ceres

UK HyRES Future Perspectives

Solid Oxide Electrolysis for Green Hydrogen Production

Edinburgh 20th April 2023

CLEAN ENERGY STARTS WITH CERES

25 April 2023

Jon Harman

Contents

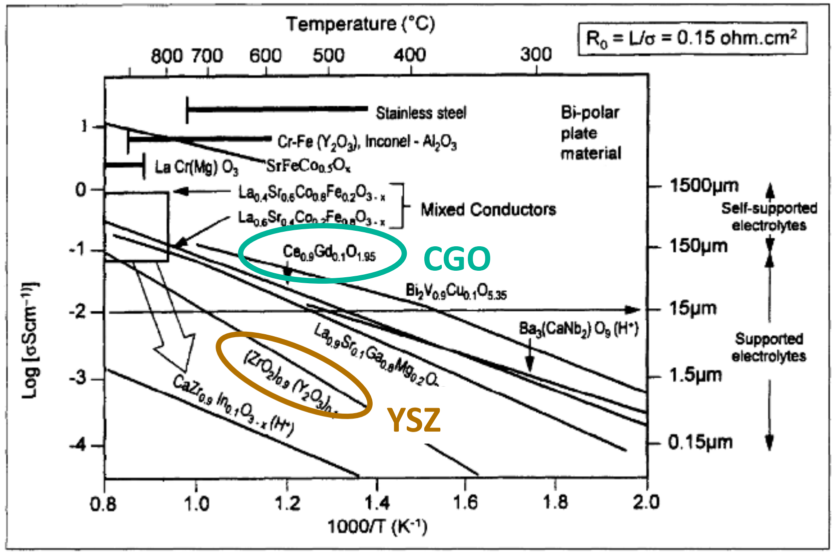
Technology

The Ceres History and Origin

Credit: Imperial College

Professor Brian Steele worked in the Department of Materials at Imperial College for 37 years and was instrumental in the development of solid oxide fuel cells. He was also a founding member of spin-out company Ceres

- Brian Steele identified CGO as low temperature electrolyte in 1990's
- CGO has superior conductivity compared to other ion conducting ceramics at temperatures that enable low cost SOFC with metal support



Specific ionic conductivity values for selected ceramic ion conducting membranes as a function of reciprocal temperature.

Ceramic ion conducting membranes

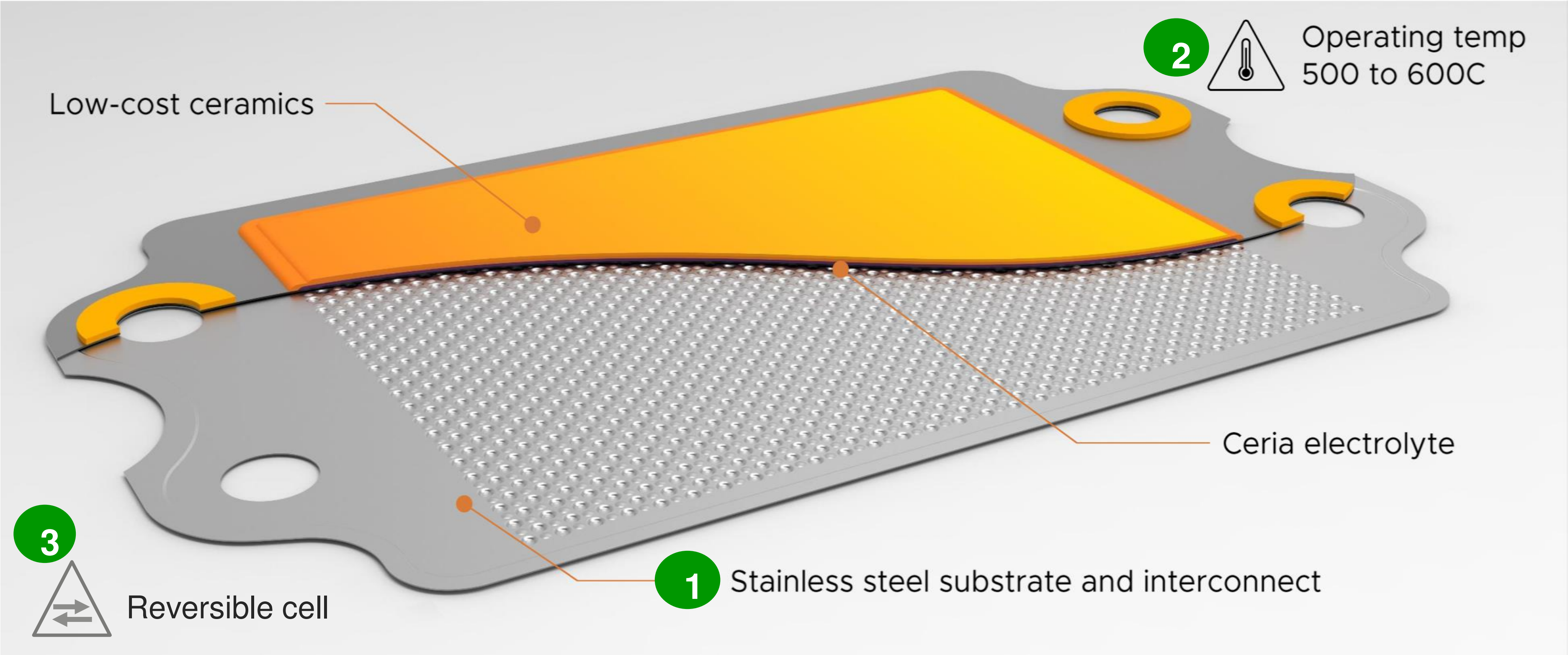
Brian CH Steele

Ceramic ion conducting membranes are a generic group of materials with many potential large-scale applications in solid oxide fuel cells, oxygen generators and partial oxidation reactors. At present the transport and surface exchange kinetic characteristics are emphasized to maximize ionic fluxes. However, as the dense membrane is often fabricated in the form of a thick film on a supported porous structure there is an increasing realization that the available processin routes and thermomechanical behaviour will also strongly influence the selection of materials. Accordingly, increasing attention is now being given to the effect of the imposed chemical potential gradient upon thermochemical stability an structural integrity.

1996: Paper written by Brian Steele on Ceramic Ion conducting membranes

2001: Ceres Power Ltd spins out from Imperial College

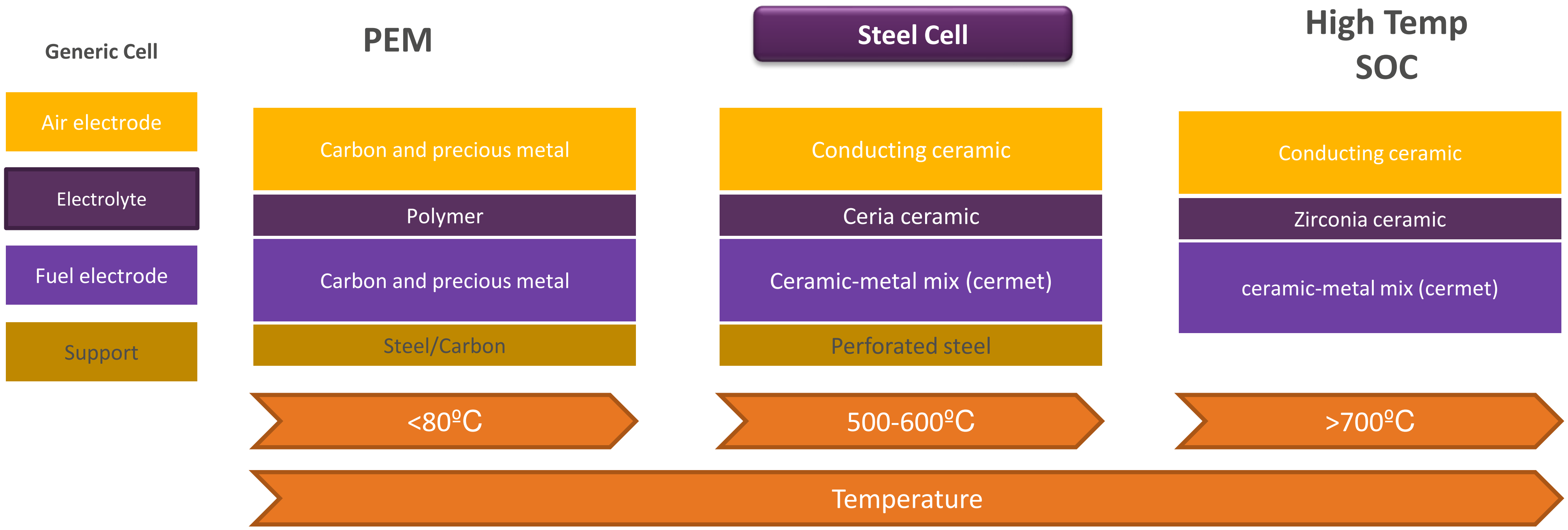
Ceres SteelCell™ technology developed over 20 years, for power generation and hydrogen production



Metal Supported Low Temperature - Solid Oxide Cell

- Low Cost
- Robust
- Efficient
- Reversible
- Manufacturable

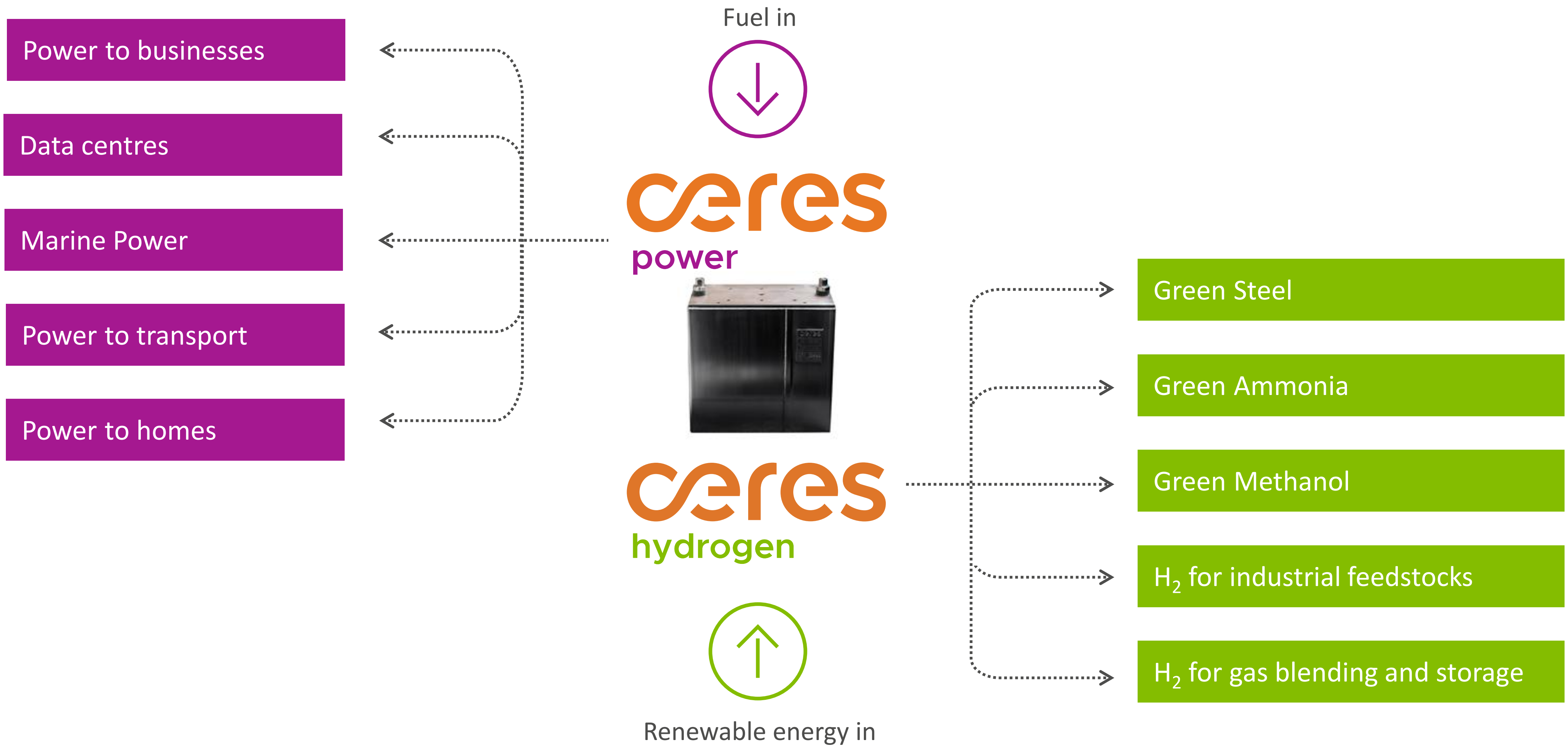
Ceres SteelCell® are a in a temperature sweet spot for performance, fuel flexibility, cost and robustness



Complex fuel infrastructure or processing requirements

Complex High Temperature Engineering

Fuel cells for power generation and electrolysers for green hydrogen



PEM

Grid balancing and refuelling stations

50 kWh/kg

Challenger:
dynamic response

Alkaline

Industrial / bulk production

48 kWh/kg

Most mature:
lowest scale, lowest cost today

SOEC

Industrial uses, steel and e-fuels

37 kWh/kg

Potential:
highest efficiency due to lower electrical energy input

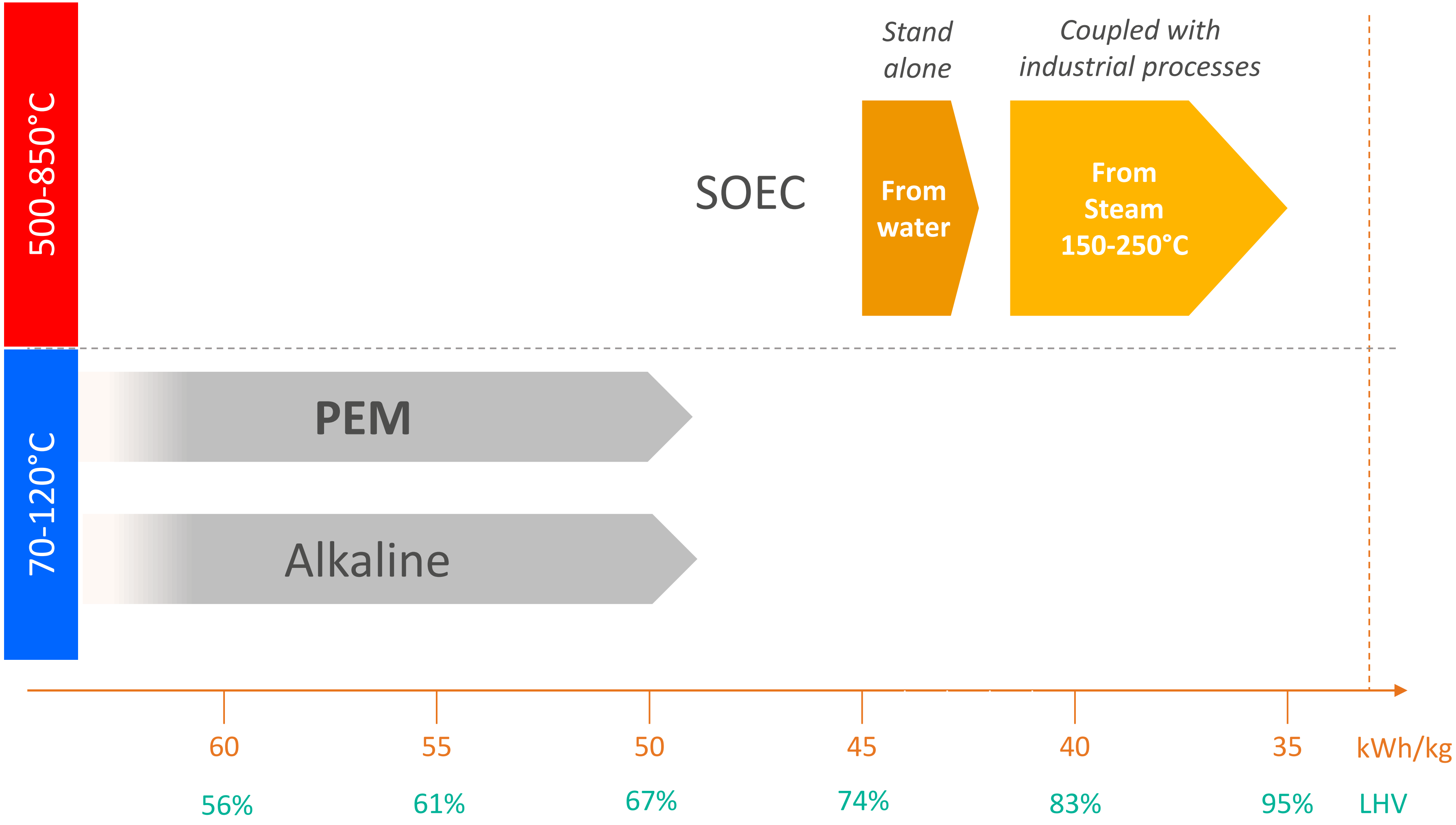
Solid oxide electrolysis is highly differentiated

ceres

SOEC has intrinsic efficiency advantage over low temperature electrolysis, when integrated with a steam source

Green Hydrogen Cost Reduction – Scaling up Electrolysers to Meet the 1.5°C Climate Goal

International Renewable Energy Agency, 2020, Abu Dhabi



Ceres SOEC enables 26% cost savings for Green Hydrogen Production

Illustration for an indicative project producing 1MT of green H2 per year

Renewables Capacity → Electrolyser Capacity → Green H2 Production for 1MT of H_2 per year

ceres

	Electricity Costs per MT H_2		Renewables Capacity	Electrolyser Capacity	
System Efficiency **37** kWh/kg	**$2.0B/yr**	26% Opex Reduction of $14B Based on 20 year plant life	**8.9GW**	**4.7GW**	26% Capex Reduction of ~$7.8B from $30B CapEx estimate for Low Temperature Electrolysis plant and supporting renewable capacity
	$0.75B/year saving		$6.8B saving	$1B saving	
Low Temperature Electrolysis System Efficiency **50** kWh/kg	**$2.75B/yr**		**12GW**	**6.3GW**	

Assumptions used in calculations: Electricity Cost: $55/MWh; Electrolyser System Installed CapEx: $600/kW; Offshore Wind Installed Cost: $2858/kW; Solar Installed Cost: $857/kW; Wind:Solar ratio: 67:33; Renewable Capacity factor: 53%; Electrolyser Capacity Factor: 90%;
References: Renewable power generation costs in 2021 (irena.org); Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5C climate goal (irena.org)

The Ceres stack also enables lower system costs compared to other SOCs

Lower Operating Temperature

- Lower cost balance-of-plant materials
- Less insulation
- Simpler gas and electrical seals

Redox Tolerance

- No need for cover gas during shut-down and emergency stop (uncontrolled)

Mechanical Robustness

- Simpler handling and transportation
- Faster start-up time

Integrated Functions (in devt.)

- No external reformer
- No reforming water system
- Direct methanation

ceres

SOEC System Development

SOEC Progress

Prototype 1MW system

Future 100MW

Specification	Target Value	Future models
Electrical Power Input (AC)	~1MW	100MW
Hydrogen Production	~600kg / day	
System Efficiency	<40kWh/kg >80%, LHV, AC	37kWh/kg

Measured

Module Efficiency

38

kWh/kg

Prototype ECM Module

Specification	Target Value
Electrical Power Input	~100kW
Hydrogen Production	~65kg / day
Module Efficiency	38kWh/kg
Steam input	150°C

First prototype system at 1MW – future plants at 100MW

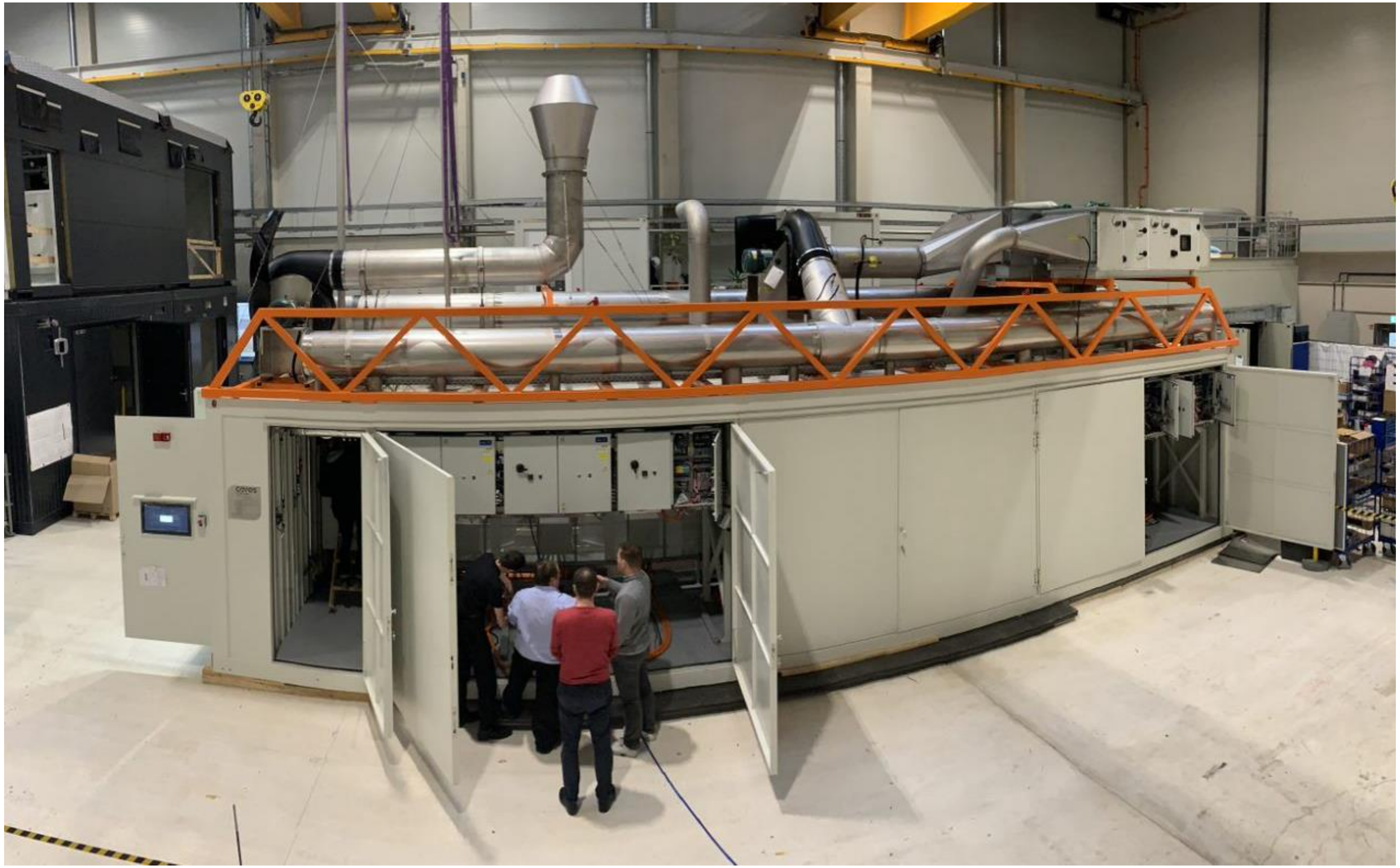
Specification	Target Value	Future plant scale
Hydrogen Production	~600kg / day	>60tn / day
System Efficiency	<40kWh/kg	37kWh/kg

Measured Efficiency 38kWh/kg

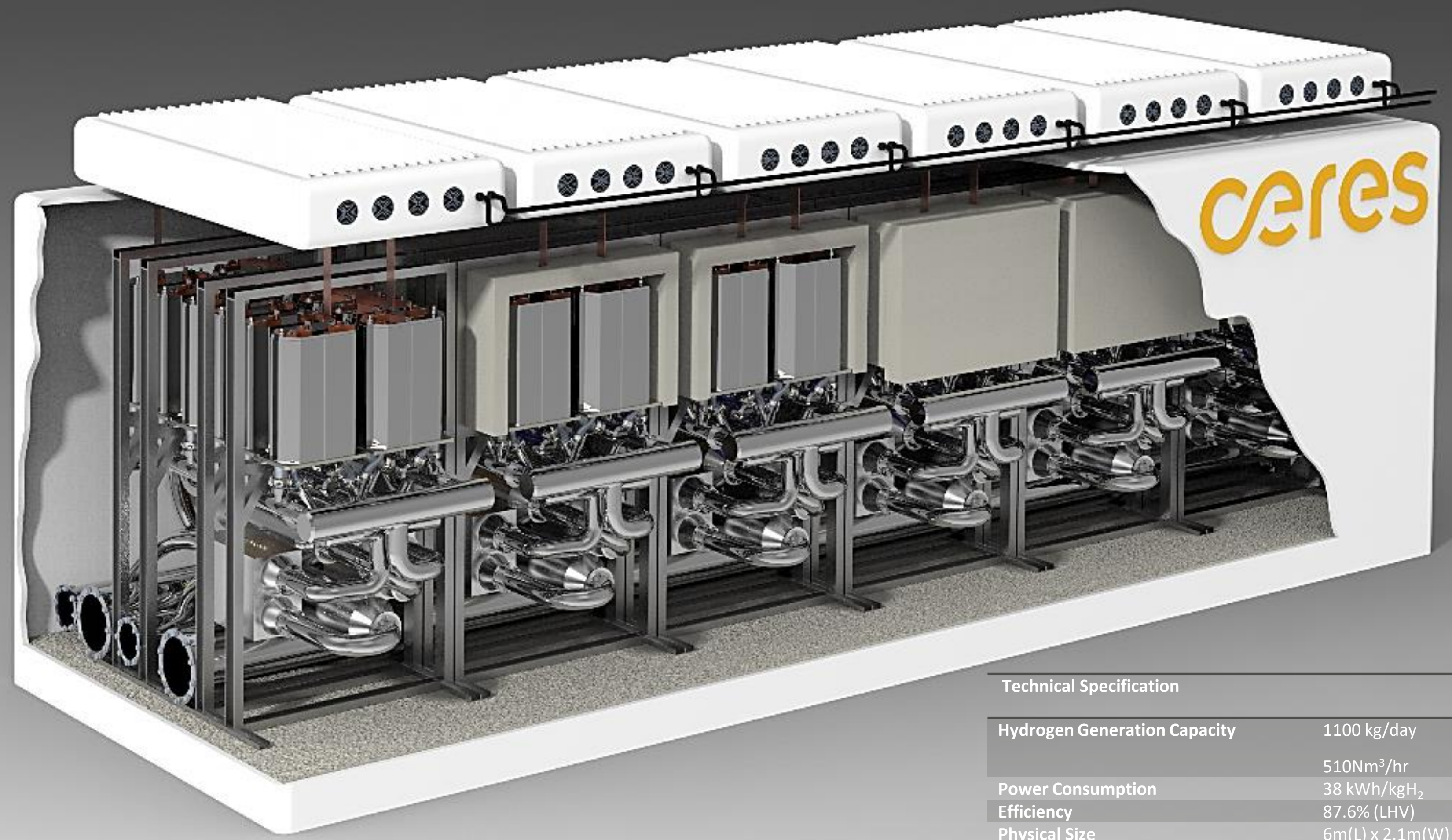
Specification	Target Value
Electrical Power Input	~100kW
Hydrogen Production	65kg / day
Module Efficiency	38kWh/kg
Steam input	150°C

ceres

1MW-class SOEC System Demonstrator due to start testing shortly



2MW-class / 20ft Shipping Container SOEC Module Concept



Technical Specification	
Hydrogen Generation Capacity	1100 kg/day 510Nm^3/hr
Power Consumption	38 kWh/kgH$_2$
Efficiency	87.6% (LHV)
Physical Size	6m(L) x 2.1m(W) x 2.2m(H)
Operating Pressure	1 barg

Applications

SOC Application Landscape

- Ceres SOC
  - SOFC
    - Marine
      - Auxiliary power — Container ships — Coastal vessels
    - Stationary
      - Small Modular Power station — Commercial building — Utility power
      - Data Centres — Large centralised datacentres — Containerised / local
      - Reversible Systems — Peaking — Long duration storage
  - SOEC
    - High Temp Low Carbon Electricity Generation
      - Reversible Systems
      - Renewables — Concentrated Solar
      - Nuclear — Retro-fit — MMR — SMR
    - High Temp Hydrogen Processes
      - Oil and Gas — Hydrocracking — De-sulphurisation
      - Ammonia — Green ammonia — Ammonia Nitrate
      - Green Steel — Direct reduction of Iron — Blast furnace coal replacement
      - E-Fuels — Methanol — SAF — SNG

Common Cell Technology

Stack Array for SOEC and SOFC

Module applicable to multiple applications

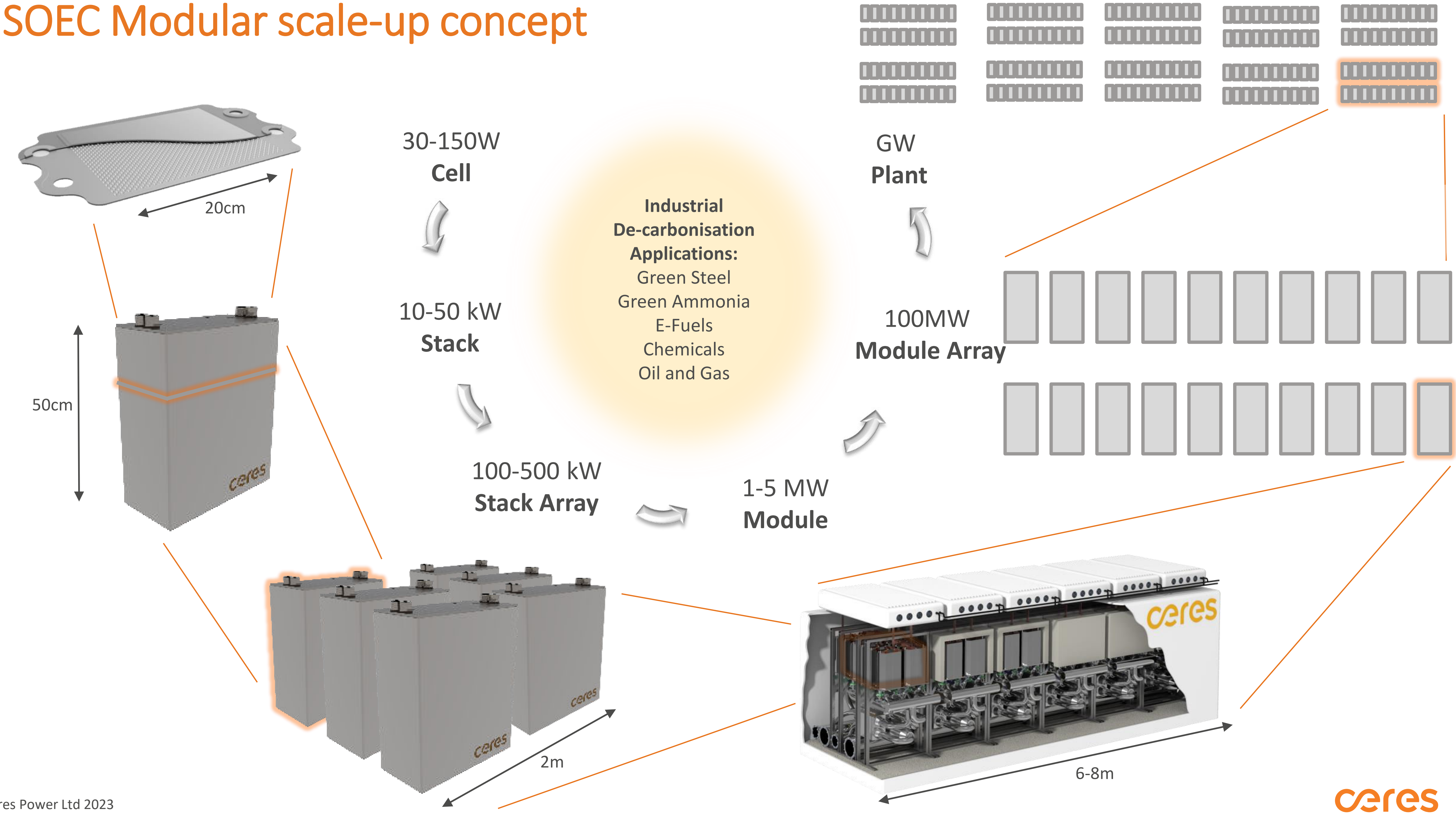
Sector focus: SOEC

Shell collaboration for green hydrogen in India

- Agreement to establish a 1MW technology pilot of Ceres' SOEC system at Shell's R&D centre in Bangalore, India
- Produce hydrogen at efficiencies around 20% greater than other technologies (80s to 90%) where it is possible to make use of waste heat in industrial processes to drive high efficiency
- Pilot start in 2023 and operate for >3 years – hydrogen will be used in industrial processes on site

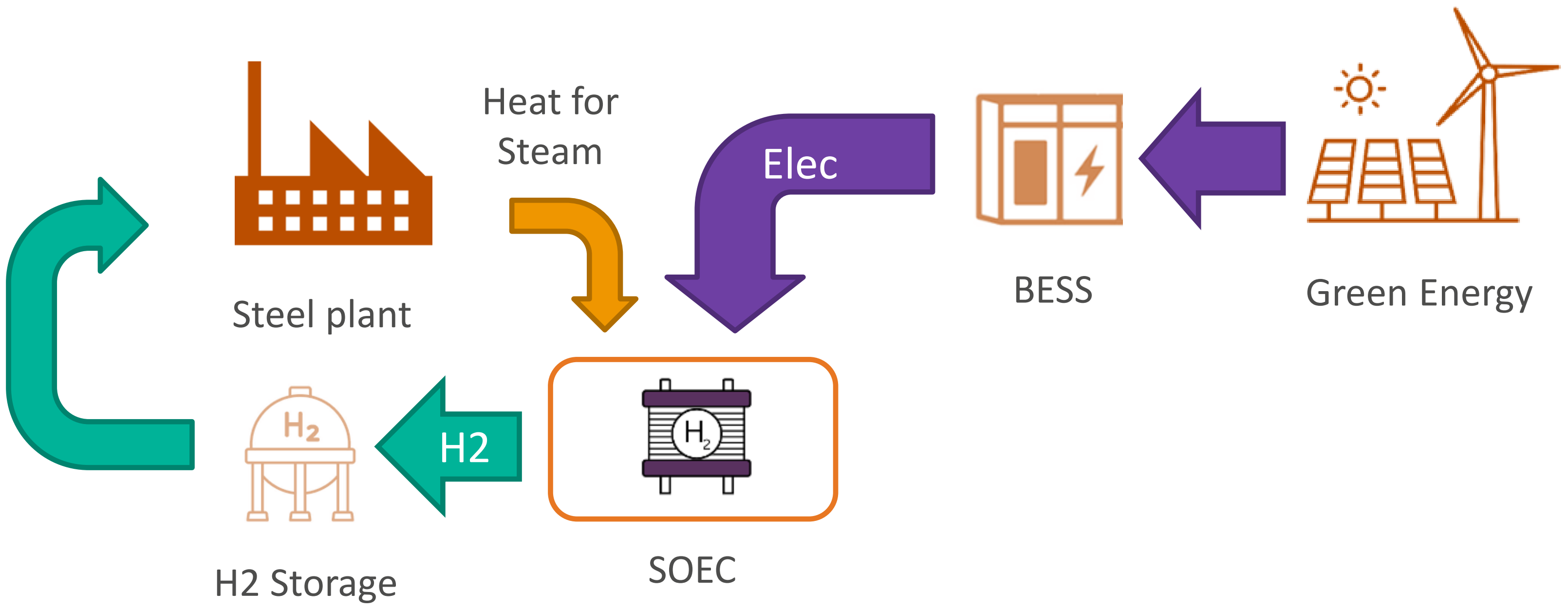
ceres

SOEC Modular scale-up concept



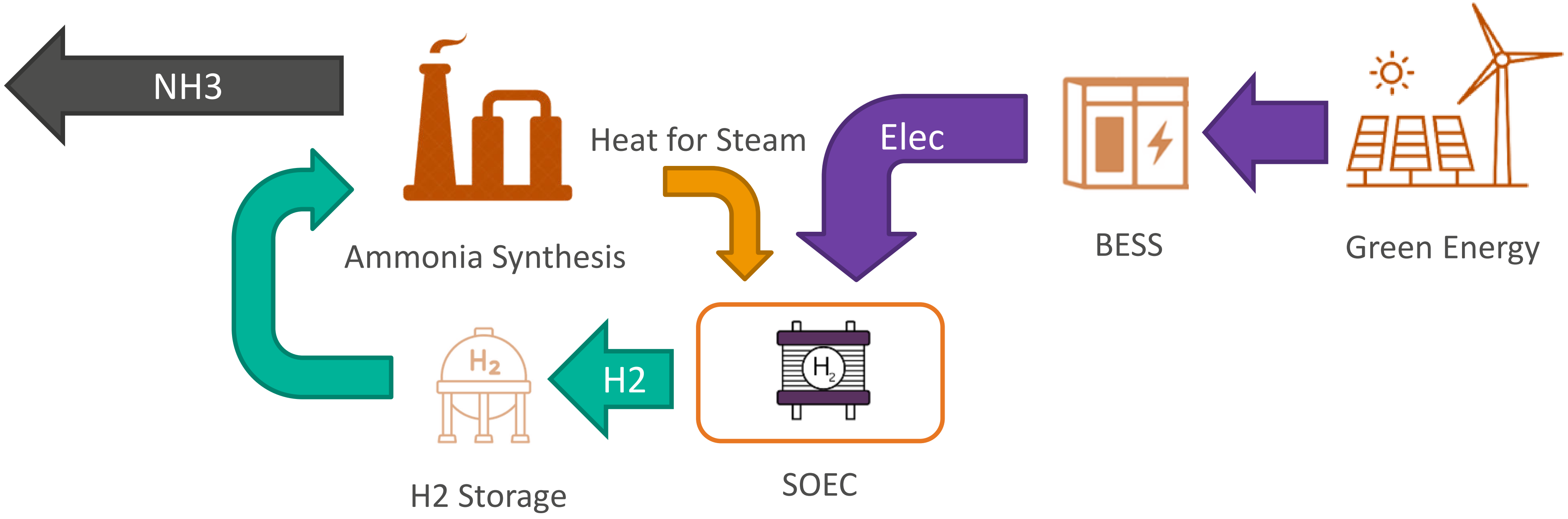
Green Hydrogen for Green Steel

- Heat from steel production can be used to generate steam for SOEC
- Green hydrogen can be used in DRI process or as fossil fuel replacement in blast furnace



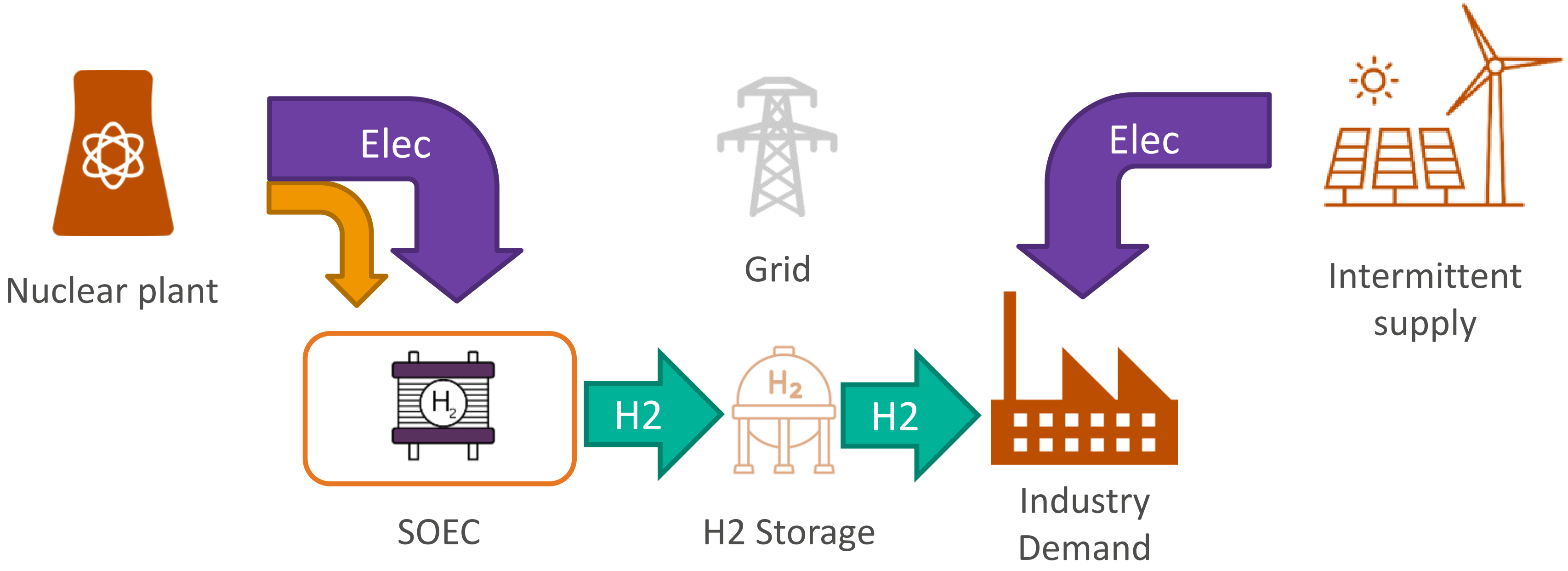
Green Hydrogen for Green Ammonia synthesis

- Heat from NH3 synthesis can be used to generate steam for SOEC



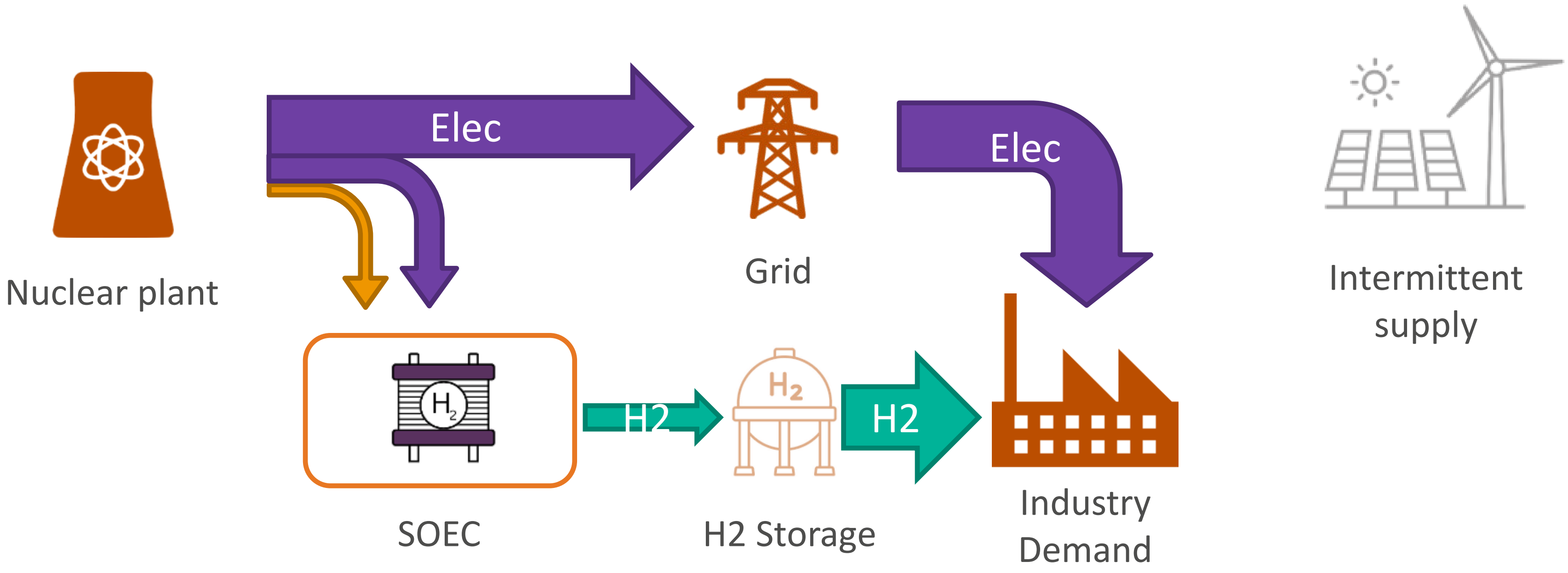
Nuclear + SOEC can provide both low carbon hydrogen and flexible electrical power to industry

- A 1GW thermal Nuclear plant could deliver approx. 350MW of electricity to the grid
- OR it could produce 70-80kT/yr of hydrogen with SOEC making use of steam
- AND it could flexibly provide power to the grid by varying SOEC heat and power input



Nuclear + SOEC can provide both low carbon hydrogen and flexible electrical power to industry

- A 1GW thermal Nuclear plant could deliver approx. 350MW of electricity to the grid
- OR it could produce 70-80kT/yr of hydrogen with SOEC making use of steam
- AND it could flexibly provide power to the grid by varying SOEC heat and power input



THANK YOU

Jon Harman

Technology Delivery Director

+44 (0)1403 273463
info@cerespower.com
Ceres Power, Viking House, Foundry Lane
Horsham, RH13 5PX UK