Understanding the Complexity of Technology Transitions

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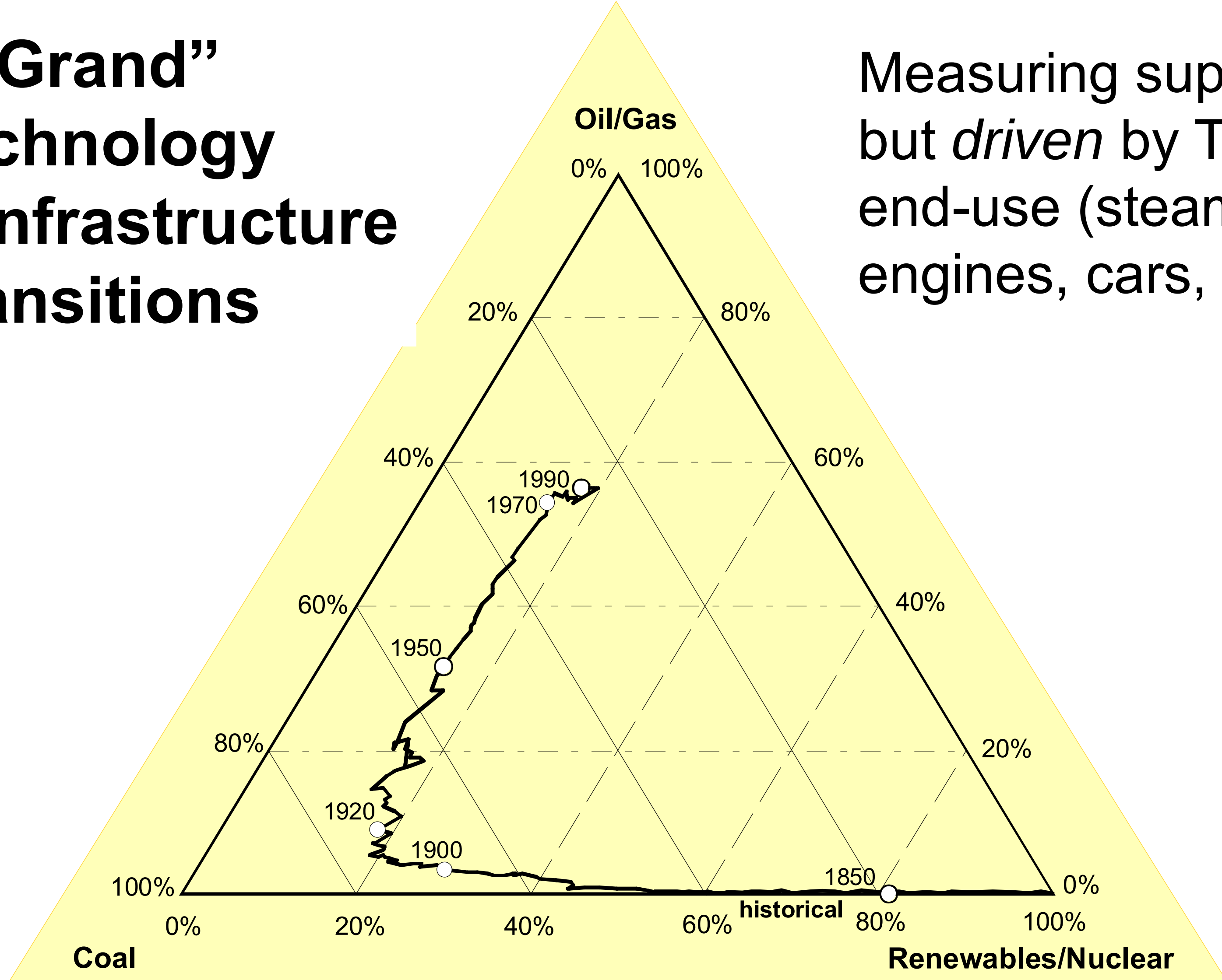
Main EnergyTransitions: A History of Technology

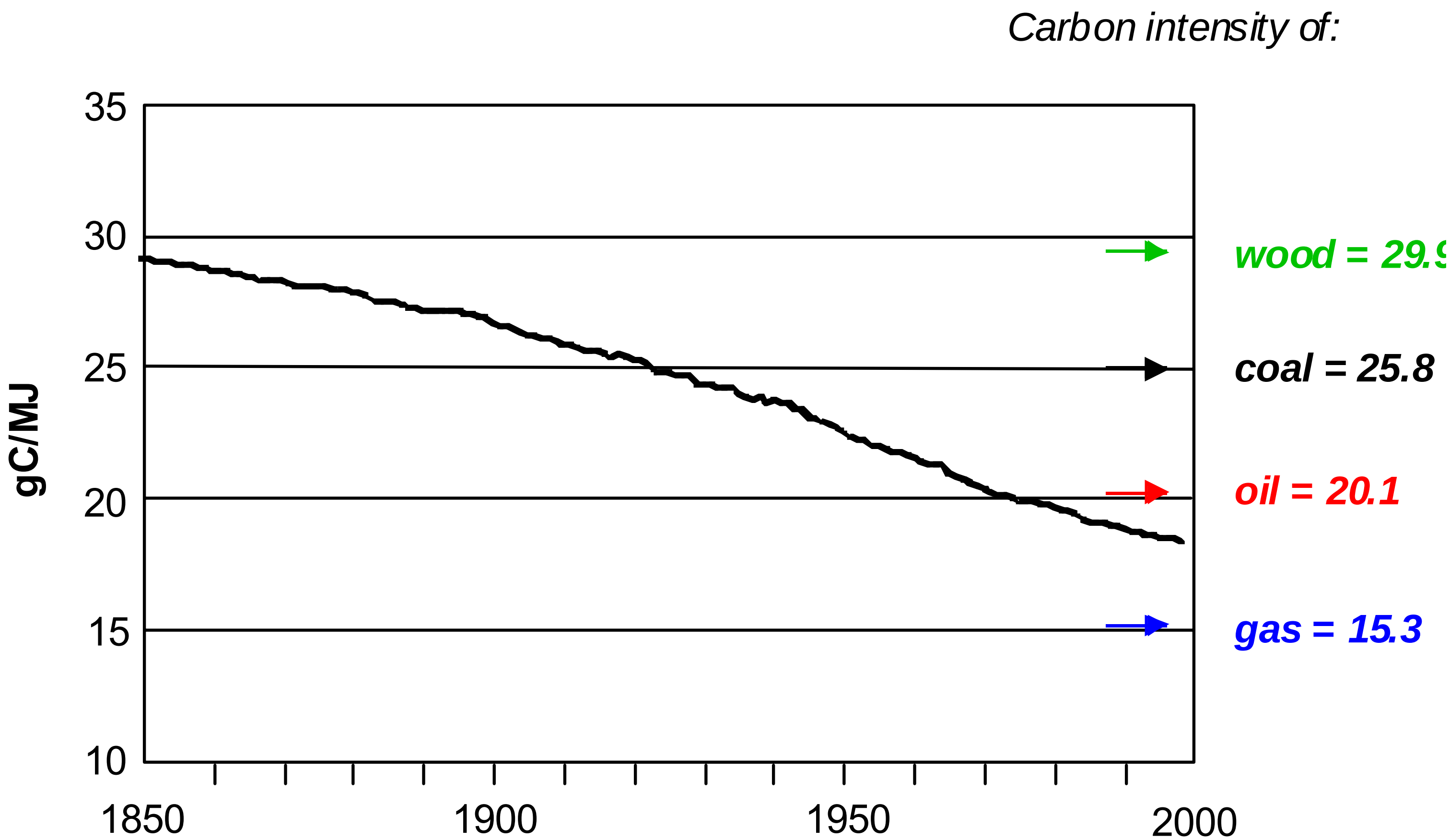
- Non-commercial → commercial
- Renewable → fossil →post-fossil?
- Rural → urban
- South → North → South
- Low exergy → higher exergy (H:C ratio↑)
- Improved efficiency/productivity
- Conversion deepening (e.g. electrification)
- Increasing supply/demand density
- Desulfurization, Decarbonization

2 “Grand” Technology & Infrastructure Transitions

Measuring supply, but *driven* by TC in end-use (steam engines, cars, aircraft..)



Decarbonization of Energy: Evolutionary Envelope of Multiple Transitions



Minds More Creative than Models

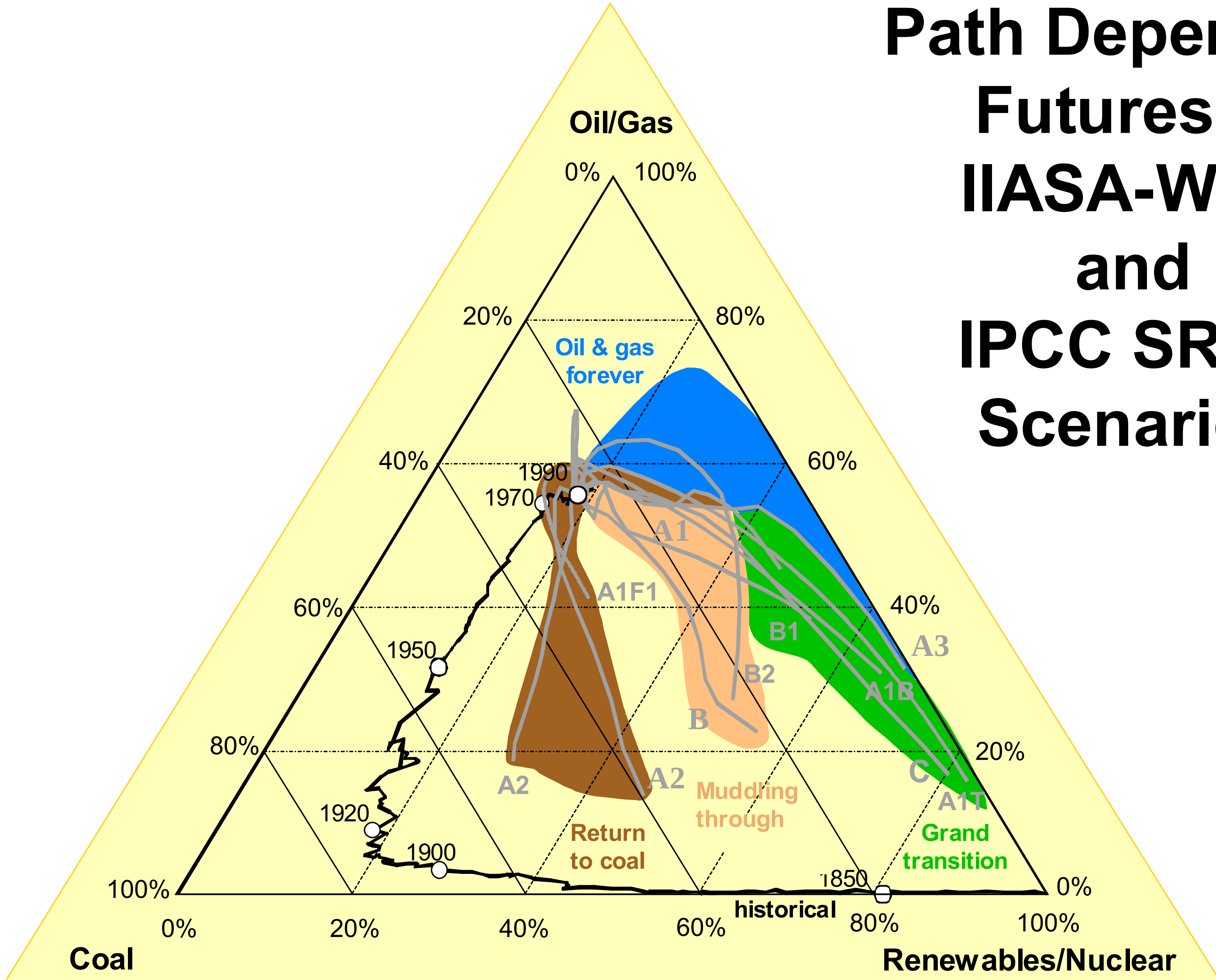
- Great Transitions (agriculture→industry; work→pleasure; renewable C→fossil C→ →hydrogen):
  few anticipated, yet fewer modeled
- Decarbonization research milestones:

  --Replicate past (Ausubel et al., 1988)

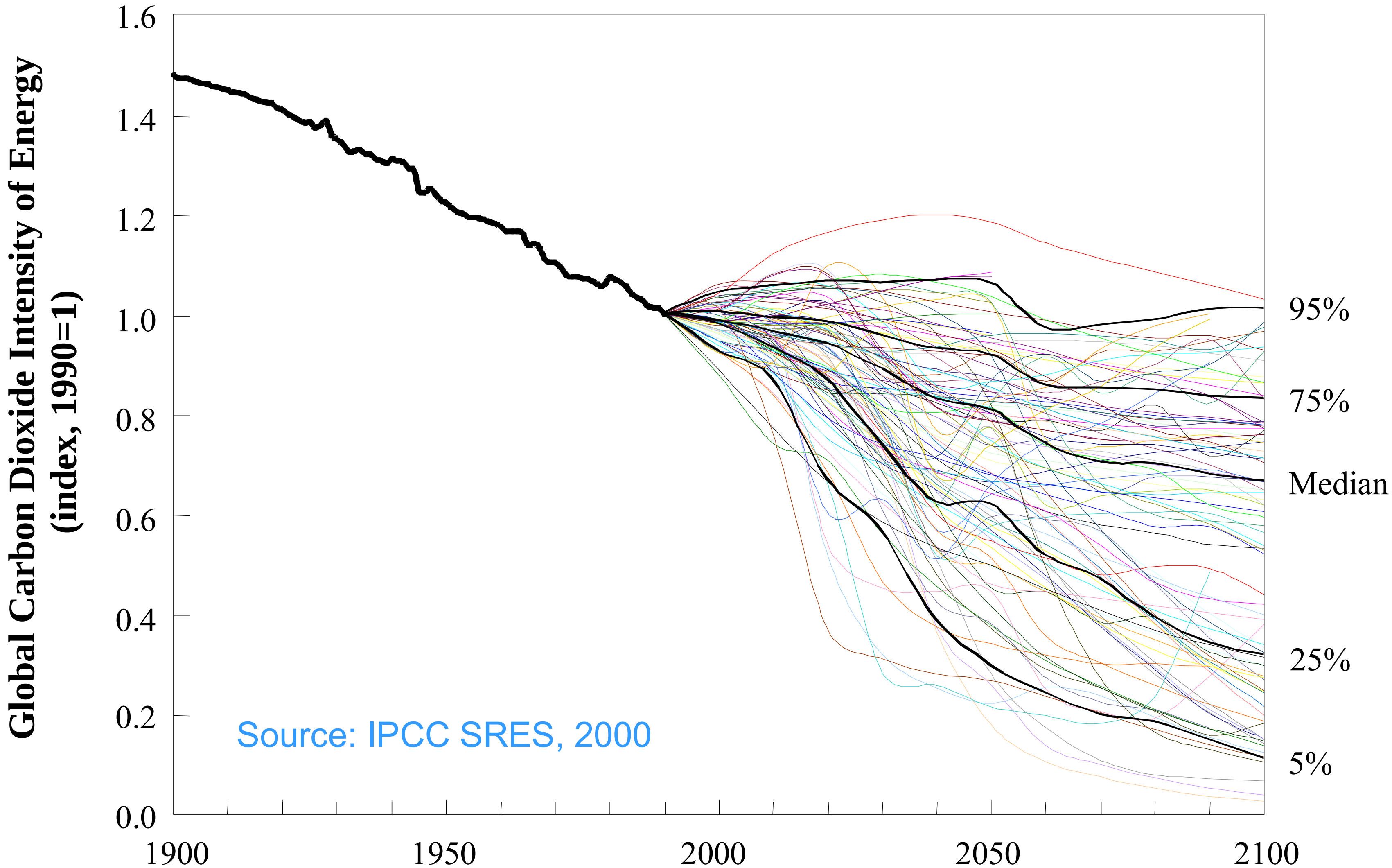
  --Design quantified normative futures (FFES, 1994)

  --Integration qualitative-quantitative transition scenarios (SRES, 2000)

Path Dependent Futures in IIASA-WEC and IPCC SRES Scenarios



Decarbonization Scenarios

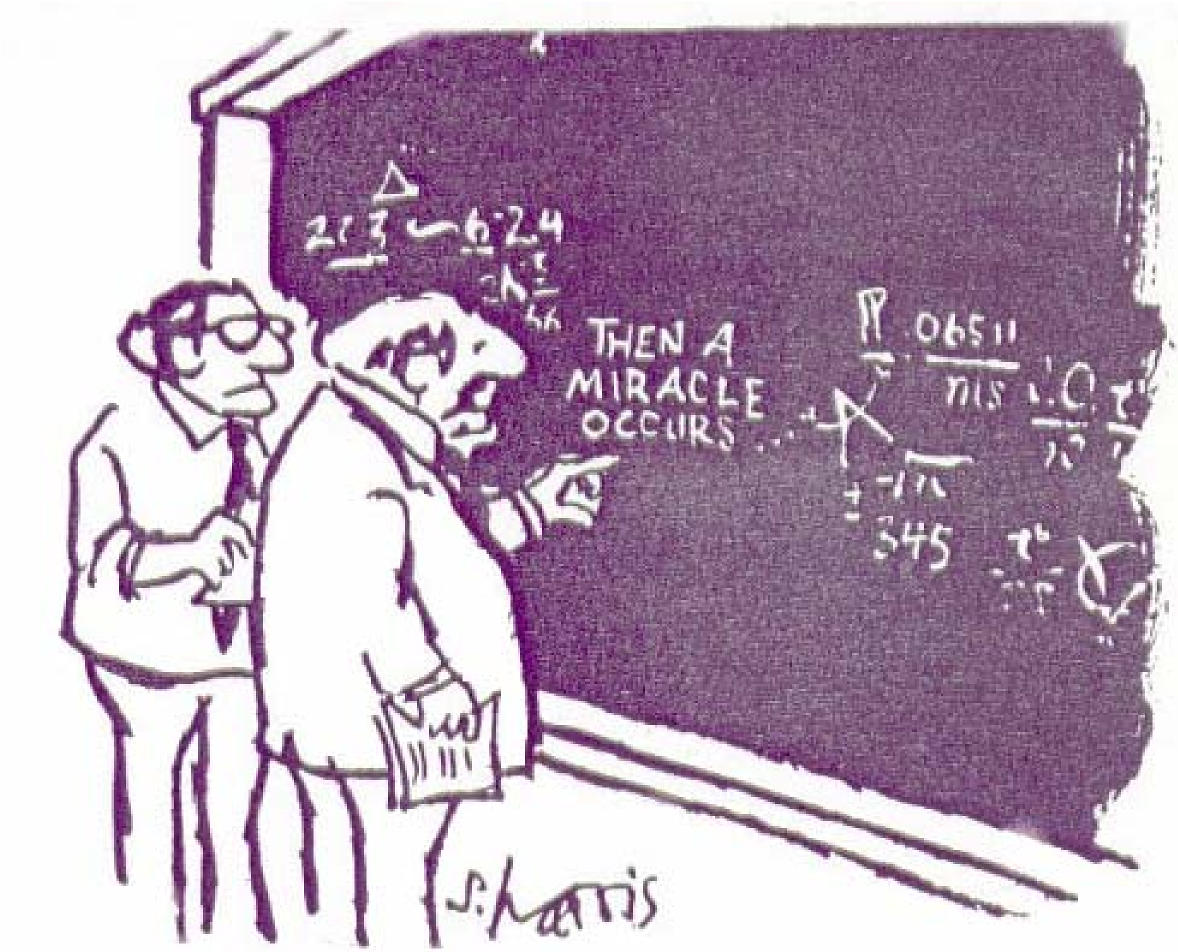


Modeling Difficulties

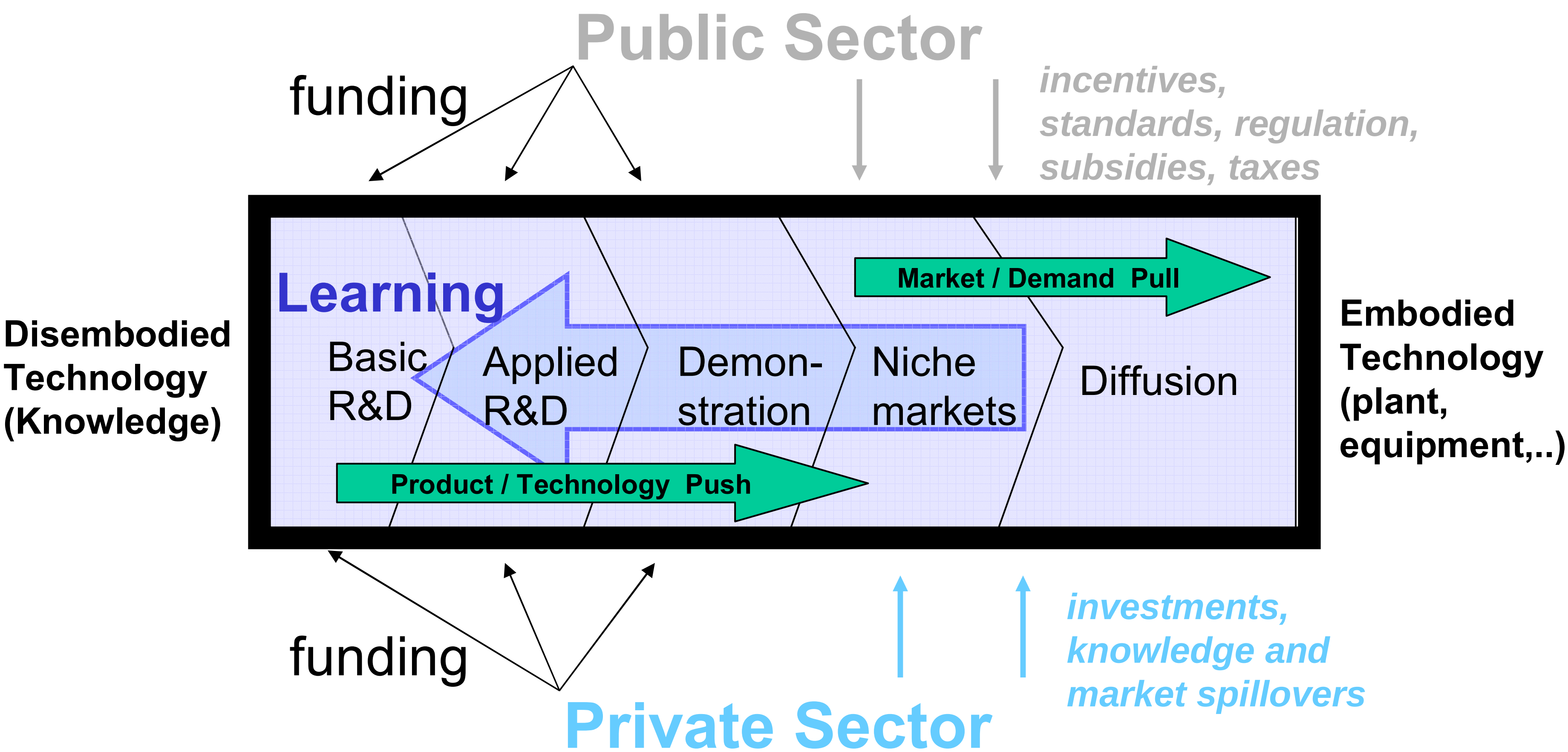
- Dominance of equilibrium (CGE, I-O)
- Chronic difficulties to capture structural change
- Ignorance of uncertainty and surprise
- Feedbacks ignored or underestimated
- Productivity growth as “manna from heaven”
- Technology: treated as exogenous

Σ: Dominance of “dumb farmer” or “business-as-usual” scenarios

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



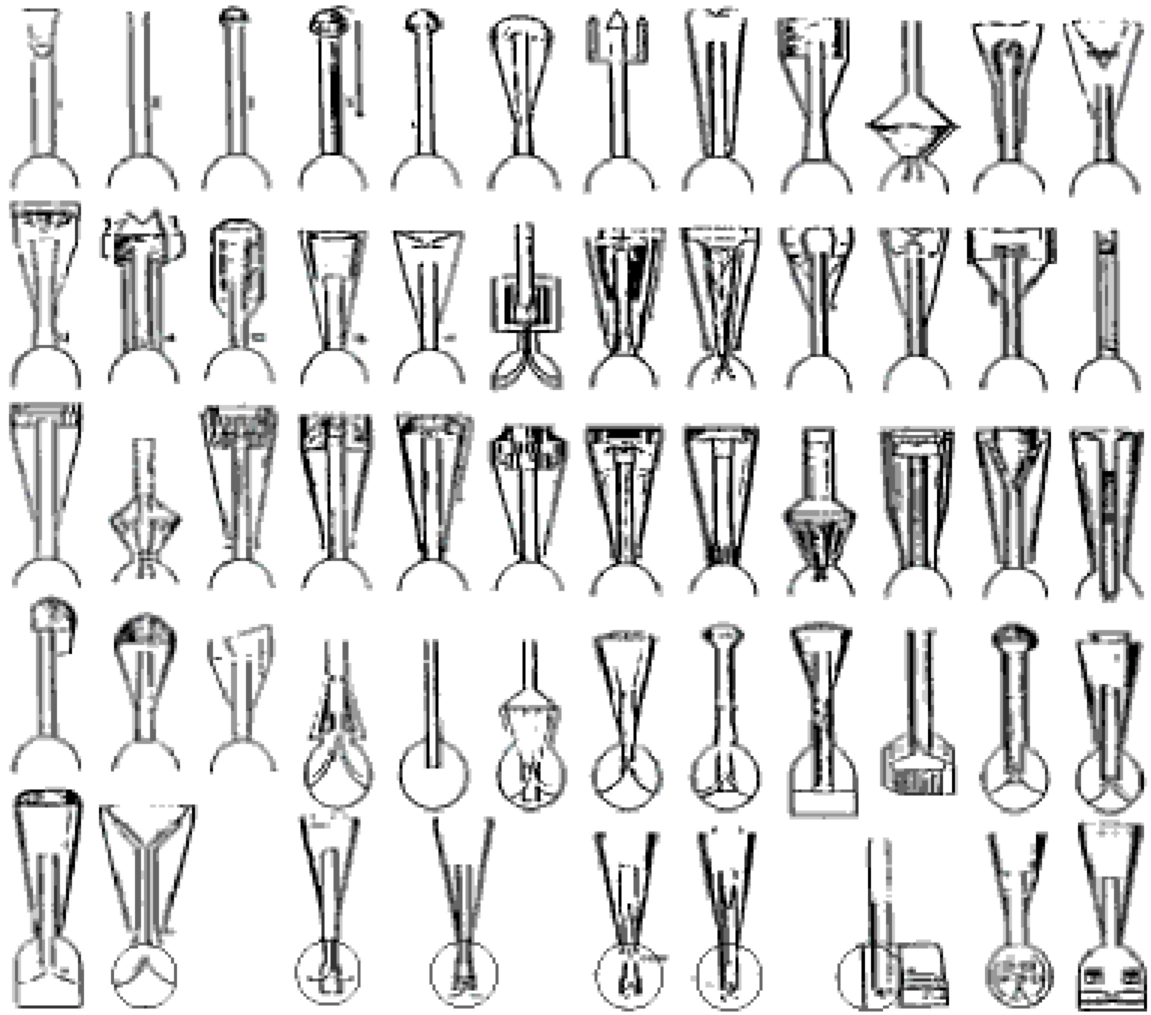
The "black box" of Technology: Stages, Actors, Feedbacks



Technological Uncertainties
(modeled at IIASA)

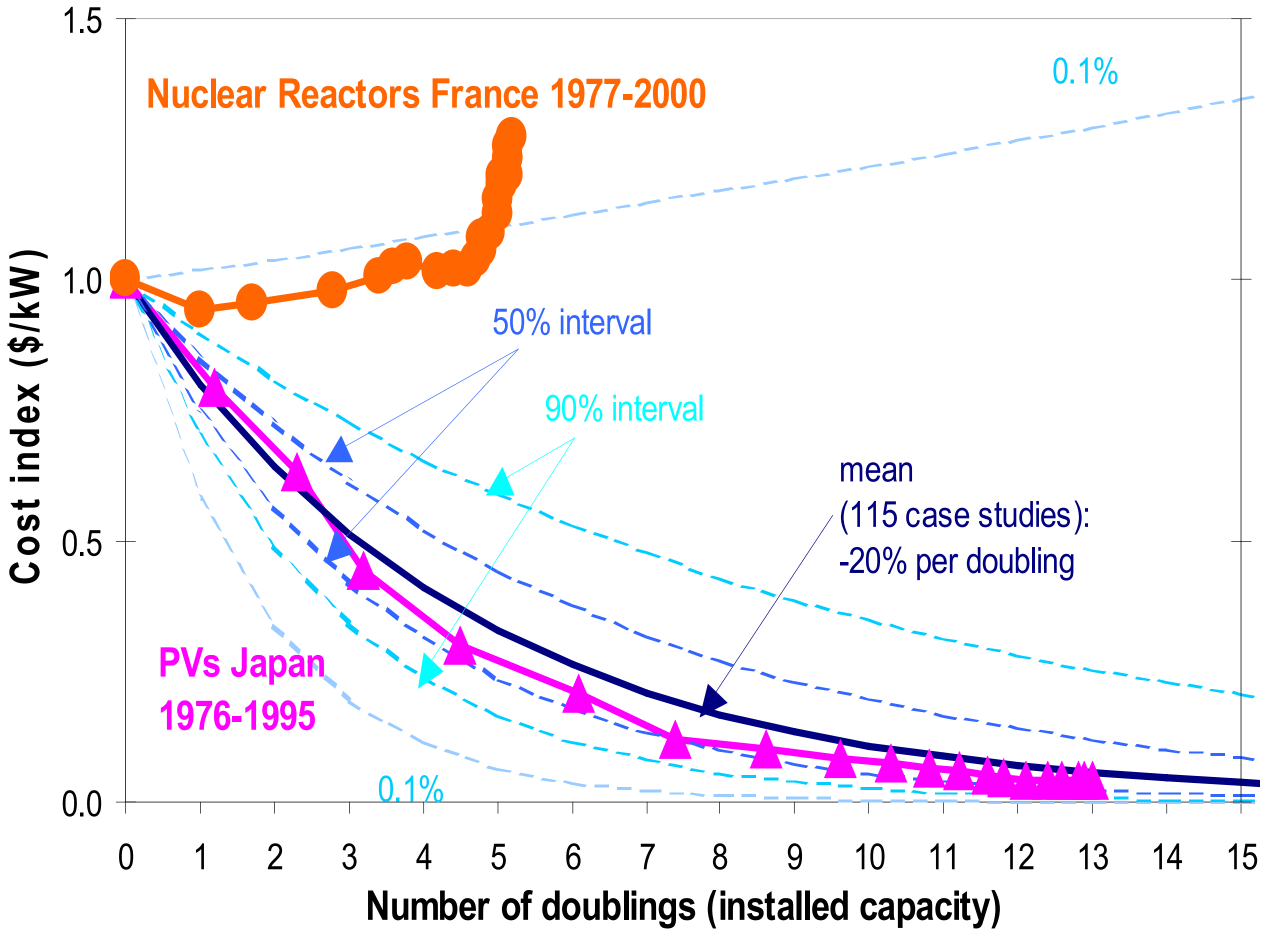
- Innovation feasibility
- Existence of increasing returns to adoption
- Diffusion environment (demand growth, capital stock turnover)
- Complementary technologies and infrastructures
- Innovation and adoption policy support

Technological Uncertainty 1:
Patented but non-functional smoke-spark arrestors



Basalla, 1988.

Technological Uncertainties 2:
Technology cost declines (push) and market growth (pull)



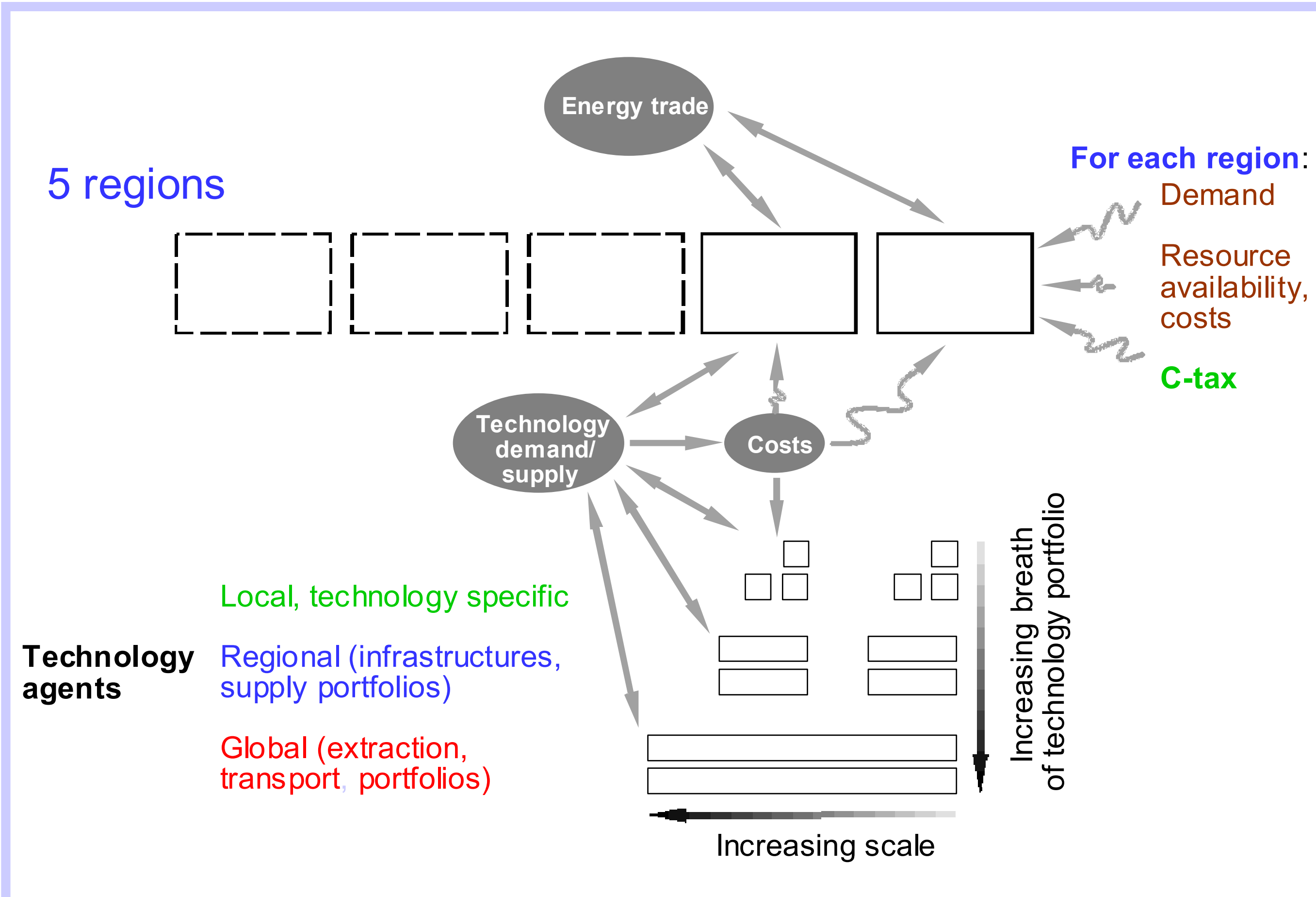
Induced Technological Change

- Inducement 1: Knowledge (generation, spillovers, trade)
- Inducement factor 2: Diffusion environment (economic, social, regulatory)

Uncertainty 1: outcomes of R&D and investment strategies ("learning")

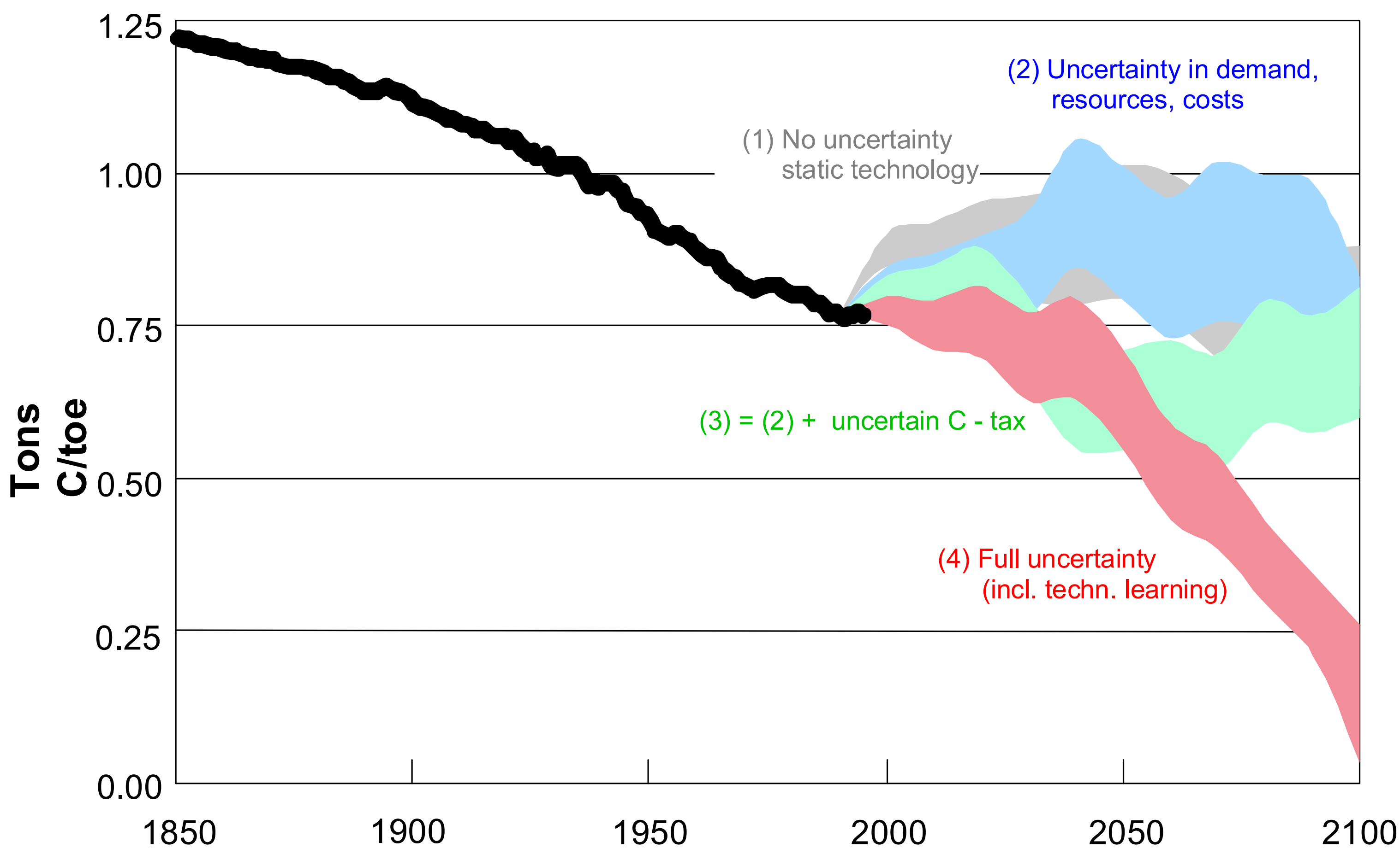
Uncertainty 2: market environment incl. demand, environmental and social constraints, etc.

A Simple Multi-agent Model



Model actors and their interactions. Zagged lines= stochastic variables

Global Decarbonization – History and Future in 4 Models of Increasing Treatment of Uncertainty



Summary of IIASA Modeling

Endogenous technological change through anticipation of (uncertain) increasing returns

Multi-agent, spatial heterogeneous change

First policy variables included (e.g. taxes)

Great Technology Transition:
Continued decarbonization only under full uncertainty model

But: Many more driving forces
of "humbling complexity"

Technology Transitions: What have we learned?

- Importance of: uncertainty, increasing returns, path dependency, heterogeneity
- Policy implications:
  -- **more** innovation not less
  -- **earlier** experimentation not later
  -- **smaller** rather than "lumpy" investments
  -- supply demand **integration**
  (R&D and deployment incentives)
  -- importance of **spillovers**
  (across technologies, regions)
- risk hedging via **portfolios**

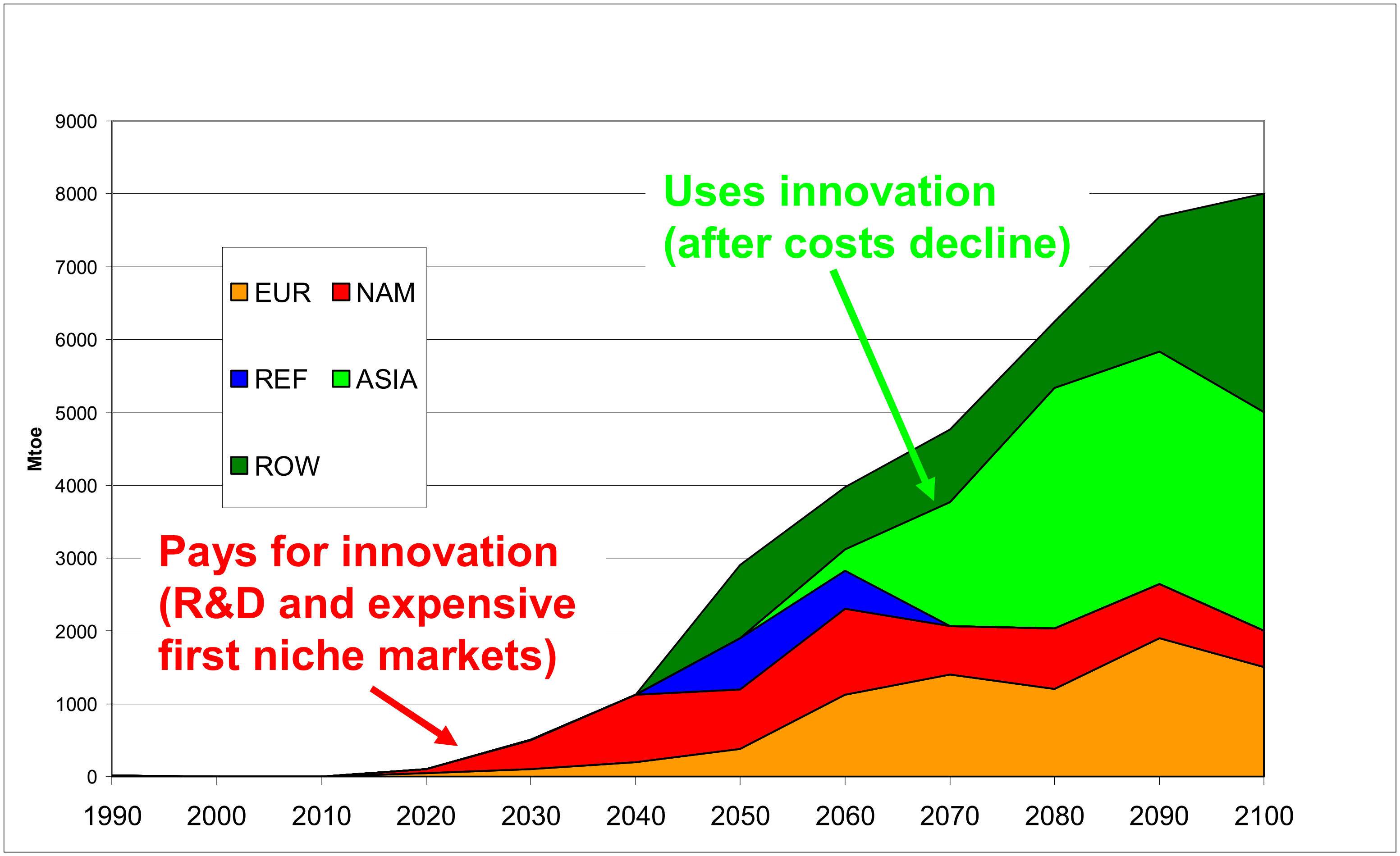
Remaining Challenges

- Technology spillovers across sectors
- Proliferation of scenarios
(even with optimal hedging strategies)
- Computational limits for simultaneous treatment of full technological uncertainty
and multiple agents
- Treatment of myopic behavior
- Representation of barriers to change
(institutions, politics)
- Social embedding: Resistance,
feedbacks ("take back" effects),
behavioral "surprises" (e.g. SUVs)

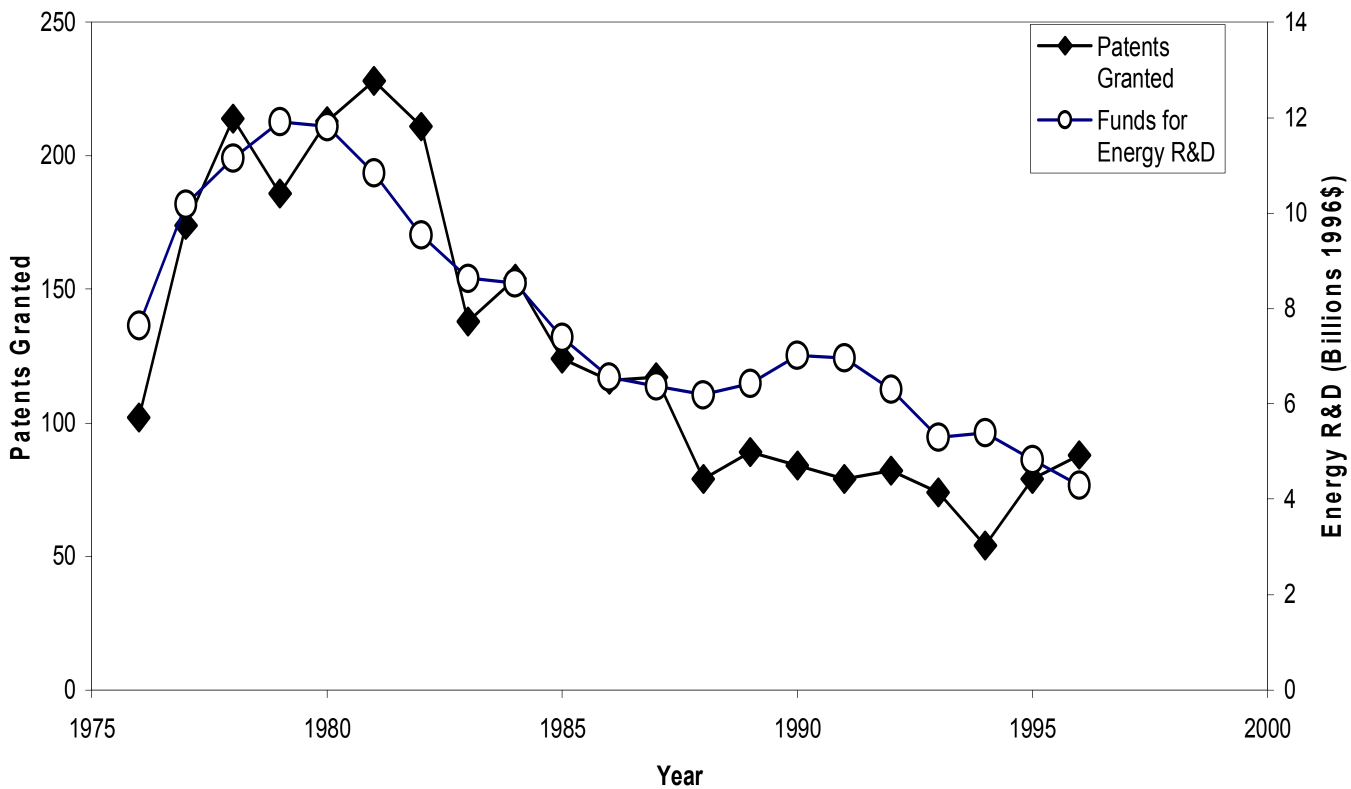
3 Challenges Models Provide no Answer (yet)

- Dealing with social “push (away)” (e.g. nuclear) and “pull” factors (e.g. cell-phones)
- Reconciling long-term technology needs with short-term disincentives (declining R&D, privatization “myopia”)
- “value of innovation” and “optimal risk hedging” technology portfolios now exist, but no actors to implement them to overcome innovation cost-benefit externality

Optimal Diffusion of Fuel Cells
Under Full Technological Uncertainty (Δt = 50 yrs)



"Needing More Technology not Less" vs. US - Decline in Energy R&D and Innovation



Source: Kammen and Nemet, 2005.