Lessons from Historical Energy Transitions and Implications for Energy Technology Innovation Systems

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Economic Challenges for Energy
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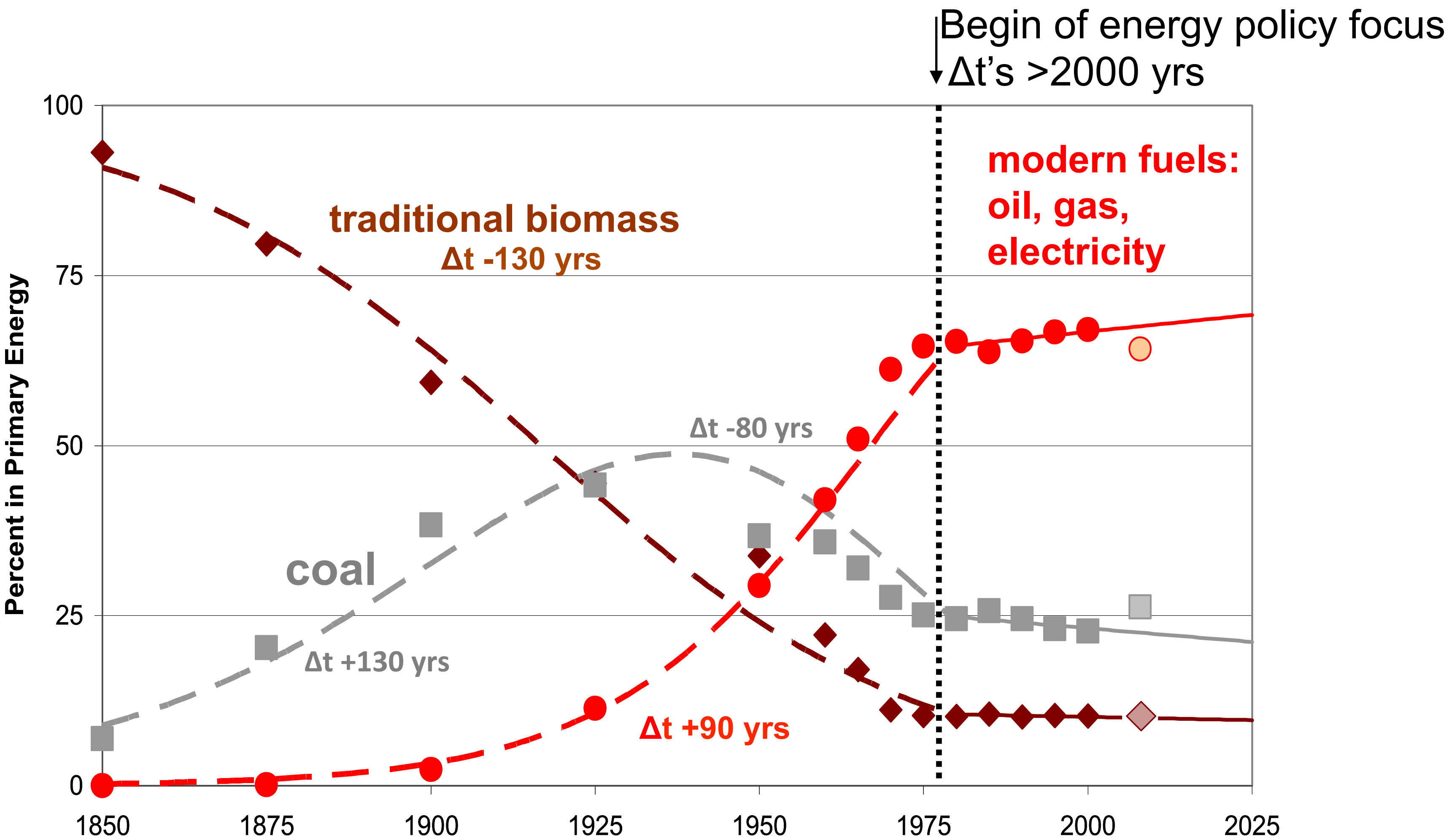
Energy Transitions - Main Messages

- Extremely long time constant of change,
  but: measurement biases (inputs instead of outputs)
- Change pervasive and systemic,
  but: end-use dominance ignored by policy
- Scaling across all scales (unit→plant→industry),
  but: granular technologies less risky and more successful
- Impact of policies mixed,
  but: <u>how</u> matters more than <u>how much</u>

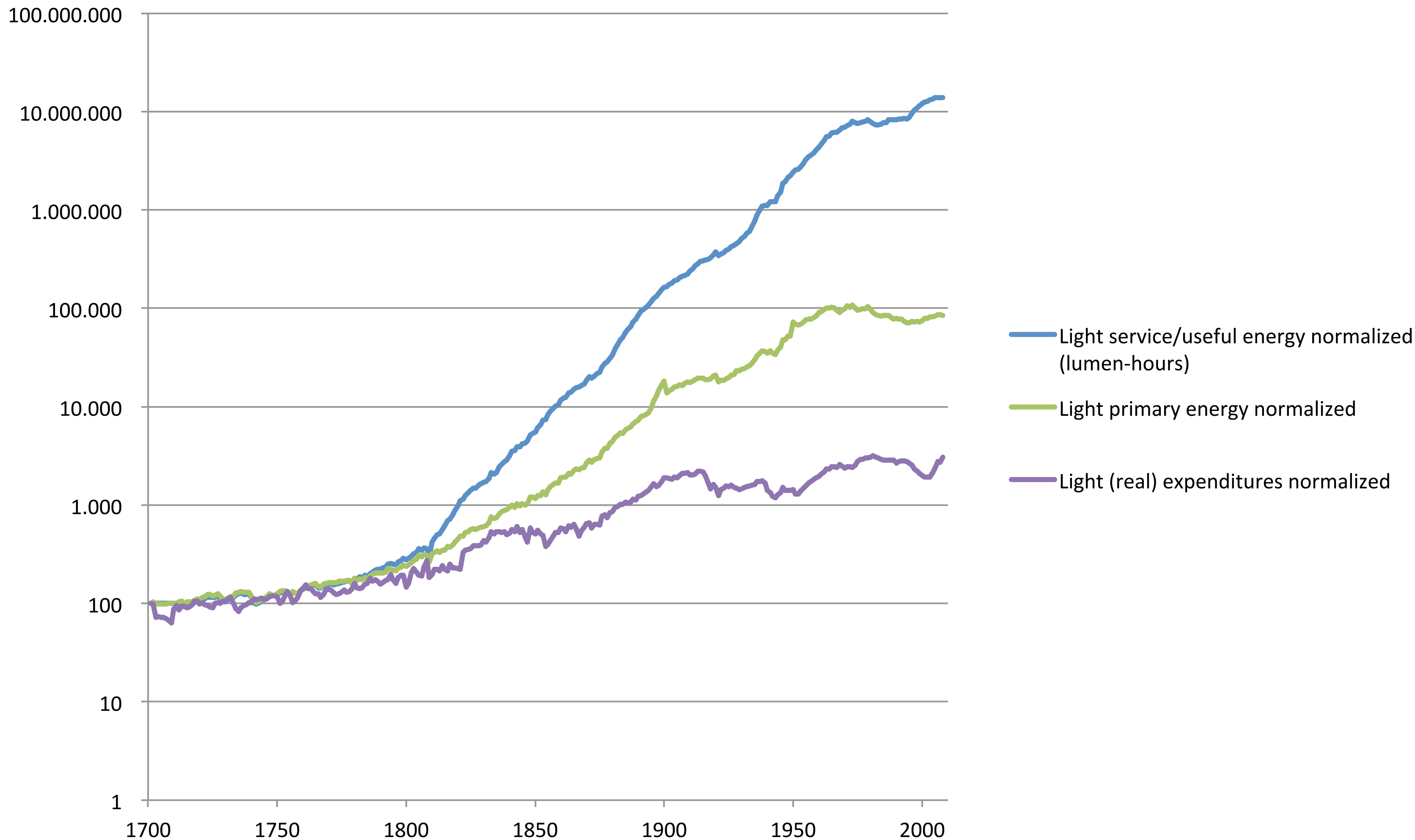
World – Primary Energy Transitions

changeover time Δts: 80-130 years



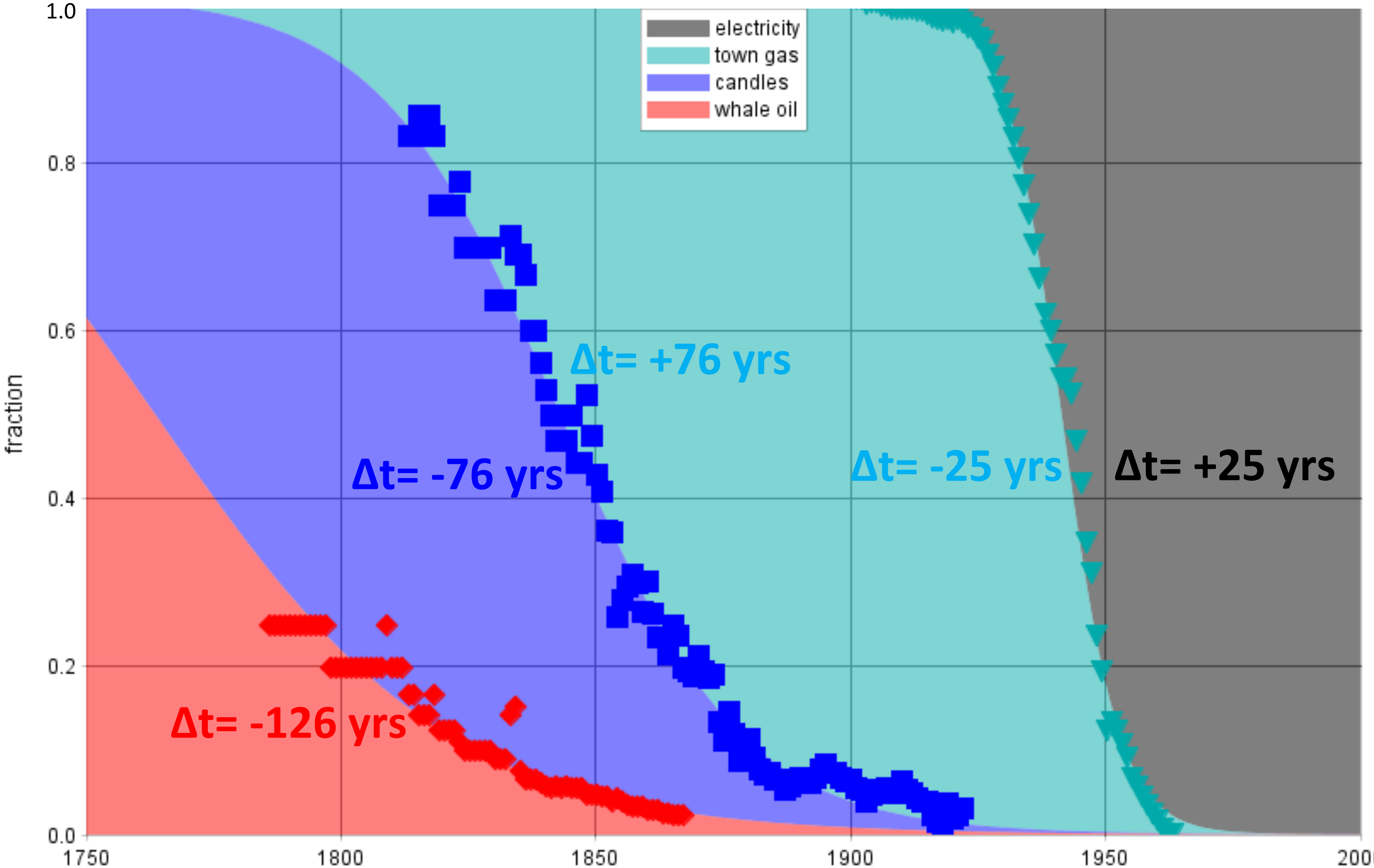
Source: GEA, Chapter 24, 2012

Input vs. Output Measures of Growth
(example lighting services UK, index 1700=100)



Source: Grubler (in press) based on Fouquet, 2008

UK – Transitions in Energy Services for Light



Source: Grubler (in press) based on Fouquet, 2008

Importance of Energy End-use

- Least efficient part of energy system, with vast improvement potentials
- Dominant in terms of installed capacity
- Dominant form of energy investment (and GDP & employment multipliers!)
- Short-rifted by systemic innovation portfolio biases

Capacity of US Energy Conversion Technologies

GW (rounded)		1850	1900	1950	2000
stationary	thermal (furnaces/boilers)	*300*	*900*	*1900*	*2700*
end-use	mechanical (prime movers)	1	10	70	300
	electrical (drives, appliances)	*0*	*20*	*200*	*2200*
mobile	animals/ships/trains/aircraft	5	30	120	260
end-use	automobiles	0	0	3300	25000
stationary	thermal (power plant boilers)	*0*	*10*	*260*	*2600*
suppply	mechanical (prime movers)	0	3	70	800
	chemical (refineries)	0	8	520	1280
TOTAL		306	981	6440	35140

Energy end-use = 30 TW or 87% of all energy conversion technologies
= 5 TW or 50% when excluding automobiles

Source: GEA Chapter 24, 2012

World Energy Technology Innovation Investments (Billion $)

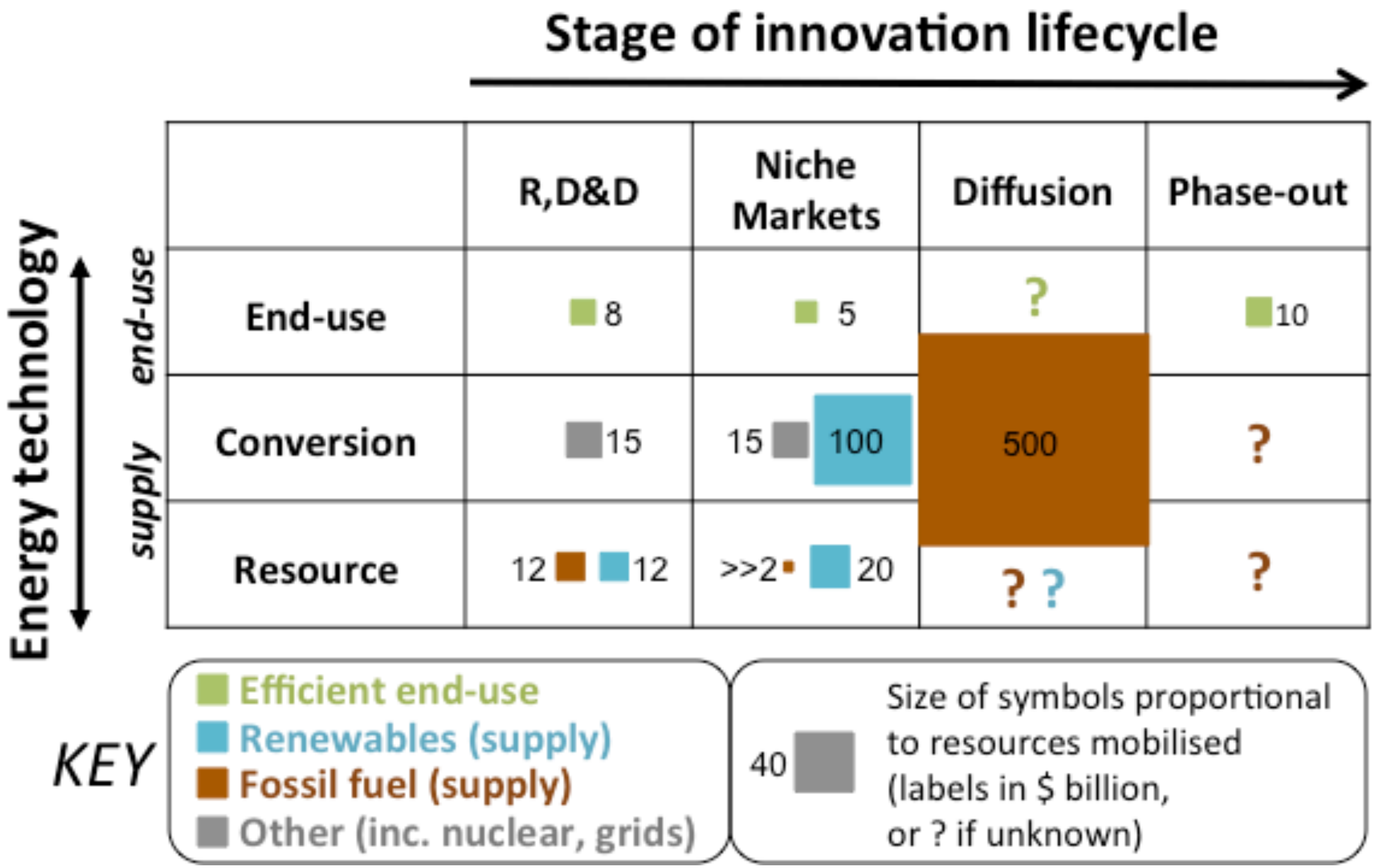
	innovation (RD&D)	market formation	diffusion
End-use & efficiency	>>8	5	300-3500
Fossil fuel supply	>12	>>2	200-550
Nuclear	>10	0	3-8
Renewables	>12	~20	>20
Electricity (Gen+T&D)	>>1	~100	450-520
Other*	>>4	<15	n.a.
Total	>50	<150	1000 - <5000
non-OECD	**~20**	**~30**	**~400 - ~1500**
non-OECD share	**>40%**	**<20%**	**40% - 30%**

* hydrogen, fuel cells, other power & storage technologies, basic energy research

Source: GEA Chapter 24, 2012

Public Policy-induced ETIS Investments

billion US$2005

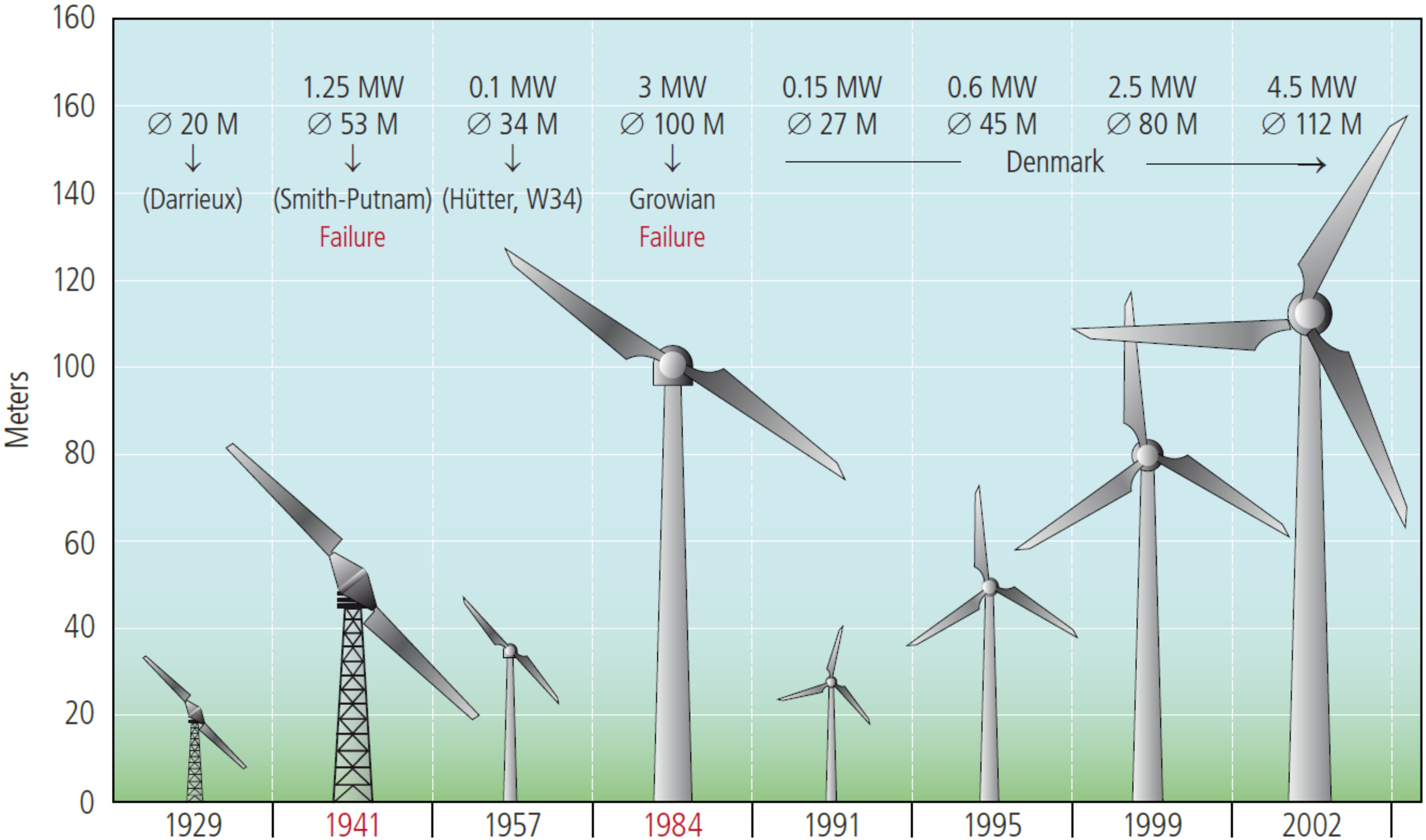


Source: Wilson et al. *Nature CC* 2012

Scaling of Energy Technologies

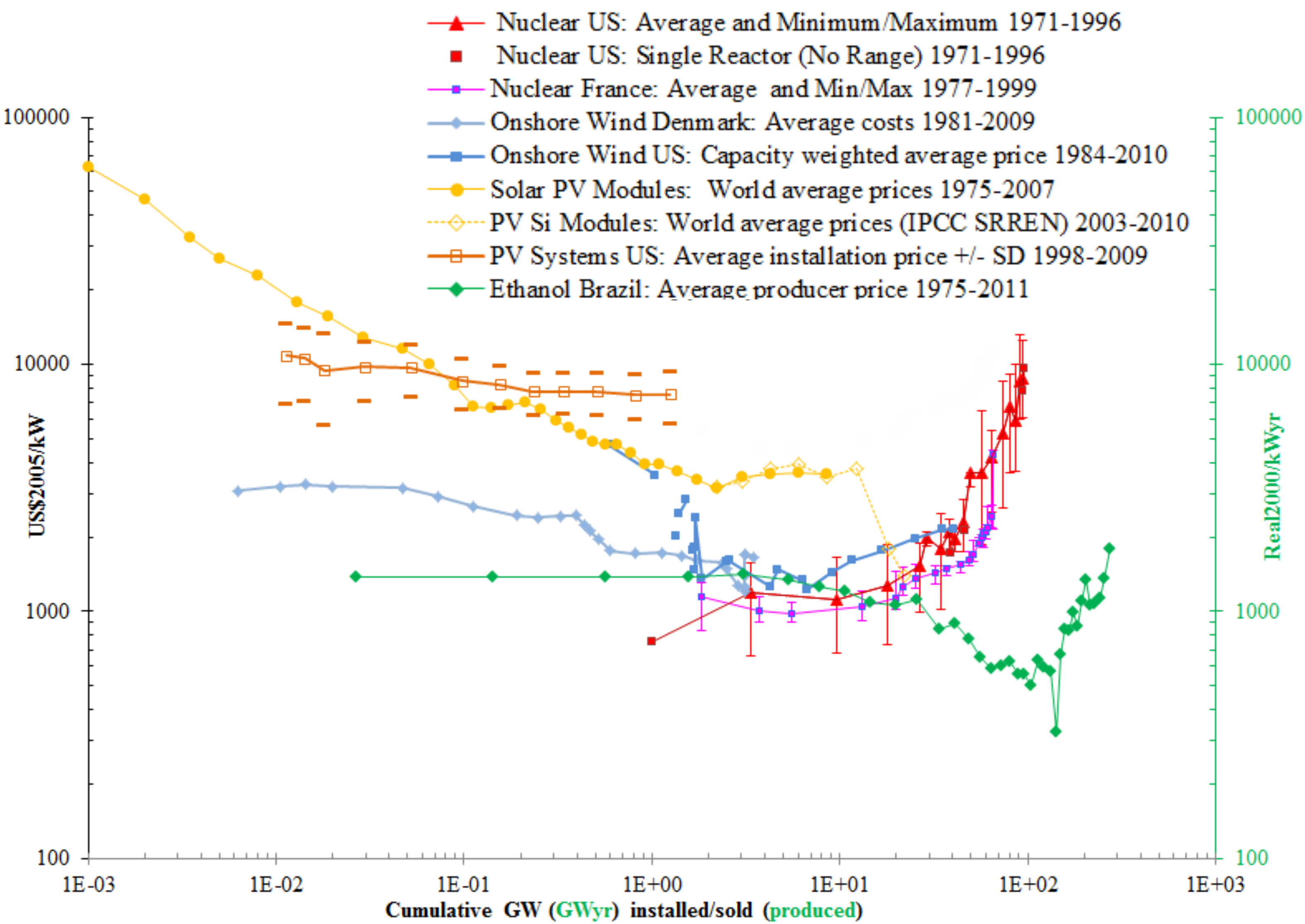
- Across scales: units – plant – industry – markets
- Prolonged experimentation needed (pre-mature scaling-up is risky)
- Scale dominant source of cost improvements (and <u>not</u> "learning by doing")
- Improvement potentials and markets largest for "granular technologies"

Unit-level Scaling of Wind Turbines



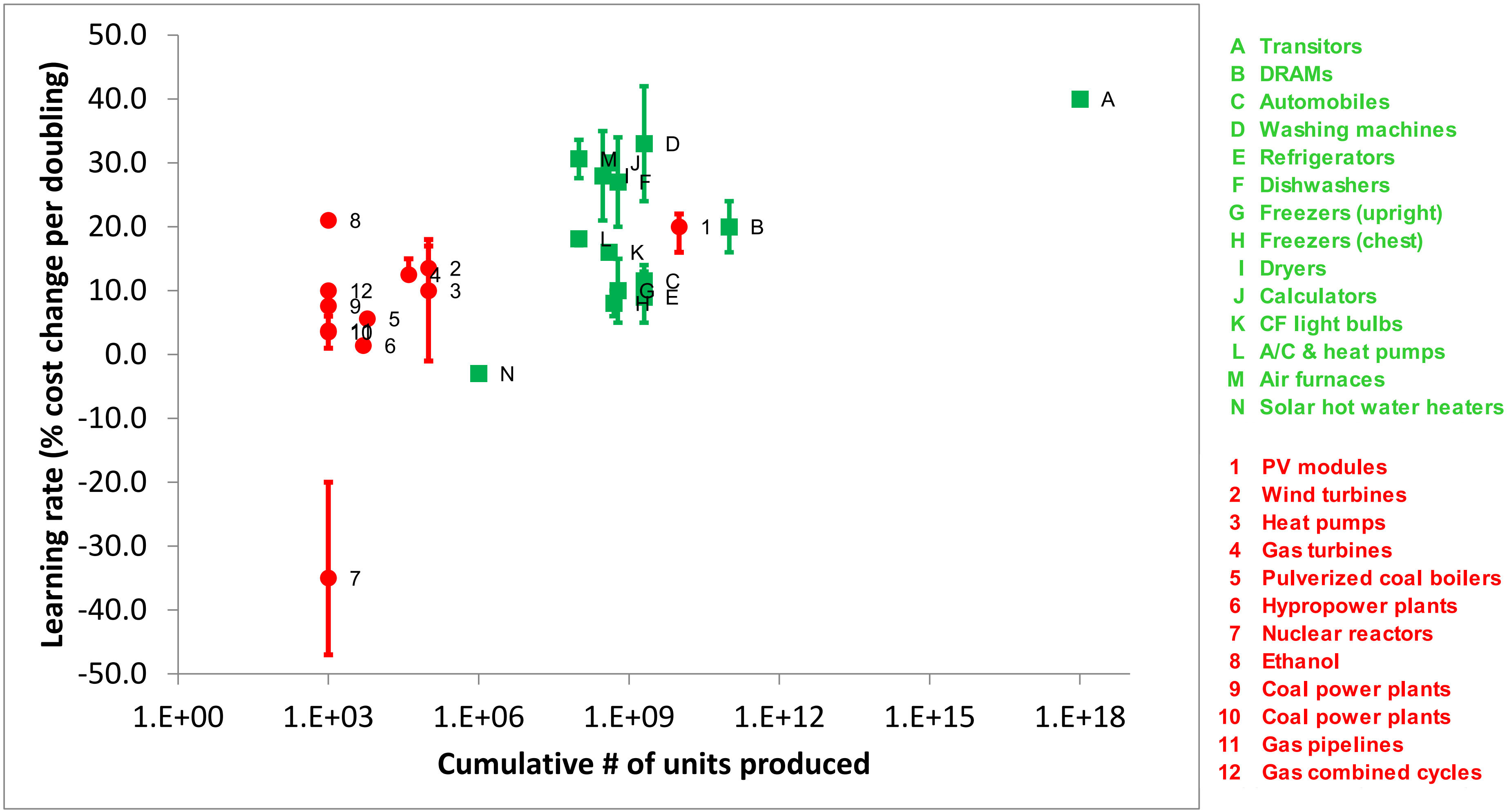
Source: Neij et al., 2014

Post Fossil Technologies Cost Trends



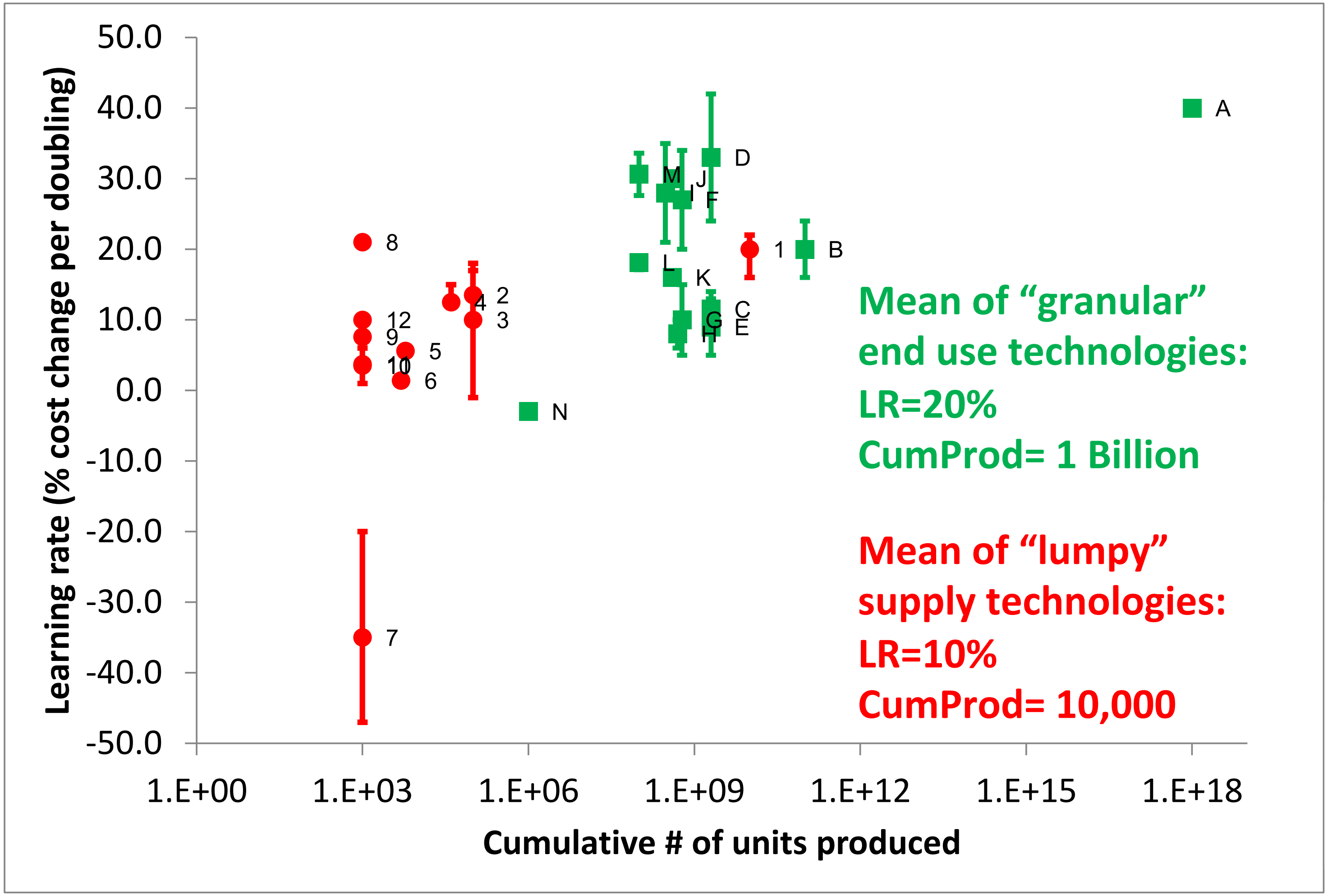
Source: Grubler & Wilson, 2014

Learning Rates vs Cumulative Experience (# of units produced)



Source: Wilson et al. *Nature CC* S1 (2012)

Cumulative Experience /Learning Favors "Granular" Technologies



A Transitors
B DRAMs
C Automobiles
D Washing machines
E Refrigerators
F Dishwashers
G Freezers (upright)
H Freezers (chest)
I Dryers
J Calculators
K CF light bulbs
L A/C & heat pumps
M Air furnaces
N Solar hot water heaters

1 PV modules
2 Wind turbines
3 Heat pumps
4 Gas turbines
5 Pulverized coal boilers
6 Hypropower plants
7 Nuclear reactors
8 Ethanol
9 Coal power plants
10 Coal power plants
11 Gas pipelines
12 Gas combined cycles

Source: Wilson et al. *Nature CC* S1 (2012)

Mixed Impact of Policies

- Significant transition "de-acceleration" since 1970s (inconsistent policy "push and pull")
- Success stories when policies are:
  <u>aligned</u>, <u>patient</u>, and <u>systemic</u>,
  e.g. Japan, Brazil, vs. US
- Systemic underinvestment in end-use and efficiency: ALL actors
- ETIS increasingly global, but too few international tech cooperation & knowledge spillovers
- Erratic policy leads to rapid knowledge depreciation

Knowledge Depreciation Rates

Knowledge Depreciation Rates (% per year)

empirical studies reviewed GEA Chapter 24 (2012) and

modeled R&D deprecation in US manufacturing (Hall, 2007)

Degree of technological obsolescence (rate of innovation)

Low → High

Degree of knowledge stock turnover (policy & human capital volatility)

Low → High

Engineering designs US: <5%

Wind US: 10%

OECD nuclear R&D: 10 – 40%

PV Japan: 30%

Chemicals, Drugs: 15-20%

Computers: 32%

Electrical, Machinery: 32-36%

Miscell. >20%

Aircraft, Liberty ships manufct. US: 40%

France breeder reactors: 50-60%

Service industries: 95%

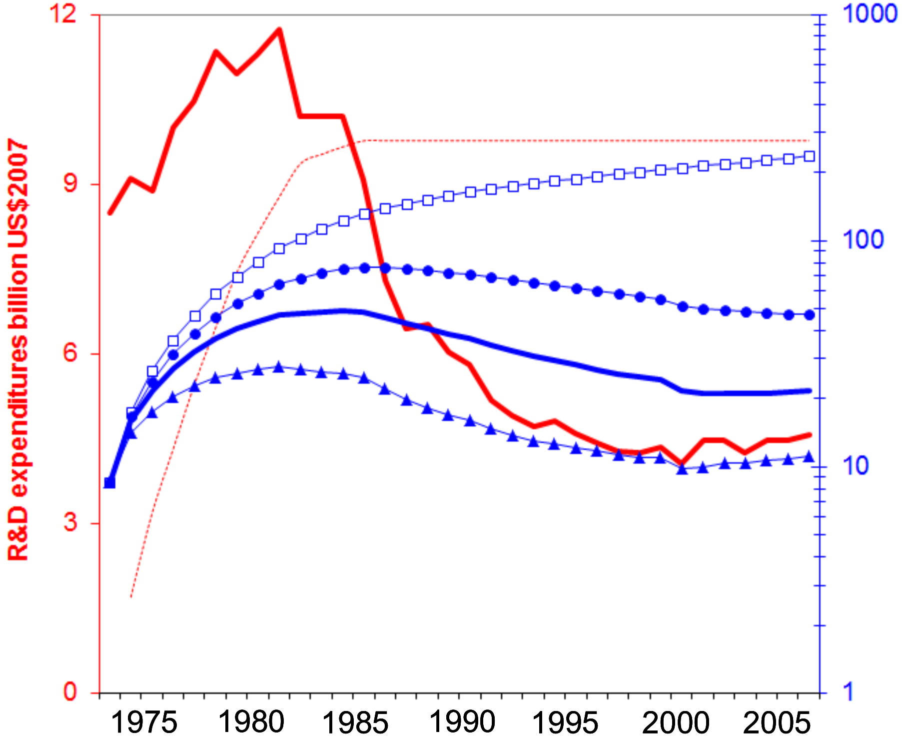
Source: Grubler & Nemet, 2014

R&D Expenditures and Knowledge Stock

(all IEA countries, billion $2007)

remaining knowledge stock (KS) calculated with 0, 10, 20, and 40% depreciation rates respectively

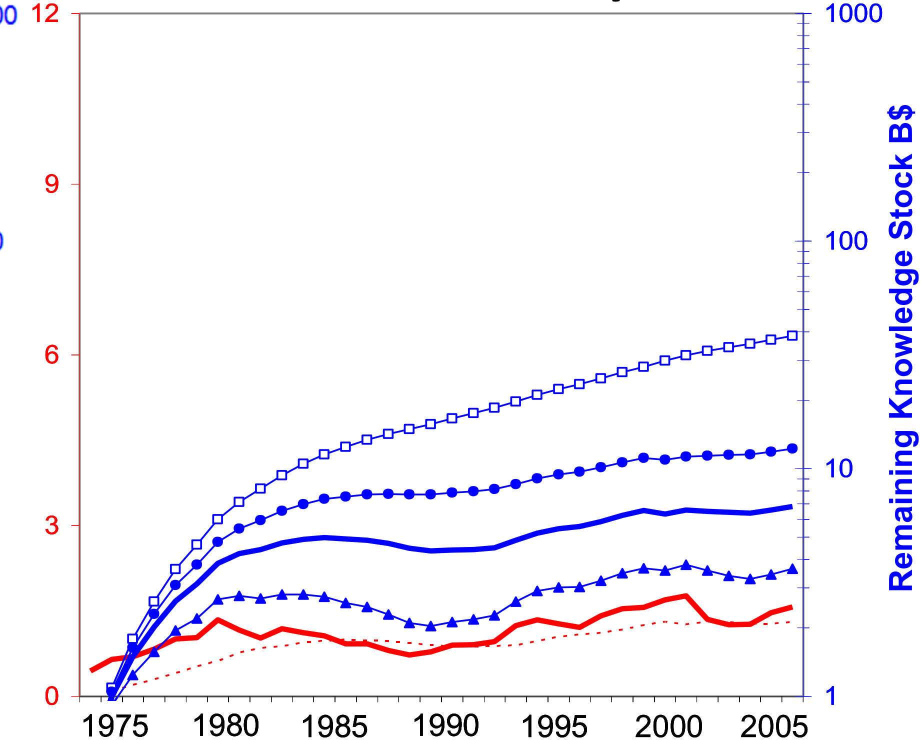
Nuclear



Cumulative R&D: 236 B$

Remaining KS: 11-47 B$

Efficiency



Cumulative R&D: 38 B$

Remaining KS: 4-12 B$

Source: Grubler & Nemet, 2014

Summary

Change <u>innovation systems</u>
and not just more of
isolated “push” (R&D) or
“pull” (renewable electricity FIT/PS)
policies

Policy <u>alignment</u> and <u>integration</u> key:
e.g.
- prices/taxes + standards + R&D Mgmt
- market creation + diffusion + phase-out