Towards clean energy supply: Hydrogen powered fuel cells

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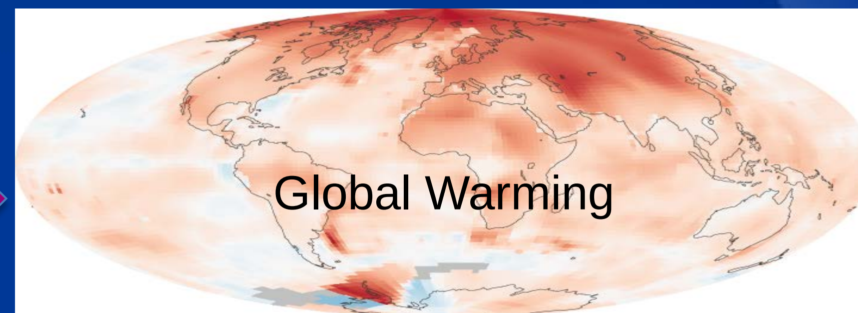
Global challenges in energy

- Security of supply

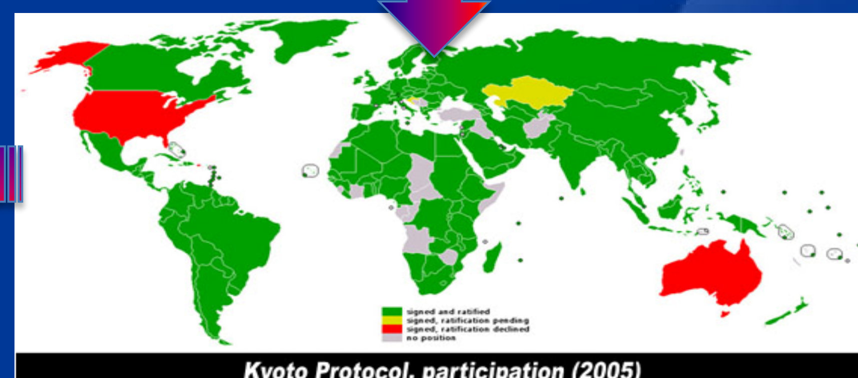
➢ Data shows the end of the 'vast oil era' in the period of 2030–2040 (Mierlo et al., 2006)

➢ Increase in the cost of energy

- Environmental degradation

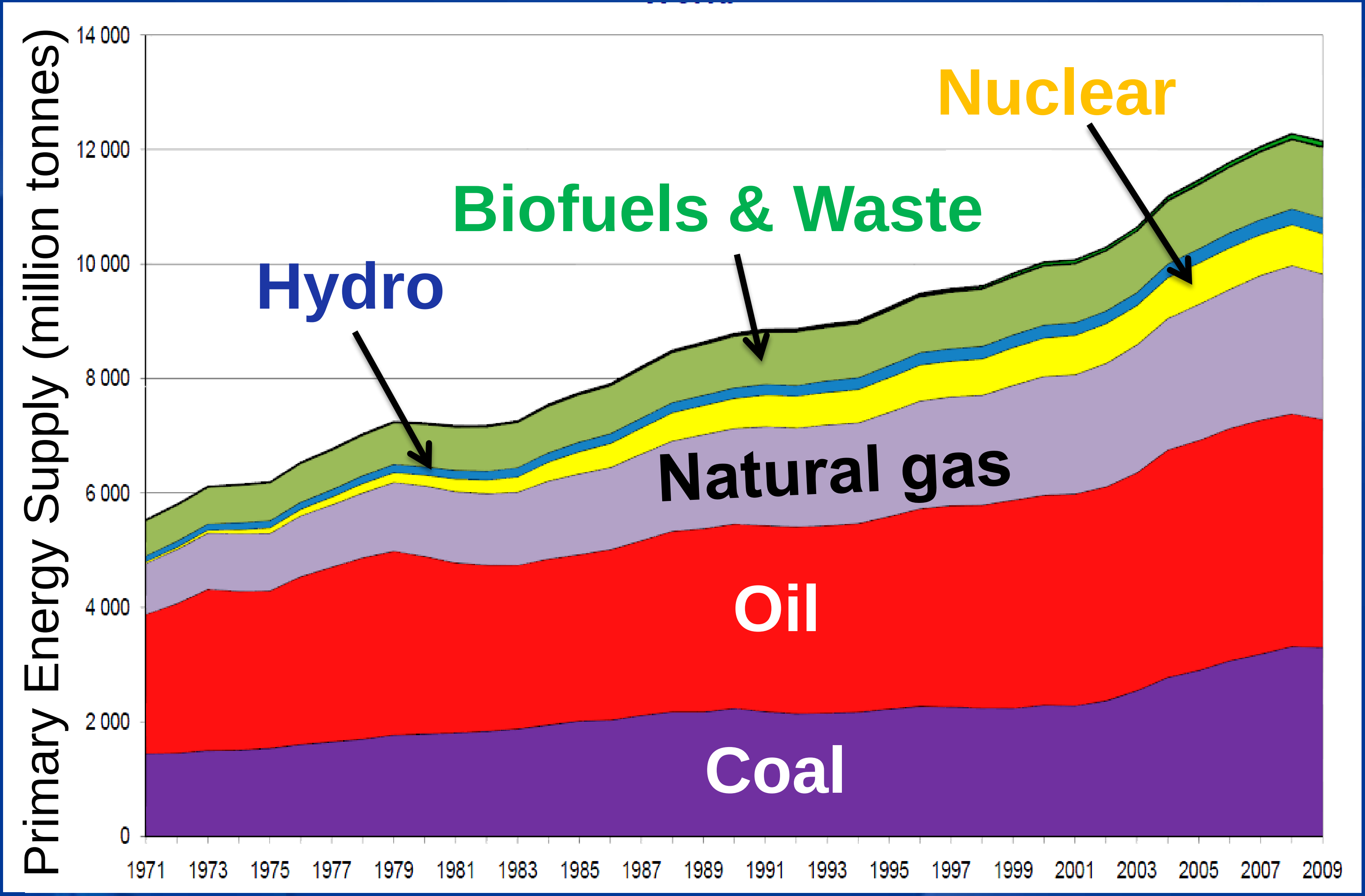


Carbon Emissions Charges
£ 55 tonne CO_2 emitted



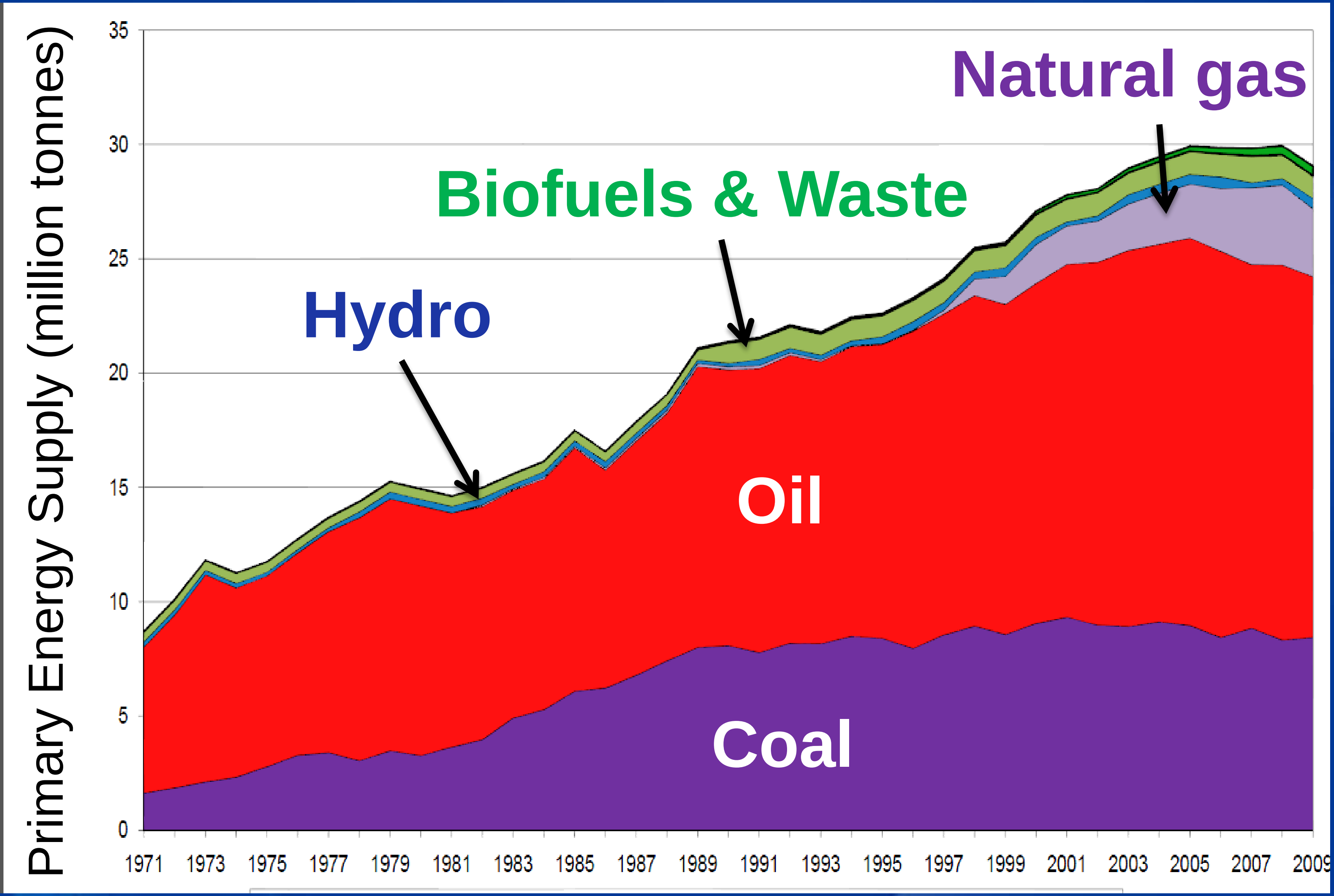
Green: countries committed to carbon reduction targets

Fossil Fuel dependency: World



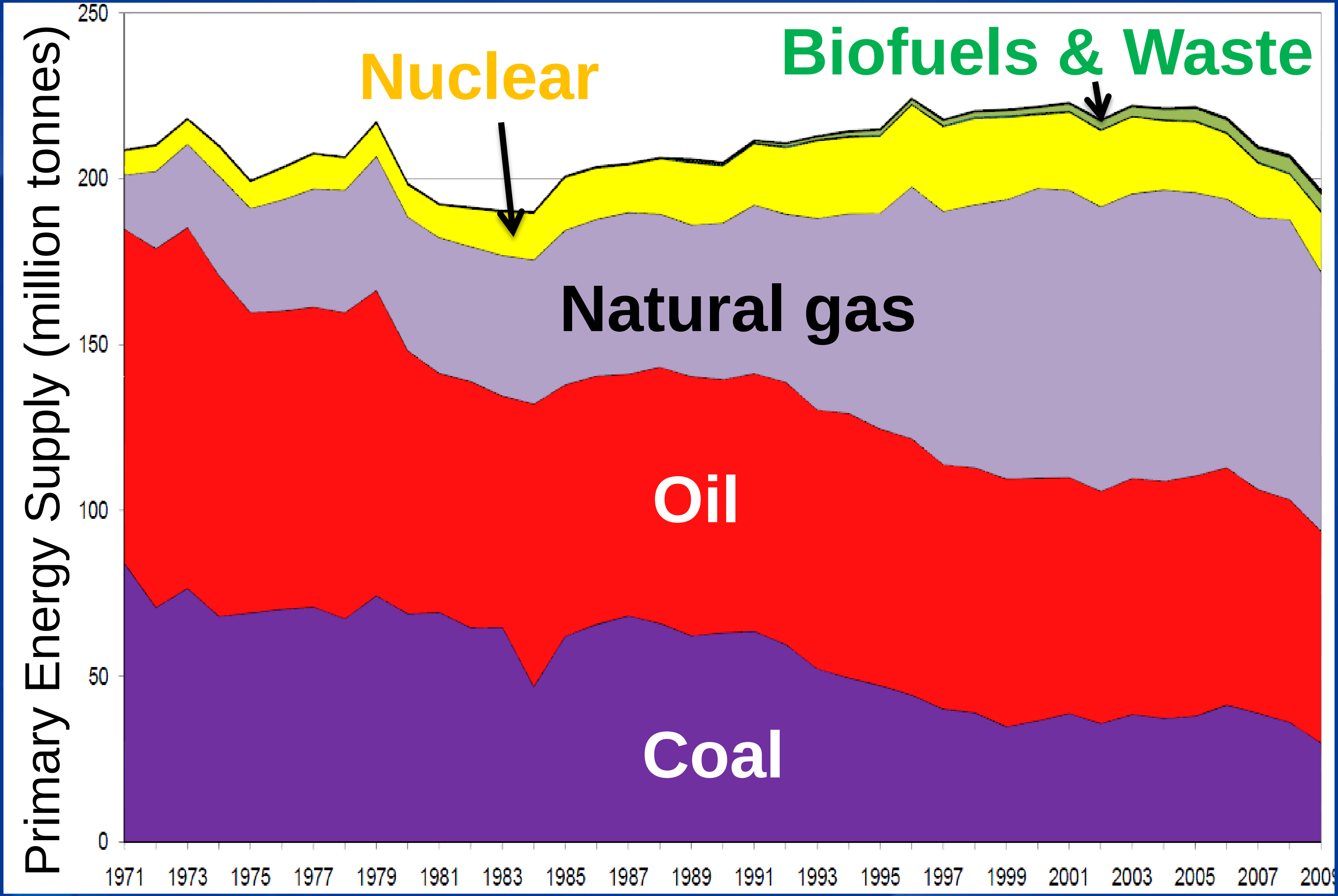
International Energy Agency: http://www.iea.org/stats/index.asp

Fossil Fuel dependency: Greece



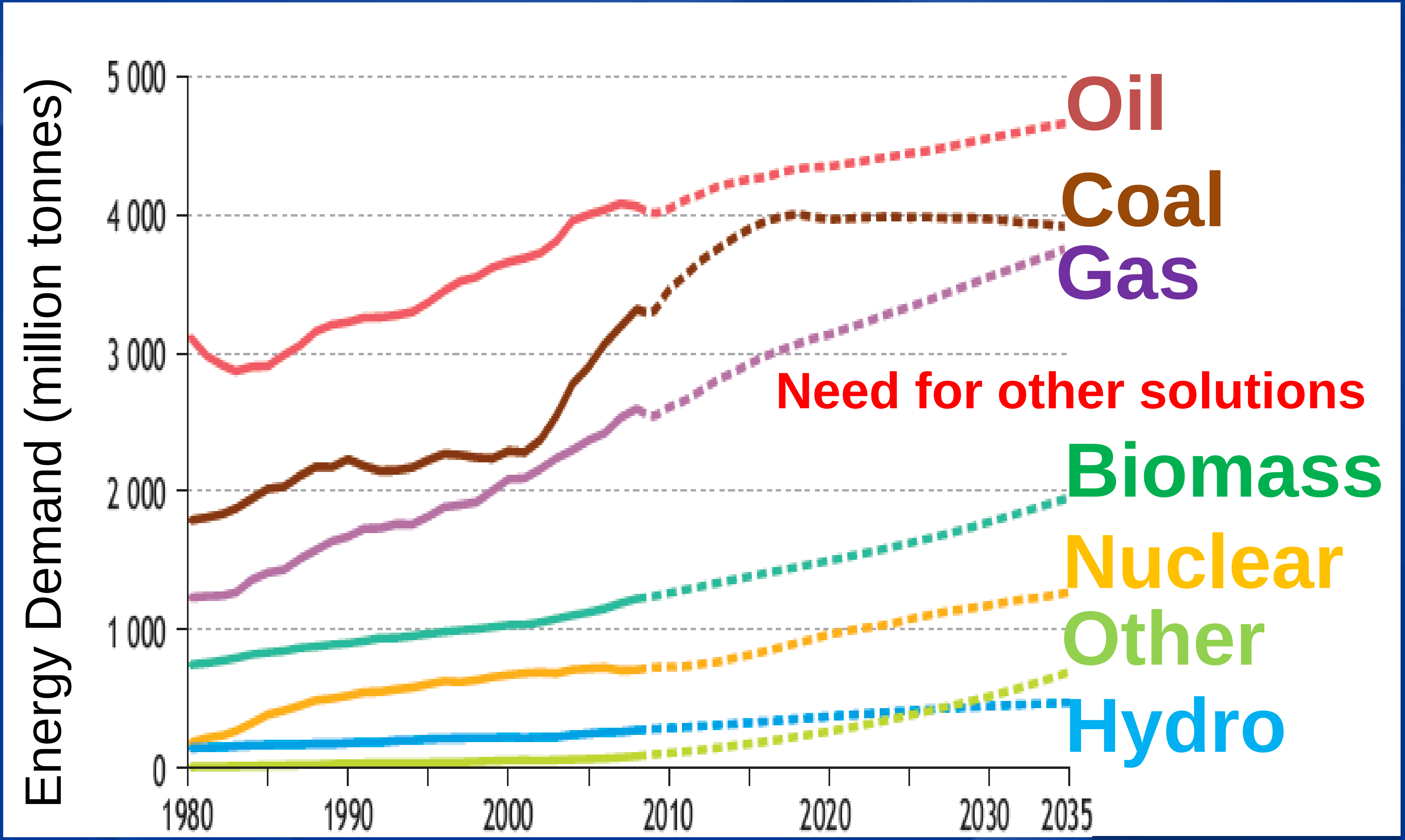
International Energy Agency: http://www.iea.org/stats/index.asp

Fossil Fuel dependency: UK



International Energy Agency: http://www.iea.org/stats/index.asp

World Energy demand by fuel with projected integration of renewables



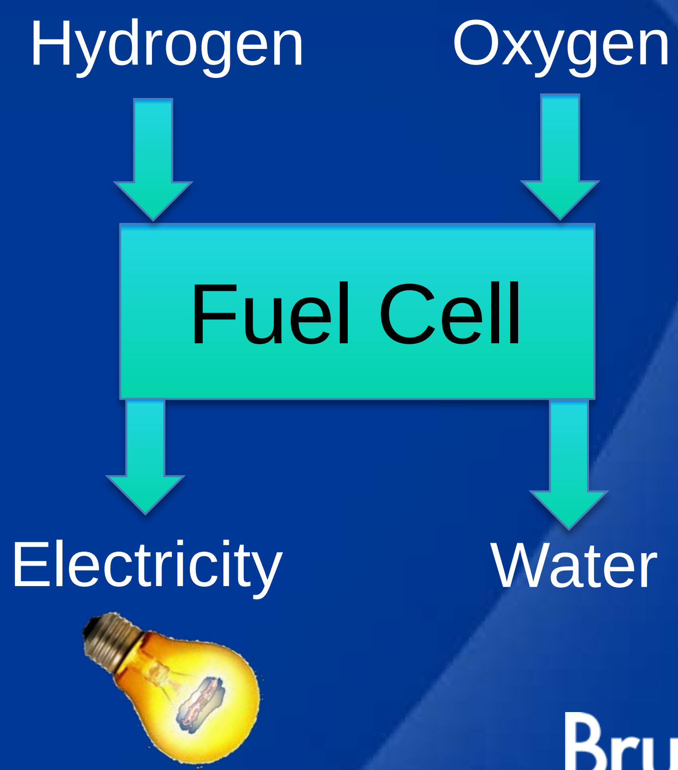
International Energy Agency: World Energy Outlook 2010,

Hydrogen powered fuel cells

'a key technology for future sustainable energy systems'

(Department of Energy UK)

- No emissions
  - Emit only water
- High efficiency
- Energy at all scales
  - Micro- to multi-MW
- Energy for all sectors
  - Vehicular transportation
  - Stationary power generation and CHP
  - Portable items



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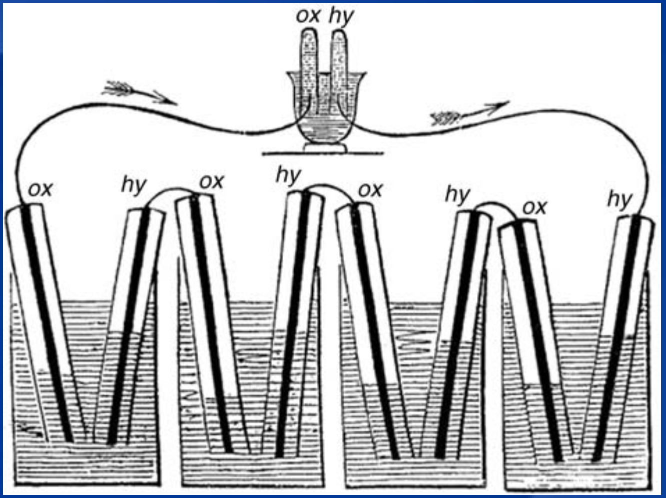
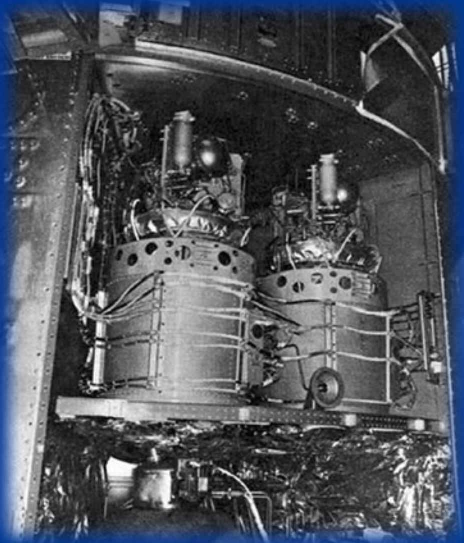
Fuel Cell History

- Sir William Robert Grove 1843
  - ✓ ''Father of the Fuel Cell''
  - ✓ First Fuel Cell Diagram 'Grove Gas Battery'



- Francis Thomas Bacon 1959
  - ✓ Developed 5 kW fuel cell
  - ✓ Called it the 'Bacon Cell'

- 1969 NASA used alkaline fuel cell for the auxiliary power in a space shuttle



The alkaline "Bacon Cells" used in the Apollo missions

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Fuel Cell History

- The key culprits of Fuel Cell commercialization in 1970s
  - ✓ High catalyst cost
  - ✓ Limited material availability
  - ✓ Low power density = large fuel cell size

1969: Bacon with the 1.5 kW alkaline fuel cell used in NASA's Space shuttles

Today: 1.5 kW Ballard fuel cell, FCgen-1020ACS . Commercialised for stationary and mobile applications

The renaissance of fuel cells

- 1970s renewed interest in fuel cell
  - ✓ Wider concerns over vehicle emissions
  - ✓ Oil shocks
- 1993 Ballard power systems exhibited fuel cell bus
  - ✓ Higher power densities achieved with fuel cell technology
  - ✓ Prompted the renaissance of major interest in fuel cells

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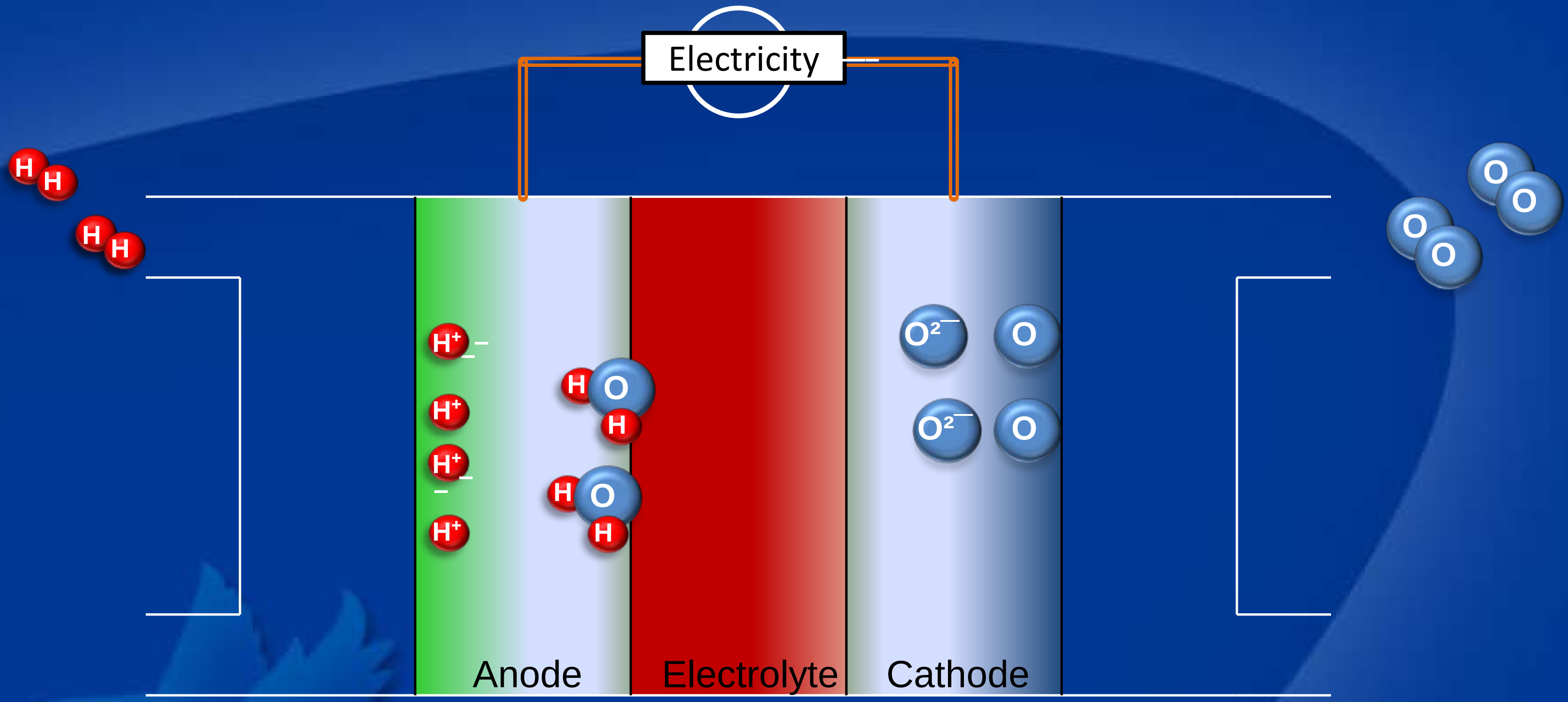
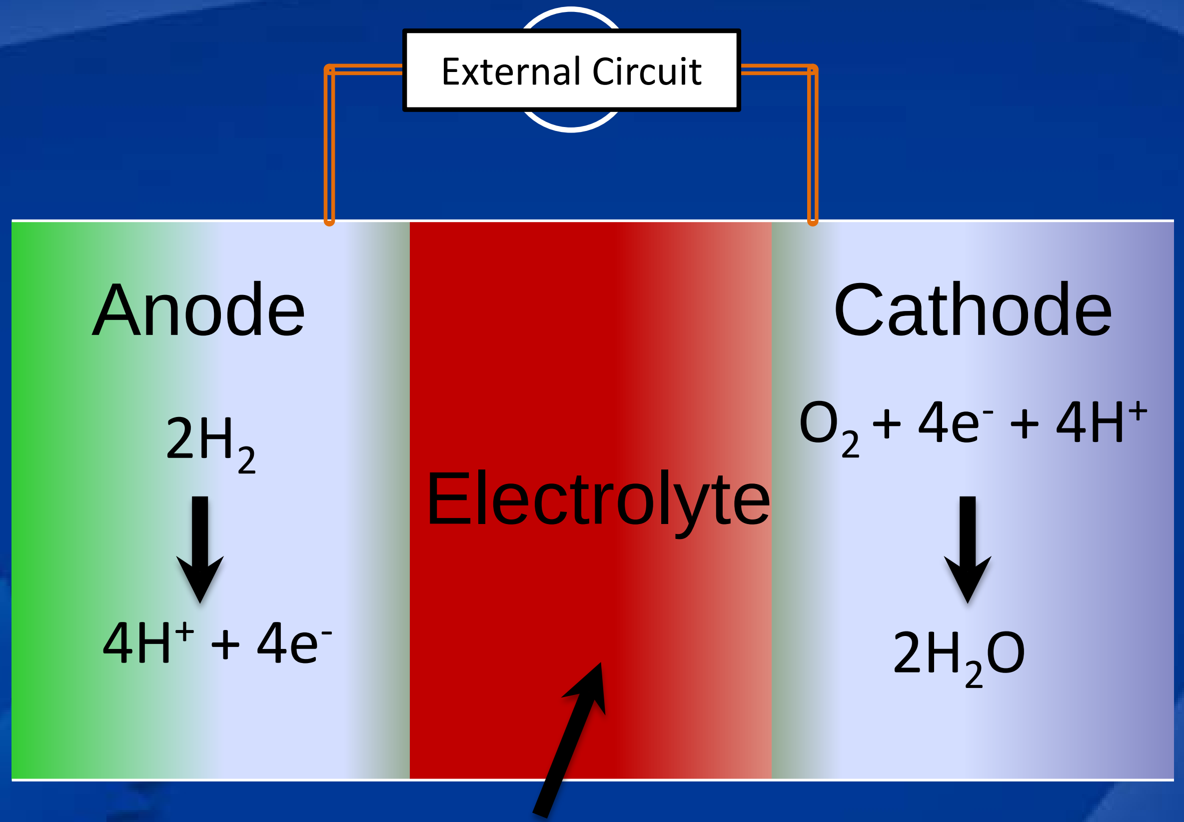
An example: Solid Oxide Fuel Cell Process



Basic Principles

Electrons travel through an external circuit to deliver electric power

Hydrogen oxidised into protons and electrons



Oxygen reduced to oxide species and reacts to form water

Protons or oxide ions transported through an ion-conductor electron insulating electrolyte

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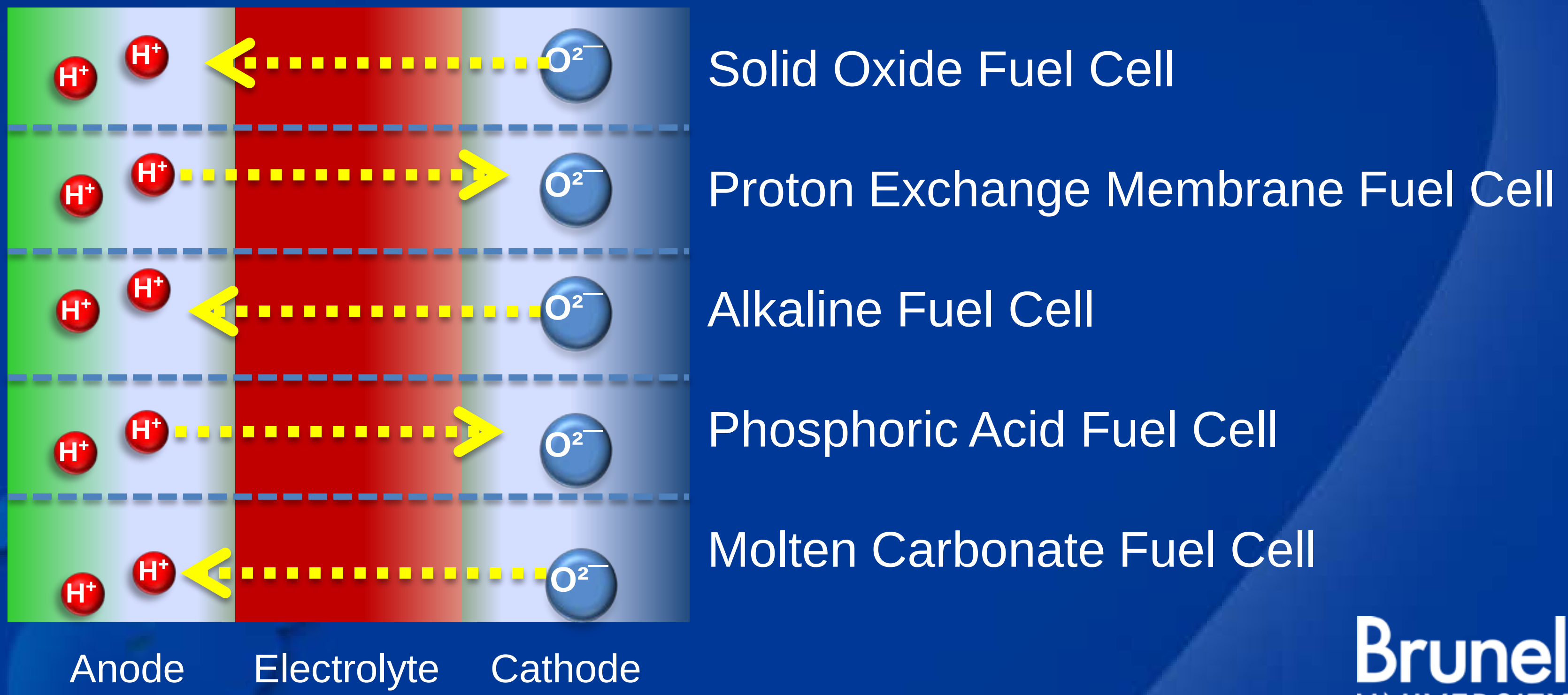
Types of fuel cells

- Fuel cell designs mainly differ in the chemical characteristics of the electrolyte
  - ✓ Protons or oxide ions are transported through the electrolyte



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Solid Oxide Fuel Cell

- Advantages
  - ✓ High efficiency
  - ✓ Fuel flexibility
  - ✓ Can use variety of catalysts
  - ✓ Suitable for CHP

Bloom Energy SOFC modules

- Disadvantages
  - ✓ Long start-up time
  - ✓ High temperature corrosion and breakdown of cell components

- Operating Temperatures: 1000 ^{o}C
- Electrical efficiency: 42 – 72 %
- Power Range: 0.5 – 2000 kW
- Applications: stationary

BlueGen (CFCL)
1.5kW m-CHP

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Proton Exchange Membrane Fuel Cell

- Advantages
  - ✓ Solid electrolyte reducing electrolyte management problems
  - ✓ Low temperature
  - ✓ Quick start-up

Honda FCx Clarity

- Disadvantages
  - ✓ Expensive catalyst (platinum)
  - ✓ Sensitive to fuel impurities
  - ✓ Low temperature waste heat

M&S Forklift in UK

- Operating Temperatures: 50 – 100 ^{o}C
- Electrical efficiency: 40 – 50 %
- Power Range: 0.01 – 250 kW
- Applications: mobile, stationary, portable

Alkaline Fuel Cell

- Advantages
  - ✓ Low cost components
  - ✓ High performance
- Disadvantages
  - ✓ Sensitive to carbon dioxide
  - ✓ Electrolyte management necessary
- Operating Temperatures: 60 – 90 ^{o}C
- Electrical efficiency: 50 – 70 %
- Power Range: 0.1 – 50 kW
- Applications: submarines, spacecraft

NASA Space Shuttle 1969

15 kW AFC tractor

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Phosphoric Acid Fuel Cell

- Advantages
  - ✓ Higher temperature enables combined heat and power
  - ✓ Increased tolerance to fuel impurities
- Disadvantages
  - ✓ Expensive catalyst (platinum)
  - ✓ Long start-up time
  - ✓ Low current and power

400 kW UTC Power, PureCell PAFC

- Operating Temperatures: 200 ºC
- Electrical efficiency: 40 – 45 %
- Power Range: 50 – 1000 kW
- Applications: stationary

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Molten Carbonate Fuel Cell

- Advantages
  - ✓ High efficiency
  - ✓ Fuel flexibility
  - ✓ Can use variety of catalysts
  - ✓ Suitable for CHP
- Disadvantages
  - ✓ Long start-up time
  - ✓ Low power density
  - ✓ High temperature corrosion and breakdown of cell components
- Operating Temperatures: 650 ^{o}C
- Electrical efficiency: 50 – 60 %
- Power Range: 200 – 100,000 kW
- Applications: stationary

300 kW DFC300 fuel cell power plant, Fuel Cell Energy

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Vehicular transportation

- Fuel cells can achieve 65 % efficiency
  - ➢ Petrol driven internal combustion engine efficiency is 25.8 %
- Comfort
  - ➢ Fuel cells are silent and vibration-free
- Examples of Fuel Cell use in transportation: UK
  - ➢ London Lotus fuel cell taxis
  - ➢ Transport for London fuel cell buses
  - ➢ A fleet of urban fuel cell vehicles in Birmingham
- 1.6 Million Fuel Cell vehicles in UK by 2030

Materials Handling vehicles

Gen-drive handling vehicles

- GenDrive
  - ✓ Developed by PlugPower
  - ✓ 1,900 units sold by 2011
  - ✓ In use by Wallmart, Coca-cola, BMW
- HyPulsion
  - ✓ Combines Plug Power’s fuel cell products with Air Liquide’s hydrogen infrastructure
- Infintium
  - ✓ Developed by ITM Power in UK
  - ✓ Exclusive European distributor
  - ✓ In use by Marks and Spencer in UK

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Combined Heat and Power (CHP)

- Provide electricity and heat
- Decentralised and domestic applications
  - Overall system efficiency can reach 90 %
  - Avoids high electricity distribution losses
  - Fuel cells more acceptable than engine technologies, which have moving parts, noise and vibration

Estimates put the achievable reduction in carbon dioxide emissions at around 30 % – despite the use of fossil fuel for hydrogen production

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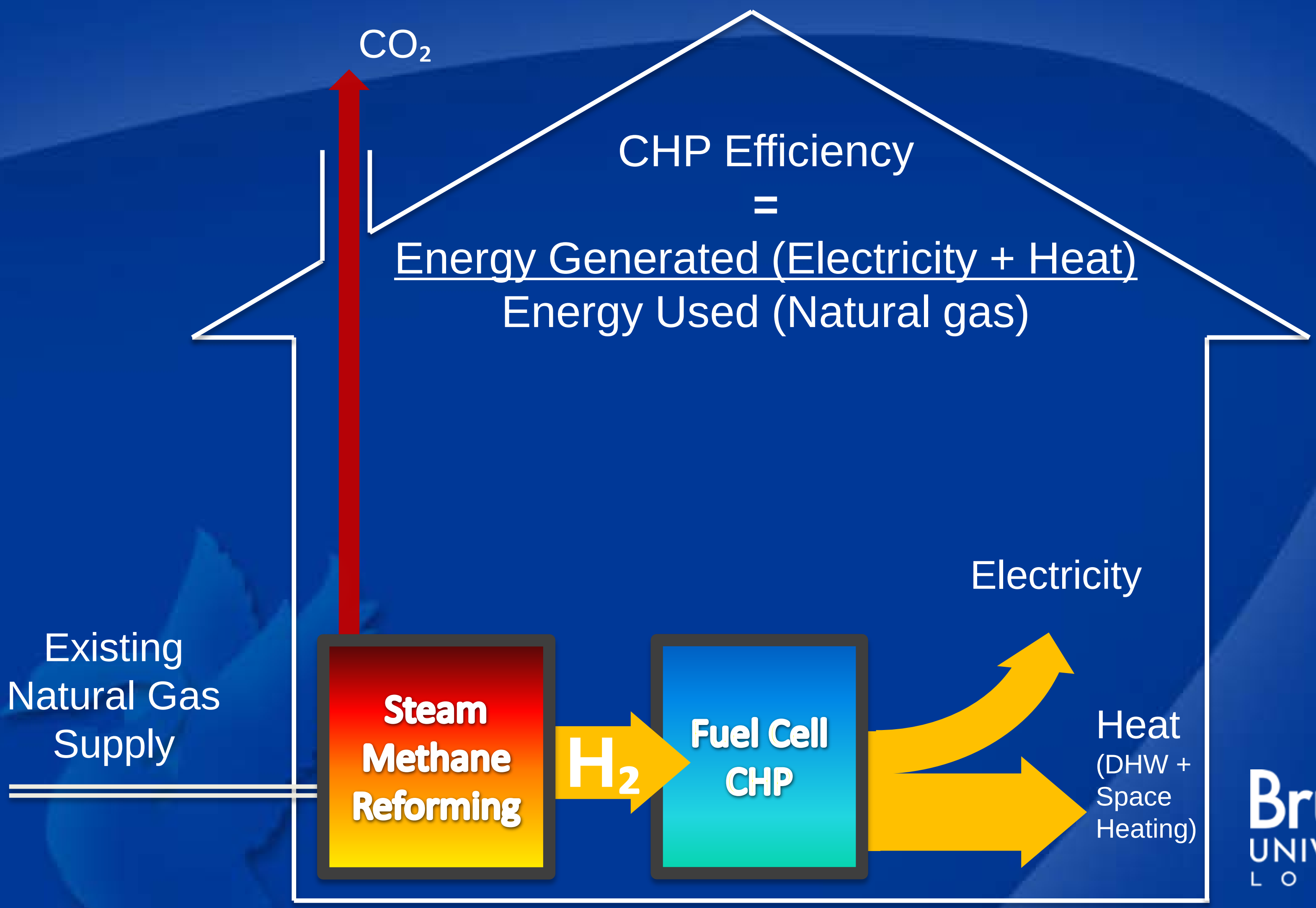
Fuel Cell Lead CHP systems



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Fuel Cell lead CHP: current state of art

- Ene-Farm, Japan
  - ✓ 13,500 households
  - ✓ 6 % reduction in primary energy
  - ✓ 11 % reduction of carbon dioxide emissions

Ene-Farm House

- Callux field test programme, Germany
  - ✓ 250 fuel cell systems installed by end of 2012
  - ✓ Systems developed by Baxi Innotech and Vailant
  - ✓ Combined 1 million of hours run time

- CFCL PEM fuel cell CHP units (picture right)
  - ✓ > 350 units installed in Korea
  - ✓ Number of units in UK and Hamburg

Financial, Environmental and Energy Analysis of Fuel Cell CHP systems

- Micro-CHP System within the UK Domestic Market
  - ✓ Sterling engine
  - ✓ Internal combustion engine
  - ✓ Solid Oxide Fuel Cell

- Representative of typical home in UK
  - ✓ Electrical and domestic hot water loads
  - ✓ Space heating demands

- Feed In Tarif
  - ✓ Financial payback for excess electricity generated by a household and exported to the National Grid

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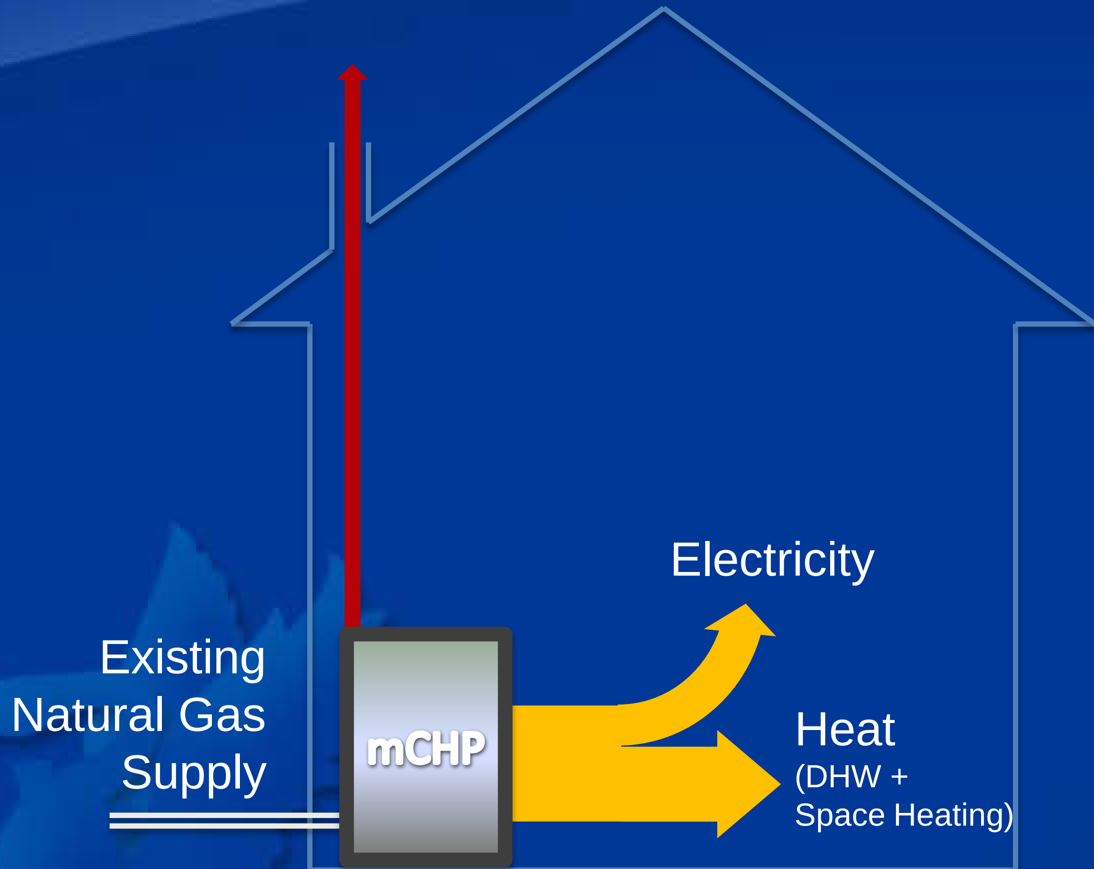
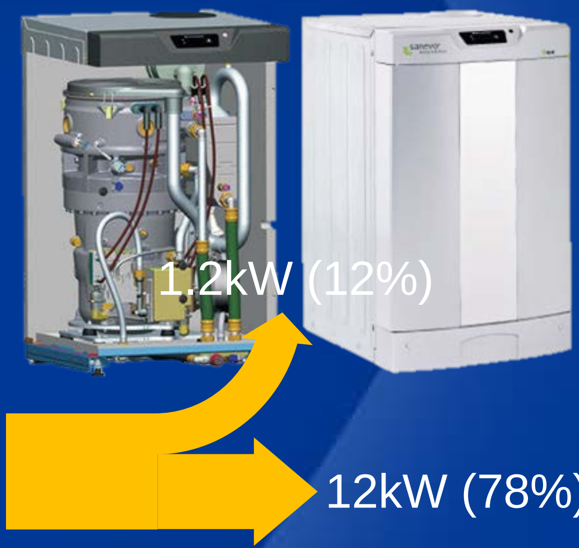
Stirling Engine lead CHP system



WhisperGen
(Stirling engine)



Total efficiency 90%

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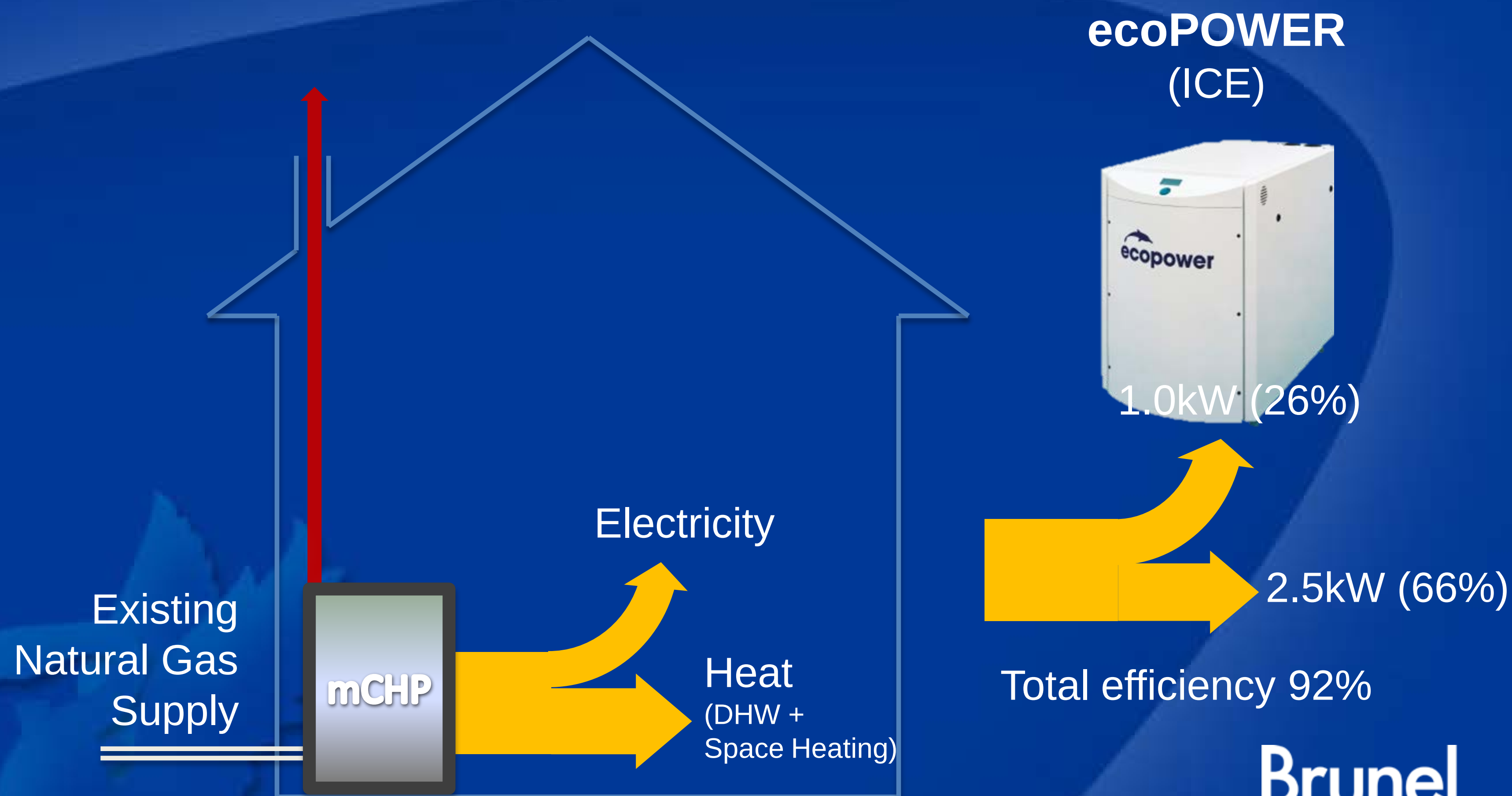
Internal Combustion Engine Lead CHP System



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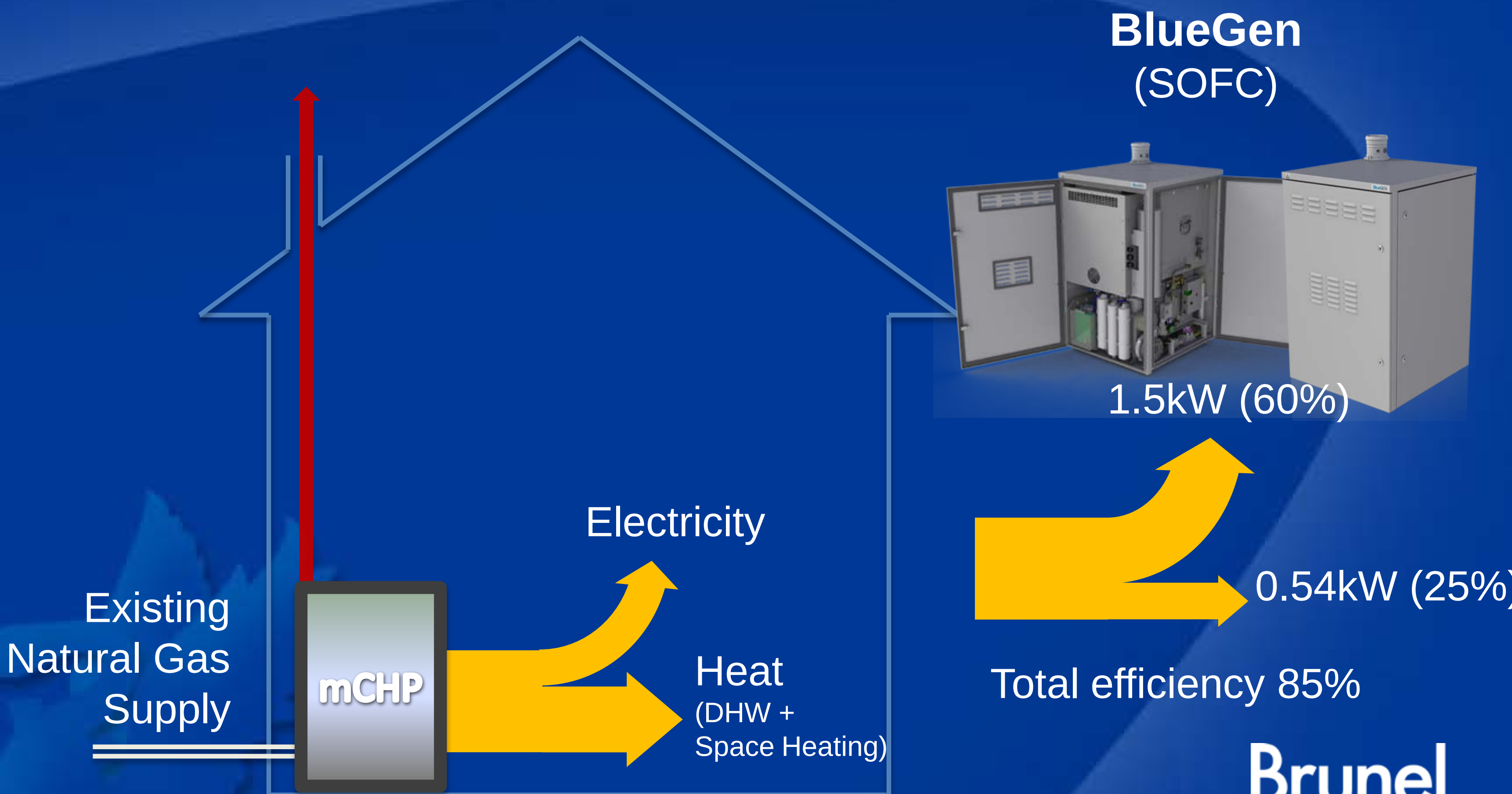
Fuel Cell Lead CHP system



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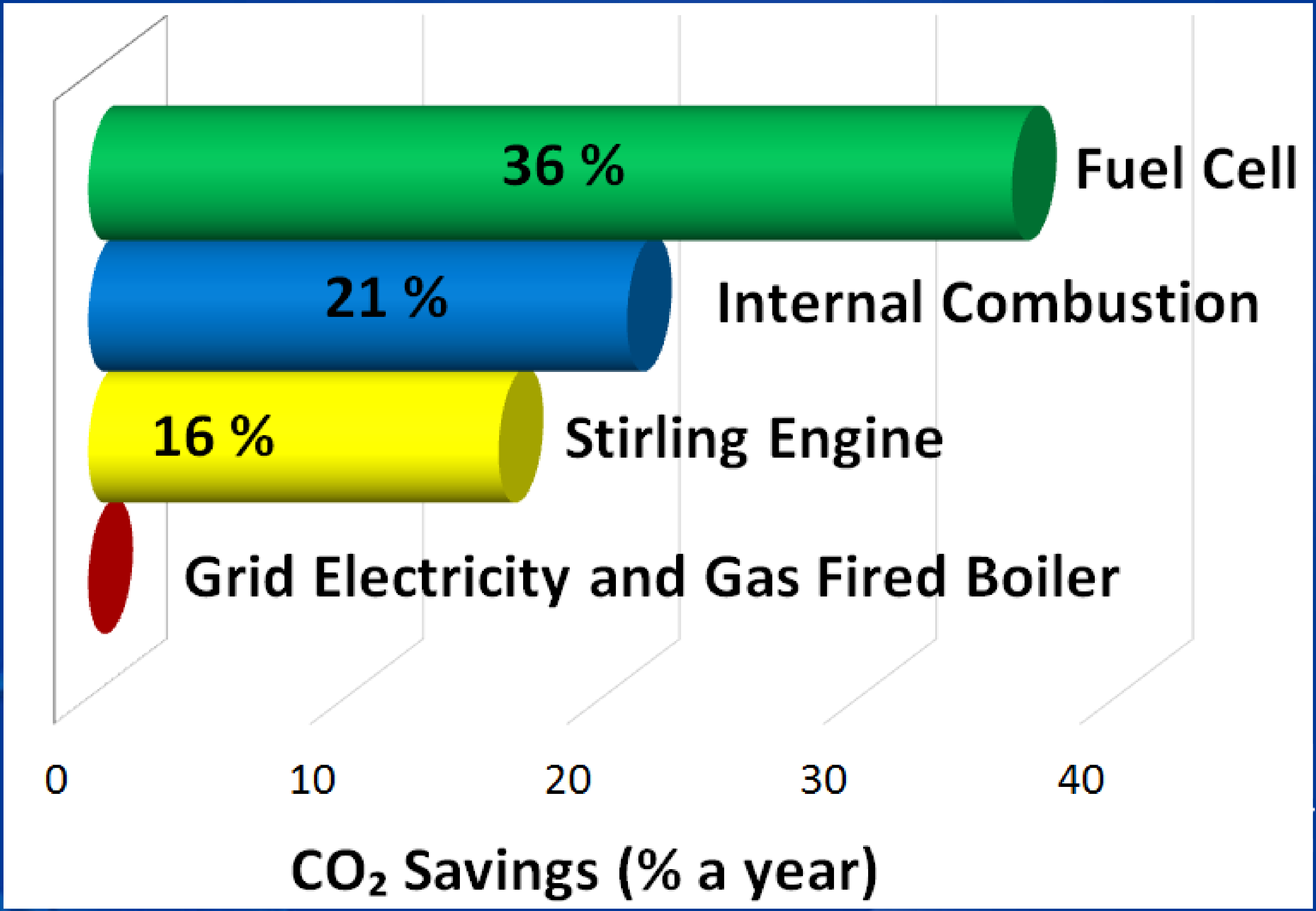
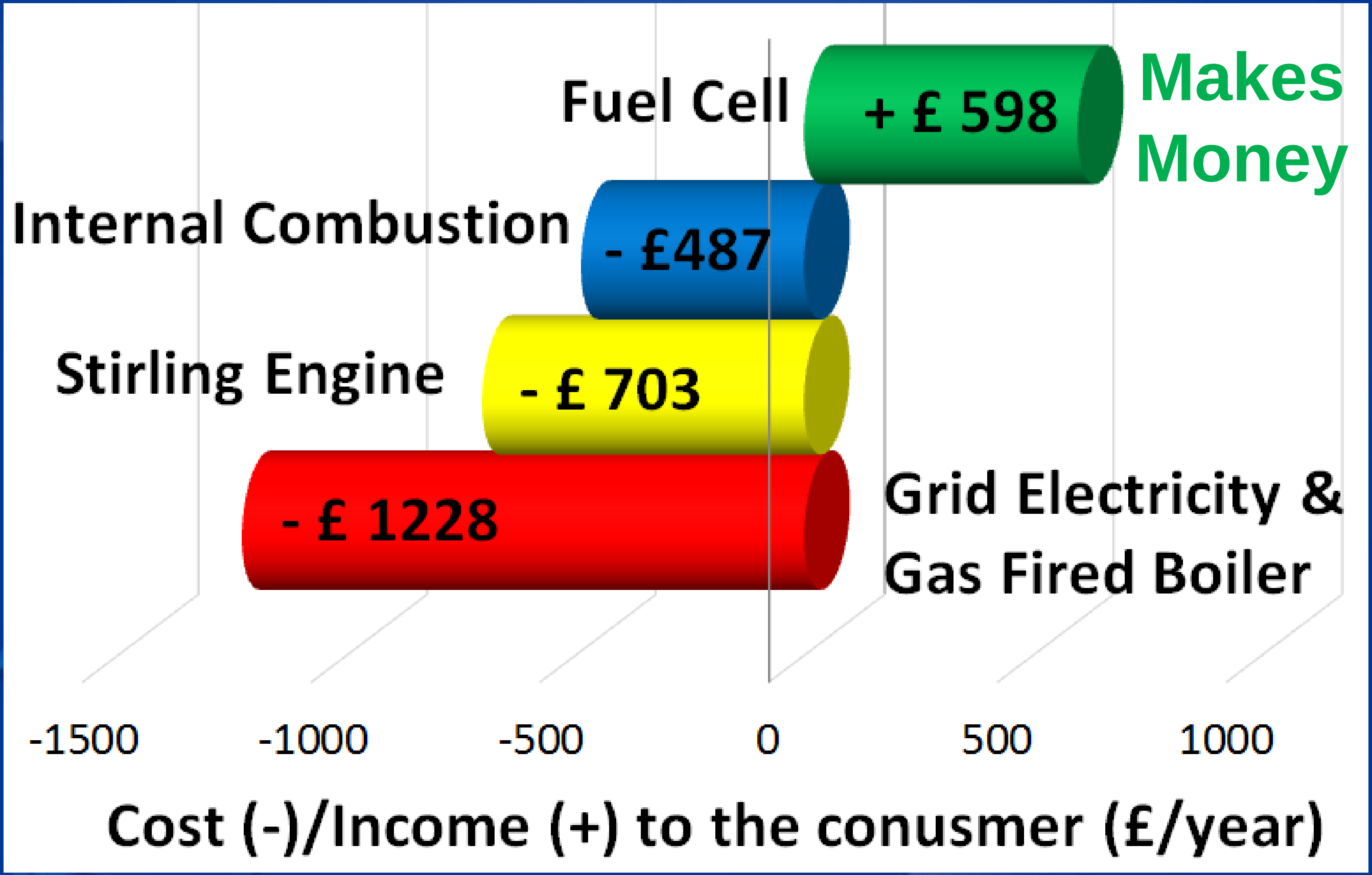
Comparing CHP systems: CO_2 savings



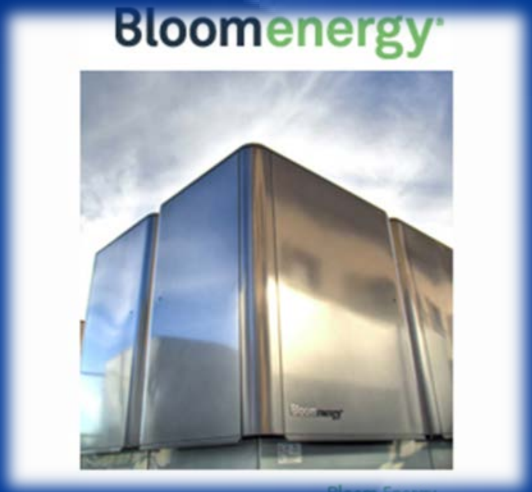
Comparing CHP systems: yearly cost/income



Prime power generation

- Fuel cell lead power stations for electricity generation

- Bloom energy fuel cell power systems
  - ✓ California: 11 systems of 7.5 MW
  - ✓ eBay data centre: 6 MW system
  - ✓ Apple data centre: 5 MW system



- POSCO energy Korea
  - ✓ Daegu: Largest fuel cell power plant in the world of 11.2 MW
  - ✓ Busan 5.6 MW plant

Other applications

- Grid support and off-grid power
  - ✓ Providing back-up power for telecommunications infrastructure
  - ✓ Germany: 5 fuel cell back-up systems installed in telecommunication industry
  - ✓ Australia: Ergon Energy is demonstrating fuel cell systems for remote energy

- Portable items
  - ✓ Laptops, phones
  - ✓ MiniPak portable PEMFC electronics charger by Horizon

Conclusions

- Hydrogen powered fuel cells
  - ✓ A key technology for future sustainable energy systems
  - ✓ Generate electricity with no emissions
- Fuel cell designs mainly differ in the chemical characteristics of the electrolyte
- Key commercialized applications of fuel cells
  - ✓ Vehicular
  - ✓ Prime and back up power
  - ✓ Combined heat and power
- Combined heat and power fuel cell systems for domestic applications
  - ✓ High savings in carbon dioxide emissions and primary energy consumption

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Fuel Cell Technology is HERE

Start using it!!!