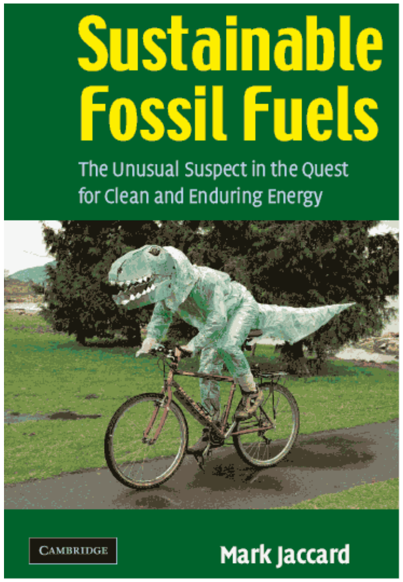
Sustainable Fossil Fuels:



The Unusual Suspect in the Quest for Clean and Enduring Energy

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Coal, oil and natural gas: a Faustian pact with the devil?

Many recent books attribute war, economic chaos and environmental harm to our use of fossil fuels – and warn that conditions will soon worsen dramatically.

We are rapidly depleting these non-renewable resources, which play a critical role in our economies and lifestyles – causing resource conflict and economic disruption.

Our use of these resources damages the natural systems that we are dependent upon for survival – intensifying environmental deterioration and major catastrophes.

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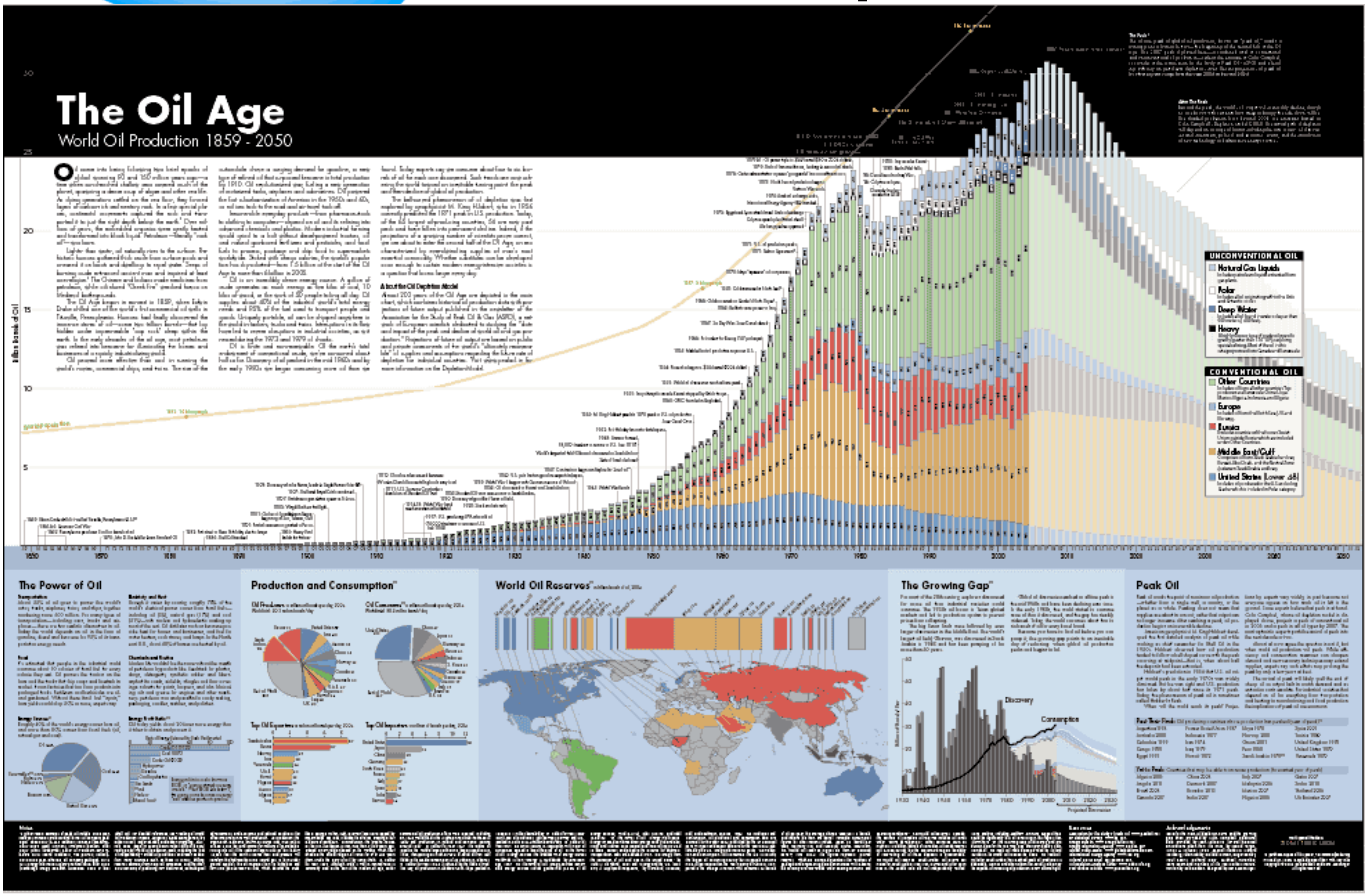
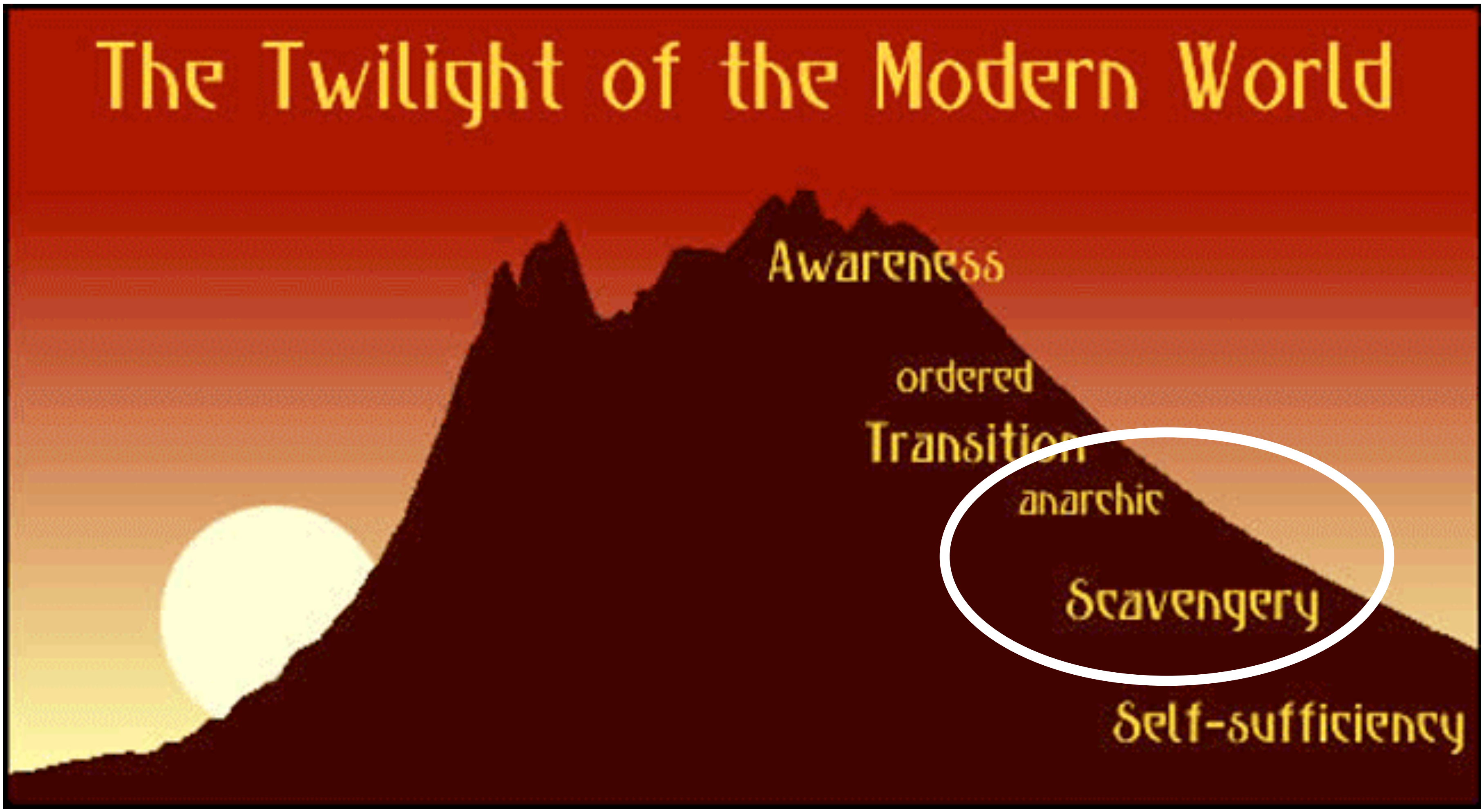
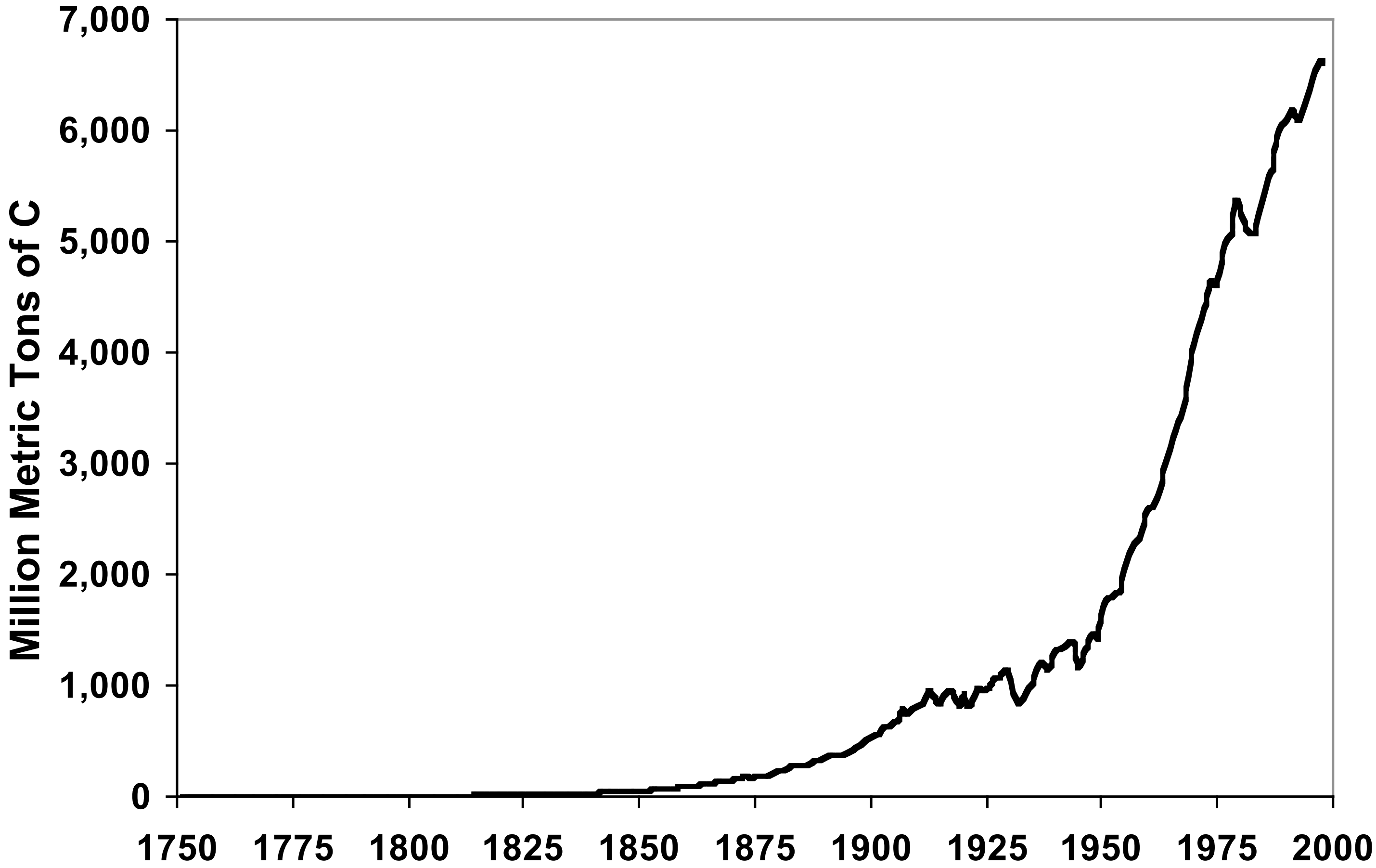
Running out: Hubbert's peak



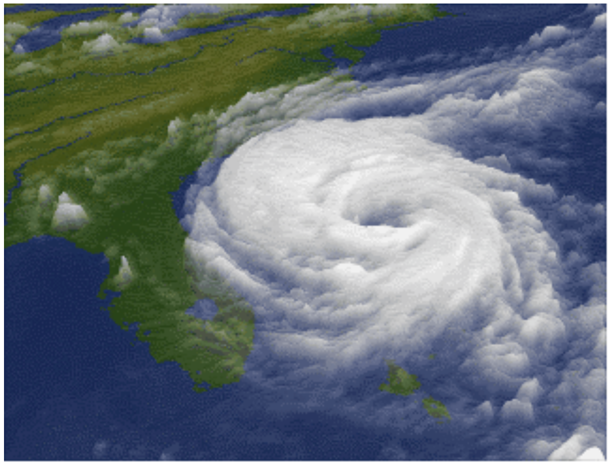
Consequences?

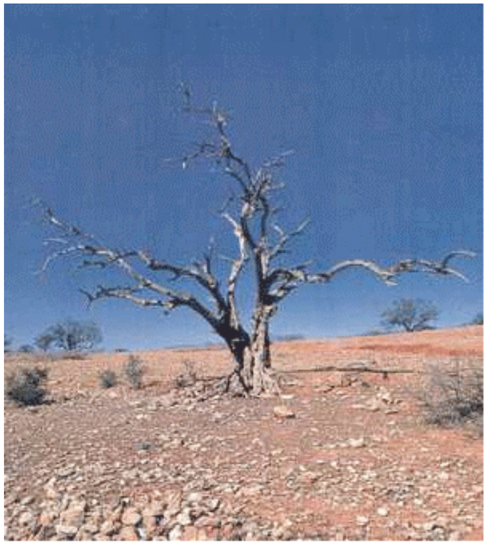


Environmental disruption: e.g., carbon emissions



Consequences?





A common theme

Ominous book titles:

"end of oil," "long emergency," "the party's over," "peak oil," "twilight in the desert," "end of the age of oil," "carbon war," "decline and fall," "energy revolution," "oil endgame," etc.

Threatening quotes:

"Exxon, Mobil, Texaco and the other residually unrepentant thugs of the corporate world look like continuing to sign the cheques that bankroll the carbon club's crimes against humanity, along with their kindred spirits in the auto, coal and utility industries."

(Leggett, *The Carbon War*, Penguin, 1999).

"Civilization as we know it will come to an end sometime in this century unless we can find a way to live without fossil fuels." (Goodstein, *End of the Age of Oil*, Norton, 2004).

Studies of our energy future

Most of these books are written by popular writers who lack expertise in the dynamic potential of energy markets and technologies.

Other visions of the energy future are written by advocates of individual alternative sources of energy (solar, nuclear, etc.).

International agency assessments of our energy future (e.g. IPCC) are constrained in their ability to draw conclusions about the relative prospects for our energy alternatives.

The limits of these other studies motivated me to conduct my own investigation, starting in 2001. My conclusions are surprising, even to me – someone who has focused on and promoted energy efficiency and renewables during 25 years as an academic researcher, policy advisor and energy regulator.

My approach: prescription and prediction of a sustainable energy system

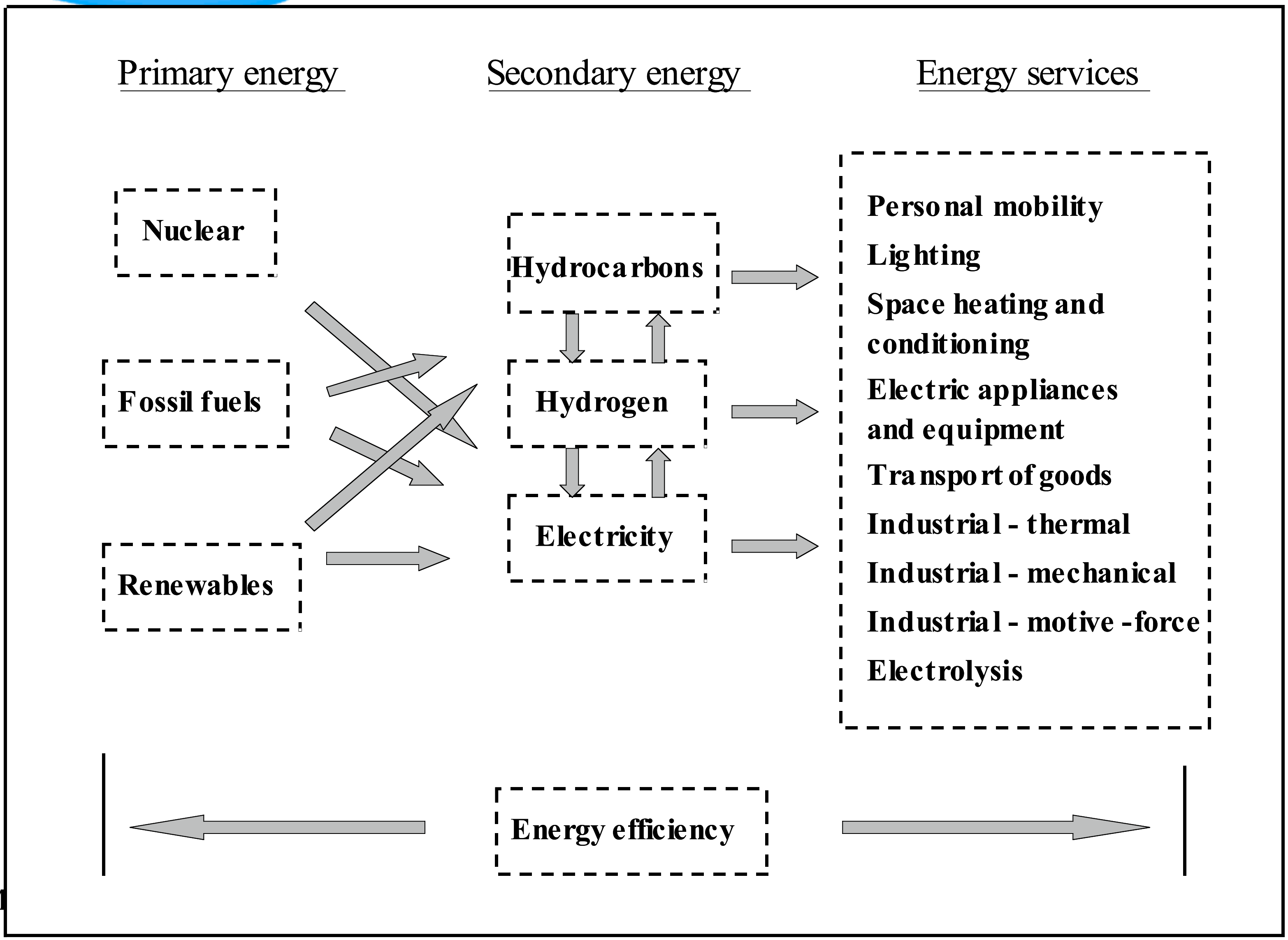
Prescription – assume humanity should strive for:

- A near-zero-emissions (indoor, urban, regional, global) energy system with low impacts and risks to land and water
- Expansion of system to meet legitimate energy service needs of the global population

Prediction – given this sustainability prescription:

- How will major energy options fare this century and beyond, given human preferences and decision making processes?
- What might such a system cost?
- How could we achieve it?

What is the energy system?



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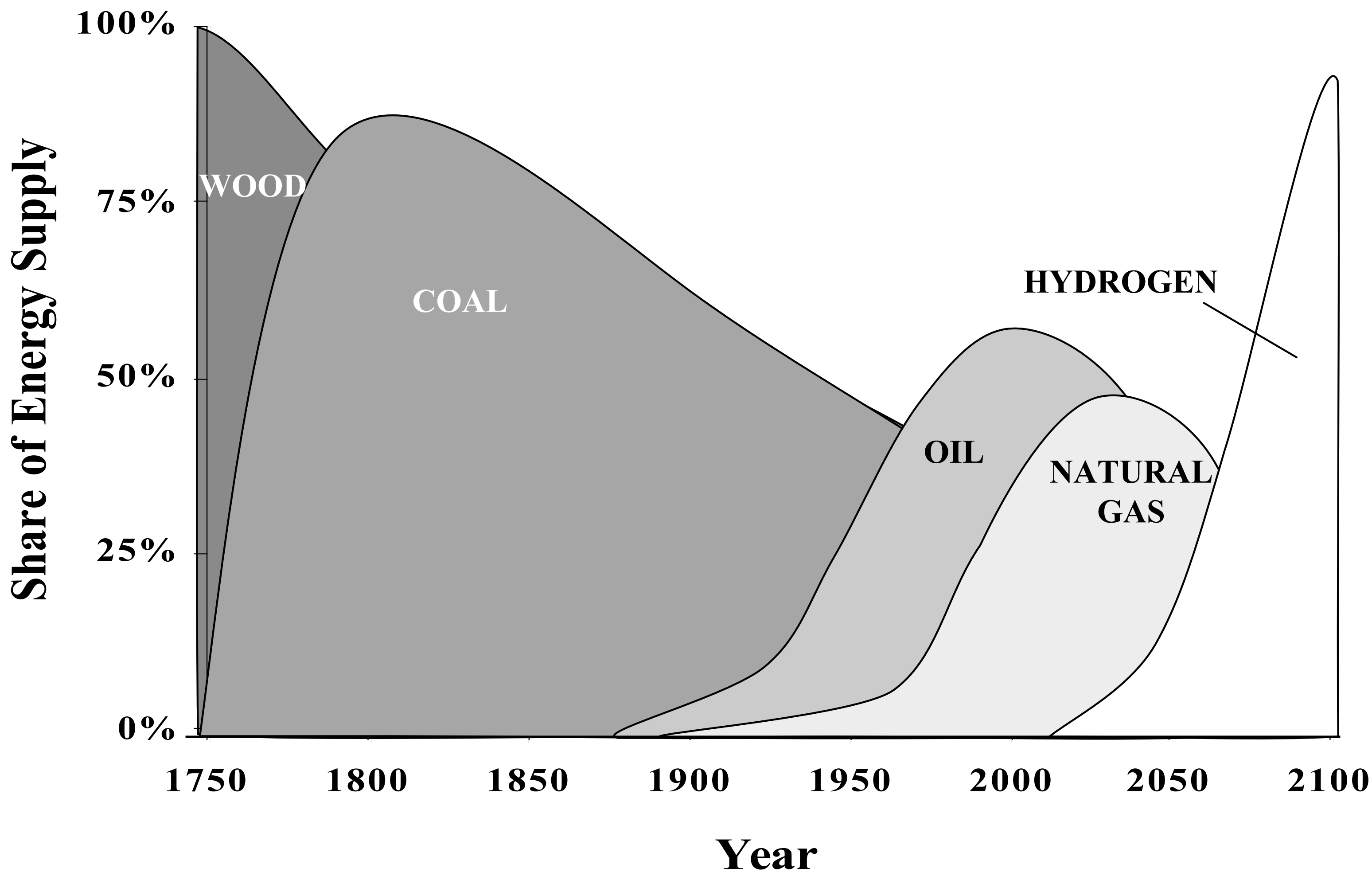
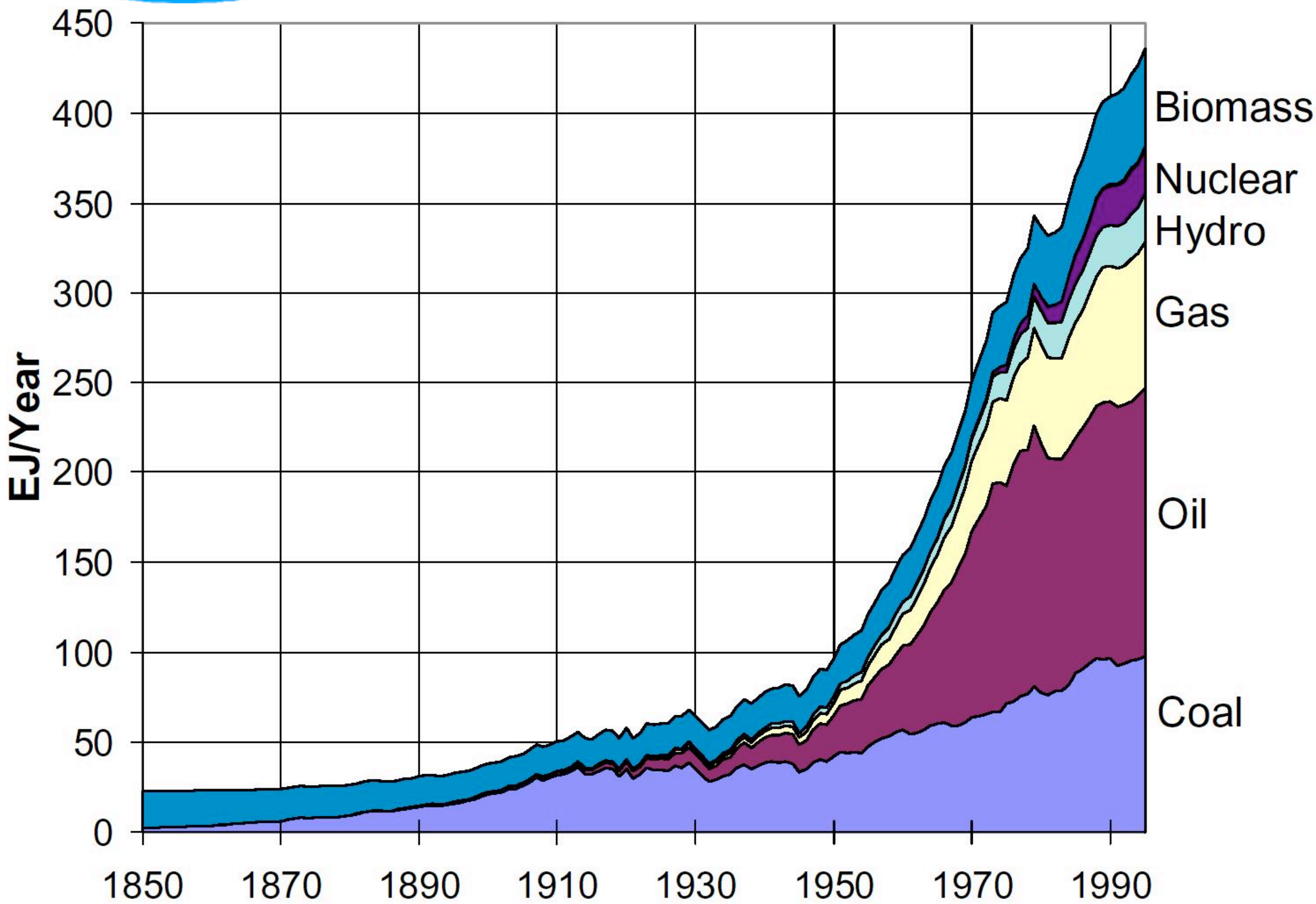
Wrong: hydrogen not a primary energy source

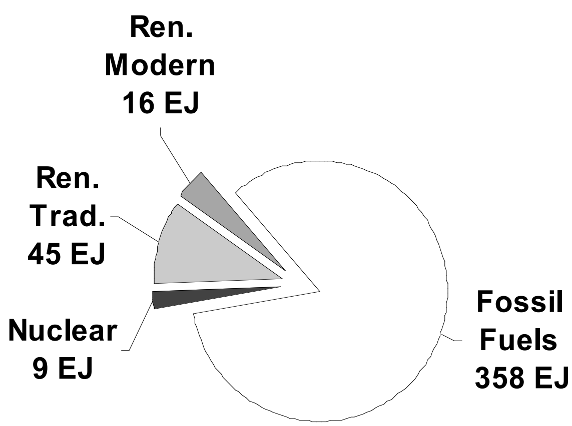


What has been our energy path?



Current trends to 2100

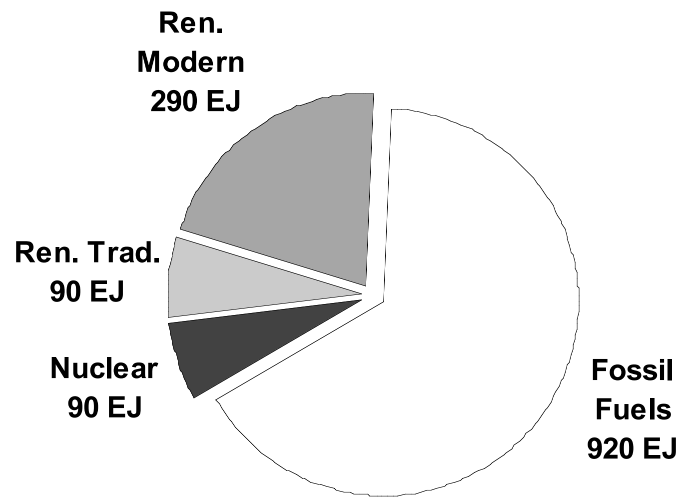
2000



Total =: 429 EJ
6 GtC/year

Population – 6 billion
E/GDP - 13.5MJ/$

2100



Total =: 1,390 EJ
>20 GtC/year

Population – 10.5 billion
E/GDP – 6 MJ/$

Sustainable secondary energy

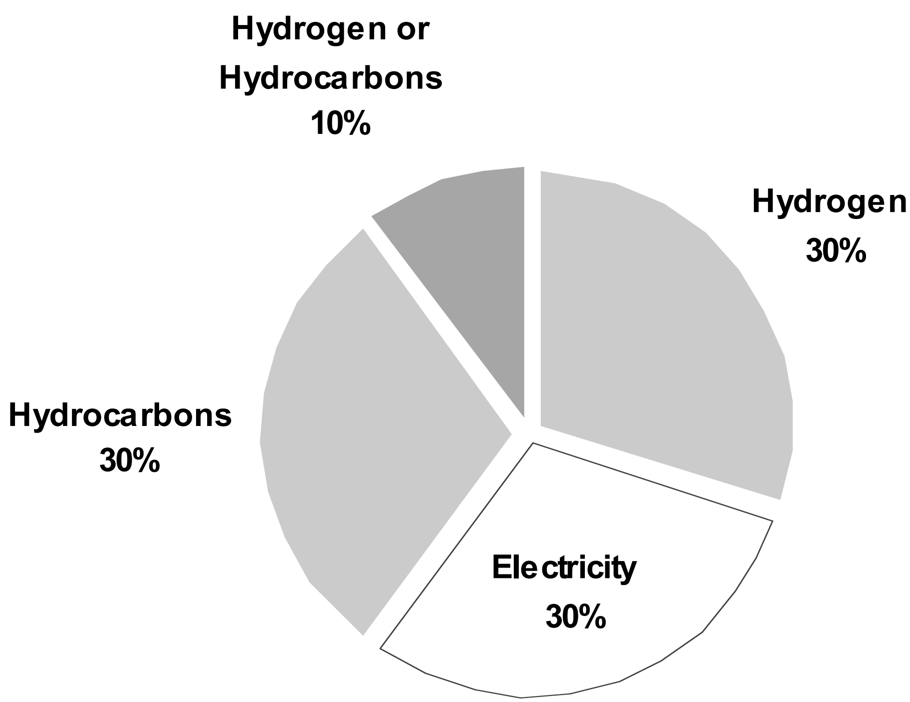
Continued growth of electricity-specific end-uses

Electricity versus hydrocarbons versus hydrogen for mobility (plug-in hybrids vs. hydrogen fuel cells)

Electricity versus hydrocarbons versus hydrogen for thermal applications

Biofuels versus fossil fuels in the hydrocarbon mix

Sustainable secondary energy in 2100?



Primary energy options: "the usual suspects"

Nuclear power

Huge potential of uranium from seawater, use of thorium, fast breeder reactors, eventually fusion.

Renewables

Everlasting, clean energy at a smaller, less risky and lower impact scale.

Energy efficiency

"Focusing on energy efficiency will do more than protect Earth's climate – it will make businesses and consumers richer" - Amory Lovins, Scientific American, Sep. 2005"

Challenges for nuclear and renewables

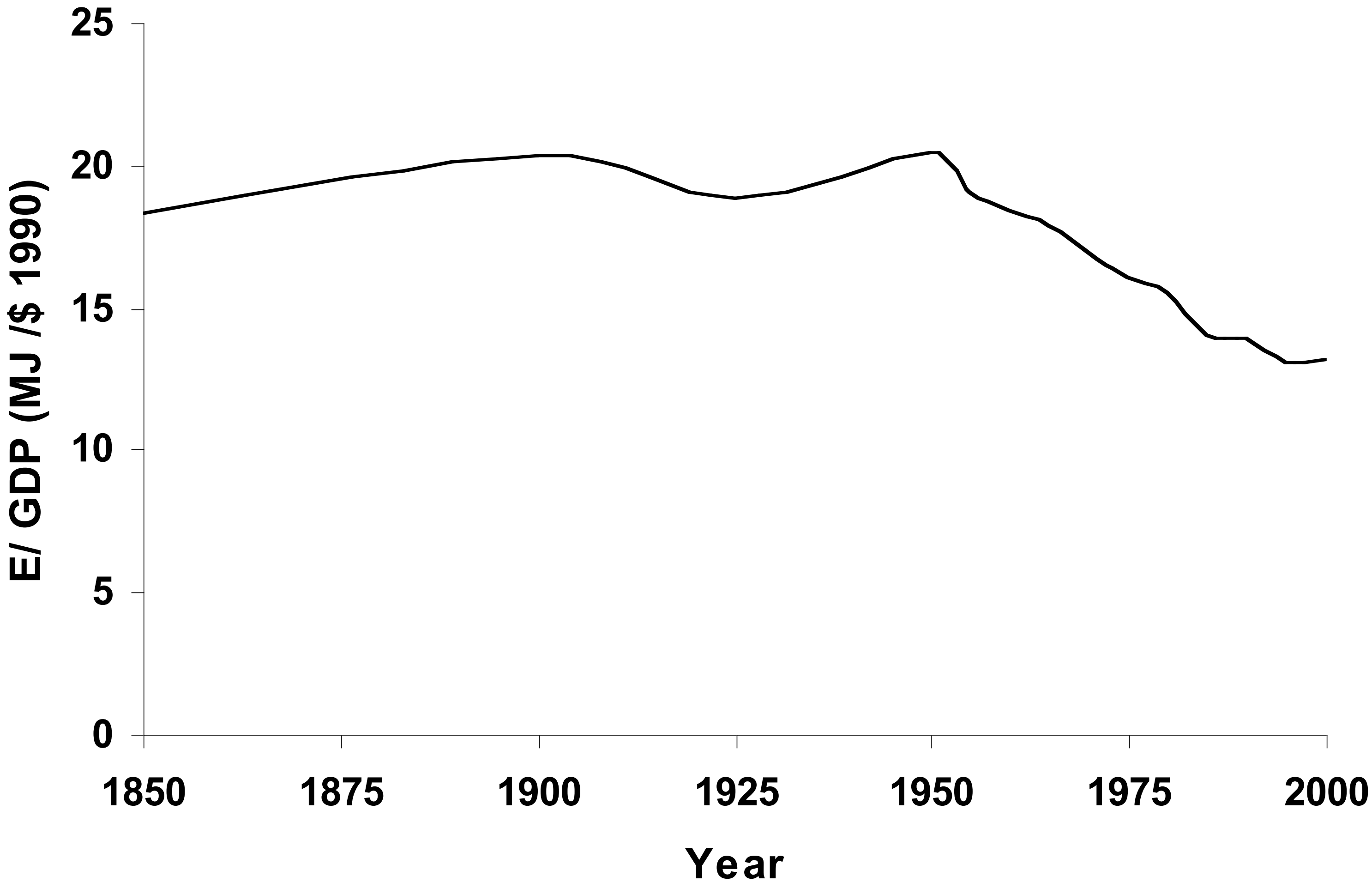
Nuclear power (risk perception)

- Aversion to extreme event risk (focus on outcomes)
- Geopolitical risk

Renewables (uncertain costs with scale-up)

- Cost declines with R&D and cumulative production
- Cost increases from scale-up related to low energy density, variable output and inconvenient location

Energy efficiency trend



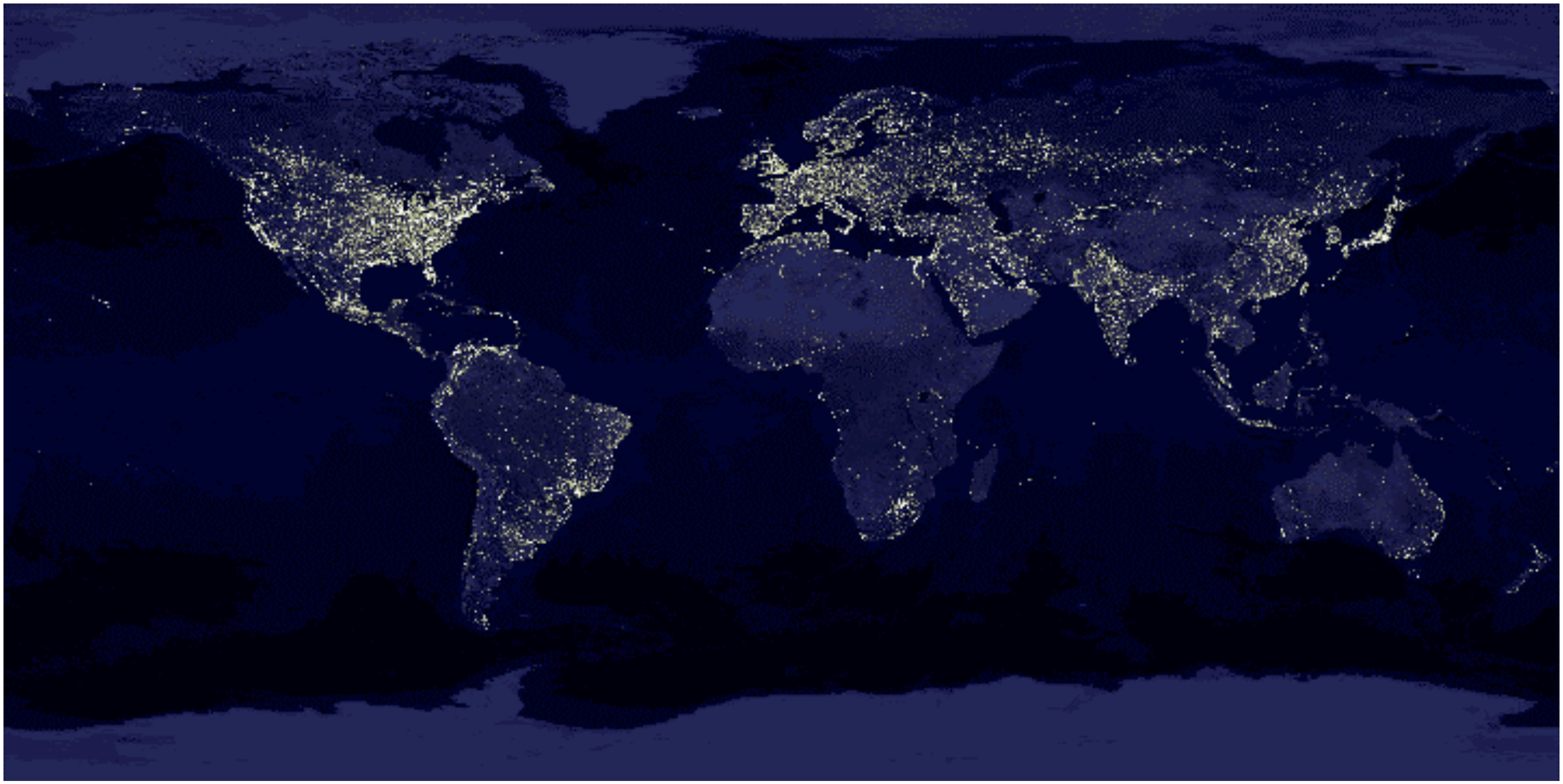
Challenges to accelerating the efficiency trend

Ignored costs of more efficient devices
- risks of long-payback and new technologies
- intangible costs of imperfect substitutes

Mega-rebound from energy productivity
- direct end-use rebound
- innovation and commercialization rebound

Policy barriers
- ineffectiveness of information and subsidies
- political challenge of higher prices and regulation

Today? 2 billion without modern energy. Tomorrow?



Fossil fuels:
"the unusual suspect"

How long can they last?

- reserves and resources of coal, oil and natural gas
- substitution between fuels and with other energy

Can we use them cleanly?

- history of cleaning up
- new and old challenges – urban, regional, global

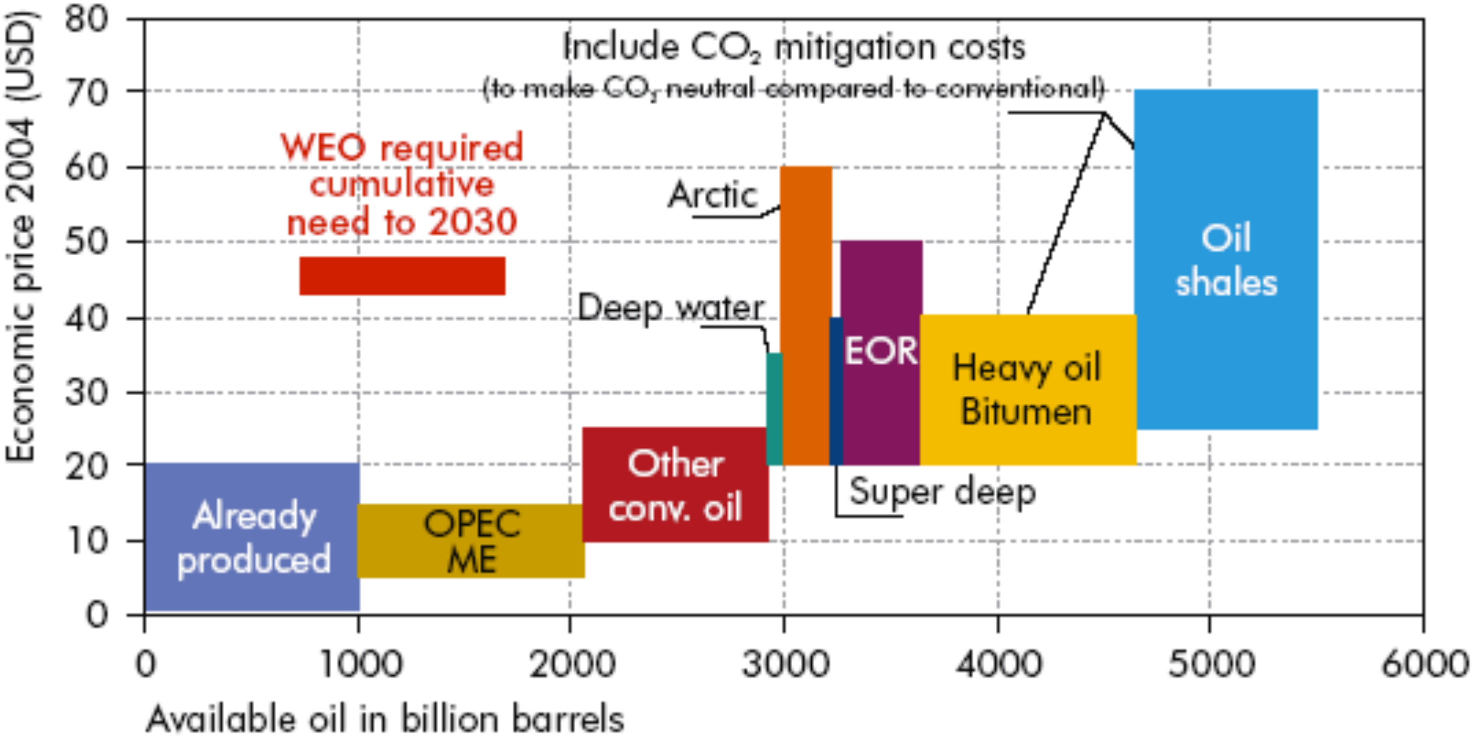
Reserves and resources

Fossil Fuel	Production in 2000 (EJ)	Total Reserves (EJ)	Total Resource (EJ)	Reserve/ Production in 2000 (years)	Resource/ Production in 2000 (years)	Resource/ Production with growth (years)
Coal	100	21,000	200,000	210	2,000	<400
Oil	163	11,000	32,000	67	196	<150
Conventional		6,000	12,000			
Unconventiona l		5,000	20,000			
Natural Gas	95	15,000	49,500	158	521	<300
Conventional		5,500	16,500			
Unconventional		9,500	33,000			
Total Fossil Fuels	358	47,000	281,500	131	786	

Source: World Energy Assessment
Unconventional natural gas does not include geopressurized gas and gas hydrates.
My assumptions for the last column are: coal grows to its BAU level of 650 EJ in 2100 (1.9% annual rate) and at 0.5% thereafter; oil grows from 2000 at 0.5% annual rate; and natural gas grows to its BAU level of 160 EJ in 2100 and continues at 0.5%.

Oil sources and substitution

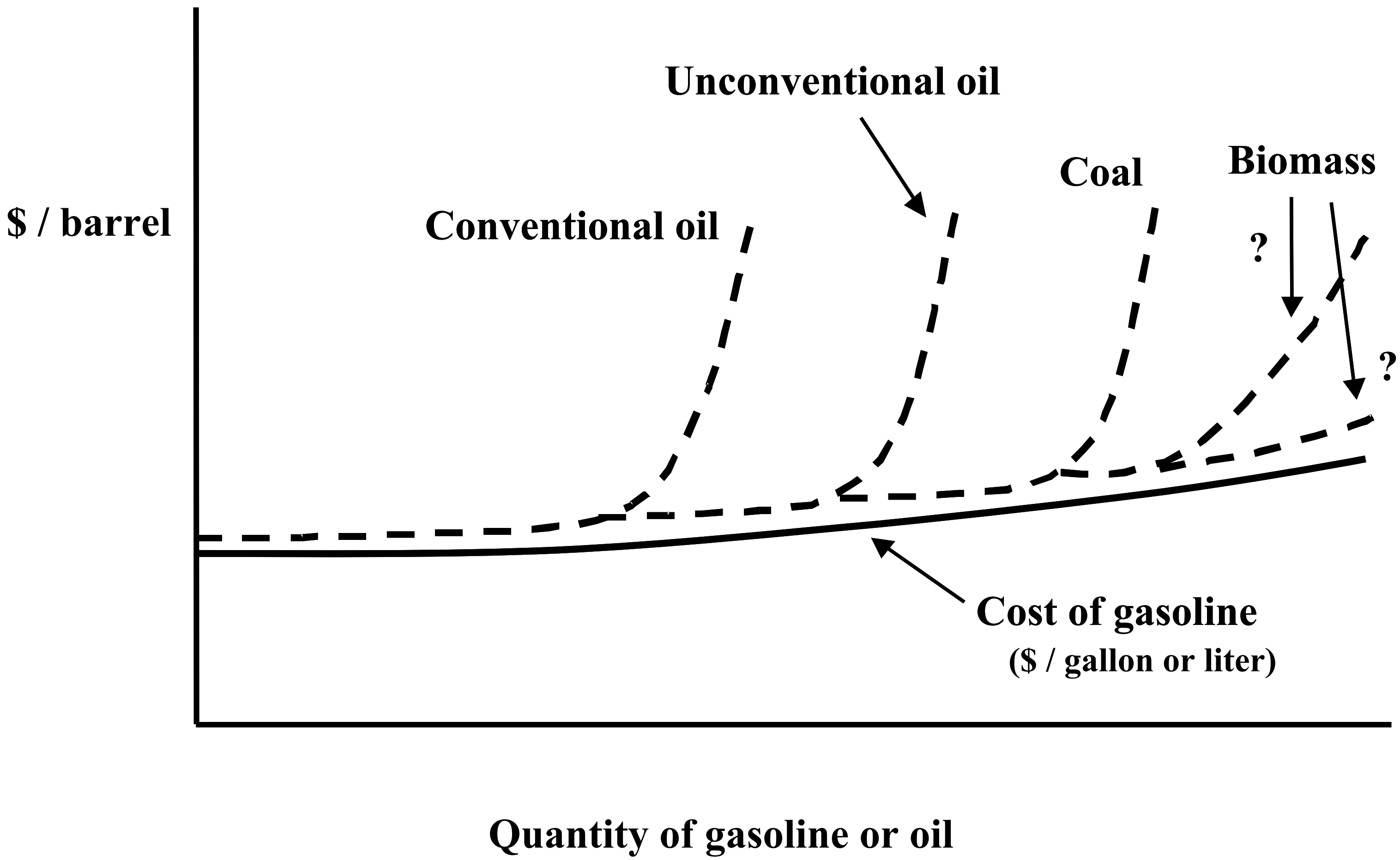
***Figure ES.1** • Oil cost curve, including technological progress: availability of oil resources as a function of economic price*



The x axis represents cumulative accessible oil. The y axis represents the price at which each type of resource becomes economical.

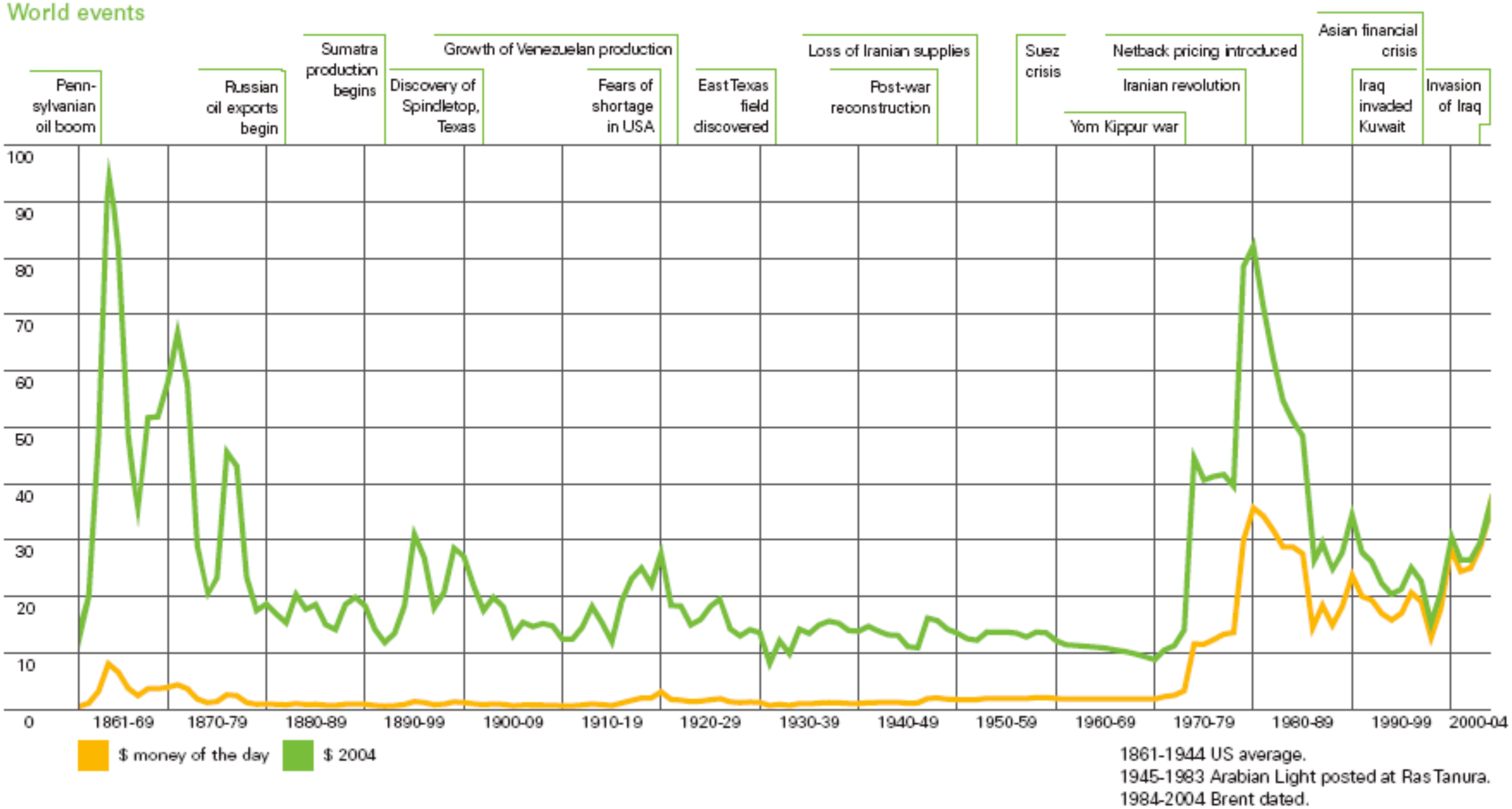
Source: IEA.

Secondary energy prices and primary energy substitution



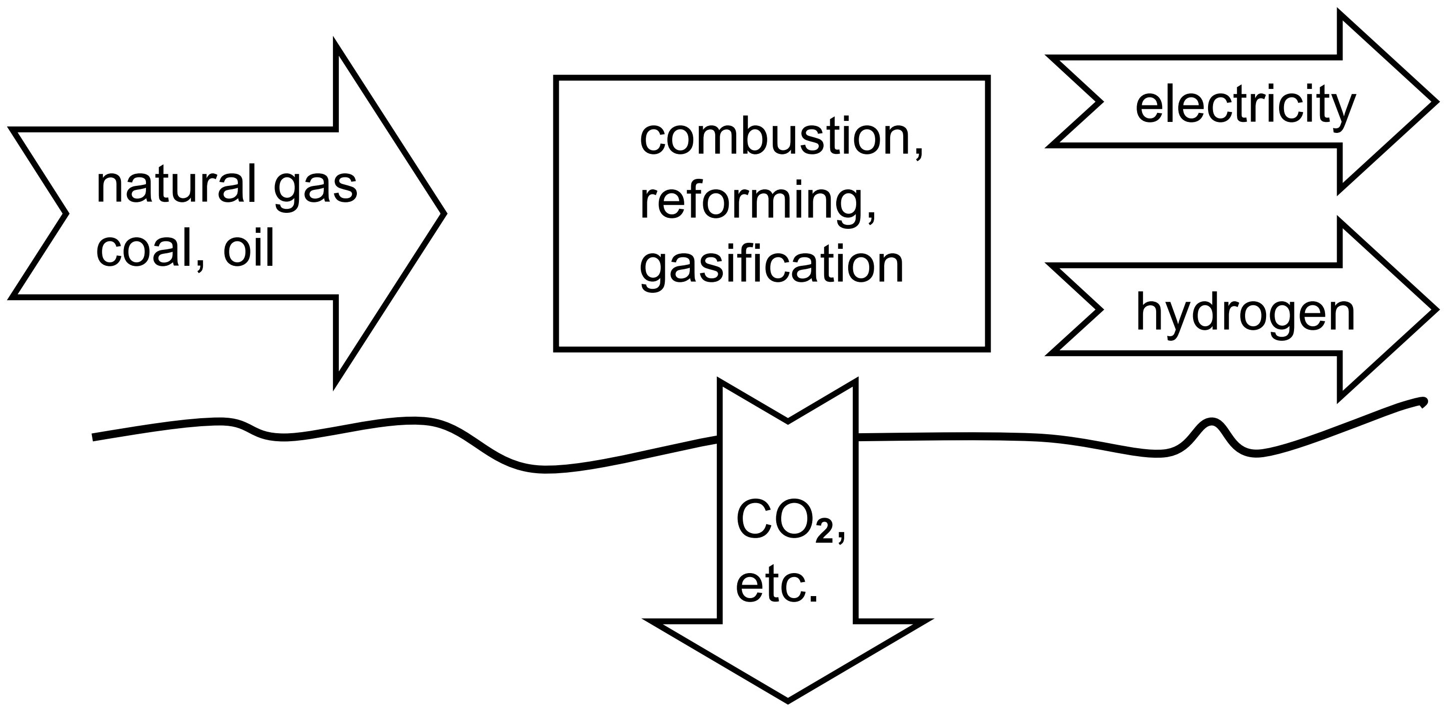
Oil price evolution

Crude oil prices since 1861
US dollars per barrel

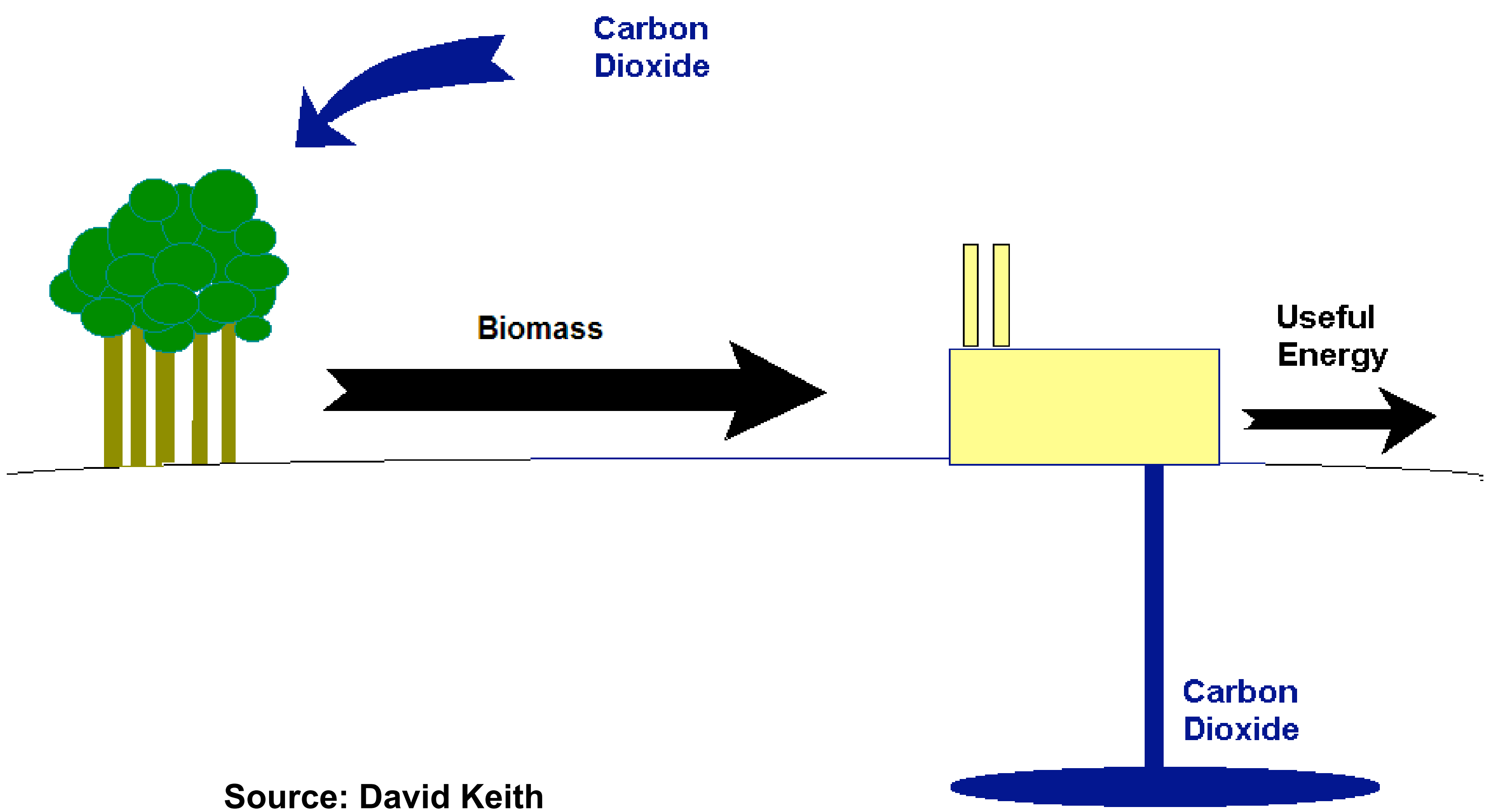


14 BP Statistical Review of World Energy June 2005

Zero-emission fossil fuel use

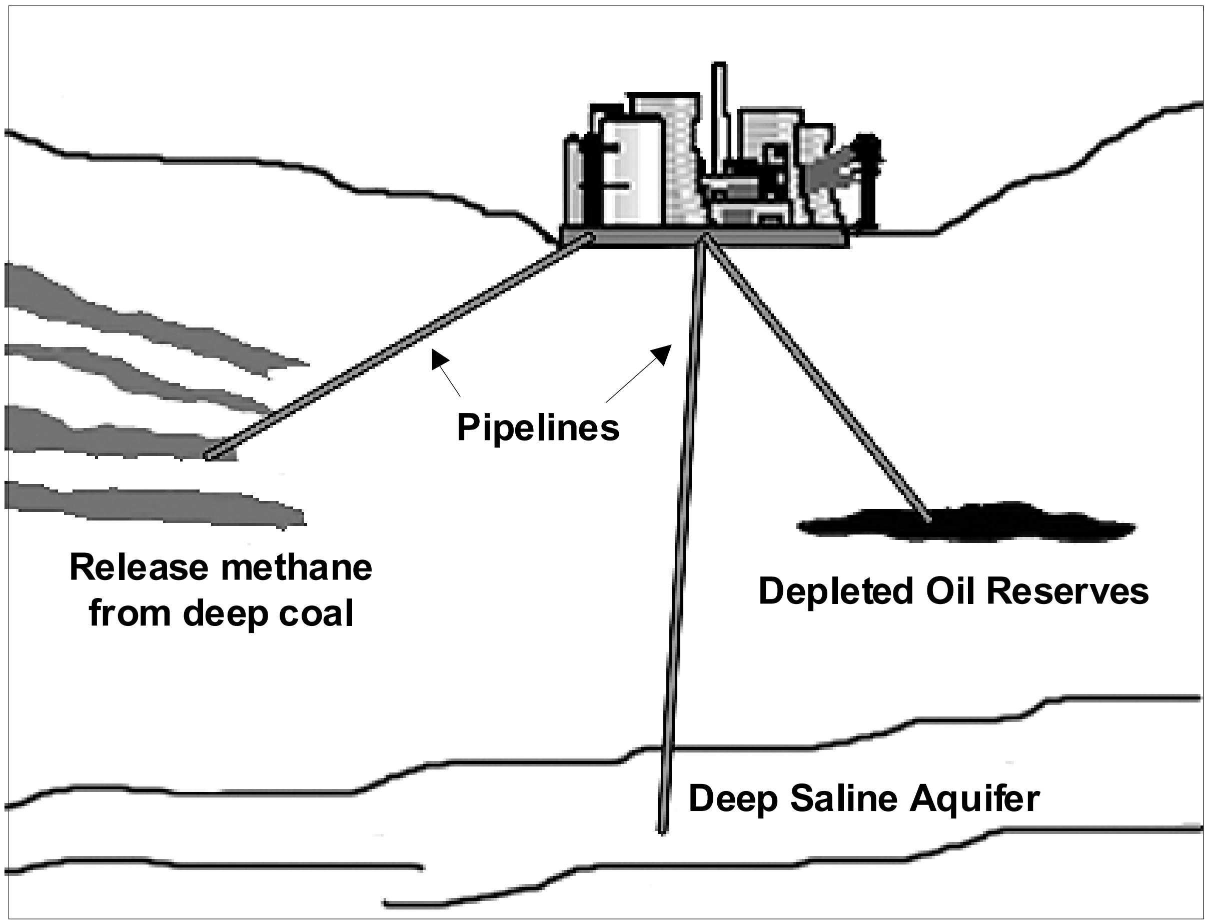


Biomass as CO_2 collector



Source: David Keith

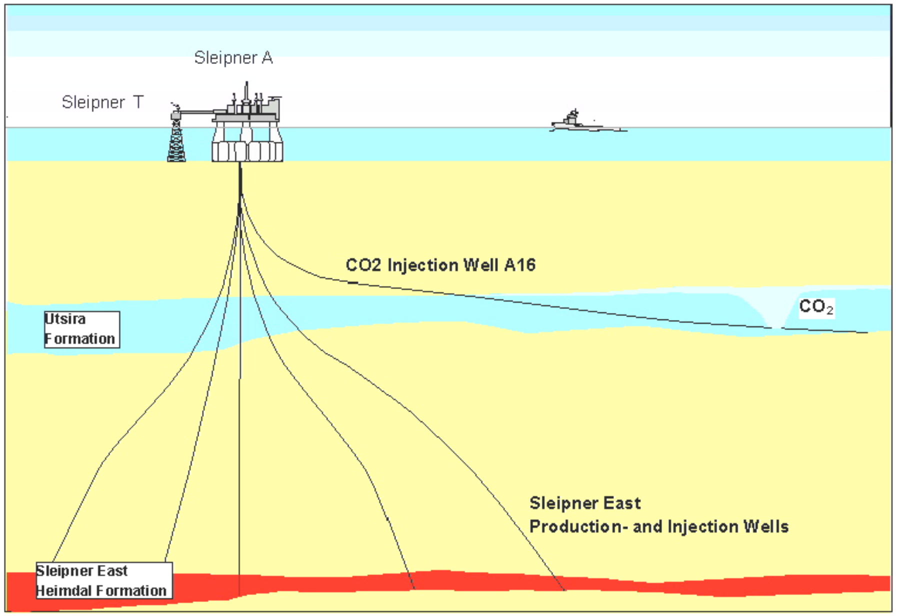
Geological storage of CO_2 and other emissions



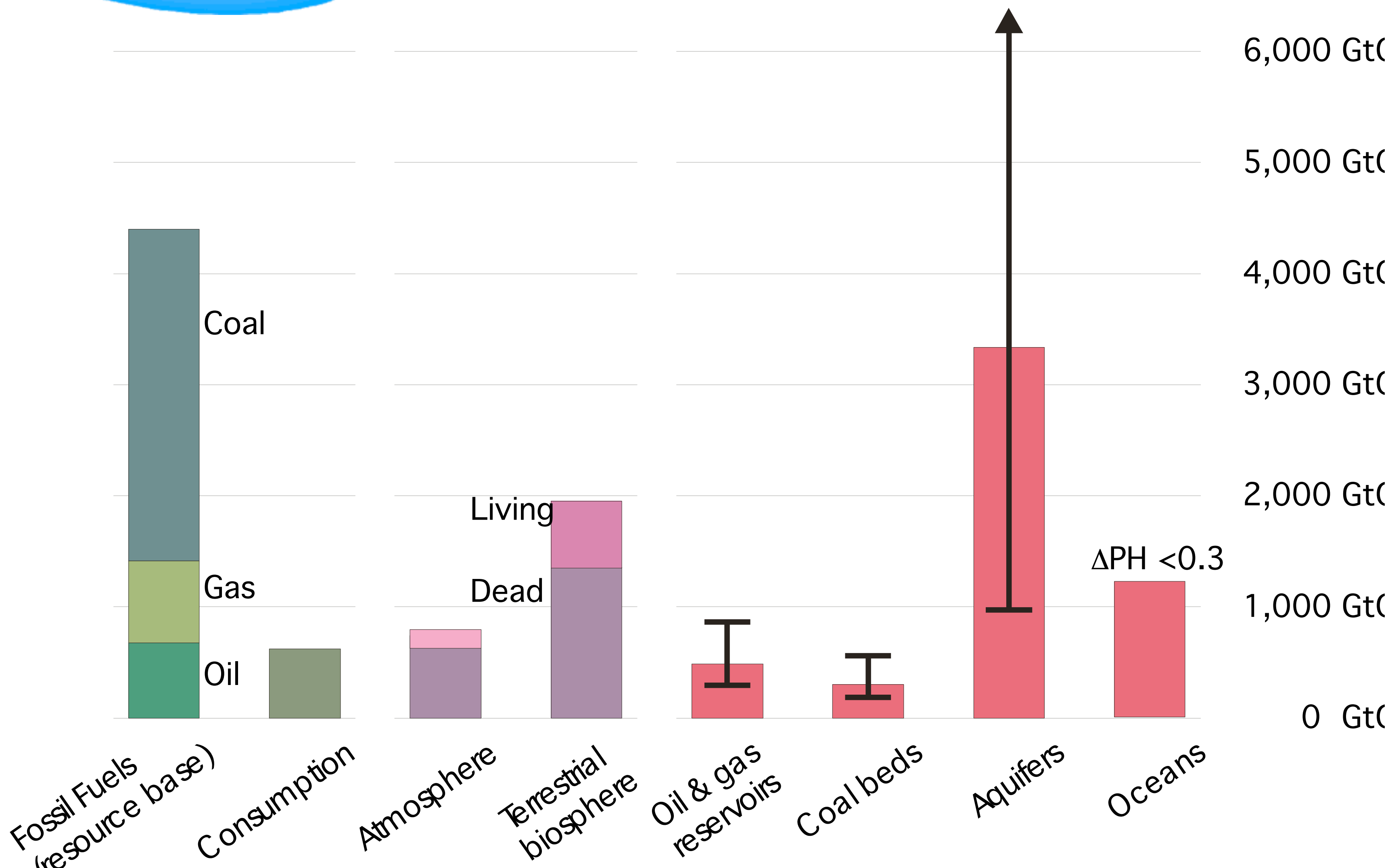
Saline aquifer CO_2 storage

Sleipner platform
North Sea

SLEIPNER AQUIFER CO2 STORAGE



Carbon sources and sinks



Source: David Keith

Risks of geological CO_2 storage

Risks of geologic storage

Local

CO_2 in atmosphere or shallow subsurface
- Suffocation of humans or animals above ground
- Effects on plants above ground
- Biological impact below ground on roots, insects and burrowing animals

CO_2 dissolved in subsurface fluids
- Mobilization of metals or other contaminants
- Contamination of potable water
- Interference with deep-subsurface ecosystems

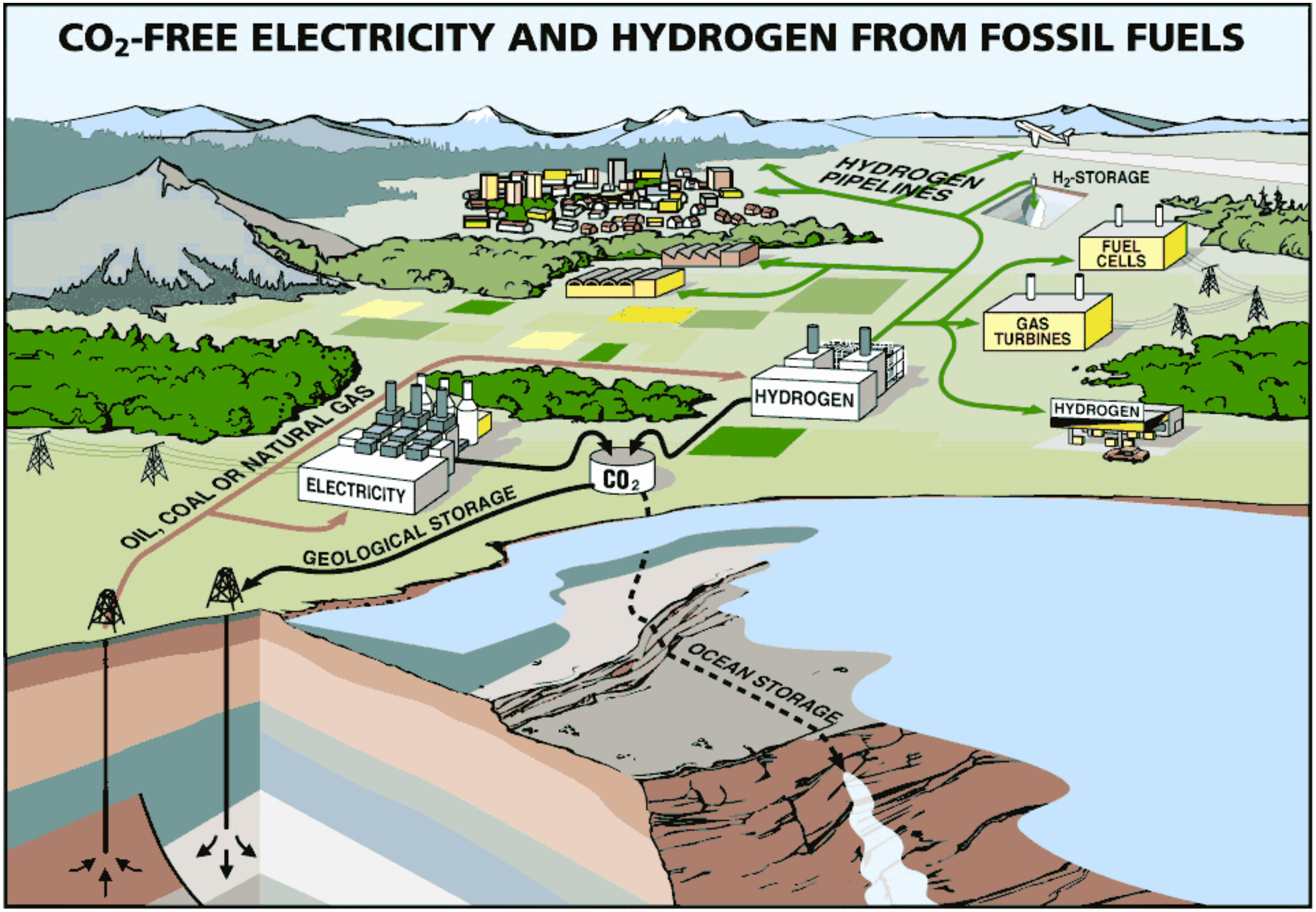
Displacement
- Ground heave
- Induced seismicity
- Contamination of drinking water by displaced brines
- Damage to hydrocarbon or mineral resources

Global

Release of CO_2 to the atmosphere

Source: David Keith

Zero-emission fossil fuels energy system



Criteria for predicting social preferences

Projected cost (synthesis of numerous studies)

- Depletion of higher quality resources and sites
- Cost reduction through innovation
- Cost reduction through greater production (economies-of-scale and economies-of-learning)

Extreme event risk

- Aversion to extreme event risk (focus on outcomes)

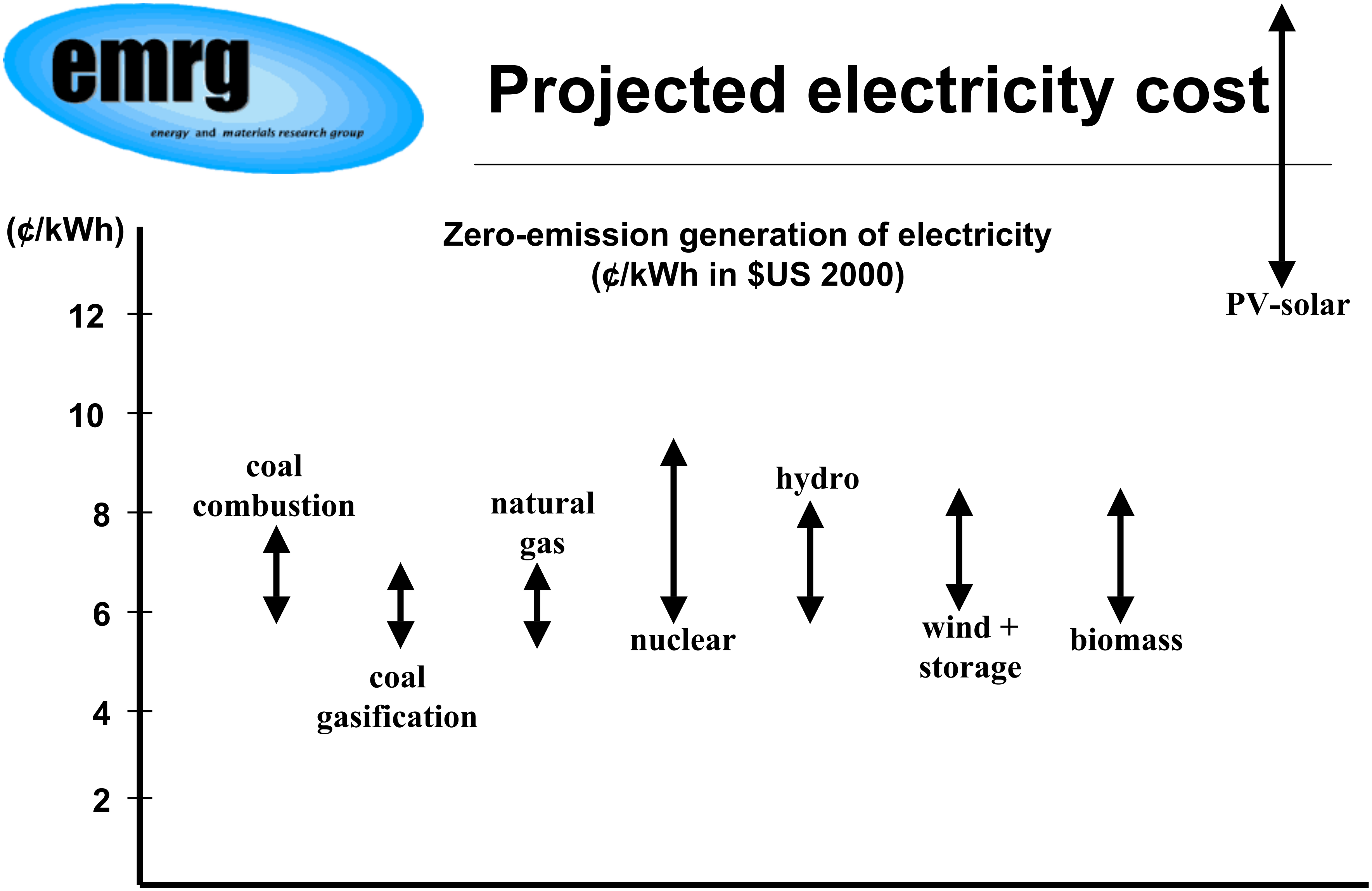
Geopolitical risk

- Energy supply security and political independence

Path dependence

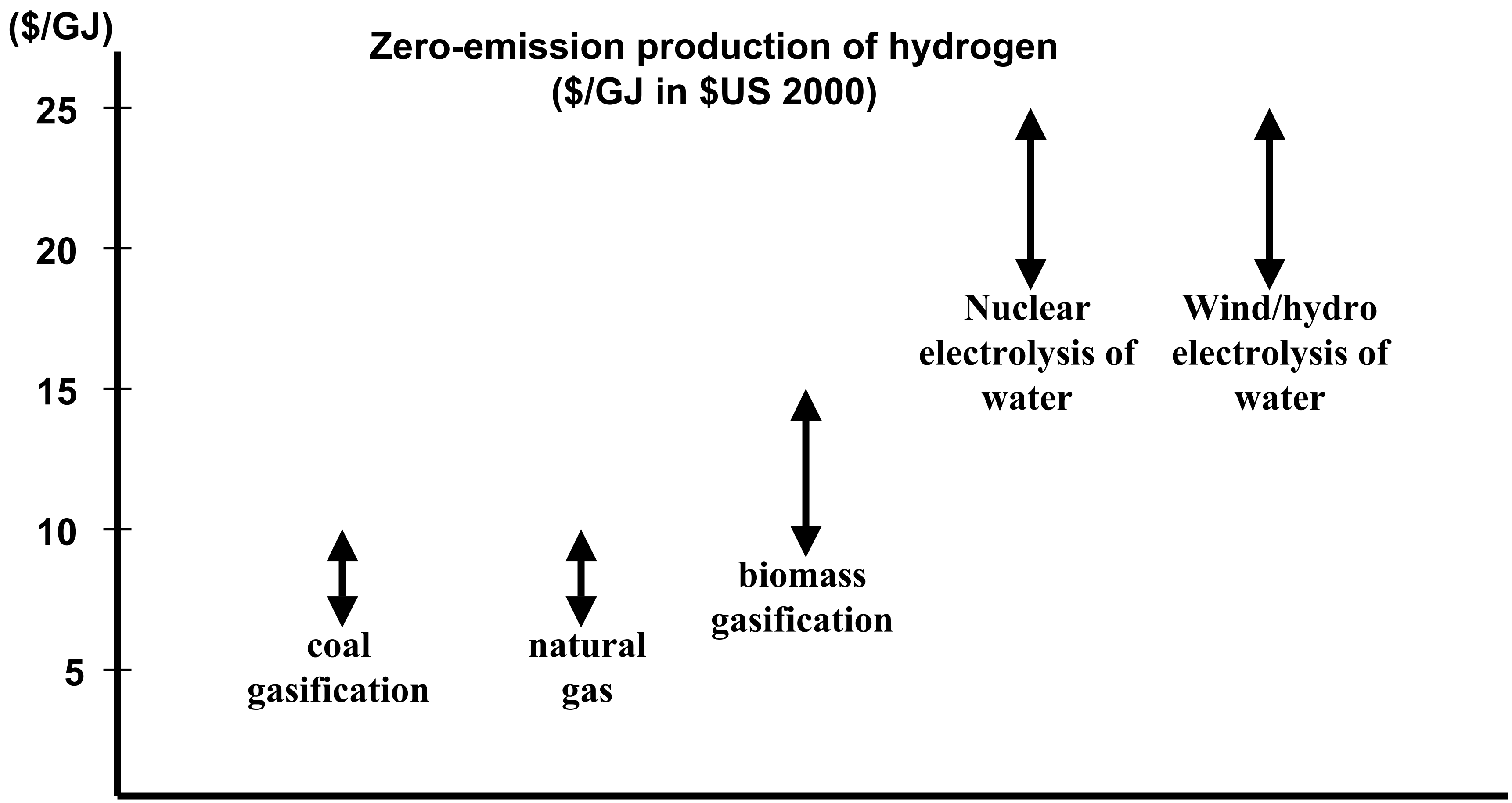
- Not a decision criterion, but a long-term cost factor

Projected electricity cost



Assumed input prices are coal $1.5 – 3/GJ, natural gas $5 – 7/GJ, and biomass $2 – 5/GJ.

Projected hydrogen cost



Assumed input prices are coal $1.5 – 3/GJ, natural gas $5 – 7/GJ, and biomass $2 – 5/GJ. See electricity prices figure for electrolysis.

Incorporating all criteria

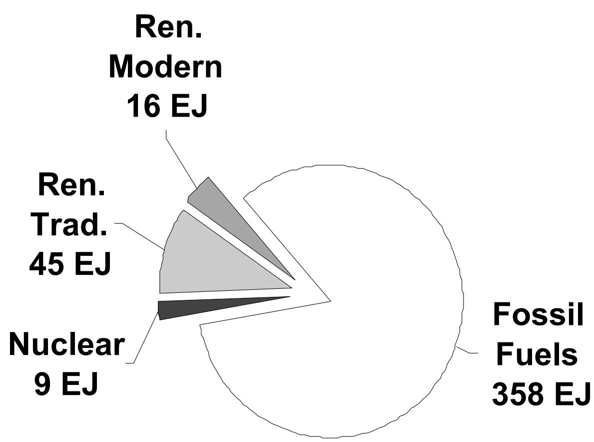
The challenge for nuclear

The limits for efficiency

Renewables versus zero-emission fossil fuels

Primary energy shares in a near-zero-emission future

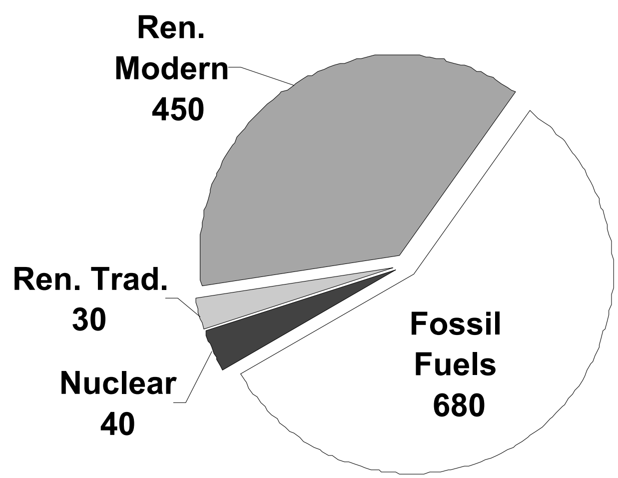
2000



Total = 429 EJ

GHG Emissions = 6Gt/C

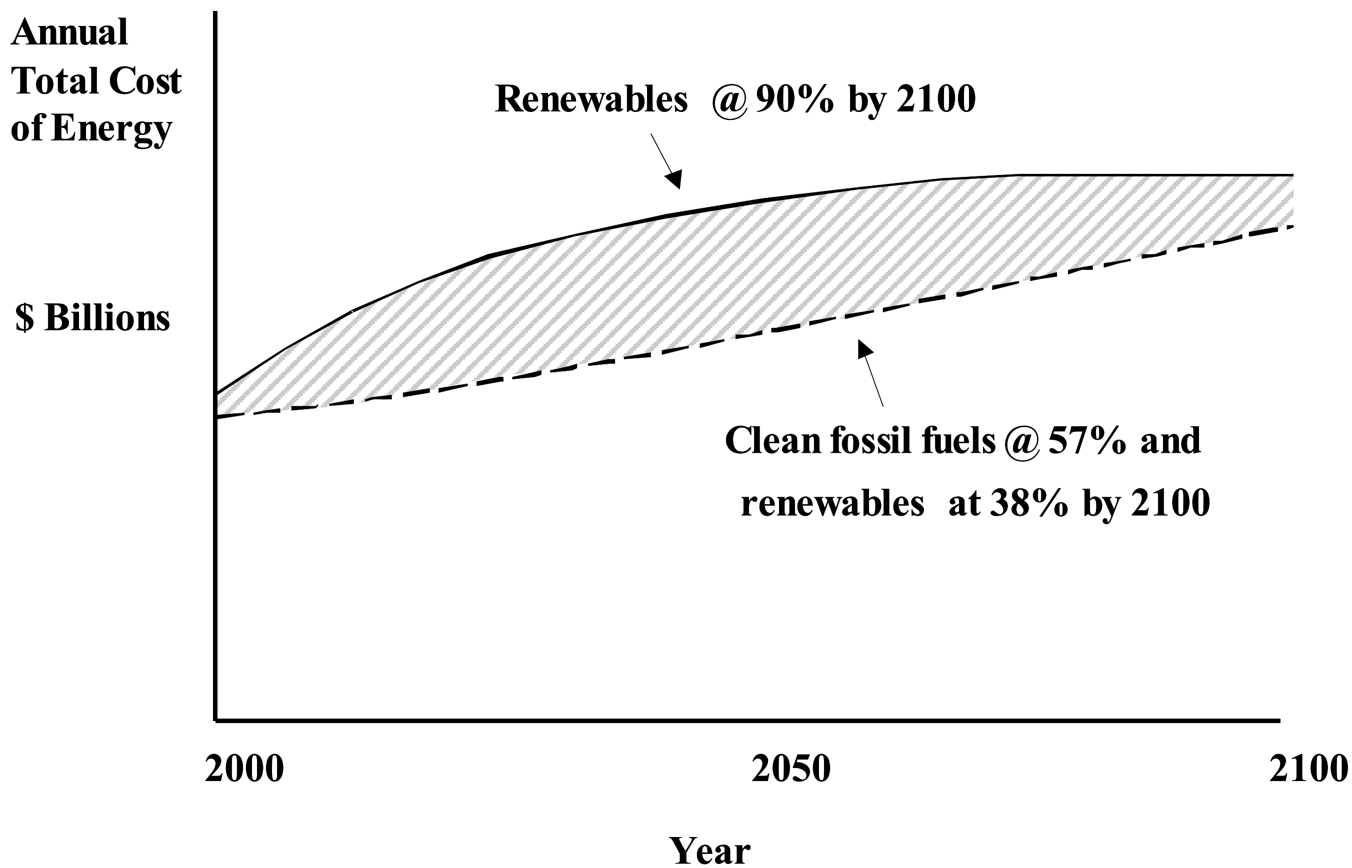
2100



Total = 1,200 EJ

GHG Emissions = 1~2GtC

Cost of abandoning fossil fuels in this century



Required policy for a near-zero-emission future

Challenges with conventional regulatory and financial incentive approaches

- Voluntarism (mostly ineffective)
- Subsidies (mostly ineffective)
- Inflexible regulations (economically inefficient)
- Environmental taxes (politically challenging as sole driver)

Newer approaches (long-run signal for tech change)

- Multi-sector or economy-wide cap and trade (with safety valve)
- Sector-specific niche market regulations

Regulated niche markets

"Set a minimum market share for types of technologies or forms of energy that gradually increases over time"

Vehicle emission standard – "low- and zero-emission vehicles must achieve minimum market shares."

(California, and other US states, ZEV and LEV requirements)

Renewable portfolio standard – "renewable energy must achieve minimum market shares."

(several US states and European countries, plus Australia)

Carbon management standard – "fossil fuel industry must achieve minimum percentage capture and storage of carbon."

(proposal by M.Jaccard)

Advantages of the regulated niche markets approach

Sends long-run signal to manufacturers to innovate and commercialize without affecting average energy prices – political feasibility.

Does not cause accelerated retirement of existing capital stocks; in sync with the rate of capital stock turnover – economic efficiency.

Gives producers flexibility to trade among themselves to minimize cost of compliance – economic efficiency.

Minimum production requirements fosters economies-of-learning and economies-of-scale – economic efficiency.

Targets can be adjusted as new information about benefits and costs emerge – economic efficiency.

Cost of innovation paid for by consumers of polluting technologies or forms of energy instead of general tax payers – political feasibility.

Demand and supply market-oriented regulations

Supply-side push:

- carbon management standard
- methane management standard

Demand-side pull:

- GHG cap and trade in industry
- vehicle emission standard
- appliance and heating emission standard

Conclusion

Energy system should be seen in terms of means and ends – not good guys and bad guys.

The end is a clean, enduring and low cost energy system – with minimal extreme event and geopolitical risk.

In the pursuit of this end, fossil fuels can and probably will be part of a sustainable energy system for a very long time.

For details

www.cambridge.org

www.emrg.sfu/sustainablefossilfuels