Hydrogen and the Realities of Technology Diffusion

Arnulf Grubler

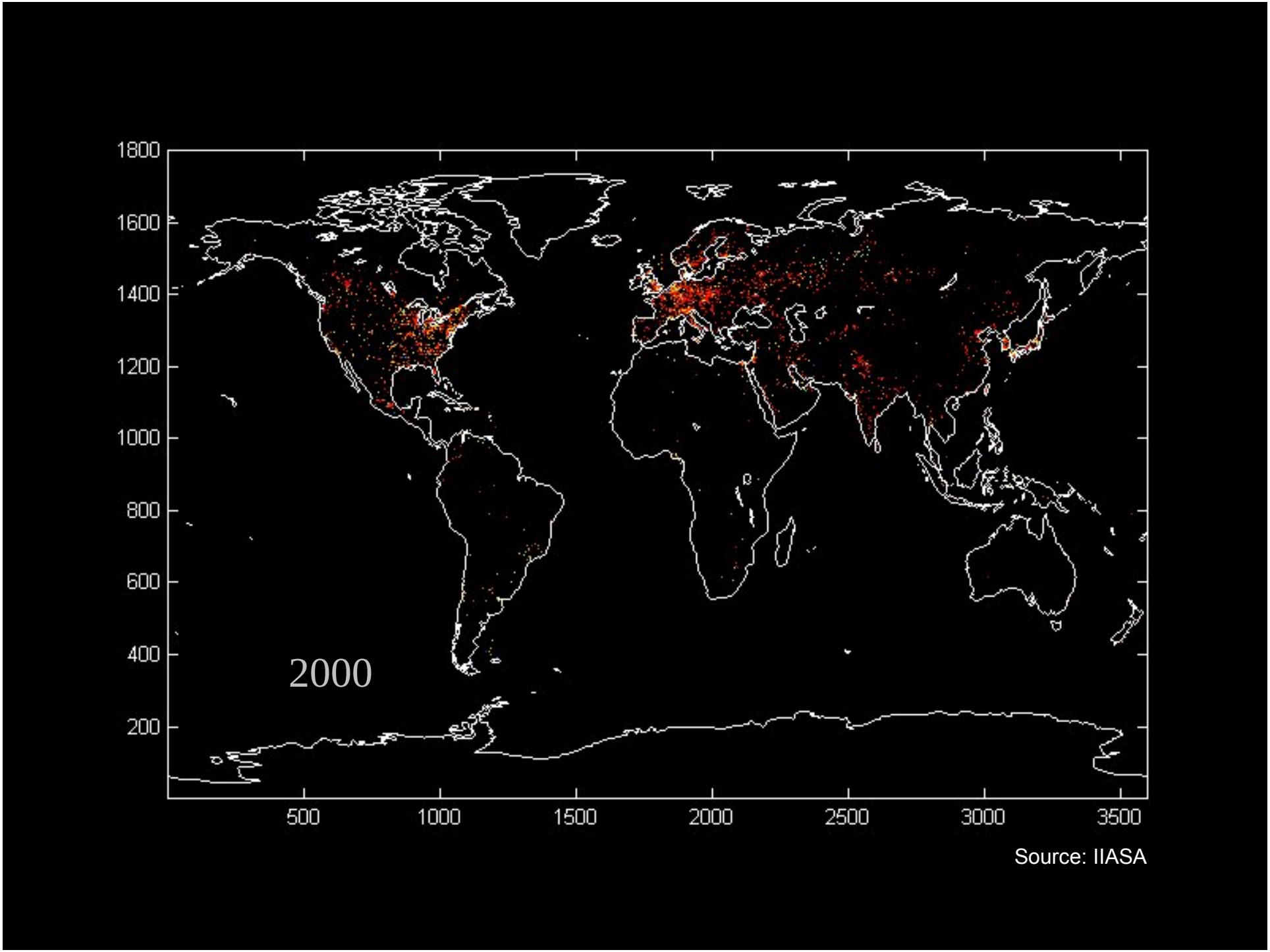
YALE FES

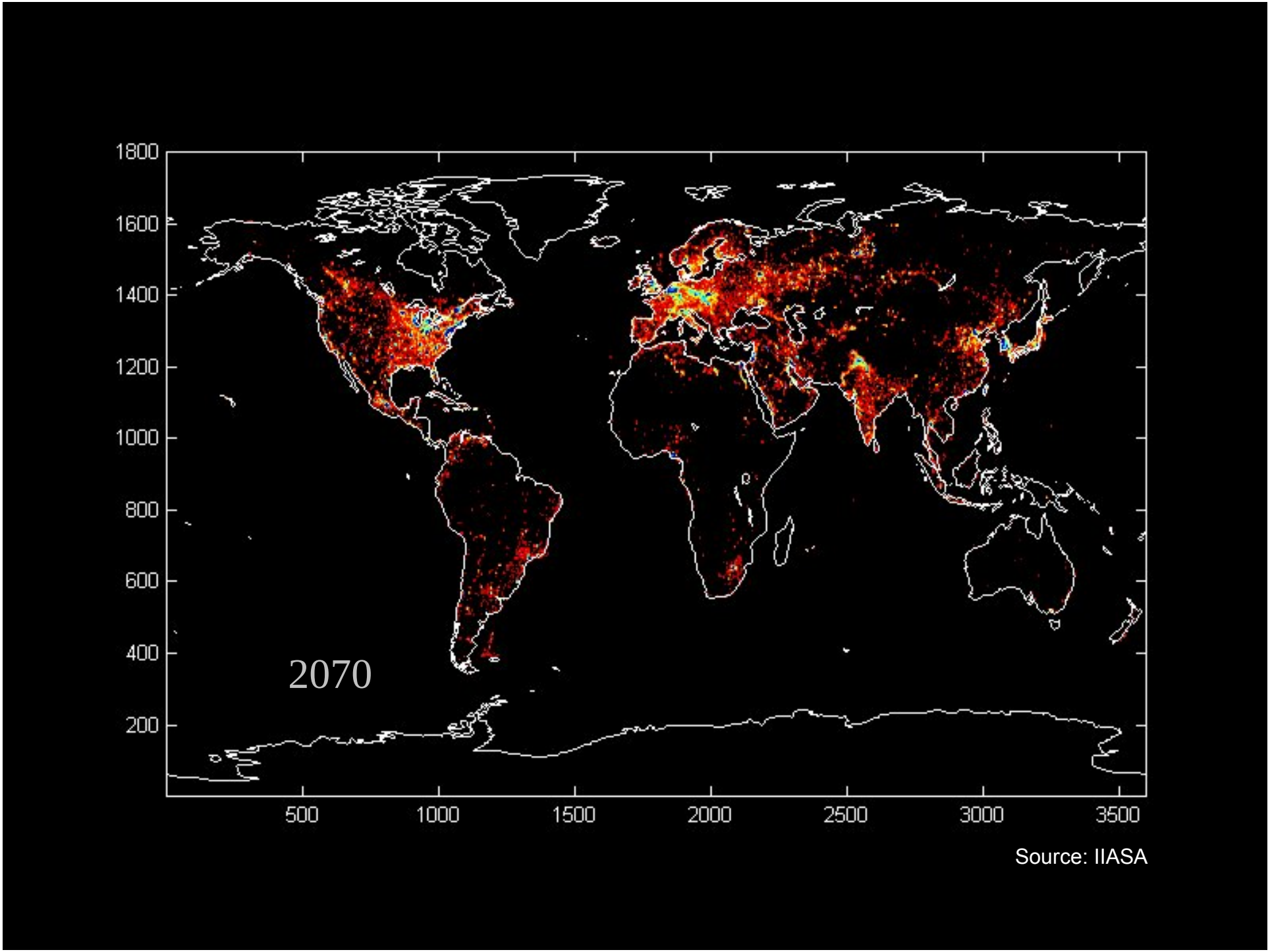
September 19, 2003

Why Hydrogen?

- Need zero-emission fuels at point of consumption (energy density)
- Climate Change: best transitional strategy for carbon management of fossil fuels (steamreforming+sequestration)
- Logical evolution of energy system

A. Grubler, 2003


1800
1600
1400
1200
1000
800
600
400
200
500
1000
1500
2000
2500
3000
3500
2000
Source: IIASA


1800
1600
1400
1200
1000
800
600
400
200
500
1000
1500
2000
2500
3000
3500
2070
Source: IIASA

When Will Hydrogen Come?

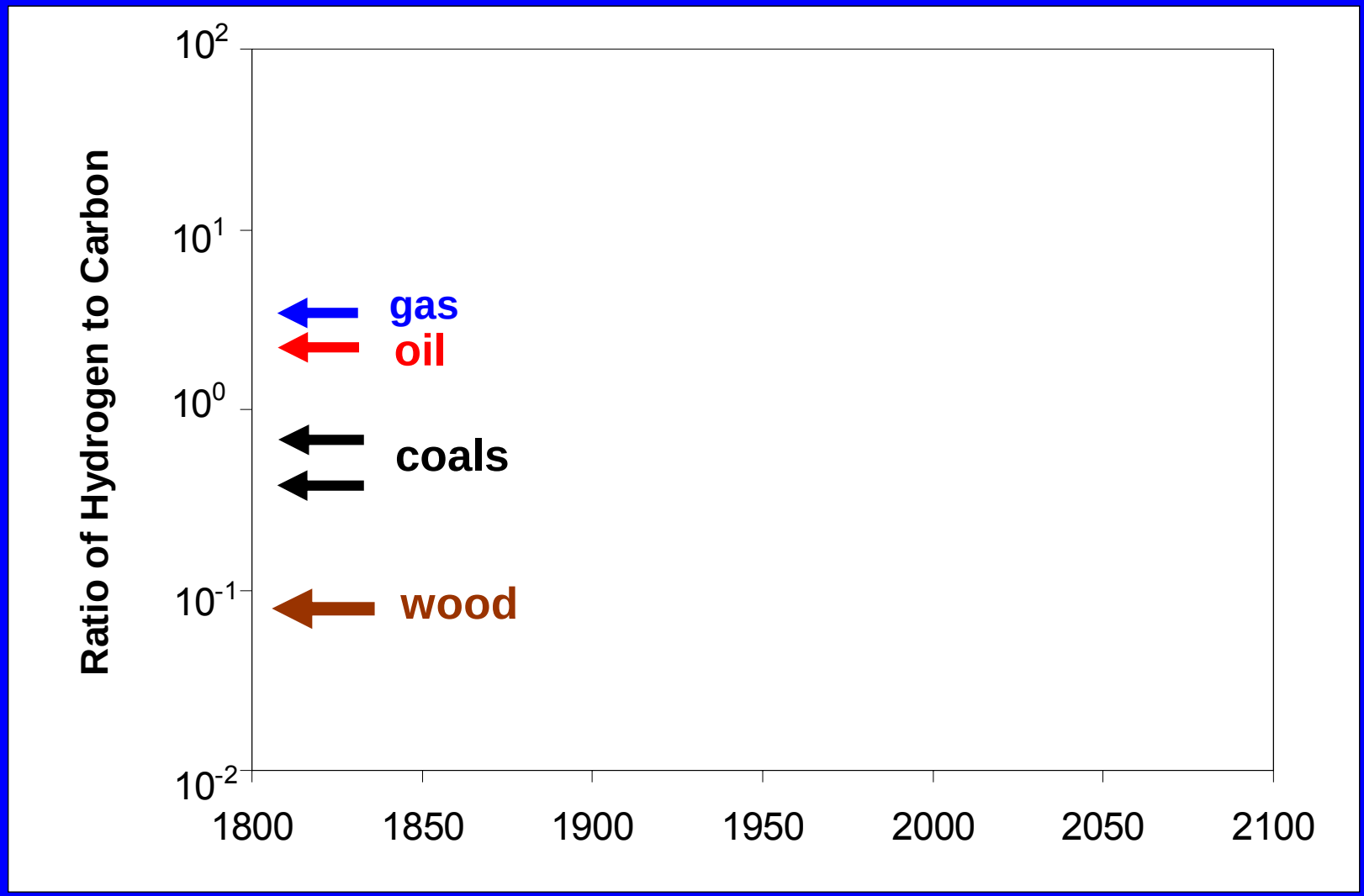
- C. Marchetti 1982: Non-fossil hydrogen via transition through „methane economy“
- Post 2000 scenario literature:

  2020: zero in BAU, small market niche (<2EJ) in „technology push“ scenarios.

  2050: Best guess 20+ EJ, much larger in climate stabilization and/or „technology push“ scenarios

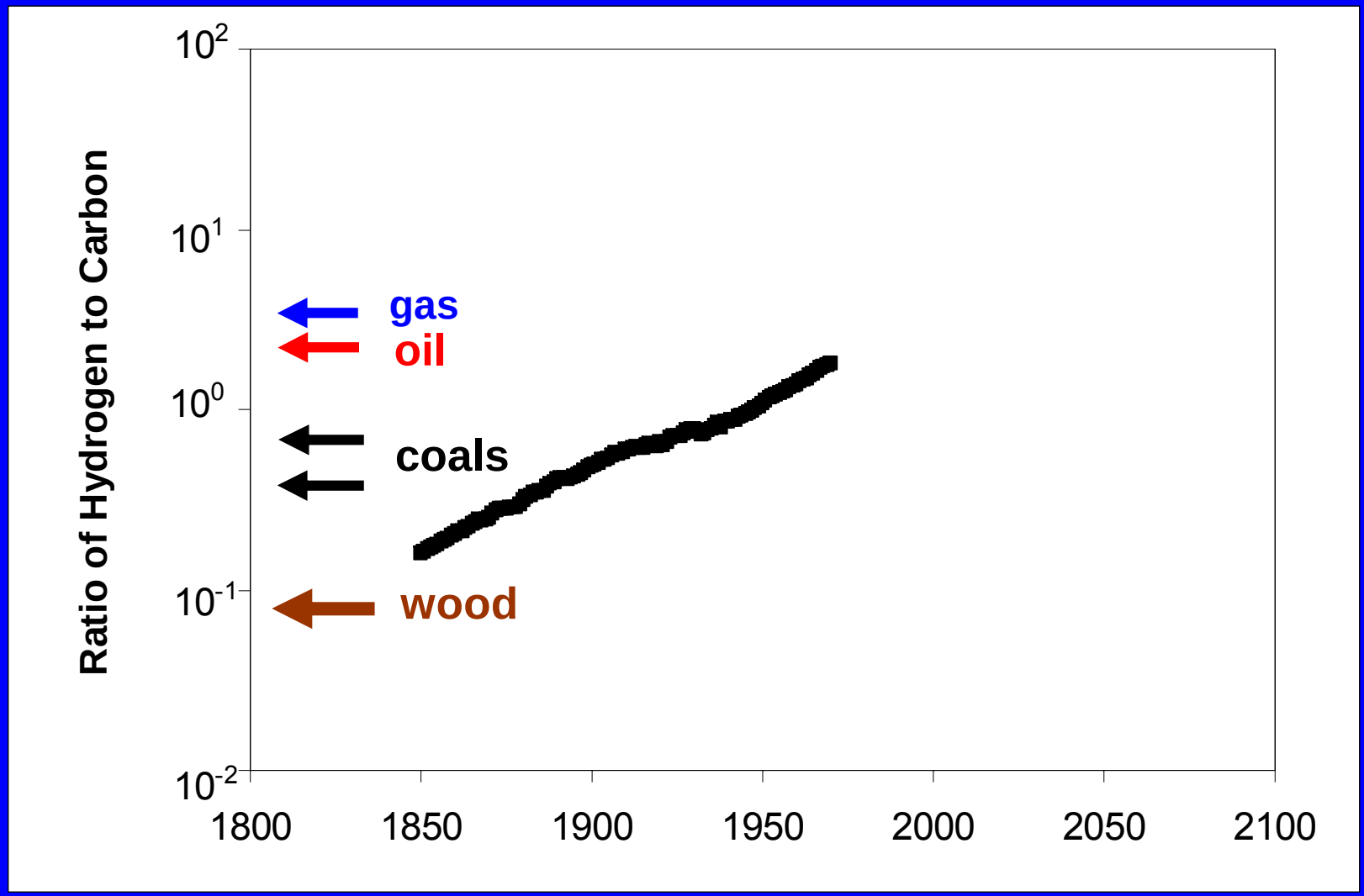
A. Grubler, 2003

World – H to C Ratio



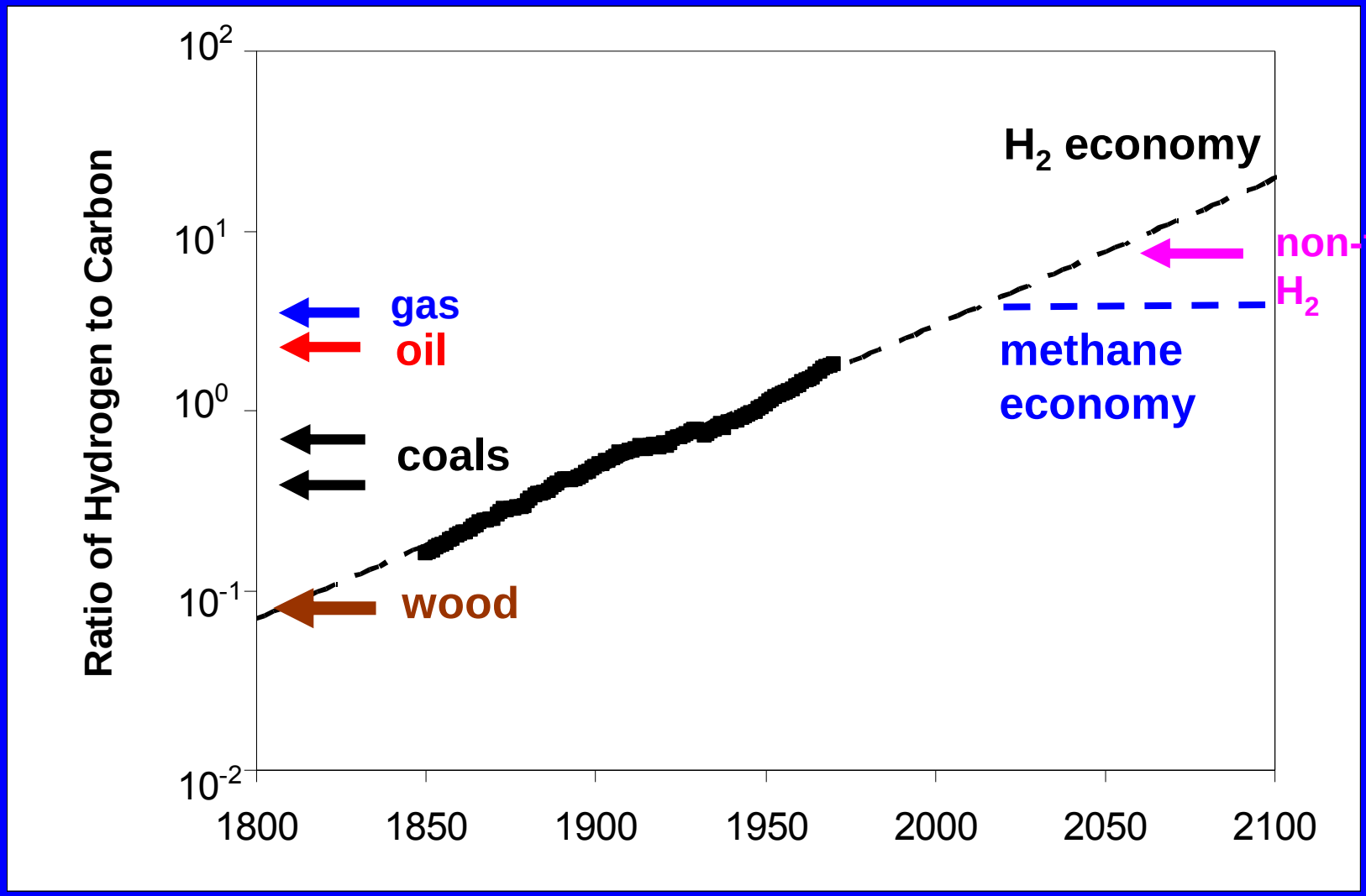
A. Grubler, 2003

World – H to C Ratio



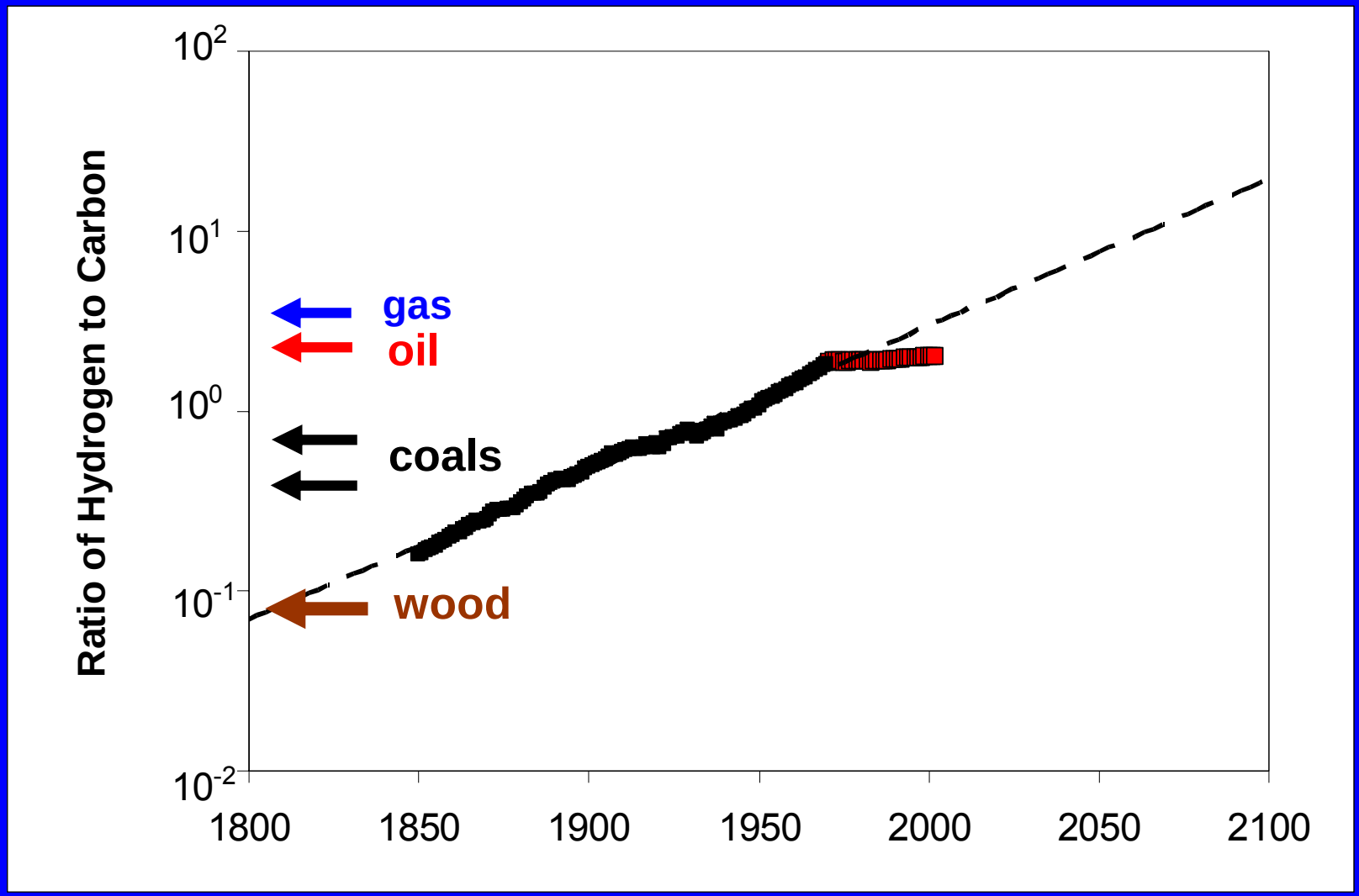
A. Grubler, 2003

World – H to C Ratio



A. Grubler, 2003

World – H to C Ratio

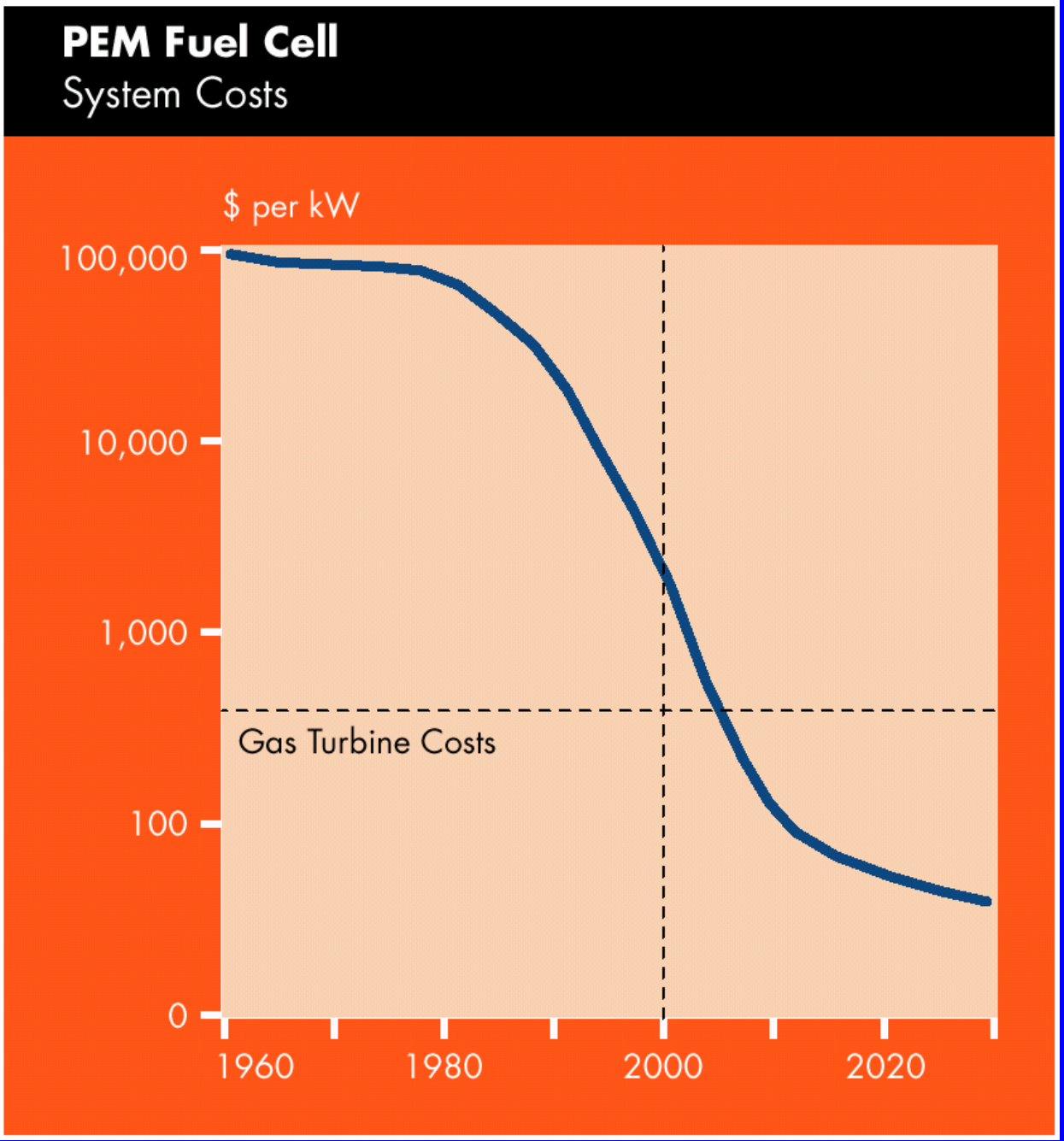


A. Grubler, 2003

How Does Hydrogen Come?

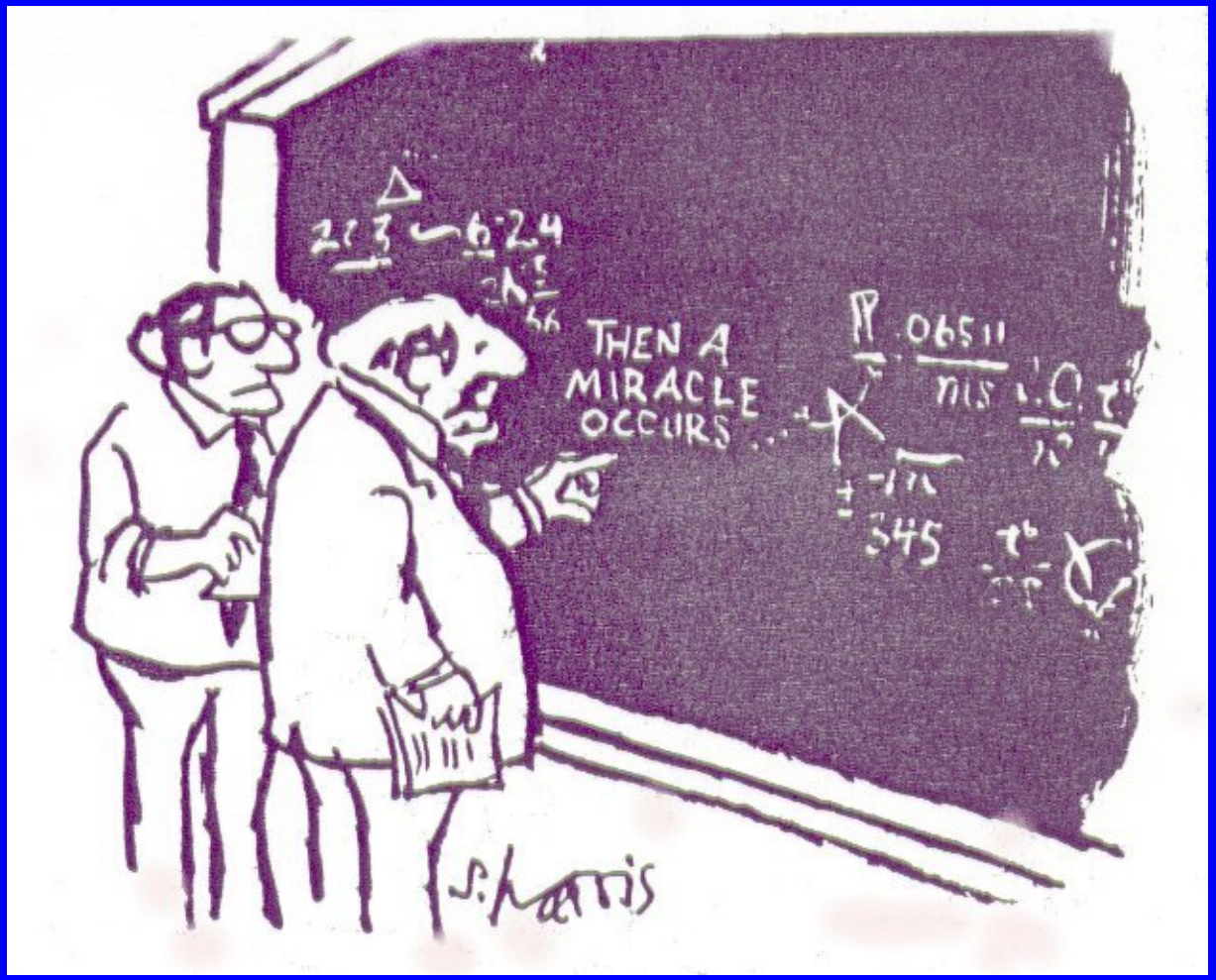
A. Grubler, 2003

After extraordinary cost reductions for PEM fuel cells over the past decade, manufacturing scale brings costs below $500 per kW by 2006 and $50 per kW shortly after 2010, to be directly competitive with internal combustion engines.



Source:
SHELL 2001

“I think you should be more explicit here in step two”



A. Grubler, 2003

Technology is...

H - Hardware (artifacts, "machines") PEM

+

S - Software (know-how, know-why) FC cogen

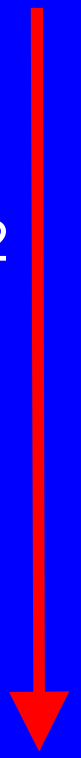
+

O - "Orgware" (institutions, regulation, "rules of the game") H_2

A. Grubler, 2003

Hierarchies of Change

Increasing Impact but also Increasing Time for Change



- Incremental **(H)**: 3-litre car
- Radical **(H^n+S)**: Fuel Cell
- Systems change **(H^n+S^n+O)**: FC cogeneration units using CH_4 and H_2 "towngas" (hythane) strategy
- Clusters, families, "paradigms" **(H^n+S^n+O^n)**: e.g. H_2 economy: H_2 + FC = all energy services; consumers = utilities

A. Grubler, 2003

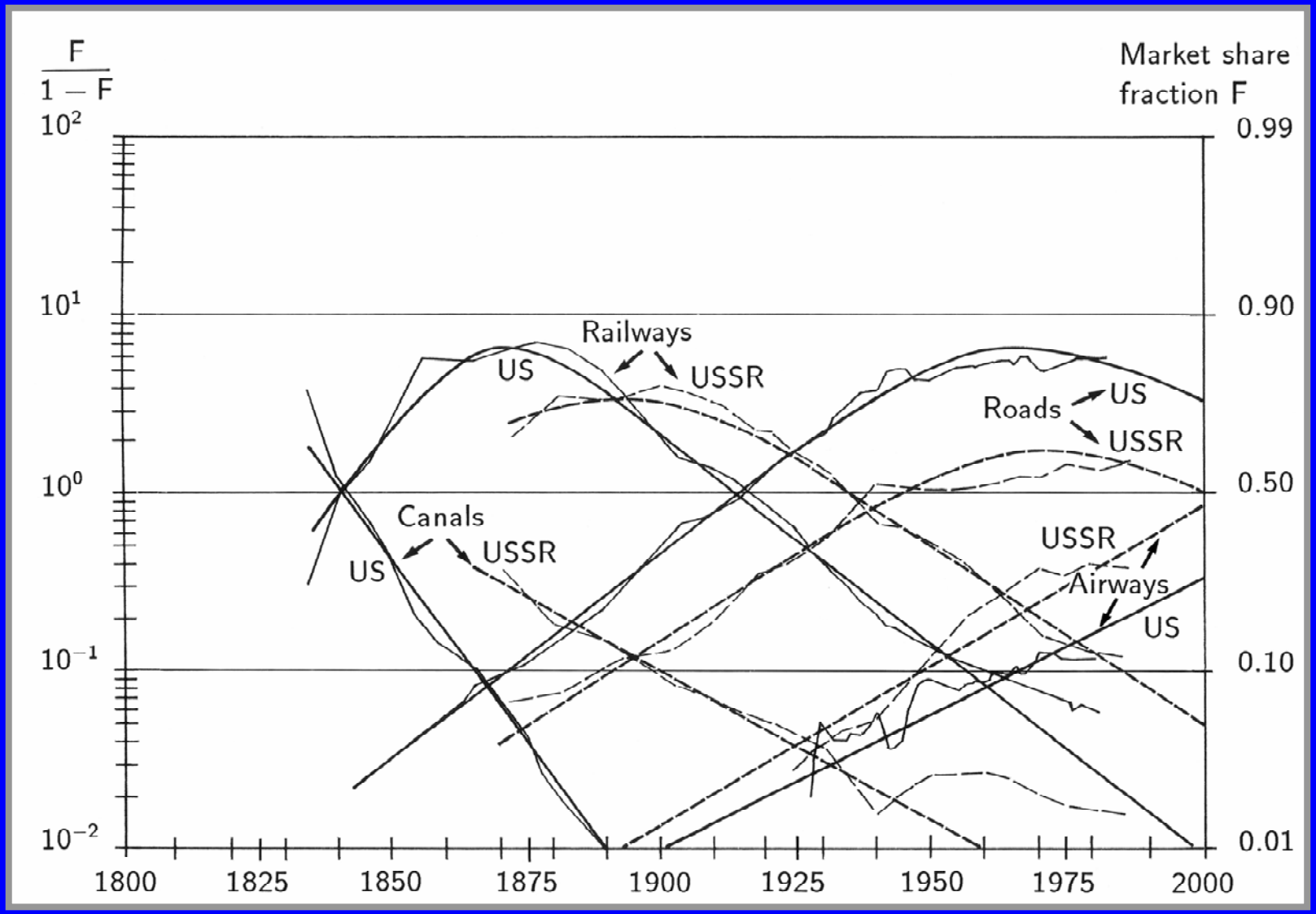
Hierarchies of Change

With increasing hierarchy of change:

- More interdependence, spill-overs and clustering
- Larger market size and social/environmental impact
- But:
  Slower diffusion

A. Grubler, 2003

USA - USSR: Infrastructure Substitution



A. Grubler, 2003

Pace of Diffusion 2 (Hierarchies)

	USA		USSR	
	t_0	Δt	t_0	Δt
Total length of transport infrastructure	1950	80	1980	80
Growth of railways				
1830-1930	1858	54	1890	37
1930-1987	Decline	Decline	1949	44
Treated ties (USA)	1923	26		
Track electrification (USSR)			1965	27
Replacement of steam locomotives	1950	12	1960	13

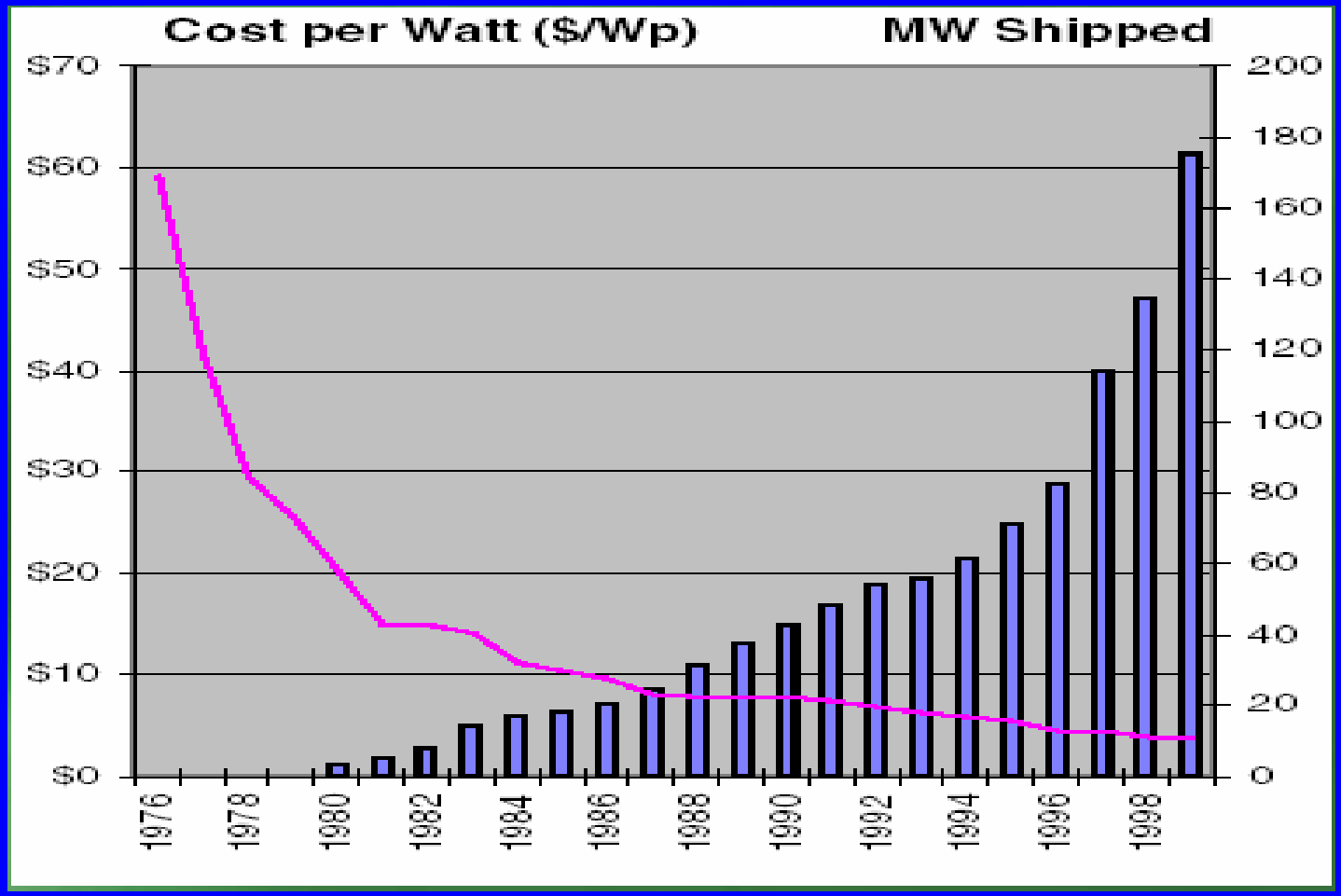
t_o = diffusion midpoint (50% completion rate)
Δt = diffusion rate (years to grow from 10% to 90%)

A. Grubler, 2003

Economics 101

A. Grubler, 2003

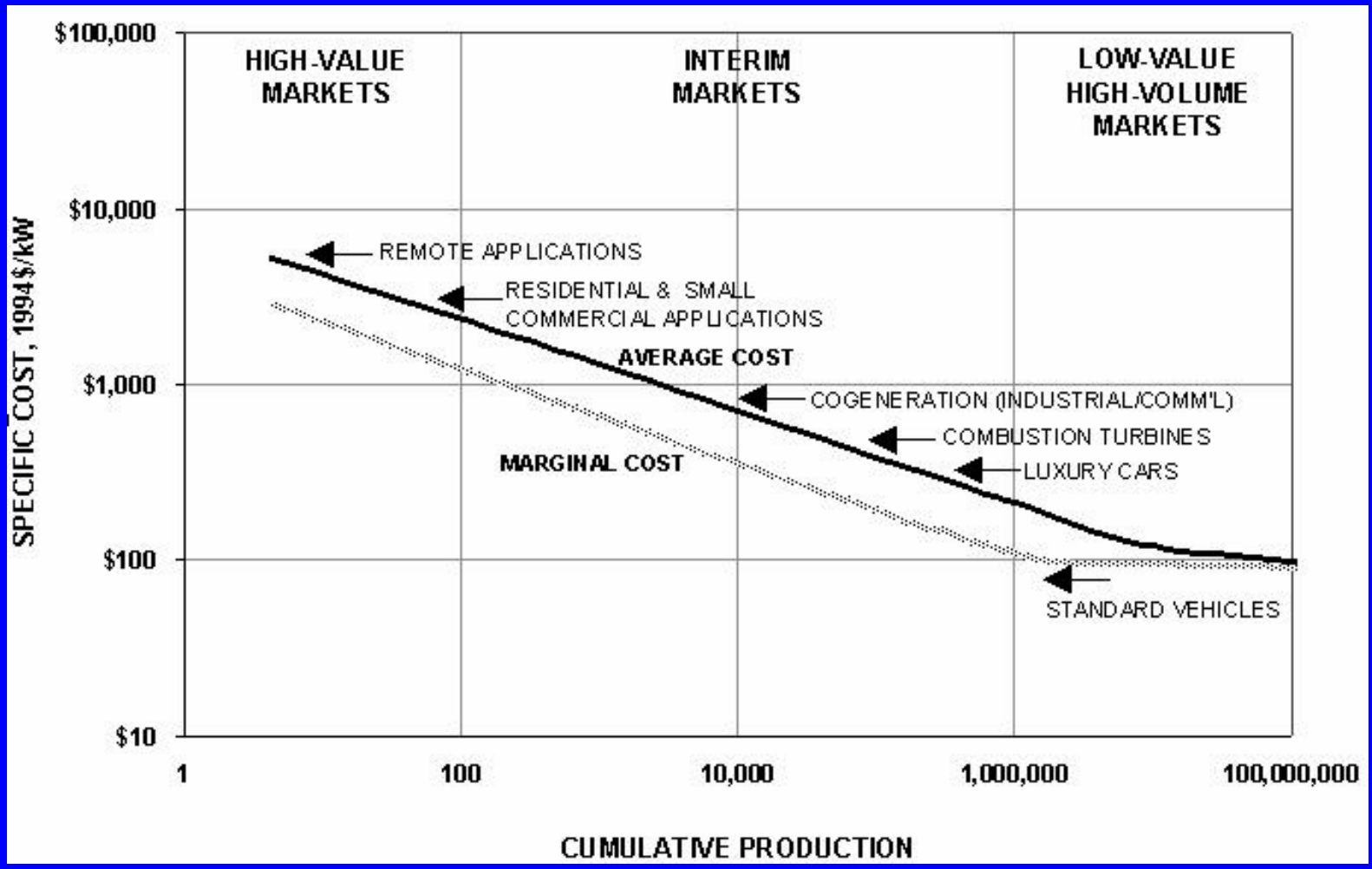
Basic Economics of PV Supply and Demand



Source: BP, 2003

A. Grubler, 2003

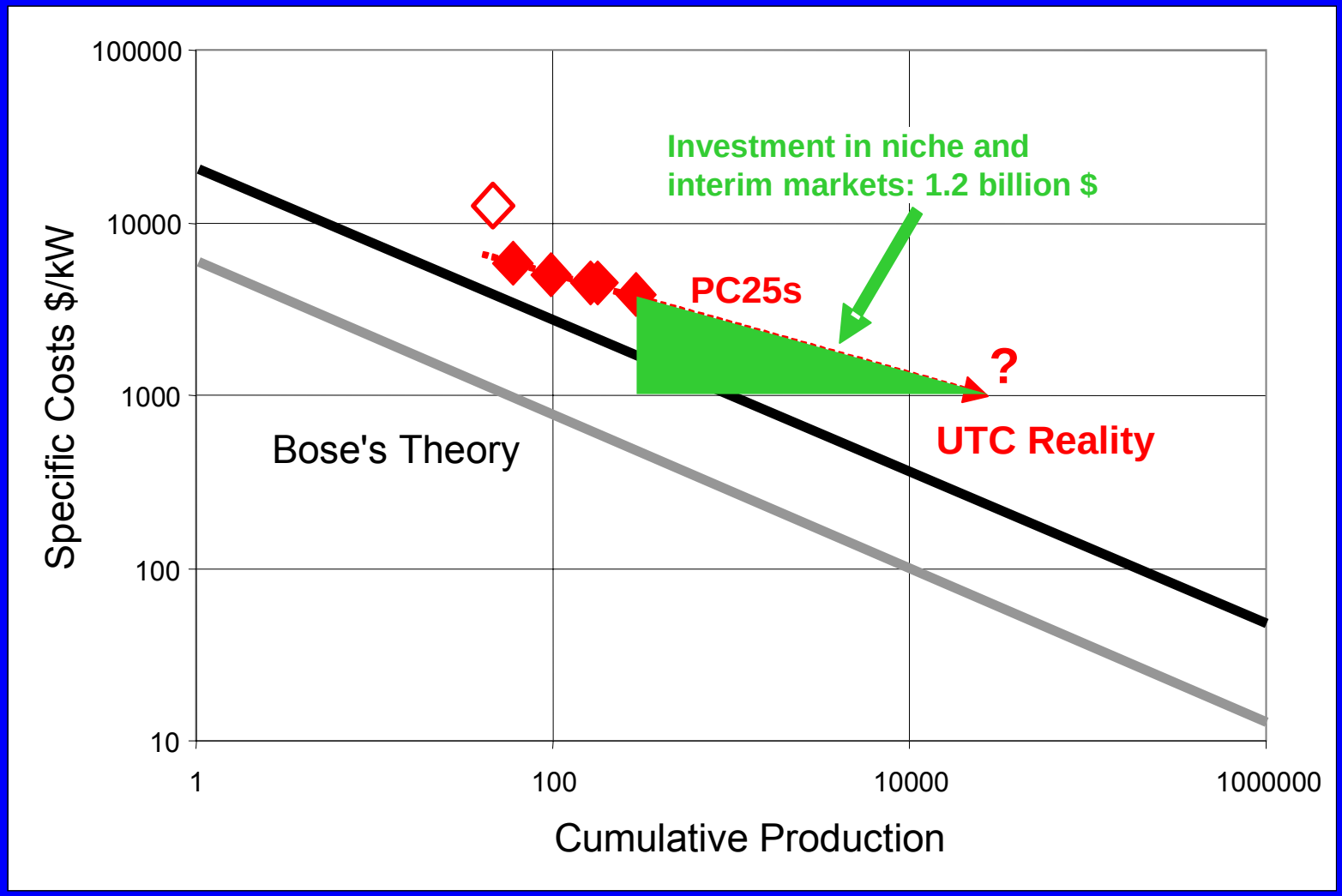
Fuel Cell Marketing Strategy: Successive Market Niches via Cost Reductions



Source: P. B. Bos, *Commercializing Fuel Cells – Managing Risks*,
Fourth Grove Fuel Cell Symposium, Commonwealth Institute London, September 19-22, 1995

A. Grubler, 2003

Theory vs Practice



A. Grubler, 2003

Innovation Challenges

A. Grubler, 2003

Innovation & Diffusion Uncertainty

- "*Heavier-than-air flying machines are impossible.*" Lord Kelvin, 1895.
- "*I think there is a world market for maybe five computers*." Tom Watson, IBM chair, 1943.
- "*But what … is it good for?*" IBM engineer commenting on the microchip in 1968.
- "*There is no need for any individual to have a computer in their home*." Ken Olson, President, Digital Equipment, 1977.
- More fun: http://my.athenet.net/~jlindsay/SkepticQuotes.html

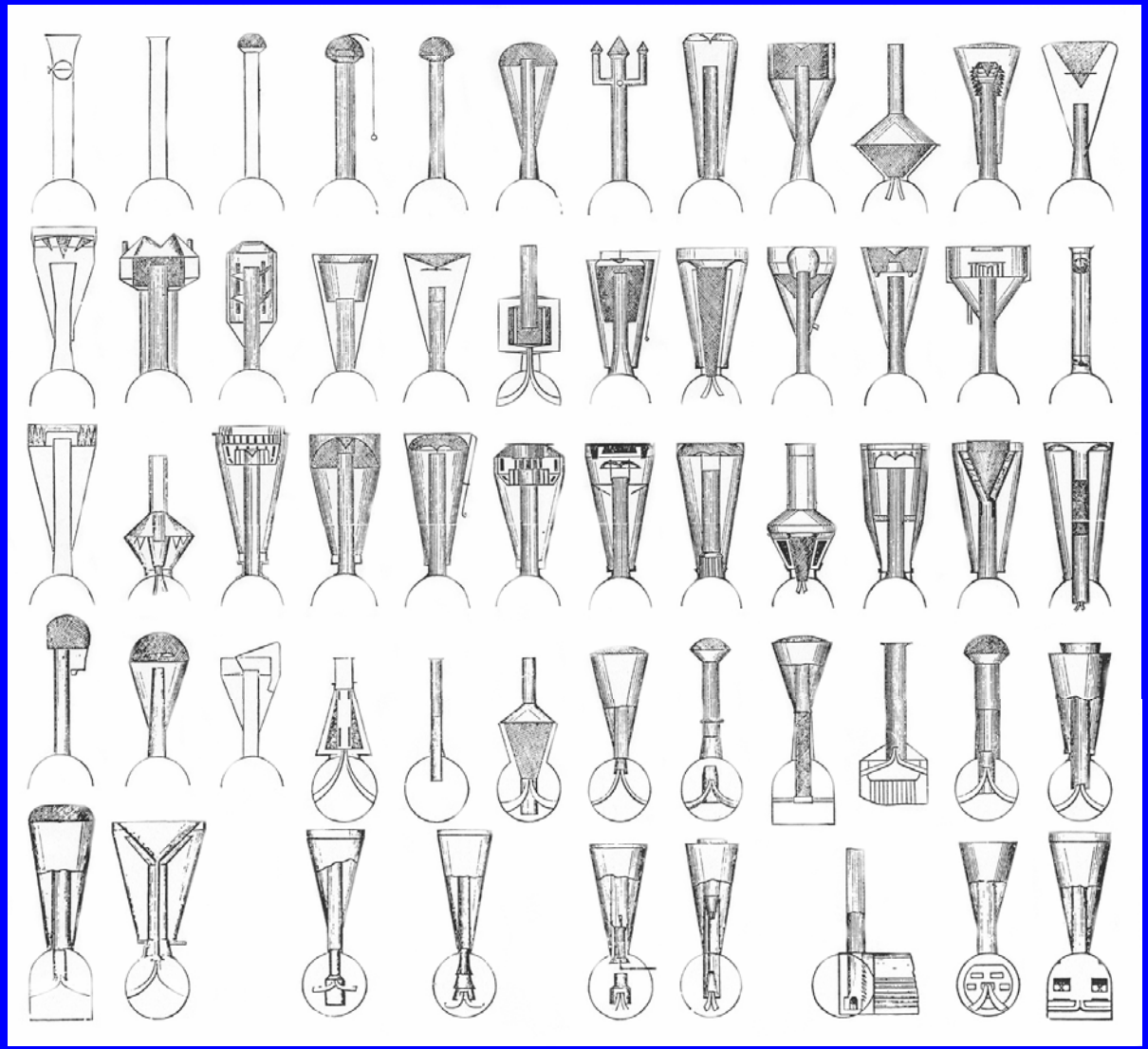
A. Grubler, 2003

Technological Uncertainties

- Invention → innovation (feasibility) +
- Standardized design
  AFC, MCFC, PAFC, PEMFC, SOFC,…. ?
- Increasing returns
  (if and how much cost reductions) ?
- Innovation "impatience"
  (the valley of death) ?
- Infrastructure needs --
- Diffusion environment
  (economic, institutional, social) ?
- Environment +/?

A. Grubler, 2003

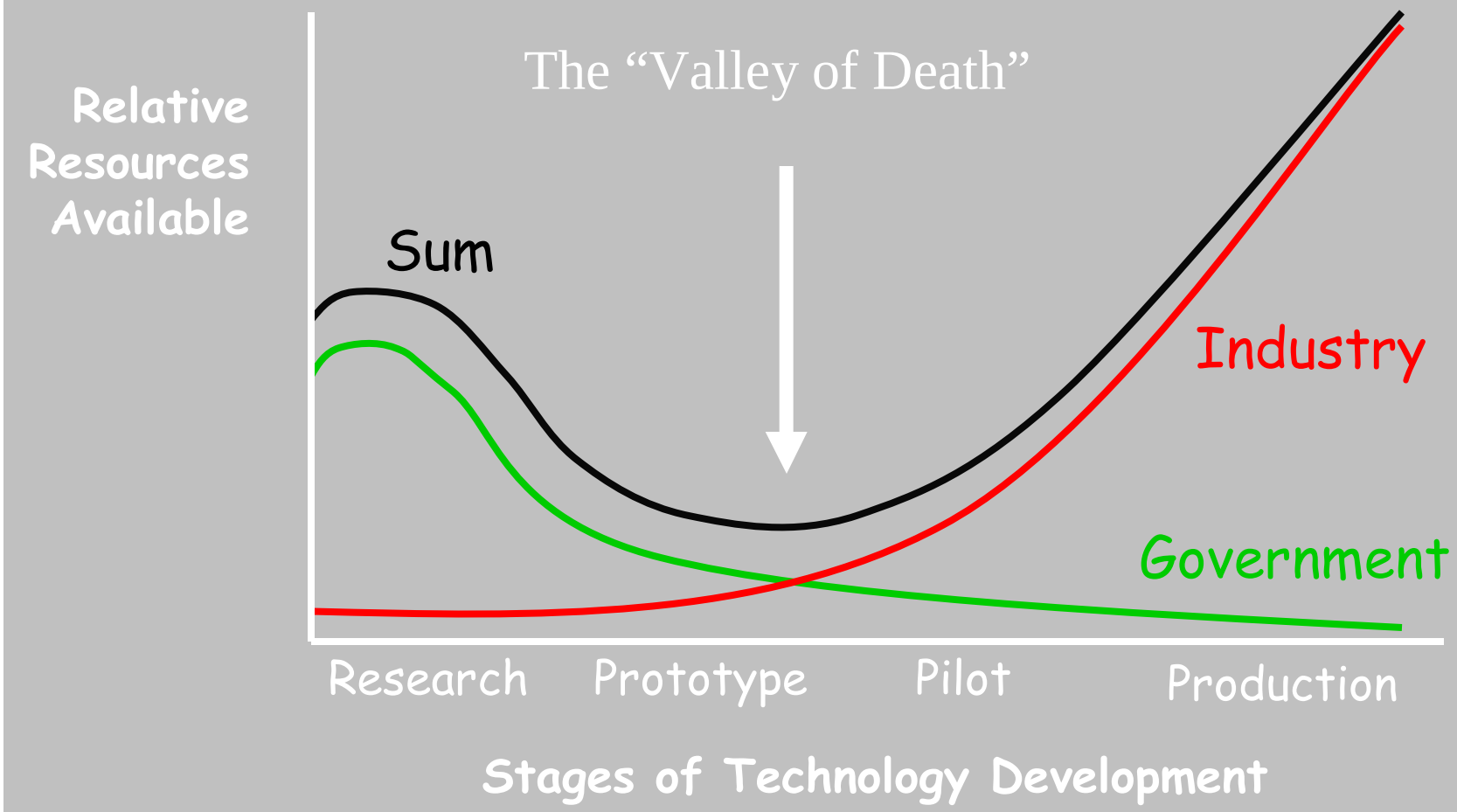
Technological Uncertainty:
Patented but non-functional smoke-spark arrestors



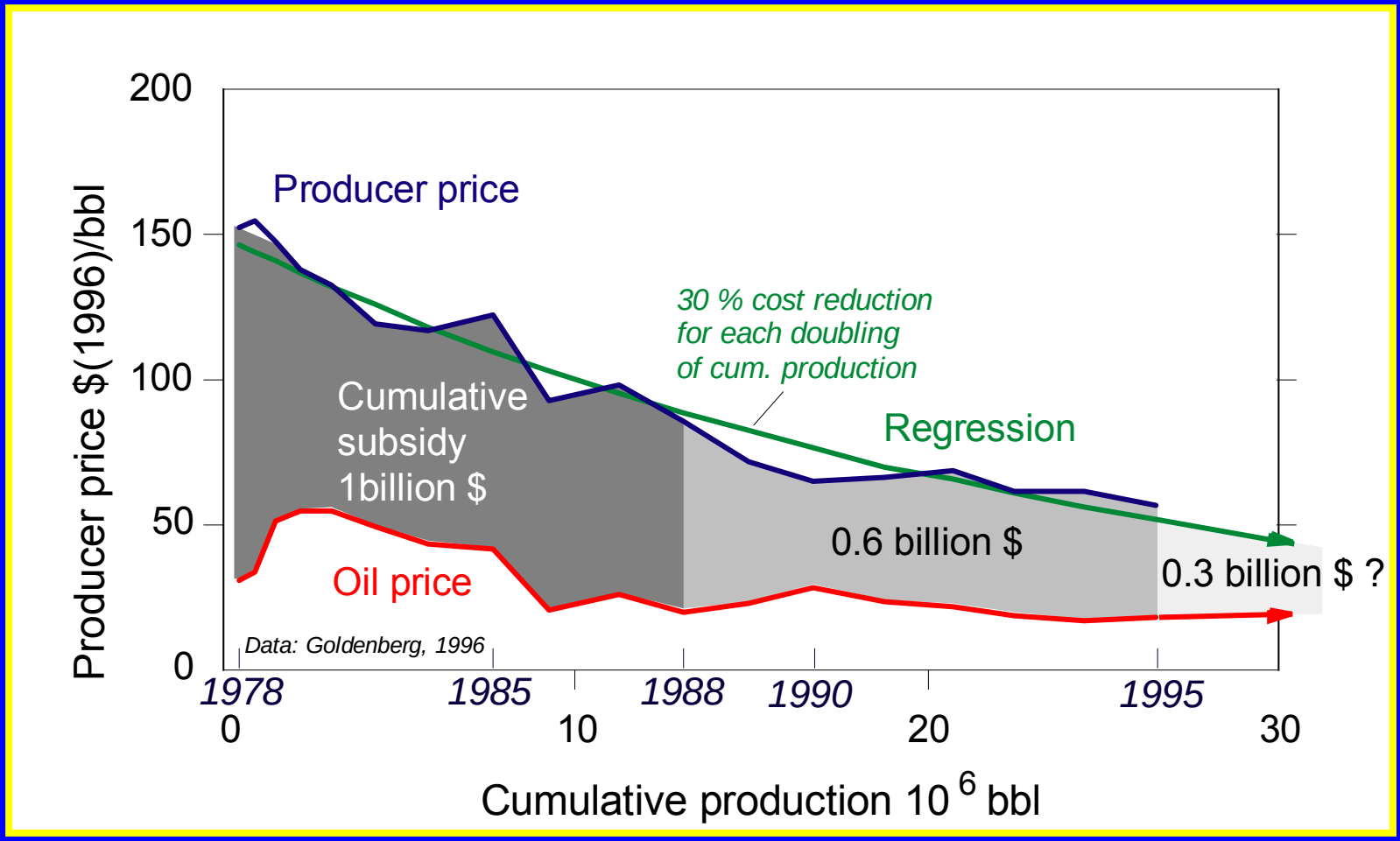
Source: J. White, *American Locomotives*, 1968.

Stages of Technology Development and the Resource Gap for Innovation

Source: M. Chertow, 2003

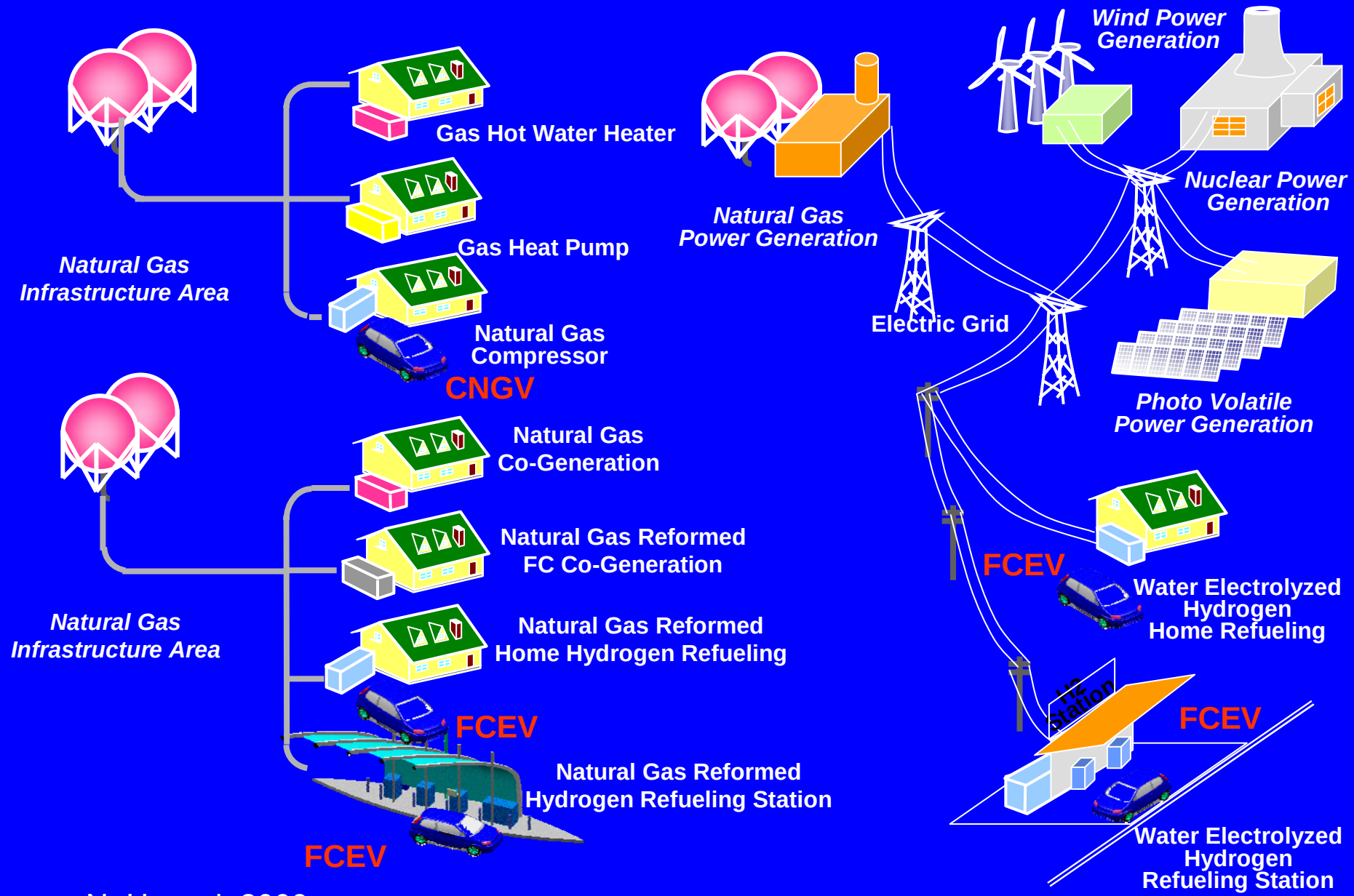


Brazil - Ethanol Learning Curve: "Hold your breath!"



A. Grubler, 2003

Infrastructure: Let 1000 Flowers Bloom?



Source: N. Uesuqi, 2003.

CH_4 vs H_2 – From Competition to Synergy

- Maximize use of existing and incremental infrastructure: gas pipelines, LNG terminals
- 21st century learns from 19th towngas (hythane) = CH_4+ H_2(10-30%)
- Separation at point of final use
- Critical technology: Membrane separation

A. Grubler, 2003

Social & Environmental Uncertainties

- Public acceptance: Perceived relative advantage is key:
  -- safety/reliability
  -- autonomy
  -- cleanliness
  -- economics
- Regulators : Running after the fact, or „precautionary principle“
- Leakage: Continuous risk assessment, but beware of early doomsdayers (that‘s how you get into *Science*)

A. Grubler, 2003

Conclusion

- Look at systems (and competitors) and don‘t dream of 1 technology „fits all“
- Supplyer-user interaction and systems integration critical for learning (avoid white elephants)
- Hierachies of change: expect long diffusion time (risk of innovation „impatience“)
- Biggest obstacles: uncertainty, and regulatory environment (e.g. lack of)
- Where to start: Find customers and develop H_2 „orgware“ (get ear of regulator)

A. Grubler, 2003