Energy and Green House Gas Mitigation Technologies

Japan Society for the Promotion of Science-Imperial College London-University of Tokyo Symposium on Climate Change

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Imperial College London, South Kensington Campus, London SW7 2AZ

Imperial College London

Decentralised Energy Systems

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Imperial College Centre for Energy Policy and Technology

ICEPT

Director: Professor Peter Pearson

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Mission

Research & policy advice at interface of energy policy & technology

An Interdisciplinary Centre

Collaborating with Imperial's Energy Futures Lab and with UK & international researchers

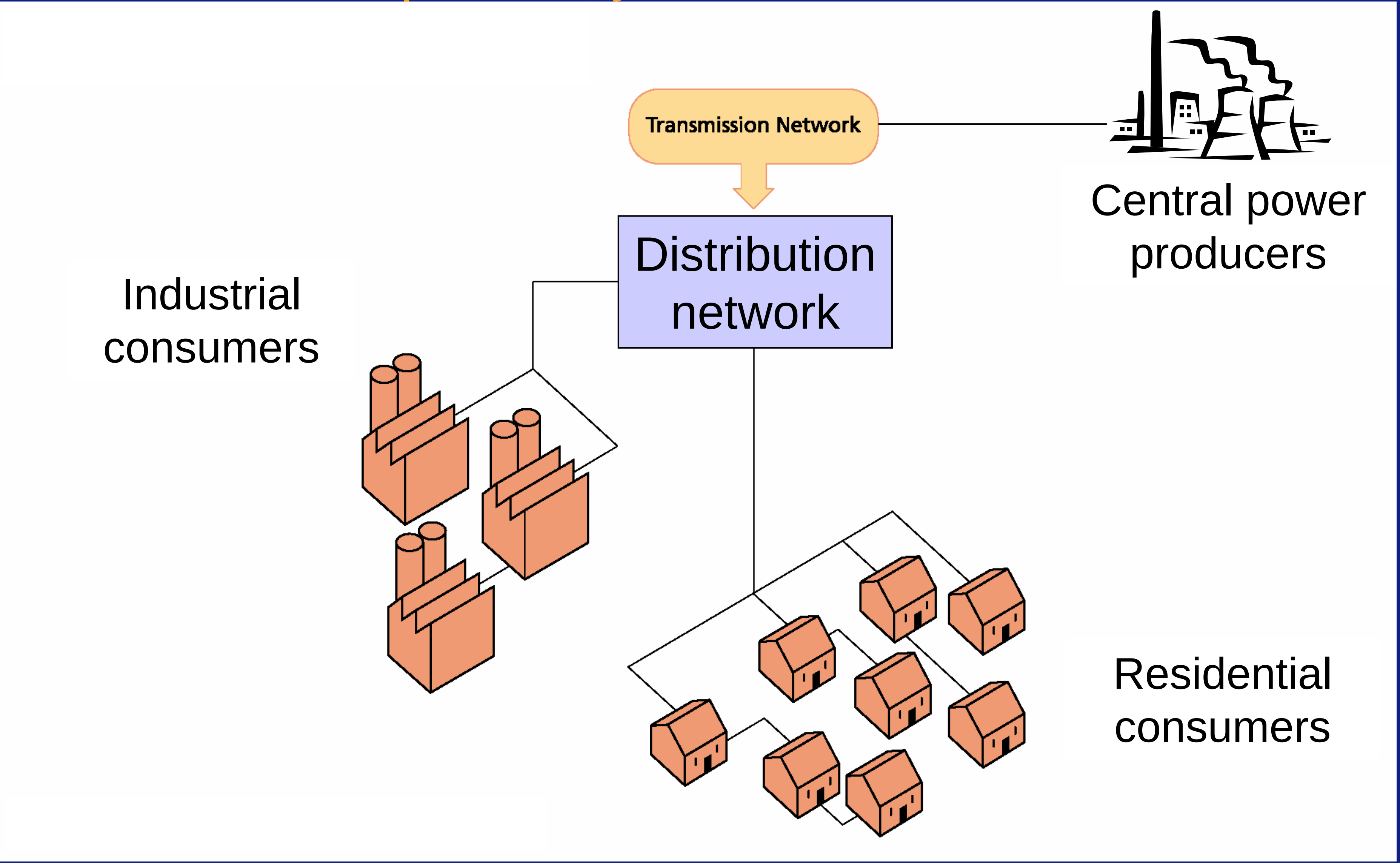
Outputs

- ❑ Research findings
- ❑ Evidence-based technology & policy review
- ❑ Postgraduate training
  - strong PhD programme
  - MSc in Environmental Technology: Energy Policy Option

Presentation outline

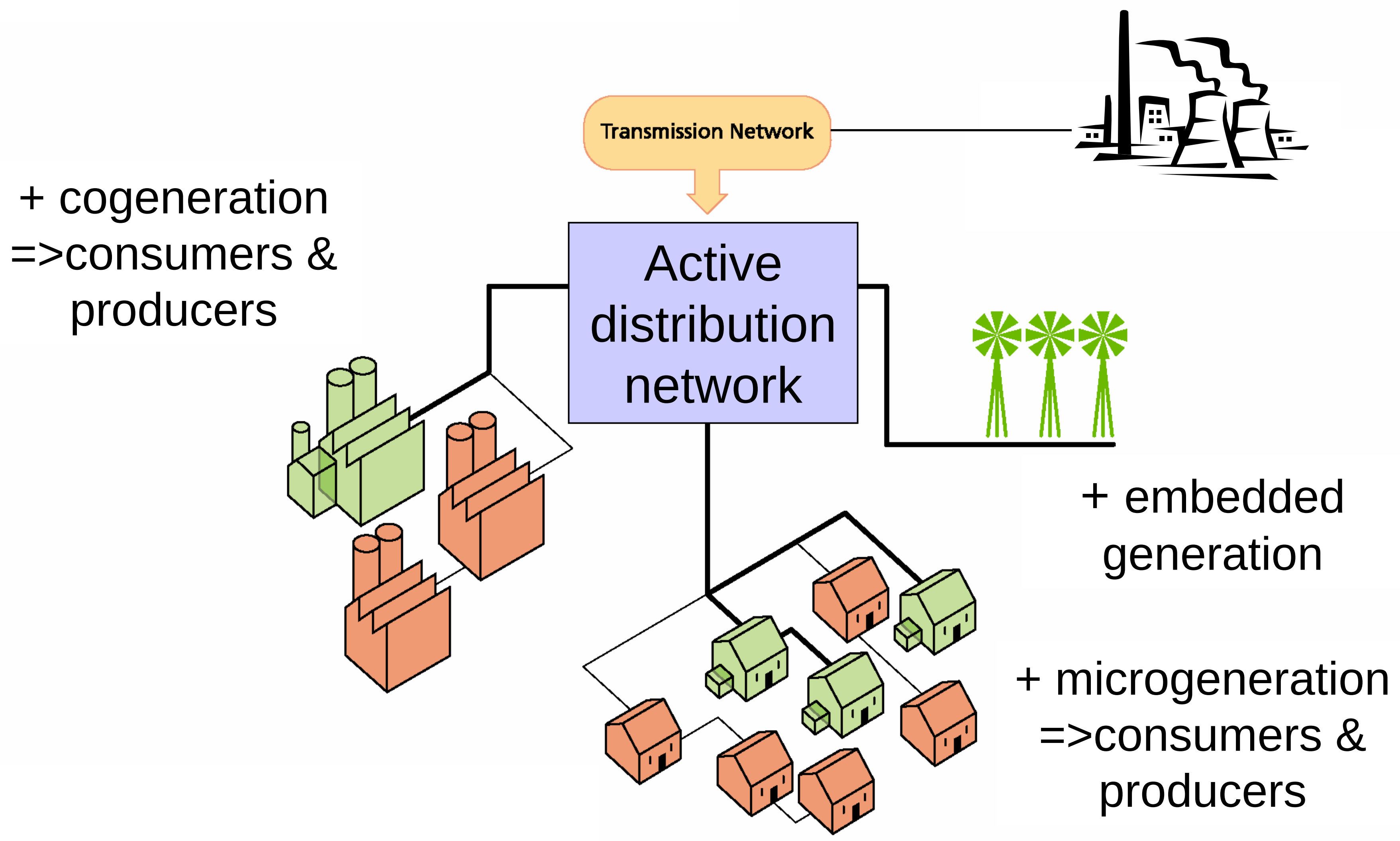
- What is Decentralised Energy?
- Decentralised Energy at Imperial
- Why interest in DE?
- ICEPT's work: illustrative examples on micro-CHP
- Conclusions

Conventional power system



Source: based on Ofgem(2002)

With decentralised energy



Source: based on Ofgem(2002)

Importance of ***networks***, ***components*** and ***people***

One vision of the future of power systems (analogy to internet evolution:-

Grid 1.0	**Grid 2.0**
Centralised	Decentralised
One-way	Multi-way
Limited feedback	Constant feedback
Small number of large investments	Large number of small investments
Emphasis on throughput of energy	Emphasis on investment and infrastructure
Active producers, passive consumers	Producers and consumers linked and active
Focus on supply of electricity and gas	Focus on providing heat and power
Expertise is centralised	Expertise is distributed
Supply based on predictions of demand (predict-and-provide)	Demand and supply linked and influenced by each other

Source: Rebecca Willis. grid 2.0 the next generation. Green Alliance, 2006

Decentralised Energy components

Source: adapted from Mariyappan (2003)

(a) Power/heat conversion (both grid-connected and off-grid…)

Fossil fuelled (some with potential for bio-fuel substitutes)

- Relatively large scale, conventional technology, eg:
  - Combined-Cycle Gas Turbine (35 MW – 400 MW)
  - Internal Combustion Engines (5 kW – 10 MW)
- Smaller scale, eg:
  - Stirling Engine (1 kW – 10 kW)
  - Microturbines (35 kW – 1 MW)
- Fuel Cells: Solid Oxide or Proton Exchange (250kW– 5MW; 1kW–250kW)

Renewables, eg:

- Small Hydro; Micro Hydro (1 MW – 100 MW; 25 kW – 1 MW)
- Wind Turbines(200 Watt – 5 MW, to GW arrays)
- Photovoltaic Arrays (20 Watt – 100 kW)
- Biomass, e.g. based on gasification (100 kW – 20 MW)

(b) Energy storage devices

(c) Demand side: information systems, intelligent control

(d) Associated infrastructures (notably active electricity distribution networks

Decentralised Energy at Imperial

- Strong technology programmes in many departments (eg Fuel Cells, PV, wind, bioenergy, waste-to-energy, …)
- Department of Electrical and Electronic Engineering: strong group on power system control, DG integration and future of networks
- Centre for Energy Policy and Technology (ICEPT): focus on techno-economic, environmental and policy analyses of emerging energy options (eg H2, fuel cells, bioenergy, building integrated and off-grid renewables, and decentralised energy specifically)
- Particular areas of interest to ICEPT
  - Modelling approaches, and sensitivities of optimum design to economic, market and environmental factors
  - Demand-Side participation
  - Micro-Grids and community heat networks
  - Small scale waste to energy systems (eg contacts with Ebara corp gasification)
  - Valuation and risk-management of decentralised energy investments
  - Transitions to DG power systems and scenarios
  - Policy aspects

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Why interest in Decentralised Energy (globally)?

- Technology
  - New, smaller, conversion devices
  - Can help overcome T&D network constraints
  - Stimulate development of ‘active’ networks
- Environment, economics
  - Some options inherently low carbon (eg renewables)
  - Can facilitate use of cleaner fuels (eg local wastes or biomass)
  - Avoidance of transmission losses
  - * Opportunity to capture ‘waste’ heat for local heat loads
  - Facilitate closer end-user engagement with energy
  - Contribution to wider transition to low carbon future…
- Economics, commercial
  - Low capital, fast revenue stream = lower risk modular investments
  - Value of flexibility, adaptability and diversity in a competitive market
  - Integration of electricity, gas & heat suppliers/markets
  - Underlying need for new power investments, globally
- Security of supply
  - * Possible improvement in power quality and security of local supply

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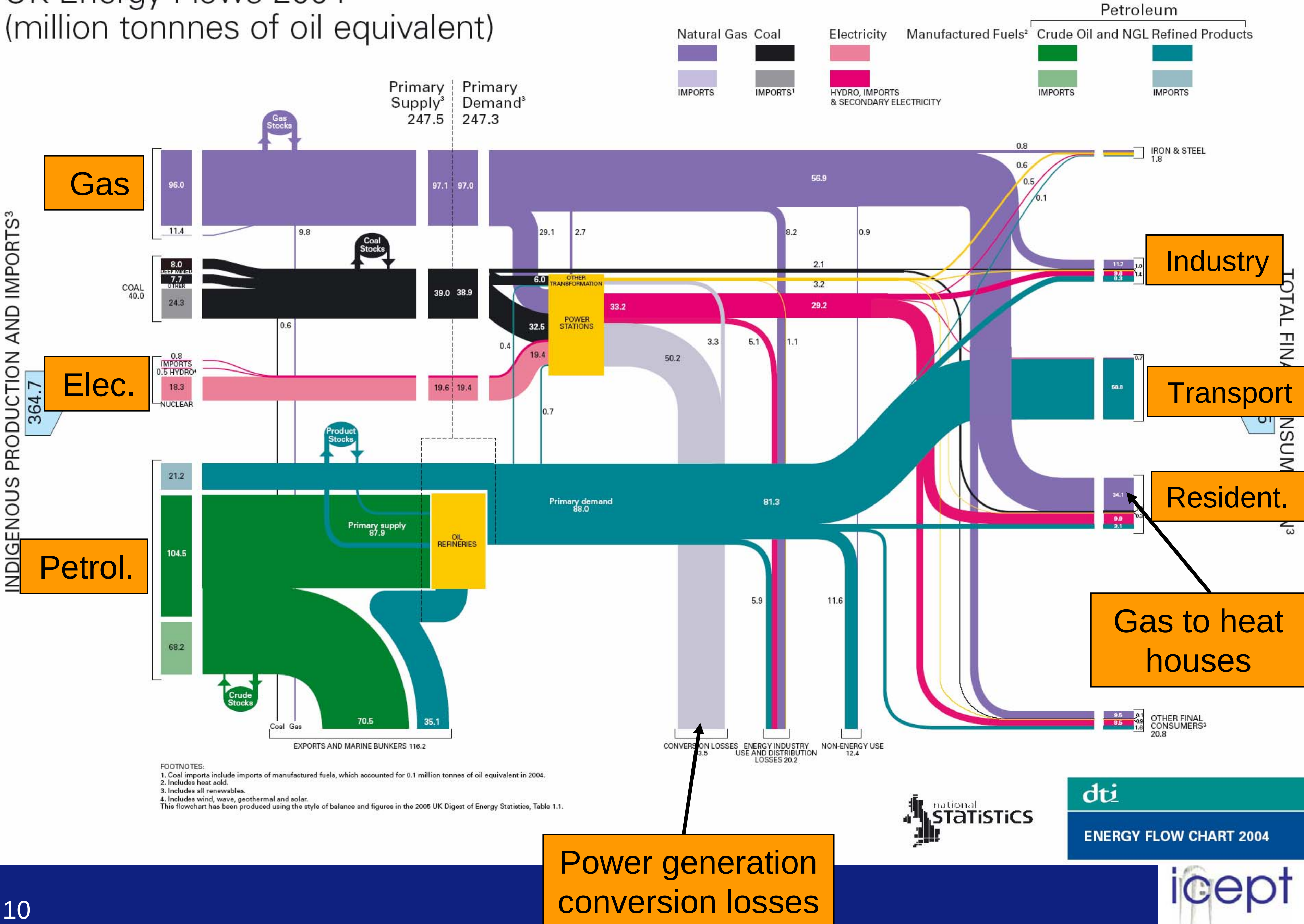
UK Energy Flows 2004
(million tonnnes of oil equivalent)



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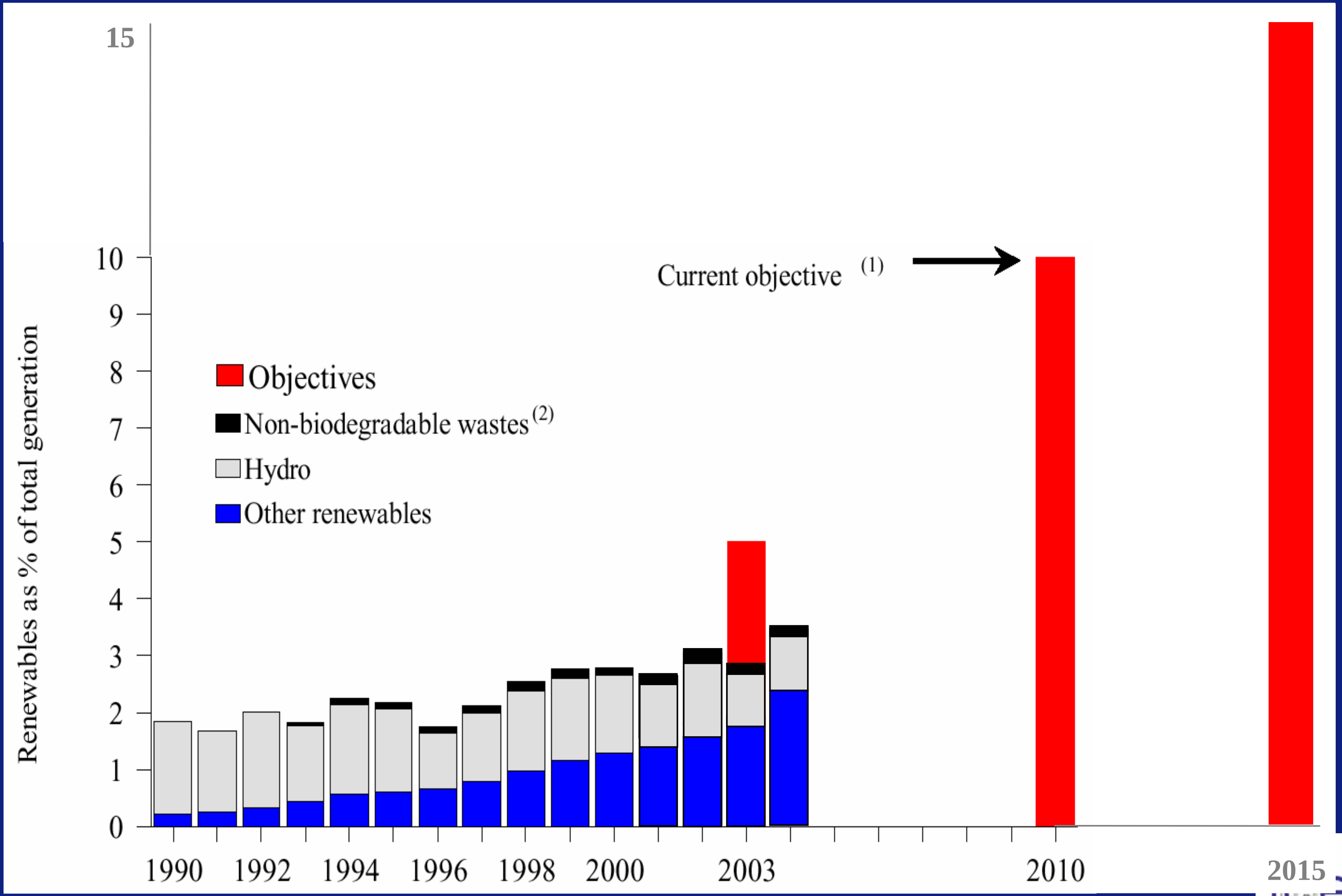
WADE (2003)

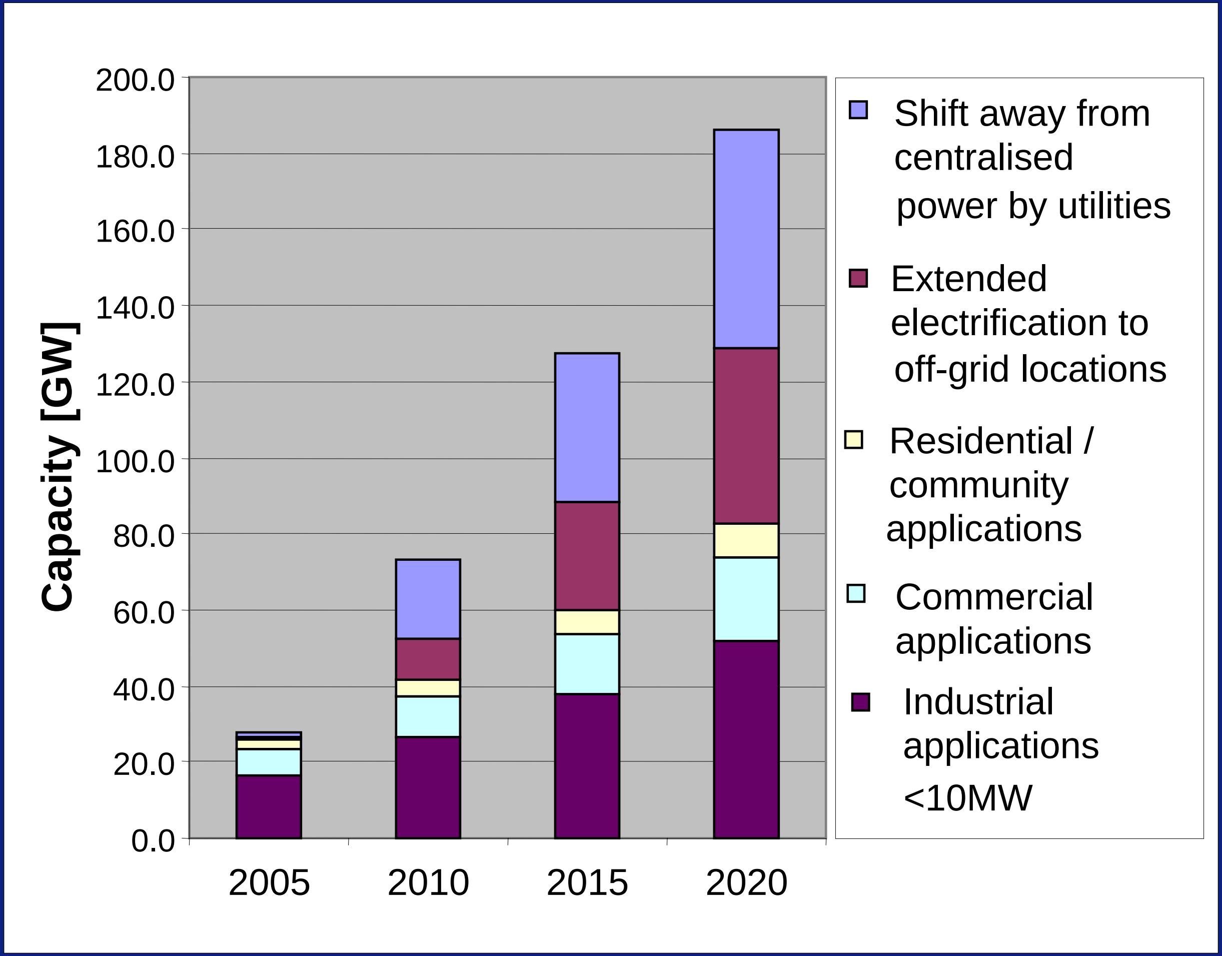
Constraints facing Decentralised Energy (in UK)

- Current market structures and rules
- Some high technology costs
- High gas prices
- Planning and connection constraints and public perceptions
- Network integration: capacity to accept is limited and not always where needed

Growth in electricity generation from renewable sources since 1990 (Source: adapted from DUKES 2002 – 2005)



Market size - Global DG capacity (< 10 MW) by market segment



Source: Imperial College / E4tech Ltd

Key Findings

- Possibly very significant shift in emphasis on the part of utilities to distributed power
- Large DG growth expected in industrial applications and extended electrification
- DG penetration in commercial and residential is lower, but characterised by a large number of smaller units

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Residential Micro-CHP

- Stirling engine, ICE, Solid Oxide Fuel Cell, PEM Fuel Cell

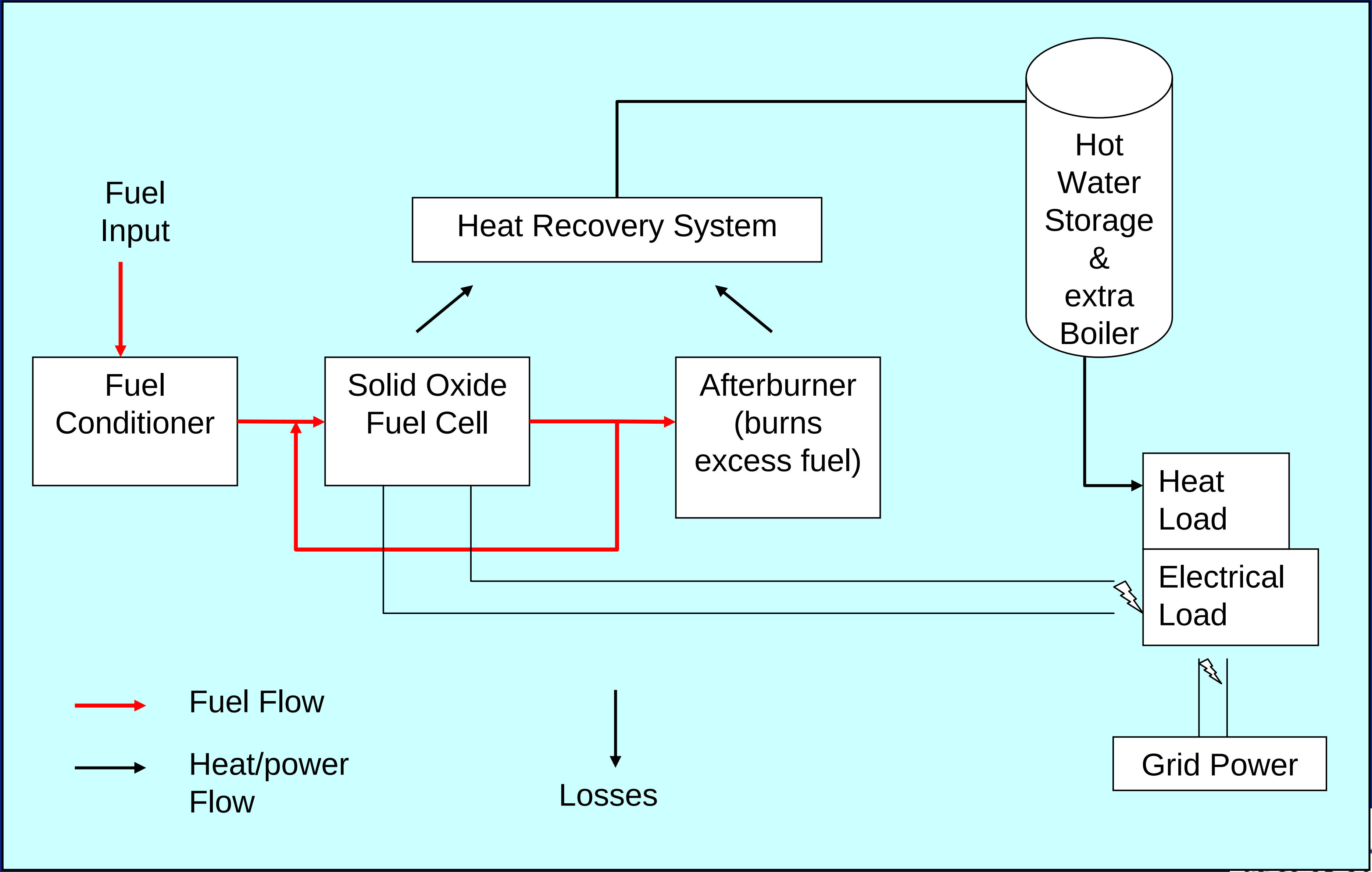
Source: WhisperGen

Source: Ballard

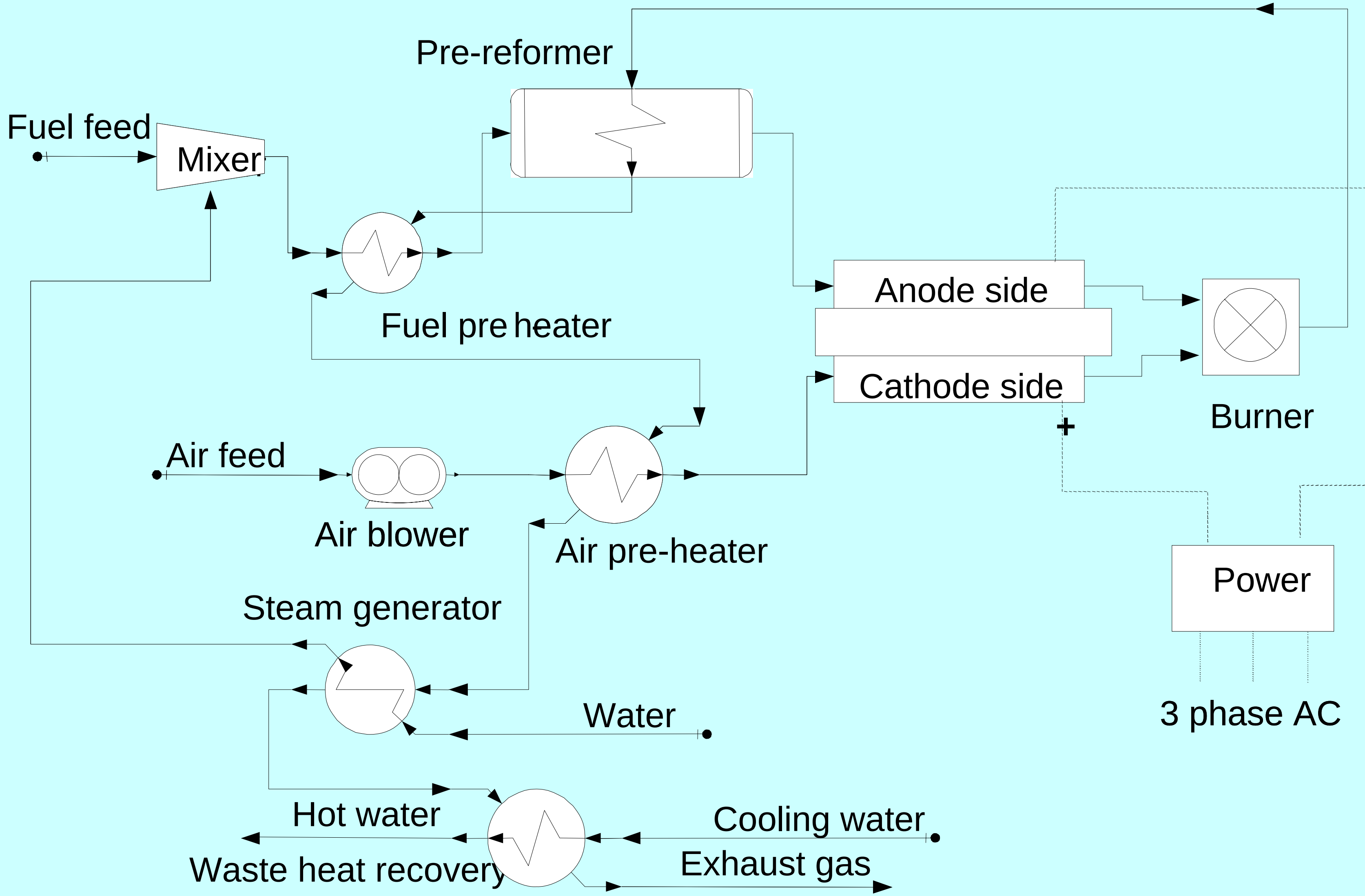
Source: Baxi

Source: Hexis

System Diagram



Stack and BOP model



Optimisation Model Applications

- How to model residential CHP applications
- Key economic drivers for SOFC-based technology
- Influence of ramp constraints on economic and environmental outcomes
- Synthesise a least cost operating strategy
- How best to meet thermal demand (eg value of thermal storage)
- Capacity credit of micro-CHP: % of installed capacity that will reliably reduce peak system demand
- Relative performance of micro-CHP and community scale
- (Next) Influence of changing patterns of thermal demand

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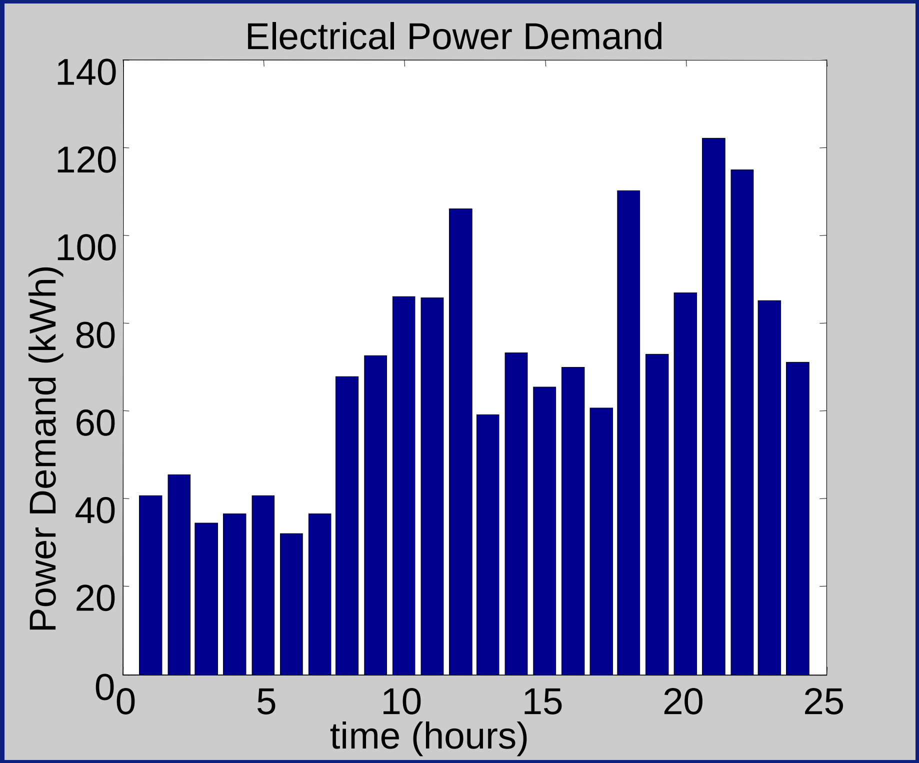
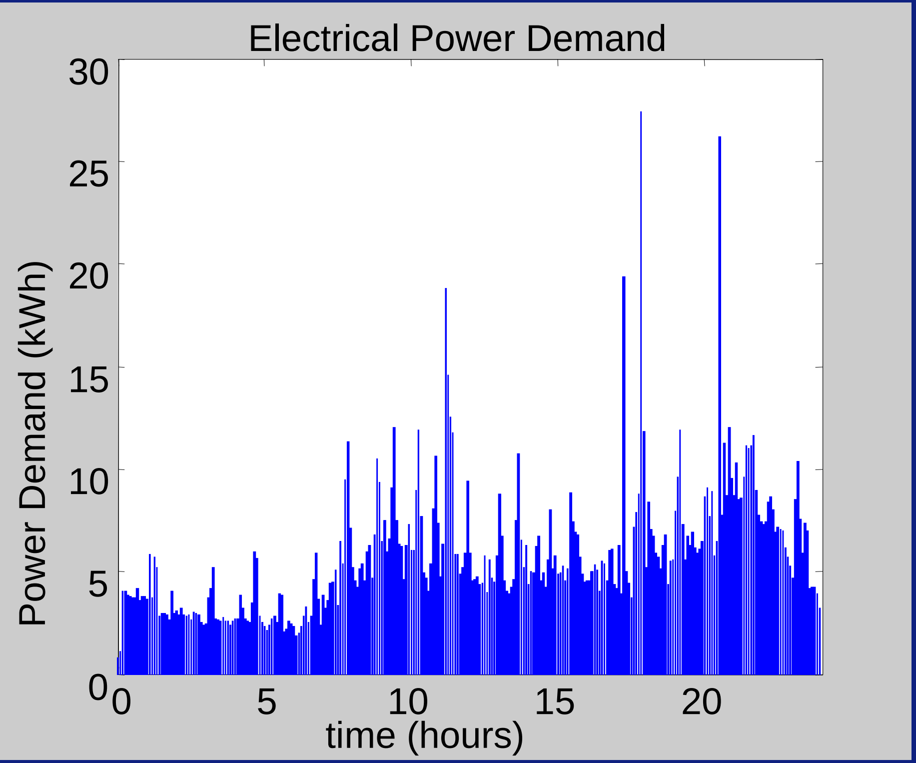
Input data time-step assumptions

Hourly Data



Five Minute Data



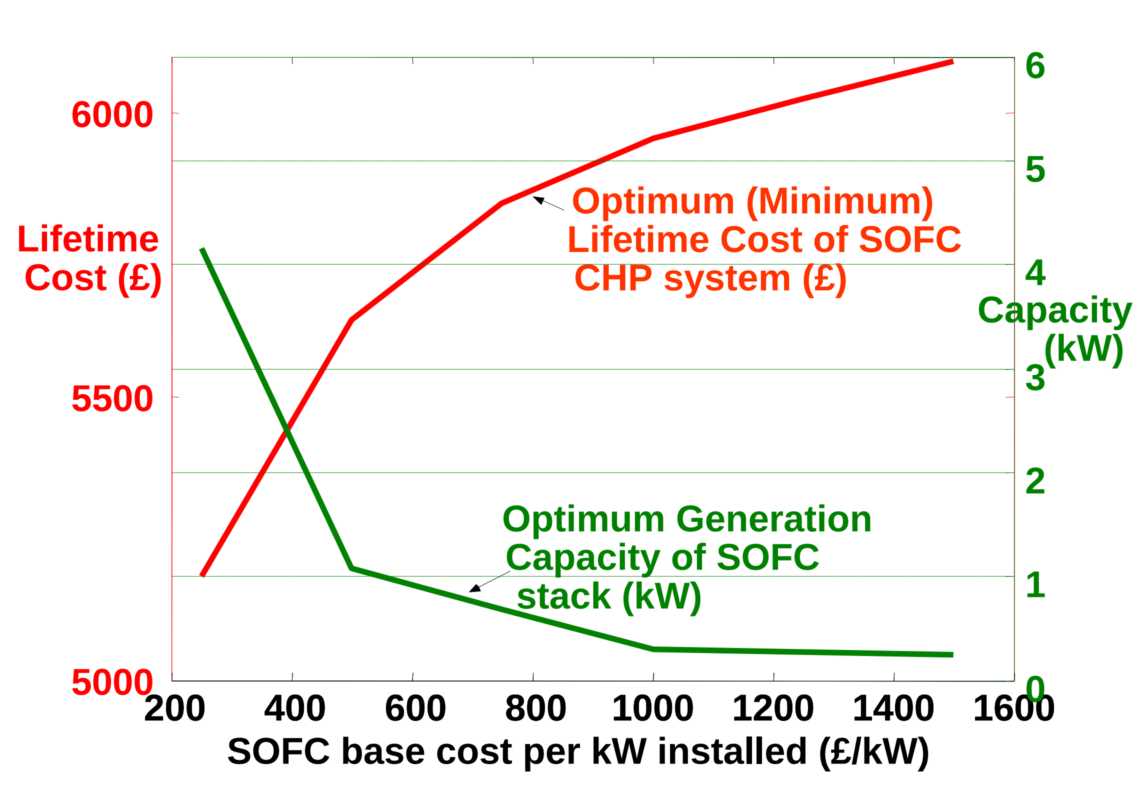
Carbon emissions reduction is overestimated by analyses using coarser temporal precision by up to 50%, and economic case overestimated by around 10%.

Coarser precision overestimates export of low-carbon electricity, and underestimates import of high-carbon grid power.

SOFC for DG in UK

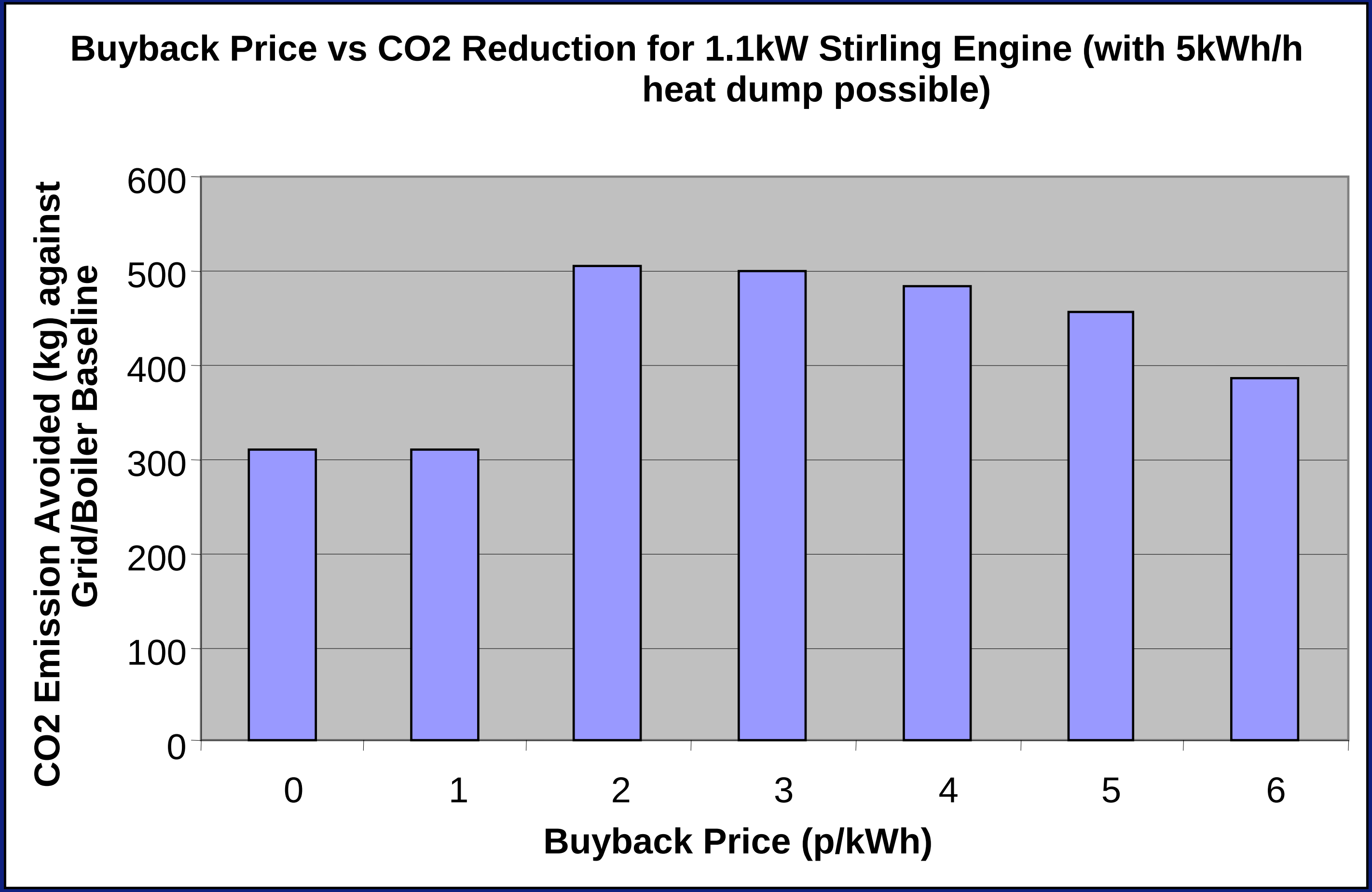
- Ceres Power, a SOFC tech. company (& Imperial spin-out) recently won the Carbon Trust innovation award in the UK.
- SOFC has the potential for a relatively low cost/kW installed
- Fuelled by natural gas or hydrogen rich fuel
- Carbon-efficient technology, very low NO_x, very low SO_x
- Research underway across the capacity range (1kW – 1MW)

Sensitivity of optimum system size to installed cost per kW



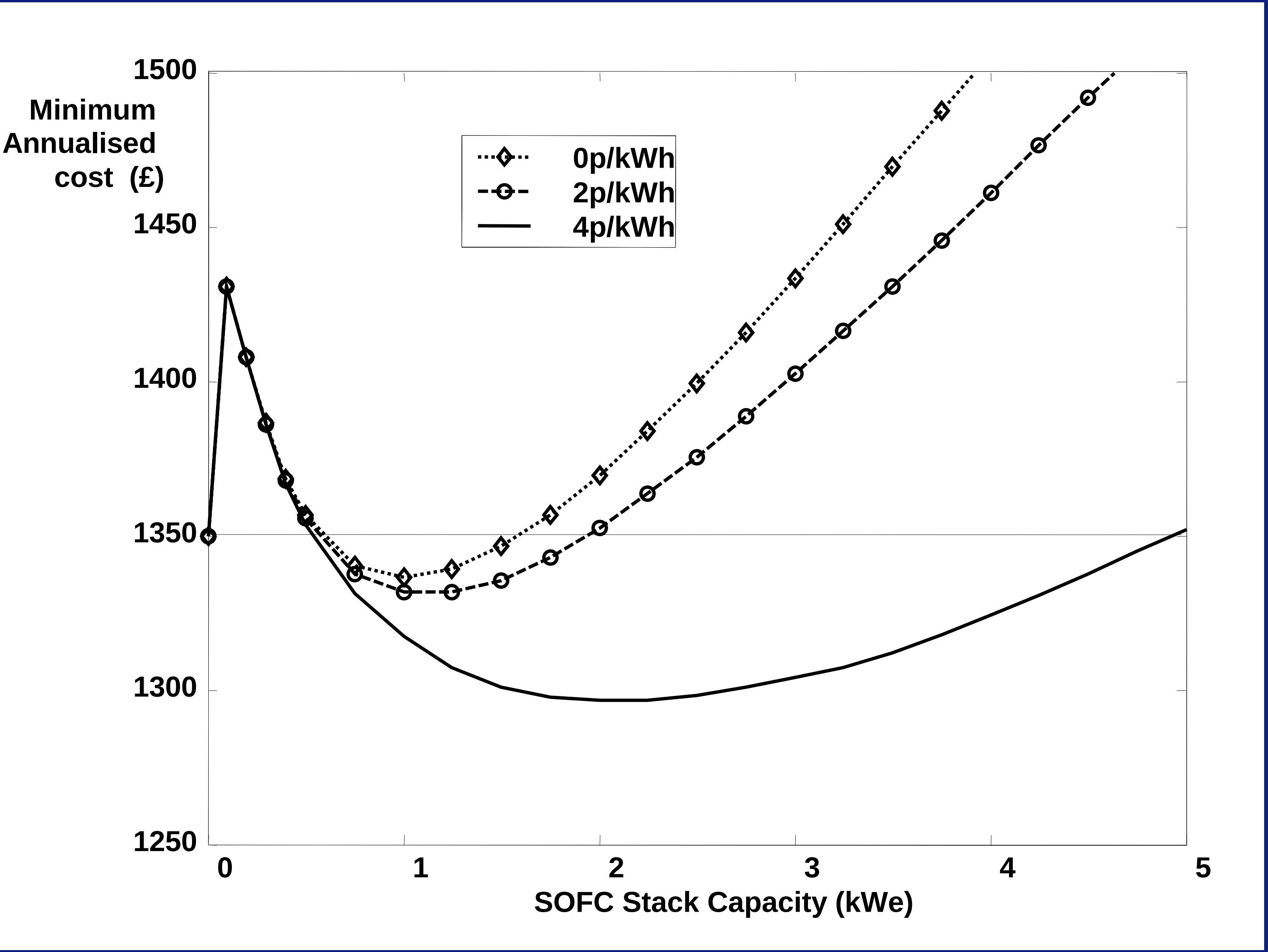
Cost-optimal size for residential applications is roughly 0.5 kWe, for capital cost of £800/kWe

DG generally has environmental benefits, but modelling helps reveal perverse effects…

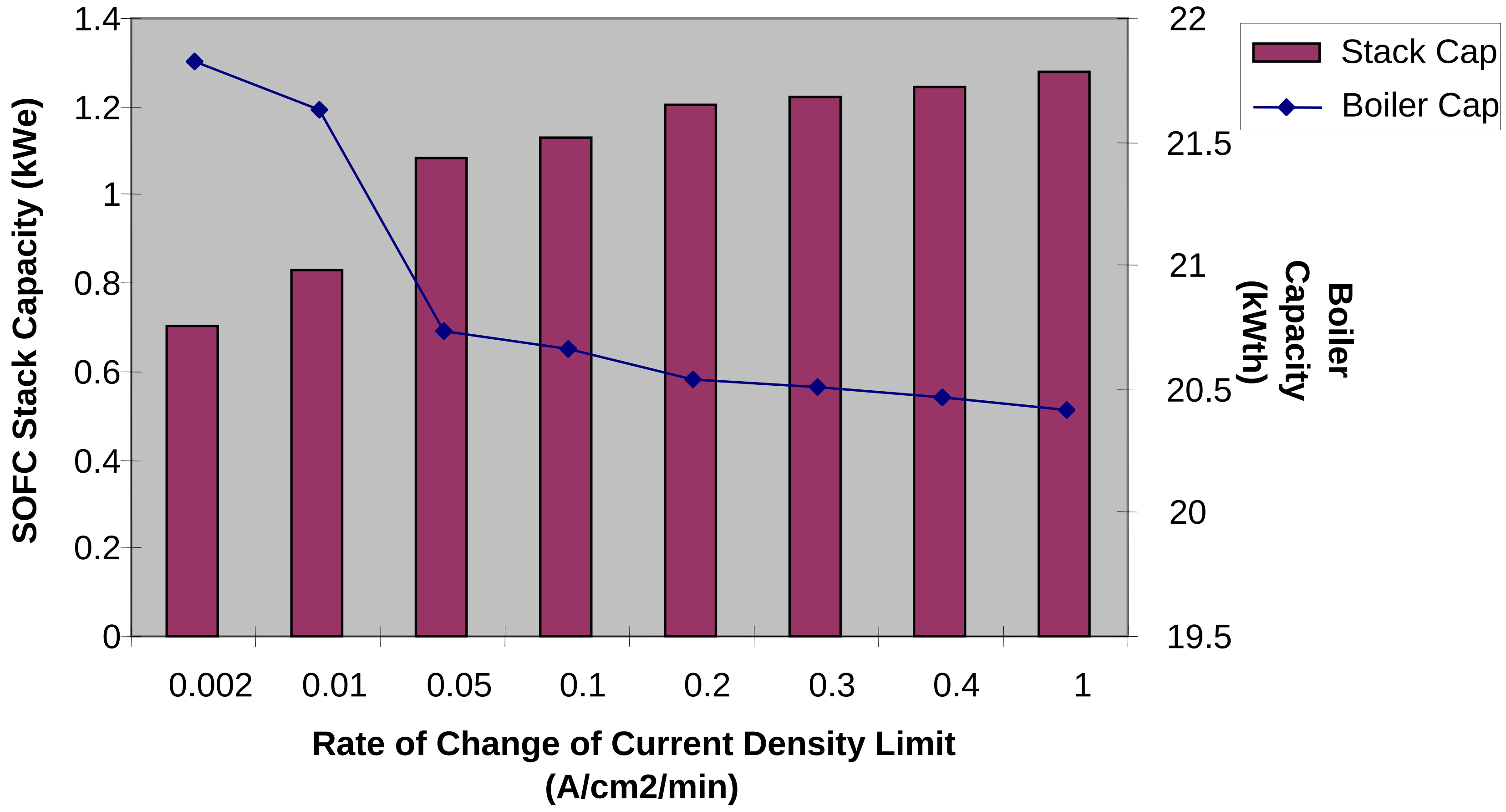


If heat can be wasted to exhaust by micro-CHP, then it is often economically optimal to generate electricity to meet onsite loads and export to the grid, and to dump some of the heat generated. Wasted heat implies higher carbon emissions

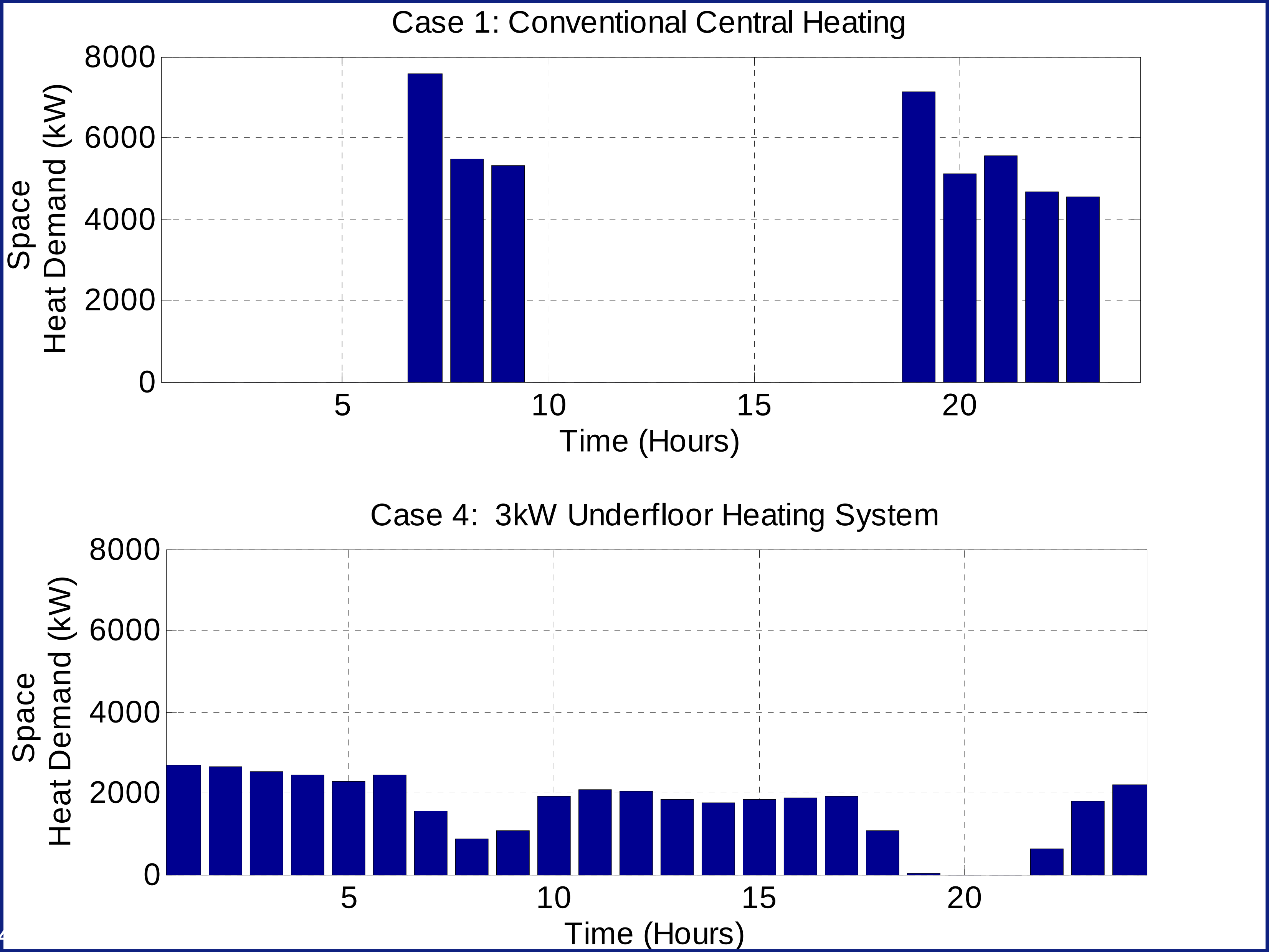
Electricity Buyback (export) Prices



Ramp Constraints



Influence of thermal demands on micro-CHP



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Conclusions

- Broadly, on DE
  - Technology options are abundant, and improving
  - ‘System approach’ appropriate – demand/supply, infrastructures, people, markets…Active networks and DSM will be an important aspect in future distribution network and DG penetration scenarios.
  - Plenty of barriers: technical, market, regulatory, …
- Micro-CHP
  - Economic and environmental benefit… depending on…
  - Economics and environment aren’t everything. Space, quality of service, etc
  - Rough and tough technology may be better than highly optimised
- Interesting questions:-
  - How do you quantify and model uncertainty in the new DE environment? Eg portfolios, real options…
  - Technical and economic questions about infrastructure transition

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Publications

A.D. Hawkes, P. Aguiar, C. A. Hernandez-Aramburo, M.A. Leach, N.P. Brandon, T.C. Green, C.S. Adjiman (2006) "Techno-Economic Modelling of a Solid Oxide Fuel Cell Stack for micro-CHP" . *Journal of Power Sources*. Vol 156/2 pp 321-333

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Hawkes A.D., Aguiar, P., Croxford, B., Leach, M.A., Adjiman, C.S., and Brandon, N.P. (September 2006 accepted). Solid Oxide Fuel Cell Micro Combined Heat and Power System Operating Strategy: Options for Provision of Residential Space and Water Heating. *Journal of Power Sources*