Biophysical Economics

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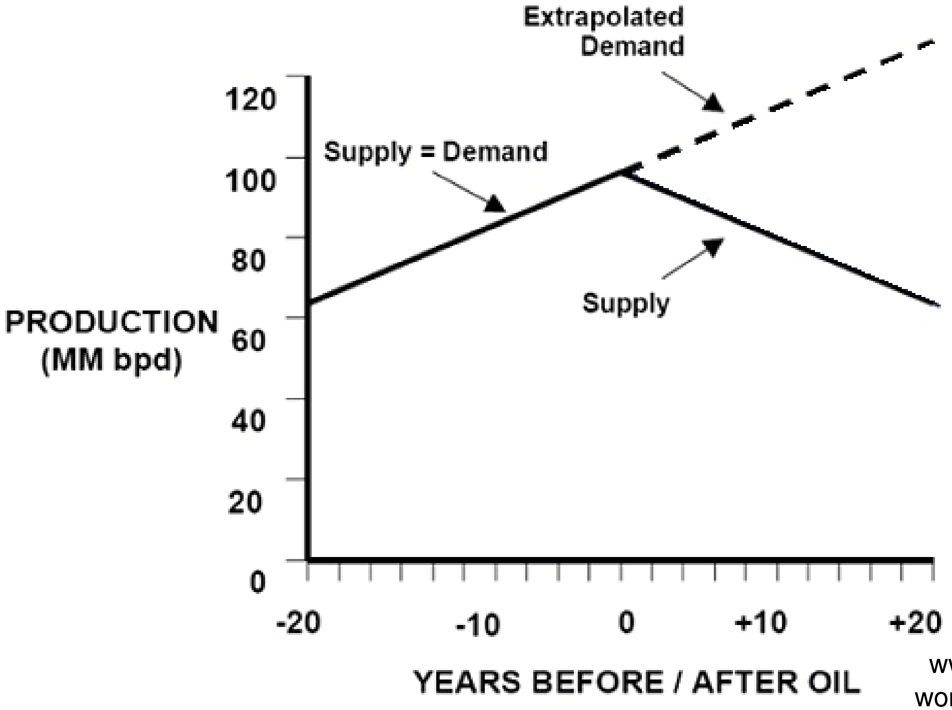
Overview

- Motivation
- Problems to consider
- What is economic growth?
- ECCO modelling framework
- ECCO applications
- Conclusions

Motivation

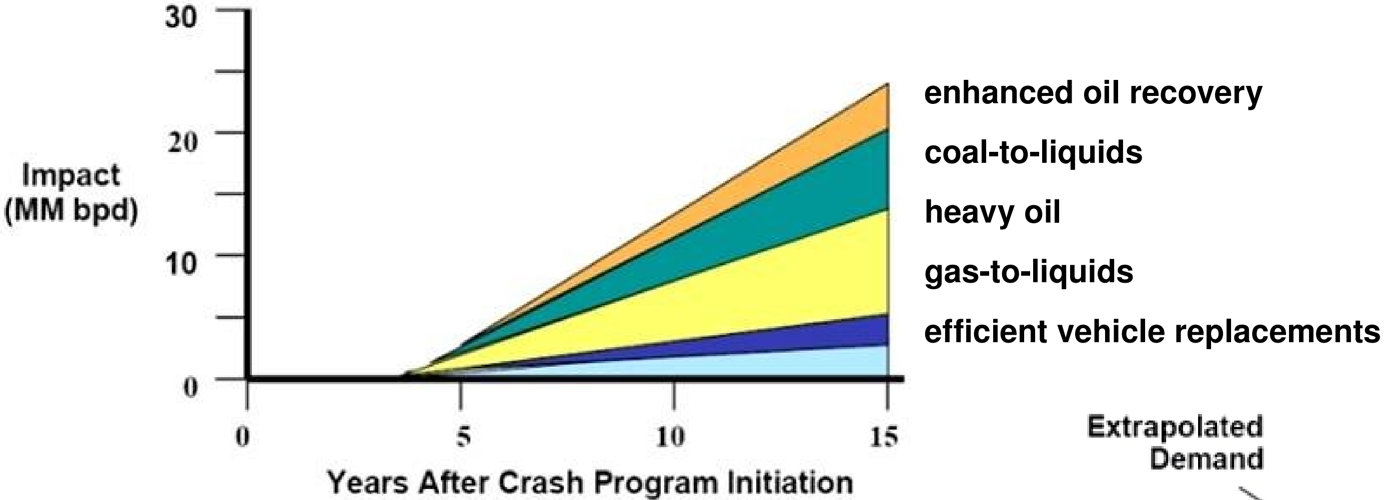
- Energy security / peak-oil
  → Transition to renewables/nuclear
  → Reduce energy use
- Climate change
  → Transition to renewables/nuclear/CCS
  → Reduce energy use
- Economic growth
  → Use cheapest energy sources first (fossil)!
  → Increase energy use!

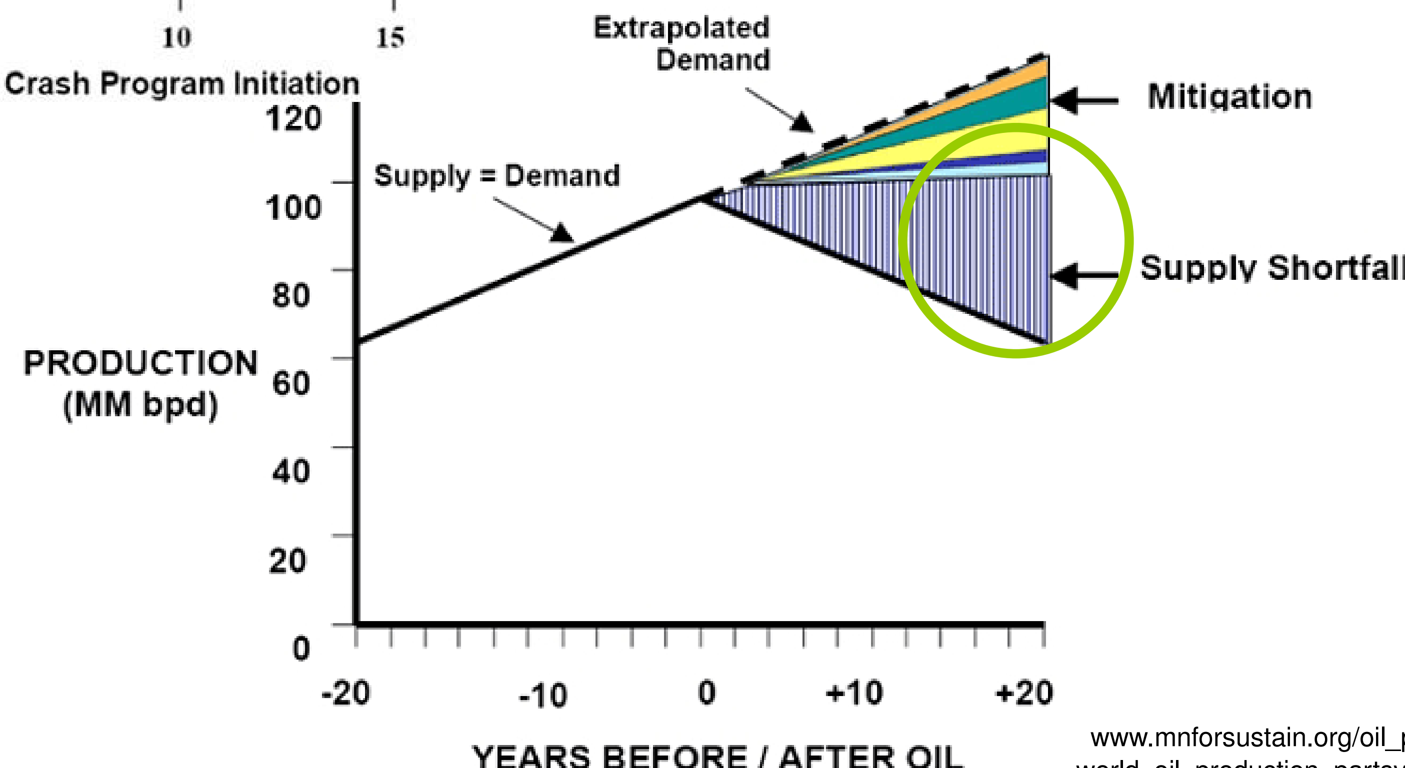
Peak oil, mitigation options Robert Hirsch et al



www.mnforsustain.org/oil_peaking_of_world_oil_production_partsviiandviii.htm

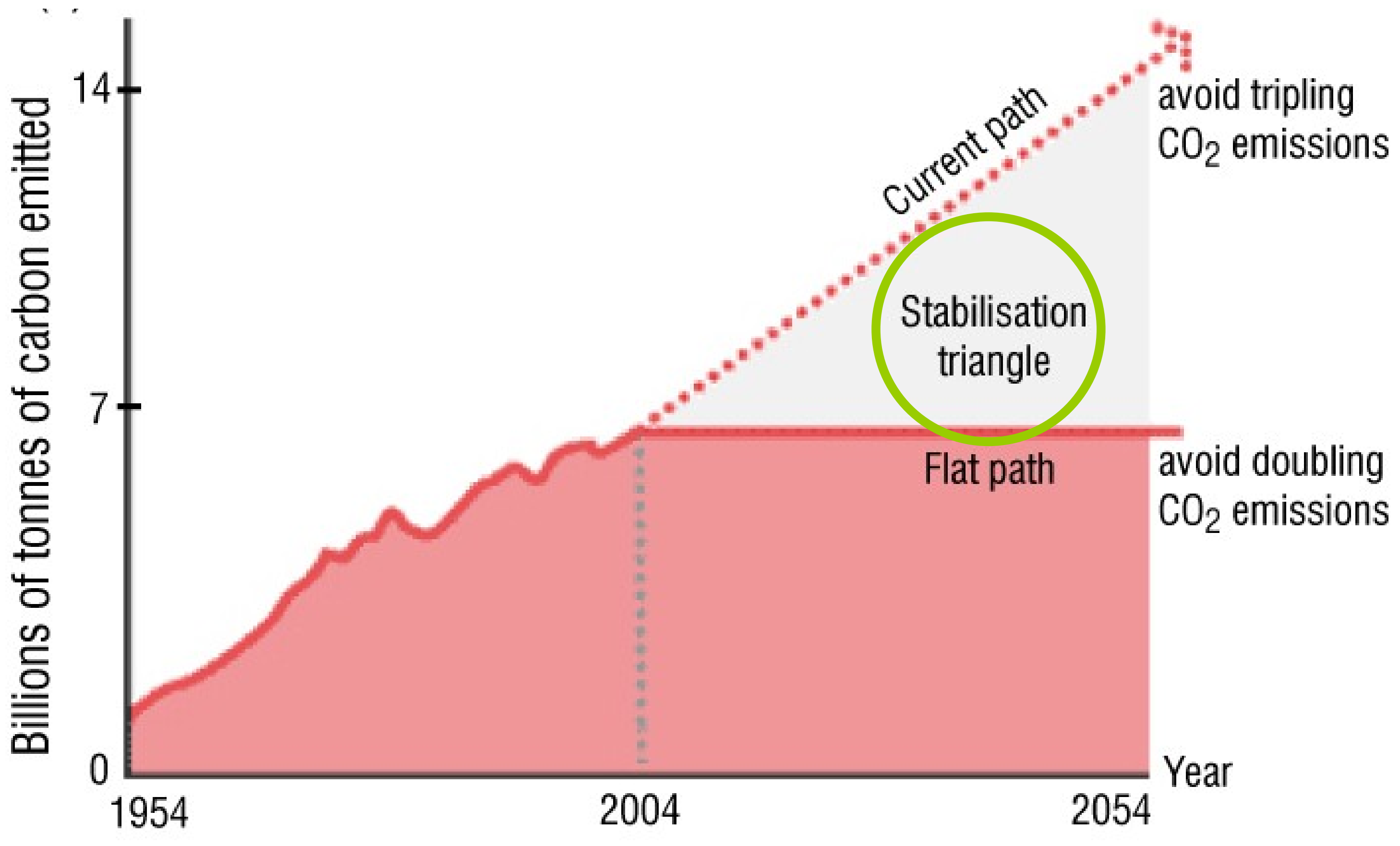
Peak oil, mitigation options
Robert Hirsch et al



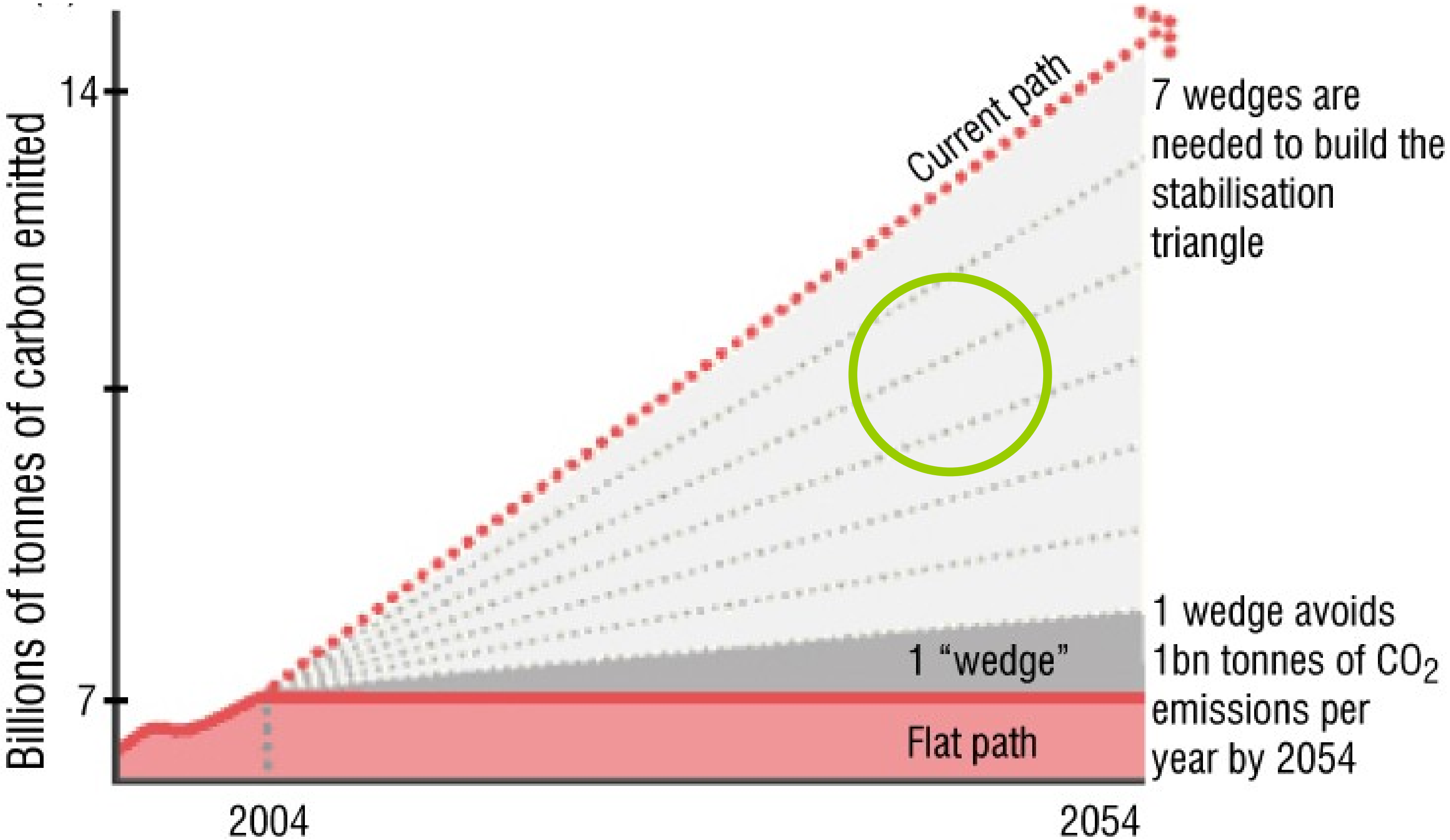


www.mnforsustain.org/oil_peaking_of_world_oil_production_partsviiandviii.htm

Avoid doubling emissions

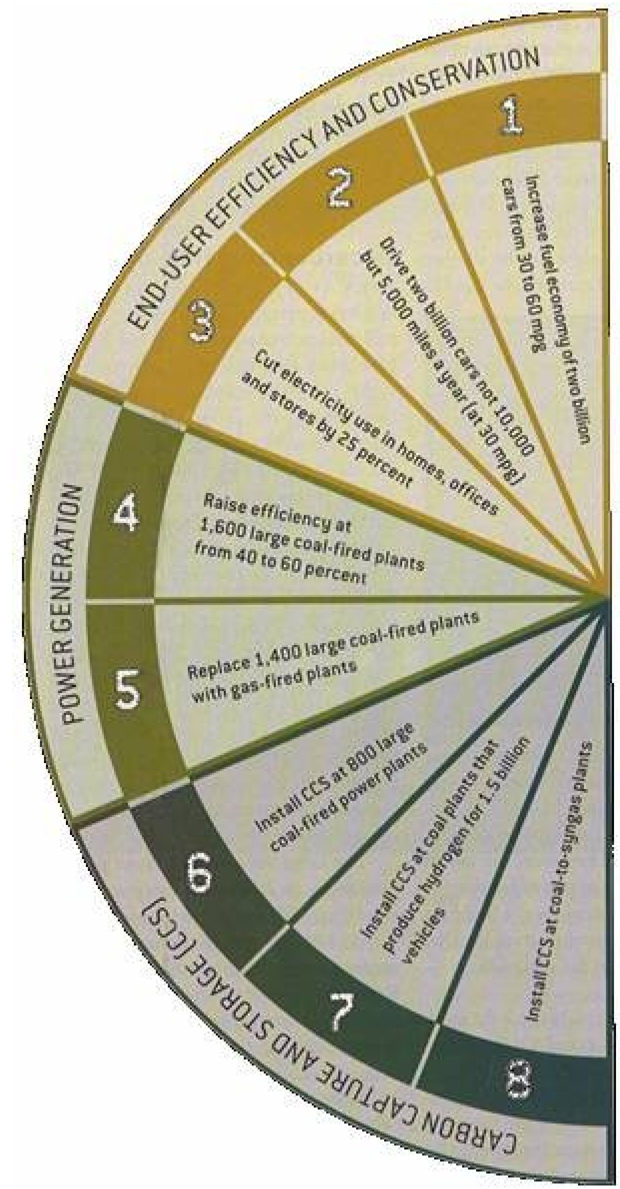


Socolow & Pacala wedges



Wedges examples

1. increase fuel economy of two billion cars from 30 to 60 mpg
2. drive two billion cars not 10,000 but 5,000 miles a year (at 30 mpg)
3. cut electricity use in homes, offices and stores by 25%
4. raise efficiency at 1,600 large coal-fired plants from 40% to 60%
5. replace 1,400 large coal-fired plants with gas-fired plants



Economic growth

- 19th century understanding
  - only increasing either population or tax rates could generate more surplus money
- Early 20th century concept of economic growth
  - produce a greater surplus of value which could be expended on something other than mere subsistence

Economic growth

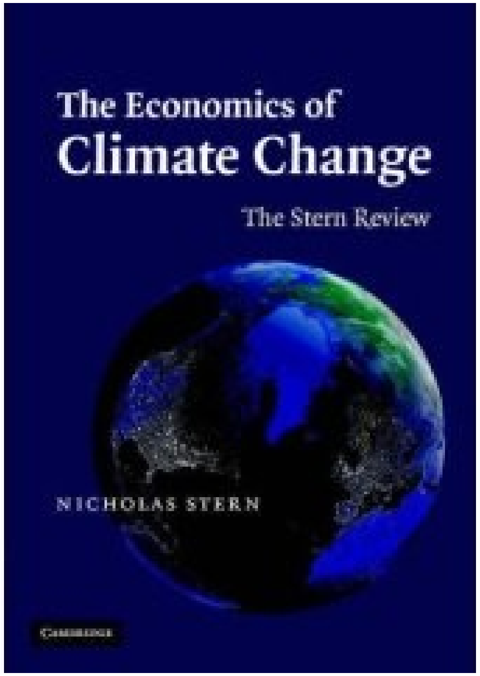
- Purpose of government policy is
  - encourage economic activity…
  - … without encouraging rise in general level of prices
- This must continue!
- The market will find the optimum mix
- More technology will deliver

Economic growth

Part III: The Economics of Stabilisation

Projected trajectories for CO_2 are sensitive to long-run growth projections, but the likelihood of economic growth slowing sufficiently to reverse emissions growth by itself is small. Most models assume some decline in world growth rates in the medium to long run, as poorer countries catch up and exhaust the growth possibilities from adopting best practices in production techniques. But some go further and assume that developed-country income growth per head will actually decline. There is no strong empirical basis for this assumption. Neither is the assumption very helpful if one wishes to assess the consequences if developed economies do manage to continue to grow at post-World War II rates.

The choice of method for converting the incomes of different countries into a common currency to allow them to be aggregated also makes some difference – see Box 7.2. But given that the growth rate of global GDP was around 2.9% per year on average between 1900 and 2000, and 3.9% between 1950 and 2000, projecting world growth to continue at between 2 and 3% per year (as in the IPCC SRES scenarios, for example) does not seem unreasonable.



- Global GDP was around 2.9%/y between 1900 and 2000
- Therefore projecting world growth to continue at between 2 and 3%/y does not seem unreasonable

www.hm-treasury.gov.uk/media/2/5/Part_III_Introduction_Group.pdf

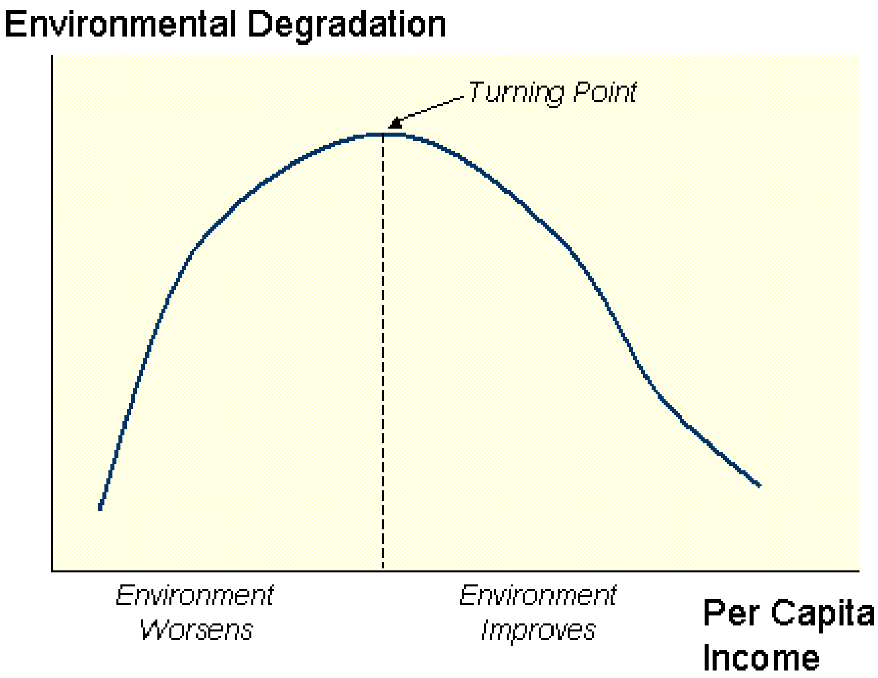
Conventional wisdom

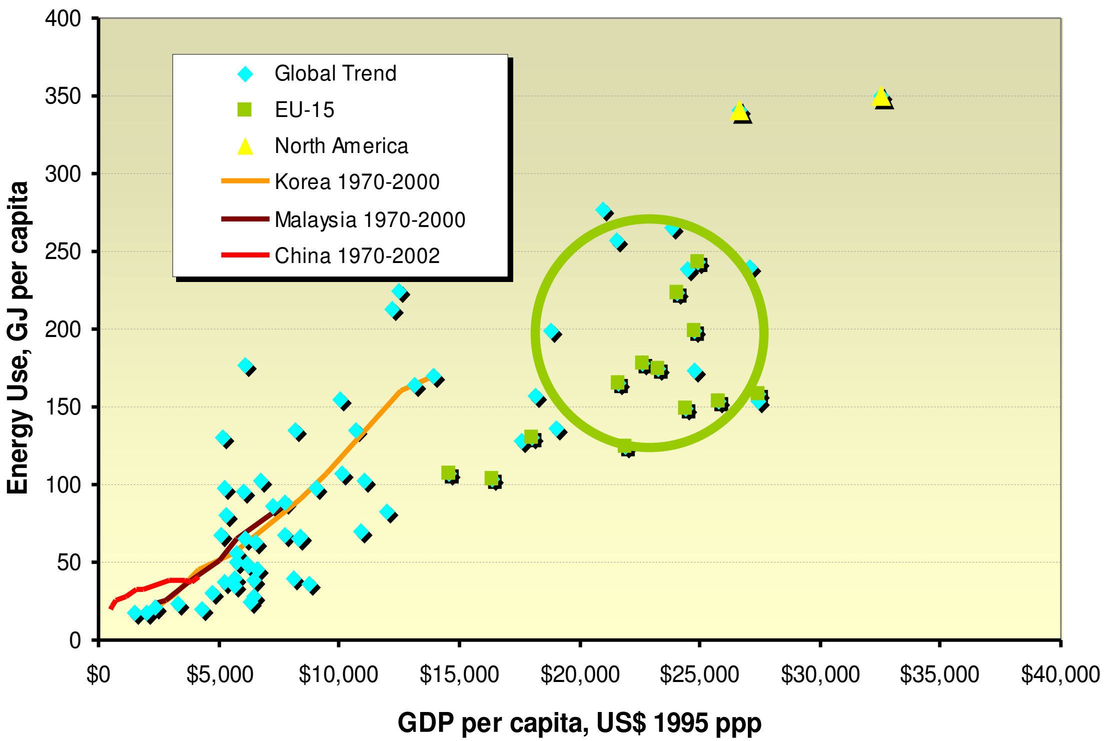
- Just a matter of technology coming to the rescue
- Arbitrary levels for investment in this new technology
- Mechanism simply involves getting the carbon price right
- Then just need societal & political will to implement
- After all, Stern's Report (UK, Oct 2006) concluded:
  - growth reduced by 1% is price for 3% growth

Problems to consider

- Rebound
- Energy cost of energy
- Recession works!

Sustainability's triple bottom line?
despite Kuznets curve, energy use increases



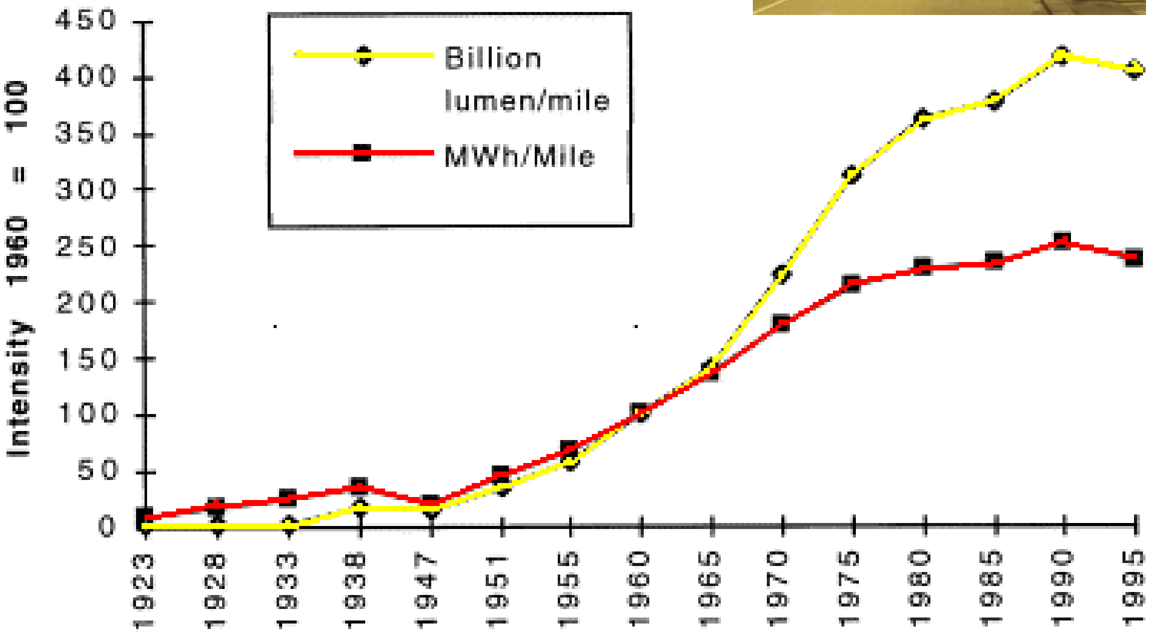


450.aers.psu.edu/trade_environment.cfm
The Rise and Fall of the Environmental Kuznets Curve, David I. Stern (2004)
www.wbcsd.org/web/publications/facts-and-trends.pdf

Energy efficiency increases energy consumption!

Jevons Paradox, rebound effect, Khazzoom-Brookes Postulate

- technological improvements increase the efficiency with which a resource is used
- energy efficiency improvements, economically justified at the micro level, lead to higher levels of energy consumption at the macro level



www.eoearth.org/article/Rebound_effect
Energy rebound and economic growth…, Reinhard Madlener and Blake Alcott (2006)

EROEI
energy return on energy investment

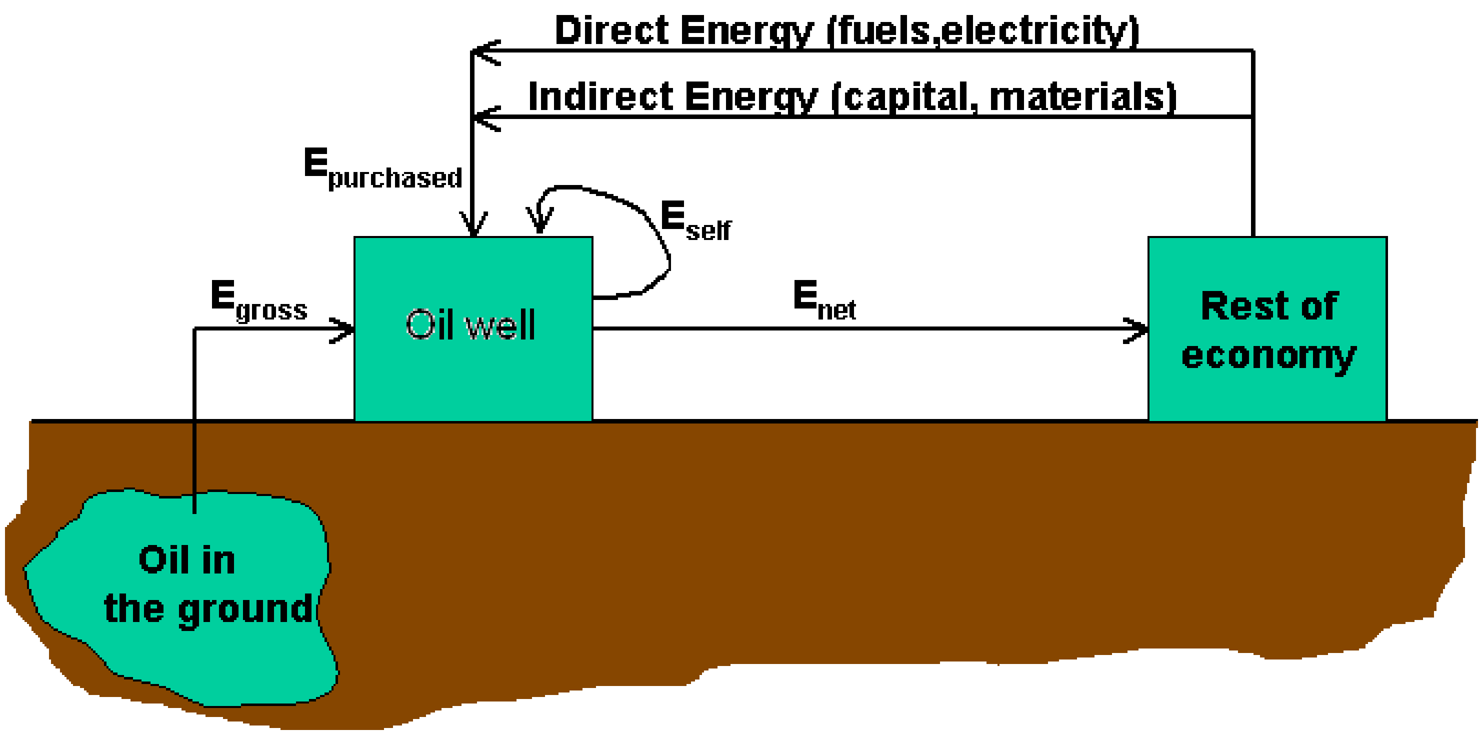


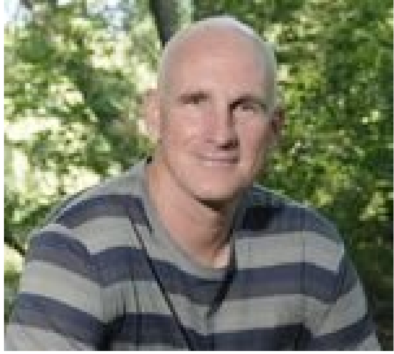
Figure 1 Definition of Energy Return on Energy Investment (EROEI)

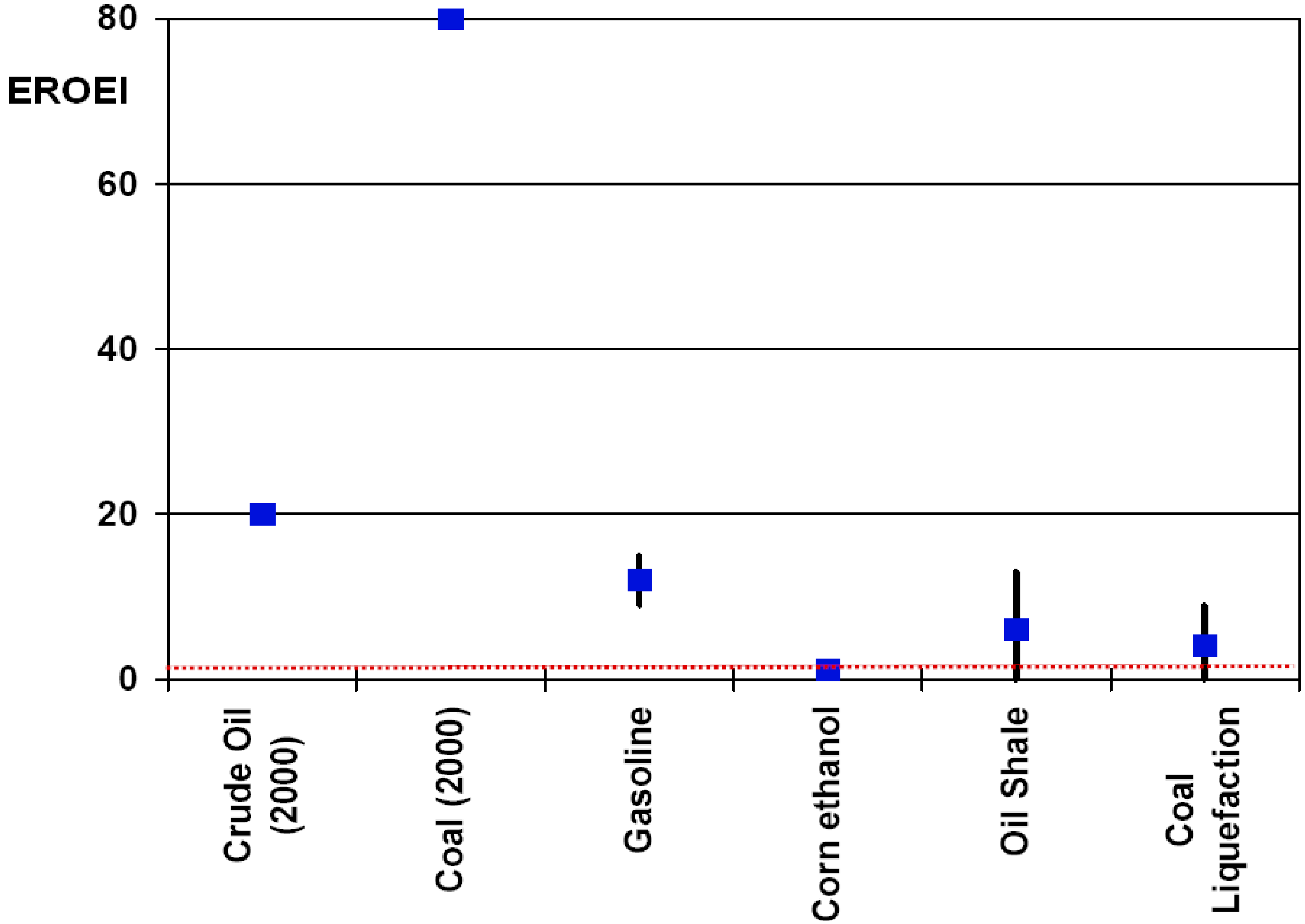
$$EROEI = \frac{E_{net}}{E_{self} + E_{purchased}}$$

www.eoearth.org/article/Net_energy_analysis

EROEI for transport fuels

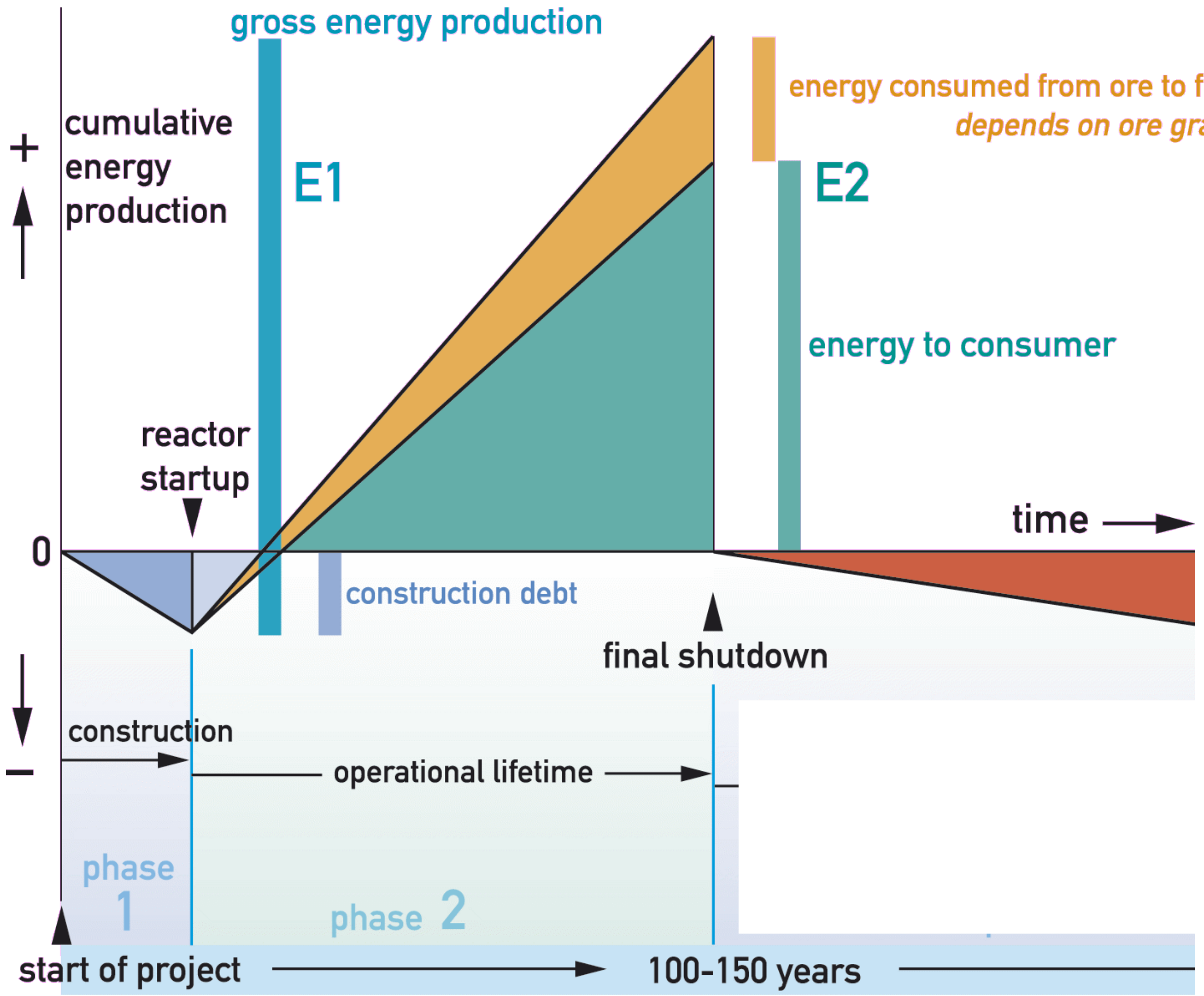
Cutler Cleveland and Charles Hall





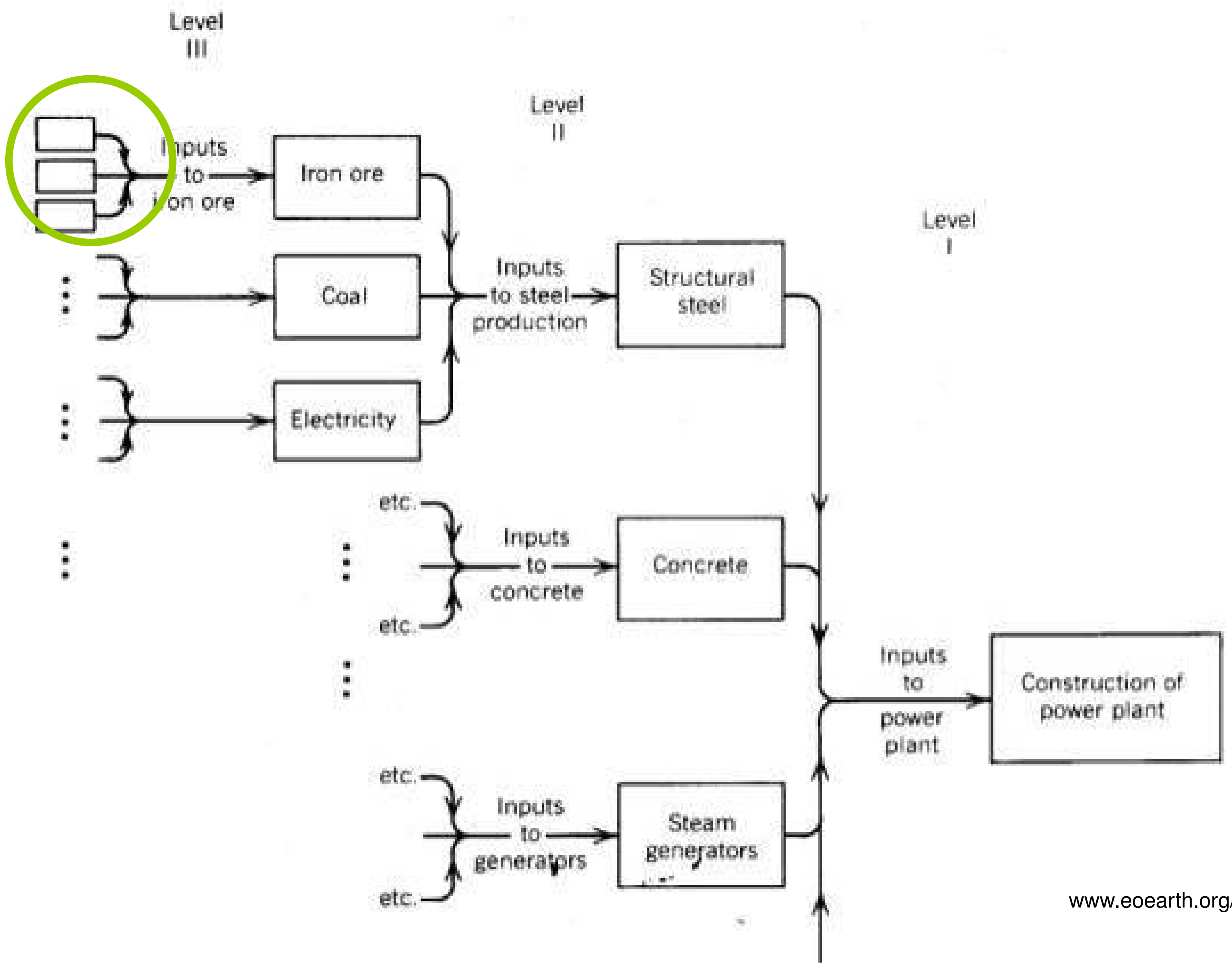
hwww.aspo-usa.com/fall2006/presentations/pdf (Cleveland)

EXAMPLE
energy and embodied energy for nuclear power



www.stormsmith.nl

Embodied energy - process analysis approach truncation problem of system boundary



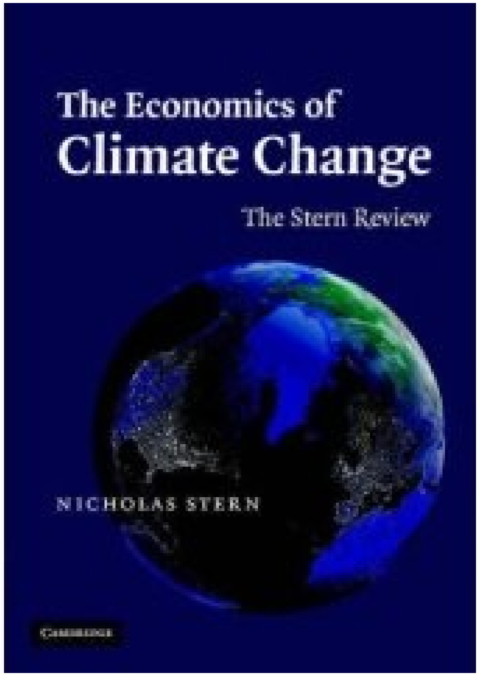
www.eoearth.org/article/Net_energy_analysis

“The Economics of Climate Change” Nicholas Stern, *only >-1%/y feasible*

- Brazil’s biofuels expanded 1977-2003: carbon emissions rose 3.1%/y rather than 3.6%/y

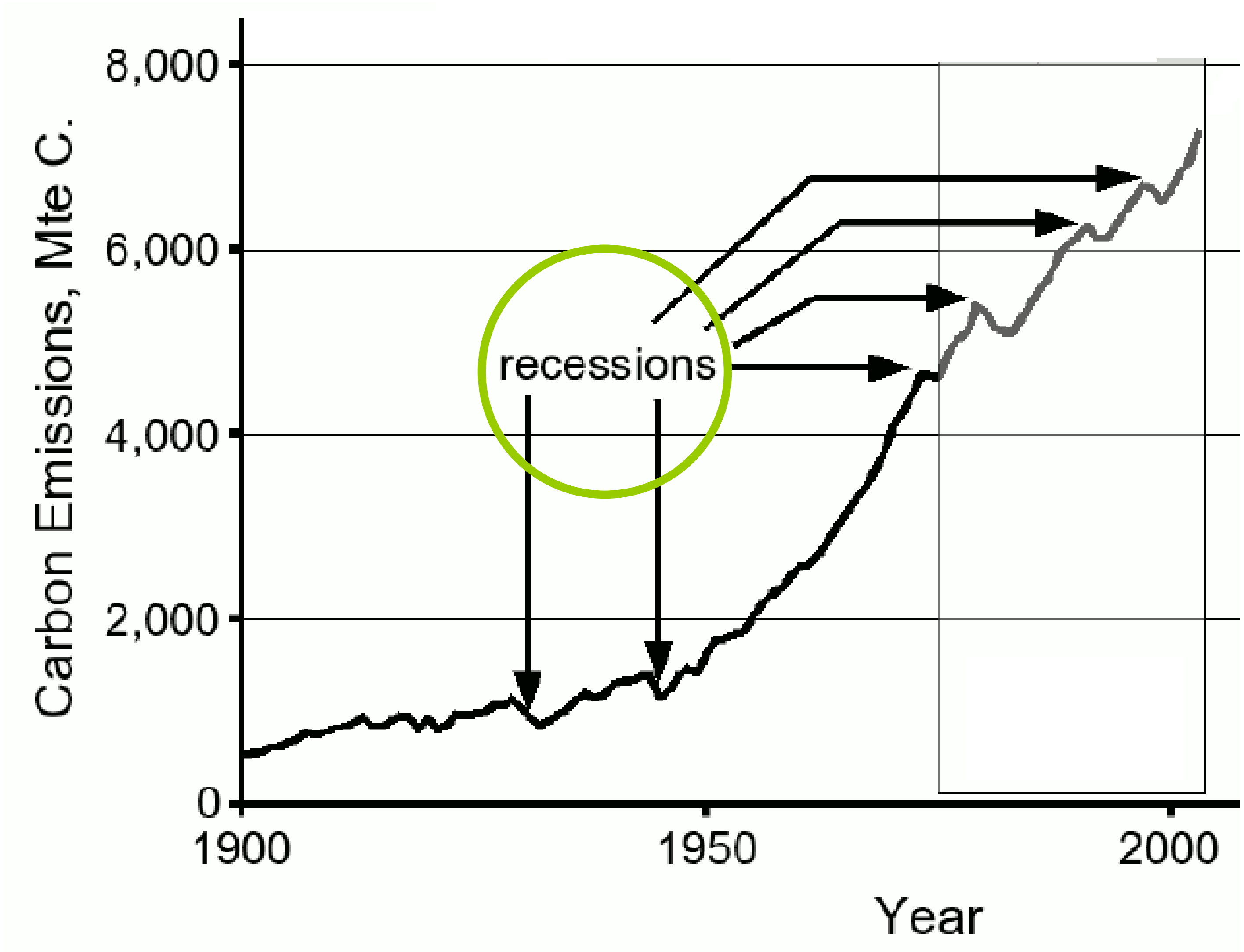
- UK “Dash for gas” 1990-2000: -1%/y

- *FSU recession 1989-1998: -5.2%/y*



www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Carbon history is of growth only dipping with recessions



Paul Mobbs

Discuss

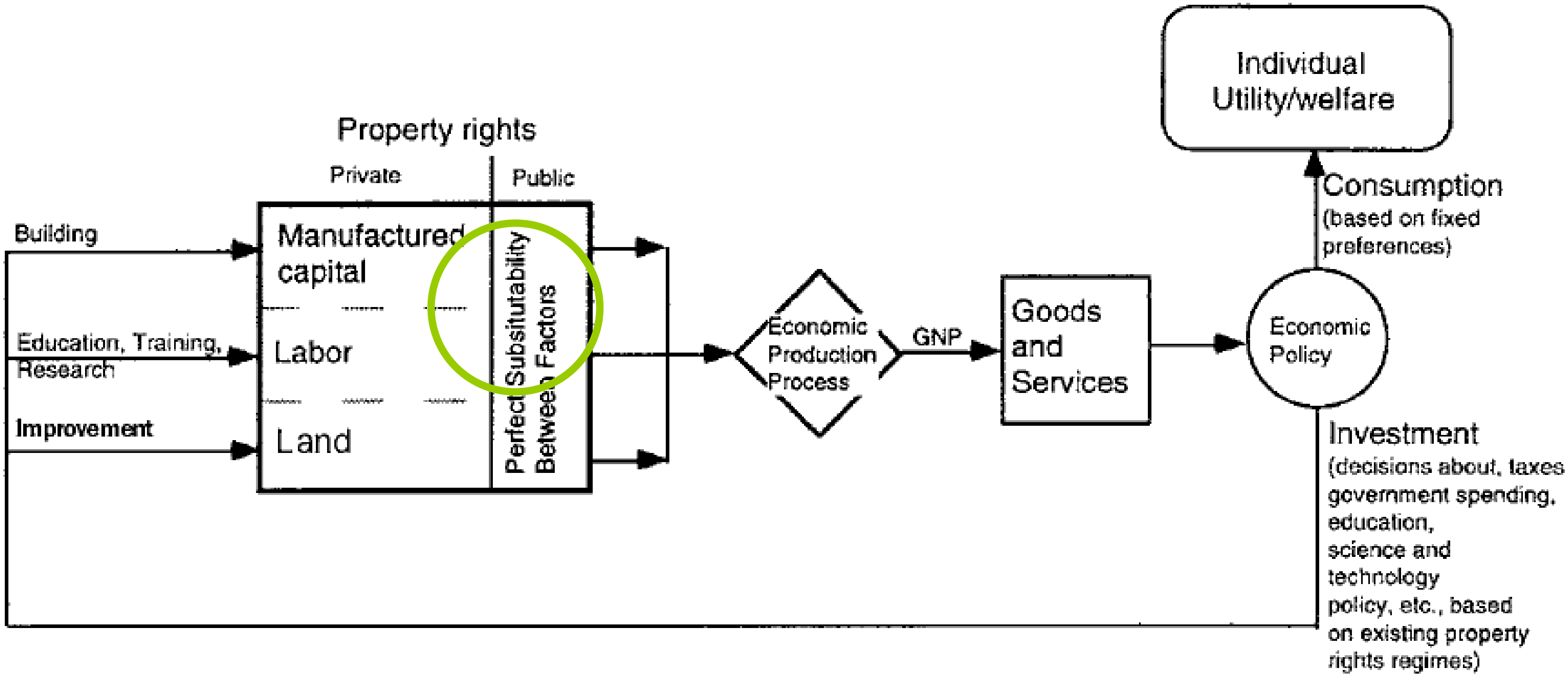
Incompatibility of climate/security with growth?
Rebound, EROEI, Recession?

Goal

Understand the energy basis of our production/consumption system

(can we grow the system and reduce energy use?)

Economic theory
conventional model of an economy



www.eroei.com/articles/the_chain/energy_economics

Growth theory

neoclassical economics, key assumptions

- marginal factor productivity equated with factor share in the national accounts
- labor, L, around 70%
- capital, K, (interest, dividends, rents and royalties) gets all of the rest
- extractive resource owners hidden in the capital accounts; perhaps 3-4% of GDP
- perfect substitutability: *oil and gas are not essential to the world because technology will always overcome resources*

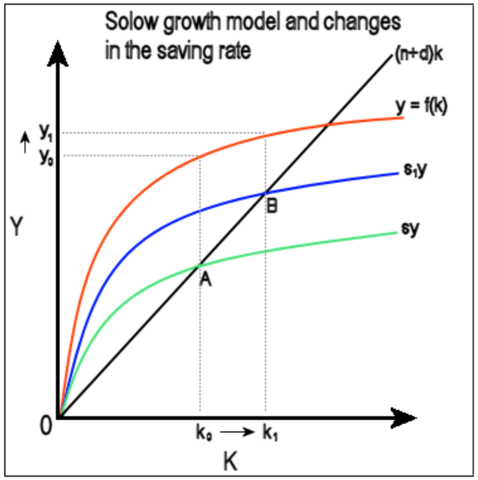
www.iea.org/Textbase/work/2004/eewp/Ayres-paper1.pdf

Growth theory
Solow

The model and changes in the saving rate

[edit]

The graph is very similar to the above, however, it now has a second savings function $s_1 y$, the blue curve. It demonstrates that an increase in the saving rate shifts the function up. Saving per worker is now greater than population growth plus depreciation, so capital accumulation increases, shifting the steady state from point A to B. As can be seen on the graph, output per worker correspondingly moves from y_0 to y_1. Initially the economy expands faster, but eventually goes back to the steady state rate of growth which equals n.

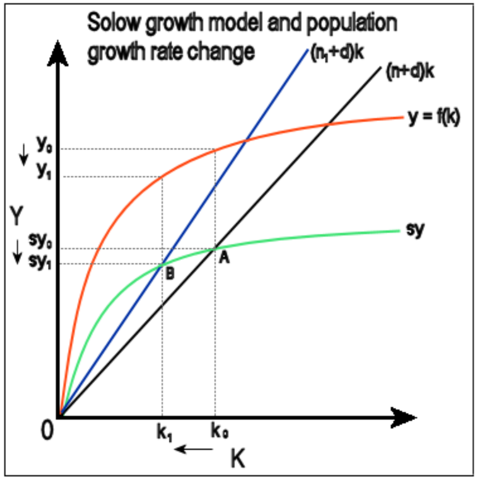


There is now permanently higher capital and productivity per worker, but economic growth is the same as before the savings increase.

The model and changes in population

[edit]

This graph is again very similar to the first one, however, the population has now increased from n to n_1, this introduces a new capital widening line $(n_1+d)k$, the blue line. The production function and the saving rate do not change. As there is now a bigger labor force, but the same amount of investment (saving), saving per worker decreases, and therefore the steady state shifts down from A to B. Capital per worker has decreased from k_0 to k_1, saving per worker has decreased from sy_0 to sy_1, and output per worker has correspondingly decreased



total investment (left side) must equal the amount of growth in effective labor in addition to the amount of capital depreciation. This modification implies that the steady state level of output per unit of effective labor is

$$\frac{Y^*}{AN} = \left(\frac{s}{\delta + g_A + g_N}\right)^{\frac{\alpha}{1-\alpha}}.$$

Similarly, the steady state level of capital per unit of effecitve labor is

$$\frac{K^*}{AN} = \left(\frac{s}{\delta + g_A + g_N}\right)^{\frac{1}{1-\alpha}}.$$

Note: Although per unit growth is zero, the absolute levels of output Y^* and capital K^* in the steady state are still growing at a constant positive rate $g_A + g_N > 0$. This result is sometimes referred to as **balanced growth**. Also note that the savings rate s **does not** affect the rate of growth in the steady state, although it does still contribute to the initial **level** of output and capital at the start of a period of balanced growth.

The **golden rule** savings rate s^* maximizes the steady state level of aggregate consumption C^* per unit of effective labor, as defined by the national income (GDP) identity:

$$\frac{Y^*}{AN} = \frac{C^*}{AN} + \frac{I^*}{AN}.$$

Assuming that the steady state level of investment I^* equals sY^*, the golden rule savings rate solves the unconstrained maximization problem

$$\max_s \frac{C^*}{AN} = \left(\frac{s}{\delta + g_A + g_N}\right)^{\frac{\alpha}{1-\alpha}} - s\left(\frac{s}{\delta + g_A + g_N}\right)^{\frac{\alpha}{1-\alpha}}.$$

Since

$$\ln\left(\frac{C^*}{AN}\right) = \ln(1-s) + \left(\frac{\alpha}{1-\alpha}\right)\ln\left(\frac{s}{\delta + g_A + g_N}\right),$$

this implies

$$\frac{\partial \ln\left(\frac{C^*}{AN}\right)}{\partial s} = -\frac{1}{1-s} + \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{\delta + g_N + g_A}{s}\right)\left(\frac{1}{\delta + g_N + g_A}\right),$$

setting equal to zero and simplifying,

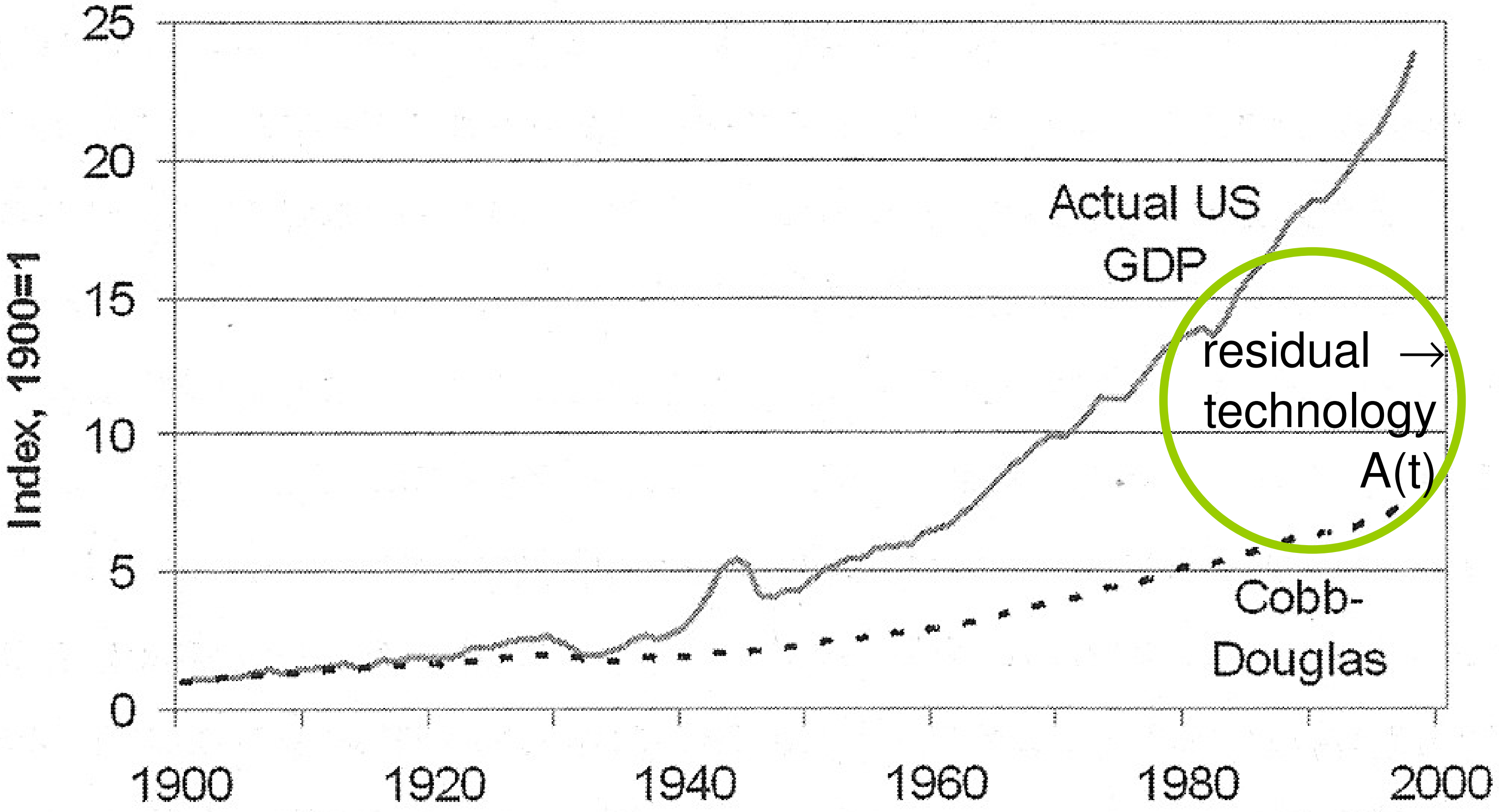
$$0 = -s + (1-s)\left(\frac{\alpha}{1-\alpha}\right).$$

finally,

$$s^* = \alpha.$$

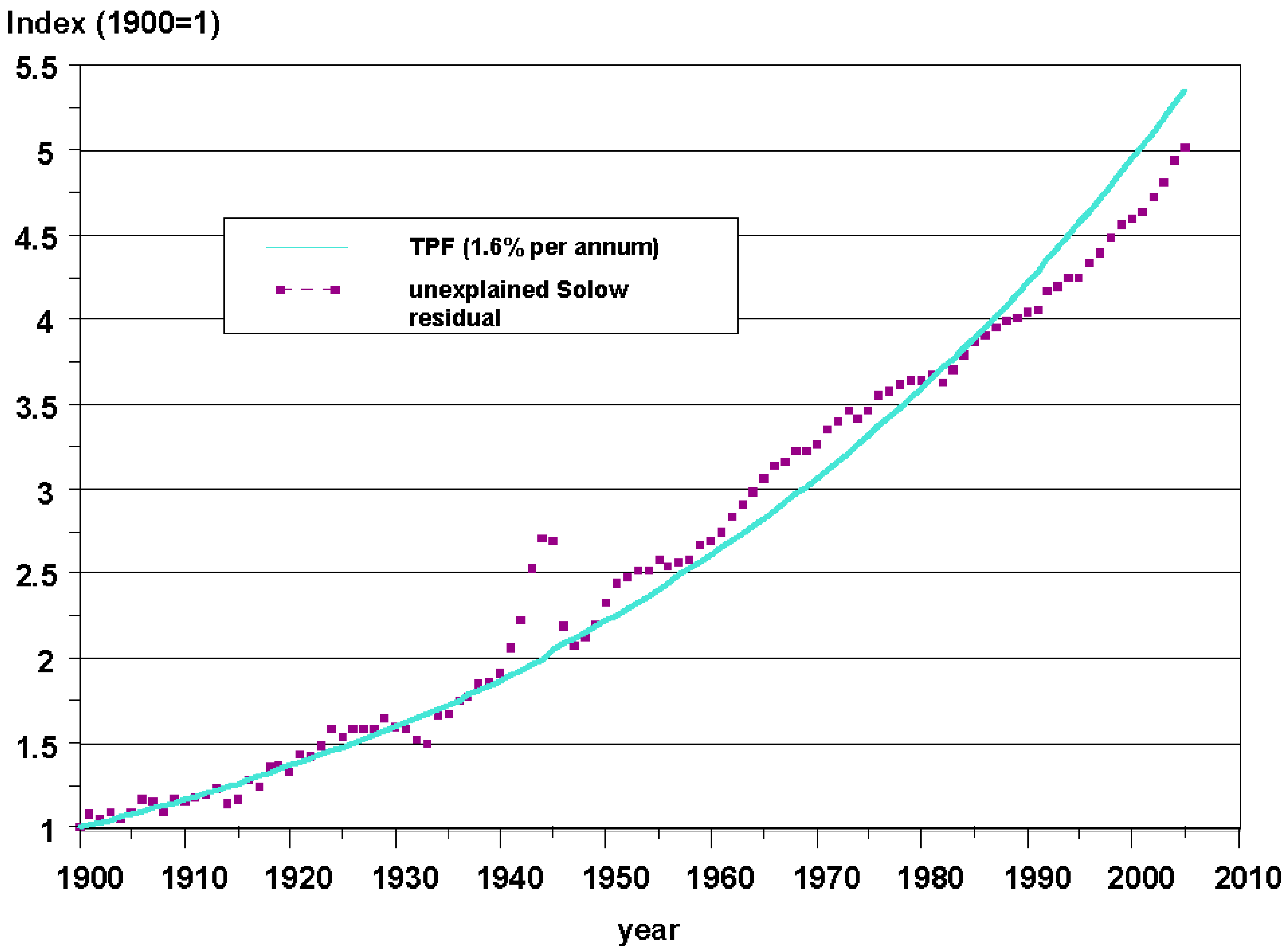
en.wikipedia.org/wiki/Exogenous_growth_model

Cobb-Douglas production functions with L & K USA 1900-2000



The last oil shock, David Strahan (2007)

Technological progress function
Solow residual
USA 1900-2005



The Biophysical Economy

- *Work* drives the economy
  - Scientific: effort expended to get something done
- Human ability to produce *work*
  - 12 hours a day, 7 days a week is about 6 KwH
- Economic development is the process of replacement of human *work* with *work* from animals and then *work* from energy resources
- Technical progress means getting the same result by applying less *work* (limits!)

Human Made Capital (Capital Stock)

- Machines require *work* to be built, and require that *work* be done to operate – need energy!
- Carnot: heat-to-work fraction = $(T-T_0)/T$
  - e.g., diesel engine (773-373)/773 = 52%
  - average efficiency economy wide ~ 20%
- *Work* required is huge: building 1 tractor takes about 28,000 days (a lifetime) of human *work*
- Human *energy* is of low value (low temperature)
- Fossil *energy* is high value (high temperature)

Human Made Capital

- All the physical infrastructure we have
  - housing
  - factories
  - energy services
  - transport services
- Life-cycle analysis
  - gives amount of *work* embodied in HMC
  - account for in primary energy terms (gigajoules)
    - one barrel oil ~ 5.7 GJ

Natural Resources

- Natural Capital
  - flow resources (e.g., fresh water)
  - stock resources
    - renewable (wood)
    - non-renewable (fossil fuels)
- Assume free and unlimited (!)
  - but... embodied energy increases as easily accessible sources are depleted/degraded
    - e.g., fresh water

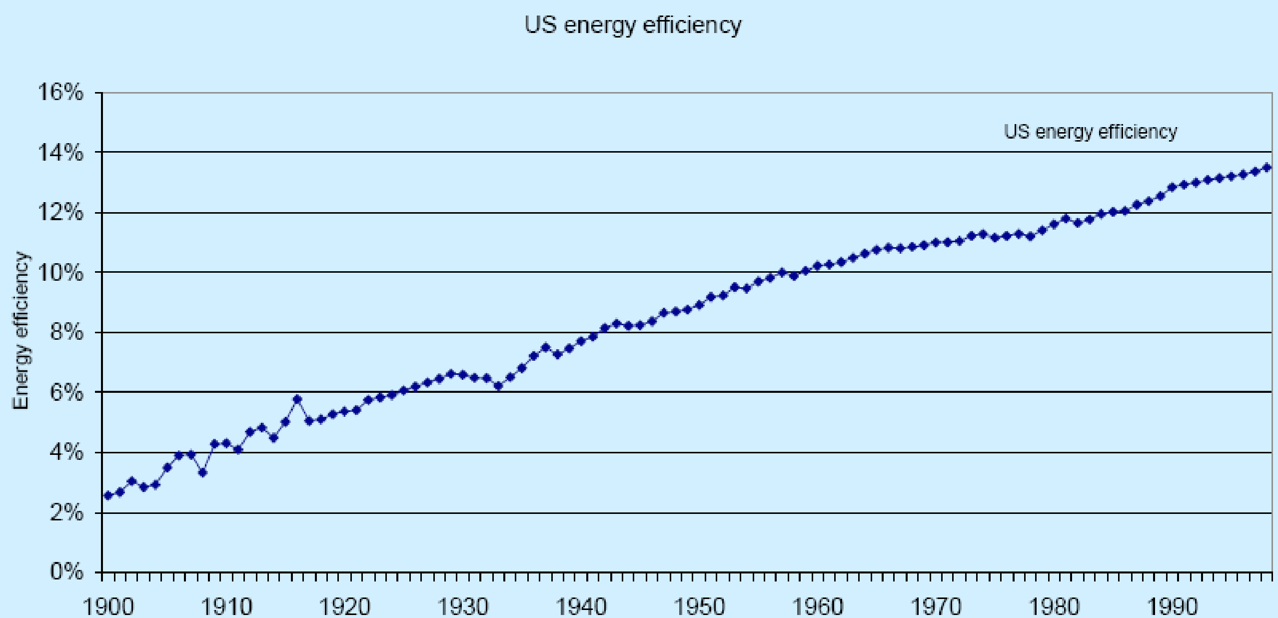
Thermodynamics

- First law: can't win (order cannot increase)
  - can't increase order in one place without decreasing it at least as much somewhere else
- Second law: can't break even (order decreases)
- Production is generating order from disorder
  - e.g., iron-ore to car
  - compensating disorder provided by energy source
    - e.g., tree to carbon dioxide and ash
- Energy is not like other natural resources!

Energy conversion efficiencies USA 1900-1998

Part III: The Economics of Stabilisation

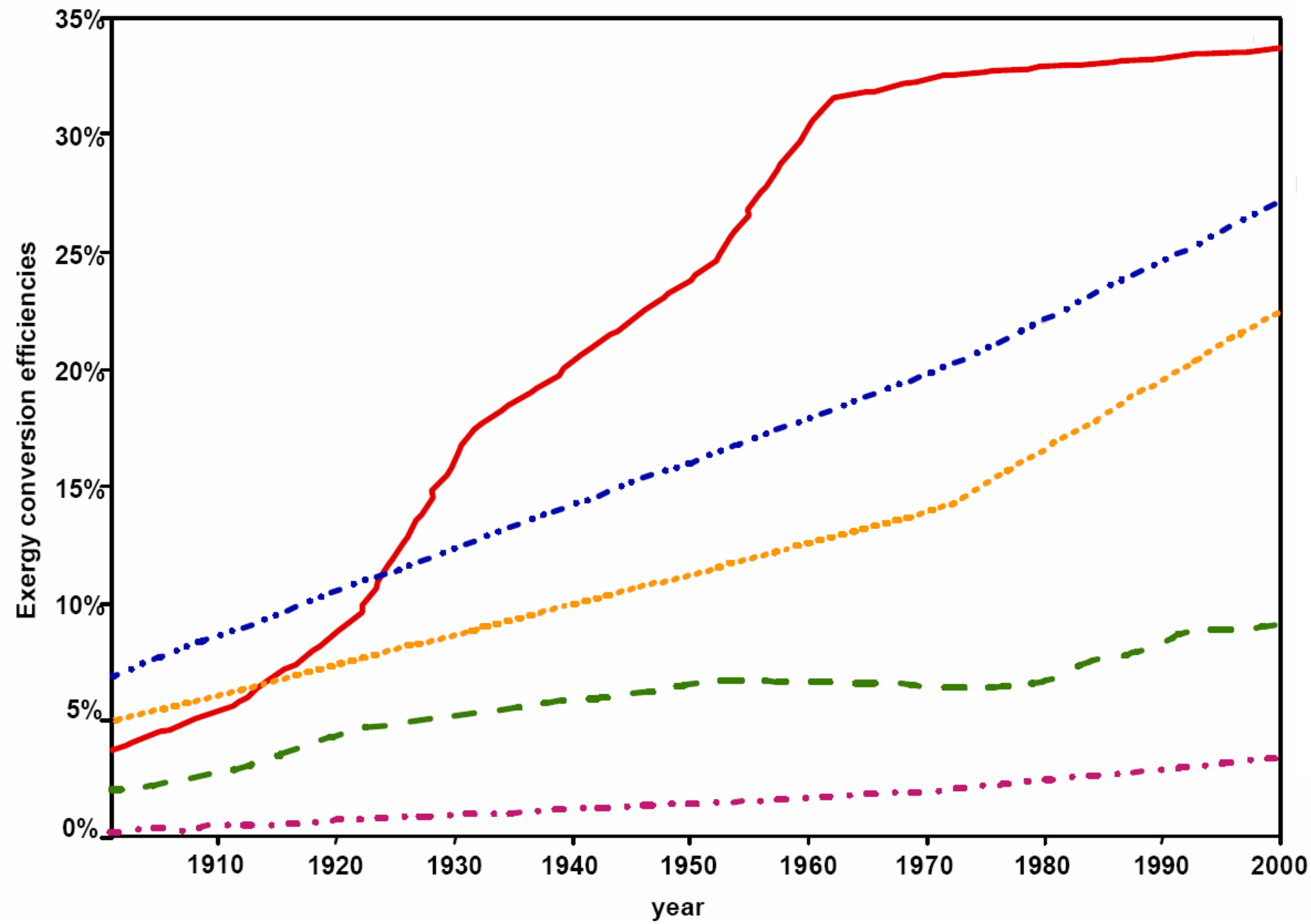
Figure 7.5 Energy conversion efficiencies, USA, 1900–1998



Source: Ayres et al (2005) and Ayres and Warr (2005) This graph shows the efficiency with which power from fossil-fuel, hydroelectric and nuclear sources is converted into useful energy services. The percentages reflect the ratio of useful work output to energy input.

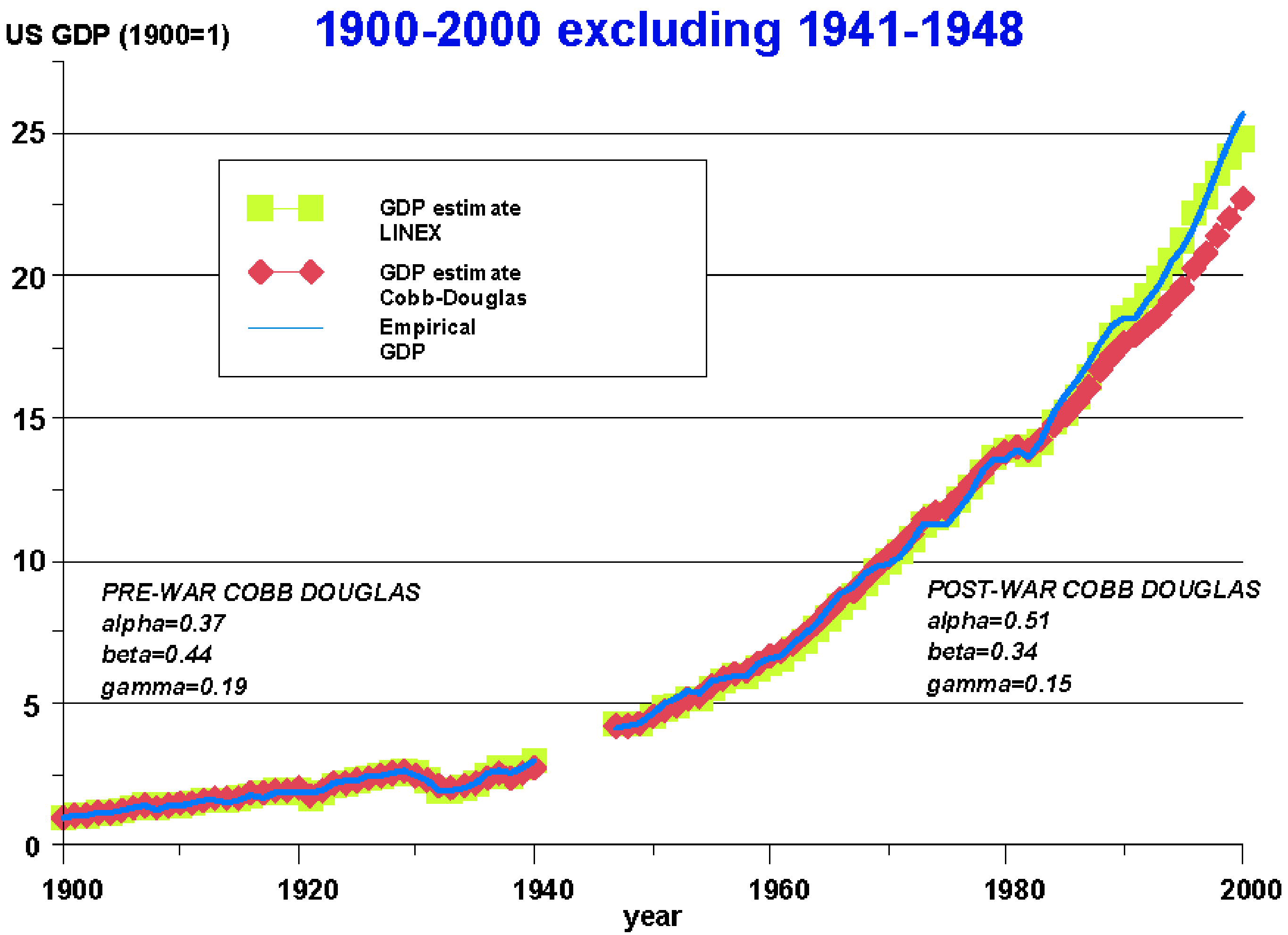
www.hm-treasury.gov.uk/media/2/5/Part_III_Introduction_Group.pdf

Energy (exergy) conversion efficiencies from available to useful energy (U) USA 1900-1998

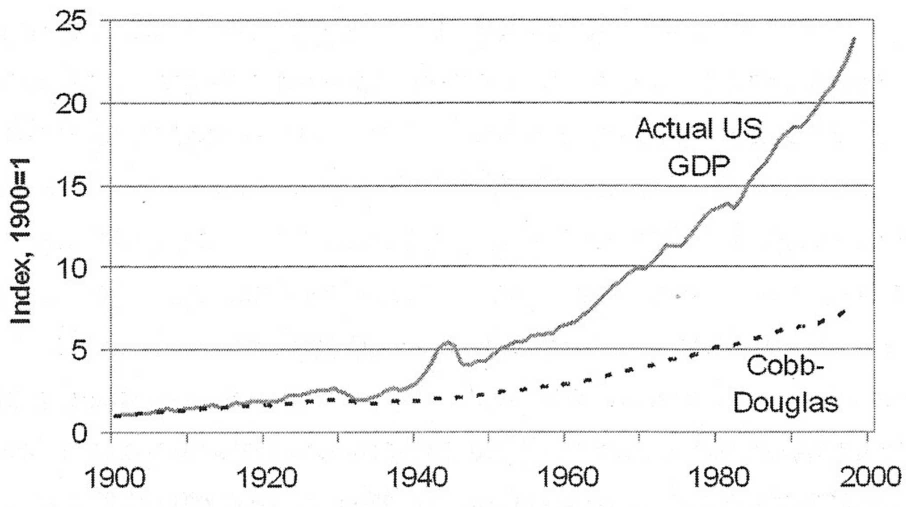


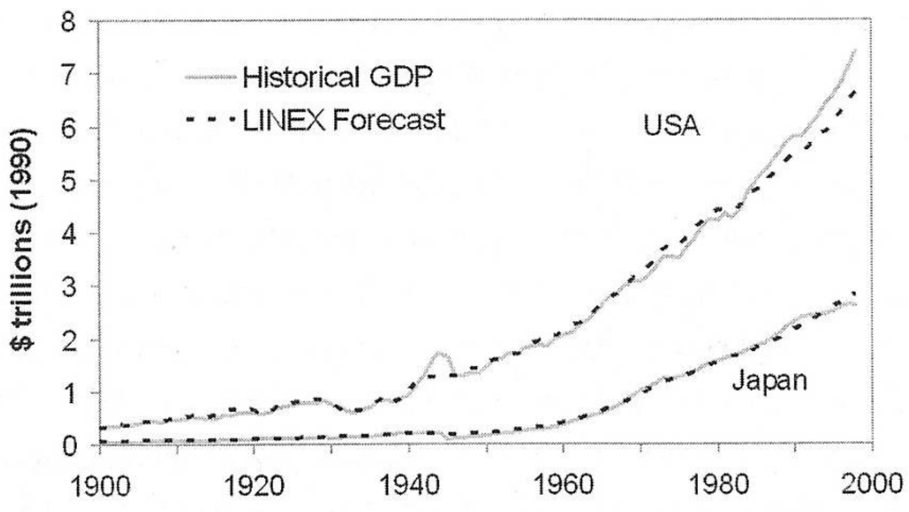
www.iea.org/Textbase/work/2004/eewp/Ayres-paper1.pdf

Production function fit USA



Real influence of energy?





The last oil shock, David Strahan (2007)

Growth theory
view of neoclassical economics (Brad DeLong)

"The bulk of the reason that Americans today are more productive than their predecessors of a century ago is better technology."

We now know how to make **electric motors**, dope semiconductors, transmit signals over fiber optics, fly jet airplanes, machine internal combustion engines, build tall and durable **structures out of concrete and steel**, record entertainment programs on magnetic tape, make hybrid seeds, **fertilize crops with nutrients**, organize assembly lines, and a host of other things our predecessors did not know how to do. Better technology leads to a higher efficiency of labor--the skills and education of the labor force, the ability of the labor force to handle modern machine technologies, and the efficiency with which the economy's businesses and markets function.

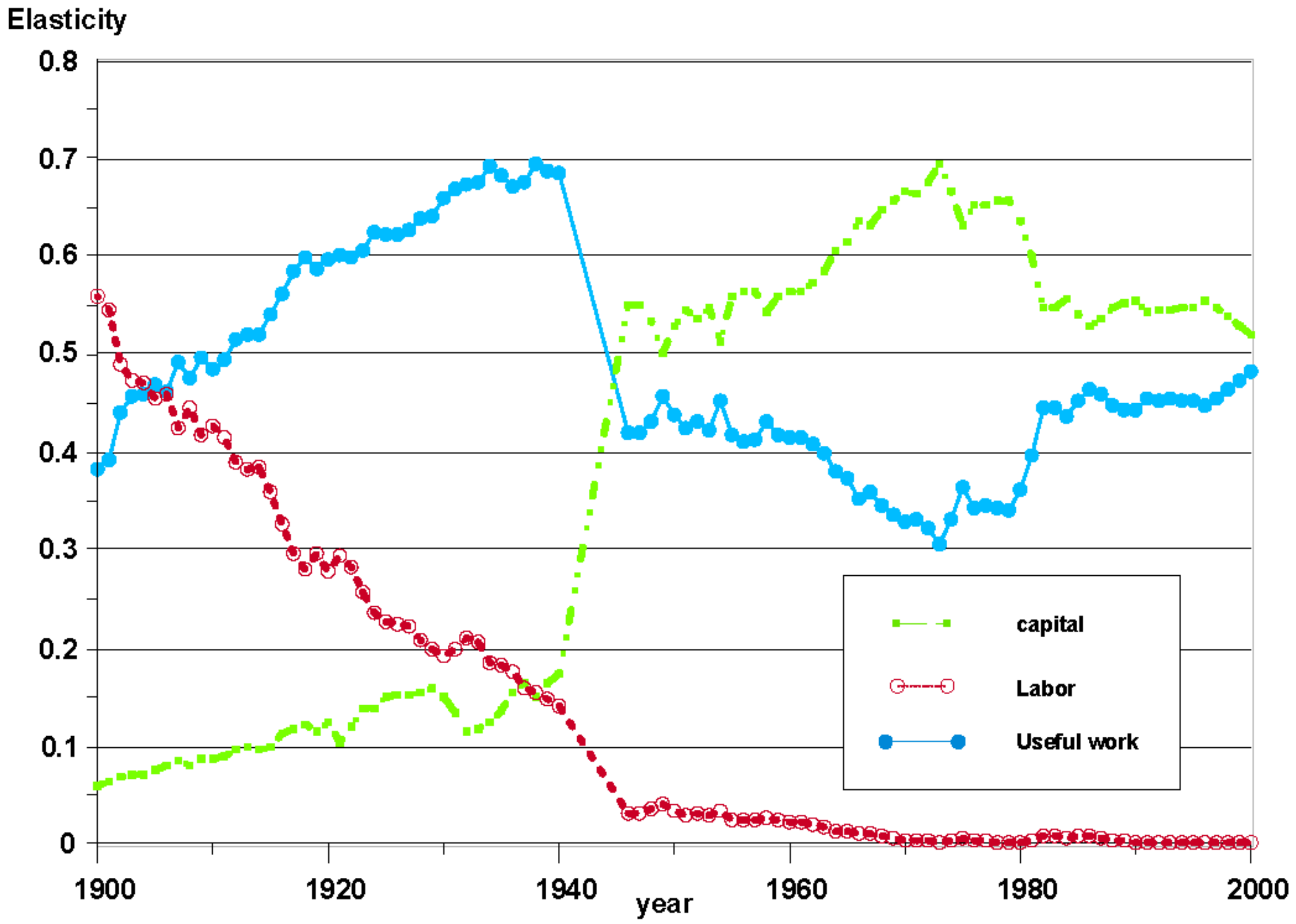
econ161.berkeley.edu/macro_online/gt_primer.pdf

Growth theory
contribution of *useful* energy (Ayres)

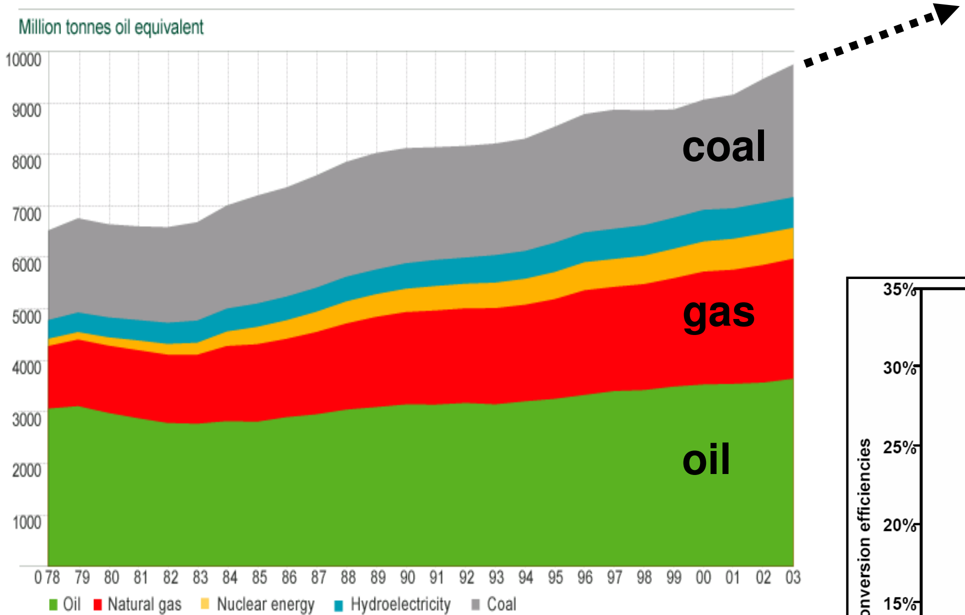
"In its present two-factor form, the Cobb-Douglas production function permits future physical economic growth even with no materials or energy consumption."

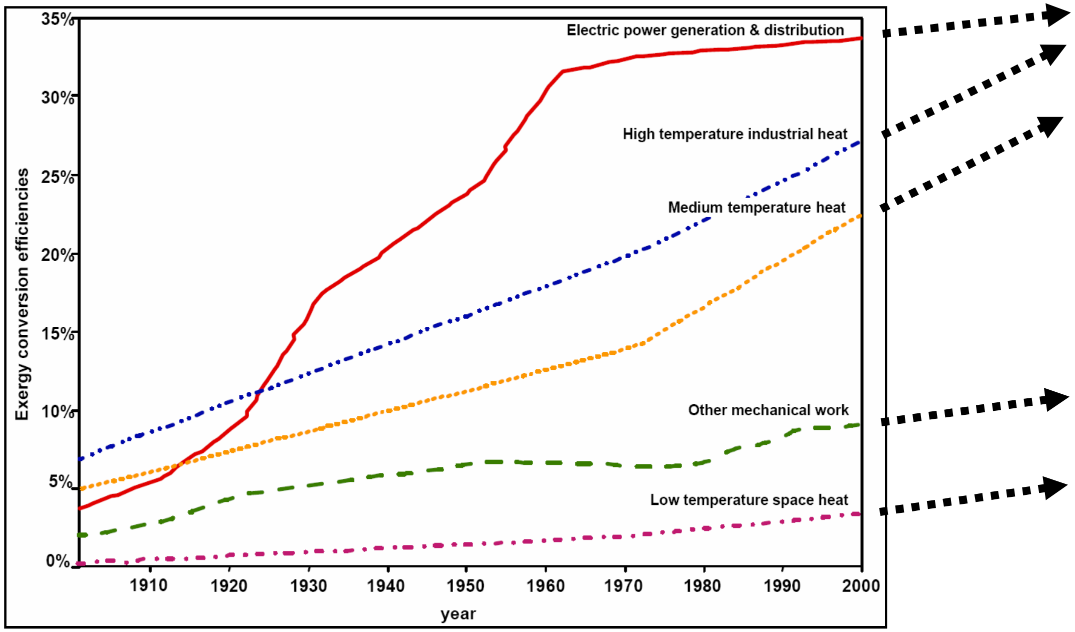
"This is significant, because if resource consumption is not needed to explain growth, then `decoupling' growth from resource consumption is conceptually easy: they were never coupled in the first place."

Elasticities of factors of production USA 1900-1941, 1947-2000



Future useful energy (U) depends on:
more cheap energy (exergy)
improved conversion efficiencies

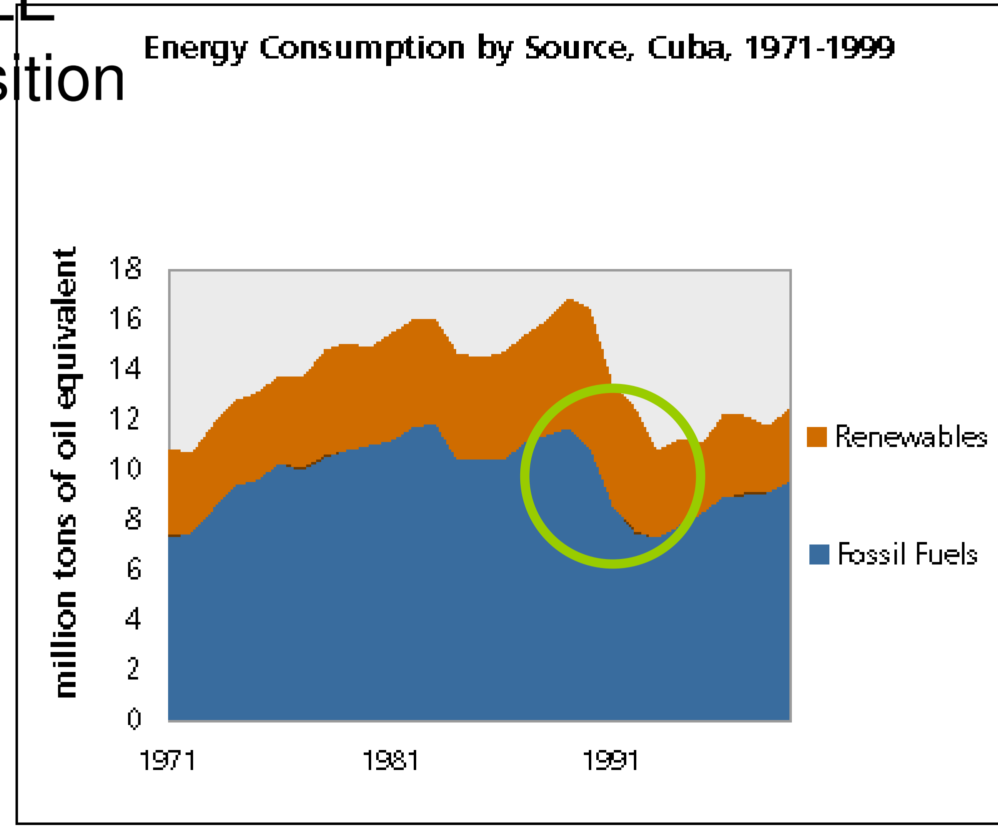


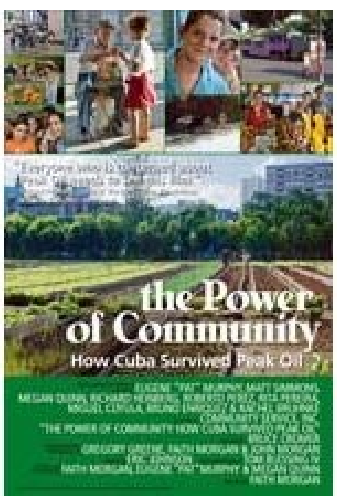


Focus on Energy

- Energy is continually embodied in production
- Current energy sources are primarily fossil fuels
  - increasingly hard to access (land vs. deep ocean)
  - decreasing quality (Saudi oil vs. Canadian tar sands)
- We need to transition to sustainable (~500 years) sources (solar, geothermal, tidal, nuclear, ...)

EXAMPLE
abrupt transition
Cuba

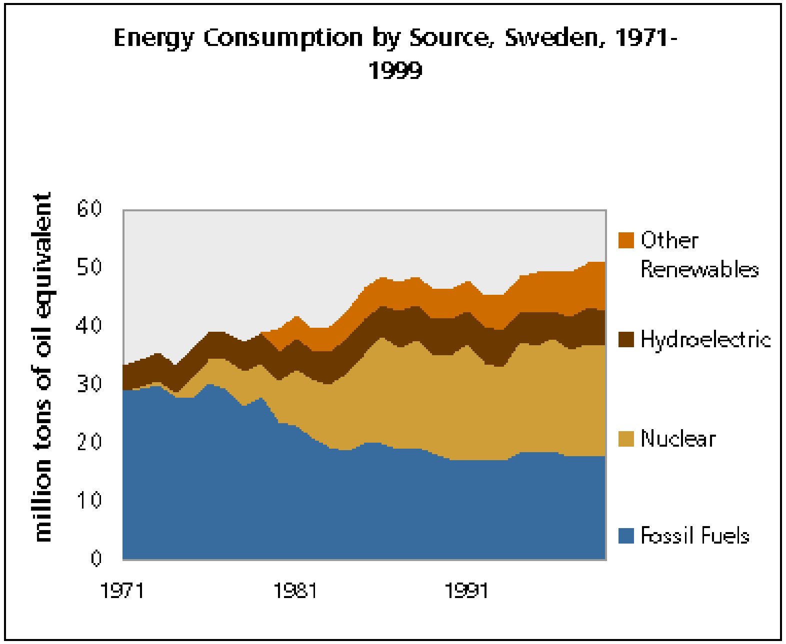




www.powerofcommunity.org

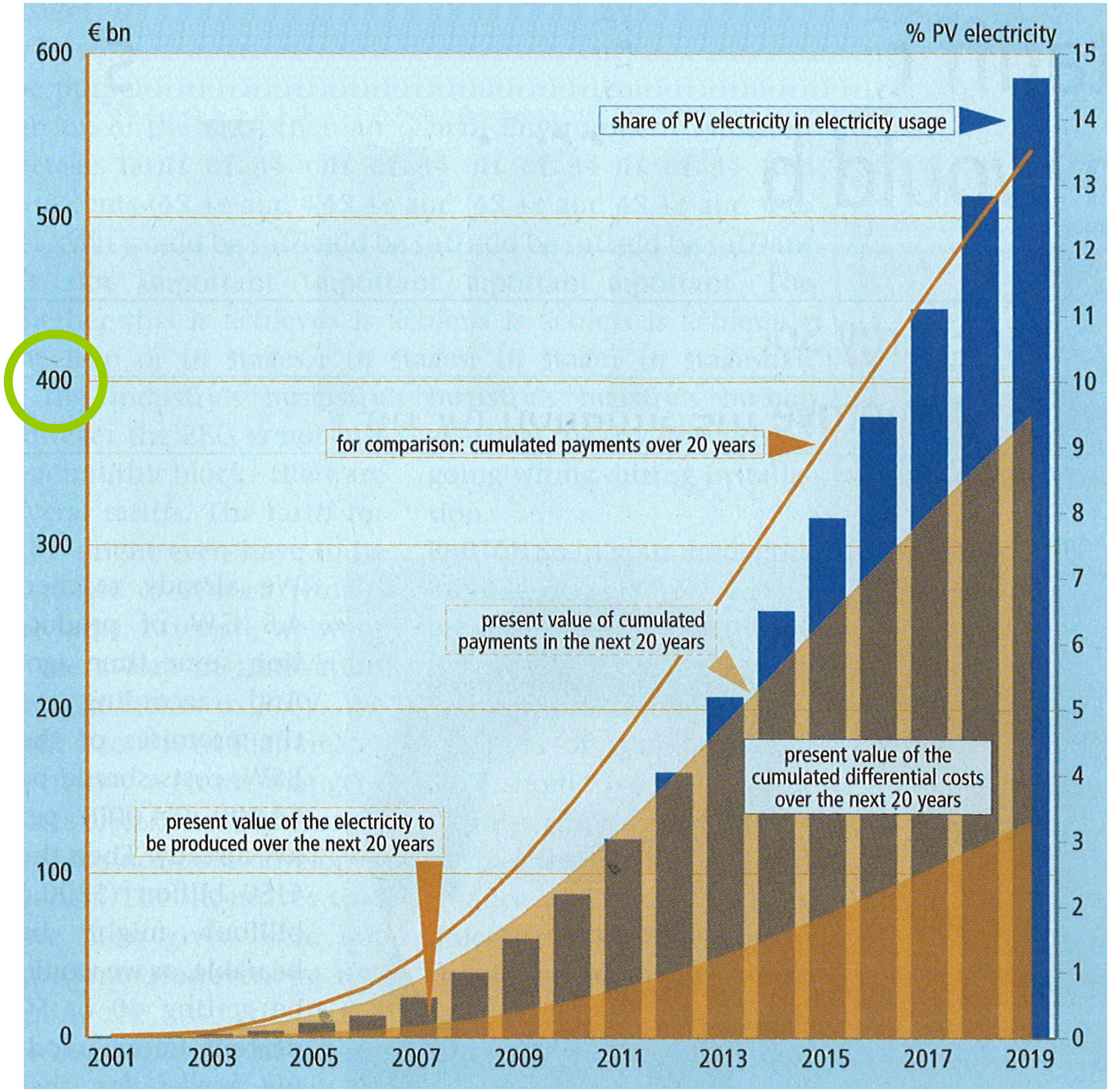
EXAMPLE
planned transition
Sweden

- "Ridding ourselves of our dependence on oil by the year 2020"
- Through more efficient use of fuel and new fuels, consumption of oil in road transport shall be reduced by 40-50%.
- No oil shall be used for heating residential and commercial buildings
- Industry shall reduce its consumption of oil by 25-40%



www.sweden.gov.se/sb/d/3212/a/51058

EXAMPLE
Can PV feed-in law be afforded?
Germany



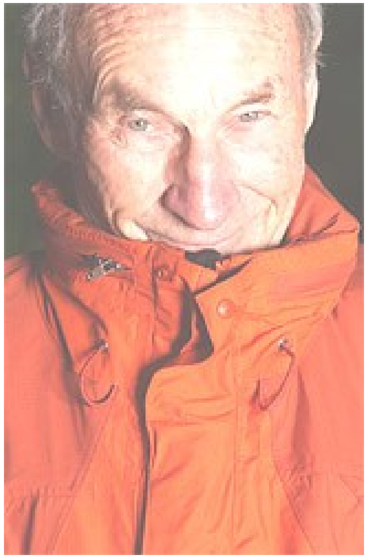
Photon International 5/2007

Discuss

Energy – is it special?

framework

ECCO model
Evaluating Capital Creation Options



Malcolm
Slesser
dedication

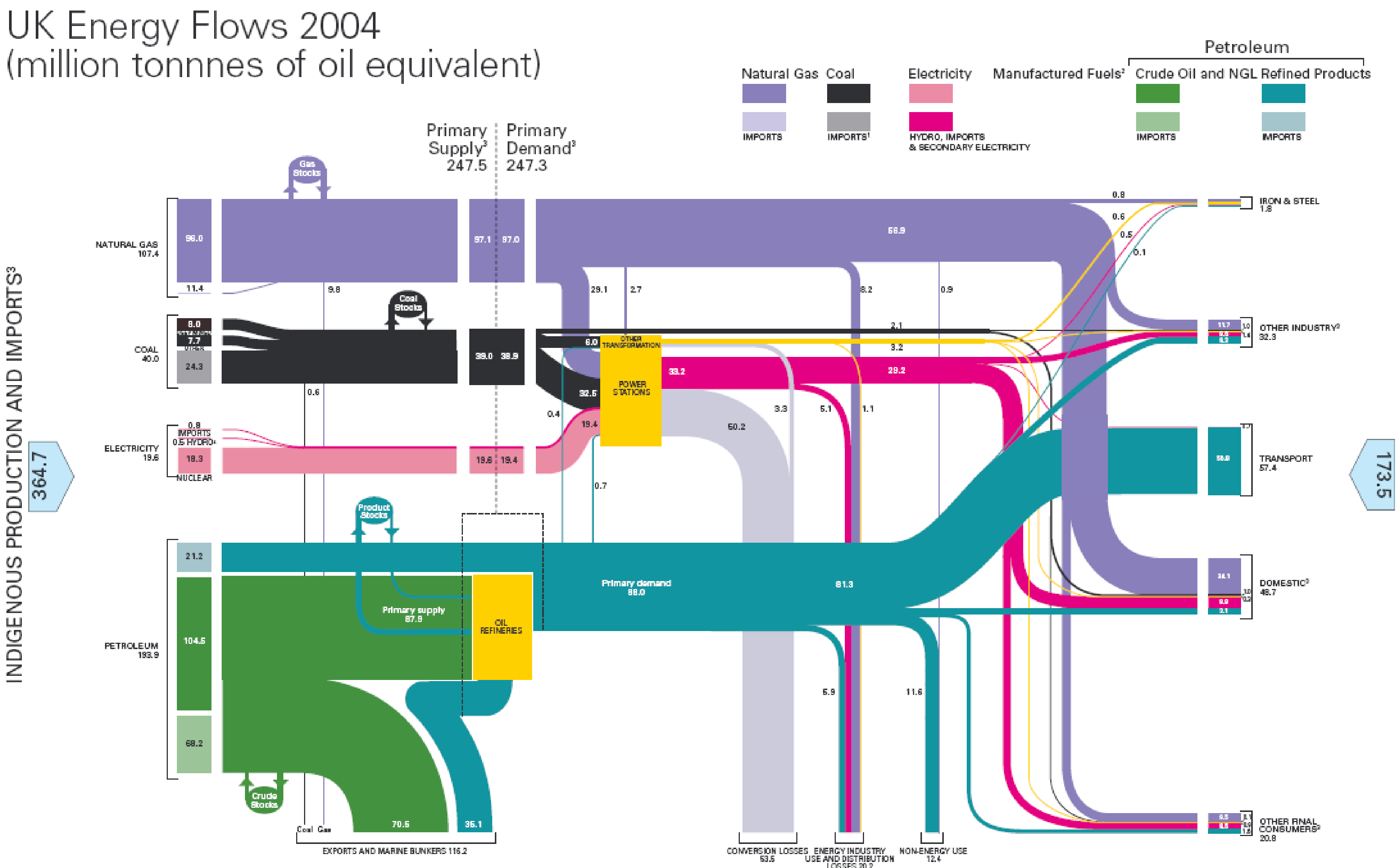
Jane
King

Dave
Crane

ECCO model
Evaluating Capital Creation Options

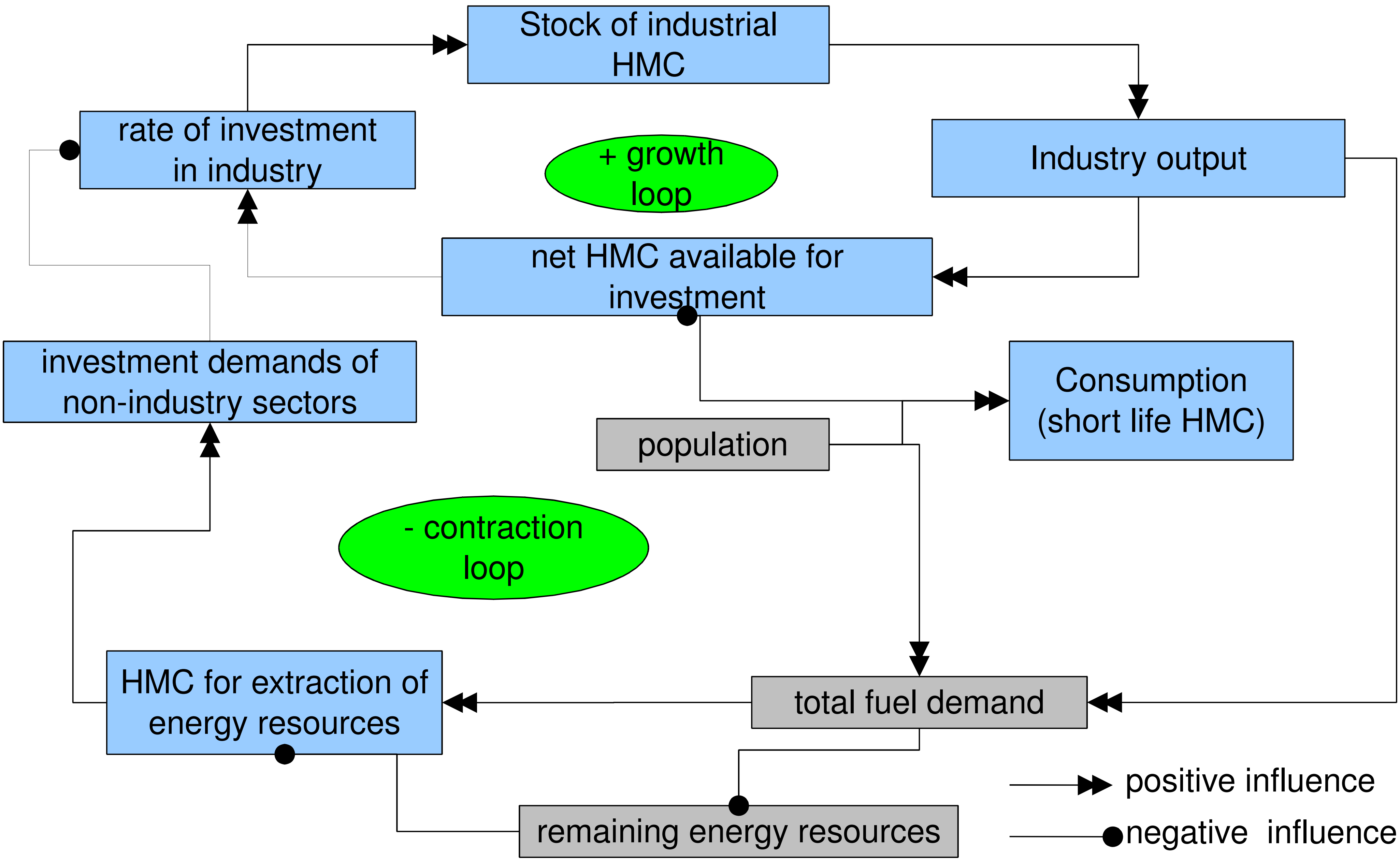
- physical economy model
- where energy and financial flows
- must conform to the laws of
  - thermodynamics and
  - mass balance

Energy flows

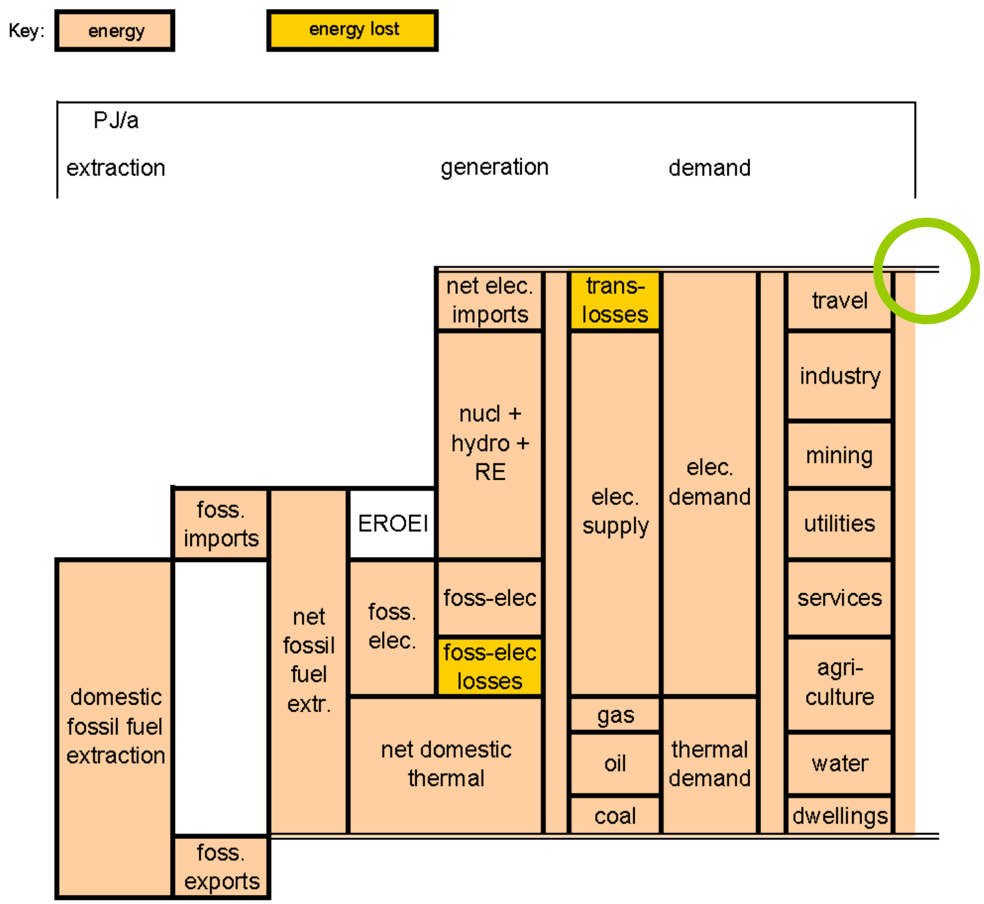


www.dti.gov.uk/energy/inform

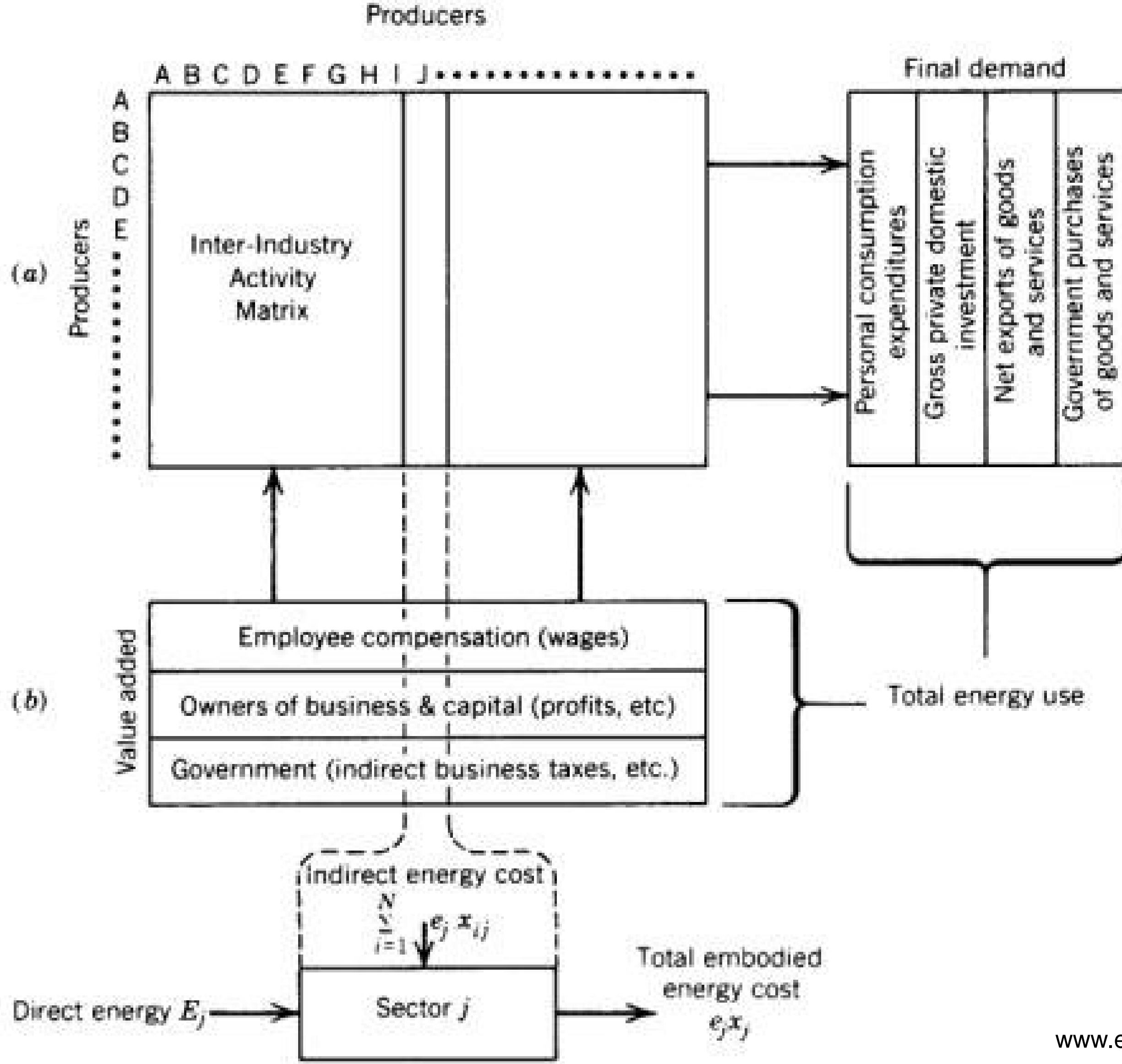
ECCO modelling



Whole economy expressed in energy units

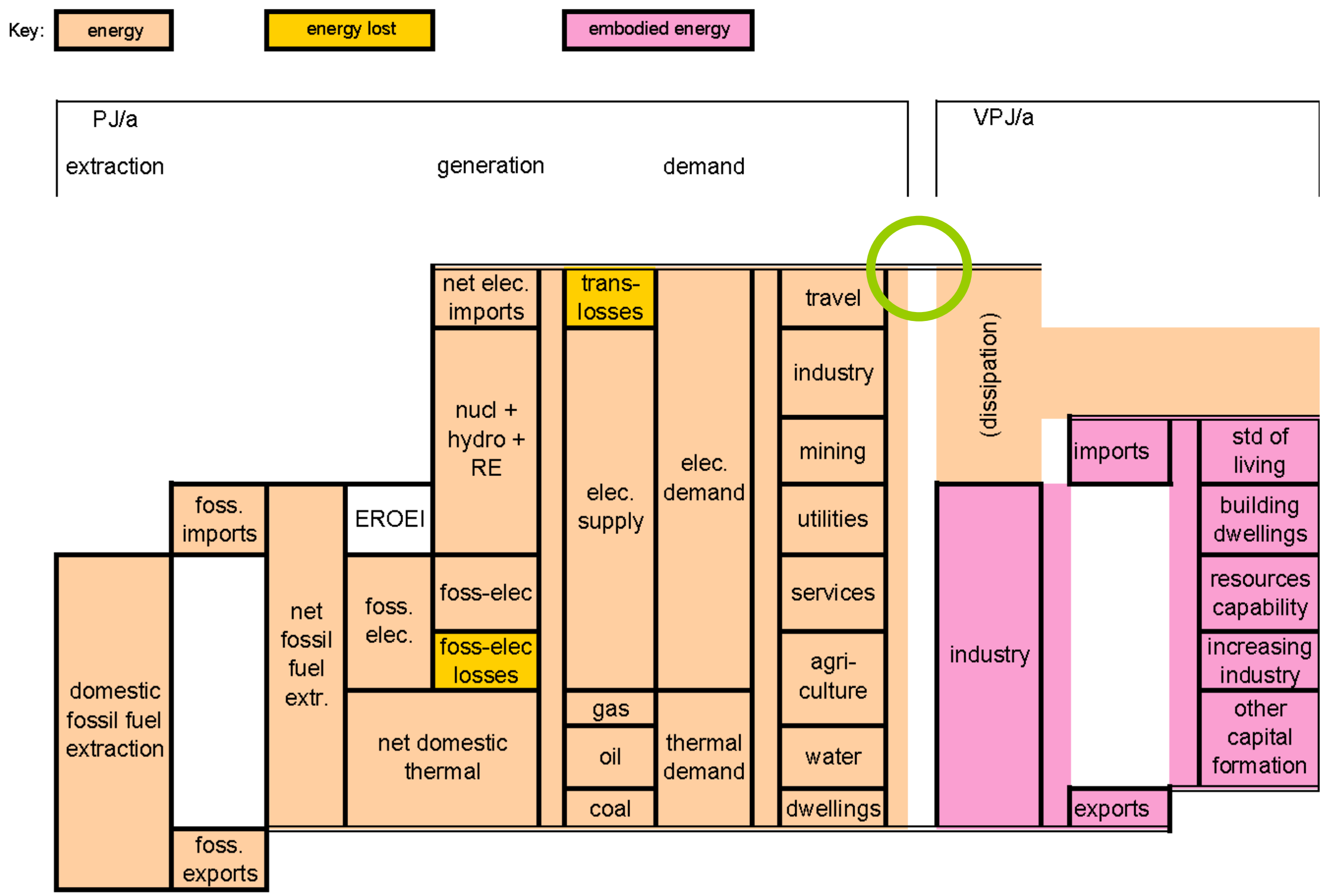


Embodied energy - input-output analysis includes both direct and indirect energies

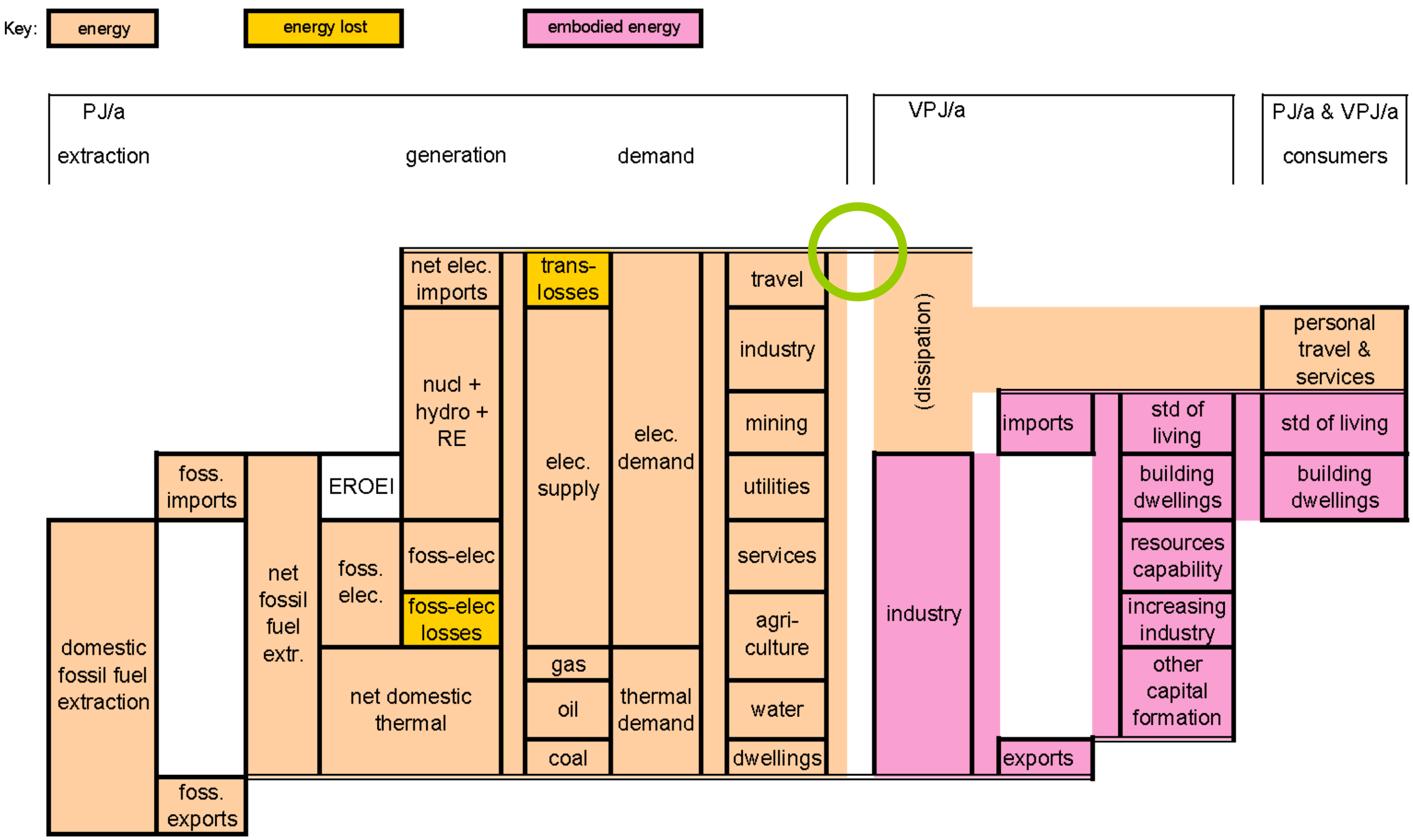


www.eoearth.org/article/Net_energy_analysis

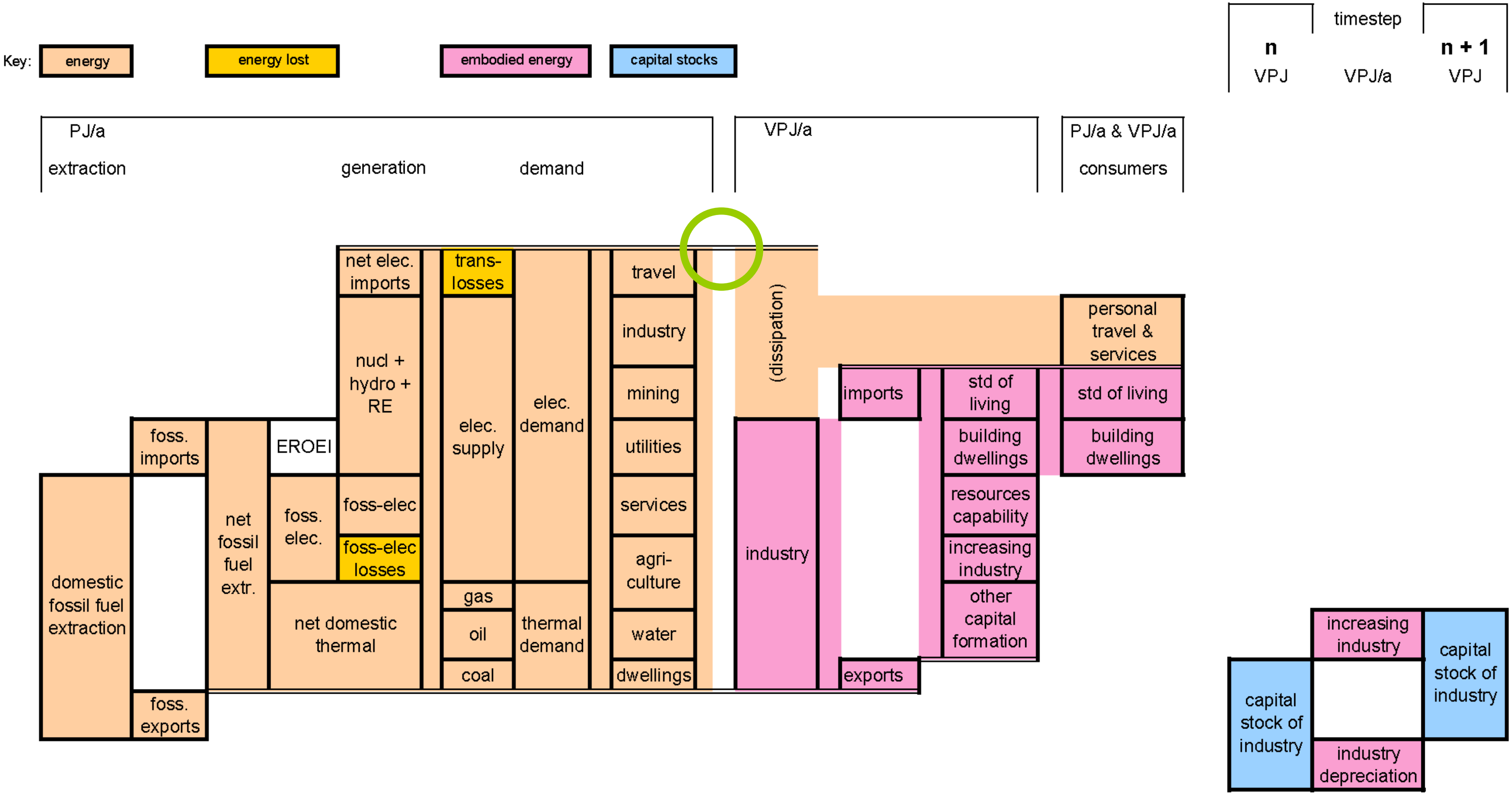
Whole economy expressed in energy units



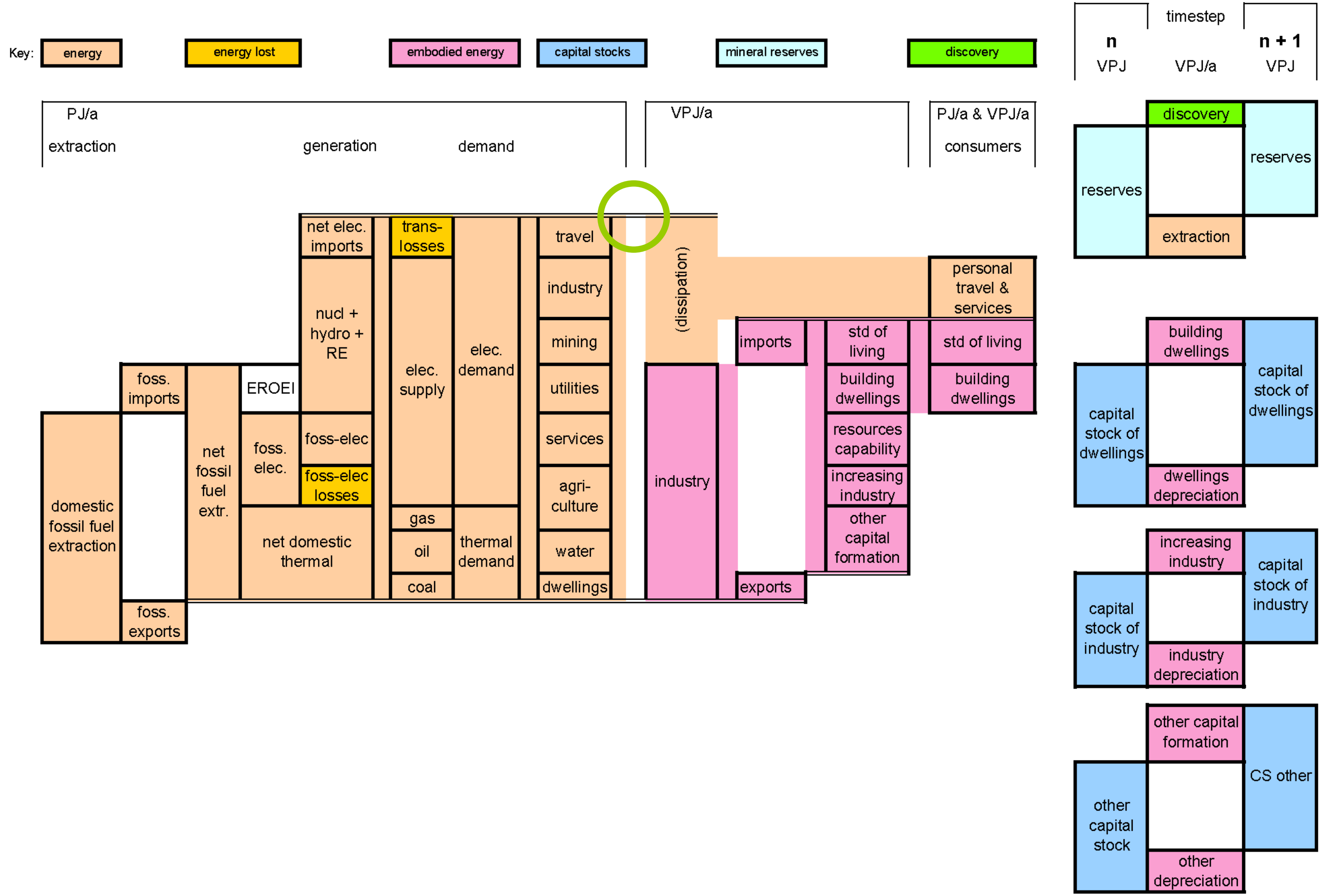
Whole economy expressed in energy units

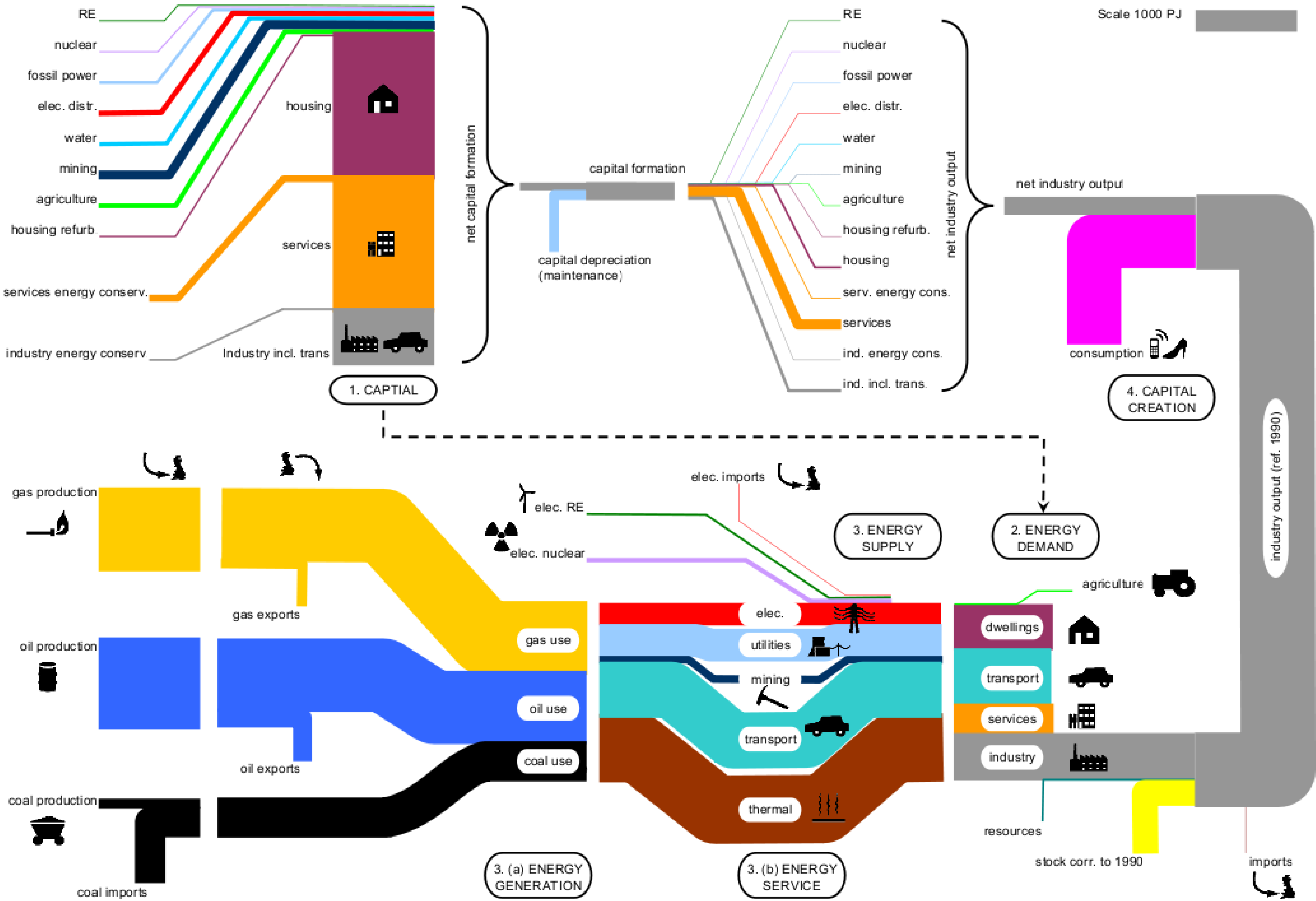


Whole economy expressed in energy units



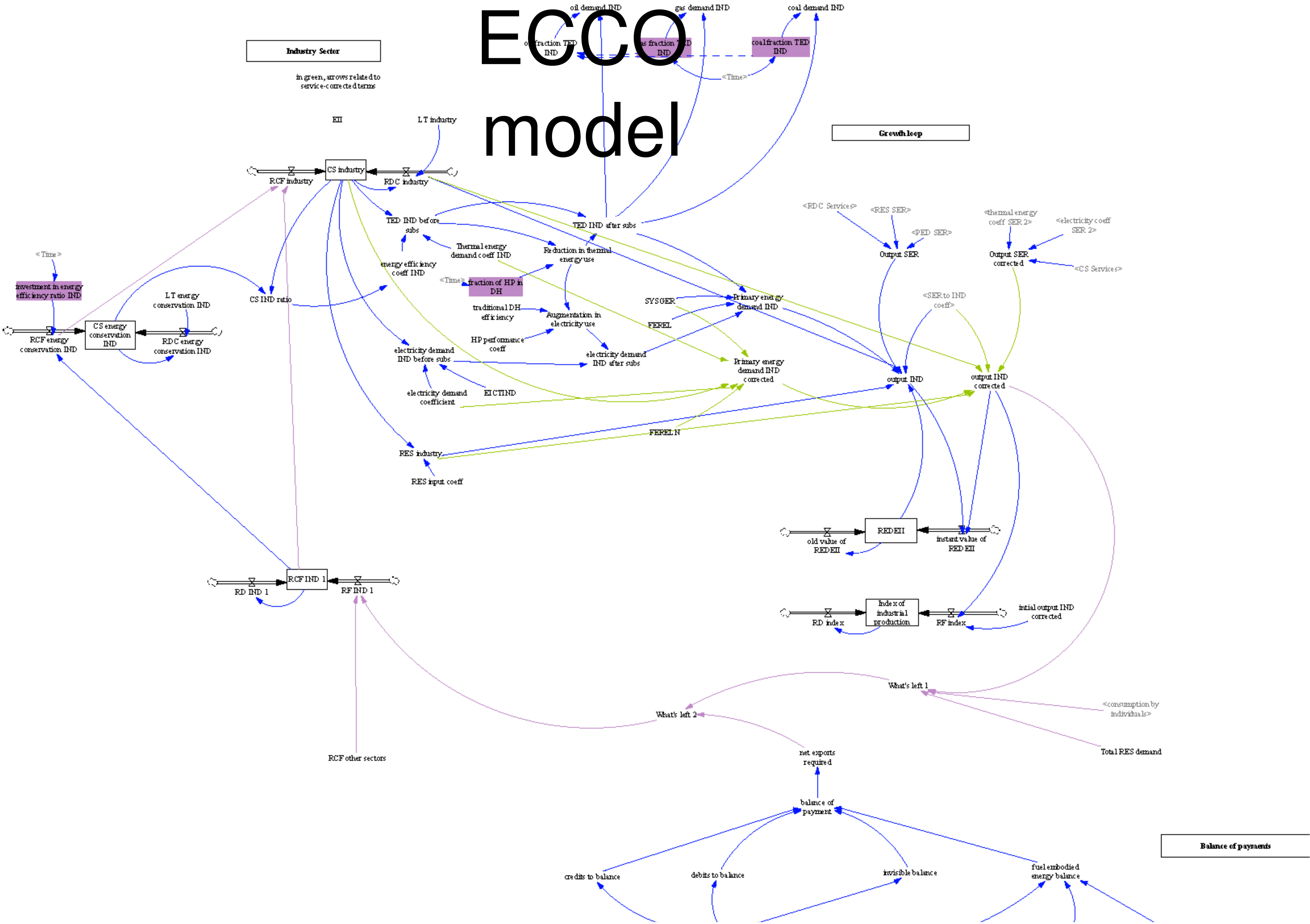
Whole economy expressed in energy units

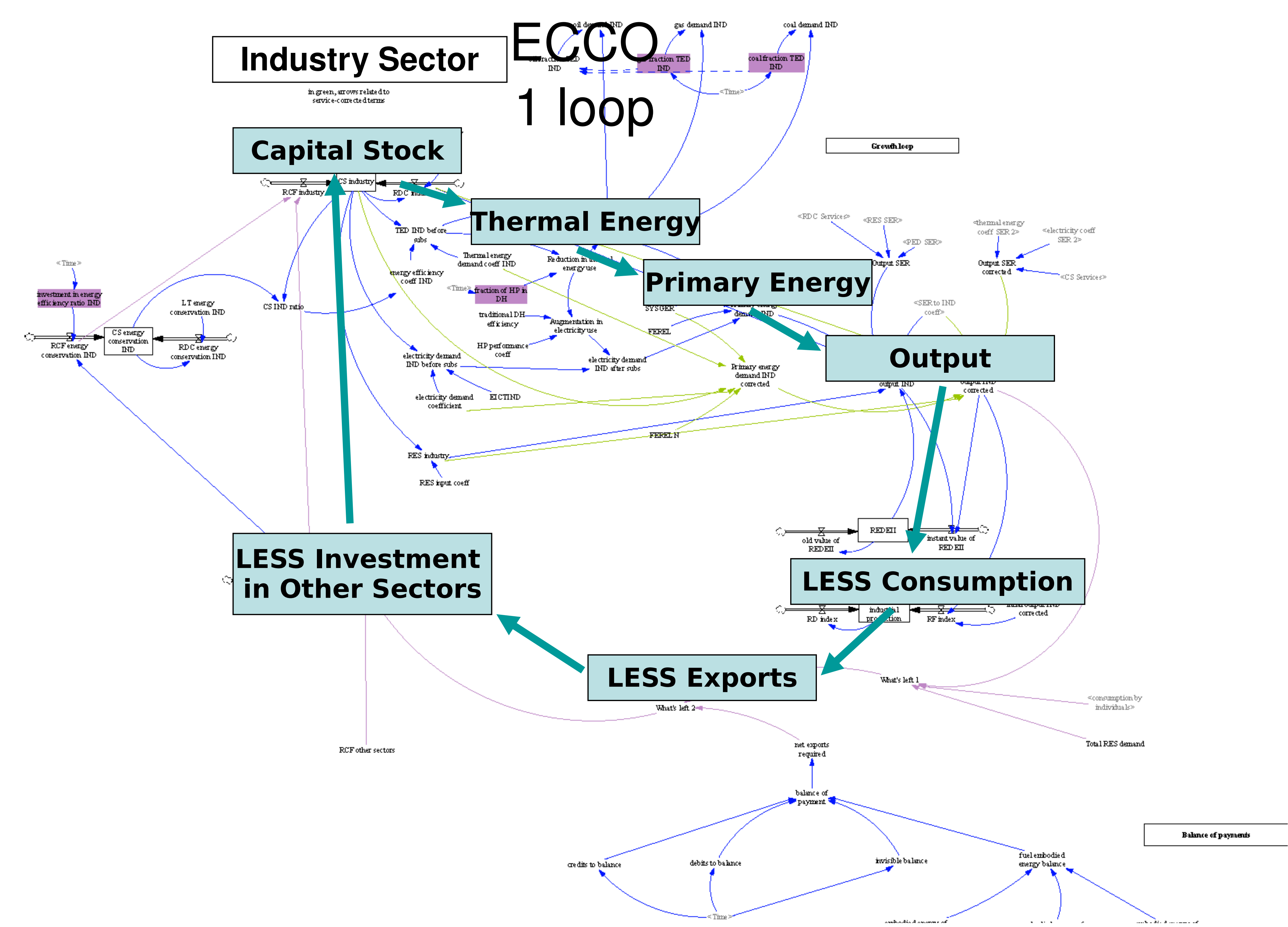




RE
nuclear
fossil power
elec. distr.
water
mining
agriculture
housing refurb
services energy conserv.
industry energy conserv
housing
services
Industry incl. trans
1. CAPTIAL
net capital formation
capital formation
capital depreciation (maintenance)
RE
nuclear
fossil power
elec. distr.
water
mining
agriculture
housing refurb.
housing
serv. energy cons.
services
ind. energy cons.
ind. incl. trans.
net industry output
Scale 1000 PJ
net industry output
consumption
4. CAPITAL CREATION
industry output (ref. 1990)
gas production
gas exports
oil production
oil exports
coal production
coal imports
gas use
oil use
coal use
elec. RE
elec. nuclear
elec. imports
3. ENERGY SUPPLY
2. ENERGY DEMAND
elec.
utilities
mining
transport
thermal
agriculture
dwellings
transport
services
industry
resources
stock corr. to 1990
imports
3. (a) ENERGY GENERATION
3. (b) ENERGY SERVICE

ECCO model


Industry Sector
in green, arrows related to service-corrected terms
EII
LT industry
CS industry
RCF industry
RDC industry
oil demand IND
gas demand IND
coal demand IND
gas fraction TED IND
coal fraction TED IND
<Time>
Growth loop
TED IND before subs
TED IND after subs
Thermal energy demand coeff IND
Reduction in thermal energy use
energy efficiency coeff IND
<Time>
fraction of HP in DH
CS IND ratio
<Time>
investment in energy efficiency ratio IND
LT energy conservation IND
CS energy conservation IND
RCF energy conservation IND
RDC energy conservation IND
traditional DH efficiency
Augmentation in electricity use
HP performance coeff
SYSGER
FEREL
Primary energy demand IND
electricity demand IND before subs
electricity demand IND after subs
electricity demand coefficient
EICTIND
Primary energy demand IND corrected
FEREL N
RES industry
RES input coeff
<RDC Services>
<RES SER>
<PED SER>
Output SER
<thermal energy coeff SER 2>
<electricity coeff SER 2>
Output SER corrected
<CS Services>
<SER to IND coeff>
output IND
output IND corrected
REDEII
old value of REDEII
instant value of RED EII
Index of industrial production
RD index
RF index
intial output IND corrected
RCF IND 1
RD IND 1
RF IND 1
RCF other sectors
What's left 1
What's left 2
<consumption by individuals>
Total RES demand
net exports required
balance of payment
credits to balance
debits to balance
invisible balance
fuel embodied energy balance
Balance of payments



ECCO
1 loop
Industry Sector
in green, arrows related to service-corrected terms
Capital Stock
Thermal Energy
Primary Energy
Output
LESS Consumption
LESS Exports
LESS Investment in Other Sectors
Growth loop
Balance of payments
oil demand IND
gas demand IND
coal demand IND
coal fraction TED IND
<Time>
CS industry
RCF industry
RDC industry
TED IND before subs
Thermal energy demand coeff IND
energy efficiency coeff IND
investment in energy efficiency ratio IND
CS IND ratio
LT energy conservation IND
CS energy conservation IND
RCF energy conservation IND
RDC energy conservation IND
fraction of HP in DH
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RES industry
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<RES SER>
<PED SER>
Output SER
Output SER corrected
<thermal energy coeff SER 2>
<electricity coeff SER 2>
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REDEII
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RD index
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What's left 1
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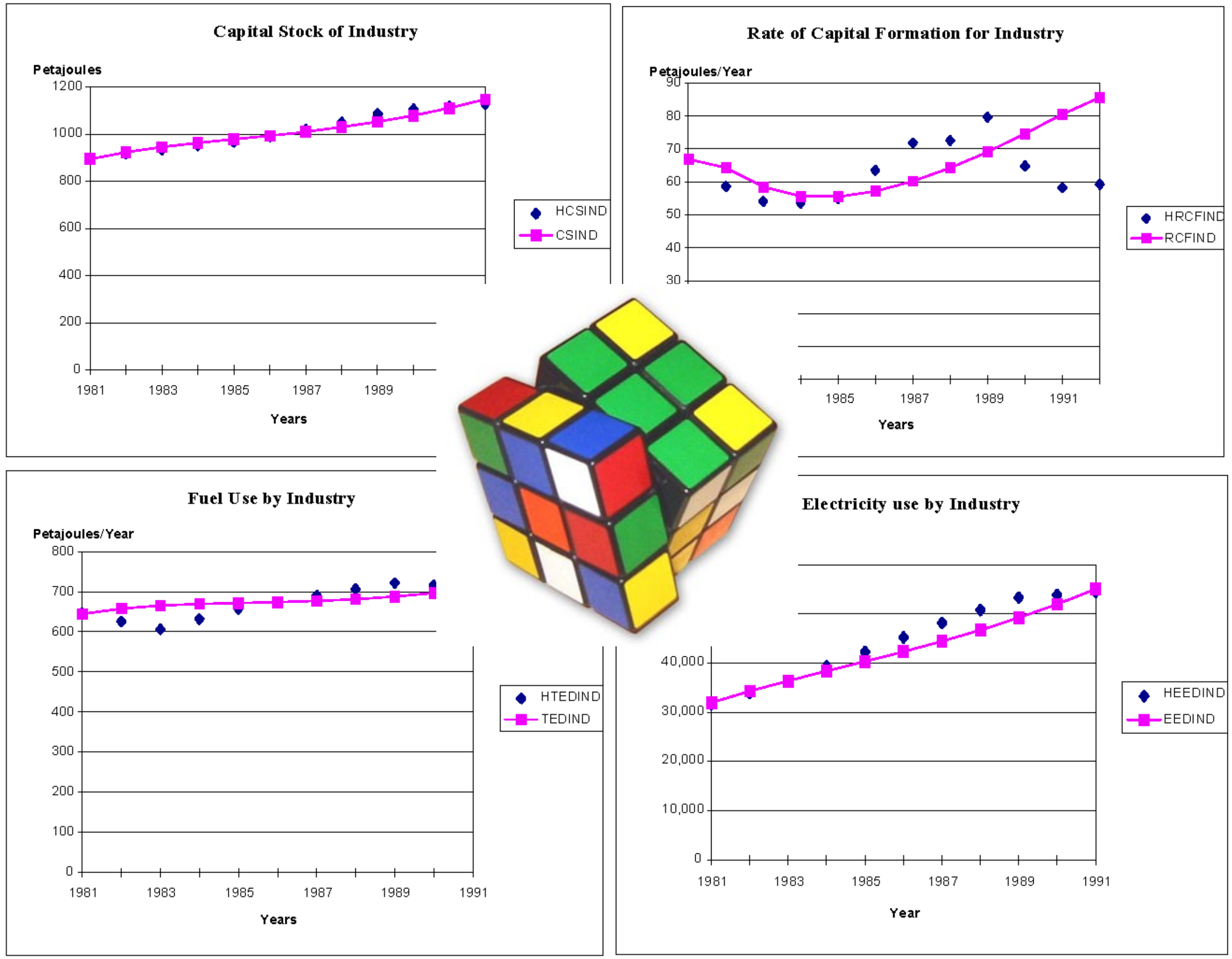
Total RES demand
RCF other sectors
net exports required
balance of payment
credits to balance
debits to balance
invisible balance
fuel embodied energy balance

ECCO
calibration, eg 1981-1991 for



www.cse.csiro.au/publications/reports.htm (Foran et al)

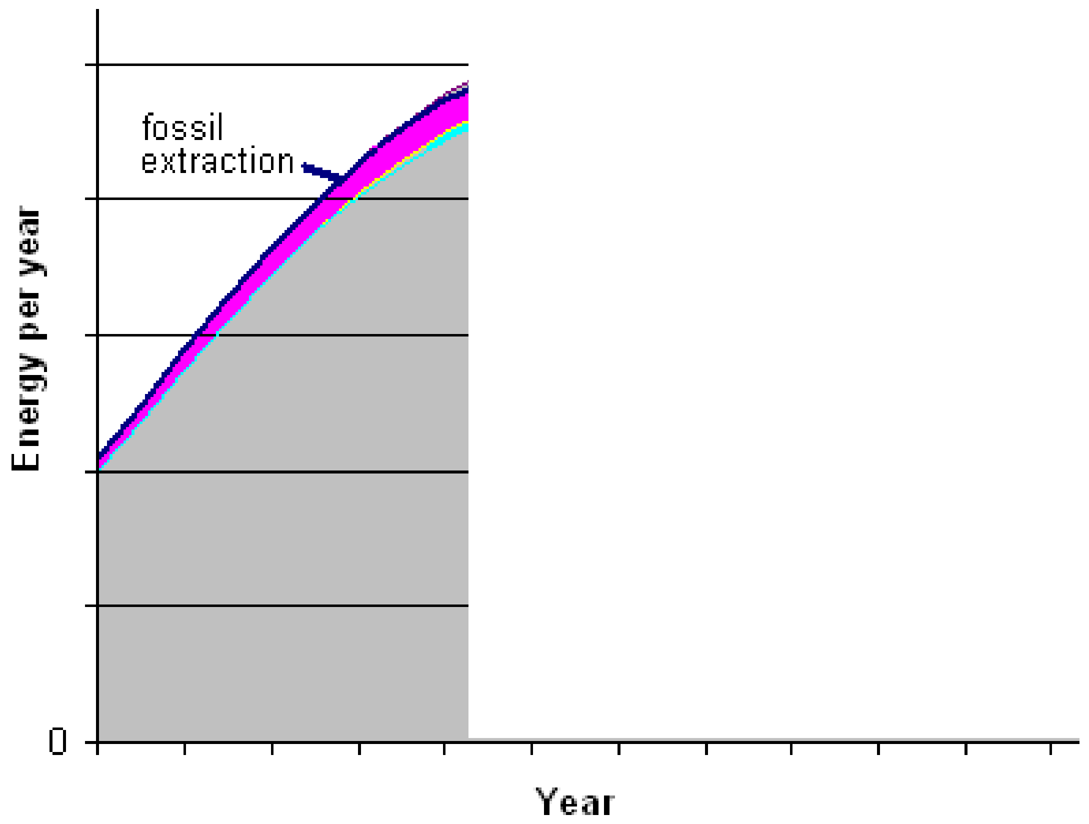
ECCO Applications

UK Model

- Currently being updated
- Being used for Peak Oil Task Force scenarios
- Suggests
  - Balance of payments crisis by 2020 if no serious action taken to develop new energy sources
  - Policies to dampen industrial output may be needed to contain rebound

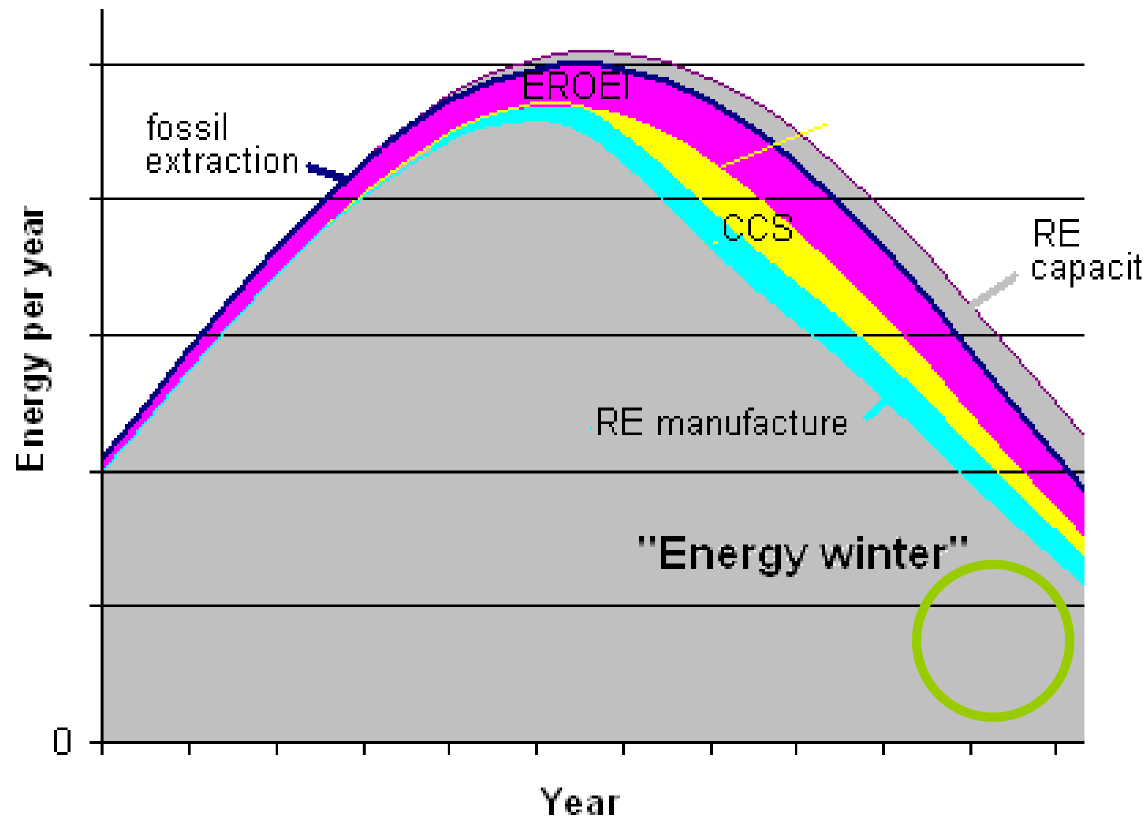
Renewables problem: the “energy winter” for transition

1. fossil extraction peaks
2. fossil extraction energy (EROEI) increases

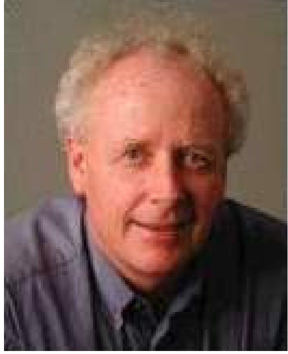


Renewables problem: the "energy winter" for transition

1. fossil extraction peaks
2. fossil extraction energy (EROEI) increases
3. carbon capture (CCS) introduced
4. energy to make RE capital
5. net energy plummets



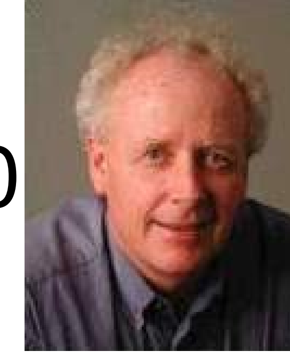
OzEcco
Barney Foran

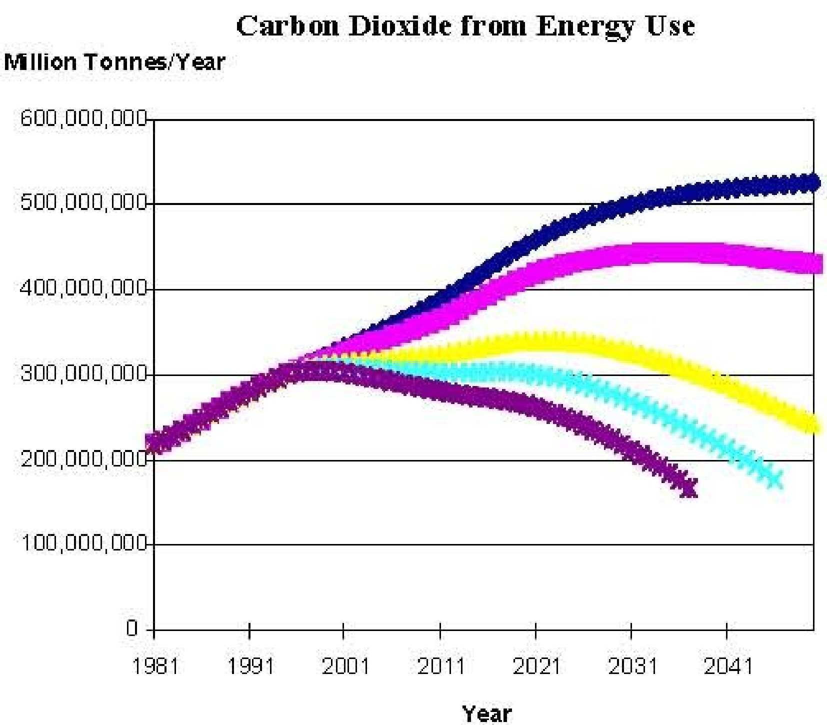


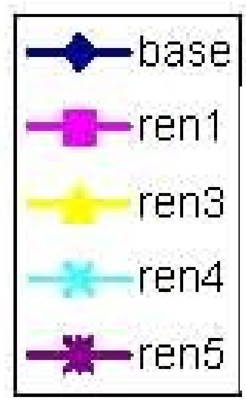
- Leader of the Resource Futures Program, CSIRO.

www.abc.net.au/4corners/stories/s718235.htm

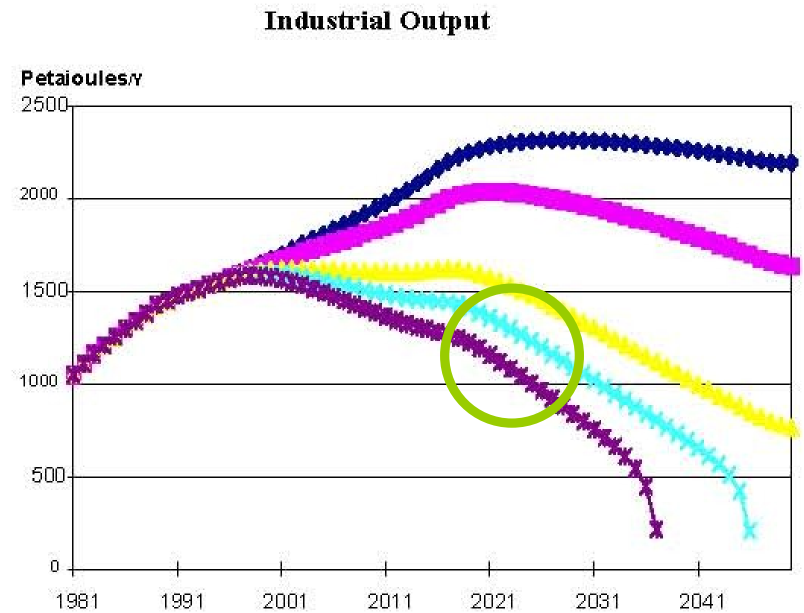
ECCO: renewable energy investment options
Oz calibrated 1981-1993, modelled 1994-2050





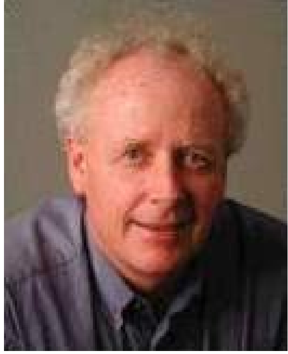


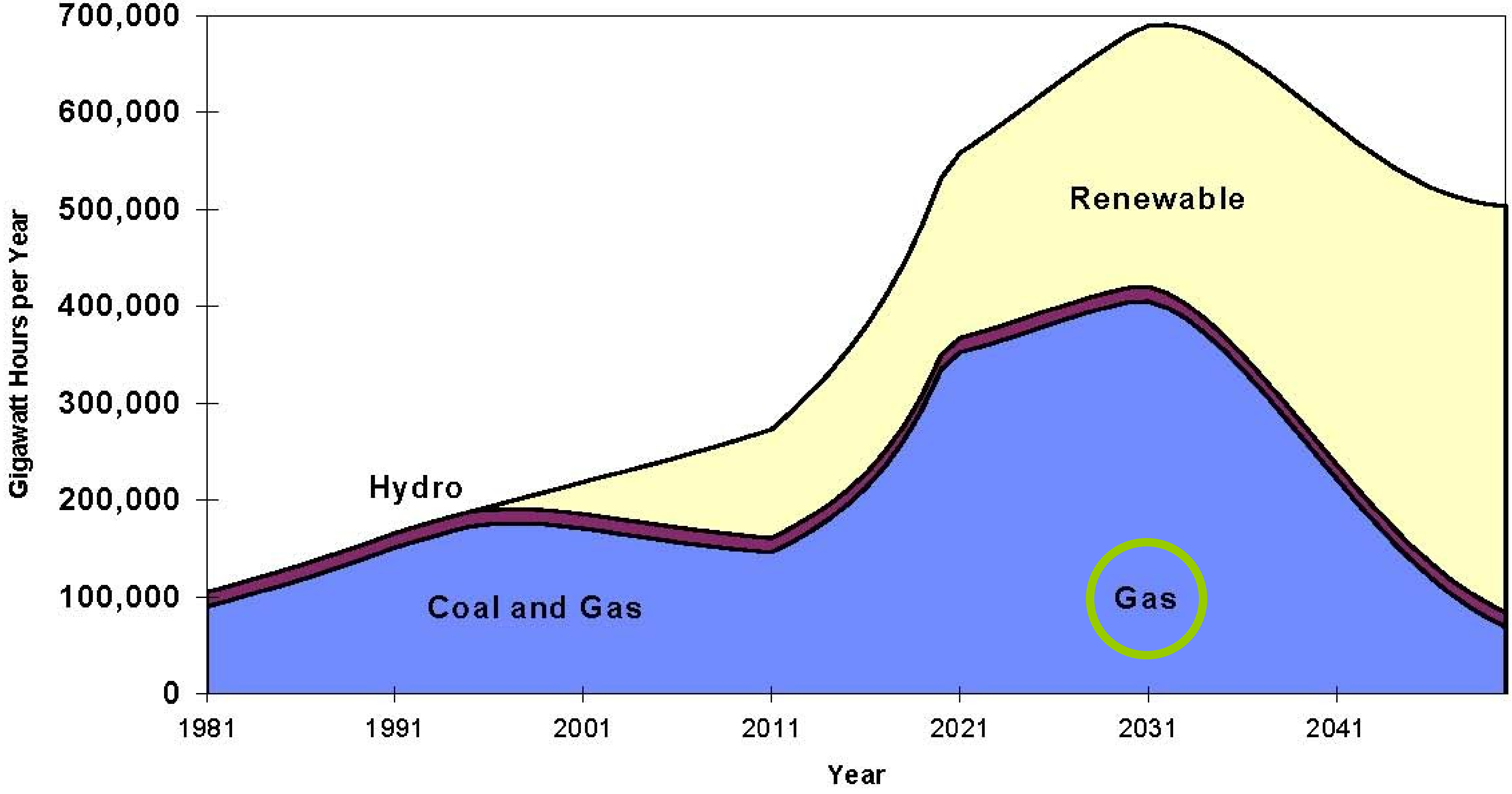
1000 MW/y
3000 MW/y
4000 MW/y
5000 MW/y



www.cse.csiro.au/publications/reports.htm (Foran et al)

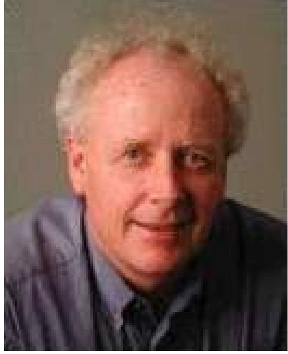
ECCO: renewable energy transition needs gas
Oz calibrated 1981-1993, modelled 1994-2050





www.cse.csiro.au/publications/reports.htm (Foran et al)

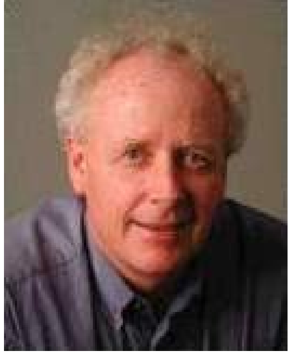
OzEcco (2006): Whole-economy transition to low-carbon

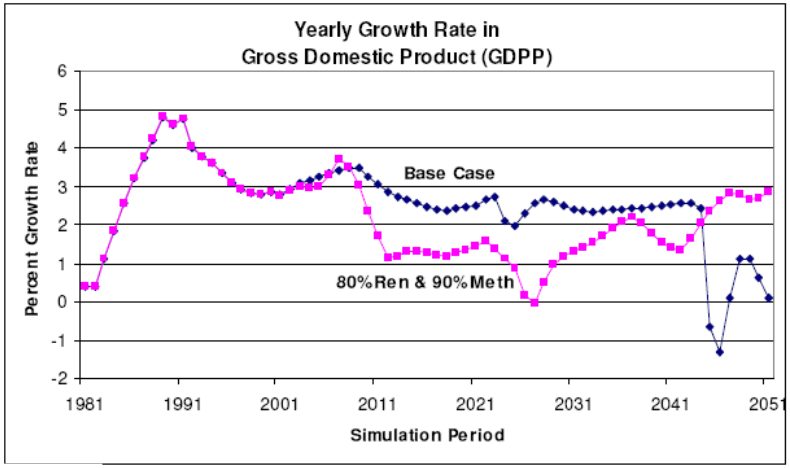


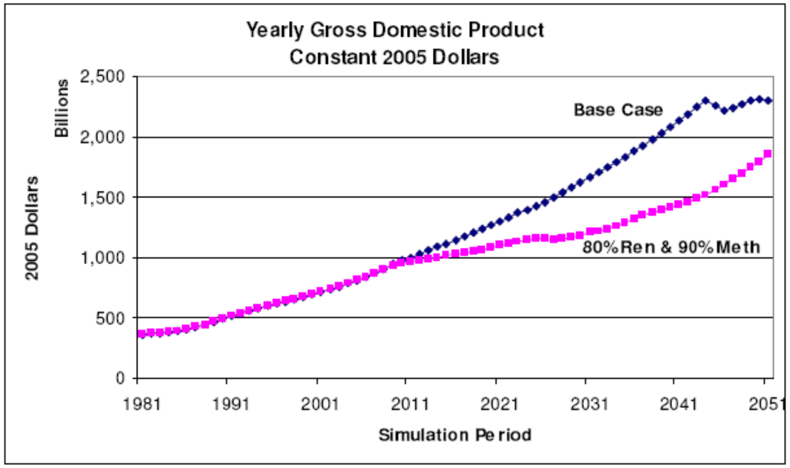
- low greenhouse emissions
- high transport fuel security
- reasonable rates of economic growth
- control of technology-rebound:
  - funds quarantined from the Australian economy into a fund
- 45-year scenario:
  - 80% renewable electricity
  - 90% methanol from wood

Foran, B.D. and Crane, D. 2006
Powerful choices: options for Australia's transition to a low carbon economy Advances in Energy Studies: Perspectives on Energy Futures
5th Biennial International Workshop, Porto Venere, Italy, 12–16 September 2006

OzEcco
80% renewable electricity, 90% methanol from wood

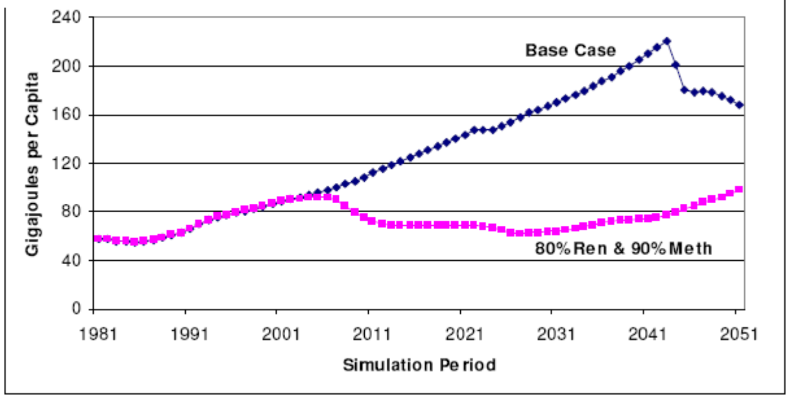


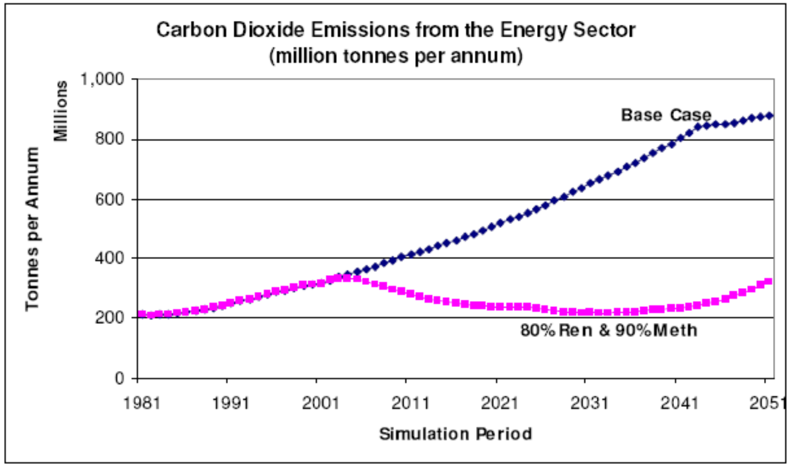




GDP

consumption





CO_2

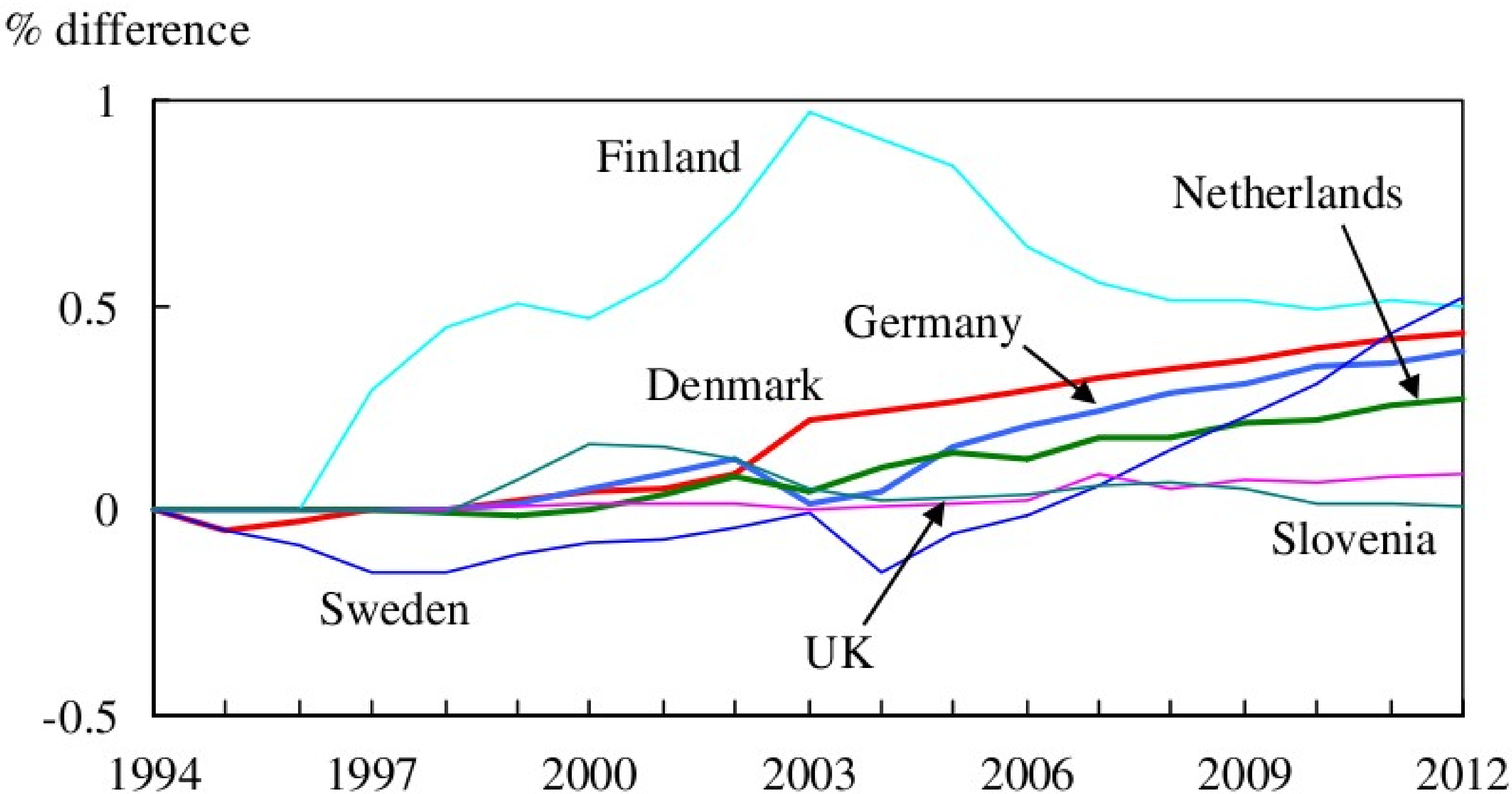
Discuss

- How can ECCO models help with policy evaluation?
- Would you use such a model for your economy if it existed?
- Would you participate in building the model?
- Would you expect to run scenarios through the model (EccoExplorer)?

Conclusions

- Serious energy-disconnect between security/climate goals and GDP growth goal
- Along with energy efficiency, rebound must be controlled

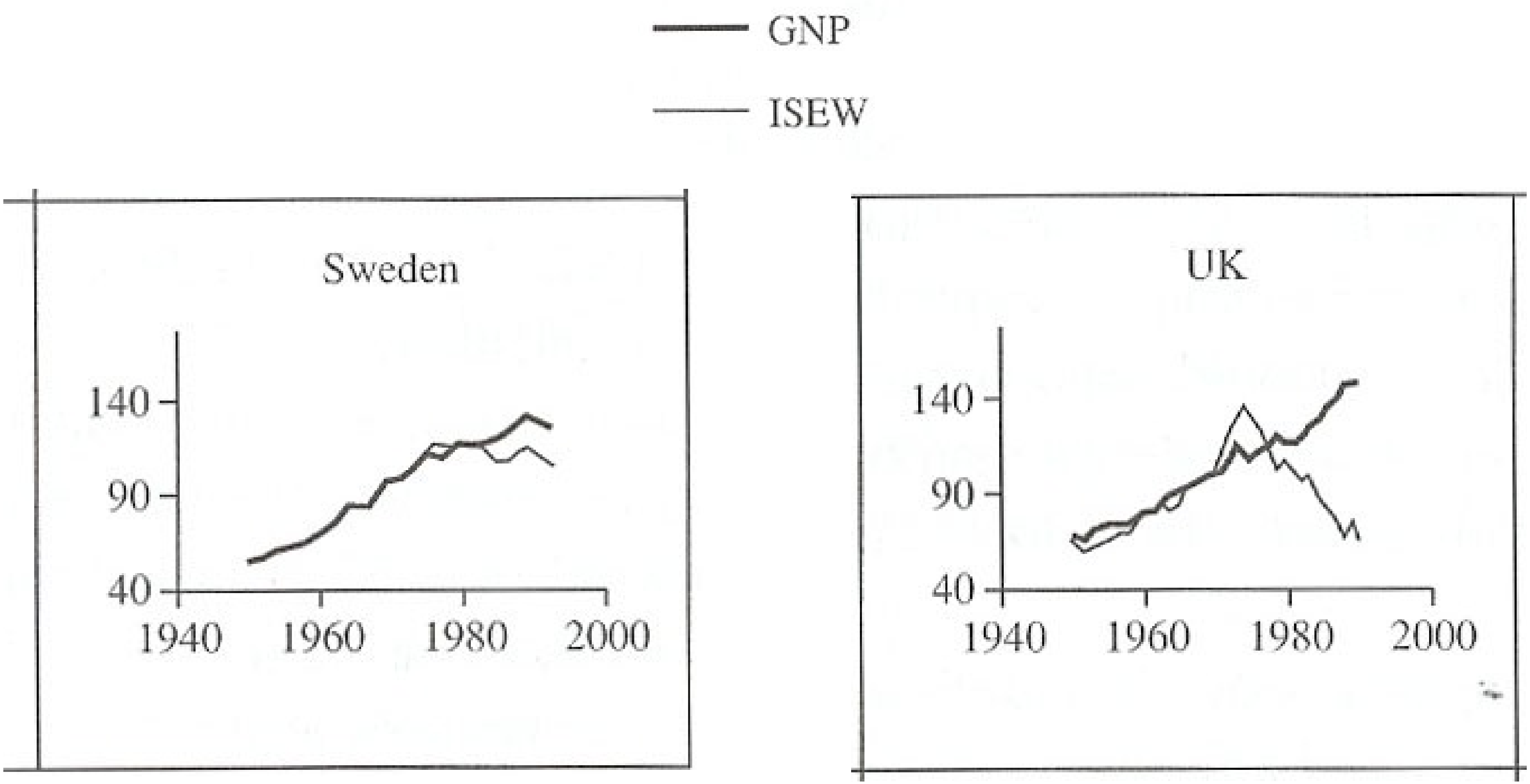
ECCO: systemic solution to rebound?
shift tax to fossil from labour



www2.dmu.dk/COMETR/

Effect of Environmental Tax Reform on GDP
Source: Cambridge Econometrics, modelled from 2006

Need better measures of “progress”
Index of Sustainable Economic Welfare (ISEW)



“Economics of Nature and the nature of economics” ed Cleveland et al, 2001

How do we reconcile growth, emissions and resources?

- Can’t reconcile for conventional (GDP) growth.
- Planned transition more important.
- Carbon price will only work if it hurts.

Addendum: Credit Crunch

- Asset bubble was creation of fictitious monetary value unrelated to underlying biophysical value
- The two must be brought into line
  - Biophysical value can't be changed rapidly
  - So monetary value must decrease rapidly (deleveraging, toxic debt writedown, ...)
- Central Banks should run ECCO models alongside their econometric models, as a sanity check