4

Environmental Impacts

Umweltauswirkungen

TC: Positive and Negative Environmental Impacts

- **Resource augmentation**
- **Substitution and conservation**
- **Environmental "fixes"**

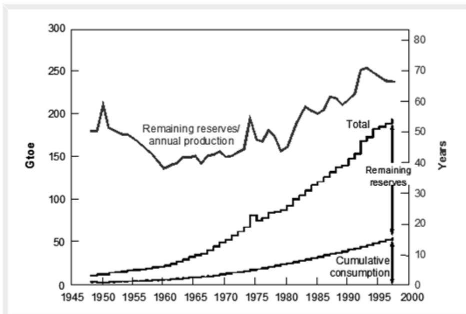
- **Growth in activities and output**
- **Novel impacts (DDT, CFCs)**
- **Global change**

- **Illustrations and a critical view on IPAT**

Resource Augmentation

- Improved knowledge (theory, diagnostics in exploration, e.g. 3-D)
- Accessibility (depth, hostile environments)
- Infrastructures (e.g. pipelines, LNG)
- Recovery factors (e.g. water, CO2 flooding, fracking)

Recoverable Conventional Gas Reserves and Cumulative Production



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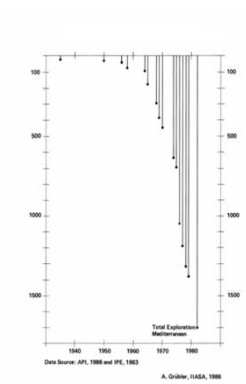
WORLDWIDE WATER DEPTH RECORDS IN EXPLORATORY DRILLING (meters)



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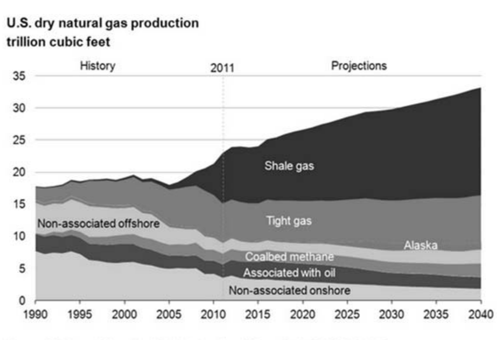
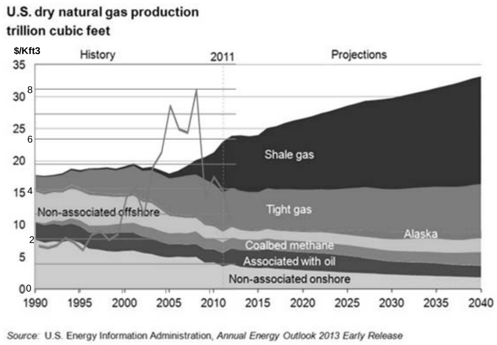
US Natural Gas Supply



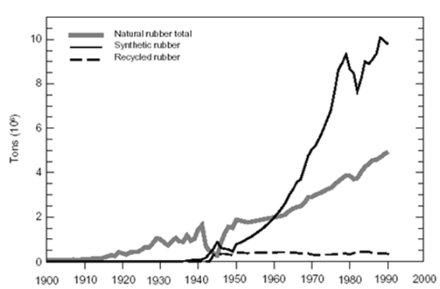
US Natural Gas Supply & Prices



Substitution/Conservation

- Man-made vs. natural
- Man-made vs. man-made
- Virgin vs. recycled
- Heavy- by light-weight
- Efficiency

World – Natural vs. Synthetic Rubber

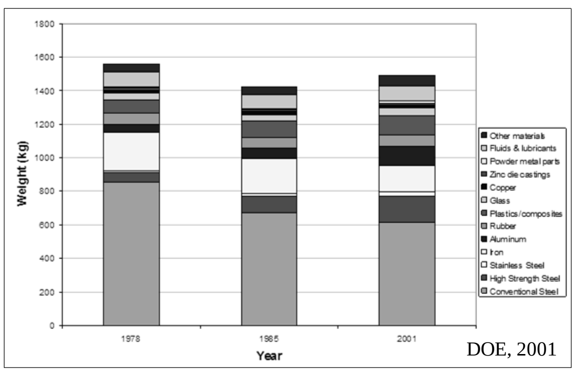


Recycling Rates for Selected Materials

	OECD Europe	OECD N. America	OECD Pacific[a]	OECD Average	Other countries	World
Aluminum	26	34	29	30	n.a.	–
Copper	52	63	48	55	n.a.	–
Glass[b]	39	20	55	33	n.a.	–
Lead	59	65	13	55	37	49
Paper	39	28	48	35	n.a.	–
Steel	54	63	47	55	36	45
Zinc[c]	17	31	26	23	n.a.	–

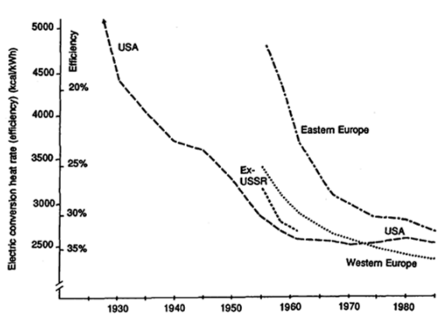
[a] Japan, Australia, New Zealand.
[b] Glass bottles and containers only.
[c] Minimum estimate.
Sources: Metallstatistik (1993:13–44), OECD (1993:149), IISI (1995:141–168), and UN *Statistical Yearbook* (1995:587).

Material Composition of Avg US Car



DOE, 2001

Thermal Efficiency of Coal Electricity Generation



Environmental “Fixes”

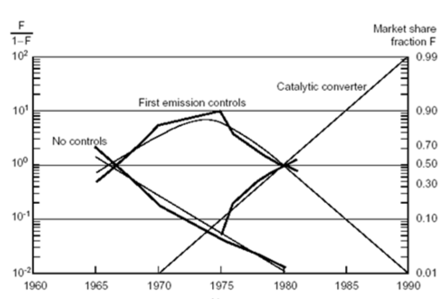
- Historical: “Byproduct” of TC (if at all)
- Since 1960s: Policy-led (particulates, sulfur, transport emissions, etc.)
- Since 1980s: Move beyond Nation State (European transboundary air emission protocols, Montreal protocol)
- Trade-offs:
  -- Incremental vs. radical change
  -- “End-of-pipe” vs. “upstream” solutions
  -- Political vs. environmental boundaries

Energy Efficiency (%) and Emissions (g/km) for Horses, and Early and Contemporary Automobiles

	Horses	Cars (ca. 1920)	Cars (1995)
Engine efficiency, %	4	10	20
Wastes			
Solid	400	–	–
Liquid	200	–	–
Gaseous, including			
Carbon (CO_2)[d]	170	120	70
Carbon (CO)	–	90	2
Nitrogen (NO_x)	–	4	0.2
Hydrocarbons	2[e]	15	0.2

d Total carbon content of fuel
e Methane

Diffusion of Catalytic Converters in US Car Fleet (Source: Nakicenovic, 1986)



US – Transport Pollutants

US transport criteria air pollutants

		1970	1980	1990	2000	2010	2010 as % of 1970
CO	road	163	144	110	68	37	22
M st	other	11	17	21	24	10	85
	Transport	175	161	132	92	45	26
NOx	road	13	11	10	8	4	34
M st	other	3	3	4	4	3	108
	Transport	15	15	13	13	7	47
VOC	road	17	14	9	5	3	19
M st	other	2	2	3	3	1	81
	Transport	19	16	12	8	4	24
PM-10	road	0.5	0.4	0.4	0.2	0.1	25
M st	other	0.2	0.3	0.3	0.3	0.2	106
	Transport	0.6	0.7	0.7	0.6	0.3	45
PM-2.5	road	0.3	0.3	0.2	0.1	0.1	28
M st	other	0.3	0.3	0.3	0.3	0.2	53
	Transport	0.6	0.6	0.5	0.5	0.3	40
Lead	road	0.42	0.06	0.02	0.02	~0	0
K st	other	0.99	0.86	0.73	0.72	0.65	66
	Transport	1.41	0.92	0.75	0.74	0.65	46

100 % cat cars

100% Lead-free gas

Negative Environmental Impacts

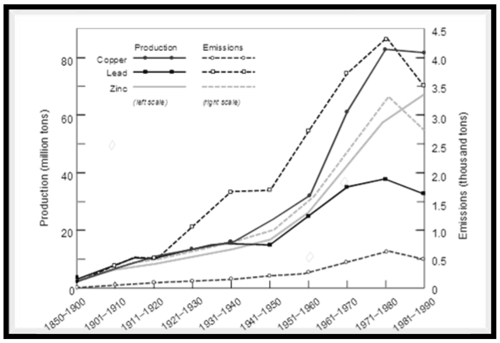
- Direct (new materials, substances)
- Indirect (productivity-led output growth)
- Amplification of traditional impacts (e.g. eutrophication)
- Novel impacts (DDT, CFCs)
- Uncertainty and surprise
- Global Change:
  -- planetary scale
  -- local scale, but ubiquitous & pervasive

Factors of Growth: The Last 200 Years

	1800	2000	factor
World population, billion	1	6	x 6
Life expectancy, years*	35	75	x 2
Work hours per year*	3,000	1,500	÷ 2
Free time over life*	70,000	300,000	x 4
Mobility, km/day* (excl. walk)	0.04	40	x 1000
World income, trillion $	0.5	36	x 70
Global energy use, Gtoe	0.3	10	x 35
Carbon, energy, GtC	0.3	6	x 22
Carbon, all sources, GtC	0.8	8	x 10

* Industrialized countries

World Metal Production (million tons) and Emissions (thousand tons).
Source: Nriagu, 1996.



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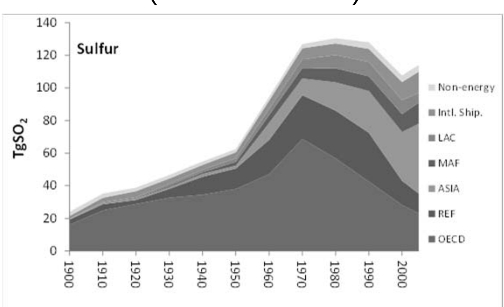
World – Sulfur Emissions by Region (cumulative totals)



Source: GEA Energy Primer, 2012

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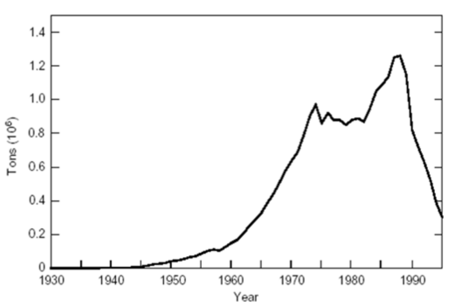
World – Emissions of CFCs

(CFC–11, CFC–12, CFC–113, 114, and 115)



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Area of Ignorance: Relative Proportions of Chemicals Known (6 Million, big rectangle), Tested for Carcinogenicity (7000, small rectangle, top-left corner), and Definitively Related to Human Cancer (30, small square, bottom-right). Source: Adams, 1995.

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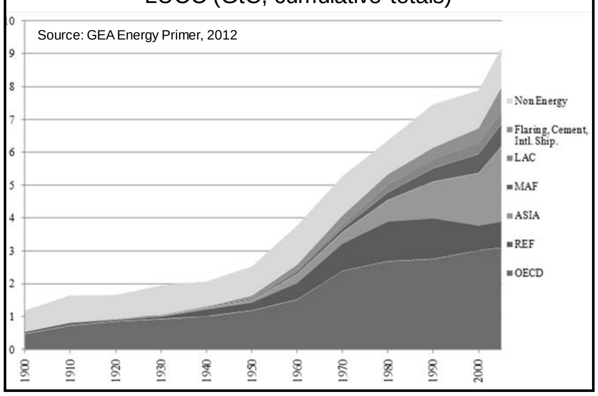
Unabated Growth: Carbon Emissions w/o LUCC (GtC, cumulative totals)



Dimensions of Global Change ca. AD 2000

	Land use 10^6 km^2	Water use km^3	Materials mobilized 10^9 t	Emissions 10^6 t			
				Arsenic	CFCs*	Sulfur	Nitrogen#
Human	47	3,000	<100	0.04	0.5	70	80
Natural	84	10,000	<25	<0.02	~0	<25	<50
Human as % of Nature	56%	30%	400%	200%	~∞	300%	200%

*Peak in 1988: >1.1 Million tons.
#1990 data.

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IPAT

Impact	=	Popula-tion	x	Afflu-ence	x	Techno-logy
Emis-sions	=	POP	x	GDP/ POP	x	E/GDP
aagr (%/yr)	=	*pop*	+	*gdp/pop*	+	*e/gdp*

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Kaya Identity for OECD 1900-2000 (**all** numbers rounded!)

	POP 10^6	GDP/POP *$/cap*	GDP 10^9 *$*	ENE/GDP *kgoe/$*	ENE *Mtoe*	C…./ENE *tC/toe*	C *MtC*
1900	350	3000	1000	.7	700	.9	600
2000	900	21000	19000	.25	5000	.7	3300
Factor In-crease	2.6	7	19	.36	7	.74	5.5
aagr %/yr	1.0	2.0	3	-1.0	2.0	-0.3	1.7

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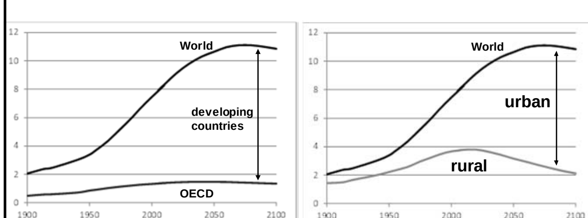
World Population (in Billion) cumulative plot



Source: UN, GEA, and Maddison

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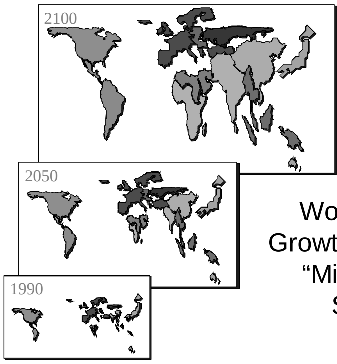
World Economic Map 1990, 2050, 2100 (IIASA-WEC B)



World Economic Growth in IIASA-WEC “Middle Course” Scenario B

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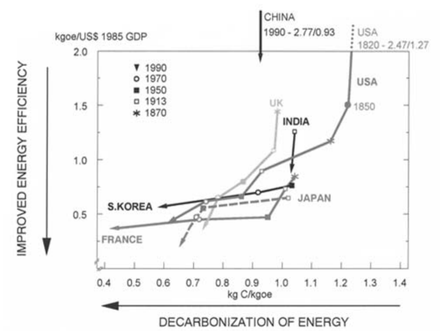
Improvements in Efficiency and Decarbonization: Diverse Paths



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IPAT Critique

- Surrogate variables, NOT drivers
- Interdependence between all variables: E.g. POP↔A, T↔A, POP↔T(?)
- Fallacy of spatial aggregation (POP growth in India, CAR (emission) growth in US)
- Temporal variability

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		1800-1900 %/yr	1900-2000 %/yr	1800-2000 %/yr
POP million	IND	0.82	0.87	0.85
	DEV	0.39	1.49	0.94
	WOR	0.51	1.32	0.92
GDP/POP $/capita	IND	1.26	1.95	1.60
	DEV	0.21	1.59	0.90
	WOR	0.80	1.60	1.20
ENE/GDP kgoe/$	IND	-0.40	-0.56	-0.48
	DEV	-0.17	-0.26	-0.22
	WOR	-0.17	-0.46	-0.32
C/ENE kgC/kgoe	IND	-0.12	-0.49	-0.30
	DEV	0.00	-0.30	-0.15
	WOR	-0.09	-0.39	-0.24
Carbon TgC	IND	1.56	1.77	1.66
	DEV	0.43	2.53	1.47
	WOR	1.06	2.07	1.56

Kaya Identity: Spatial and Temporal Heterogeneity

Arnulf Grübler

People Behind IPAT

- Barry Commoner (blames technology)
- Paul Ehrlich (blames population)
- John P. Holdren (stresses interdependence)
- Esther Bosserup (POP ↔ T related!)
- Moses Abramovitz (interdependence, T's ["residual's"] importance even greater)
- Gus Speth ("a Luddite recants")
- Marian Chertow (review): Jrnl.Ind.Ecol. 4(4):13-29(2001)
- Arnulf Grubler (data): Encyl.Glob.Env.Change 3:35-53(2001)

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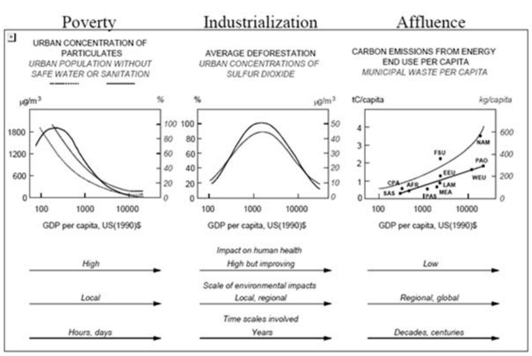
A Taxonomy of Environmental Problems (after WB, 1992):



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A Word of Caution

- Cross-sectional data (comparing different countries) only first step
- Longitudinal analyses needed too (track changes across countries and in time).
- Income is surrogate indicator and not a causality driver!
- Elasticity of impacts and peaks:
  -- pollutant dependent
  -- exposure dependent
  -- time dependent ("leap-frogging")

Summary Block 4 (Environmental Impacts)

- **Positive = resource augmentation, substitution, efficiency & productivity, (conservation), "fixing" of environmental problems,**
- **Negative = novel impacts, growth in human numbers & activities,**
- **Global change = planetary change + change all over the planet**
- **Non-linear dose-response relationships (e.g. acidification)**
- **Orders of magnitude of global change: land, water, minerals, metals**
- **Kaya identity or IPAT model (impact = pop X affluence X technology)**
- **Critique of IPAT model (interdependence, spatial aggregation)**
- **typology of environmental problems (poverty, industrialization, affluence) and caveats**