Energy Criteria for Sustainable Energy Solutions

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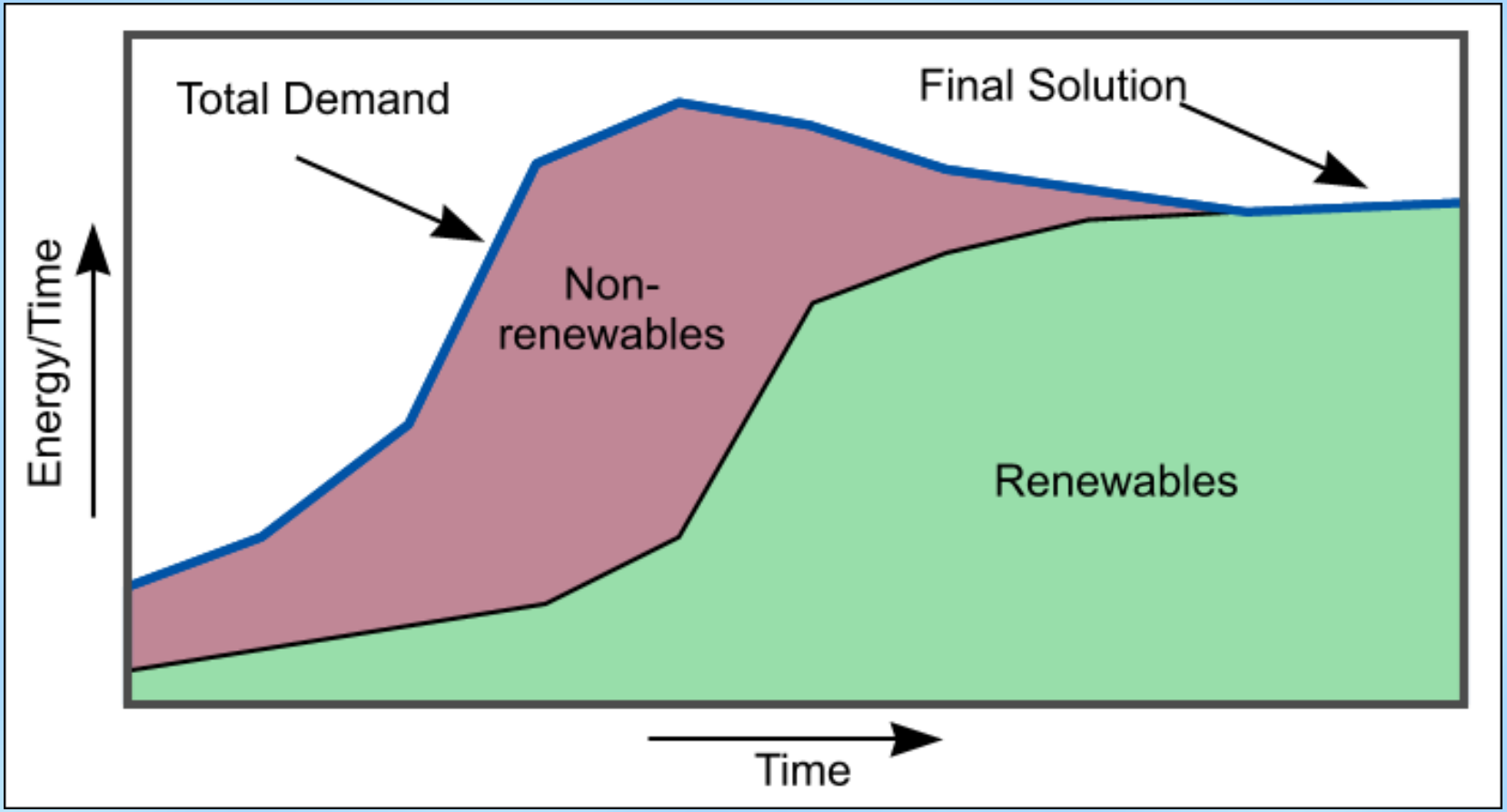
G T Systems

Overview

- Transitions - Smooth and Abrupt
- Energy Analysis
- Climate Limits and Carbon Reserves
- Criteria for Sustainable Energy Solutions
- Sectoral examples
- Transition studies for World and OECD
- A smooth transition to sustainability requires the energy choices to be science-based

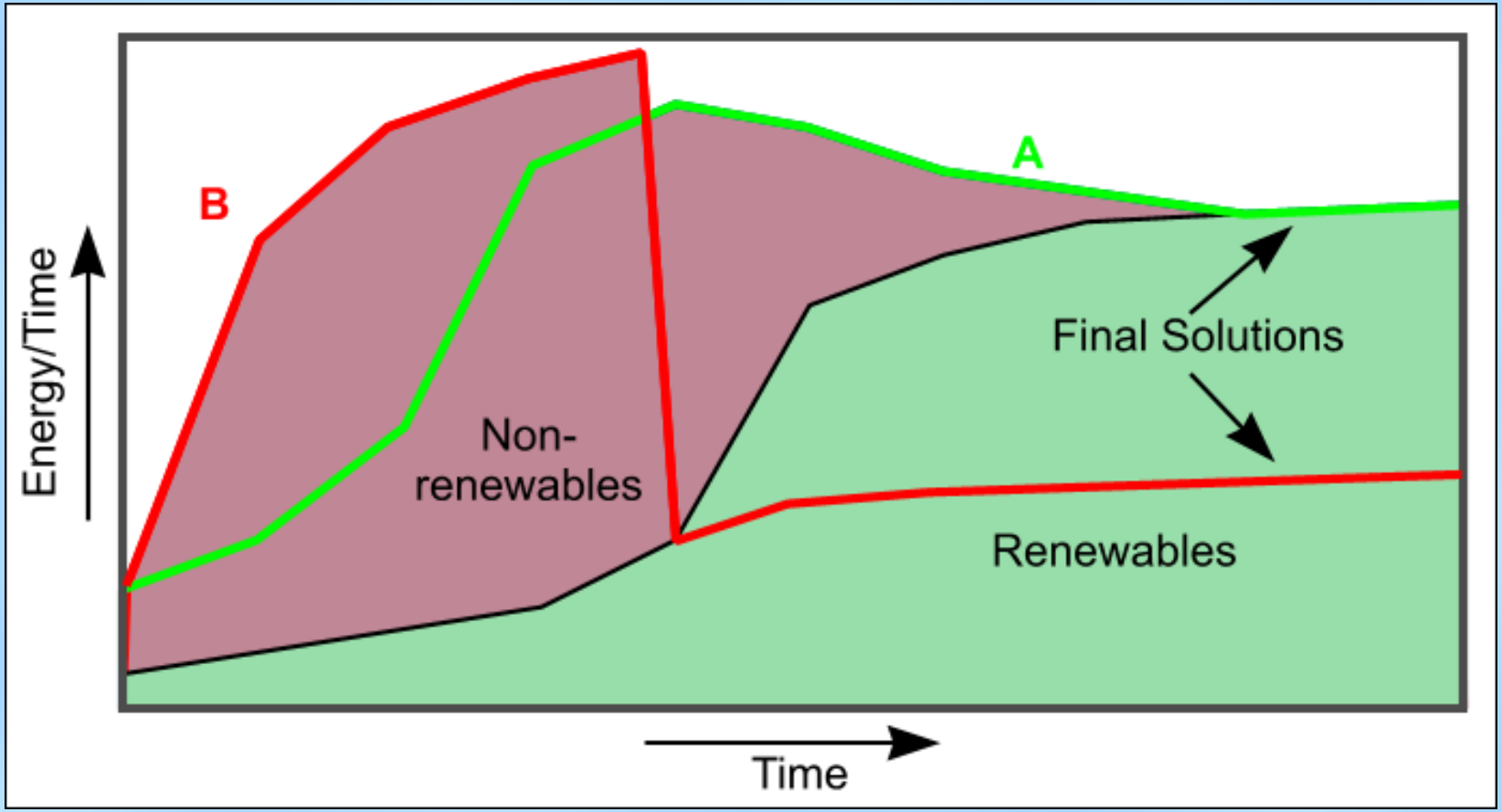
Transitions - Smooth

A transition to a sustainable society can be found using 'backcasting' and energy modelling (Mulder, 1995).



Transitions - and Abrupt

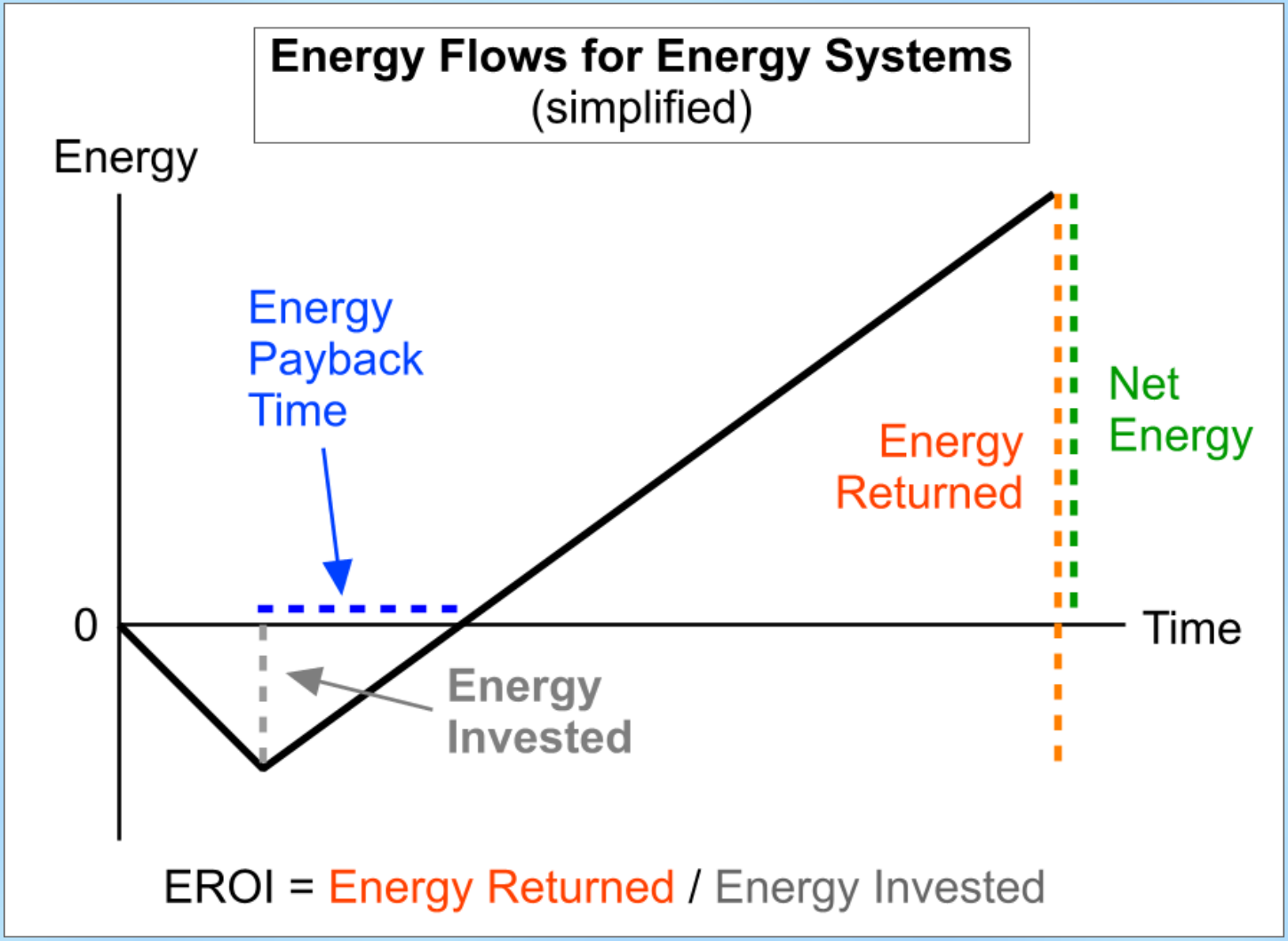
Unfocussed use of the limited carbon budget would give much less sustainable energy/time (curve B).



Energy Analysis

- Energy is invested and flows much like money.
- Energies may be quantified by ‘Life Cycle Analysis’.
- This uses ‘Process Analysis’ or ‘Input-Output Analysis’.
- There are databases of LCAs, such as the Swiss ‘EcoInvent’ and the German ‘GEMIS’.
- There are software packages for accessing these.

Energy System Metrics



Climate Limits for Energy

Gross Climate Limit: **4.90** GtCeq/y (IPCC for 2000-2100)

- Land use change: **1.60** GtCeq/y (IPCC for 2000-2100)

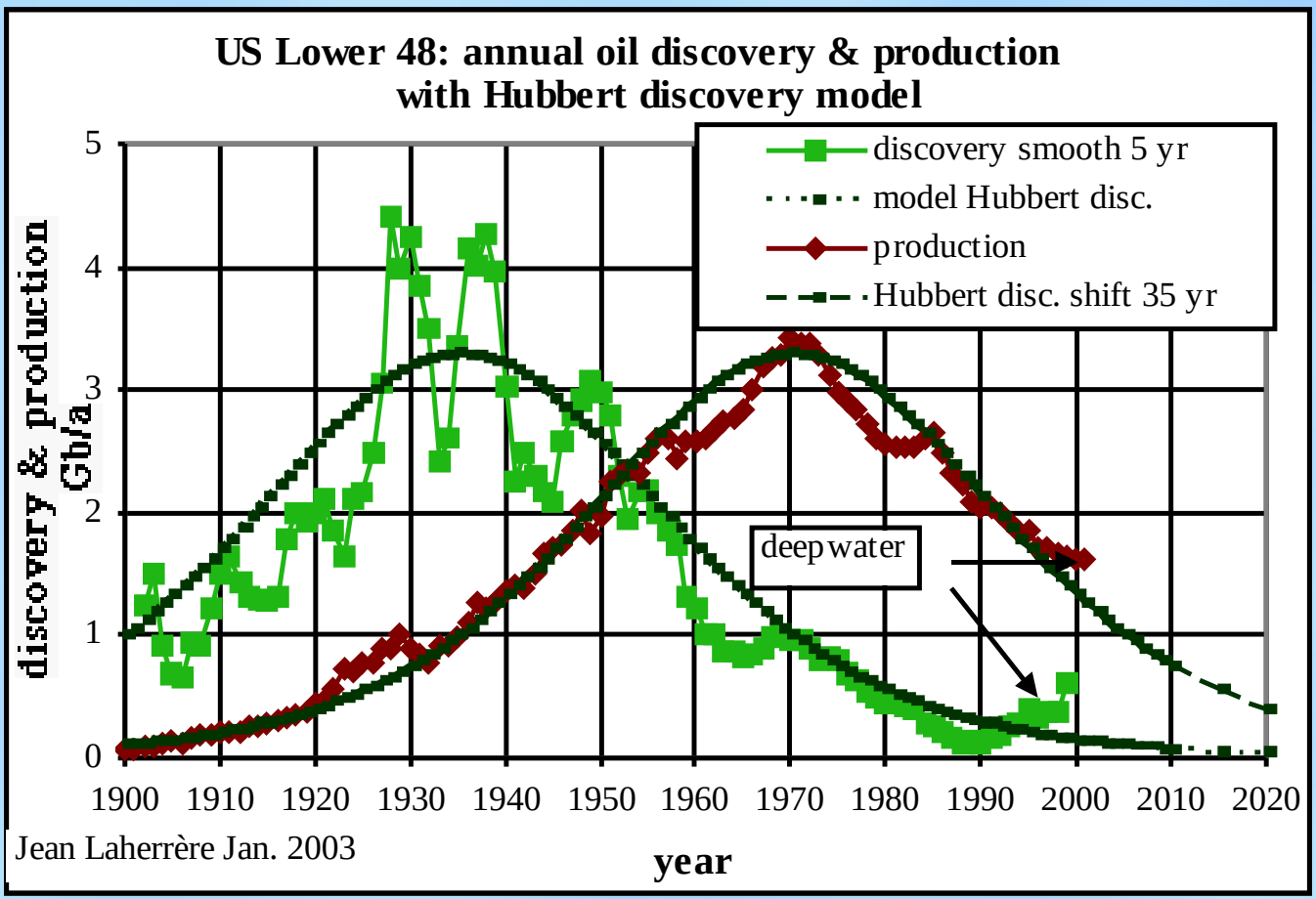
- Livestock GHG: **1.25** GtCeq/y (FAO, for 2004)

= Net Climate Limit for Energy: **2.05** GtCeq/y max.

I.e. Net Climate Limit for Energy for 2000-2100: **205** GtCeq

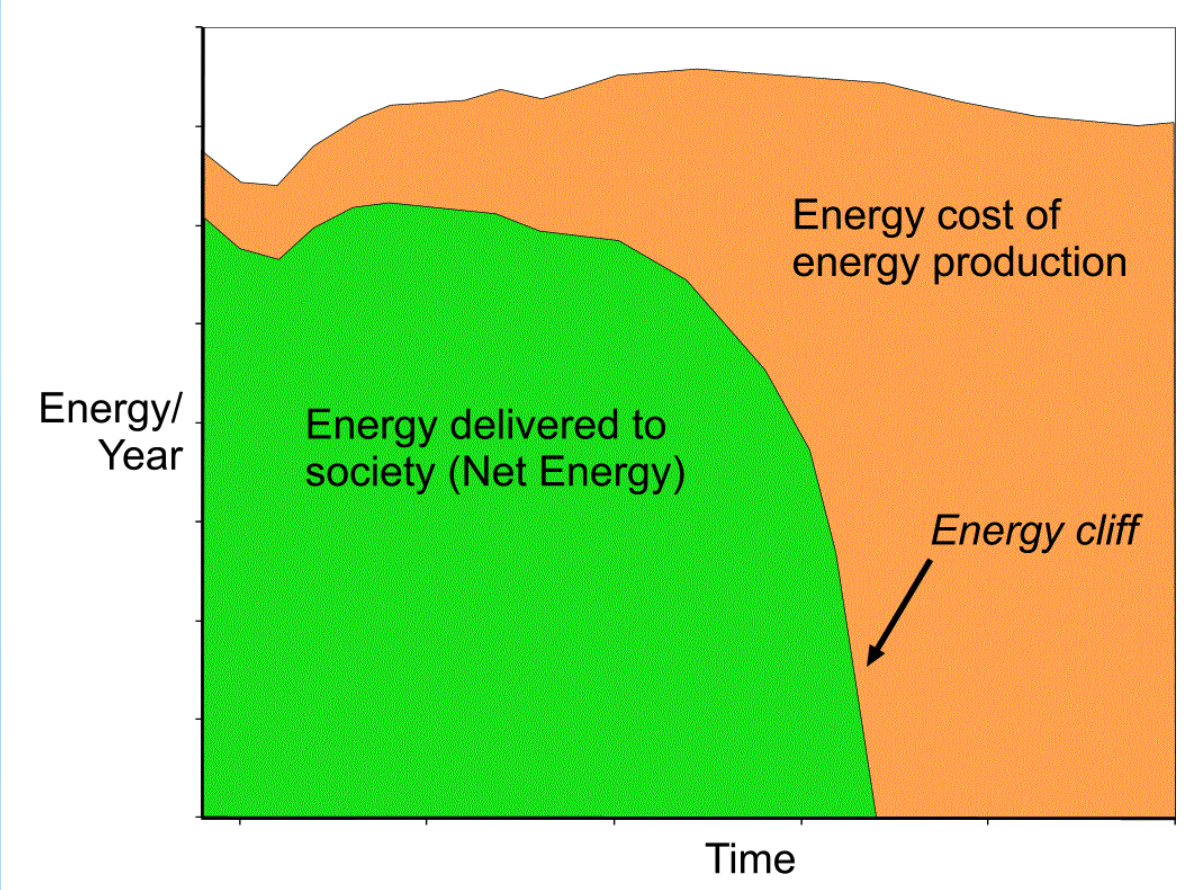
Carbon Reserves - ‘Peaking’

All depletable energy and material sources are finite.
Hence the yields must ‘peak’ as in ‘Peak Oil/Gas/Coal’.



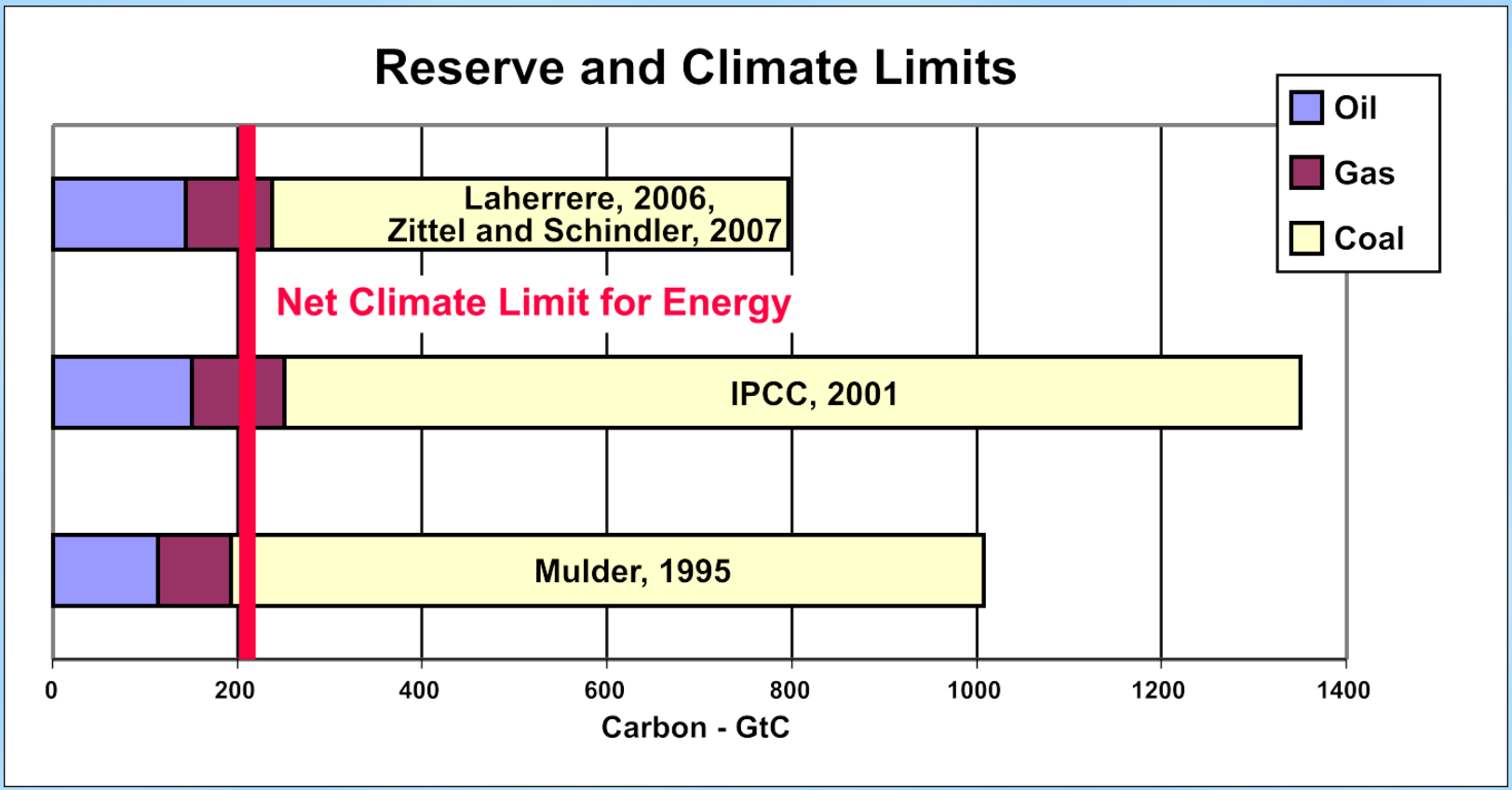
Carbon Reserves - ‘Energy Cliffs’

Depletable energy sources suffer declining ‘net energy’ and finally an ‘energy cliff’.



Carbon Reserve and Climate Limits

With this Net Climate Limit, should we burn **any** coal?

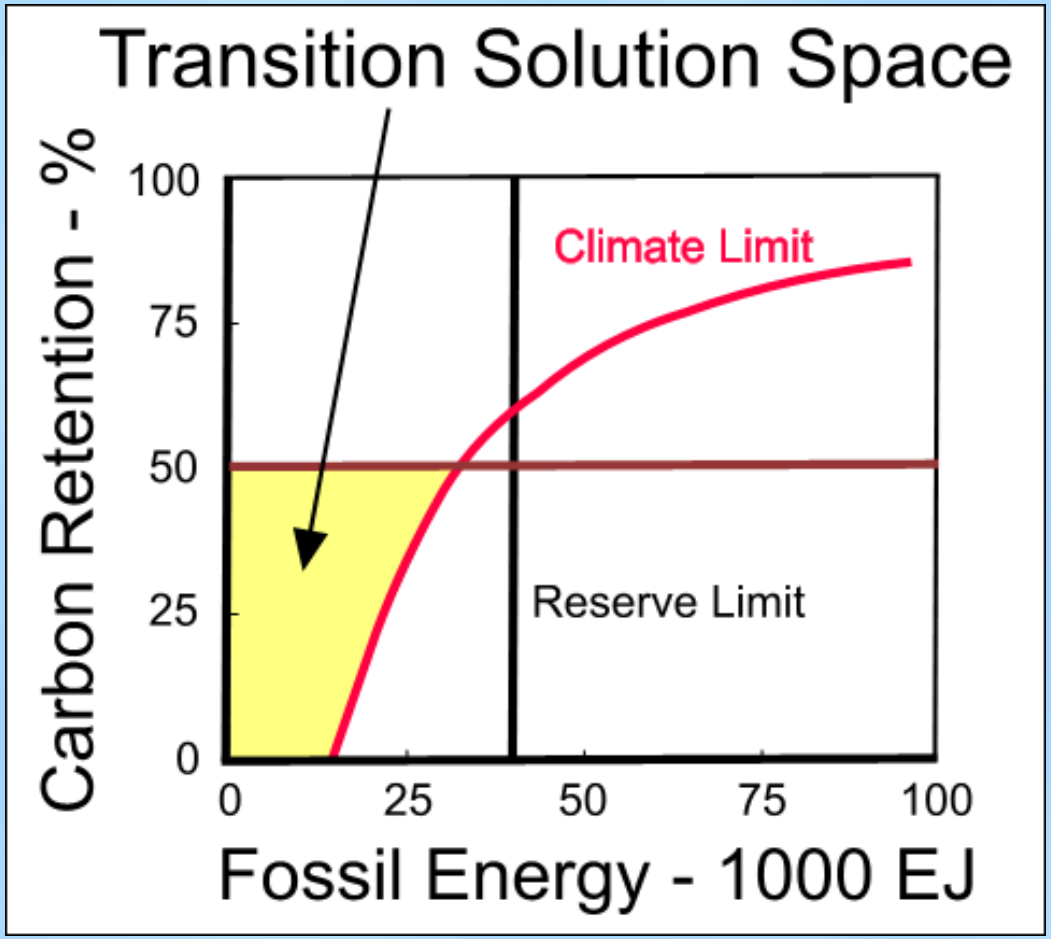


Carbon Budget

- For any transition, some fossil energy must be invested in current sustainable energy options.
- The ‘carbon-equivalent’ limit of fission is small, maybe 5-10%.
- Any fossil energy beyond the Net Climate Limit would require Carbon Capture and Storage (CCS).
- This would increase the invested and operating energies, while still being unsustainable.
- Also, CCS would be restricted to large stationary sources.

Transition Solution Space

Carbon Retention (CCS) could not exceed 50%, which might increase fossil energy from 13,000 to 30,000 EJ. (Mulder)



Criteria for Sustainable Energy Solutions

Option Type	Criteria
• Energy Saving (e.g. Insulation)	EROI
• Energy Efficiency (e.g. CHP)	EROI Thermodynamics
• Renewable Energy (e.g. WT)	EROI, Land Area Thermodynamics

EROIs are determined by Life Cycle (Energy) Analysis.

Thermodynamic savings are found by Exergy Analysis.

Exergy Analysis and Energy Saving

- ‘Exergy’ is the thermodynamic ‘quality’ of energy:
  i.e. the potential to do work (often to generate electricity).
- Ranking: electricity, chemical energy, heat < 100°C
- Exergy Analysis of energy conversion compares current practice with the theoretical limits (Gibbs, Carnot, Nernst).
- Energy can be saved by reducing exergy losses.
- Material energy can be reduced by recycling and substitution.

Exergy Analysis: Materials Systems

- For mineral, fossil and biomass chemicals, the theoretical energy intensity is defined by thermodynamics (Gibbs).
- For mined materials, the theoretical energy intensity also depends upon the type of mineral and it's ore-grade.
- Depletion will increase the energy intensity on both counts.
- Recycling is unlimited in theory.
- Substitution is limited by engineering requirements.

Exergy Analysis: Space Heating

- The largest exergy losses occur in space heating.
- They can be reduced by ‘cascading’ energy, as in ‘Combined Heat and Power’ (CHP) generation.
- Fuel savings for heat can be from 0% to 80%, strongly dependant on the type and scale of the CHP unit. Hence we should invest only in large units $\approx$ > 1 MWe.
- Heat from large-scale CHP is used in industry and distributed to towns and cities via District Heating (DH).
- DH is fuel-neutral, so can use renewable sources and become sustainable.

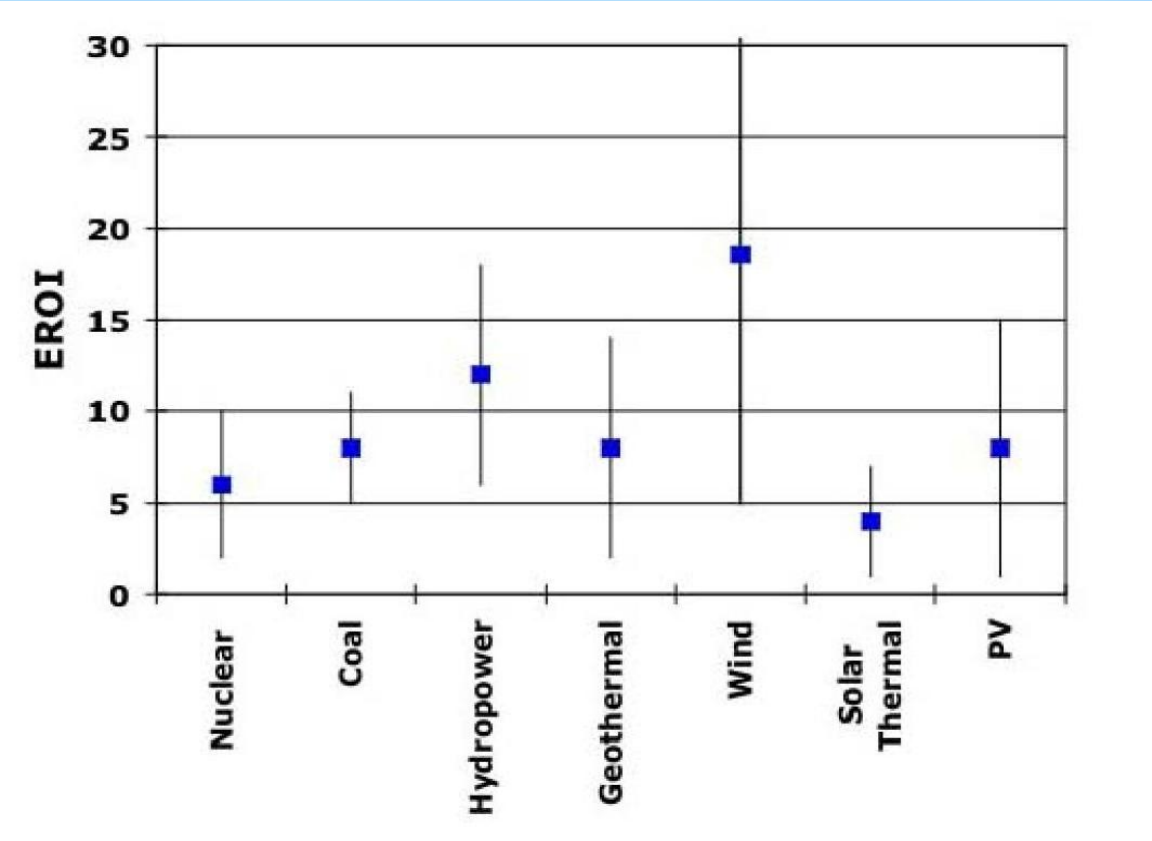
Energy Savings: Electricity

- For electric motors and transformers, more - and higher purity - copper and iron increase efficiency.
- For electric motors, Permanent Magnet fields and power electronics - for easier speed control (cube-law savings).
- For lighting, by changing from incandescent to fluorescent to Light Emitting Diodes (LEDs).
- For example, fluorescent lighting gives 65 to 90 lm/W, but the limit for white light is about 330 lm/W.
- LEDs are expected to give 150 to 200 lm/W by 2020.

EROIs of Electricity Sources

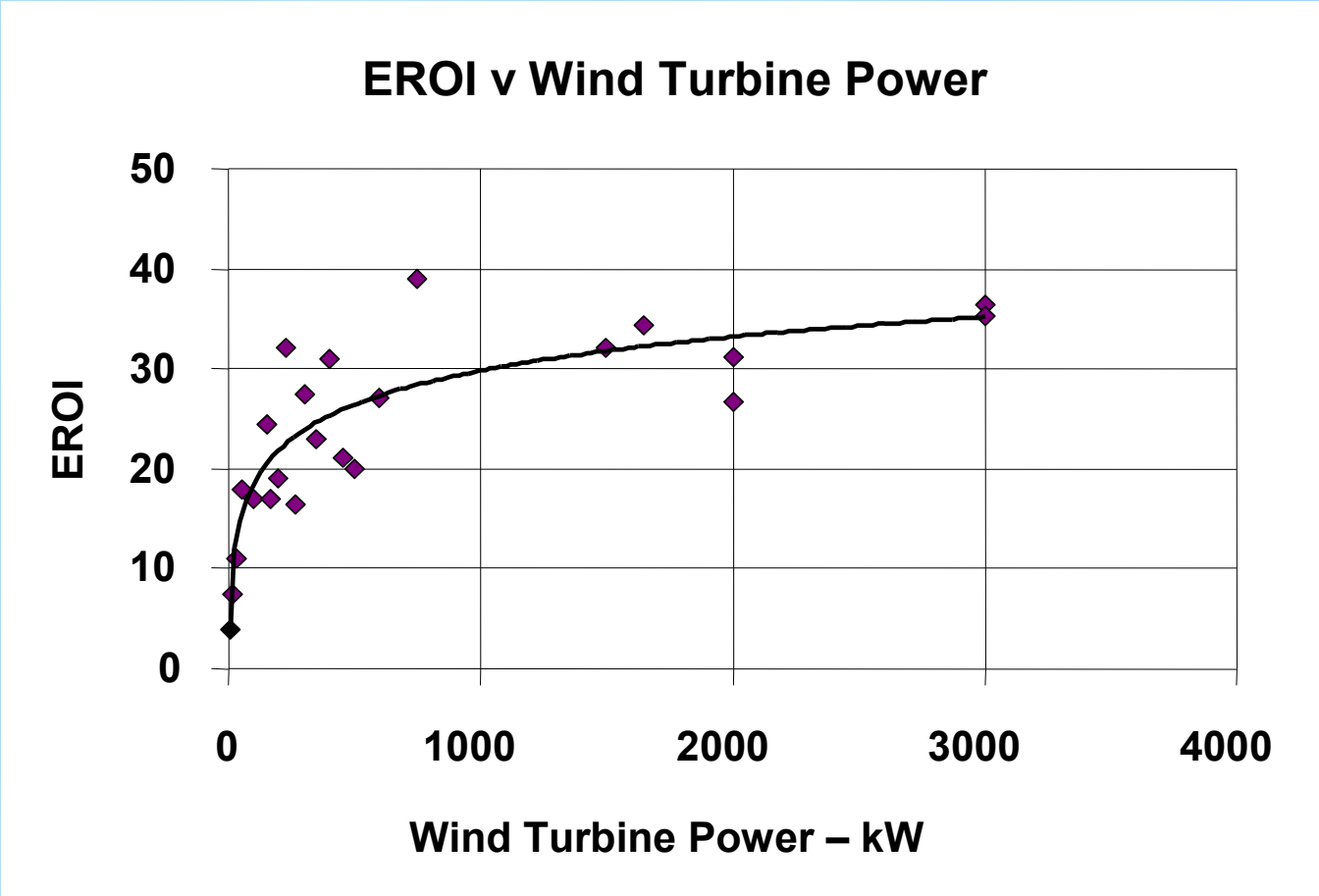
Of the renewable electricity sources:

- Hydropower and Geothermal are good but site-limited.
- Wind Turbines are much better than PV or Solar Thermal.



EROIs of Electricity Sources: Scale Effect

The EROI of Wind Turbines shows a marked scale effect.
Hence we should invest only in large machines - MW class.



Energy Use - Housing/Buildings Sector

- In conventional housing/buildings, most energy is used in operation - notably for space and water heating.
- 'Passive Houses' reduce space heating energy by ~ 90%, yet have similar invested energy of about 100 GJ/capita.
- For existing housing/buildings, replacement would require too much invested energy.
- Hence they should be renovated to PH standards, which can save e.g. 90%, or supplied from DH, saving e.g. 80%.

Energy Use - Transport Sector - 1

- Transport energy must be reduced, with fuels ‘carbon capped’ and vehicles of increased energy efficiency.
- Invested energy must be minimised by using the reinvestment cycles.
- ‘Modal switching’ to train, tram, bus, cycling and walking requires long-term integrated planning.
- There are about 800 million road vehicles world-wide, which would take some 15 years to replace.
- Heating and A/C energy is proportional to journey time.

Energy Use - Transport Sector - 2

- Consider the whole energy chain - ‘well-to-wheel’.
- For biofuelled vehicles, this includes biomass feedstock, processing, and distribution - as well as use in vehicles.
- For battery electric vehicles, this includes renewable electricity, with additional plant if more than off-peak.
- The energy invested in batteries is significant ~ 2x. Lead and Nickel are scarce and Lithium is reactive.
- Battery recharging rates may be an issue - MW.

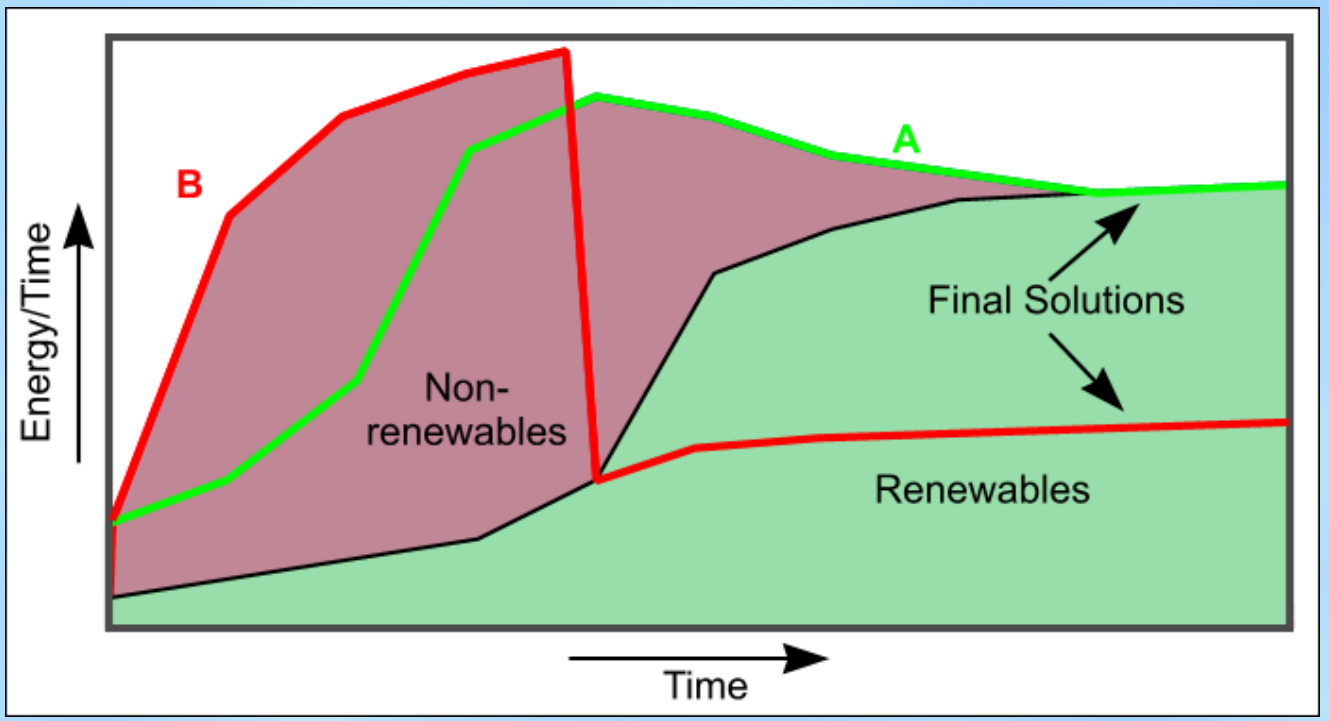
Transition Studies - World and OECD

- Mulder's Basic (world) model gives sustainable energy flows of e.g. 3500 Watts/capita.
- More detailed studies have been done for some OECD countries - Germany, the UK, and Switzerland.
- These suggest that a transition is possible to a sustainable society, with energy of about 2000 Watts/cap.
- This is about 4000 W of energy savings,1500 W of renewable energy and 500 W of carbon-equivalent energy.
- The sustainable energy service of about 6000 W/capita would be comparable to that of Switzerland today.

Conclusions

- The fossil energy invested in sustainable energy options and time define the transition - whether smooth or abrupt.
- A smooth transition to a sustainable society requires the energy choices to be science-based.
- The sooner and smoother the transition, the higher the sustainable energy service.
- We must soon reach a consensus on the energy options and acquaint politicians world-wide with this science.
- These are the purposes of this Forum.

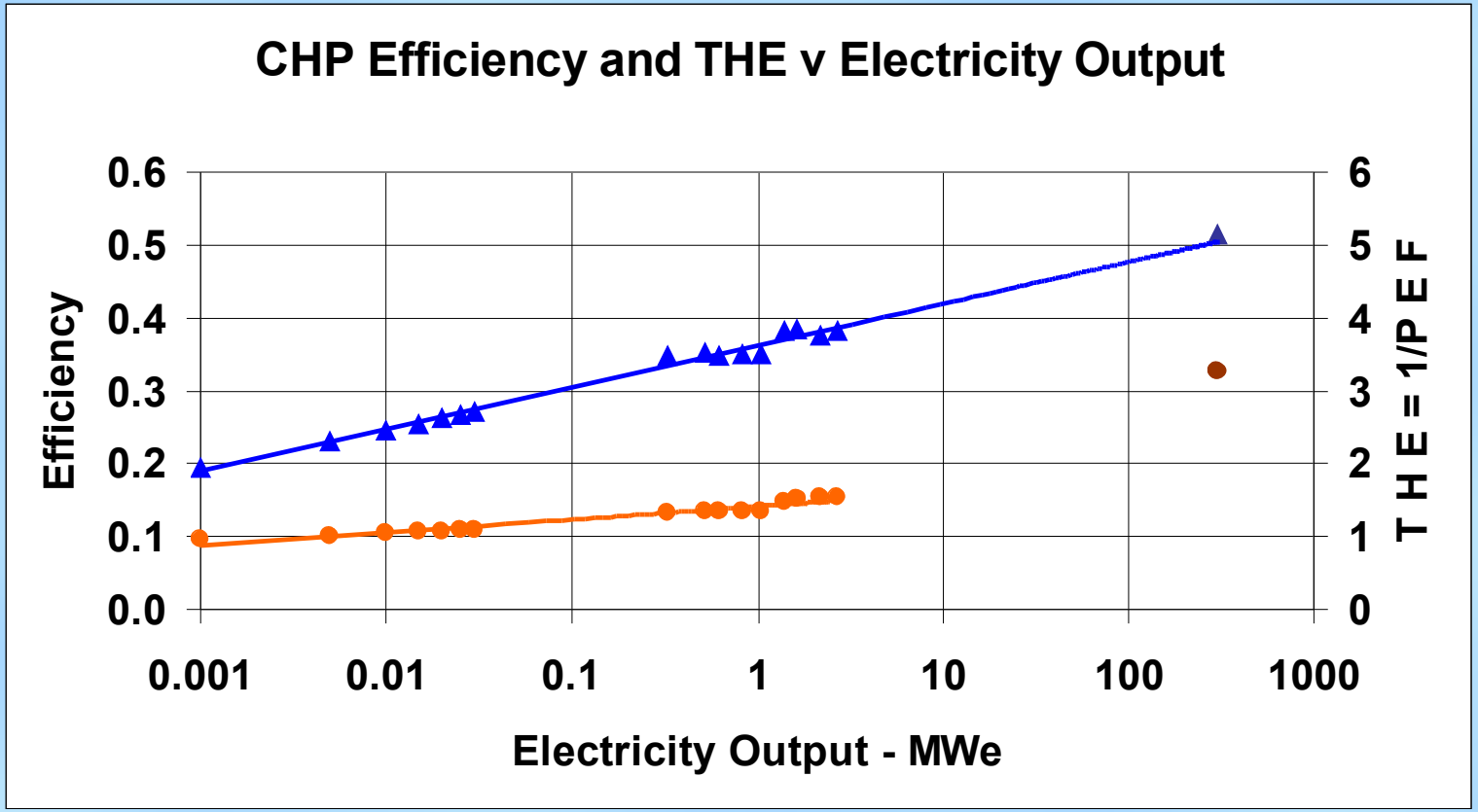
We must now choose our future !



Thank You Any Questions ?

Exergy Analysis of CHP

For CHP, the Thermal Efficiency for power, and the Primary Energy Factor for heat vary markedly with scale. Hence we should invest only in large units ≈ > 1 MWe.



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