



## *Peak exergy and the exergy multiplier effect: Results and implications of 1900-2010 exergy efficiency studies for the UK, US and Japan*

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ARUP

# Exergy efficiency study 1900-2010

## UK, US & Japan



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- 1. Background: Useful work and exergy**
- 2. Ayres & Warr studies UK, US and Japan 1900-2000**
- 3. 2000-2010 update: methodology**
- 4. Results & 3 propositions**
- 5. Conclusions and further research**

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# Exergy and energy (1)

## Definitions



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1. The **usable energy** in a system is called **exergy**, and is the total of the free energies (e.g. kinetic, thermal, potential) in the system **relative to its surrounding environment**
2. **Energy** = **exergy** (useable energy) + **anergy** (useless energy)
3. Unlike energy, exergy can be **consumed**.
4. When **exergy diminishes** in a system, **entropy increases**
5. Exergy is a measure of **quantity and quality**, due to entropy



# Exergy and energy (2)

## Some examples



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**Exergy** of a system is the maximum useful work possible during a process that brings the system into equilibrium with its surroundings



Thermal



Kinetic

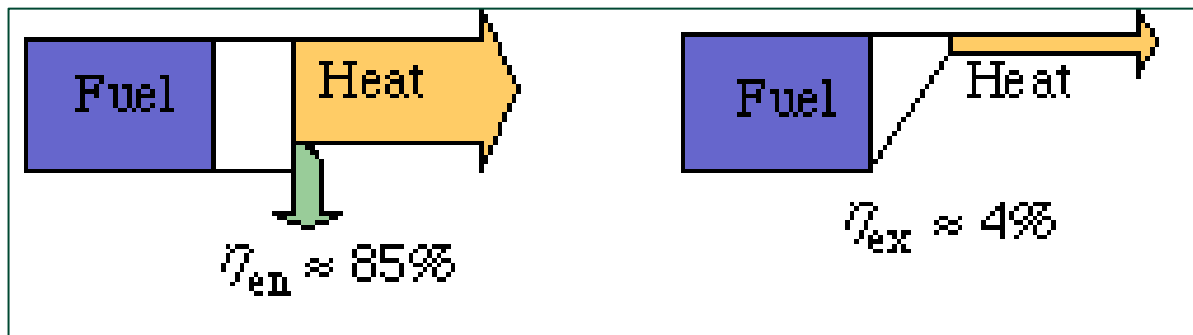


Potential energy

(1st law) **Energy** efficiency,  $\eta = \frac{\text{Energy}_{out}}{\text{Energy}_{in}}$

(2nd law) **Exergy** efficiency,  $\varepsilon = \frac{\text{Useful work (out)}}{\text{Exergy (in)}}$

Example: domestic gas boiler



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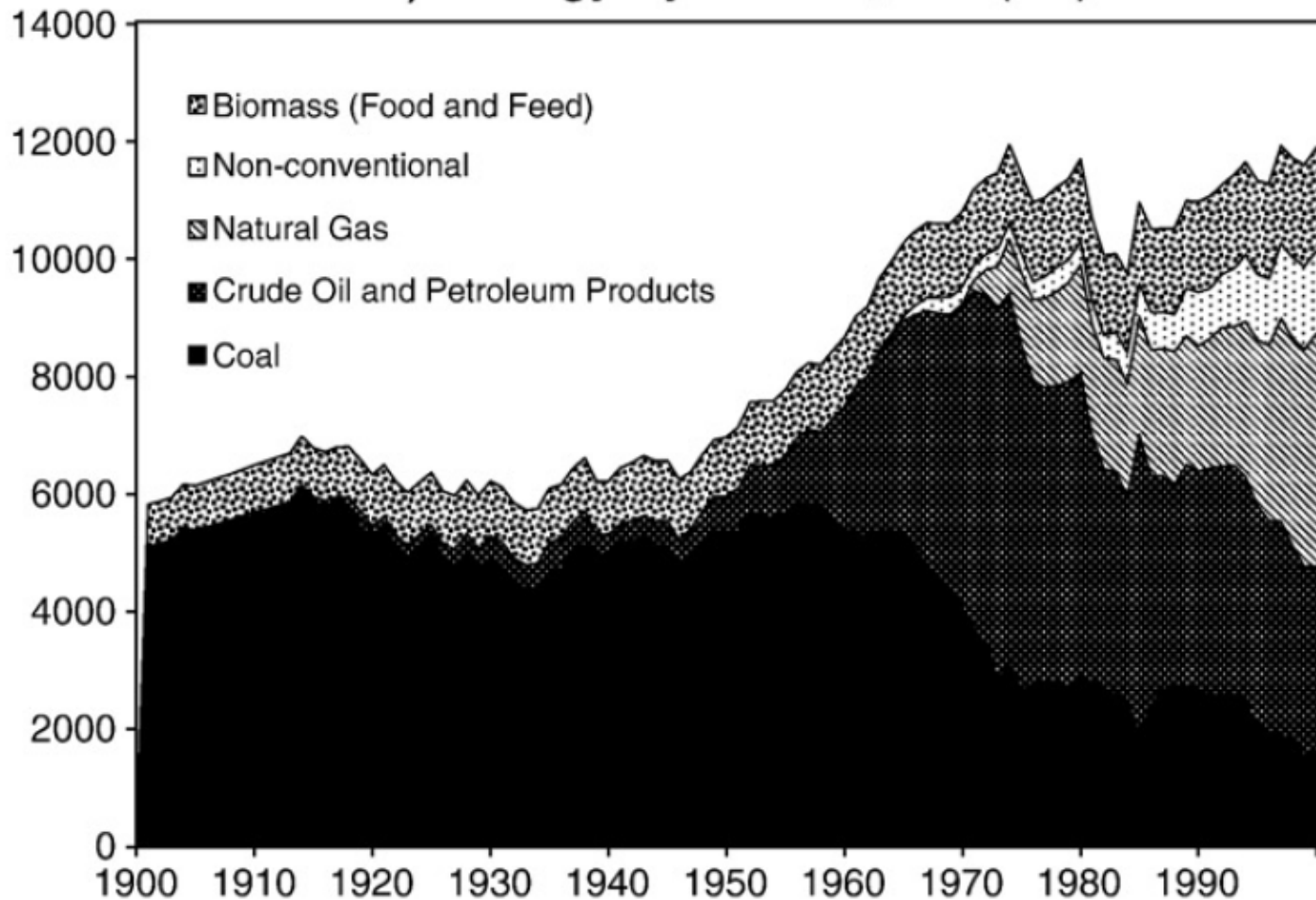
# Ayres & Warr (1)

## Useful work and exergy 1900-2000



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a) Exergy by source, UK (PJ)





# Ayres & Warr (2)

## Linking energy (exergy) and growth

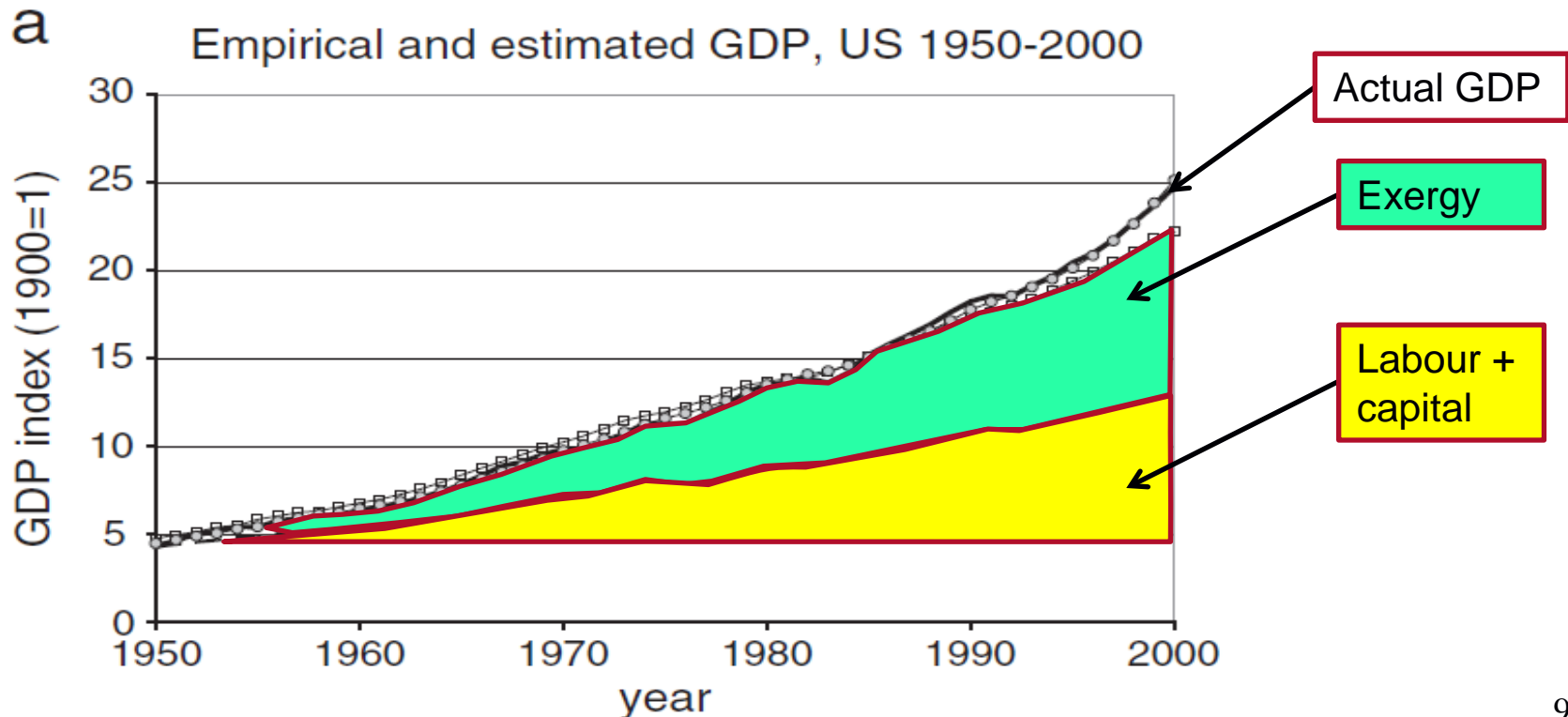


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### Ayres & Warr propose

- Exergy (energy) fills most of the Solow residual  $A(t)$
- Energy share is 10 x cost-share theorem value (3-4%)

$$Y(t) = A(t) \cdot L(t)^\alpha \cdot K(t)^\beta$$



# Useful work and exergy

## What? & Why?



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**What?** There is a need to explore exergy analysis as a tool to see what insights can be gained into **future energy use** and **economic growth**

### Why?

1. Renewables transition is coming
2. 1<sup>st</sup> transition based on policy
3. Best evidence needed for policy
4. All the 'tools in the box'
5. Thus use exergy as alternative to traditional energy analysis

### Why?

1. Economic growth is entering new era of instability
2. Understanding building blocks of growth aids future economic policy
3. Thus use exergy to explore links between energy and growth

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## UK, US & Japan



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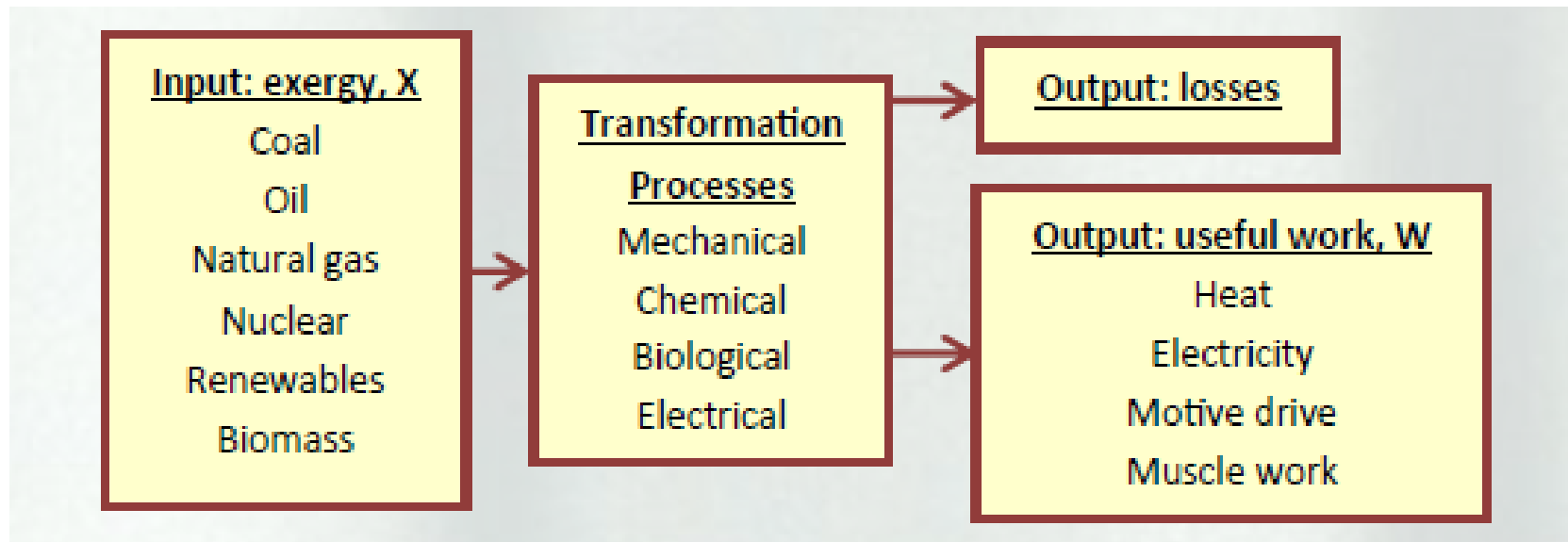
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# Exergy conversion to useful work

## Basic overview

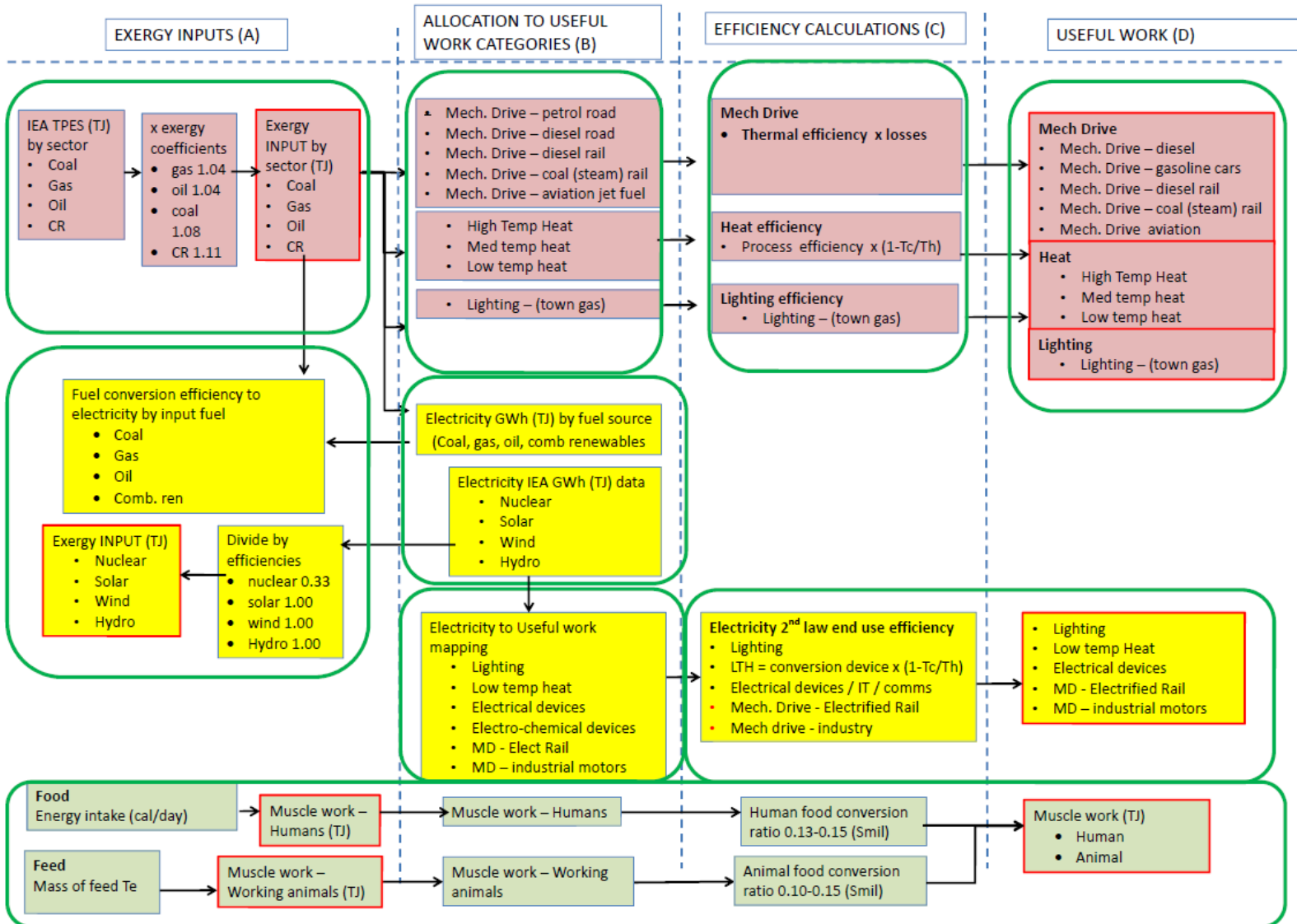


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# Exergy conversion to useful work

## More detail



# Exergy efficiency study 1900-2010

## UK, US & Japan



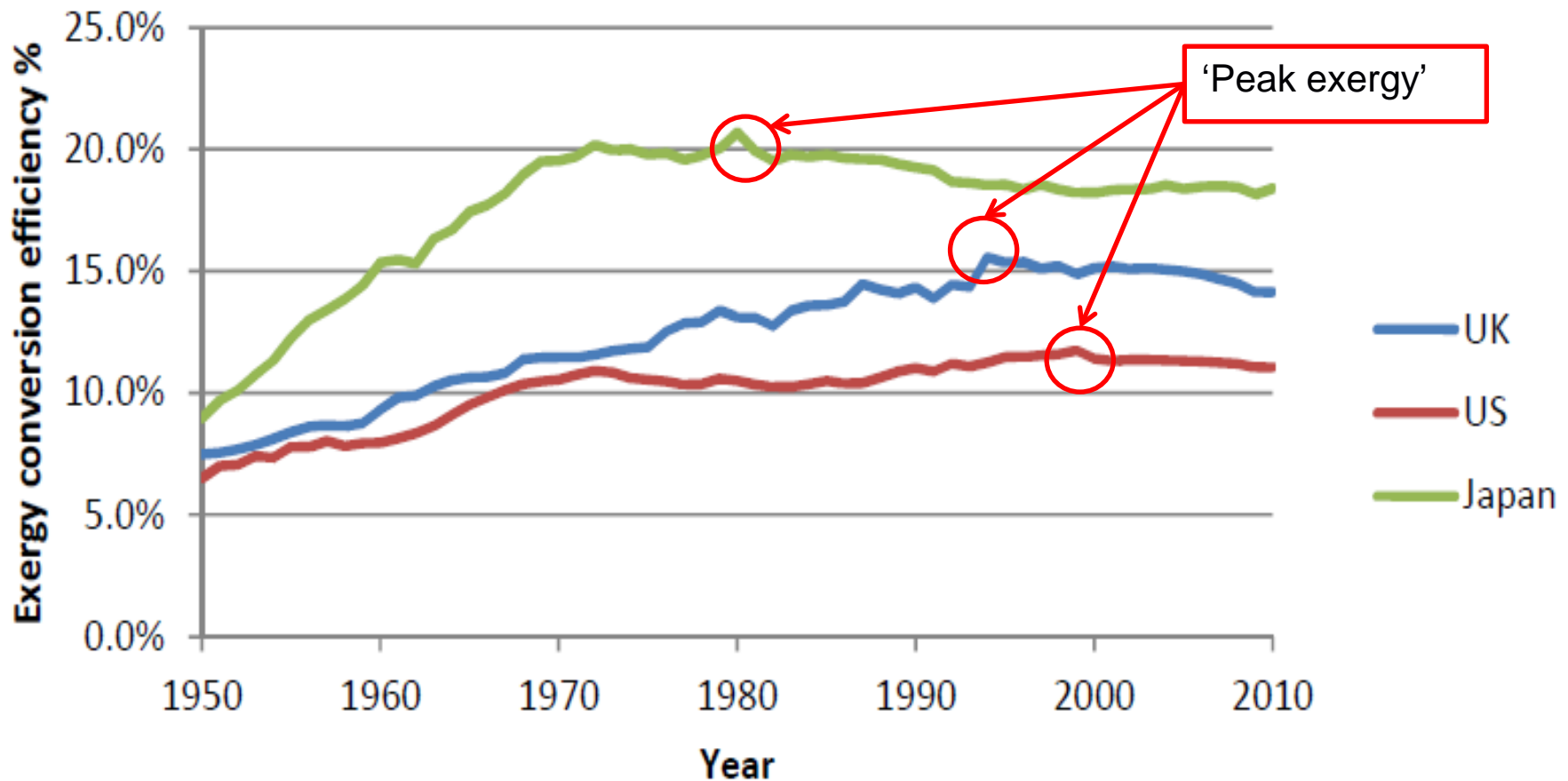
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# 2000-2010 results: Finding #1 'Peak exergy' efficiency



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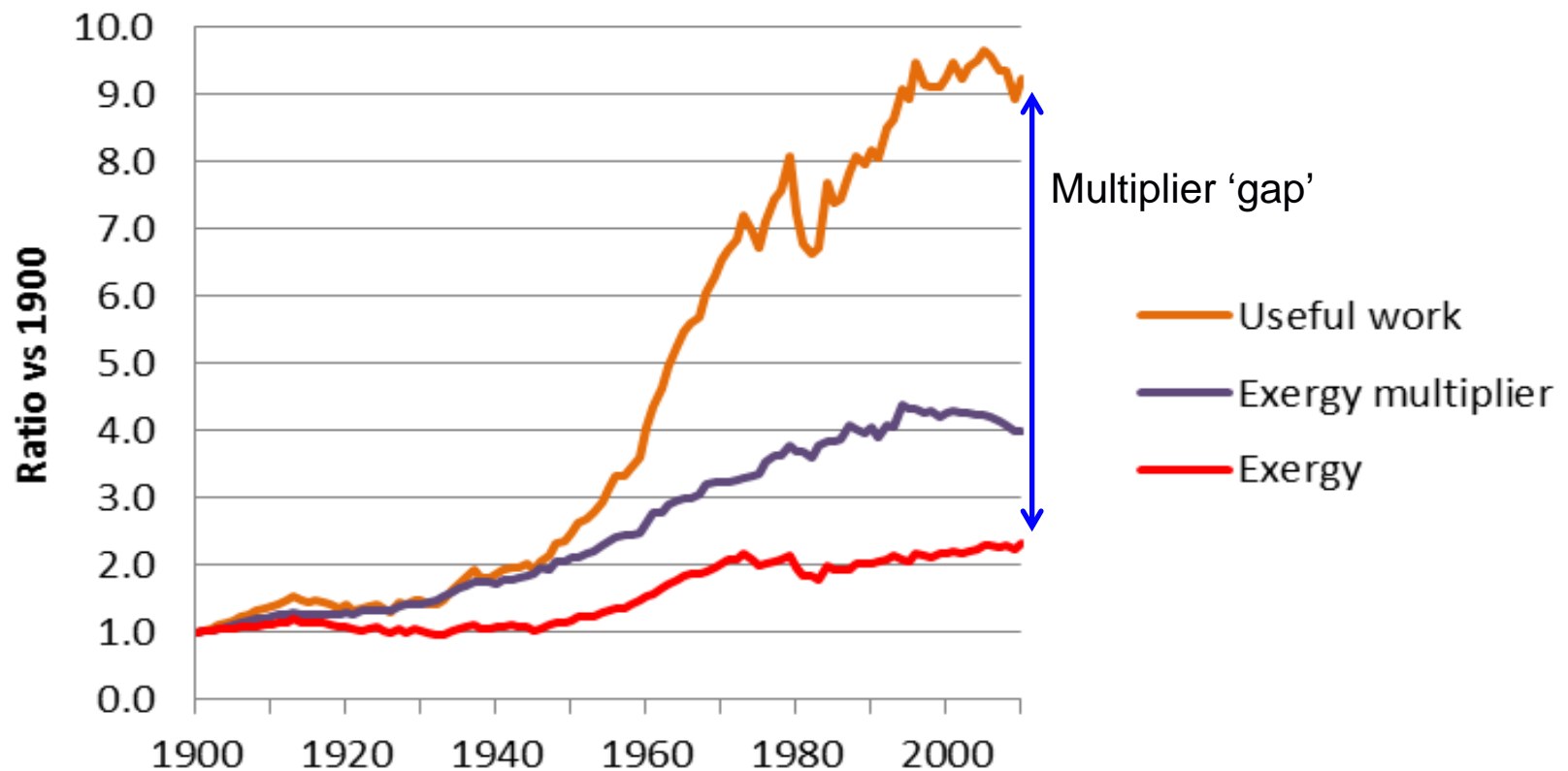


# 2000-2010 results: Finding #2

## The 'exergy multiplier' - UK



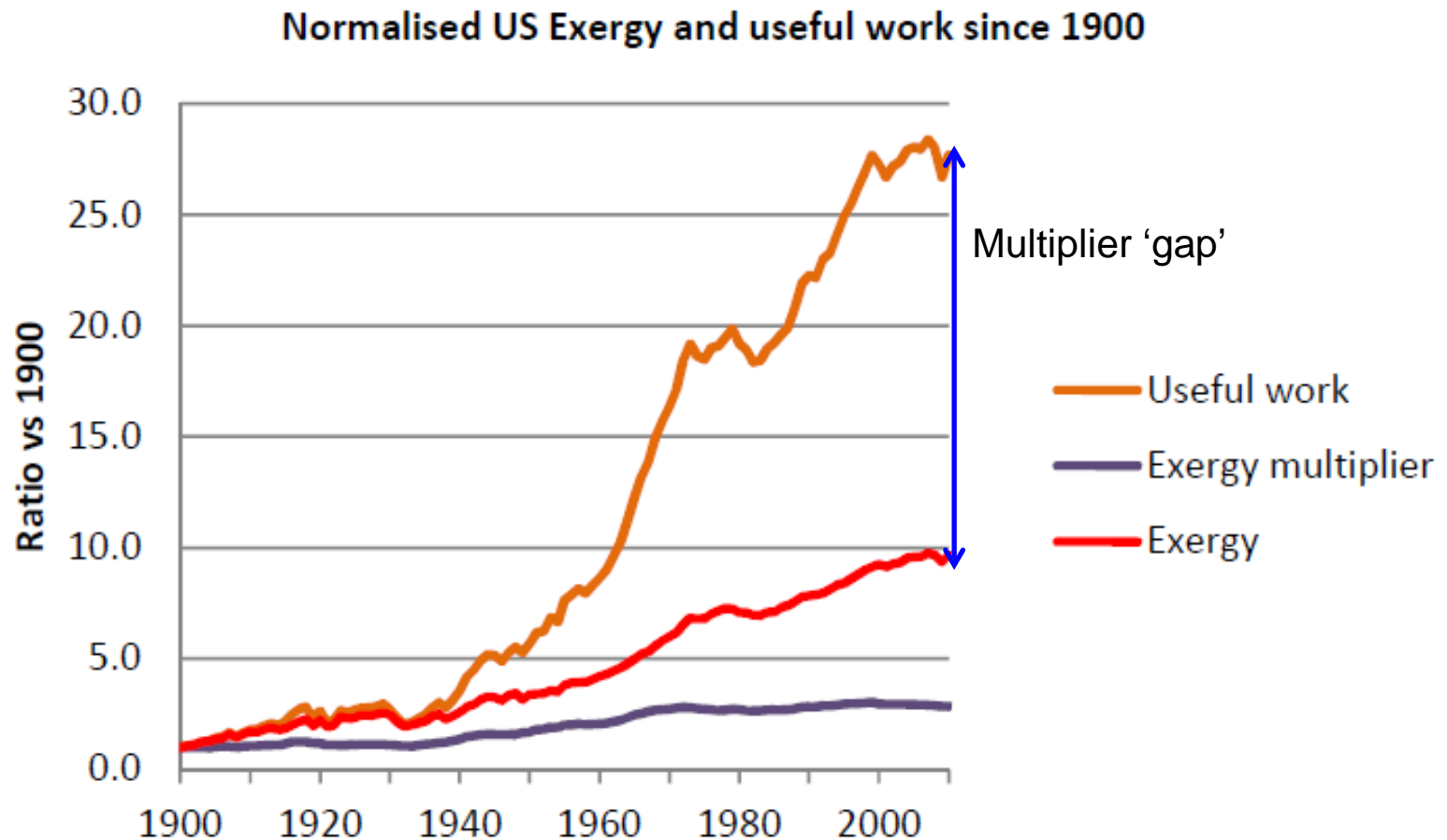
### Normalised UK Exergy and useful work since 1900





# 2000-2010 results: Finding #2

## The 'exergy multiplier' - US

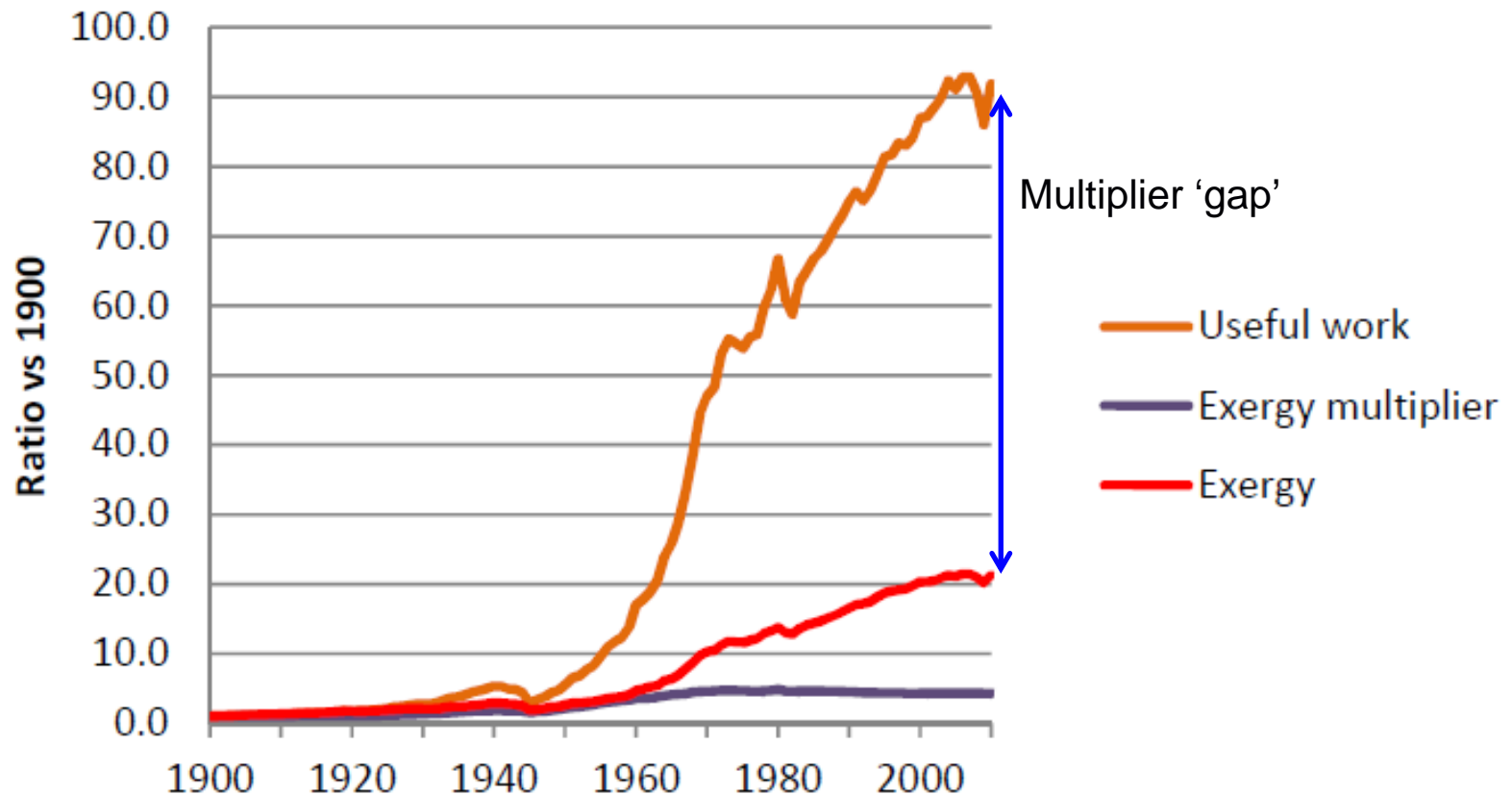


# 2000-2010 results: Finding #2

## The 'exergy multiplier' - Japan



### Normalised Japan Exergy and useful work since 1900



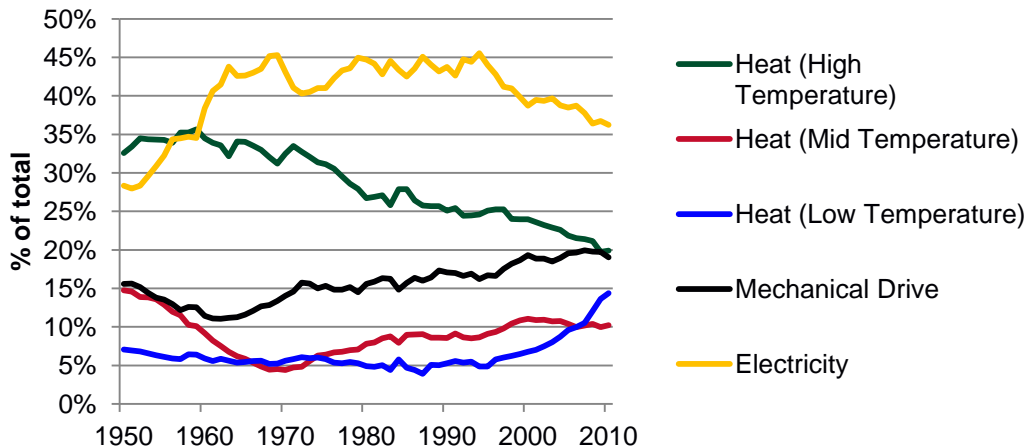
# Proposition #1: Peak exergy exists



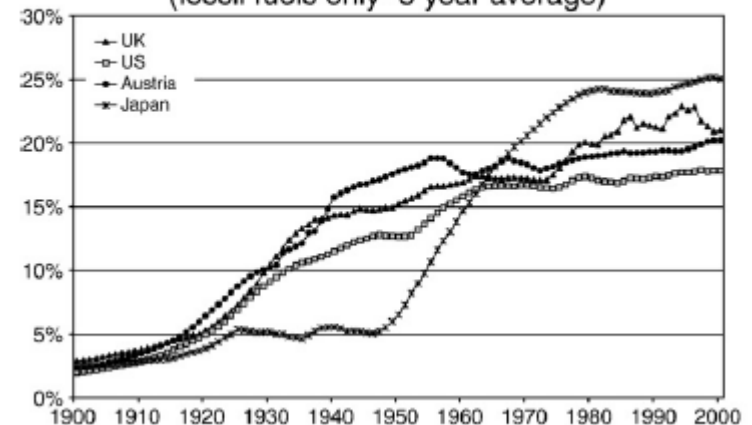
Exergy efficiency is **peaking** in OECD countries due to:

- a) Efficiency dilution
- b) Asymptotic efficiency limits

UK - useful work contribution from different energy uses 1950-2010



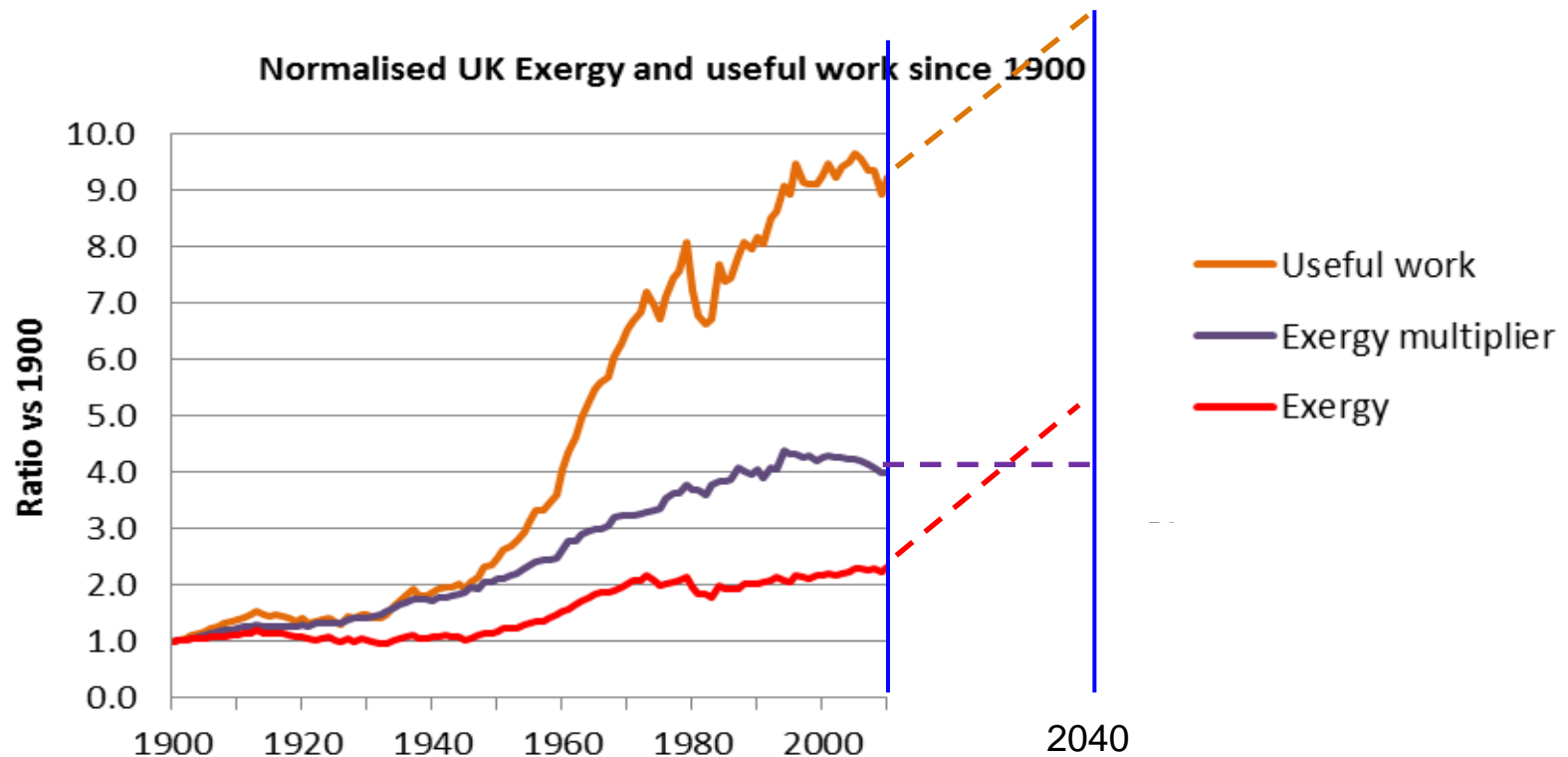
a) Efficiency of electricity generation (fossil fuels only- 5 year average)



# Proposition #2: Exergy multiplier effect & energy use



The 'exergy multiplier' effect means future energy (exergy) demand is currently **underestimated**

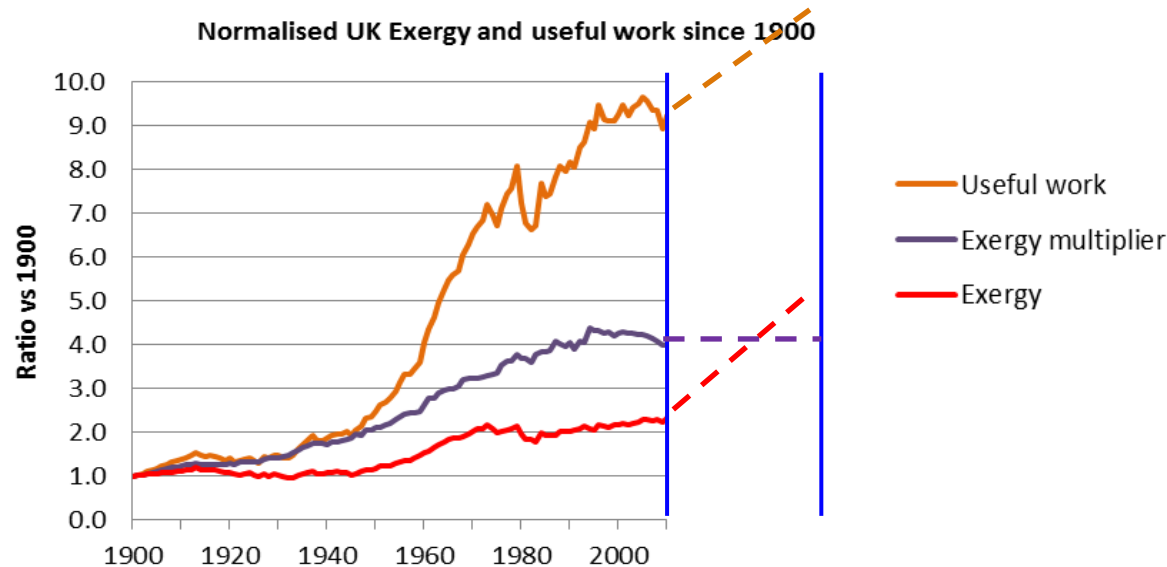


# Proposition #3: Constraints to economic growth



Assuming the causal link between useful work & growth exists (i.e. cost-share theorem is invalid) then **GDP may be constrained in future** by:

- a) Engine of growth (energy efficiency) being turned off / slowed down – proposition #1
- b) Lack of exergy (energy) supply – proposition #2



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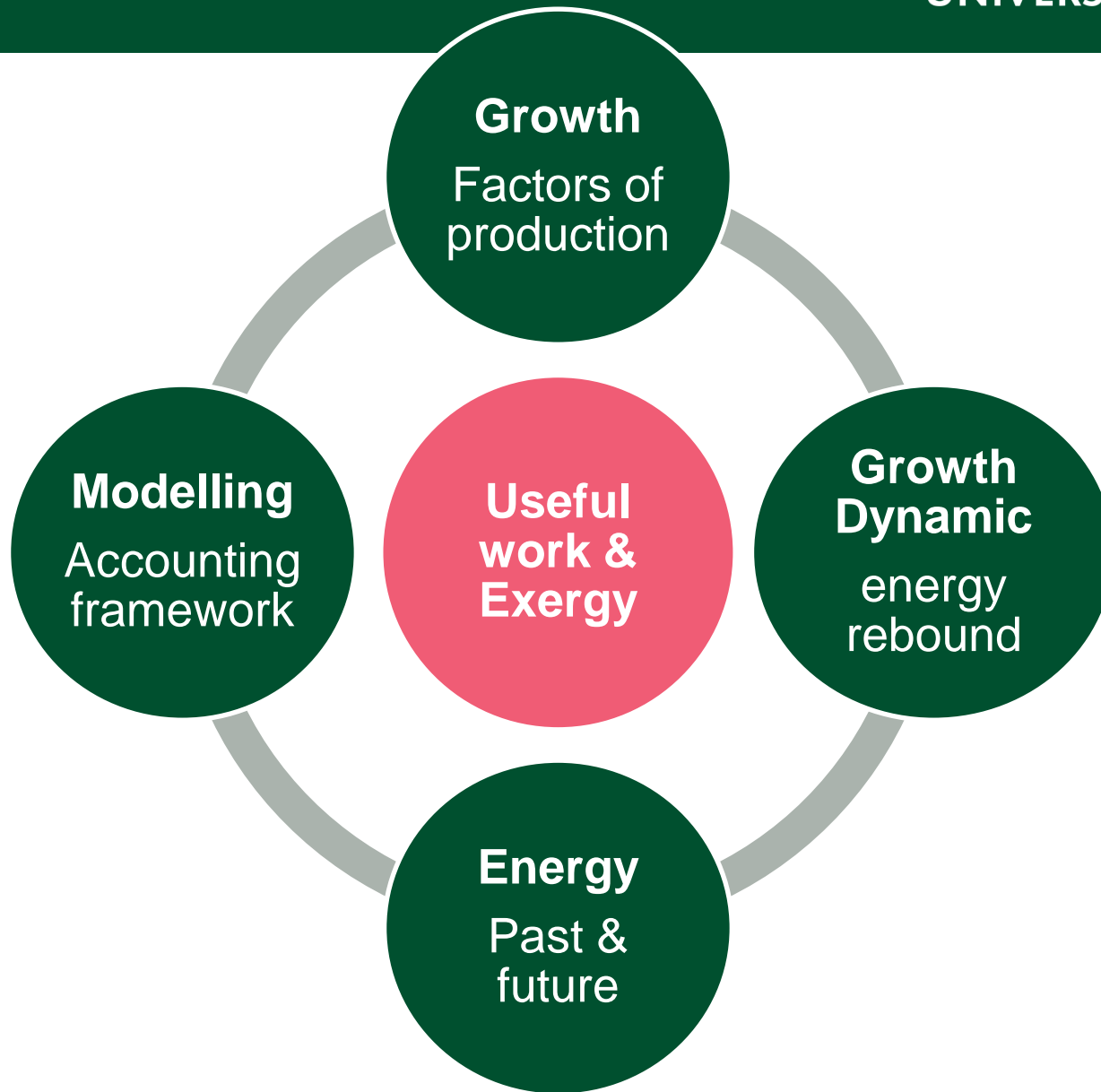


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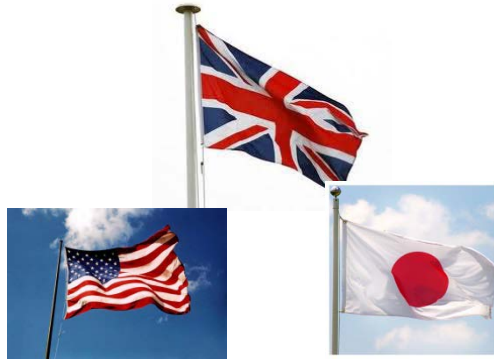


1. 1900-2010 preliminary results suggest:
  - a) 'Peak exergy' efficiency has occurred in UK, US and Japan
  - b) 4-fold 'multiplier' will not be repeated this century which has potential implications for future energy use and growth
2. Exergy analysis is the 'poor cousin' of energy analysis
3. Exergy can be a useful complementary approach for energy and economic growth studies





## 1. Repeat Ayres/Warr analysis



## 2. Include China



## 3. Growth linkages



## 4. The future



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**Project page:**  
<http://www.see.leeds.ac.uk/people/p.brockway>