SUPERGEN

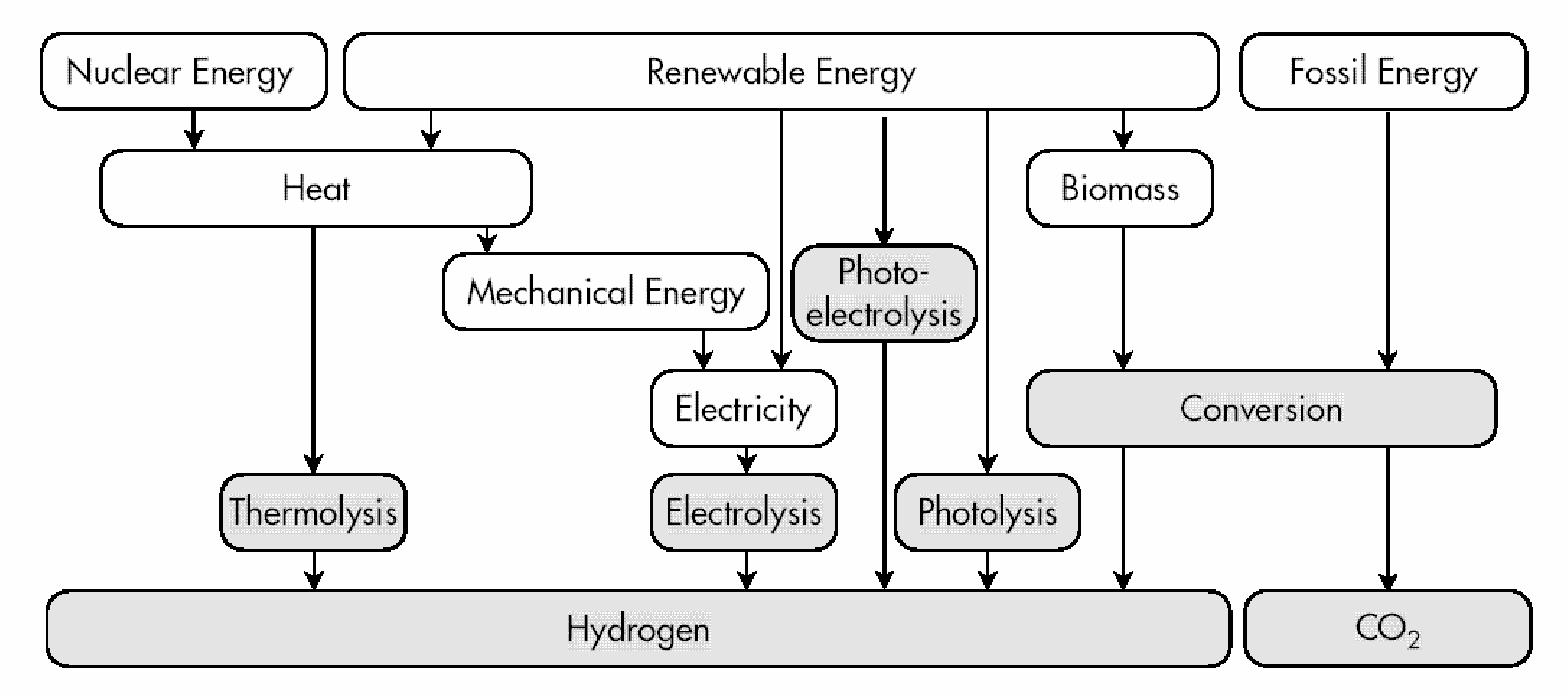
HDelivery

Delivery of Sustainable Hydrogen

John Irvine

UK EPSRC Supergen Consortium XIV
1st October 2008 - 2012

Hydrogen Production



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Mission

- The hydrogen economy needs large volumes of hydrogen produced with much lower carbon footprint.
- We address a significant gap in the EPSRC portfolio, as production of sustainable hydrogen is largely absent.
- We seek to convert electrons, hydrocarbons and biomass-derived fuel sources into hydrogen or indirect hydrogen carriers.
- We focus on lower cost and improved efficiency catalytic and electrocatalytic processes and their socio-technical impacts.
- Complementarity of the different processes based on what might be termed multi-chemistry approaches.

Delivery of Sustainable Hydrogen

13 Universities £5M 71 man-years
6 PhD Students and 500 researcher months

University of St Andrews. John TS Irvine
Newcastle University. Ian S Metcalfe
University of Manchester, JC Whitehead
Cambridge University, Bartek Glowacki,
Strathclyde University, David Infield .
Andrew Cruden
University of Birmingham, David Boo k
University of Warwick, Martin Wills

Imperial College,. Kang Li
Marcello Contestabile.
Heriot-Watt University, Shanwen Tao
Cardiff University, Neil B. McKeown
Oxford Chemistry, Edman Tsang
Brunel University, Malcolm Eames
Leeds University , Valerie Dupont

Industrial Involvement

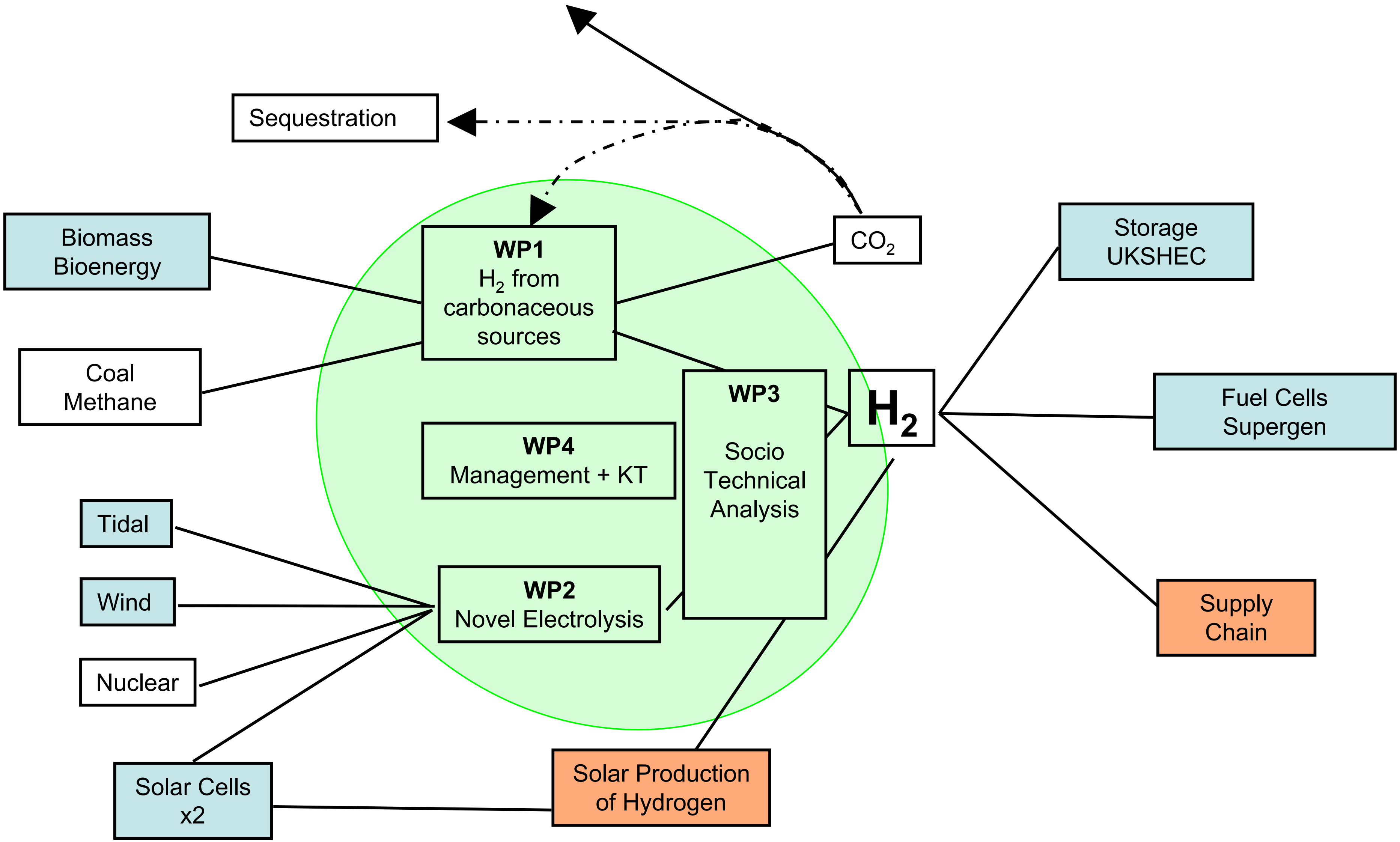
Carbon-> Hydrogen
Johnson Matthey, GKSS DSTL

Electrons -> Hydrogen
Ravensrodd, Valeswood, Bryte Energy

Demonstration
PURE The Hydrogen Office

KT
Scottish Enterprise, SHFCA, UKHA,
The Centre for Process Innovation, IChemE

Positioning



Project Structure

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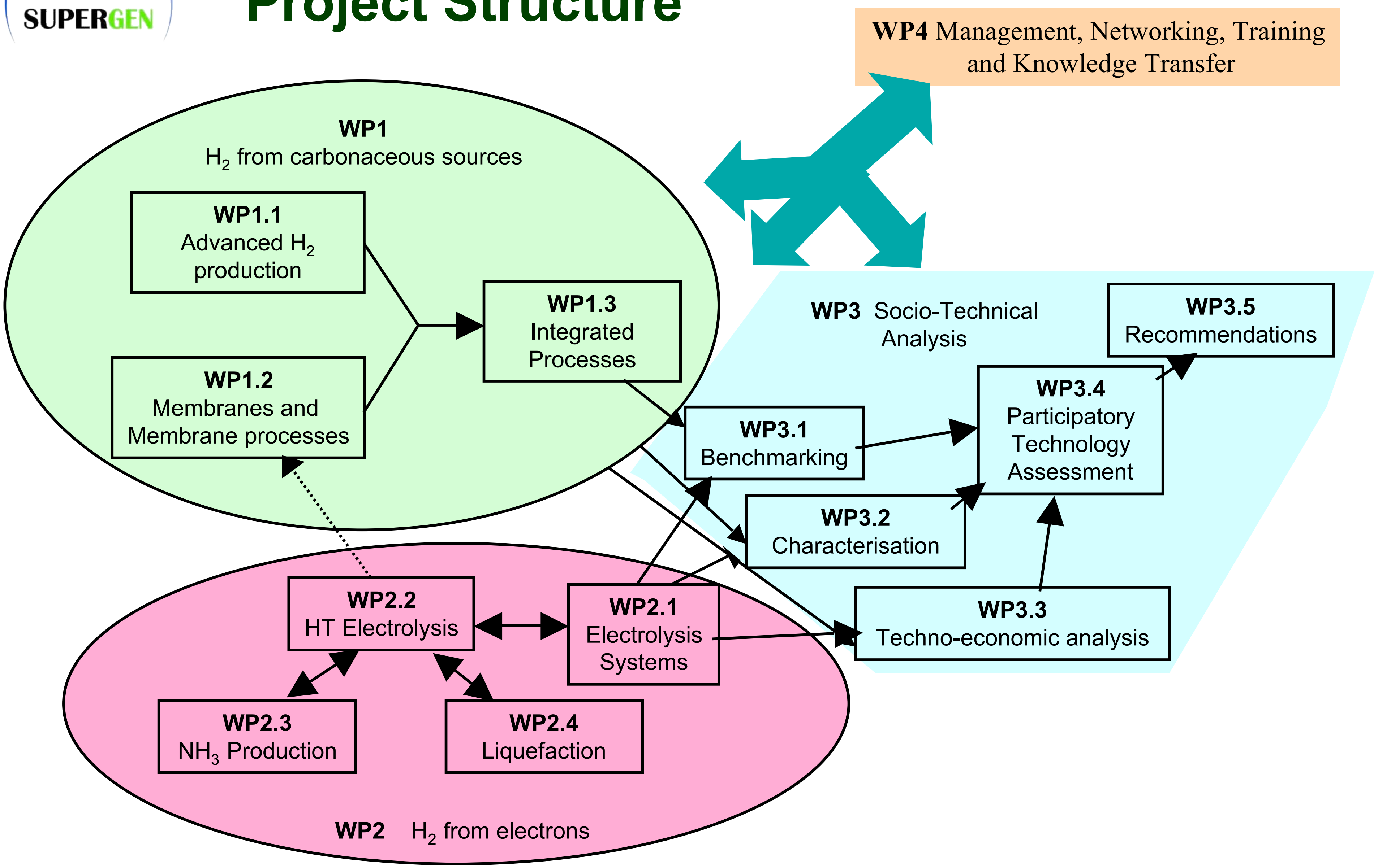

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WP1

H_2 from carbonaceous sources

Ian Metcalfe

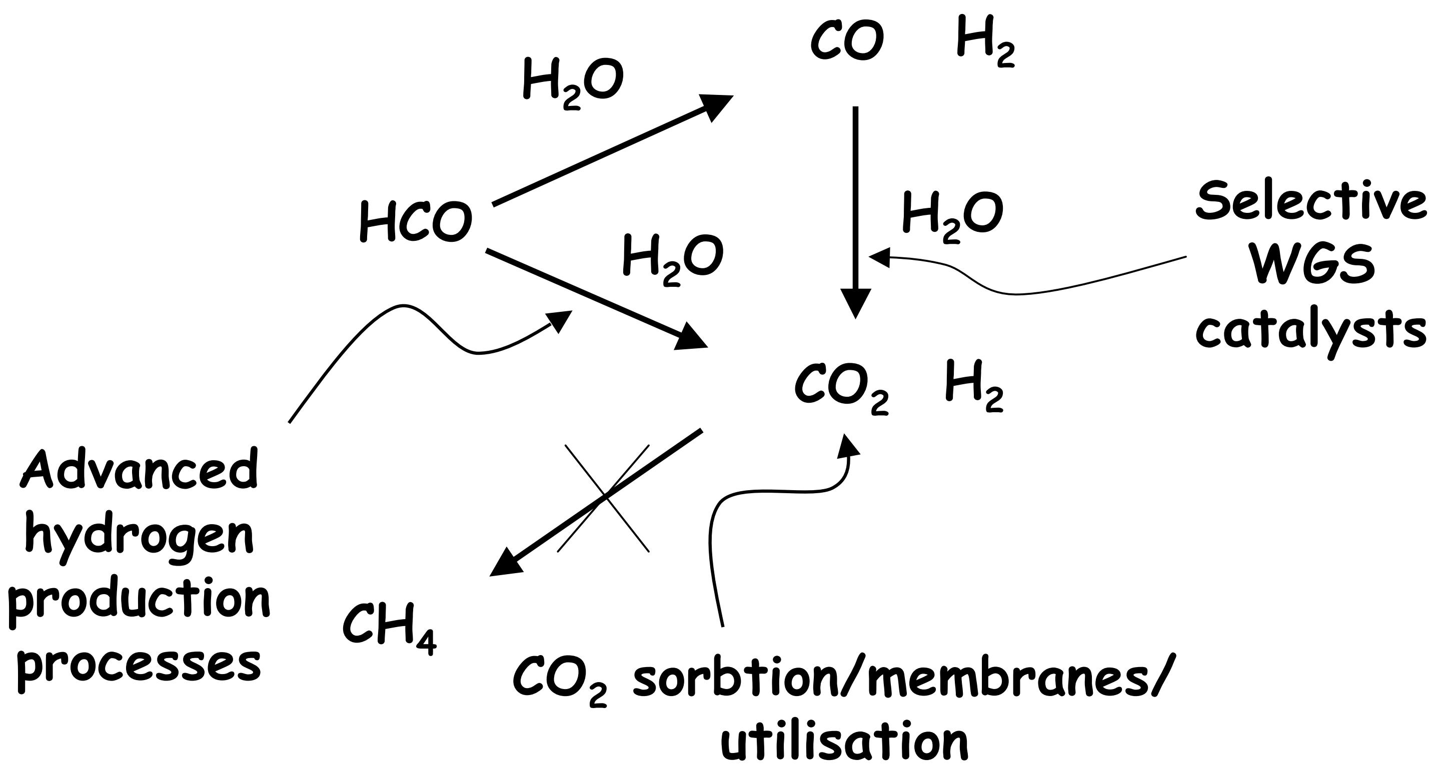
Hydrogen SUPERGEN: WP1

Combined reaction and separation using:

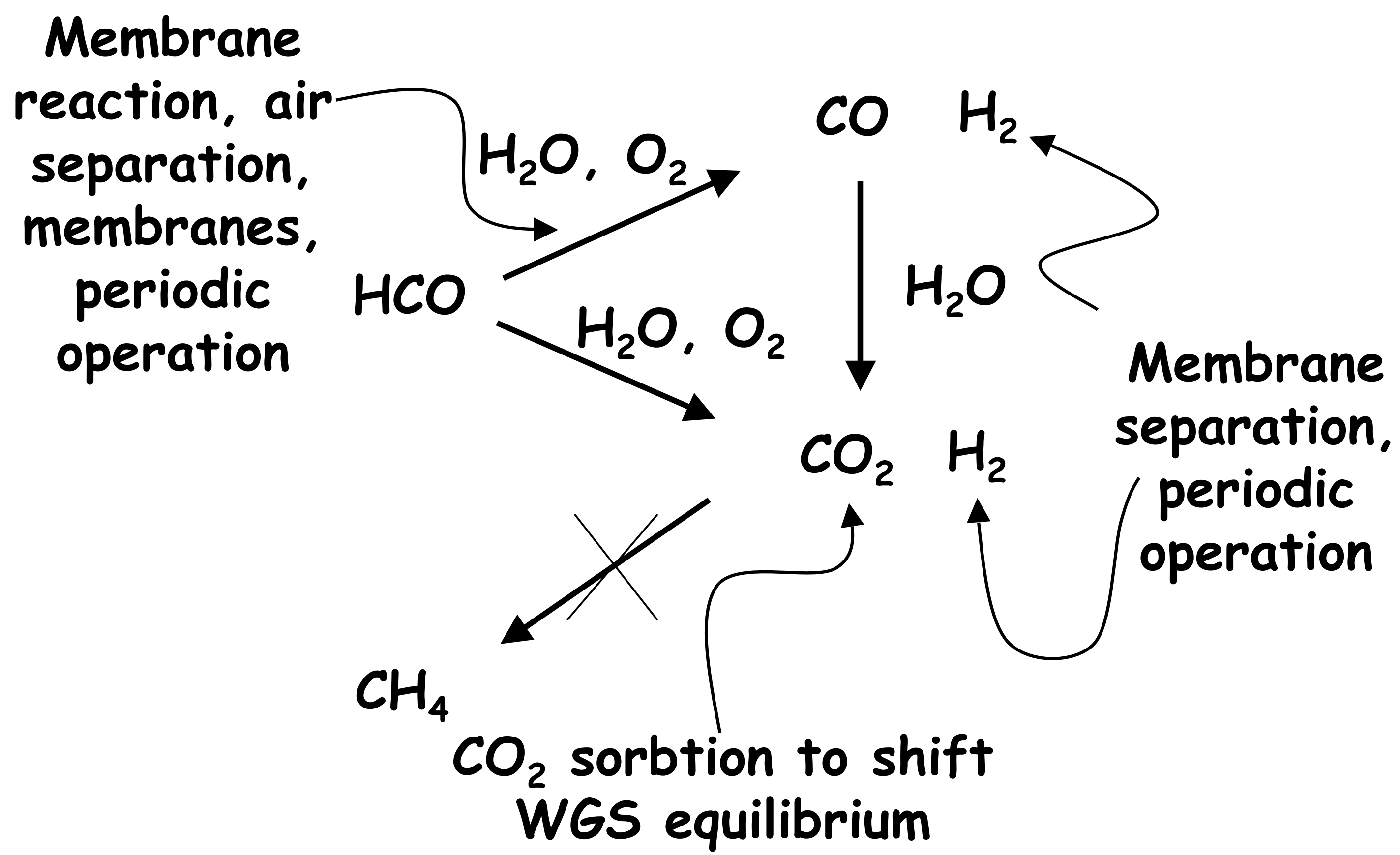
- ➢Membranes
- ➢Periodic reactor operation

The chemistry and materials are the same/similar

Reaction pathways – low temperature



Reaction pathways – high temperature



Advanced hydrogen production processes

- 1.1 Advanced hydrogen production processes (Leeds, Manchester, Warwick, Oxford, Newcastle)
- Hydrocarbon and oxygenated hydrocarbon reforming through
  - Nanostructured catalysts (low temp selective WGS)
  - Organometallic catalysts (Selective H_2 + CO_2)
  - Plasma catalysis (Poor selectivity – need WGS cat)

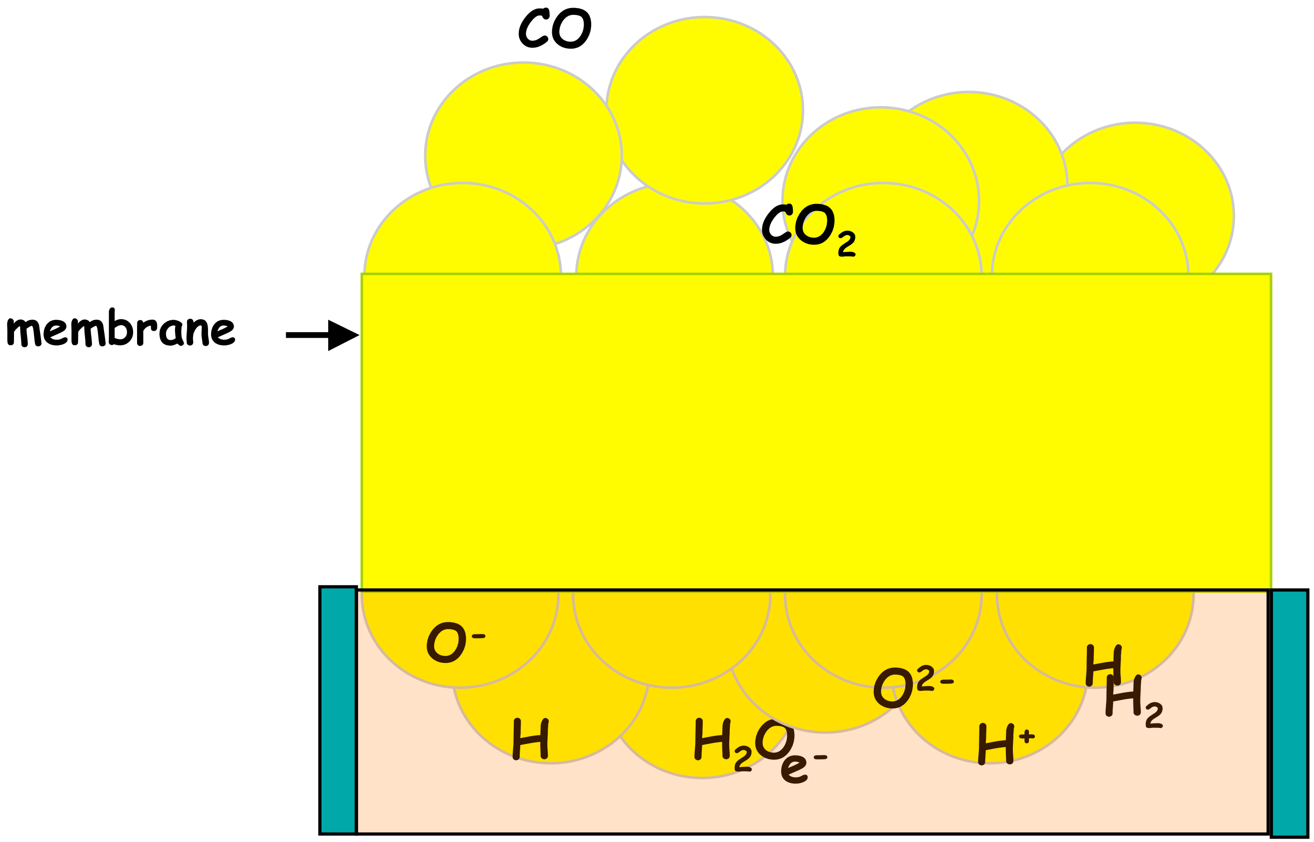
Membranes and membrane processes

- 1.2 Membranes and membrane processes (Newcastle, Imperial, Cardiff, Birmingham with St Andrews, Heriot Watt)
  - Organic membranes (polymers of intrinsic microporosity for CO_2 separation from H_2)
  - Metallic membranes (new Pd alloy membranes)
  - Ceramic membranes (mixed conducting – oxygen ion and electron and proton and electron – membranes)

Integrated processes

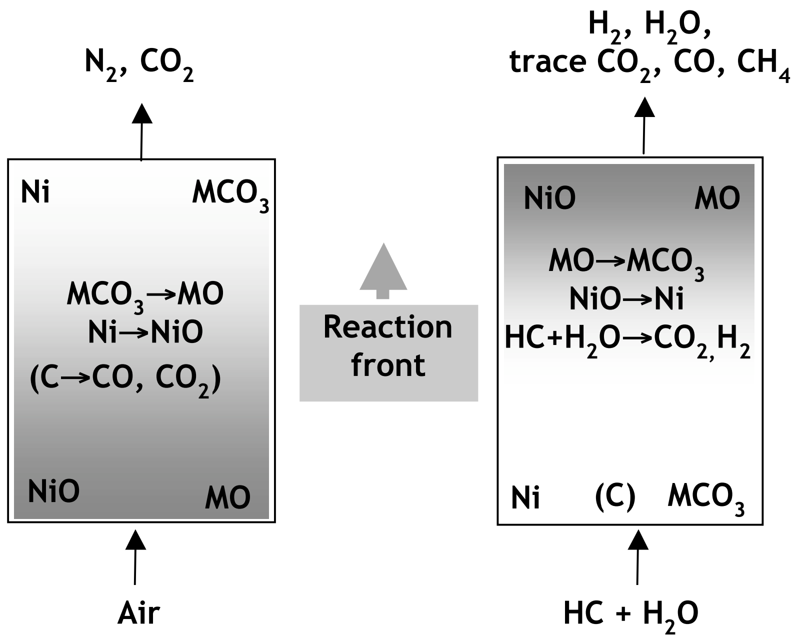
- 1.3 Integrated processes (Newcastle, Imperial, Cardiff, Birmingham, Leeds, Manchester, Warwick, Oxford)
  - Membrane and membrane combination
  - Integration of plasma-activated processes with ion-conducting membranes
  - Periodic reactor operation
  - Carbon dioxide utilisation

Hydrogen production from water vapour with plasma



Chemical looping with in-situ CO_2 sorption

Mechanism illustration for fixed bed reactor



New materials, e.g., perovskite OTMs

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WP2

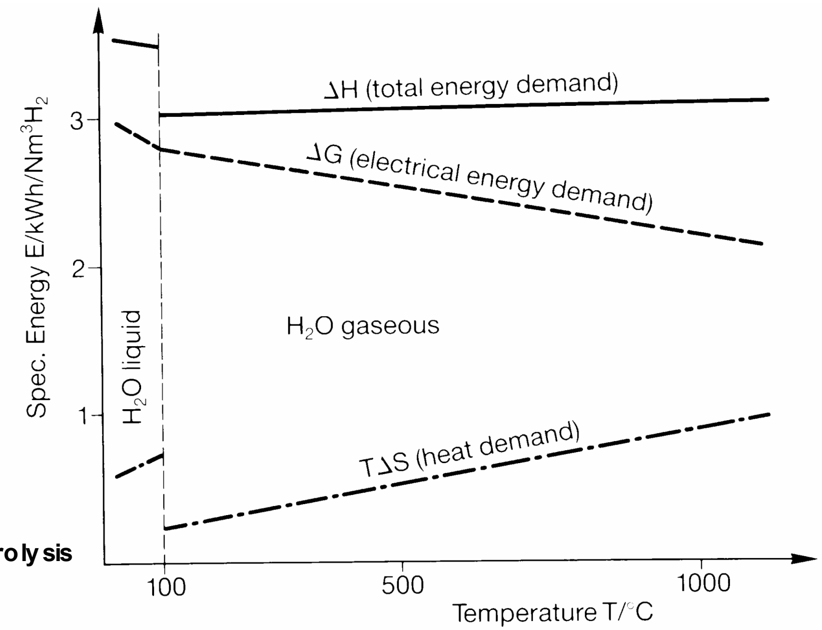
H_2 from electrons

John Irvine

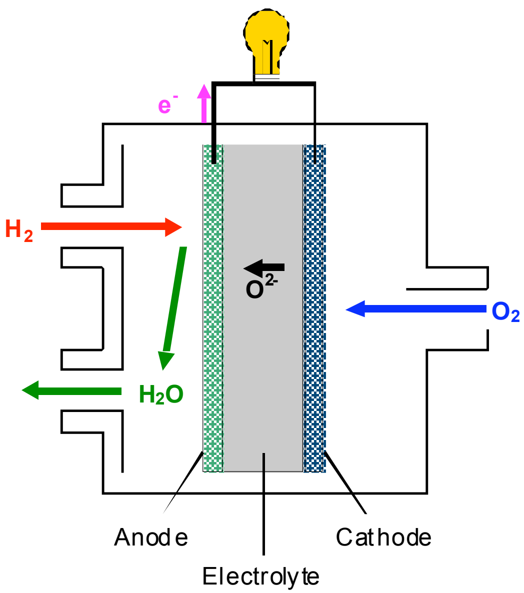
2.1 Optimisation and Development of Electrolyser Systems

- Alkaline electrolysers
- Optimise for cost and variable output operation
- Modelling and laboratory testing of highly distributed H_2 generation system

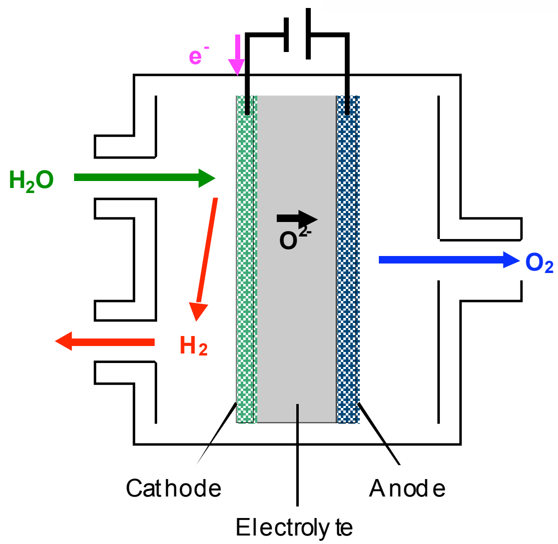
2.2 High Temperature Electrolysis



Solid oxide fuel cell



Solid oxide electrolysis



2.3 Ammonia Production

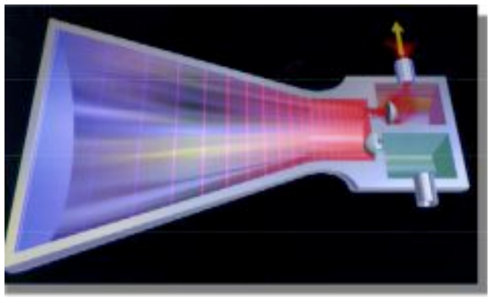
Measure	Production Method		
	Natural Gas	Electrolyzer + H-B	SSAS
Energy required per ton of NH_3	33 MBtu = 9700 kWh	~12,000 kWh (H2 production only)	7000-8000 kWh
Capital cost per ton/day NH_3 capacity	~$500,000	~$750,000 (Cost dominated by electrolyzer)	<$200,000
"Fuel" cost to produce 1 ton of NH_3 at large scale [1]	Depends on location and NG cost	$420 (3.5 ¢/kWh) $240 (2 ¢/kWh)	$245 (3.5 ¢/kWh) $140 (2 ¢/kWh)
Cost of 1 ton NH_3 at moderate to large scale [2]	Depends on location and NG cost	>$600 (3.5 ¢/kWh) >$400 (2 ¢/kWh)	~$315 (3.5 ¢/kWh) ~$210 (2 ¢/kWh)
Tons of CO_2 emitted per ton of NH_3 produced	1.8	-0-	-0-

LANL

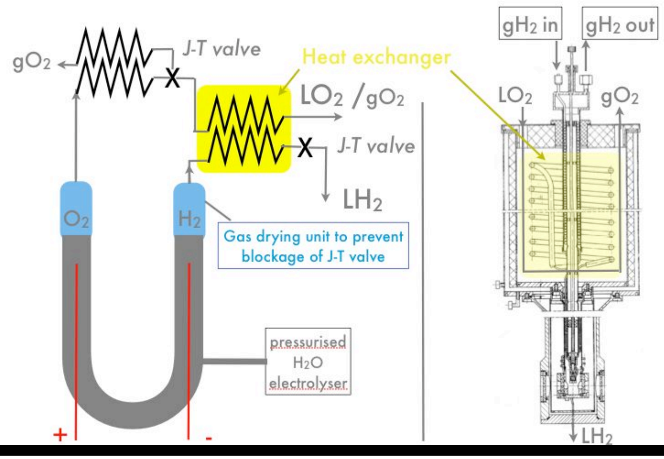
2.4 compression and liquefaction of H_2

The energy requirement for hydrogen liquefaction is high: typically 30% of the calorific value of hydrogen; new approaches that can lower these energy requirements and thus the cost of liquefaction are needed. Here, we seek to develop new concepts that exploit the characteristics of high pressure electrolysis to address this:

a) oxygen-hydrogen thermo-acoustic compressor



b) Liquefaction of the hydrogen using products of high pressure electrolysis (O_2 and H_2)



Delivery of Sustainable Hydrogen

WP3

Socio-Technical Analysis & Appraisal of Hydrogen Production

Malcolm Eames

Hydrogen SUPERGEN: WP3

- **WP3 Socio-Technical Analysis & Appraisal of Hydrogen Production (Brunel, ICEPT, St Andrews & Newcastle)**
  - Interdisciplinary WP integrating engineering & socio-economic knowledge and expertise
  - Will illuminate both the technological & economic potential and environmental & social impacts of the prospective technologies being developed by the consortia
  - Quantitative and qualitative analysis: infrastucture and demand modelling, multi-criteria, participatory and deliberative methods
  - Distinctive and complementary to existing UKSHEC & UKERC research portfolio

Hydrogen SUPERGEN: WP3

WP3 Sub Tasks

- **3.1 Benchmarking (St Andrews & Newcastle, ICEPT & Brunel)**
- **3.2 Characterisation of prospective technologies (Brunel & ICEPT)**
- **3.3 Techno-economic analysis (ICEPT)**
- **3.4 Participatory technology assessment of novel H2 production technologies (Brunel)**
- **3.5 Recommendations for policy and industry (Brunel & ICEPT)**

Hydrogen SUPERGEN: WP 4.2

4.2 Innovation systems and socio-technological transitions (Brunel)

- **International comparative analysis of hydrogen innovation systems (UK, Germany, Japan, Korea, US & Canada)**
- **Technology Specific Innovation Systems (TSIS) functional approach (entrepreneurial activities, knowledge development, networks, guidance of search, market formation, etc) will provide:**
  - **Insights for policy regarding promotion of low Carbon economy**
  - **Empirically and theoretically grounded evidence-base to underpin innovation, KT and rapid commercialisation of hydrogen technologies**

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WP4

Management, Networking, Training and Knowledge Transfer

John Irvine,

Knowledge Transfer

- Advisory Group/Panel
- Open Meetings
- Dissemination
- Project Manager
- Specialist Consultancy Support

Outreach

Outreach

- International linkages
  - China, South Africa, Denmark, Canada, …
- Training schools
- Open meetings/workshops
- Advisory Group
- Project Manager

Summary

- Clear technical focus – Intensified Hydrogen Production Processes
- Genuine interdisciplinary research focus
- Socio-economics research facilitating emergence and development of prospective technologies
- Changing the economics of distributed Hydrogen Production