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HEAT - THE 'WHOLE SYSTEMS' CONTEXT

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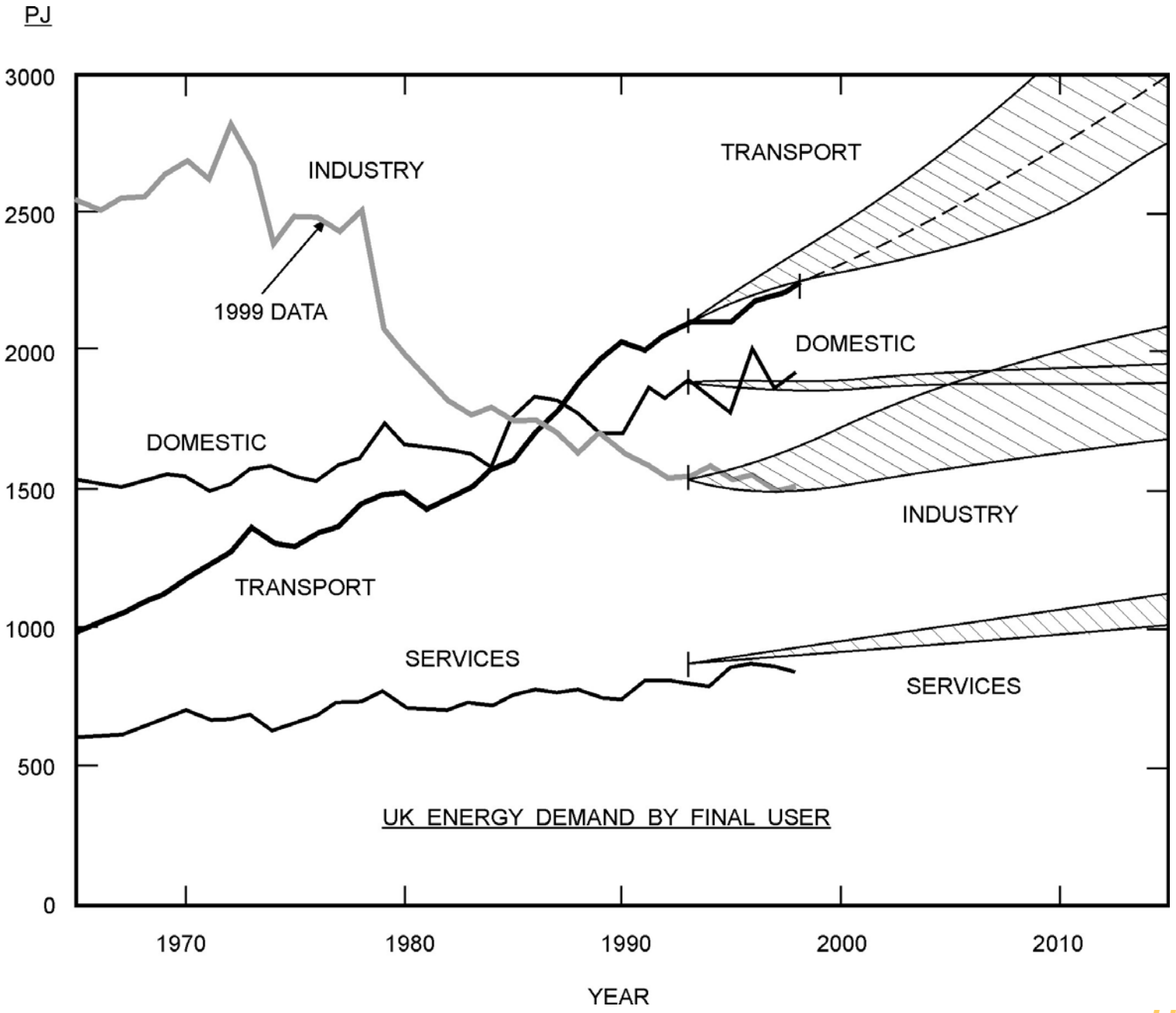
Speaker – **Prof. Geoff Hammond** [Email: ensgph@bath.ac.uk]

CONTENTS

- Energy End-use in the UK Economy
- Whole Systems Analysis of Energy Generation and Use - The Sustainability Context
- Thermodynamic Concepts and Tools – The Quantity and Quality of Energy Resources
- Electricity as an Energy Carrier
- Embodied Energy and Carbon in Materials, Products and Structures
- Energy Saving Potential in Buildings and Industry
- Concluding remarks

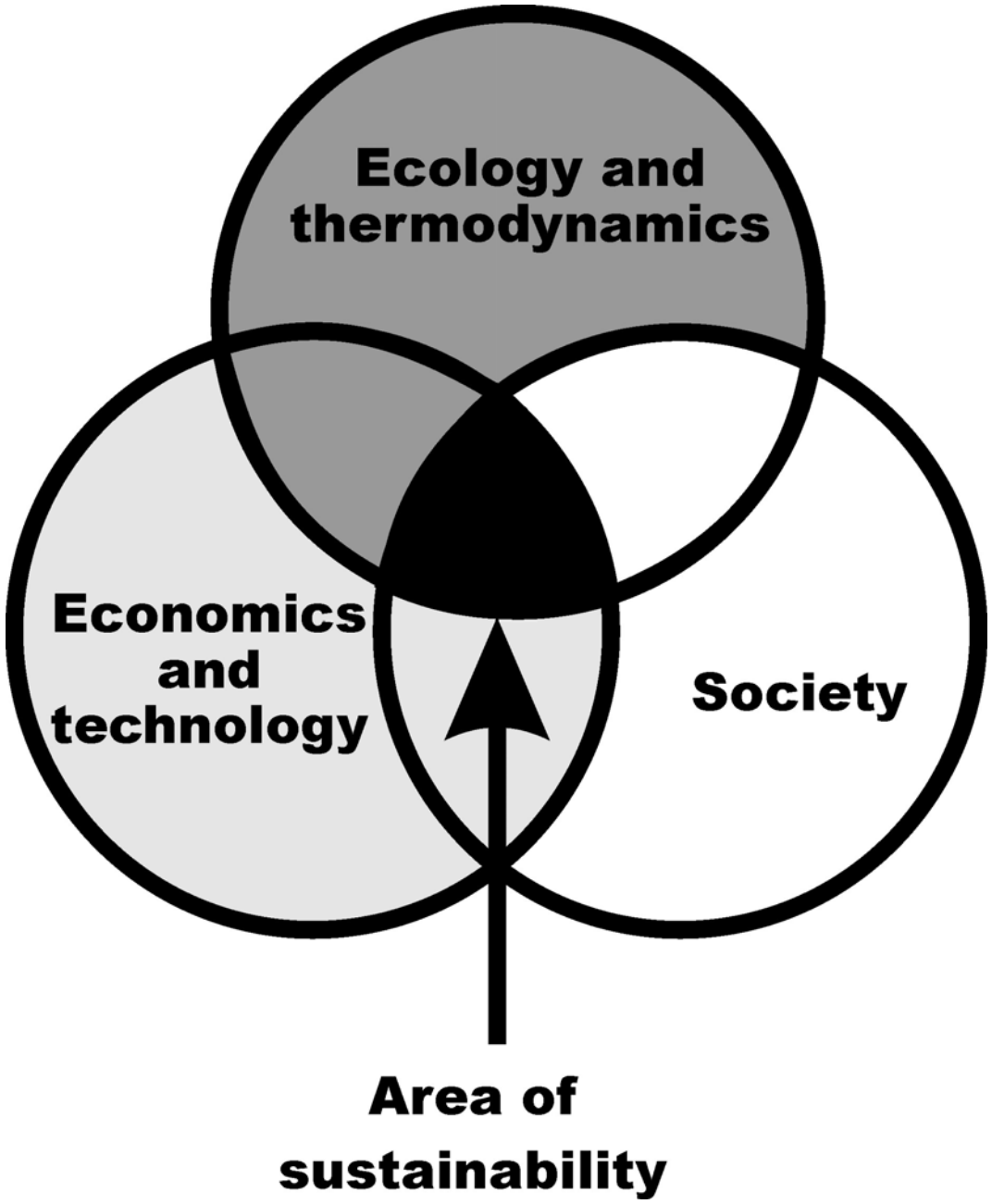

PJ
3000
2500
2000
1500
1000
500
0
INDUSTRY
1999 DATA
TRANSPORT
DOMESTIC
DOMESTIC
INDUSTRY
TRANSPORT
SERVICES
SERVICES
UK ENERGY DEMAND BY FINAL USER
1970
1980
1990
2000
2010
YEAR

Heat

WHOLE ENERGY SYSTEMS ANALYSIS

- Interdisciplinary and integrated appraisal toolkit -
  - THERMODYNAMICS: energy, exergy, and exergoeconomic analysis
  - ENVIRONMENTAL LIFE-CYCLE ASSESSMENT (LCA): from ‘cradle-to-grave’ or ‘cradle-to-gate’
  - ENVIRONMENTAL COST-BENEFIT ANALYSIS (CBA); with colleagues in Economics
- Sustainability analysis –
  - THE THREE PILLARS: balancing economic and social development with environmental protection

Heat


Ecology and thermodynamics
Economics and technology
Society
Area of sustainability

THERMODYNAMIC CONCEPTS AND TOOLS

- **FIRST AND SECOND LAW CONCEPTS**

  ENERGY ⇒ QUANTITY EXERGY ⇒ QUALITY

- **IDENTIFYING PROCESS IMPROVEMENT POTENTIAL**

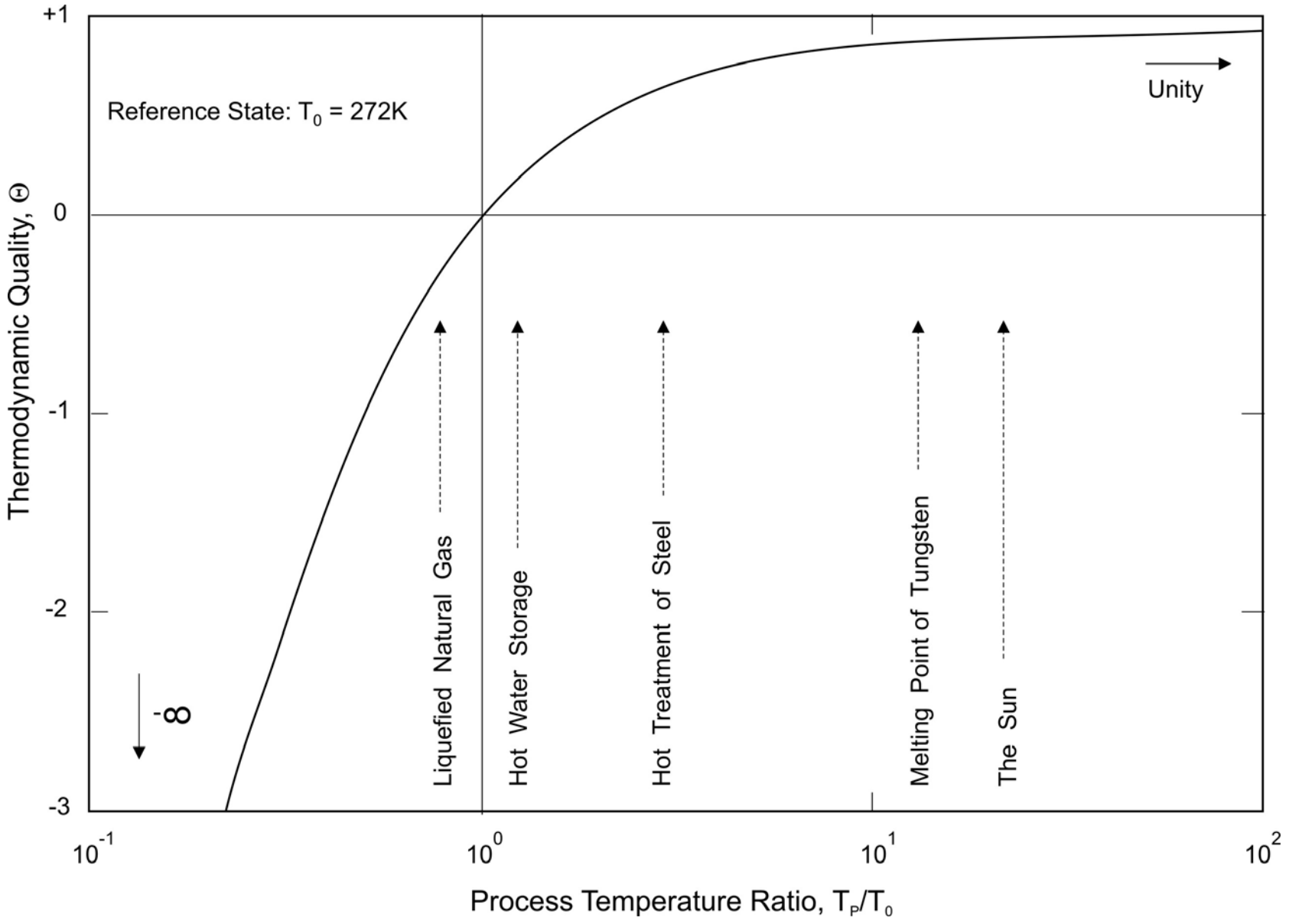
  ⇒ ENERGY ANALYSIS: CONSERVATION

  ⇒ EXERGY ANALYSIS: ENERGY (OR HEAT) CASCADING

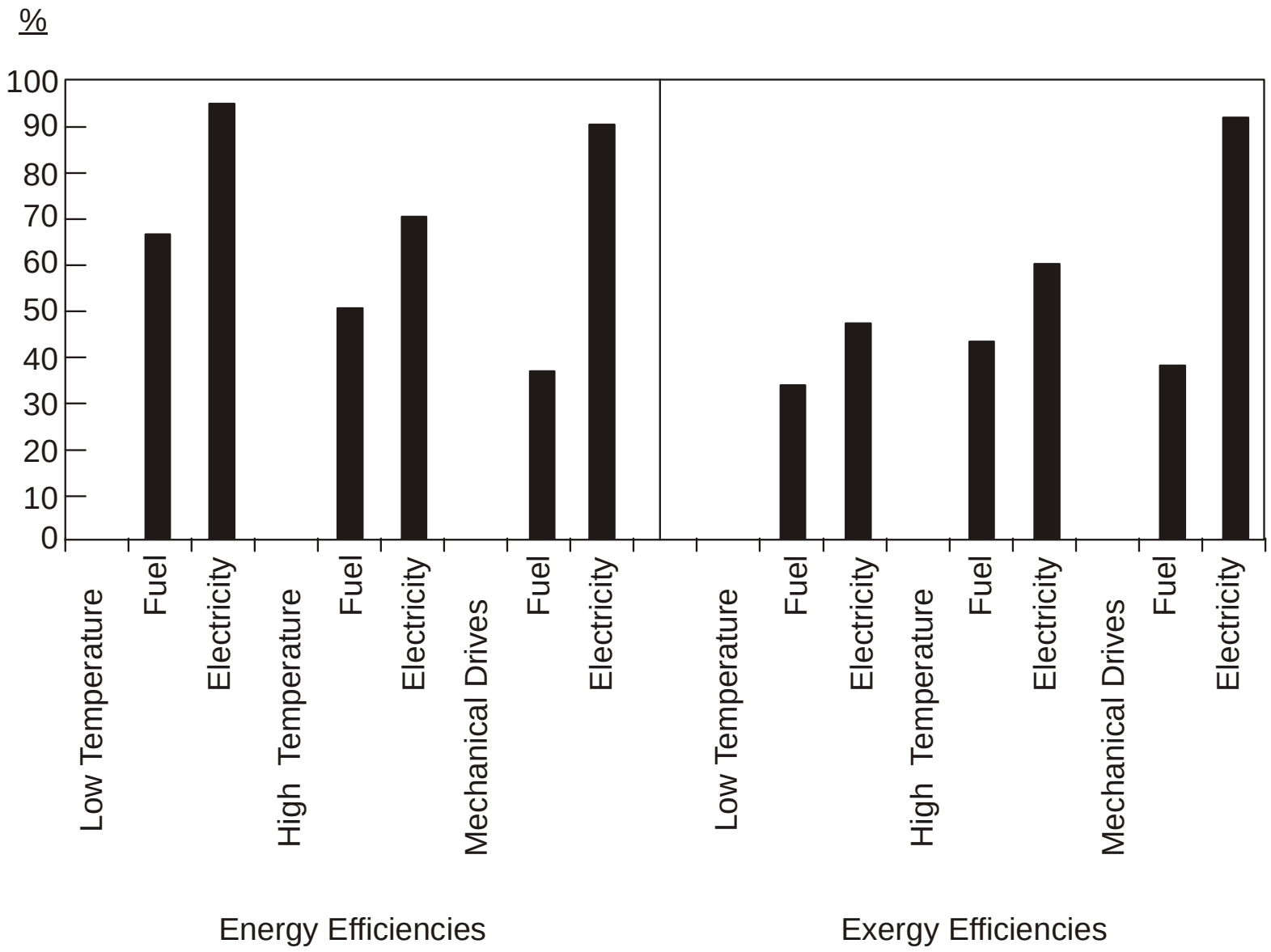
- It identifies scope for improvement potential; 80% in just three sectors of the UK economy - power generation, space heating in buildings and transport

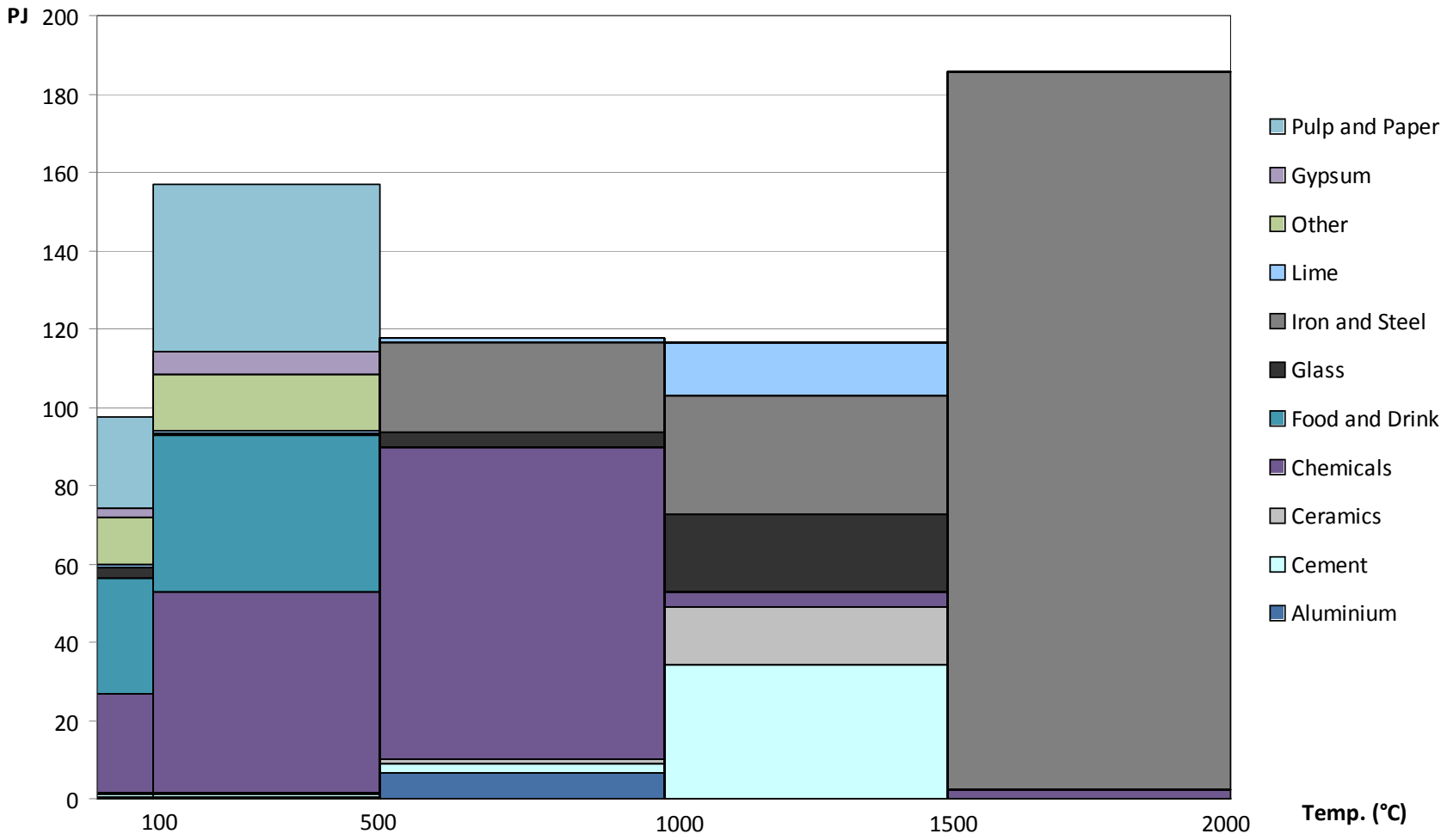
A Cautionary Note: Exergy analysis should not be elevated to a pivotal position

Heat

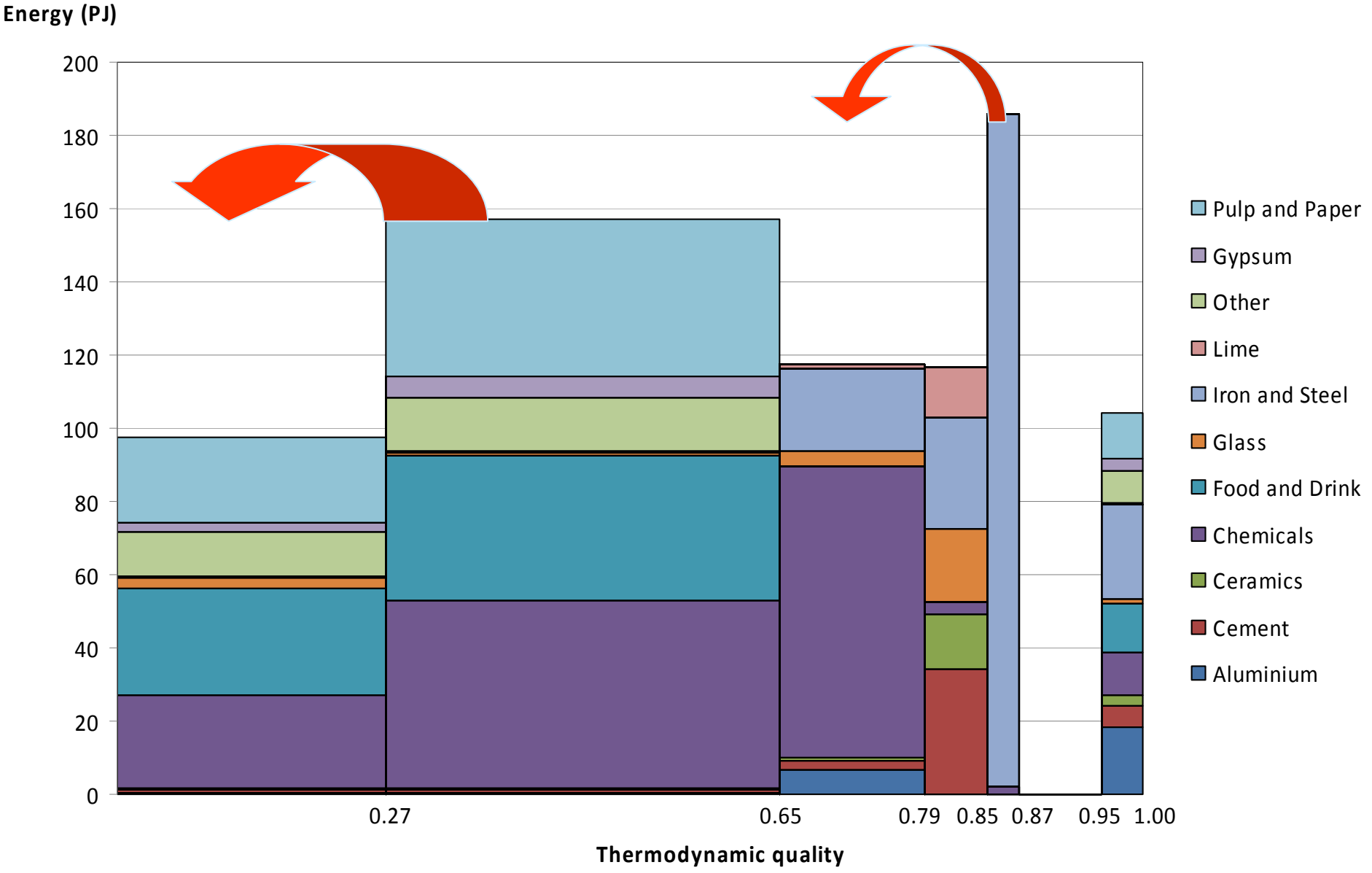

+1
0
-1
-2
-3
Thermodynamic Quality, Θ
Reference State: T_0 = 272K
Unity
-∞
Liquefied Natural Gas
Hot Water Storage
Hot Treatment of Steel
Melting Point of Tungsten
The Sun
10^{-1}
10^{0}
10^{1}
10^{2}
Process Temperature Ratio, T_P/T_0

Heat


%
100
90
80
70
60
50
40
30
20
10
0
Low Temperature
Fuel
Electricity
High Temperature
Fuel
Electricity
Mechanical Drives
Fuel
Electricity
Low Temperature
Fuel
Electricity
High Temperature
Fuel
Electricity
Mechanical Drives
Fuel
Electricity
Energy Efficiencies
Exergy Efficiencies


PJ
200
180
160
140
120
100
80
60
40
20
0
100
500
1000
1500
2000
Temp. (°C)
Pulp and Paper
Gypsum
Other
Lime
Iron and Steel
Glass
Food and Drink
Chemicals
Ceramics
Cement
Aluminium

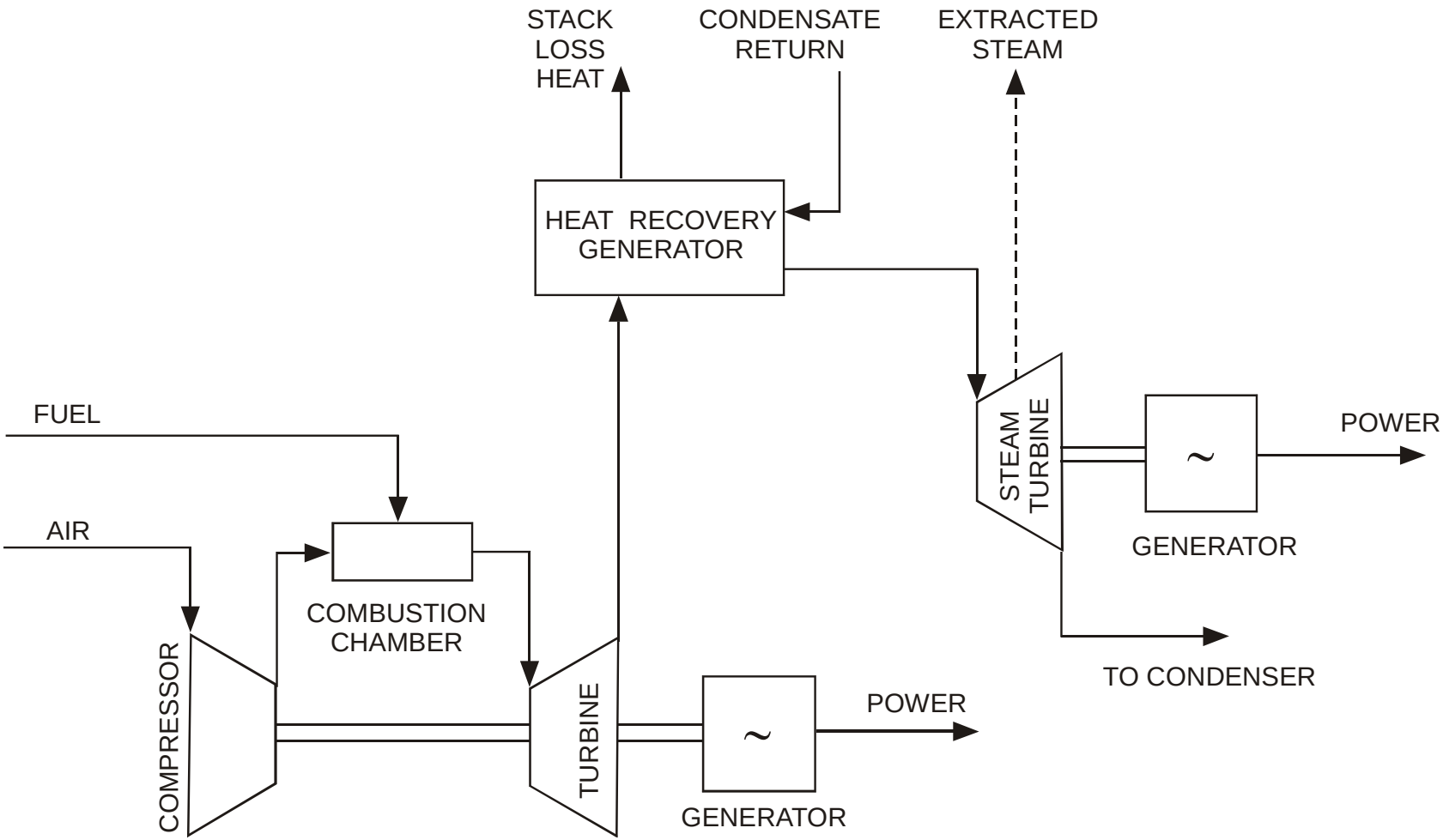
Heat

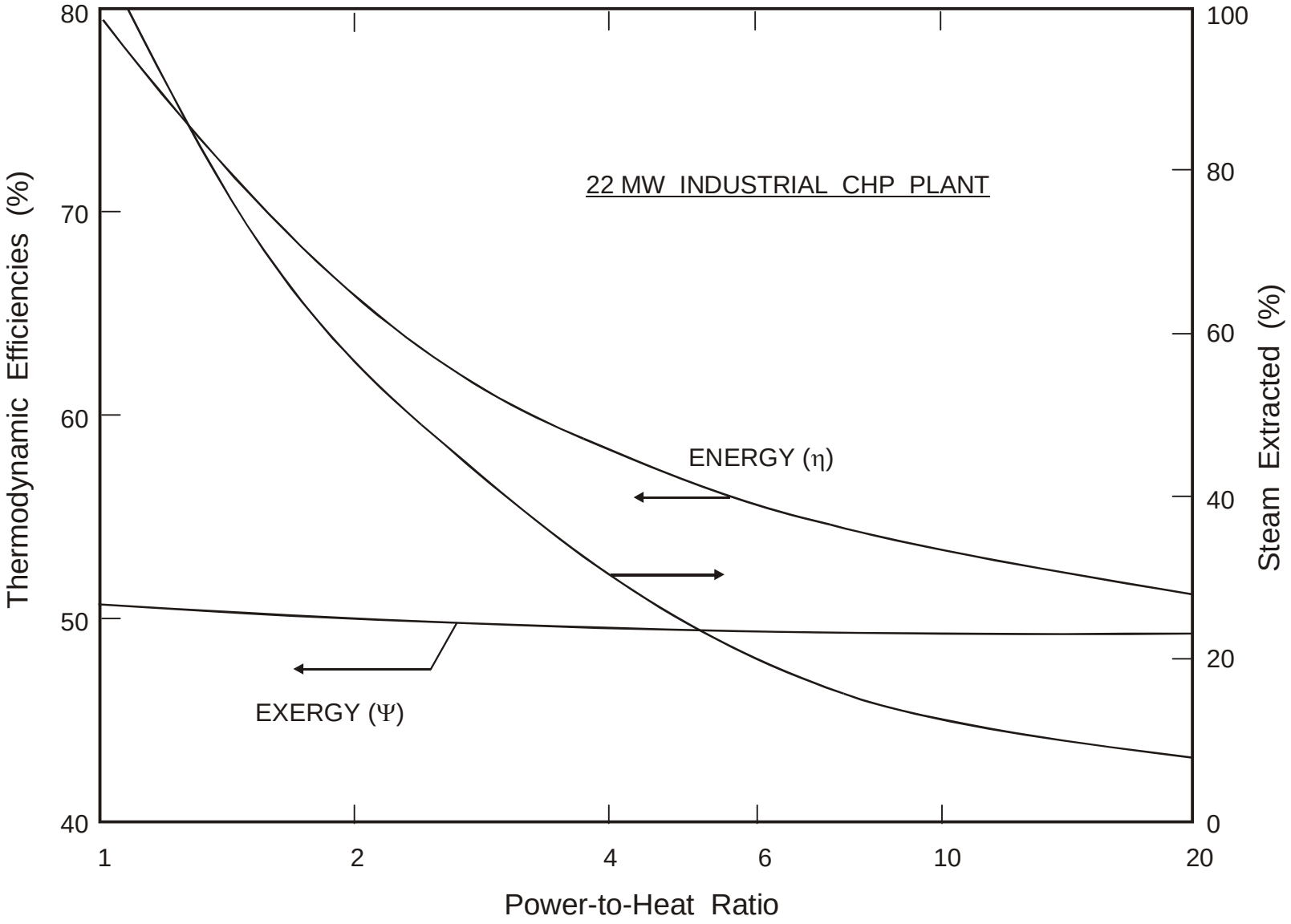

Energy (PJ)
200
180
160
140
120
100
80
60
40
20
0
0.27
0.65
0.79
0.85
0.87
0.95
1.00
Thermodynamic quality
Pulp and Paper
Gypsum
Other
Lime
Iron and Steel
Glass
Food and Drink
Chemicals
Ceramics
Cement
Aluminium
Heat

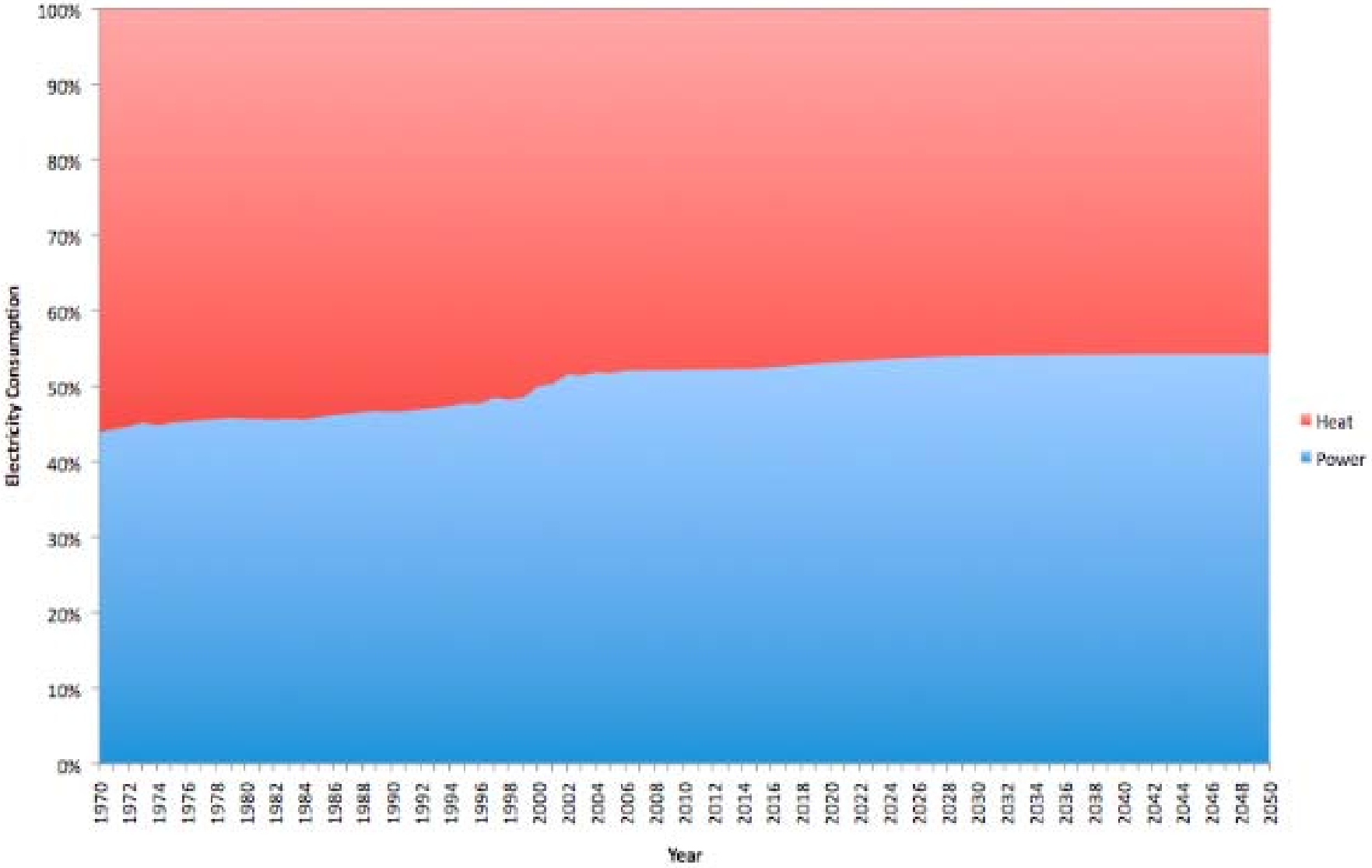
ELECTRICITY AS AN ENERGY CARRIER

- "CAPITAL RESOURCE"
  - Primarily based on depleting fossil and nuclear fuels
  - Contrast with renewable (income) sources – biomass, solar, tidal, wave and wind
- VERY DIFFICULT TO STORE – mainly instantaneous use
- LARGE ENERGY LOSSES IN GENERATION
  - Unless used in conjunction with combined heat and power (CHP) plant
- HIGH GRADE RESOURCE
  - High thermodynamic quality or 'exergy' ($\theta = 1$) , but inefficient when used for meeting space and water heating demand
  - Amory Lovins suggested that power is only required for 10% of final energy use (USA, 1977). What for the UK in 2005?

Heat


STACK
LOSS
HEAT
CONDENSATE
RETURN
EXTRACTED
STEAM
HEAT RECOVERY
GENERATOR
FUEL
AIR
COMBUSTION
CHAMBER
COMPRESSOR
TURBINE
~
GENERATOR
POWER
STEAM
TURBINE
~
GENERATOR
POWER
TO CONDENSER

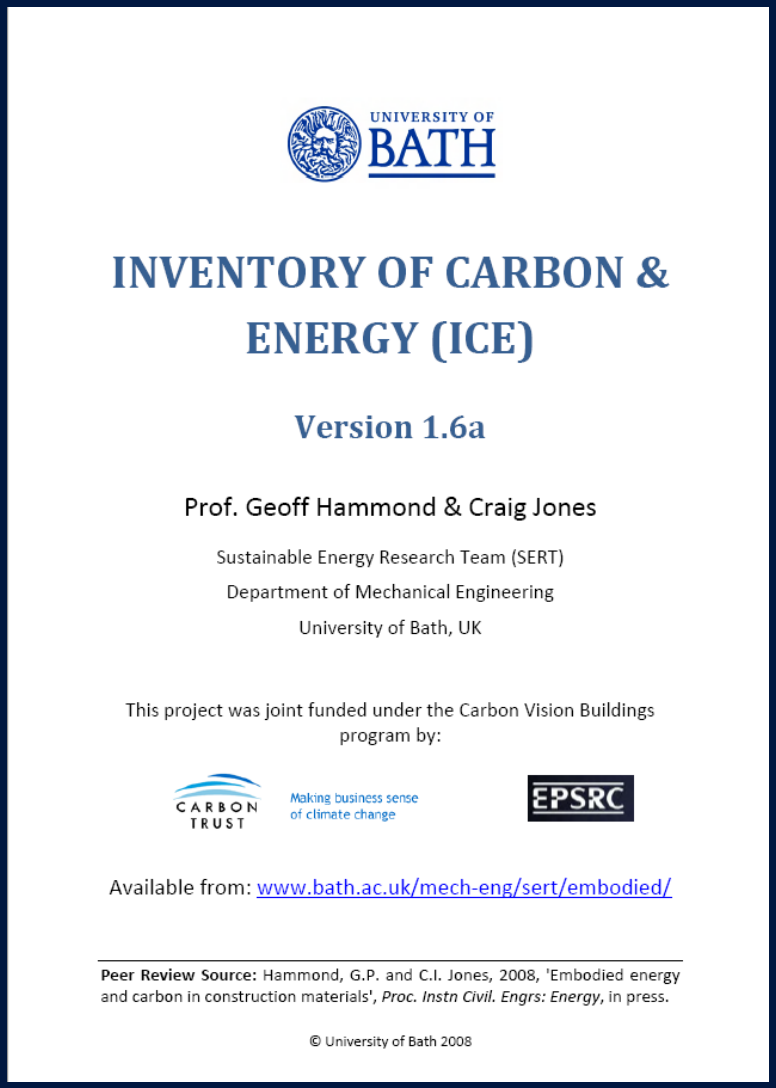

22 MW INDUSTRIAL CHP PLANT
Thermodynamic Efficiencies (%)
Steam Extracted (%)
Power-to-Heat Ratio
ENERGY (η)
EXERGY (Ψ)
80
70
60
50
40
100
80
60
40
20
0
1
2
4
6
10
20


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Electricity Consumption
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
Year
Heat
Power

Heat

INVENTORY OF CARBON & ENERGY (ICE)

- An embodied energy and carbon database for building materials
- ICE Excel and *pdf* files created to summarise data
- Draws from over 160 references
- Embodied energy & carbon coefficients ~ 400 selected values
- Aim: Typical & usable market products
- Identifies primary & secondary materials
- Available freely online



UNIVERSITY OF BATH

INVENTORY OF CARBON & ENERGY (ICE)

Version 1.6a

Prof. Geoff Hammond & Craig Jones

Sustainable Energy Research Team (SERT)

Department of Mechanical Engineering

University of Bath, UK

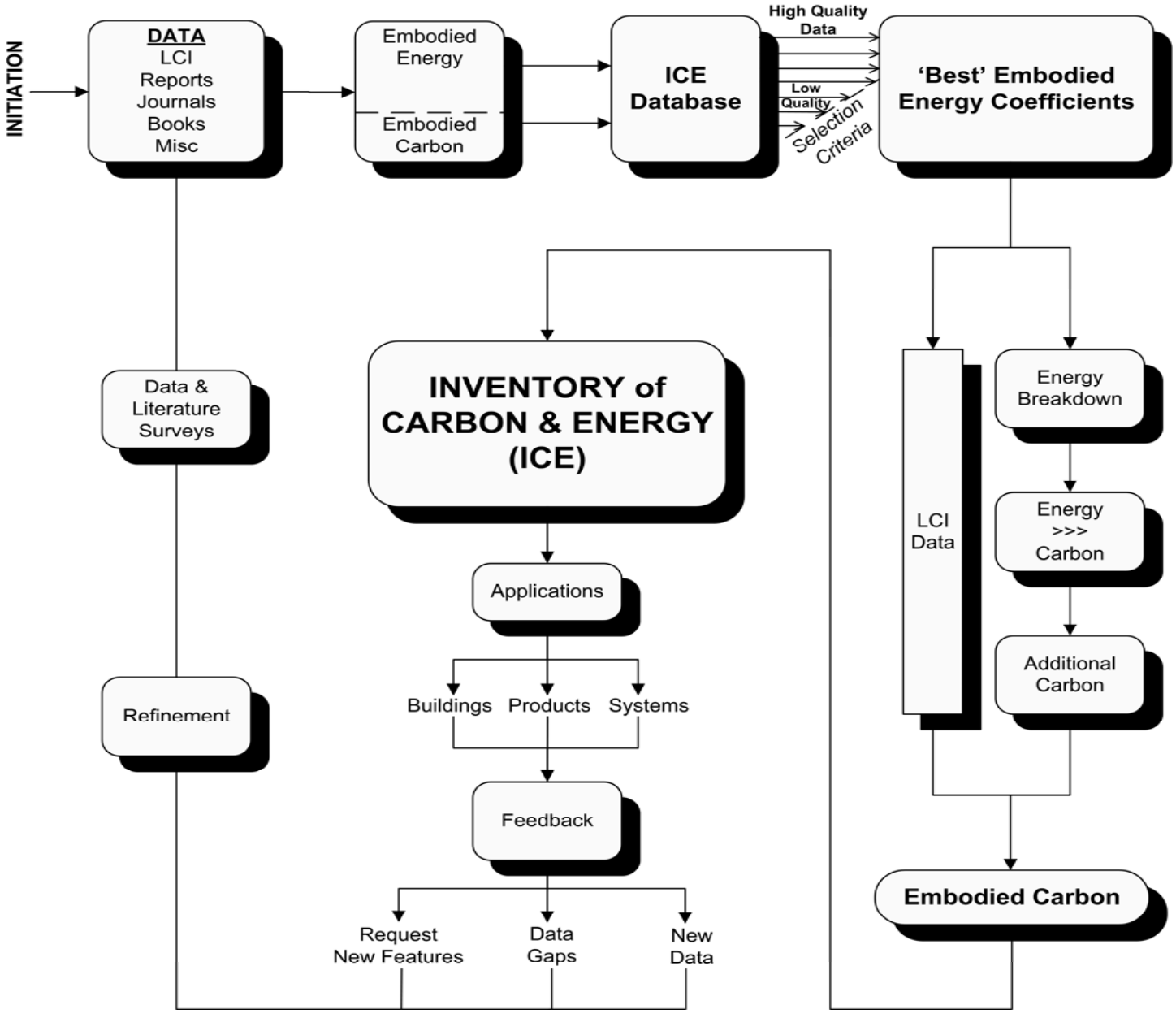
This project was joint funded under the Carbon Vision Buildings program by:

CARBON TRUST Making business sense of climate change

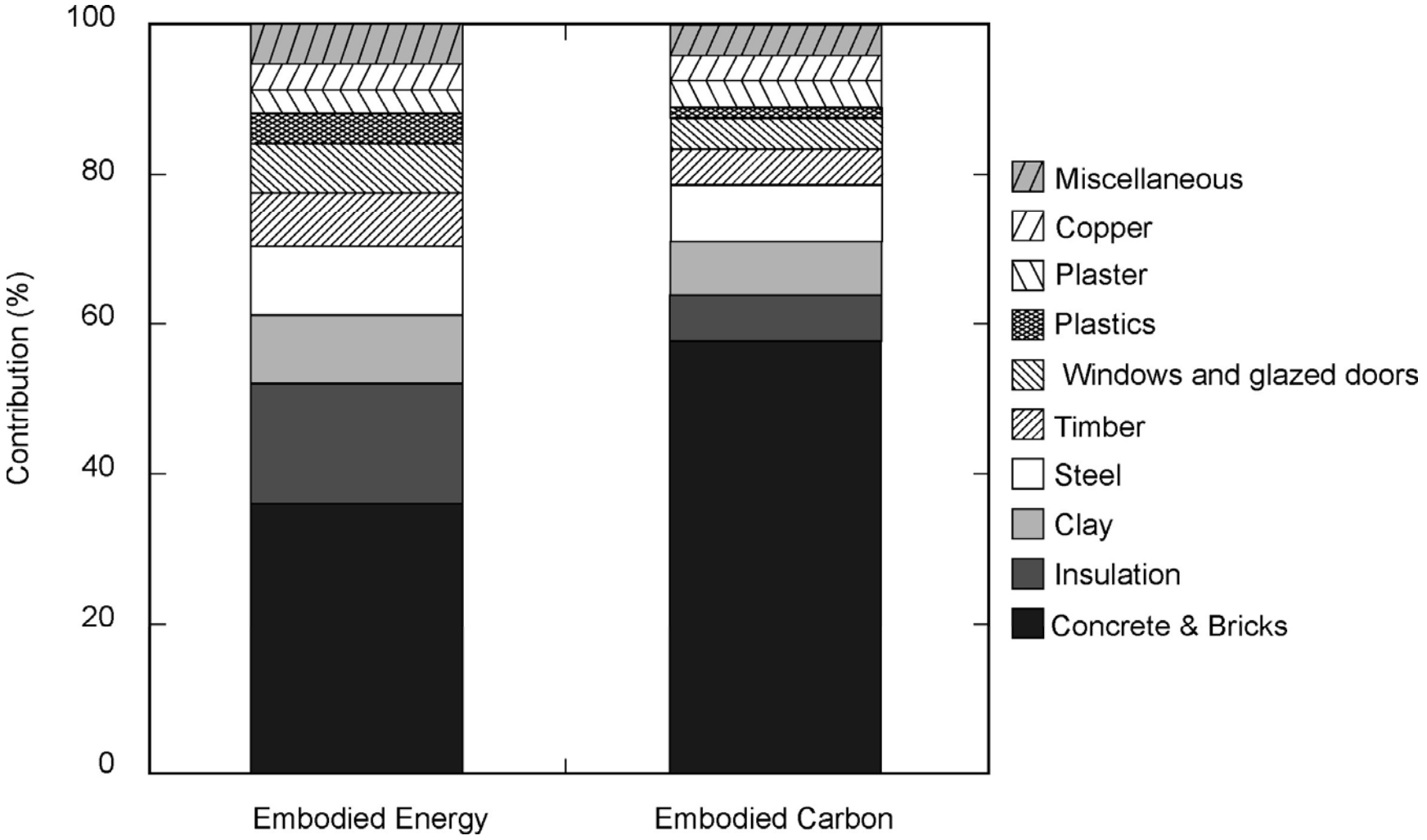
EPSRC

Available from: www.bath.ac.uk/mech-eng/sert/embodied/

Peer Review Source: Hammond, G.P. and C.I. Jones, 2008, 'Embodied energy and carbon in construction materials', *Proc. Instn Civil. Engrs: Energy*, in press.


INITIATION
DATA
LCI
Reports
Journals
Books
Misc
Embodied Energy
Embodied Carbon
ICE Database
High Quality Data
Low Quality
Selection Criteria
'Best' Embodied Energy Coefficients
Data & Literature Surveys
INVENTORY of CARBON & ENERGY (ICE)
Applications
Buildings
Products
Systems
Feedback
Request New Features
Data Gaps
New Data
Refinement
LCI Data
Energy Breakdown
Energy >>> Carbon
Additional Carbon
Embodied Carbon

Heat

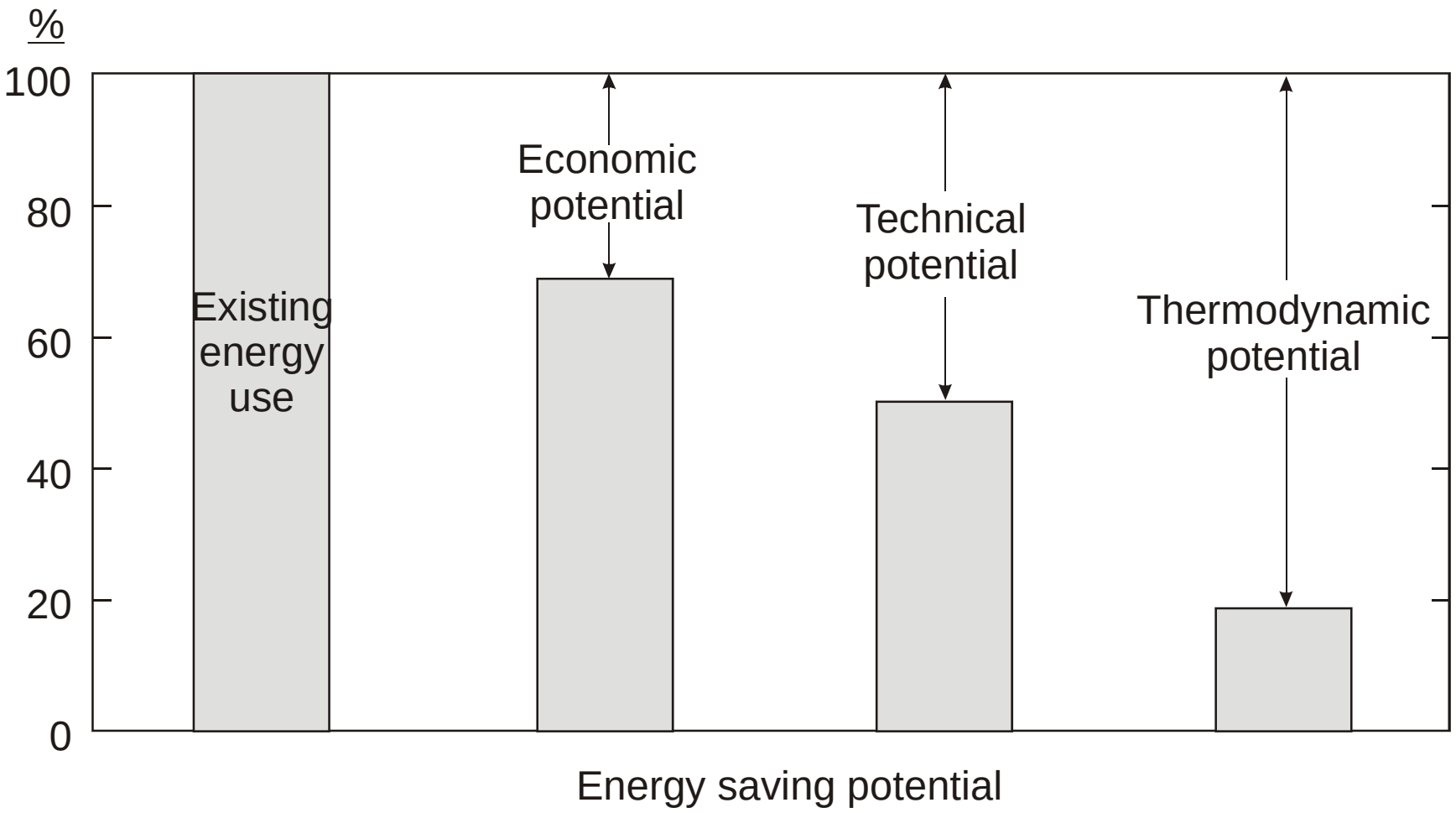

100
80
60
40
20
0
Contribution (%)
Embodied Energy
Embodied Carbon
Miscellaneous
Copper
Plaster
Plastics
Windows and glazed doors
Timber
Steel
Clay
Insulation
Concrete & Bricks

ENERGY EFFICIENCY OPTIONS

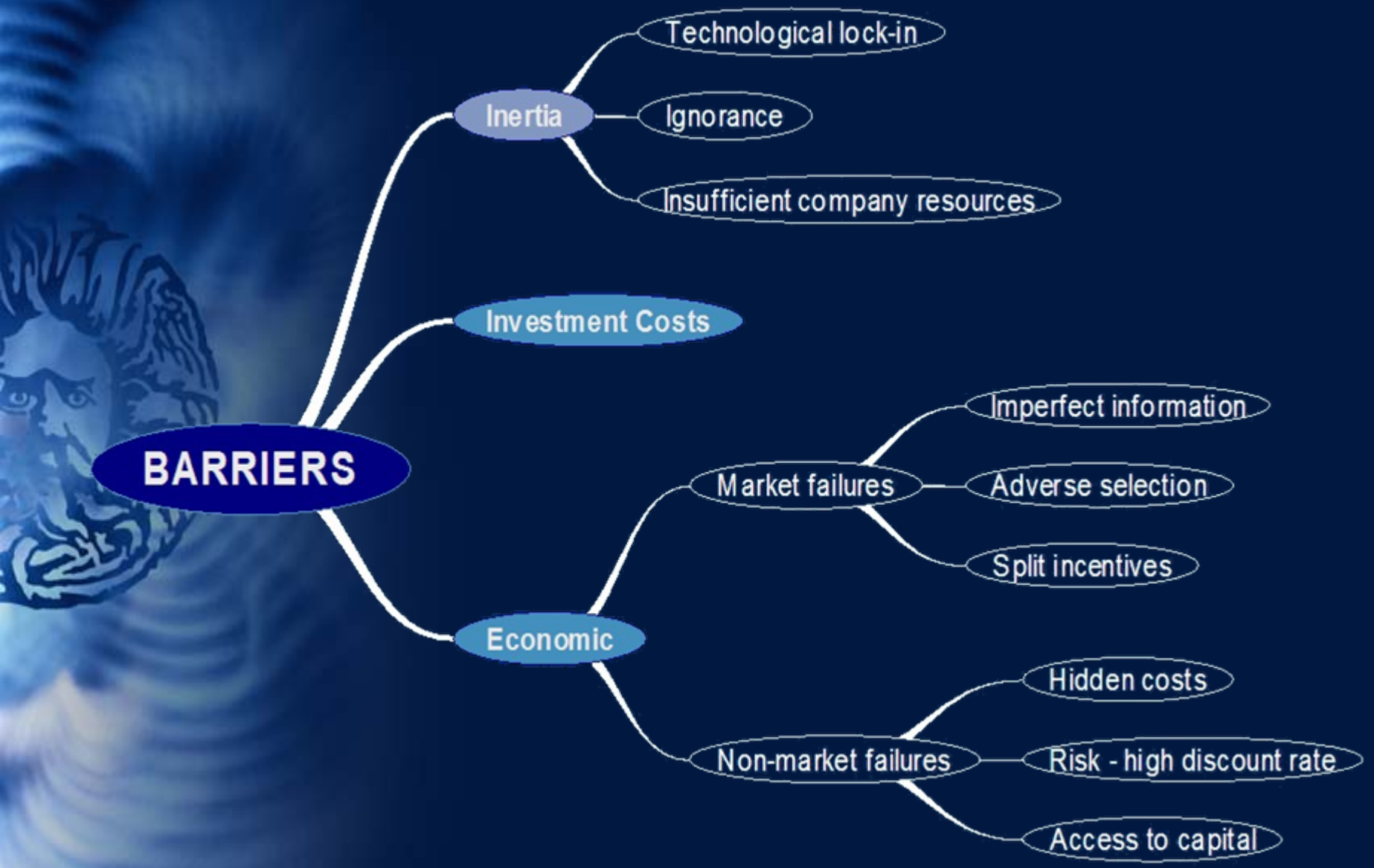
- **BUILDINGS: Domestic, commercial, institutional and industrial**
  - ⇒ improved thermal insulation
  - ⇒ condensing boilers
  - ⇒ automatic heating controls
  - ⇒ high efficiency and long-life lighting systems
  - ❖ Potential residential energy saving: ~210 PJ (or ~ 60 TWh); BERR *Heat Call for Evidence*, 2008
- **INDUSTRY:**
  - ⇒ improved combustion processes
  - ⇒ dematerialisation and the use of innovative materials
  - ⇒ process optimisation
  - ⇒ better process monitoring and control
  - ❖ Heat recovery potential: 39-77 PJ (or 11-22 TWh); ETI/Bath

IMPROVING ENERGY PRODUCTIVITY IN INDUSTRY

- **Improved exergetic efficiencies,** e.g., through:
  - Heat cascading and recovery
  - Co-generation (CHP) and tri-generation
  - Community/district heating schemes
  - Co-location and eco-industrial parks
- **Dematerialisation ("more with less") –** Factor 4, 10, X …
  - e.g., glass bottles
- **Barriers remain …**


%
100
80
60
40
20
0
Existing energy use
Economic potential
Technical potential
Thermodynamic potential
Energy saving potential

BARRIERS TO INDUSTRIAL ENERGY EFFICIENCY



Heat

‘THE ENERGY HIERARCHY’

- Strategic energy options advocated for the UK [House of Commons’ Environmental Audit Committee (1999)] –

- **end-use energy efficiency**
- **renewable energy technologies**; for both heat and power
- **combined heat and power (CHP)**
- **(low carbon) fossil fuels** ⇒ replacing coal by natural gas, or adding carbon capture and storage (CCS)
- **new nuclear power reactors** – that the industry claims are inherently safer than previous designs, but would need operational approvals and take ~15 years to plan, construct and commission

Heat

CONCLUSIONS REMARKS - 1

- '*Whole systems*' and '*sustainability*' perspectives are important in analysing energy systems.
- Thermodynamic concepts and tools provide a means for identifying where the improvement potential lies.
- The quantity and quality of energy carriers should be considered.
- *Energy-intensive industries* – Savings from the development of high-temperature processes and heat recovery at lower temperatures.
- Economic barriers will limit the technical improvement potential to only some 50%.
- Even that would make a significant contribution to energy demand and carbon reduction in UK buildings and industry.

CONCLUSIONS REMARKS – 2

Work in progress at Bath -

- Little “low hanging fruit” left in industry due to price-sensitive management?
- Decline in “heavy” industry to cease/stabilise?
- Increased demand for electricity offset by decarbonisation?
- Direct emissions (process+combustion) will dominate by 2020?
- Options for decarbonising buildings and industry further...
  - Low carbon heat – e.g., biomass, heat pumps
  - Heat from electricity – e.g., heat pumps, induction heating
  - CCS for some sectors, e.g., cement

THANKS TO OUR SPONSORS AND LISTENERS

ANY QUESTIONS?