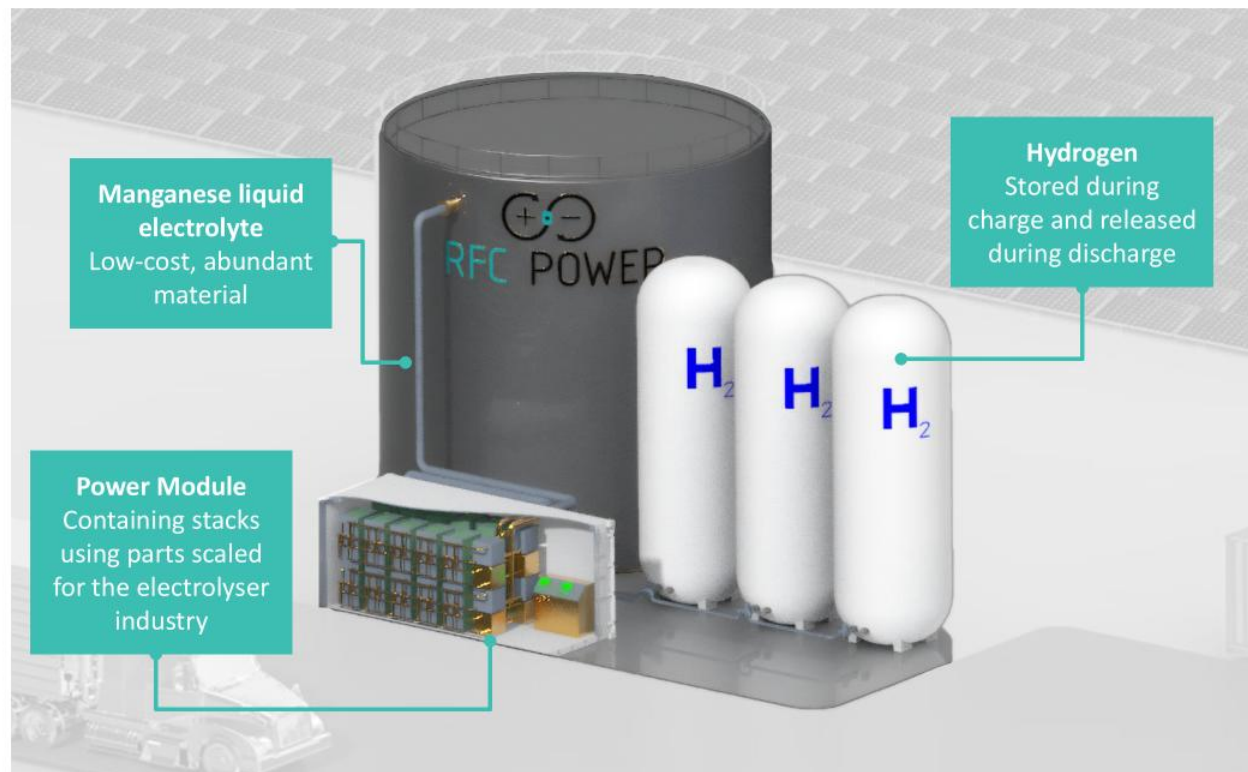
(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)
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(43) International Publication Date 22 June 2017 (22.06.2017)
(10) International Publication Number WO 2017/103578 A1

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(32) International Application Number: PCT/GB2016/059922
(33) International Filing Date: 13 December 2016 (13.12.2016)
(34) Filing Language: English
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(36) Priority Date: 13 December 2015 (14.12.2015)
(37) Applicant: IMPERIAL INNOVATIONS LIMITED (GB) 15 Avenue Gate, London SW7 2PG (GB)
(72) Inventors: BRANDON, Nigel, Imperial College, Exhibition Road, London SW7 2AZ, (GB); YUJITI, Vladimir, Imperial College, Exhibition Road, London SW7 2AZ, (GB); KYCERNAK, Andrew, Imperial College, Exhibition Road, London SW7 2AZ, (GB); RYBKO-GARCIA, Javier, Imperial College, Exhibition Road, London SW7 2AZ, (GB)
(73) Agent: KILBURN & STRODE LLP, 20 Red Lion Street, London EC1R 4PP (GB)
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BR, BS, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GR, GU, HK, HN, HU, ID, IL, IN, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LR, LS, LU, LV, MA, MD, ME, MG, MK, MN, MW, MX, MY, NG, NA, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, UA, UG, US, UZ, VC, VE, VI, ZA, ZM, ZW.
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(94) Title: REGENERATIVE FUEL CELLS

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(43) International Publication Date 18 July 2013 (18.07.2013)
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(32) International Application Number: PCT/EP2013/00296
(33) International Filing Date: 9 January 2013 (09.01.2013)
(34) Filing Language: English
(35) Publication Language: English
(36) Priority Date: 1300203 9 January 2012 (09.01.2012)
(72) Inventors: and
(73) Applicant: IMPERIAL INNOVATIONS LIMITED (GB) 15 Avenue Gate, Exhibition Road, London SW7 2PG (GB)
(74) Agent: HEDLEY, Nicholas James Matthew, 20 Red Lion Street, London WC1R 4PP (GB)
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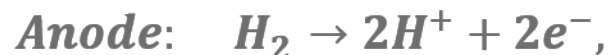
RFC's Hydrogen-Manganese (H-Mn) flow battery



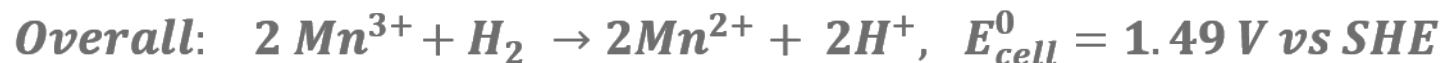
DURATION	8hr+ Charge / discharge
EFFICIENCY	75%+ AC TO AC
CYCLES	No Capacity Loss With continuous cycling
CAPEX	< \$100/kWh For 12h system (fully installed)
PATENTS	7 patent families 5 granted in multiple territories



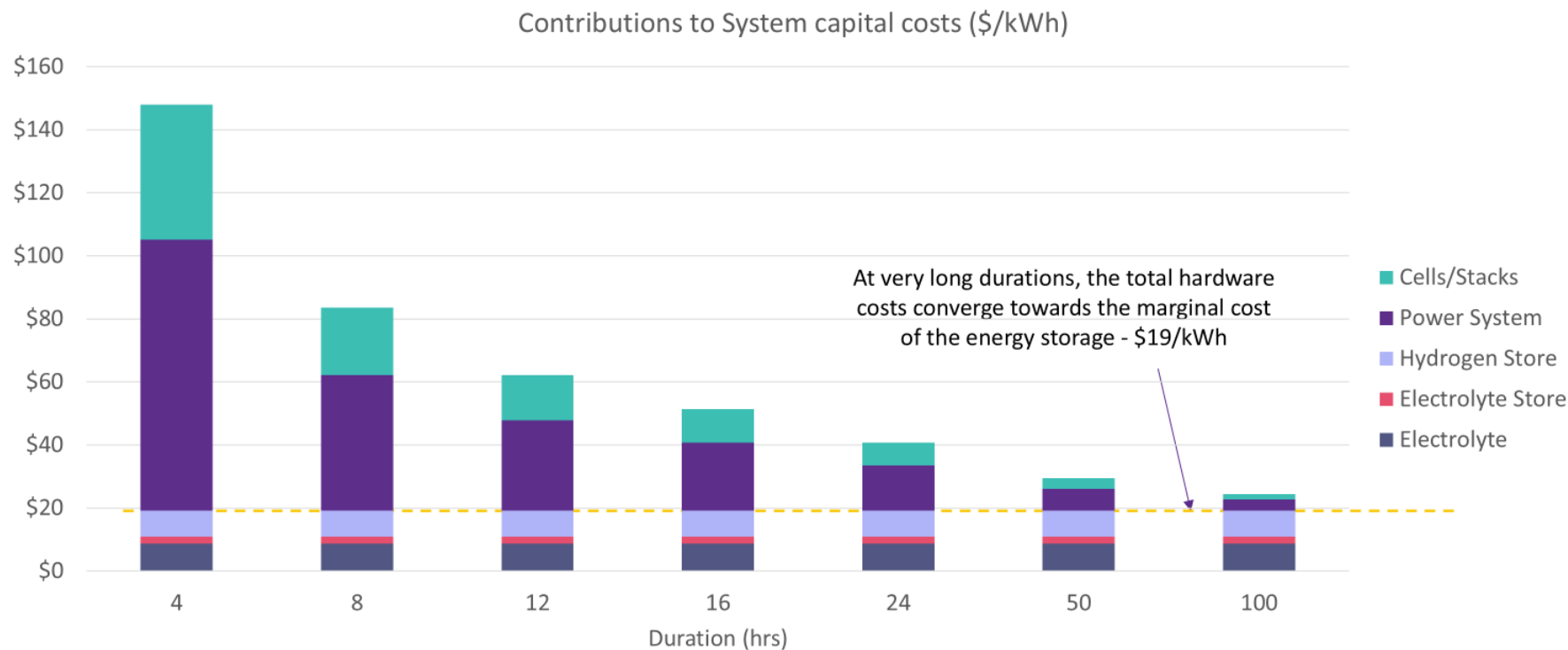
$$E_{\text{cathode}}^0 = 1.49 \text{ V vs SHE (7 M H}_2\text{SO}_4\text{)}$$



$$E_{\text{anode}}^0 = 0 \text{ V vs SHE}$$



Hardware costs at 100h are <\$25/kWh



CERTAIN ENERGY



centrica

ceres®



CATALYTIC CAPITAL
FOR CLIMATE & HEALTH
By Temasek Trust

Wednesday 26th August — Certain Energy, the British long-duration energy storage company, announces it has received £10m Series A funding for its pioneering manganese flow battery technology. The investment will be used to commercialise Certain Energy's technology and prepare it for deployment to stabilise grids and provide power during periods of low renewables production.

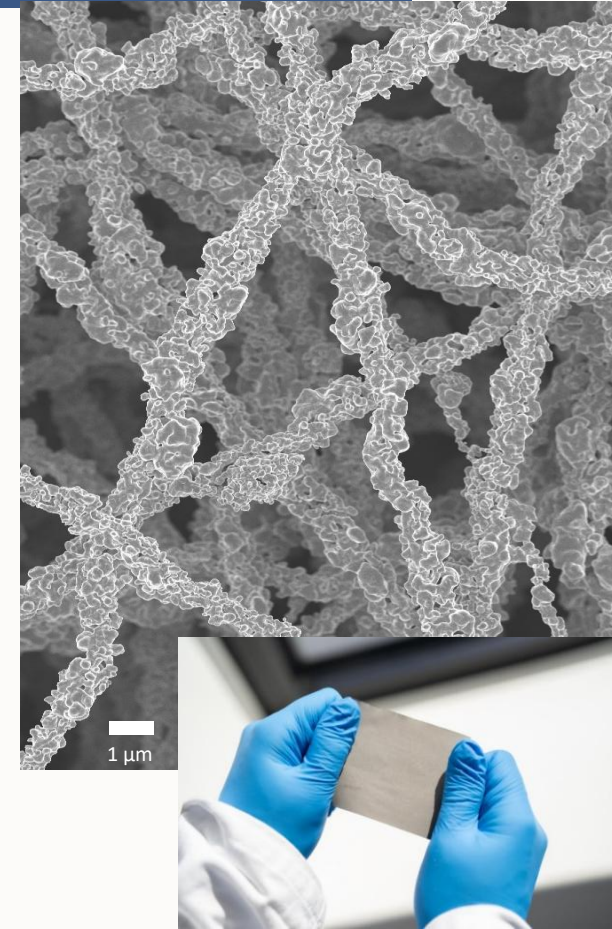
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M-Spin: Advanced materials for improved IC chip cooling & green fuels



- Advanced materials for the **enhanced cooling of AI devices, and datacentres, as well as electrodes for green hydrogen production**
- **Performance validated by customers**
- Technology core is a proprietary electrospinning process to produce mechanically durable nanofibrous metallic sheets – **M-Spin is the only company in the world able to electrospin nanofibrous metals and alloys**
- Developed at the **Brandon lab at Imperial College London**
- **Process is low cost & highly scalable** – volume roll-to-roll production demonstrated
- Porosity up to 97%, surface area $>10^8 \text{ m}^2/\text{m}^3$
- **Raising \$5M for pilot production facility**



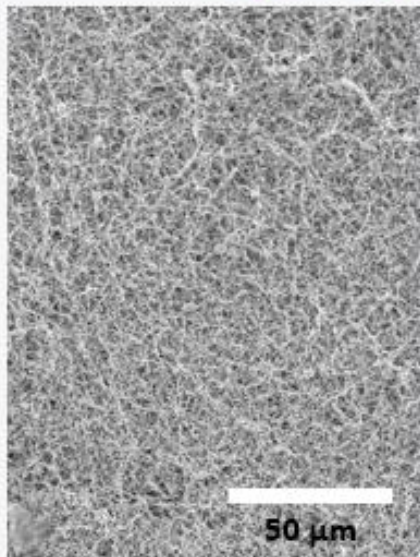
(Top) Microscopic structure of M-Spin materials showing metallic nanofibers (in this case nickel)

(Above) 5x5 cm sheet showing macroscopic appearance (much like paper)

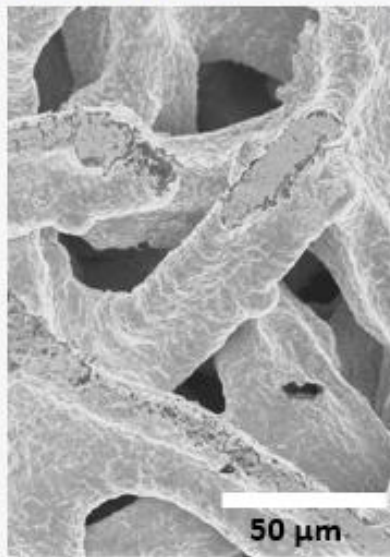
State-of-the art performance in alkaline electrolysis

- 5x current density
 - More hydrogen production per area – **Lower capex**
 - 50% overpotential reduction
 - Higher efficiency, lower energy use – **Lower opex**
 - Overall: **20-30% reduction in green H₂ cost**
 - Excellent durability - No significant degradation after 10,000 cycles (accelerated testing simulating 10,000 hours)
- **Performance benefits independently validated by industrial customers**

>1,000 X surface area



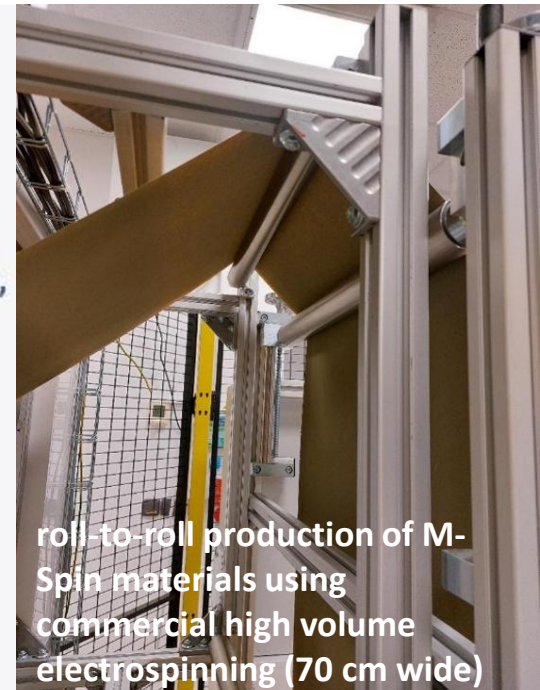
M-Spin



Commercial foam

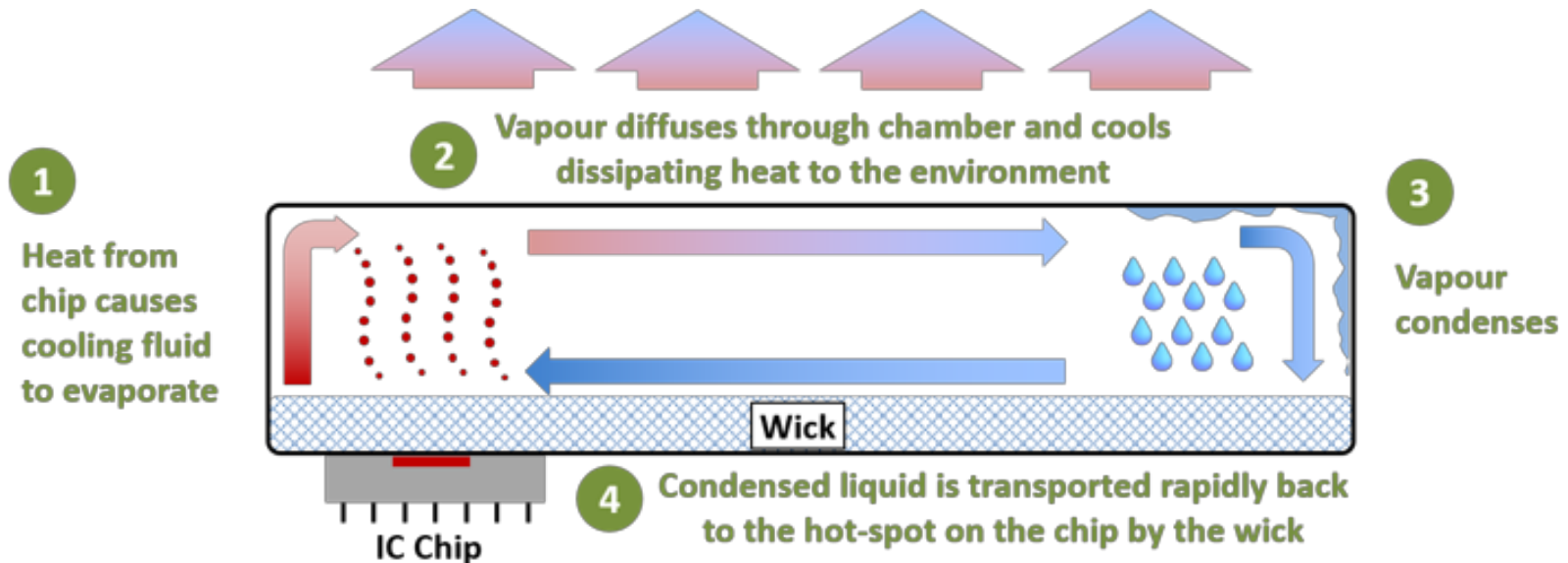
Key Properties

Materials	Ni, Fe, Cu, Co, Zn, others
	<u>Plus alloys</u>
Purity	>99.9%
Porosity	60-97 %
Pore size	0.5-10 μm
Fibre diameter	0.05-2 μm
Thickness	0.05-2 mm
Surface area	>10 ⁸ m ² /m ³



World class performance for thermal management of AI chips and electronics

- >50% increase in fluid transport versus competing materials (<30 micron thick, high porosity, high thermal conductivity, very fast capillary transport of coolant)
- = 2x cooling performance for chips and electronics
- **Benefits confirmed in tests by globally top-5 smartphone & electronics manufacturer**
 - Enables higher sustained performance for computing and AI while lowering cost: Potential for 5-10% gain in compute output per watt



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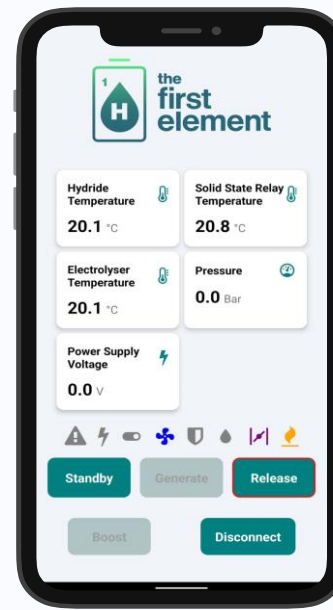
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- **Innovation in distributed hydrogen systems.**

The Smart Tank

Our core product, The Smart tanks are able to safely generate, store and deliver hydrogen gas. A modular approach allows for a combination of options, from a complete system with electrolyser that generates and stores (with the option to scale up by linking units together) to standalone Hydride H₂ storage tanks.

They are easy to use and control via the smart phone application and connect to the IoT service for remote monitoring and management.

- **Generating at point of use:** Replacing costly and complex supply chain of fossil fuels
- **IOT-enabled:** Demand response algorithms and time-of-use tariffs ensure hydrogen generated when grid electricity derives from lowest-cost, lowest-carbon sources.
- **Smartphone-connected:** User friendly interface = convenient management of hydrogen inventory, cost and safety features:
 - **Automatic shut-off in event of a leak with wireless gas sensor**
- **Low cost solution:** Can be mass produced in a factory
- **Solves** issue of domestic accessibility and **distribution**
- **Footprint** is similar to that of a standard 47Kg LPG canister



**Prototype 1
Demonstrator
Completed
Nov 2023**



Prototype Board In Test

The global H₂ Metering and Monitoring market is forecast to reach \$6bn by 2050
Hydrogen Innovation Initiative Report

Hydrogen Detector



Safety drives the need for sensors and monitoring systems across all sectors of the hydrogen economy, to build public and industrial confidence.

Existing hydrogen detectors are not well suited to our needs. They are either prohibitively expensive, designed for lab environments or susceptible to interference.

There is a market opportunity to build a cost-effective range of hydrogen detectors. Initial research, engaging with business including the UK's largest network distributor of natural gas, who will supply Hydrogen to the home has shown that no viable market solution exists but is very much needed.

- ✓ Detectors can shut off the gas when a leak is detected
- ✓ The detector will be IoT enabled and integrate with our Smart grid and tank.
- ✓ Detectors can detect other flammable gasses and potentially smoke.

We will be the first business to establish a domestic hydrogen brand starting with the "hydrogen sensor". The product will be beautifully designed and offer a range of additional IoT related services.

We are already working with a factory for production. We will be able to get to market much faster with this product and hereby generate initial revenue ahead of forecast.

2 pre-commercialisation grants won June 2024 (IUK and London and Partners) to expedite



One of 10 finalists in the Hydrogen Innovation Challenge run by CPI and Hydrogen Innovation Initiative

Smart Hydrogen and Resilient Energy Decarbonisation

Led by UKPN this Ofgem project has shown that low-cost hydrogen production and storage offers a promising option to improve the energy resilience of rural communities.



Smart Web, Monitoring & Electrolyser

We are also developing a complementary range of products based on our Smart Tank technology, to enable the safe, accessible and scalable generation and storage of green hydrogen.



Smart Web

The Smart Web system is our core IoT service application. All of our products, from our Smart Tank to our Hydrogen Detectors can connect to the Smart web IoT system. As well as providing centralised management and alerts, the Smart Web can interface with 3rd parties such as electricity providers or weather feeds.



• **Professor Prakash Ghosh,**
 Indian Institute of Technology Bombay

- Doctorate in Mechanical Engineering RWTH Aachen, Germany
- BOYSCAST Fellowship
- EU Erasmus Mundus fellowship
- Research areas:
 Low temperature fuel cells and solar hydrogen research and energy storage
- 50 + International Journal papers on solar energy, fuel cells and hydrogen energy
- 5 awarded and 4 filed international patents
- Principal Investigator and Co-Principal Investigator for National and International projects (UK, Canada, Australia and USA)

TFE are collaborating with Professor Ghosh to build a low cost electrolyser

Thankyou

- I would like to thank the numerous colleagues and students at Imperial College who worked with me over the years, along with the many colleagues at Ceres Power, RFC Power, M-SPIN and The First Element, without whom none of the work presented here would have been possible.
- I would like to thank the funding agencies who continue to support our underlying research at Imperial College, and the programmes in the UK who have and continue to support the innovation journeys in the UK and beyond.

IMPERIAL



Engineering and
Physical Sciences
Research Council



Innovate
UK

