

# INDUCING *TRANSFORMATIONAL ENERGY* TECHNOLOGICAL CHANGE: Some Non-traditional Perspectives

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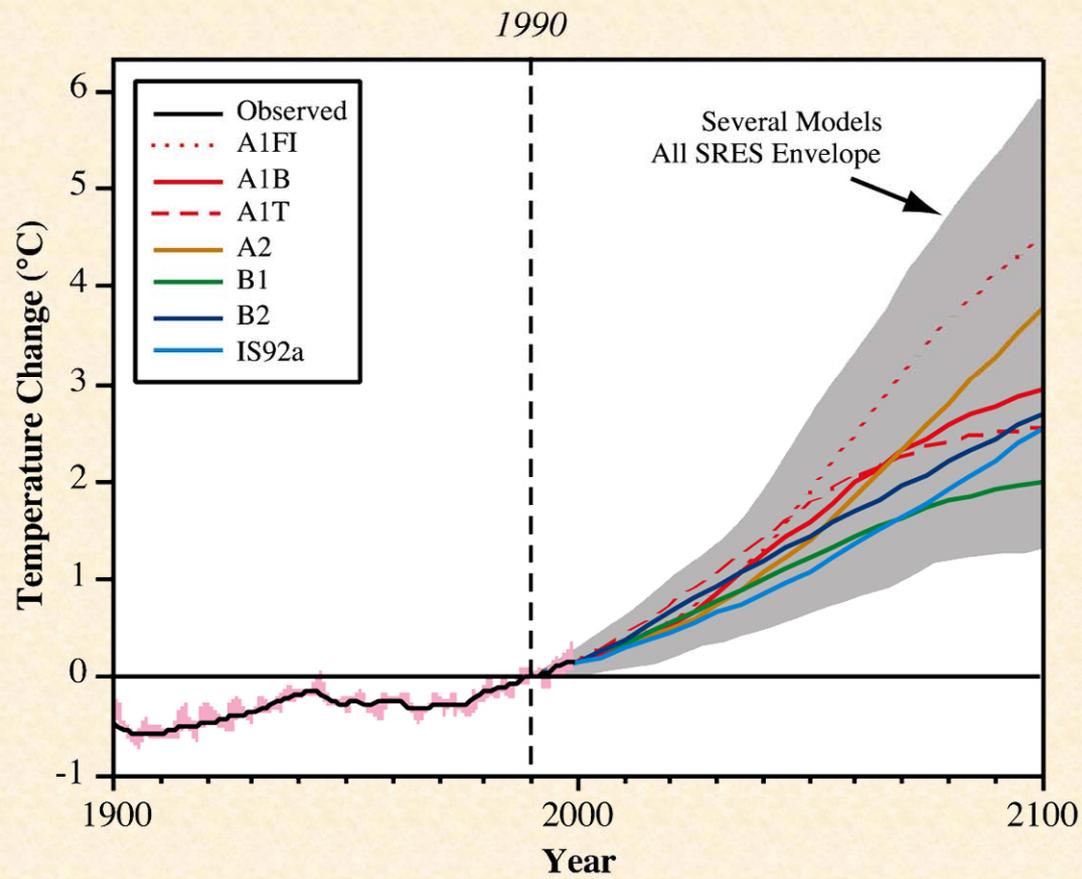
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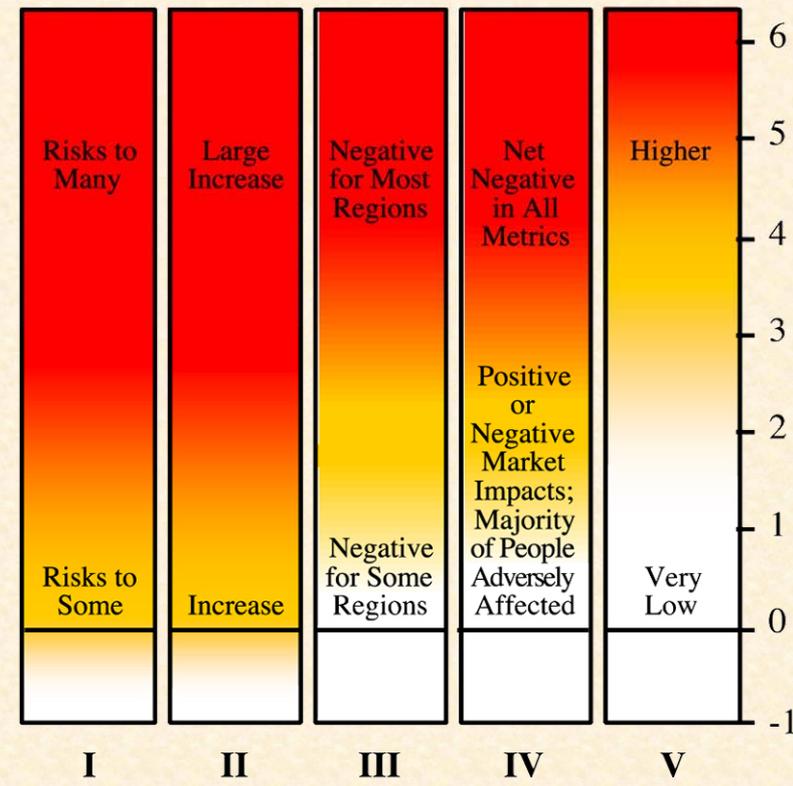


# Studies of Technological Change Have Always Included Two Elements:

- **How transformational innovations occur**
- **How those innovations, once discovered, get developed and deployed**
- **Attention to inducing development and deployment, as important as they are, does not necessarily answer questions about inducing discovery**



*Reasons for Concern*

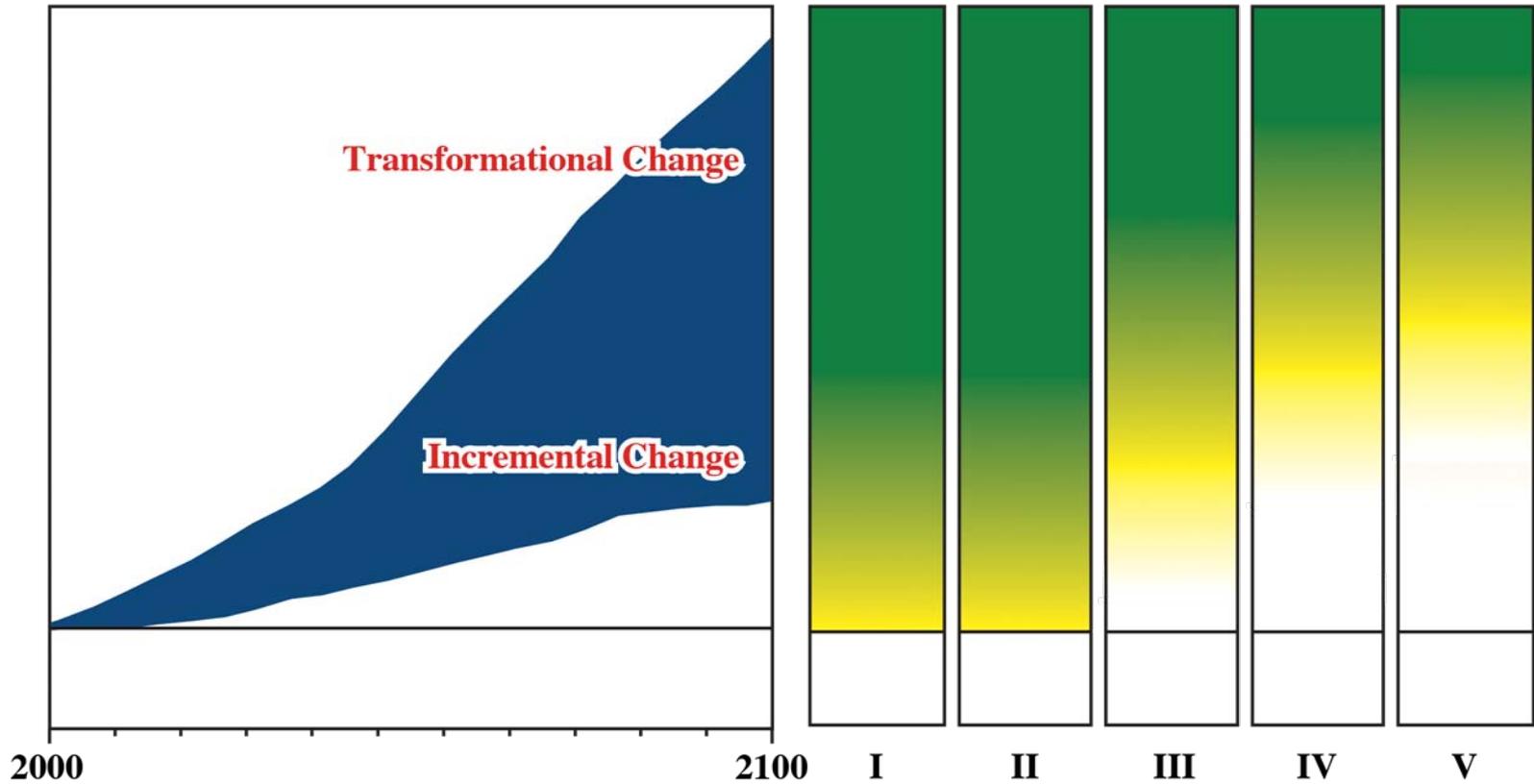


- I Risks to Unique and Threatened Systems
- II Risks from Extreme Climate Events
- III Distribution of Impacts
- IV Aggregate Impacts
- V Risks from Future Large-Scale Discontinuities

# TECHNOLOGICAL CHANGE AND ENERGY/ENVIRONMENTAL SECURITY

## Technological Change

## Potential Benefits



# Some Definitions of Terms:

- **Incremental change: changes resulting from science- and engineering-based improvements in known science and technology**
  - Improvements in the efficiency of heat pumps
  - Improvements in vehicle fuel economy
  - IGCC
- **Transformational change: changes resulting from new scientific discoveries**
  - Electricity, vehicles powered by liquid hydrocarbon fuels,  $E=mc^2$
  - Near ambient-temperature superconductivity
  - Truly novel ways to get energy from biology
- **Straddling the boundary: changes based on known technologies but requiring scientific discoveries for market penetration**
  - New concepts for energy (e.g., electricity, hydrogen) storage
  - Affordable carbon capture and sequestration

# The Case for Considering that Transformational Technological Change Is Essential (or at Least Very Highly Desirable):

- **Energy futures as an aggregation of wedges: what if the wedges are unlikely to add up to a solution (e.g., Hoffert et al.)?**
- **Limitations of current options are especially problematic if energy services to the world are to be increased by several orders of magnitude**
- **A further set of pressures could emerge from discoveries about oil peaking**
- **Meanwhile, it appears that the benefit-cost ratio for a low-cost technological breakthrough is strikingly attractive**

# Estimated Benefit-Cost Ratio for Alternative Climate Policy Options (*Nordhaus, 2008*):

- **Optimal** 2.4
- **Concentration limits** 0.5 - 2.4
- **Temperature limits** 0.5 - 2.1
- **Kyoto Protocol** 1.1 - 5.0
- **Stern Review** 0.5
- **Gore proposal** 0.4
- **Low-cost technological backstop** 39.9

# A Particular Concern Is the Time Lag between Changes in Greenhouse Gas Emissions and Changes in Atmospheric Concentrations, e.g.: (I)

- **According to global climate models, the climate of 2080 will be substantially determined by emissions up to 2030**
- **Significantly changing emissions by 2030 would require truly major changes in technology portfolios for energy production and use between now and then:**
  - **Major increases in the deployment of current technologies: e.g., nuclear or solar energy – sufficient?**
  - **Development and market penetration of new, “transformational” technologies: e.g., carbon capture and sequestration (or more novel breakthroughs)?**

# **A Particular Concern Is the Time Lag between Changes in Greenhouse Gas Emissions and Changes in Atmospheric Concentrations, e.g.: (II)**

- **From time of development, a new technology typically takes 25 years or more to penetrate the market...**
- **Even in an optimistic case, new transformational breakthroughs might be needed by 2015 to make a big difference by 2030**
- **So: how might it be possible to induce an increase in the likelihood of such breakthroughs in the next decade or so?**

# If There Are Reasons to Consider Accelerating Transformational Energy Technological Change, What Approaches Have Promise in Making That Happen?

- **Technological change induced through market forces**
  - Known to accelerate incremental technological change
  - Known to be susceptible to huge government mission investments: Manhattan Project, Apollo Mission to the Moon
  - Effects on the pace of scientific discovery less clear: e.g., recent analyses of payoffs from investments in relatively basic research -- discount rates? attribution?
- **Alternative (or complementary) views of drivers of scientific discovery:**
  - Discovery is embedded in historical forces
  - Discovery is a matter of serendipity
  - Discovery is induced by stimulating and exchanging knowledge

# Regarding Historical Forces, Are There “Long Waves” of Innovation and, If So, Where Do We Stand? (I):

- **The basic argument:** the world economy shows regular cycles, 50-60 years in length (“Kondratiev waves”), that are linked to invention/innovation cycles grounded in logistic curves of learning, with periods of structural discontinuity toward the end of the wave stimulating technoeconomic restructuring
- **Examples of sources (most late 70s - early 90s) I:**
  - C. Marchetti and N. Nakicenovic, *The Dynamics of Energy Systems and the Logistic Substitution Model*, IIASA, 1979.
  - C. Marchetti, “Society as a Learning System,” *Technological Forecasting and Social Change*, 1980.
  - A. Gruebler and N. Nakicenovic, “Long Waves, Technology Diffusion, and Substitution,” *Review*, 1991 (1989).

# Regarding Historical Forces, Are There “Long Waves” of Innovation and, If So, Where Do We Stand? (II):

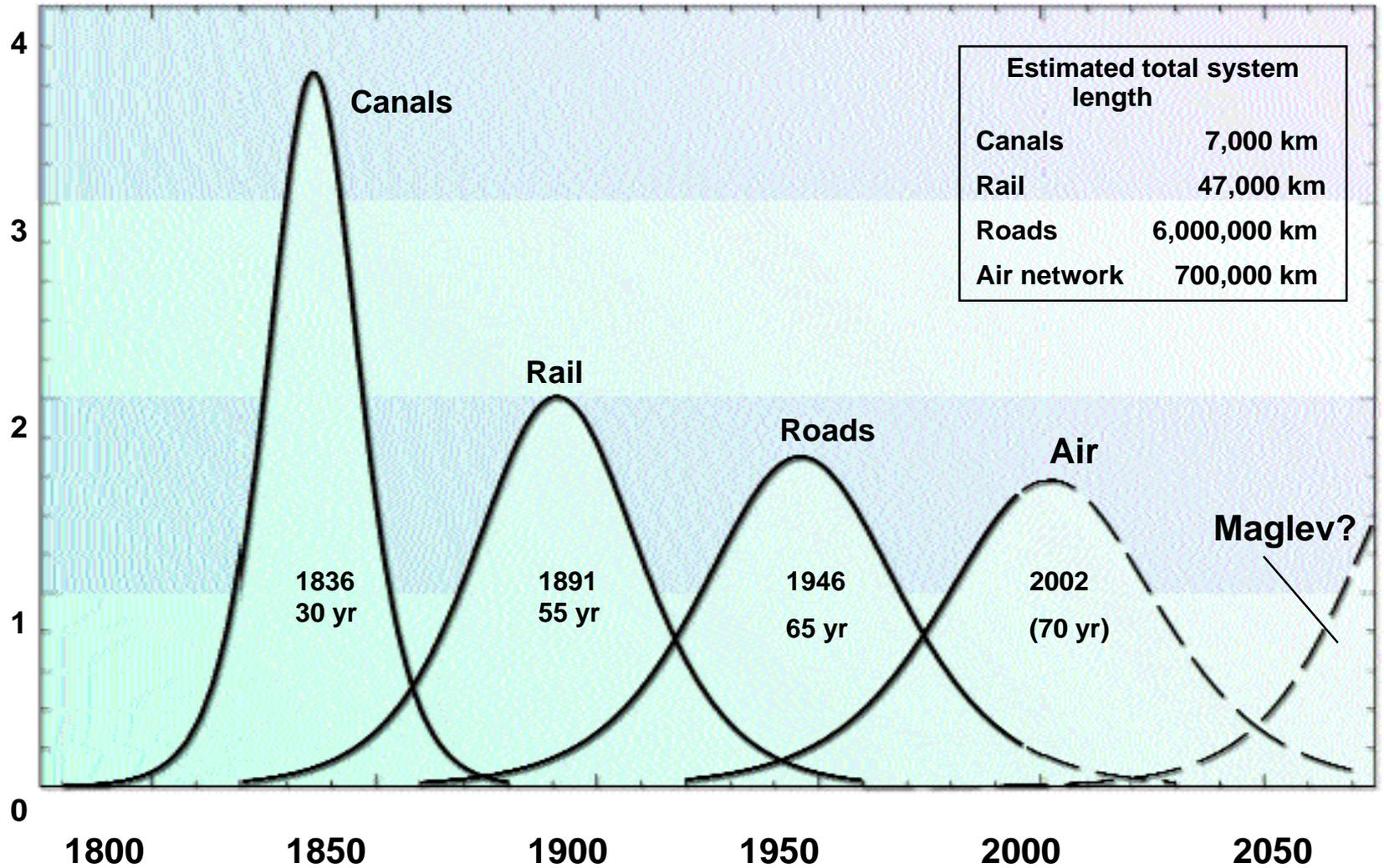
- **Examples of sources (most late 70s - early 90s) II:**
  - **B. Berry, *Long-Wave Rhythms in Economic Development and Political Behavior*, 1991.**
  - **A. Gruebler, *The Rise and Fall of Infrastructure*, 1992.**
  - **C. Freeman, ed., *Long Wave Theory*, 1996.**
- **If long waves are a driving force, where are we now?**
  - **No universal agreement about the start or end of particular cycles**
  - **At least two views of current economic long waves:**
    - **Most recent wave started about 1981: new wave in early 2030s**
    - **Most recent wave started in 1949: new wave starting any time now...**

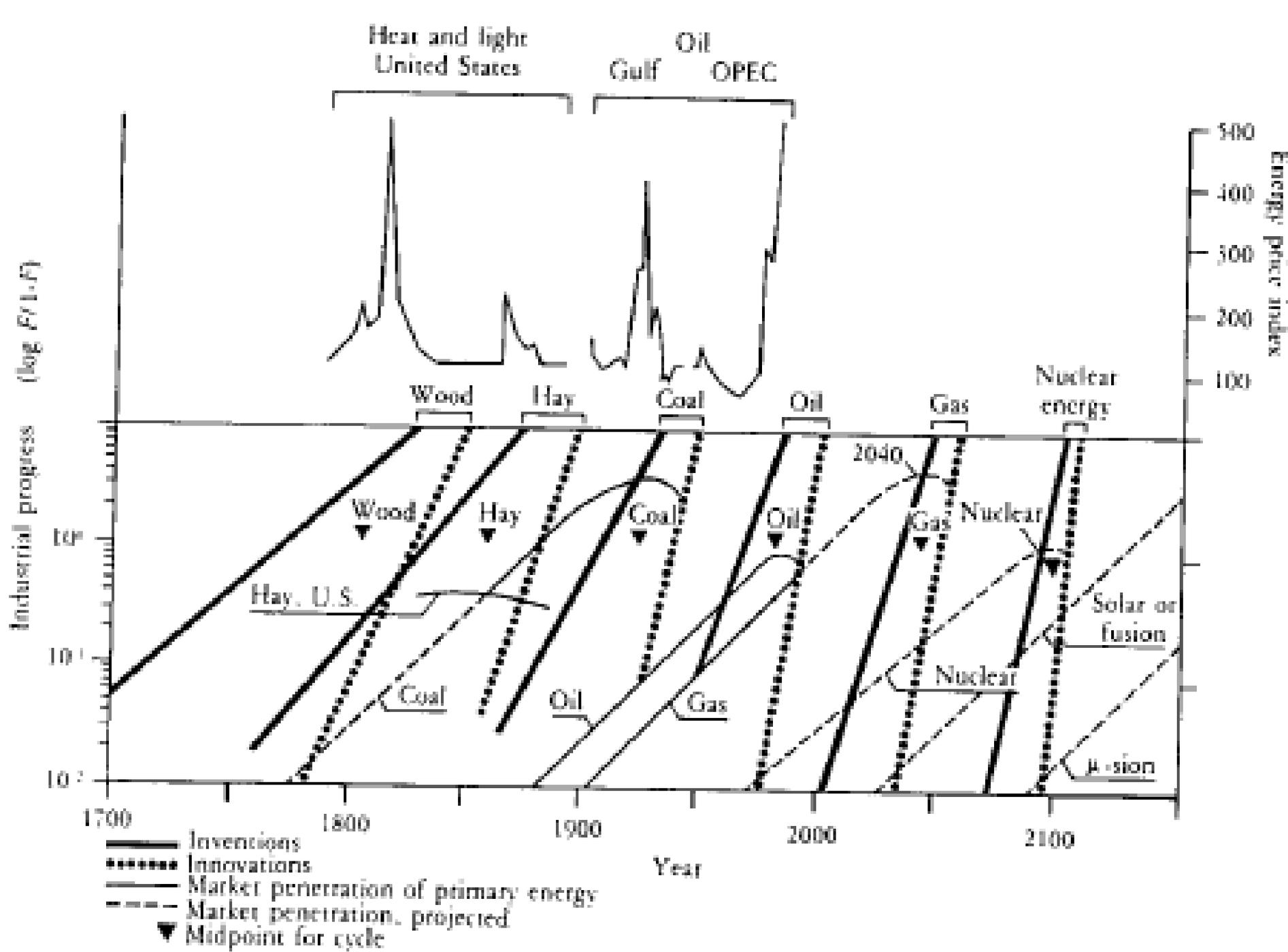
# Regarding Historical Forces, Are There “Long Waves” of Innovation and, If So, Where Do We Stand? (III):

- **Some attention to energy system “waves”:**
  - **Rooted in Marchetti and Nakicenovic: cycles of thermodynamic efficiency improvement**
  - **Volland: relating long waves to technological revolutions related to primary energy sources**
  - **Gruebler and Nakicenovic: development of an elaborated infrastructure to support a new energy technology infrastructure can inhibit the development of another new energy technology for some time**
  - **Ausubel: for energy-related technologies, monetary factors are indicators of what is happening technologically, not causes**

# Regarding Historical Forces, Are There “Long Waves” of Innovation and, If So, Where Do We Stand? (IV):

- **Some recent attention to energy system changes:**
  - **Consistent with different interpretations of long waves, current technoeconomic/energy system stresses might indicate that a notable period of transformational technological change is at hand now, while other observers would suggest that it is 20-30 years ahead**
- **Whether or not such historical forces can be shaped by inducements could be a matter of discussion**





# Regarding Serendipity as the Driver, Are We Subject to a Random Process? I:

- **The basic argument: large-impact, hard-to-predict, rare breakthroughs are beyond the realm of normal expectations from any known causes: can't be “gamed”**
- **Sources include:**
  - Taleb, *The Black Swan: The Impact of the Highly Improbable*.
  - Meyers, *Happy Accidents: Serendipity in Modern Medical Breakthroughs*.
- **This perspective argues that:**
  - Almost all consequential events in history come from the unexpected: we develop explanations in hindsight...
  - Technological breakthroughs usually occur by accident: generally cannot be foreseen based on knowledge of past events and observations
  - We think we are good at inventing, but in fact we are good at tinkering: in fact, “random tinkering is the path to success”

# Regarding Serendipity as the Driver, Are We Subject to a Random Process? II:

- **Does this mean that breakthrough discovery is a random process, or can serendipity be fostered?**
  - **By moving toward greater freedom in the use of research support: highly targeted research reduces the chances of breakthroughs**
  - **By supporting more free-wheeling trial and error research**
- **If so, serendipity is subject to inducements as well as accidents**

# Is It Possible That the Provision of Knowledge Is a Stronger Driver than Economic Incentives Alone?

- Obviously an attractive idea to people who make a living providing knowledge, but there is some evidence -- at least anecdotal -- that this can be a powerful factor
- Supported by a number of research traditions: e.g.
  - Robert K. Merton on concept formation in a context of the sociology of science: e.g., scientific discovery in “multiples” (earlier data collection by Ogburn and Thomas, 1922) -- discovery as a product of the intellectual climate at a specific time and place, with scientific foundations in place (combined with serendipity?)
  - Arthur Koestler, *The Act of Creation*: innovation through the marriage (“bisociation”) of previously unrelated ideas
  - A more recent example is Zucker and Darby, “Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the Formation of the Biotechnology Industry,” *PNAS*, 1996.

# Is It Possible That the Provision of Knowledge Is a Stronger Driver than Economic Incentives Alone?

- **Suggested approaches include:**
  - **Commons-like non-market information networks encouraging individual initiatives, e.g.:**
    - **Peter Hall: “Golden Ages” of cities associated with extensive “open source” information transfer**
    - **Science Commons: reach out with accessible scientific information to engage many more smart people in the global community...**
  - **Platforms for person-to-person collaboration, e.g.:**
    - **Gates/Microsoft: “quests”**
      - **Focused on desired outcomes/customers**
      - **70 areas of software innovation needing discoveries, grouped in 6 categories: e.g.,” rewiring the economy”, “adding a semantic level”**
      - **Communicate the challenge to everyone in the company, inviting them to come online with ideas and react to each other – see where it goes**

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- **Suggested approaches include:**
  - **Peer-to-peer collaborative brainstorming, e.g.:**
    - **Nathan Myhrvold: “innovation sessions”**
      - **Founded a firm called Intellectual Ventures: expected 100 patents a year, filing 500 a year, with a backlog of 3000**
      - **Operates by bringing together a diverse but small group of really smart people to brainstorm for a day: start with an interesting question and let the discussion take off, often in entirely unexpected directions (refined plastics evolving to innovative footwear, minimally invasive surgery evolving to improved materials for Army helmets in Iraq...)**
- **Because these knowledge-based approaches involve investments, they can to some degree be economically induced...**

# What Do These Views Suggest about Possible Courses of Action? (I)

- **If the main drivers of discovery are serendipity or historical forces, maybe all we can do is watch and react -- and we should be doing that...**
- **But to the degree that transformational change is induced by knowledge (and/or that serendipity can be fostered), it is possible to be more proactive in inducing scientific discovery -- remembering lessons from history, e.g.: breakthroughs are more likely if multiple paths are pursued than a single path (Manhattan Project)**

# What Do These Views Suggest about Possible Courses of Action? (II)

- **Possible strategies generally focus on valuing discovery more highly than valuing ownership of the results, e.g.:**
  - Increasing the emphasis on communicating much more widely about transformational energy S&T needs and the current state of the science, globally as well as nationally: get more smart people involved in idea generation
  - Reducing obstacles to idea-sharing and collaboration, e.g., revisiting policies governing international public-sector energy R&D collaboration and revisiting WTO policies on IPR as they apply to energy technologies
  - Organizing collaborative blue-sky group brainstorming about transformational energy S&T ideas -- apart from targeted competitive solicitations of proposals
- **Such strategies are usually very inexpensive indeed compared with benefits of even a single important resulting discovery**