Understanding, Modeling, and Accelerating the Development and Diffusion of New Energy Technologies - Beyond the “Valley of Death”

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Session on:

The Economics Of Technologies To Combat Global Warming

Snowmass Workshop on CCI and IA

August 3, 2009

Outline

- What is the Valley of Death?
- Is it Important?
- Trends in Energy R&D
- Technological Forecasting/Managing Innovation
- Theoretical Background on Technological Change
- A History of Science and Technology Perspective
- Revisiting the Valley of Death and Its Environment
- Implications for Policy and Modeling

What Is the Valley of Death

"Yea, though I walk through the valley of the shadow of death, I will fear no evil…"

* Psalm 23:4, King James Bible

"Into the valley of Death
Road the six hundred"

*The Charge of the Light Brigade , Alfred, Lord Tennyson, 1854

The key to this process <of innovation> lies in transitioning from R&D to the market --a stage in business development so perilous that it's often called the Valley of Death. Traversing it requires an intelligent blend of public and private sector investment, targeting the most promising innovations.

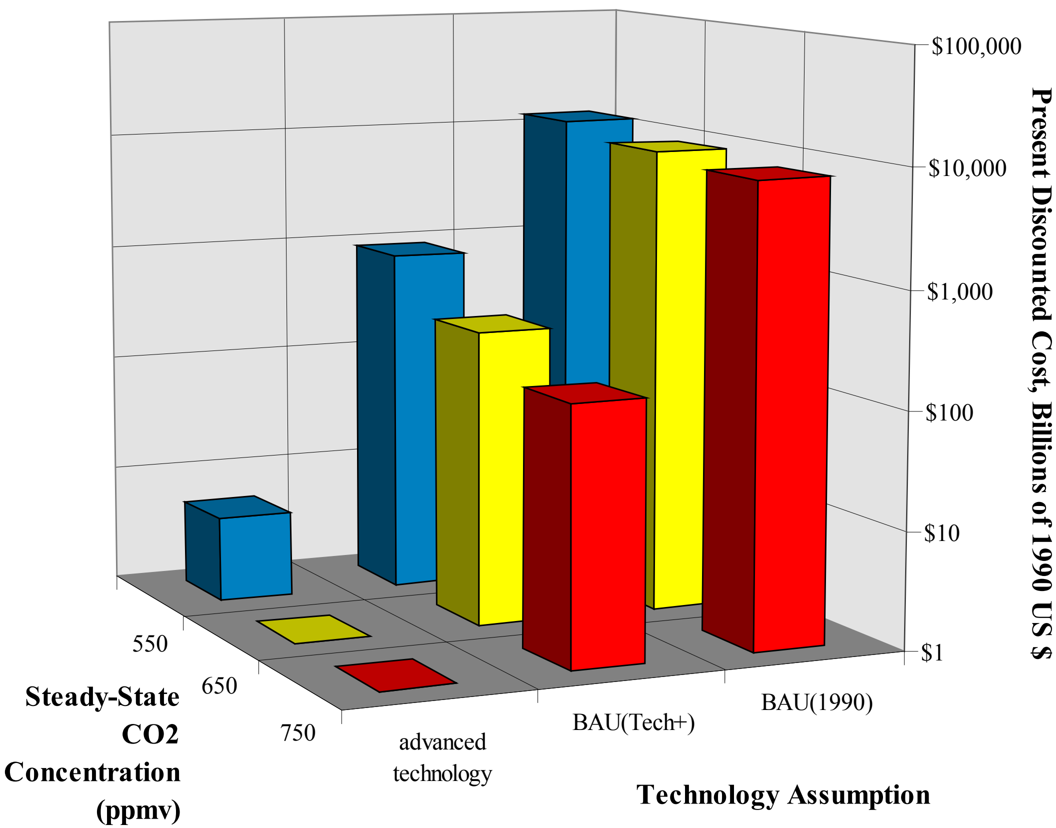
*Evan Mills and Jonathan Livingston Forbes-11.17.05, 4:00 PM ET

Updates From Last Year

- More **Public** Money for Strategically Aligned Science and Applied Energy R&D Now
  - Is it real?
  - Is it sustainable?
  - Should it be?
- Clarification of the Role of the **Private** Sector
  - How perfectly competitive are firms in the energy sector?
  - Should it be in charge of achieving societal objectives?
  - Should it be the keeper of the "technological state of the art"
  - "They are who we thought they were"- Coach Denny Green

The VALUE OF DEVELOPING NEW ENERGY TECHNOLOGY

(Present Discounted Costs to Stabilize the Atmosphere)



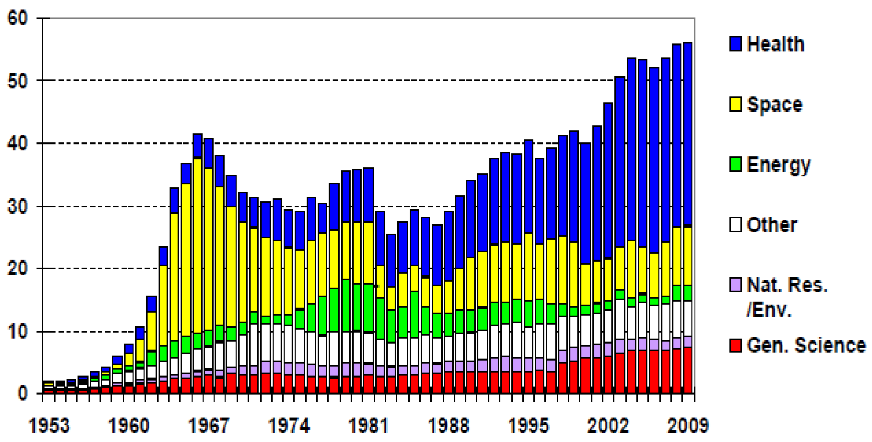
Minimum Cost Based on Perfect Where & When Flexibility Assumption. Actual Cost Could be An Order of Magnitude Larger.

Battelle Pacific Northwest Laboratories

Trends in Federal R&D by Function

Trends in Nondefense R&D by Function, FY 1953-2009

outlays for the conduct of R&D, billions of constant FY 2008 dollars



Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2009*. Constant dollar conversions based on GDP deflators. FY 2009 is the President's request.
Note: Some Energy programs shifted to General Science beginning in FY 1998.
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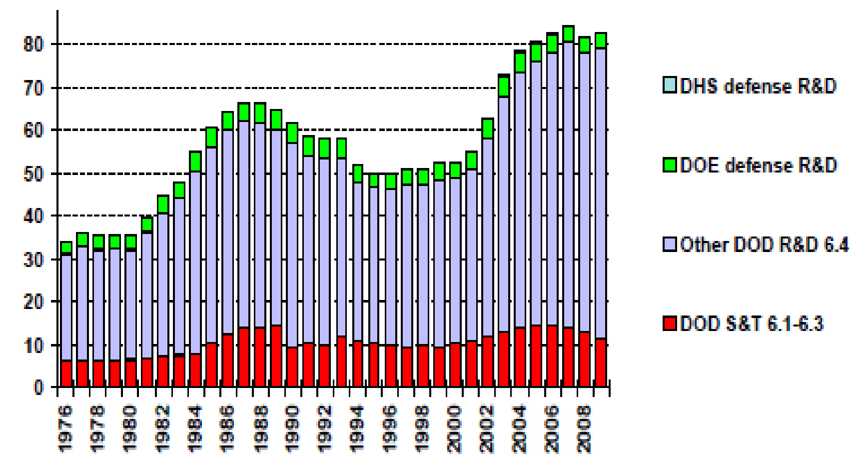
Trends in Defense R&D, FY 1976-2009 *

in billions of constant FY 2008 dollars



Source: AAAS analyses of R&D in annual R&D reports. * - FY 2009 figures are latest AAAS estimates of FY 2009 request. FY 2008 figures exclude pending supplementals. R&D includes conduct of R&D and R&D facilities. DOD S&T figures are not comparable for all years because of changing definitions.
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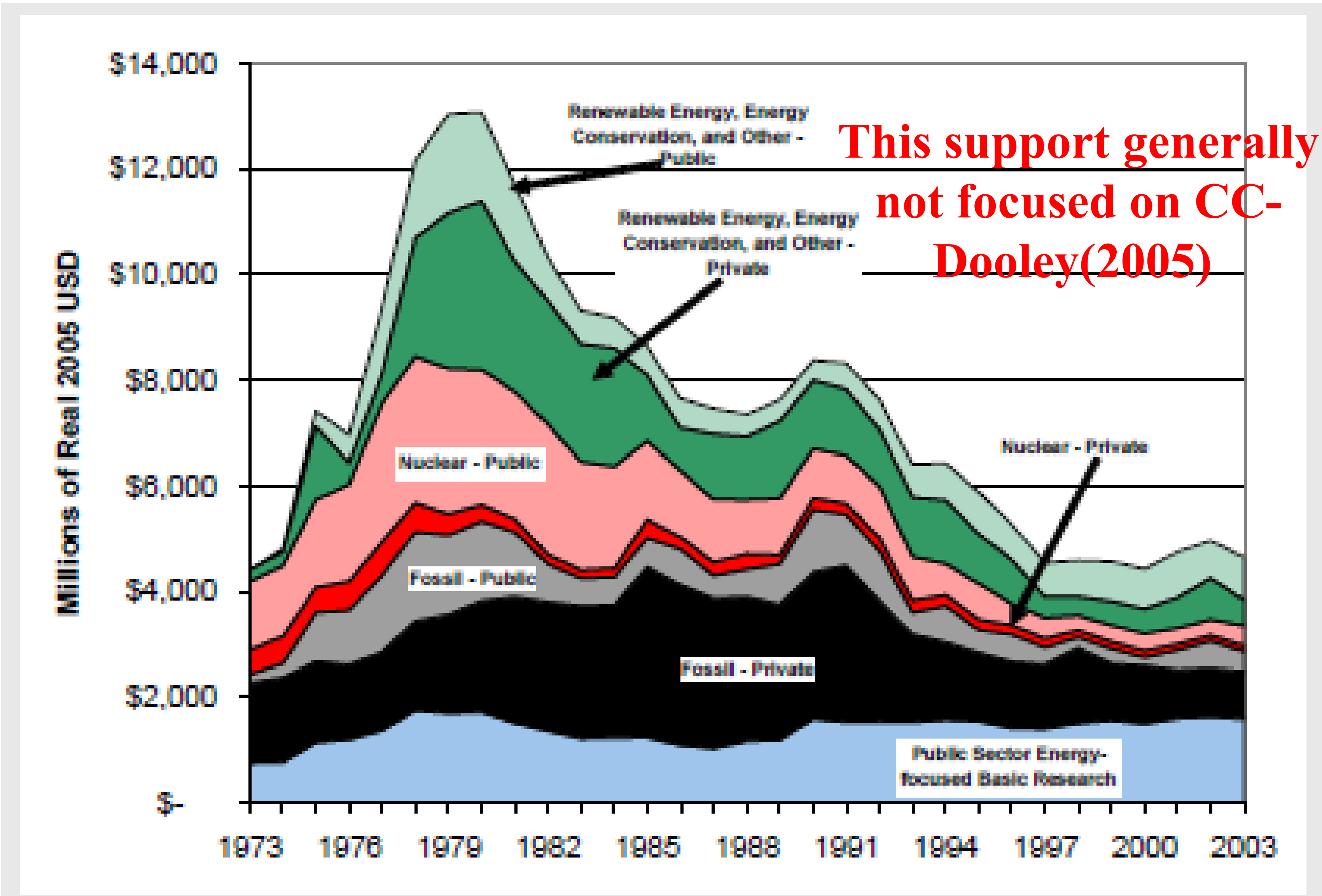
Trends in Public and Private Energy R&D



What You Hear Now

- VCs don’t see enough new deals
- Researchers can’t get enough R&D money for
  - Revolutionary technologies
  - Some more modest evolutionary technologies
- Idea – this gap needs to be plugged
- Help is on the way, but how much?

New DOE Initiatives

- ARRA - $39 billion – technology jumpstart with half to be spent on technology programs in coming year.
- Energy Frontier Research Centers – FY 2009 science funding of $100 M base with $277 million ARRA additional jumpstart (total requested $777 million over five years); presently 46 EFRCs spanning 36 states.
- Eight Energy Innovation Hubs – $280 million requested in 2010
- ARPA-E- $400 million ARRA funding with $10 million requested in FY 2010 (modeled after 3 Bio-Fuels Centers).
- Overall Pledge to request $150 Billion over ten years on energy technology development

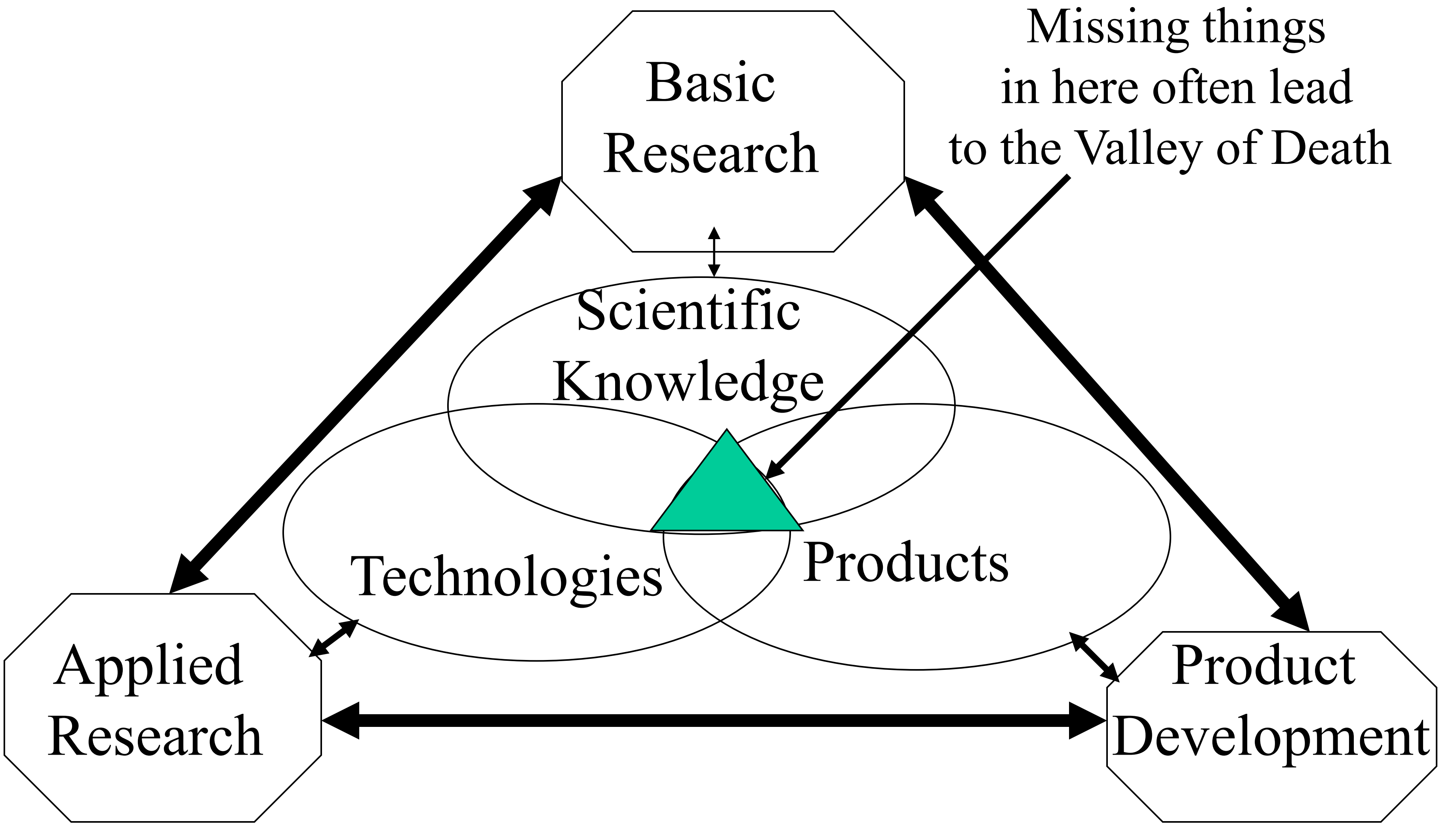
Back to the Valley of Death

- Startups Generally Fail for Three Reasons
  - Marketing people don't understand technology
  - Engineers don't understand business
  - Market conditions change dramatically
- Current Energy Technology Problem
  - Not one of too many deaths, but not enough **births**
  - Not easy to fix, but possible, if done sensibly

Conceptual Ideas in R&D Policy

- Why we might be under-investing in R&D
  - Appropriability
  - Managers with wrong incentives
  - Misunderstanding of private sector incentives
  - We applaud Schumpeter (father of entrepreneurship?) and then mostly ignore him
- Types of spill-overs
- Generic policy responses
  - Increase appropriability
  - Subsidize R&D
  - Increase pool of inventors/innovators
- Potential pitfalls with public support
  - Pork
  - Other incentive problems

A Non-Linear Model of the Innovative Process



How the Nature of S&T and Who Does What Have Changed

- Changing Modes
  - Much of the work is now at the nano scale
  - Still some large machines, big IT
  - But there is a lot of virtual design via computer simulation
  - Permits more distributed work
  - Globalization can have a big impact
- Changing Roles
  - Universities do more applied research
  - Industry does more basic research
  - Product development life cycles much faster

Example: Inorganic Thin-Film Photovoltaics

Materials

- (Novel) low-cost, abundant, non-toxic, and stable semiconductor materials
- Thin films: low volumes and lower requirements for charge transport
- Low-cost deposition processes

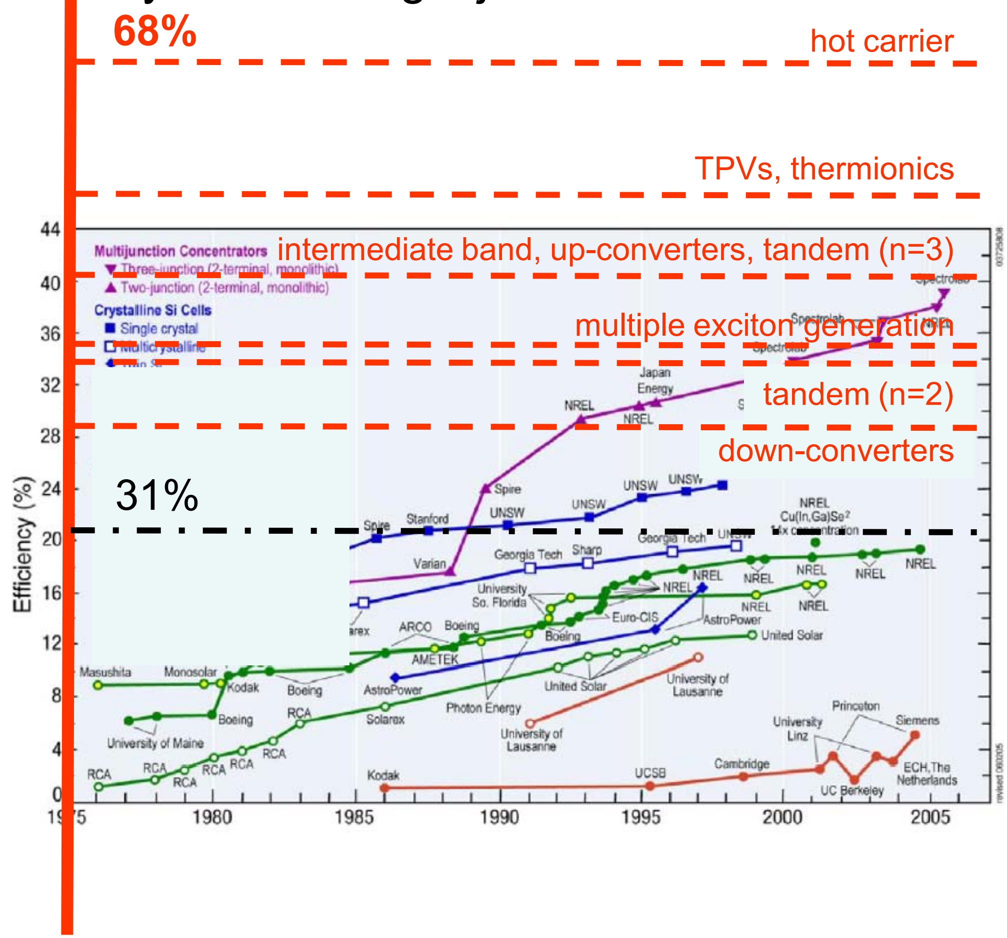
Nanoscale morphology

Performance enhancement through

- optimized geometry
- quantum effects

High efficiency

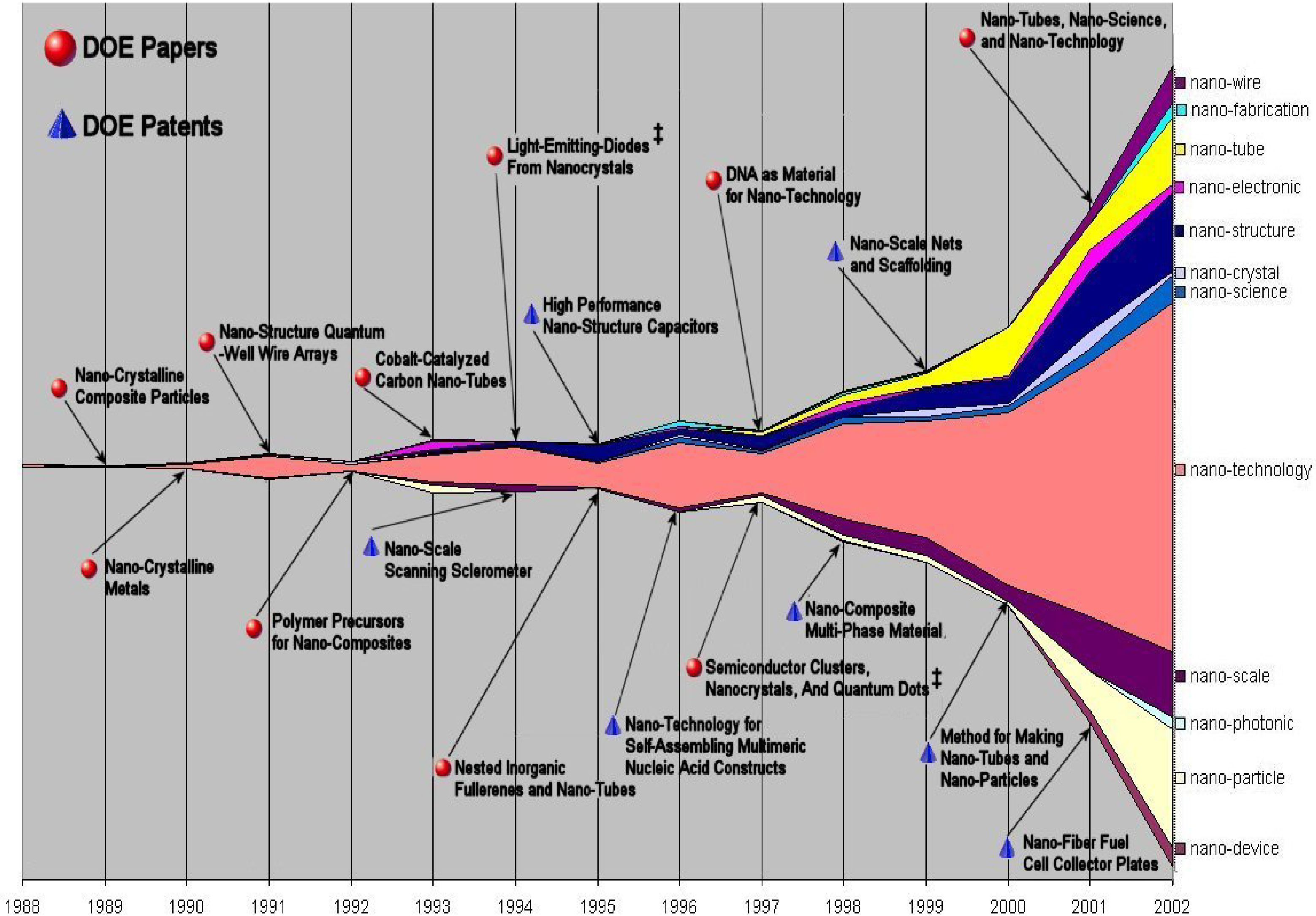
III generation concepts with efficiency limits beyond the single junction limit of 31%



Methods for Forecasting/Managing Breakthroughs

- Regression and statistical analysis of performance curves (e.g., temperature improvements or wear resistance of materials, manipulation size/speed of nano-materials) superimposed on rates and changing rates of patents and citations
- Knowledge diffusion network analysis
- Patent and Citation Analysis (Example)
- Datamining in Open Literature

Emergence of the Term "Nano" in the Open Literature and Growth/Decline of Specialty Terms as One Possible Indicator of Maturity Levels or Transformation: Showing Representative DOE Papers and Patents



Back to the Valley of Death

- Many innovative ideas die or are never born because some of the requisite science, technology and business plan elements are missing, especially in the green zone
- Much of what is missing has the same public good nature as R&D in general
- There are two cases here:
  - Small scale proof of concepts
  - Scale up of bench scale demonstrations-beware of pork
- Appears to be a bias towards energy supply technologies
- Who could, should, would fund such activity

Context for Funding the Missing Links

- They are still often public good like
- A historical perspective
  - The big industrial labs in the late 1800s, and before and after the WWs – Used Monopoly Profits
  - NSF/AEC/DOE (starting in 1950)
  - Defense contractors during the cold war
    - Dual role – military and civilian
    - Huge – DARPA, IR&D, etc.
  - More modern
    - NSF, BER, Other DOE
    - VCs (jump from IT to Clean Tech?)
    - Industry Consortiums (EPRI, GRI)
    - University Initiatives (GCEP, BFI)
    - KAUS&T, Google, Kleiner Perkins (R&D grants)
  - But given the problems we have now, the scale seems way off and a lot of the state of the art in applied energy research is proprietary

Some Ideas for Rising to the Occasion

- Need a large, directed science & technology innovation fund
- Discussions with some suggest that $10 Billion/year might work
- Can't come at the expense of other critical dimensions of the innovation process, e.g., inquiry based science at DOE and NSF. (Careful of robbing Peter to pay Paul!)
- Needs to be as public as possible
- But avoid political interference…to the extent possible
- Separate mission oriented science, pre-commercial & demo functions (Cohen /Noll)

Some Ideas (Contd.)

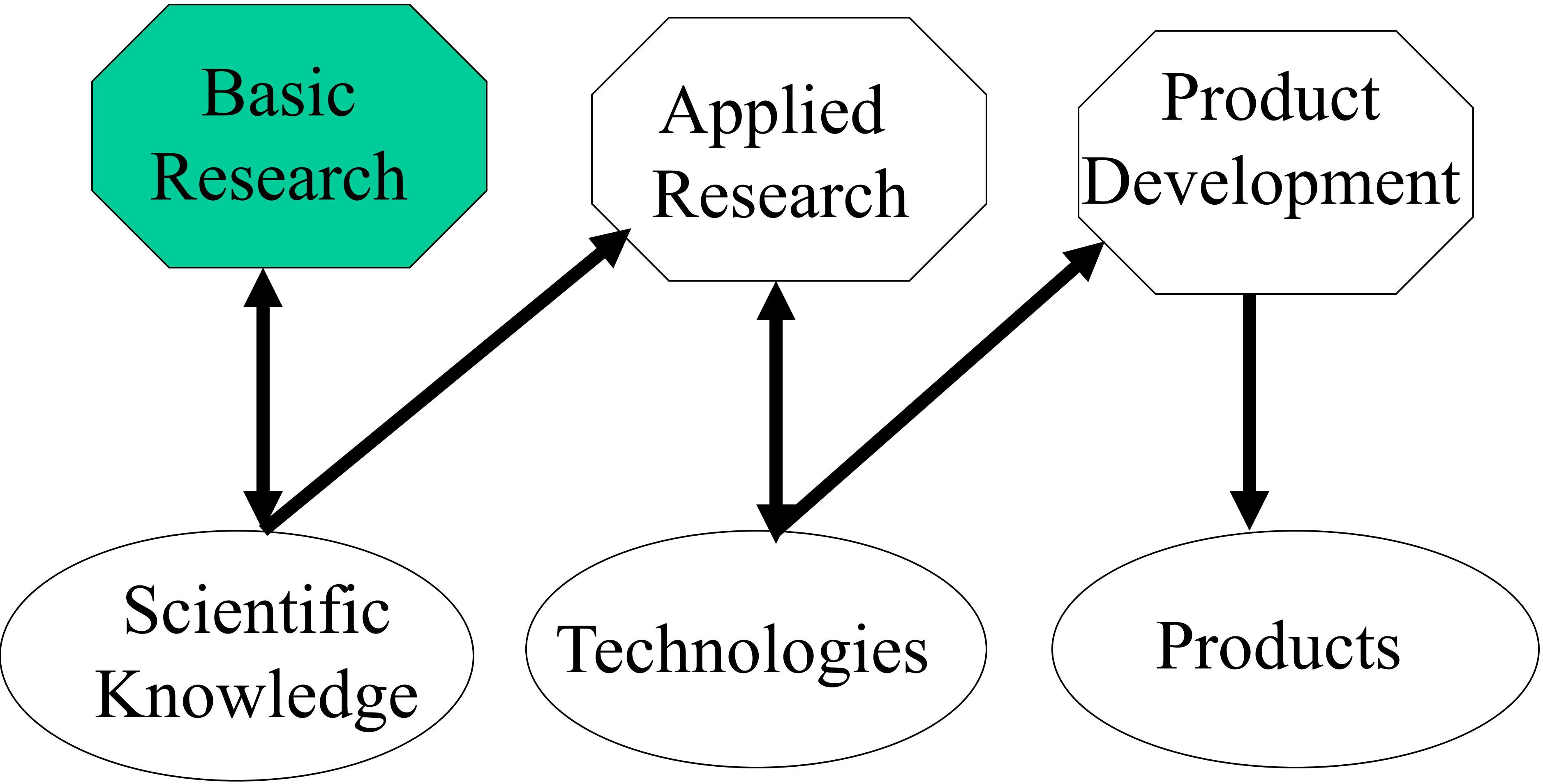
- Large demo projects hard to control (Cohen and Noll).
- Needs tough "technology advisory council" supporting high risk, high payoff, relevant research
- Models? DARPA, ITRI, CIRM, CICS, PNGV, other?
- Is CC a big enough societal priority (IAMs in SAP 2.1a) to sustain a large basic and applied energy R&D program (Cohen &Noll?) Billions not millions?
- If at first you don't succeed, try, try, again.

The End

General Approaches to Modeling Technological Change

- Exogenous Assumptions (e.g., AEEI, Changing Menu of Technologies)
- Price Induced Technological Change
  - Learning by Doing
  - R&D and Knowledge Capital
- Learning Curves
  - With Respect to Cumulative Experience
  - With Respect to Cumulative R&D Expenditures
- Other Modifications to Model Parameters With Respect to Time or Policies

The “Linear Model” of Innovation



Successes and Failures

- Successes
  - Transistors
  - Combined Cycle Turbines
  - “Pulse” Furnaces
  - Carbon-60
  - Wind Turbines
  - Sensors and Automatic Controls
- Failures so far
  - Beta Max
  - Fuel Cells
  - Advanced Batteries*
  - IGCC
  - Carbon Capture and Storage
  - LEDs/OLEDs
  - Next Generation Nuclear
  - Solar Cells
  - Really Smart Houses and Buildings*
  - Advanced Electricity Trans. And Distribution Systems

*Ready to make quantum leap

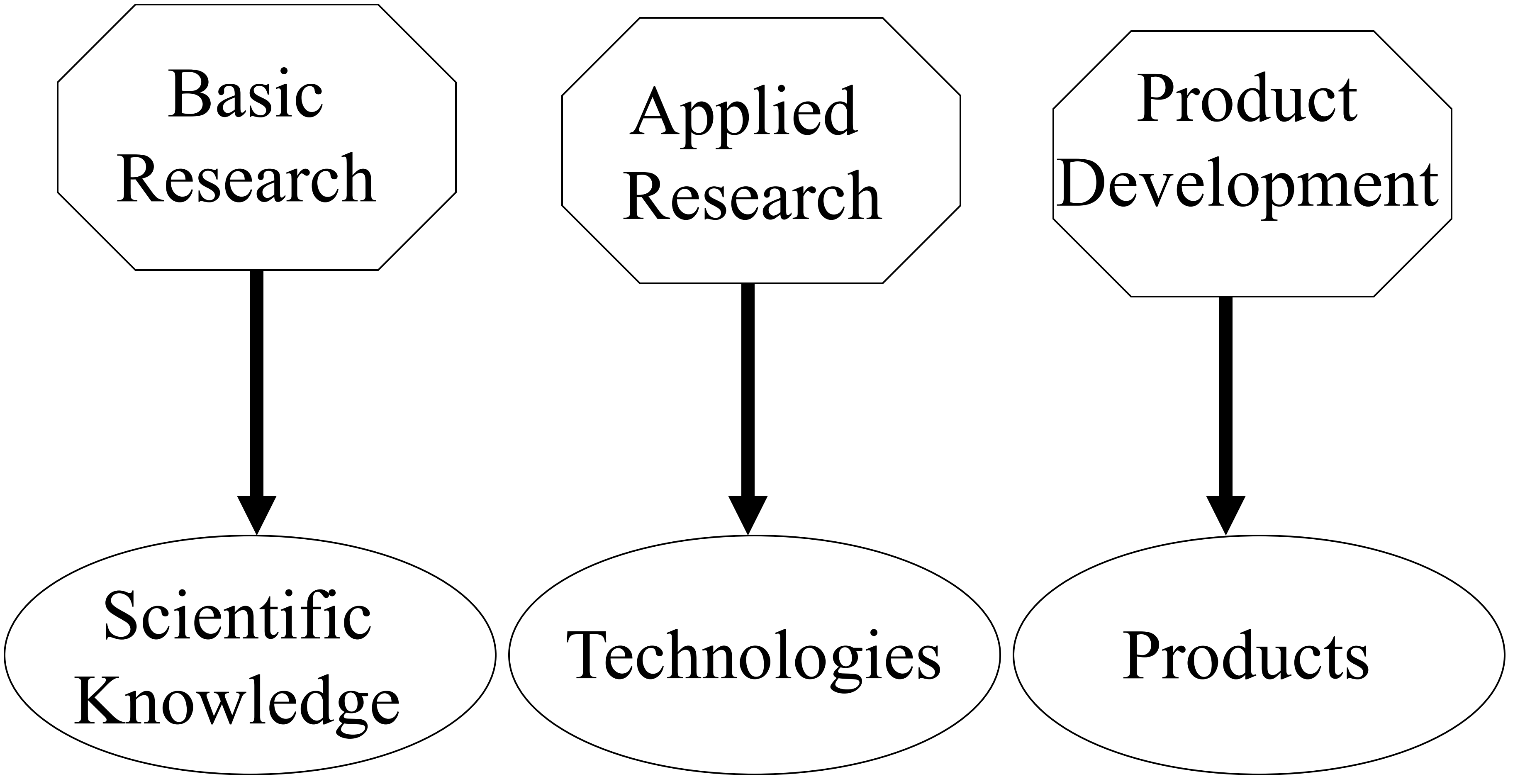
Possible New Research Directions

- To learn from history
  - Case studies (including failures)
  - Surveys (including failures)
  - Patent analysis (more in depth, less econometrics)
- To improve modeling
  - In depth look at current and possible future gaps
  - In depth probability assessments
  - Sync up all the above with existing modeling approaches

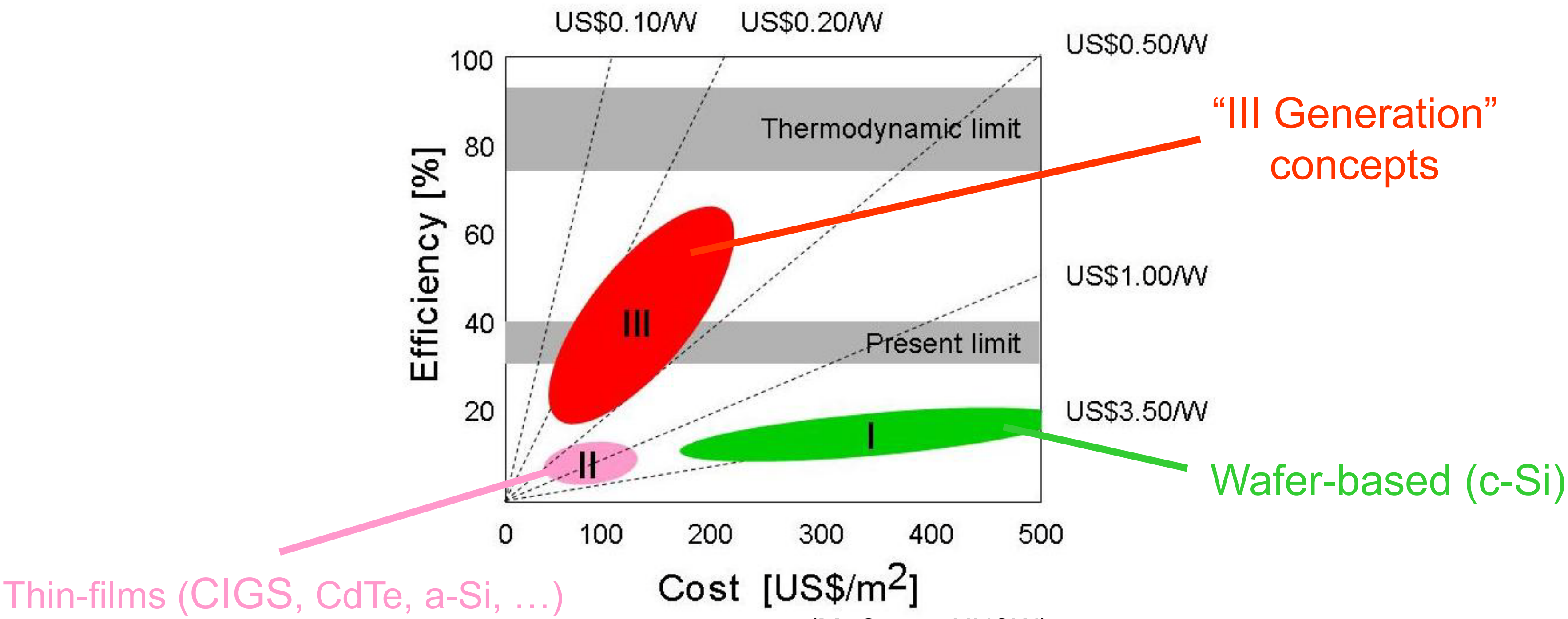
Observations Regarding Current Approaches to Modeling ITC

- Current approaches to ITC provide a good foundation:
  - spillovers
  - innovation incentives and knowledge capital
  - heterogeneous firms and technologies
- Current approaches suggest weak or ambiguous effect of ITC, but underestimate importance:
  - Focus only on R&D-based technological change
    - » learning-by-doing
    - » diffusion or imitation by existing technology
  - Assume continuous, known returns to R&D function (no surprises or discontinuities)
    - » No provision for major innovations
    - » Model only one dimension of technological change (cost)
  - Neglect path-dependence and inertia in changing technology dynamics
- Modeling challenge will be to incorporate enough complexity to realistically capture technology dynamics in a meaningful way.
- Policy challenge will be to use insights from models, but qualify findings with a more complete understanding of technological evolution.

Elements of the Innovative Process



Reducing Cost and Increasing Efficiency of Photovoltaic Systems



(M. Green, UNSW)

Cost ↓

- Cheaper Active Materials (abundant inorganic or organic)
- Lower Fabrication Costs (low-cost deposition / growth)
- Cheaper BOS Components (substrates, encapsulation, …)

Efficiency ↑

Reduce the Thermodynamic Losses at Each Step of the Photon-to-Electron Conversion Process

- Light Absorption
- Carrier Generation
- Carrier Transfer and Separation
- Carrier Transport

Solar Technology Assessment: Four Categories

Technology	Funding Trajectory	Definition of success (Efficiency, stability, cost)	Ex 1	Ex 2	Ex 3
Purely organic	$10M 10yrs	15%; 30 yrs; $50/m^2	.34	.04	.01
	$80M 15yrs	31%; 15 yrs; $50/m^2	.03	.08	.006
CIGS	$15M 10yrs	15%; 30 yrs; $50/m^2; no indium shortage	.04	0	.02
New inorganic	$5M 10yrs	15%; 30 yrs; $50/m^2	.64	.16	.001
	$10M 10yrs	15%; 30 yrs; $50/m^2	.85	.43	.013
	$20M 10yrs	15%; 30 yrs; $50/m^2	.85	.43	--
3rd Generation	$15M 10yrs	36%; 30 yrs; $100/m^2	.02	.02	.14

Source: Erin Baker, et al.

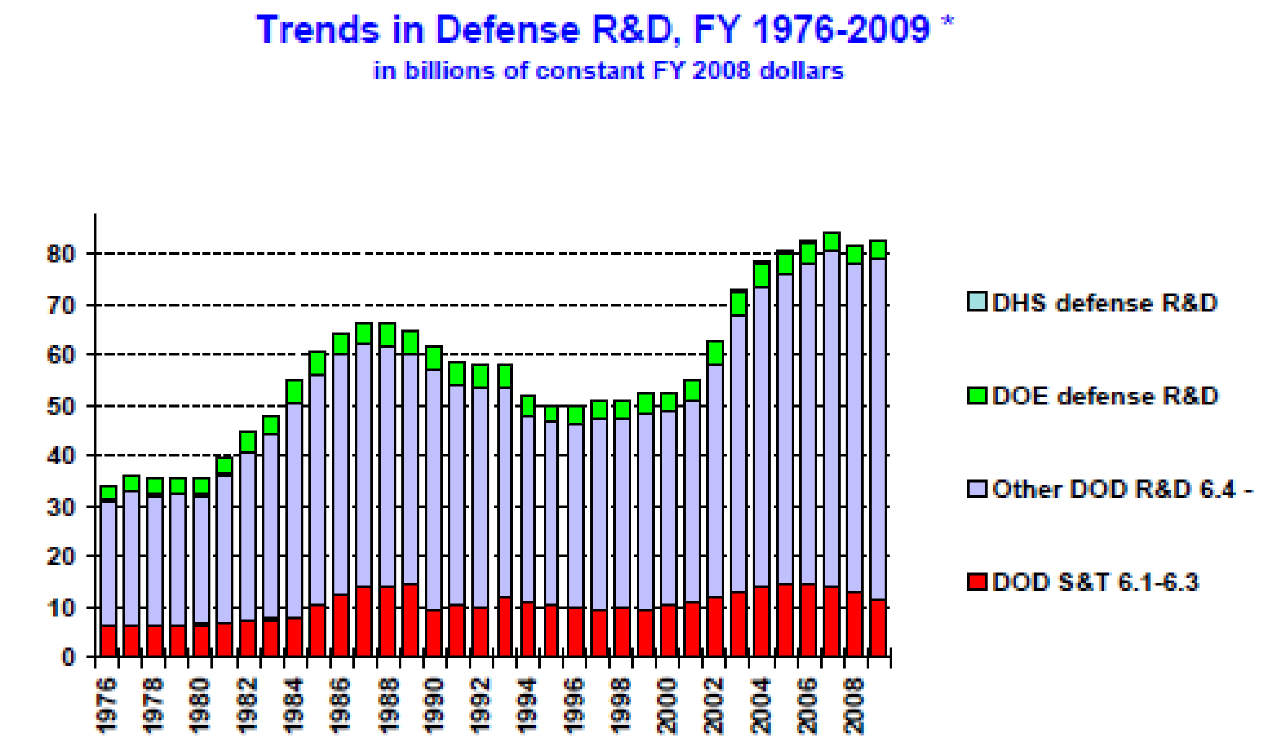
Three Approaches to Strategy

Comparison

	Position	Resources	Simple Rules
Strategic logic	Establish position	Leverage resources	Pursue opportunities
Strategic steps	Identify attractive market Locate a defensible position Fortify and defend	Establish a vision Build resources Leverage across markets	Jump into the confusion Keep moving Seize opportunities Finish strong
Strategic question	Where should we be?	What should we be?	How should we proceed?
Source of advantage	Unique, valuable position with tightly integrated activity system	Unique, valuable, inimitable resources	Key processes and unique simple rules
Works best in…	Slowly changing, well-structured markets	Moderately changing, well-structured markets	Rapidly changing, ambiguous markets
Duration of advantage	Sustained	Sustained	Unpredictable
Risk	It will be too difficult to alter position as conditions change	Company will be too slow to build new resources as conditions change	Managers will be too tentative in executing on promising opportunities
Performance goal	Profitability	Long-term dominance	Growth

Reference: Eisenhardt and Snull, 2001

Defense R&D Spending



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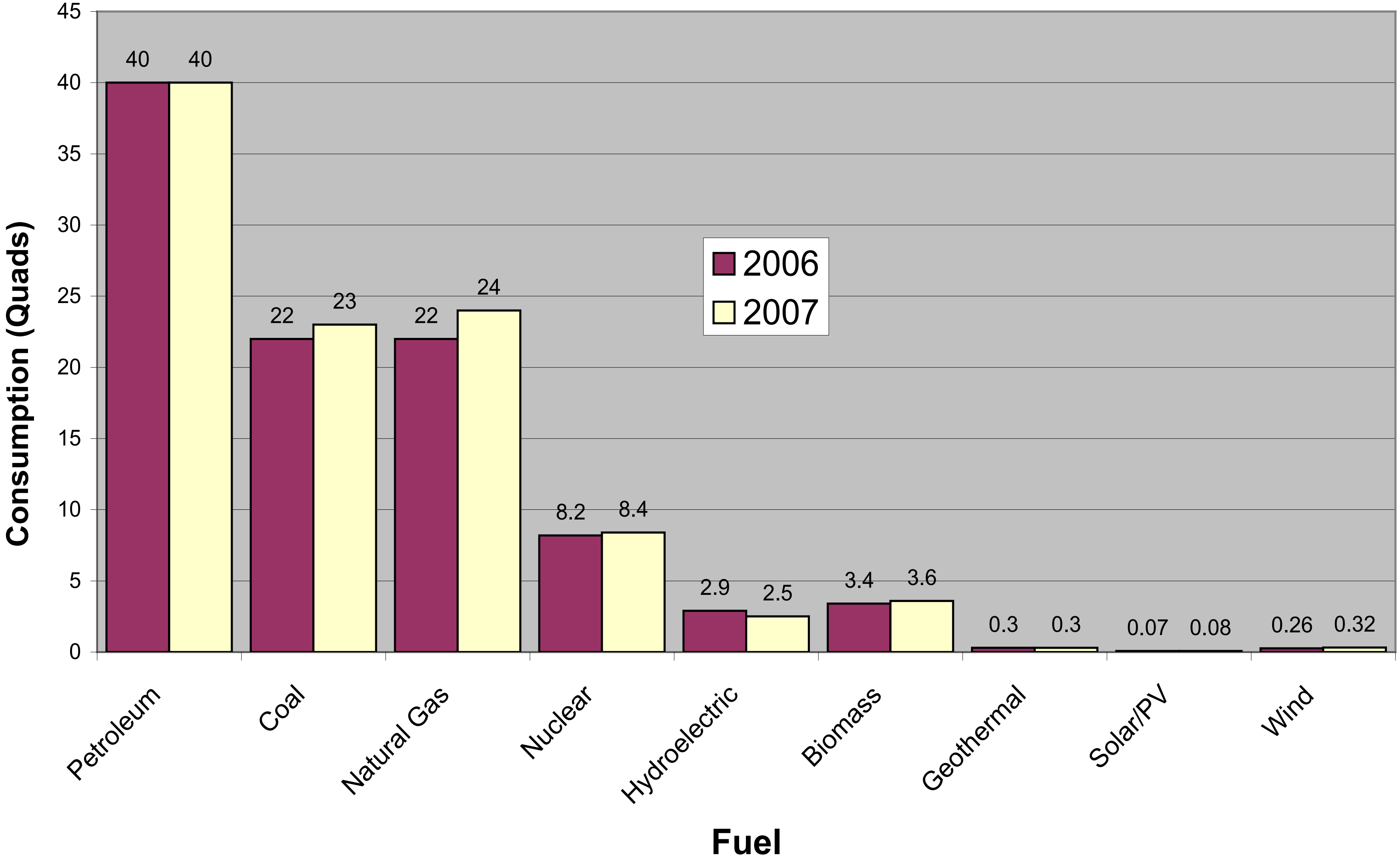
Possible Climate Change Policy Simple Rules

- Rely on markets as much as possible
- Correct market failures using market principles where possible
  - Information
  - Decision making
  - Innovation
  - Demonstration
- Carefully factor in side benefits
  - Criteria Pollutants
  - Congestion
  - Economic development
  - Environmental justice
- Pay attention to states
- Don't let the perfect be the enemy of the good and useful
  - Adopt broad strategic framework
  - Experiment at small scale, preparing to accelerate or stop

US Energy Consumption By Fuel



Energy Efficiency Compared to CO_2-Free Energy Supply

- **A 10% reduction in all energy intensity implies that 8.5 quads of fossil fuels are not used, reducing CO_2 emissions by 8.5%**

- **A 20-fold increase in wind plus solar can displace about 8.5 quads of fossil fuels. If solar and wind grow for 35% per year from today's .4 Quads it reached 8 Quads in 10 years.**

- **A doubling of nuclear power can displace 8 quads of fossil fuels.**

- **1 billion tons per year of celluosic conversion of biomass can displace 5 quads of gasoline**

Some High Priority Areas for New Project Development

- Accelerating Adoption of New Energy Efficient Technologies
  - Disseminating Information
  - Changing Behavior
  - Policy Options
  - New Business Models
- OLED TV and Computer Screen Development
- Advanced Electric Drive Technologies
- Advanced Electricity Storage Technologies
- Micro-grid/Utility/Home Generation Linkages
- Grid/Vehicle/Home Electricity Interactions

Why We Might Be Under-Investing in R&D

- Appropriability/Spill-Over Effects
- Financing Difficulties With R&D Investments
- Poor Management of Past R&D Programs
- Hard to Sell R&D to Decision Makers

Types of Spill-Overs

- To Other Firms in Industry (Appropriability)
- To Other Industries
- To Consumers
- To Productivity and Economic Growth
- To Other Countries

Generic Policy Responses to Underinvestment in R&D

- Increase Appropriability
  - Patents
  - Protect Intellectual Property Rights
  - Industry Consortiums
- Reduce the Costs of R&D
  - Direct Funding
  - Subsidies
  - Government/Industry Consortiums
  - Increase Supply of Inventors

Potential Problems With Public Support for Private R&D

- Pork Barrel Politics (Cohen/Noll)
  - Distributive Politics-Potential Losers Outnumber Winners
  - Neither Dems. nor Reps. Can Form Support Coalition
  - Exception – Major Threats to the Nation, security, etc. CC?
- Incentive Problems
  - Govt. Can’t Pick winners
  - Might Just Displace Private Funding
  - Govt. Managers Only Interested in Winners
  - Hard to Terminate Bad Projects
- Move Creative Assets Out of Other Industries
- Decision Makers Do Not Understand Options

Market Failures in Energy Markets

- Environmental
- Innovation
- Information

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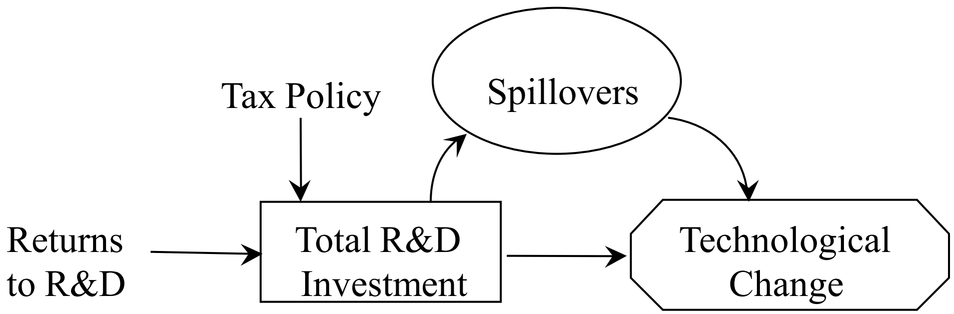
Current ITC Modeling Approaches: Overview

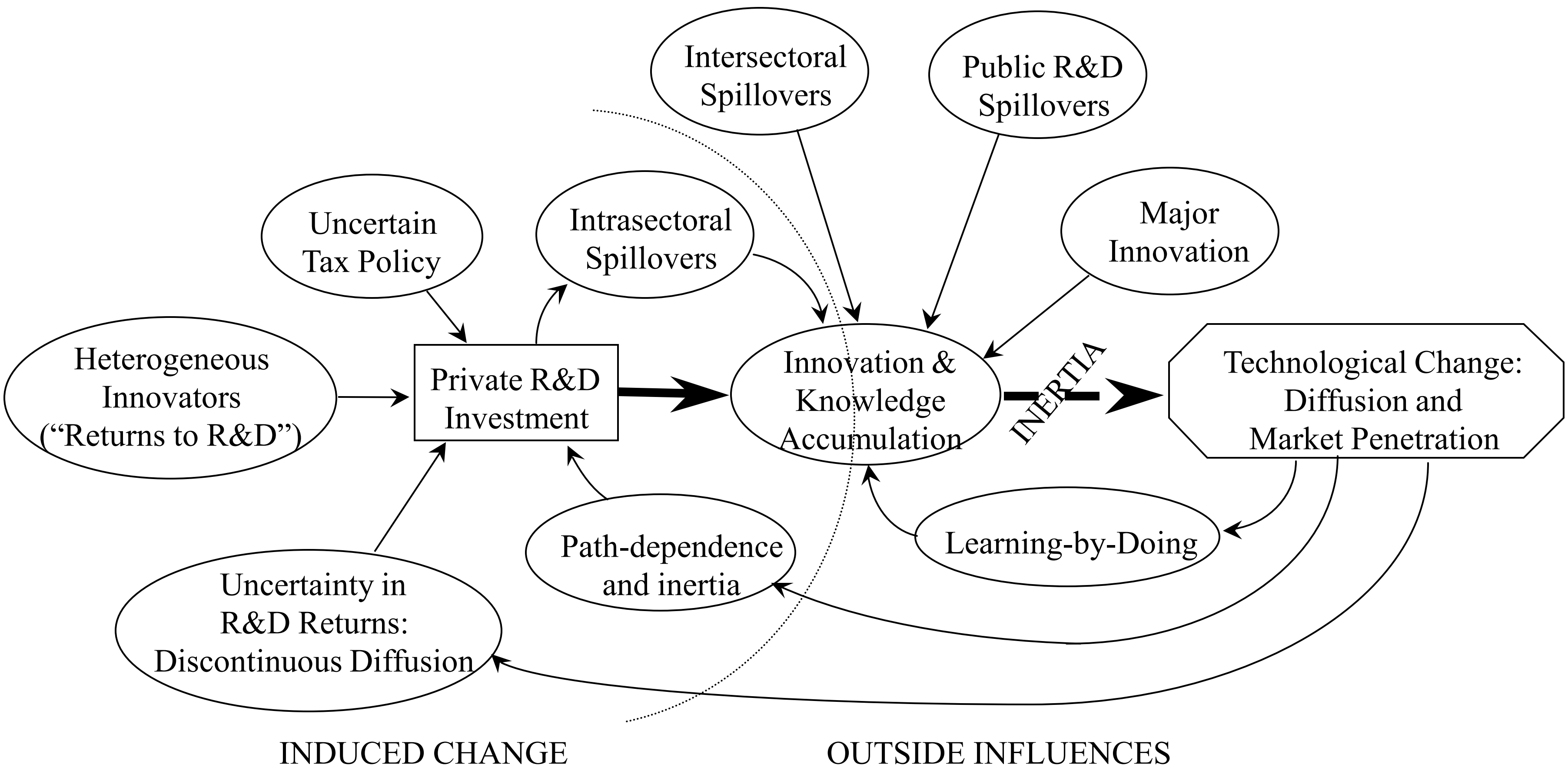
- Linear, deterministic dynamics of technological change



- Various economic frameworks
  - Empirical (Jorgenson & Wilcoxen, 1993)
  - Cost-function (Goulder & Mathai, 1997)
  - Macroeconomic
    - » Neoclassical growth (Nordhaus, 1997)
    - » General equilibrium (Goulder & Schneider, 1998)

Limitations and Possible Extensions to Current Methods for Modeling ITS

Current approaches omit important dynamics of technological change. A broader framework for analyzing ITC is needed.



Types of Technological Change

- Invention
- Innovation
- Diffusion

Policy Options in Two Key Areas

- Research and Development
  - Invention
  - Innovation
- Technology Diffusion
  - Domestic Diffusion
  - Technology Transfer

Outline

- Types of Technological Change (TC)
- General Approaches to Modeling TC
- Induced Technological Change (ITC)
- Public Support for R&D
- Public Support for Technology Diffusion