Energy R&D Prioritization: Applications of IAMs and Improving Representations of Innovation

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Two Parts: Coming Full Circle

- The Present ---- Application of IAMs for DOE Applied Technology R&D Priority Setting

- The Future ---- Strengthening the Understanding and Treatment of Science-Driven Innovation in IAMs

Use of IAMs to Inform DOE Portfolio Analysis

- CCTP uses scenario analysis based on integrated assessment modeling results
  - “Reference” and “advanced” technology depictions allow for study of scenarios in which certain technologies improve relative to others
  - Provides quantity and timing of GHG reductions, energy consumption, fuel mix, cost, etc.
  - Analysis shows cumulative costs of meeting climate change goals are much less with advanced technologies – no surprise
  - This “first order” result allows CCTP to quantify benefits of advanced technologies in meeting climate goals – sales pitch to policymakers

Recent Approaches to Portfolio Analysis

- Methodology to incorporate CCTP scenario approach into DOE budget process was developed, applied to FY09 budget
  - Based on limited range of scenarios from CCTP Strategic Plan
- Current efforts are focused of the use of scenarios in transition planning in preparation for a new administration
  - Larger group of scenarios run using updated model components and technology assumptions

FY09 Budget Planning Methodology

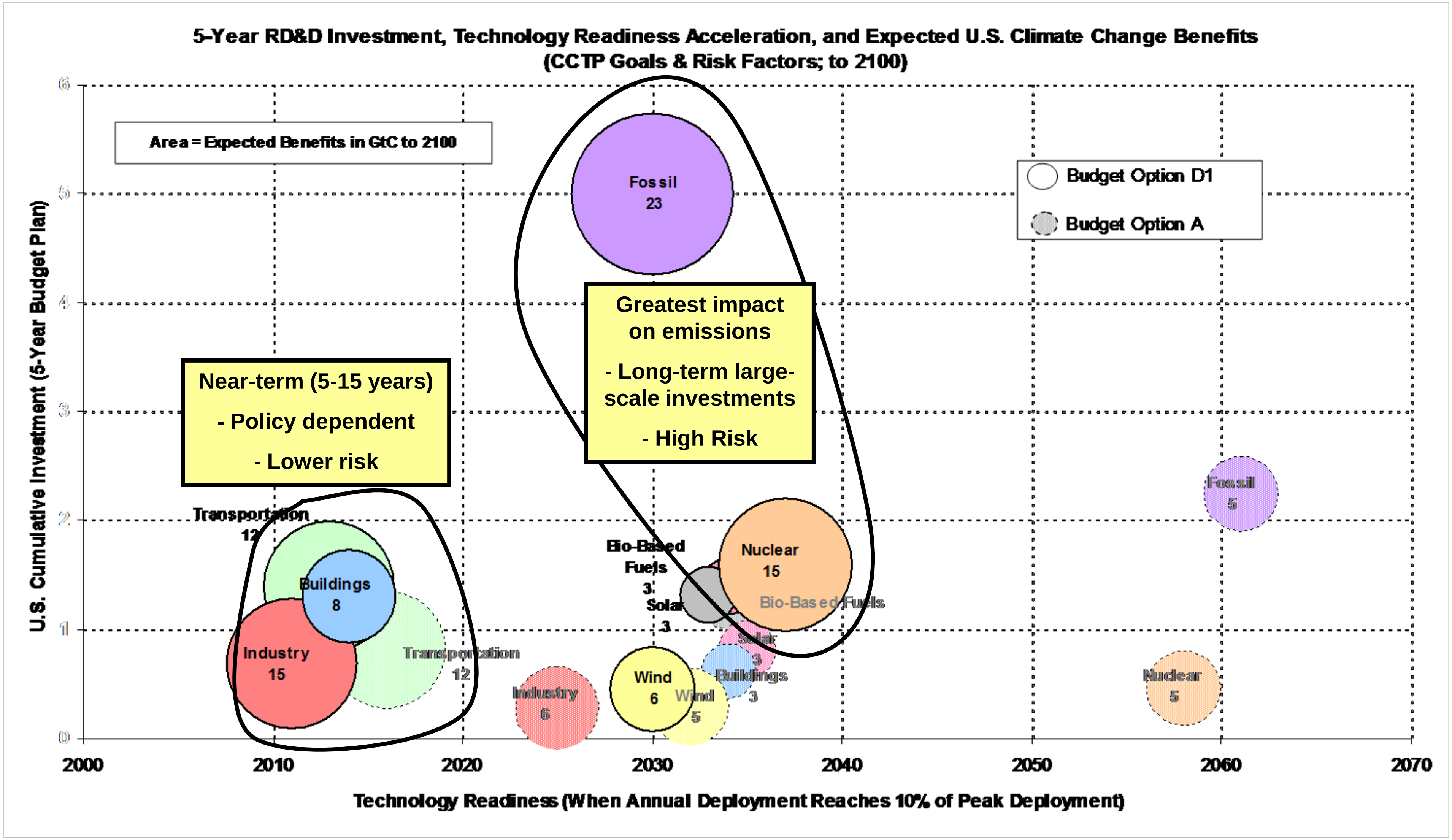
<u>Goal</u>

- ❖ Develop a portfolio that is hedged against risk, knowing that:
  - ➢ Not all technologies will succeed in making it to the market place
  - ➢ Even if they do succeed, their deployment may be limited by barriers

<u>Approach</u>

- ❖ Use scenario analysis to define the most aggressive deployment trajectory for each technology
  - ➢ Use this as a program planning goal
- ❖ Develop a 'likelihood of success' score that will discount benefits by factoring in barriers to deployment
  - ➢ Requires independent, expert judgment
- ❖ Use 'expected benefits' results divided by R&D investment to determine ROI
  - ➢ Build portfolio accordingly, within prescribed funding increments

Return on U.S. Federal RD&D Investment



Current Approach for Transition Analysis

Goal

- Inform incoming administration of key portfolio options and characteristics, including policy options
  - Continue to emphasize importance of hedged portfolio and need to address non-market barriers

Approach

- Use improved scenarios to identify key points derived from "second order" analysis – how to actually realize the benefits of advanced technology
  - Common themes in scenarios
  - Nature of R&D required
  - Path dependence and optimal deployment
  - Non-technical barriers and role of policies in addressing them

"Second Order" Analysis of Scenarios

- Focus on common themes
  - Carbon constraint drives decarbonization of the grid – impact on transport is much smaller (role for policy)
  - Decarbonization of the grid will drive increased electrification in the absence of advanced end-use technologies
  - Incorporating renewables (and potentially PHEVs) into the grid will require infrastructure changes
- Focus on nature of R&D required
  - R&D often treated generically in economic analysis, but practical R&D maps to basic research, applied technology development, and early stage demonstration
  - Examples: Large scale renewables drive basic research on energy storage; CCS requires TD and demonstration

"Second Order" Analysis of Scenarios

- Focus on path dependence and optimal deployment
  - Large-scale wind dependence on energy storage and enhanced transmission
  - Distributed solar PV and advanced end-use dependence on smart grid
- Focus on identifying non-technical barriers and role of policies in addressing them
  - Technologies have to deploy in real markets, subject to various types of barriers (in contrast to adoption of energy-efficient technologies at "net-zero" cost - McKinsey report)
  - Technology or sector-specific policies, e.g. appliance standards, building codes, life-cycle carbon analysis

A Balanced Approach…

Part II: Representing Science-Driven Innovation

- What's happening in science? Why is it important?
- Science – technology linkage
- Complementary tools for IA
- Implications for IAMs
- Summary

Our Perspective on Science

- Scientific discoveries have broad impacts --- results translate across many areas.

- Innovation is a **non-linear** process and the relationship between basic and applied research is far from simple.

- Implications: we can't predict the breakthroughs but analyses can yield important insights that might inform Integrated Assessments

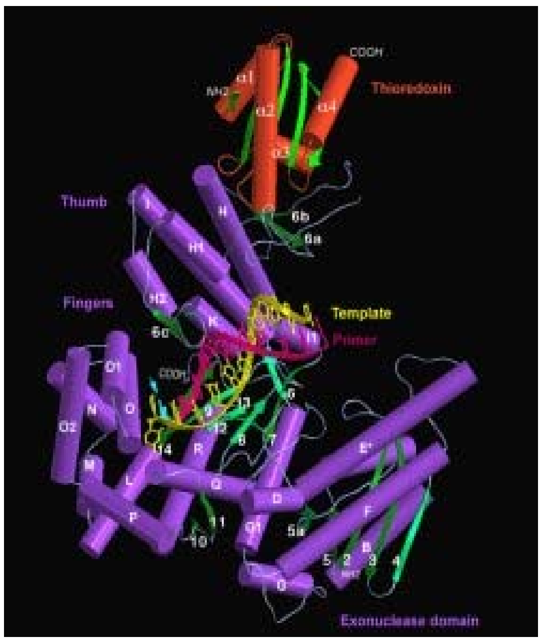
- IAMs are an important…but not the only… toolset.

> ***"The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny….'"***
> ***Isaac Asimov***

The Broad Reach of Scientific Discoveries: One of Many DOE Breakthroughs in Genomics

The Science:

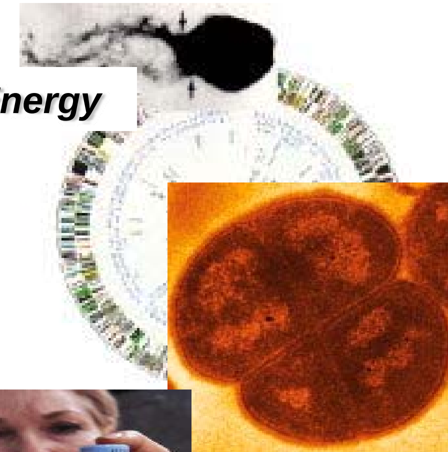
Basic research into DNA polymerases resulted in new and improved enzymes that solved long-standing problems in DNA sequencing.



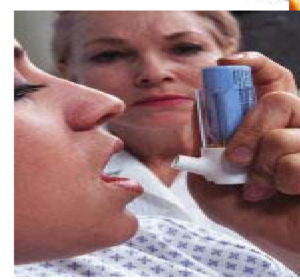
The Impacts:

DNA Sequencing: taking a year just a few years ago now completed in hours.

Energy



Health



Environment

Science

…and more!

Critical New Enablers for Innovation?

Or put differently, might the "waves" finally come faster for energy?

- ❖ **Nano-science** – ability to manipulate matter at the nano-scale for desired properties
- ❖ **Genomic Science** – ability to manipulate organisms at the genetic level based on improved understanding of the genome and gene expression
- ❖ **Computational Simulation** - emergence as the third pillar of science, taking its place with theory and experimentation

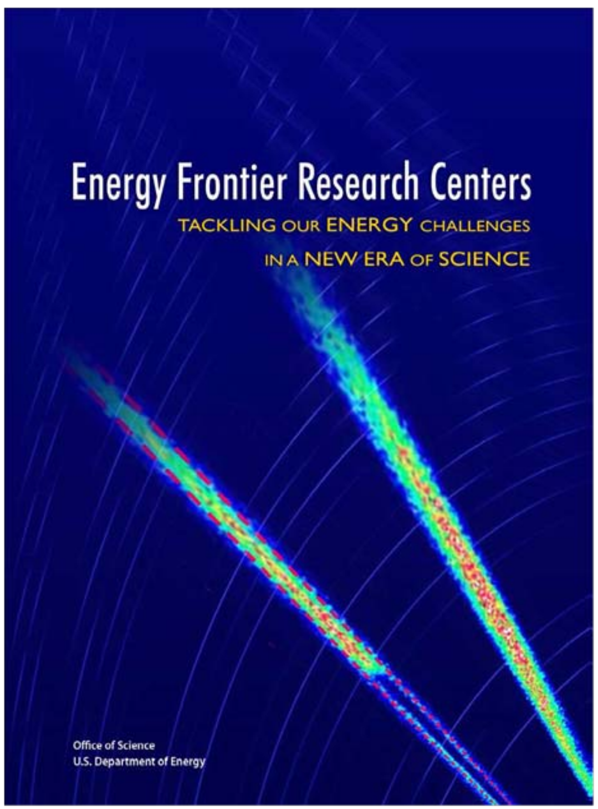
A Third Wave in Solar?

Technology Wave	I. Wafer Cells	II. Vacuum-Based Thin-Film-on-Glass	III. Roll-Printed Thin-Film-on-Foil
Process:	Silicon wafer processing	Sputtering, evaporation in a vacuum chamber	Printing in plain air
Process Control:	Fragile wafers	Expensive metrology	Built-in bottom-up reproducibility
Process Yield:	Robust	Fragile	Robust
Materials Utilization:	30%	30-50%	Over 95%
Substrate:	Wafer	Glass	Conductive Foil
Continuous Processing:	No -- wafer handling	No -- glass handling	Yes
Cell Matching:	Yes	No	Yes
Panel Current:	High	Low	High
Energy Payback:	3 years	1.7 years	< 1 month
Throughput/CapEx	1	2-5	10-25

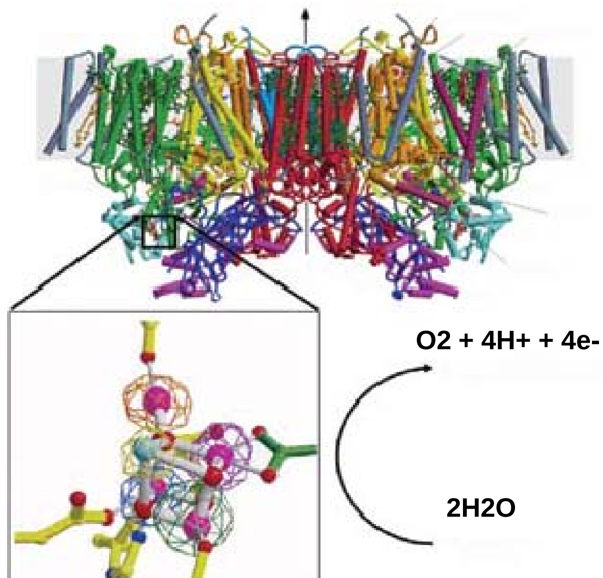
- Proprietary four component nano-ink used by *Nanosolar*
- Co-sponsorship by founders of Google and by DOE
- Low cost top layer handles order of magnitude higher current
- Bottom foil layer is 20 times more conductive than typical stainless steels
- Handles 5-10 times higher current than other thin films

Organizing Around a New Vision for Basic Energy Science

"Imagine a virtually unlimited supply of electrical power from solar-energy systems, modeled on the photosynthetic processes utilized by green plants, and power lines that could transmit this electricity from the deserts of the southwest to the Eastern Seaboard at nearly 100 percent efficiency. If the technological advances in information of the 20th century serve as a guide, disruptive advances borne out of pushing the science frontiers will be a key to addressing 21st century energy challenges."



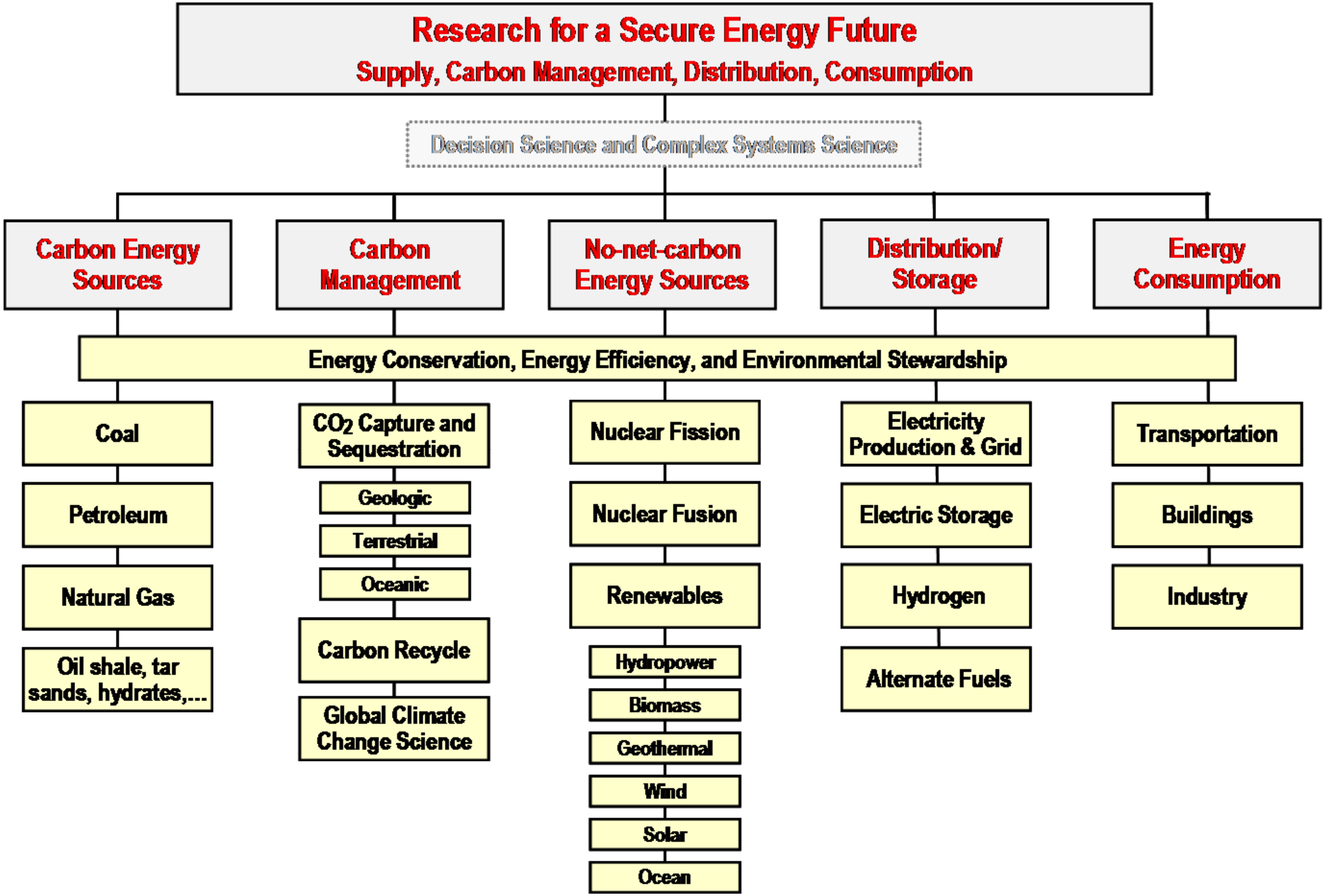
Direct conversion of solar energy to electricity and chemical fuels



The natural photosynthetic system of a green leaf provides the biological inspiration for artificial systems designed to do what a plant does: split water into molecular oxygen and hydrogen fuel.

(Derived from Figures 1 and 5 of K.N. Ferreira, T.M. Iverson, K. Maghlaoui, J. Barber, and S. Iwata, "Architecture of the photosynthetic oxygen-evolving center," Science ***303****, 1831-1838 [2004].)*

A Framework for Exploring Science – Technology Linkages



Can Other Tools Inform IAMs?

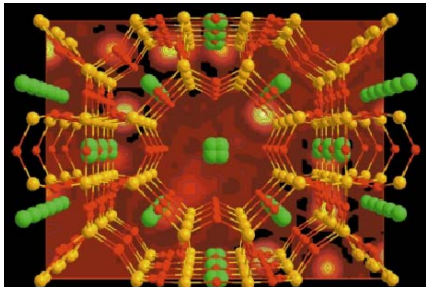
- Science - Technology Mapping – qualitative and quantitative frameworks
- Detailed Linkage and Prioritization Studies
- Foresight Studies & Data Mining
- Citation & Bibliometric Analyses
- Knowledge Diffusion Networks
- Prospective Case Studies
- Expert Elicitation Methods
- Others

Science - Technology Mapping

Example: Clean Fuels

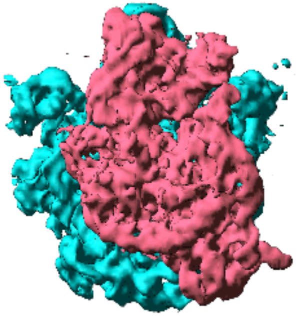
Catalysis for Efficient Pathways

Molecular understanding of catalysts for petroleum refining and chemical manufacturing…. catalysis of carbon-hydrogen bonds….catalysis for fuel cells…biocatalysis



Bio-fuels Through Microbial Conversion

Organisms and processes for conversion of lignocellulosics into fuels…biochemistry… bioenergetics microbial fermentation…..

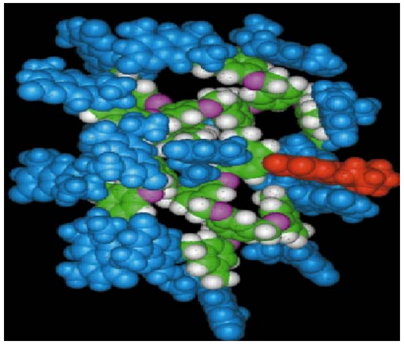


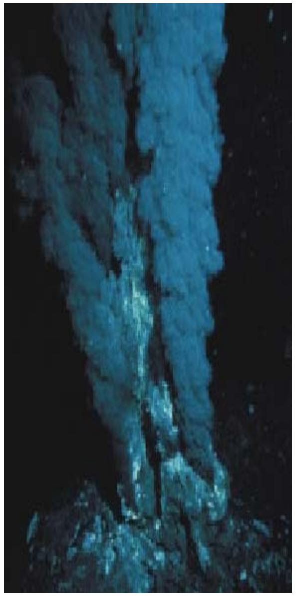
Improved Fuel Feedstocks Through Plant Biology

Genetic, metabolic, and enzymatic properties of plants supporting biomass fuels….. regulation of photosynthetic processes…biochemistry … bioenergetics…

New Approaches for Capturing Solar Energy

Photochemical processes for solar energy conversion….. ….photocatalysis …. foundations for future efficient light energy to chemical energy conversions…





Hydrogen/Clean Fuel Systems through Exotic Microbial Processes

Genetic components that regulate methane and hydrogen producing organisms….enzymatic processes for possible fuel conversion….possible exploitation of extremophiles to ingest feedstocks, sequester carbon, and give off hydrogen…

Detailed Linkage and Prioritization Studies

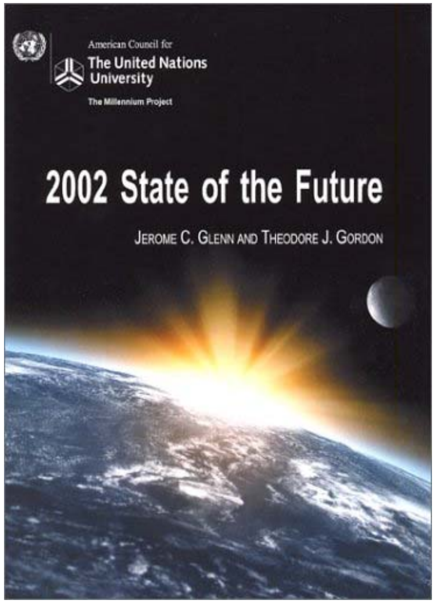
- Basic Research Needs to Assure a Secure Energy Future
  BESAC Workshop, October 21-25, 2002
  The foundation workshop that set the model for the focused workshops that follow.
- Basic Research Needs for the Hydrogen Economy
  BES Workshop, May 13-15, 2003
- Nanoscience Research for Energy Needs
  BES and the National Nanotechnology Initiative, March 16-18, 2004
- Basic Research Needs for Solar Energy Utilization
  BES Workshop, April 18-21, 2005
- Advanced Computational Materials Science: Application to Fusion and Generation IV Fission Reactors
  BES, ASCR, FES, and NE Workshop, March 31-April 2, 2004
- The Path to Sustainable Nuclear Energy: Basic and Applied Research Opportunities for Advanced Fuel Cycles
  BES, NP, and ASCR Workshop, September 2005
- Basic Research Needs for Superconductivity
  BES Workshop, May 8-10, 2006
- Basic Research Needs for Solid-state Lighting
  BES Workshop, May 22-24, 2006
- Basic Research Needs for Advanced Nuclear Energy Systems
  BES Workshop, July 31-August 3, 2006
- Basic Research Needs for the Clean and Efficient Combustion of 21st Century Transportation Fuels
  BES Workshop, October 30-November 1, 2006
- Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems
  BES Workshop, February 21-23, 2007
- Basic Research Needs for Electrical Energy Storage
  BES Workshop, April 2-5, 2007
- Basic Research Needs for Materials under Extreme Environments
  BES Workshop, June 10-14, 2007
- Basic Research Needs for Catalysis for Energy
  BES Workshop, August 5-10, 2007

Foresight Studies and Data Mining

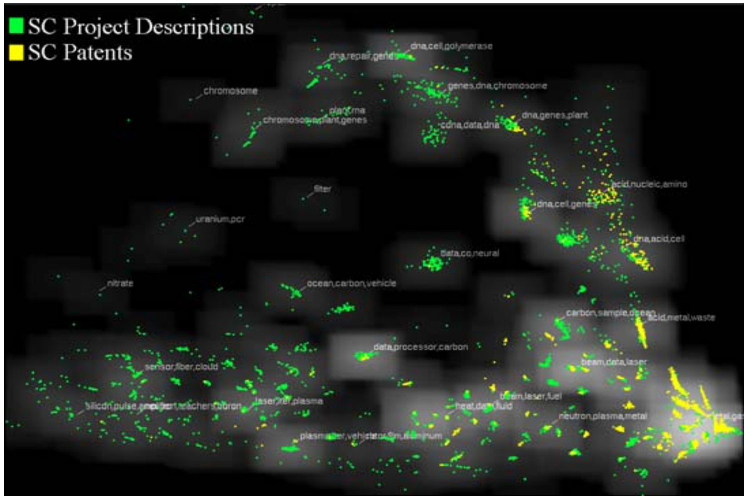
Foresight Studies

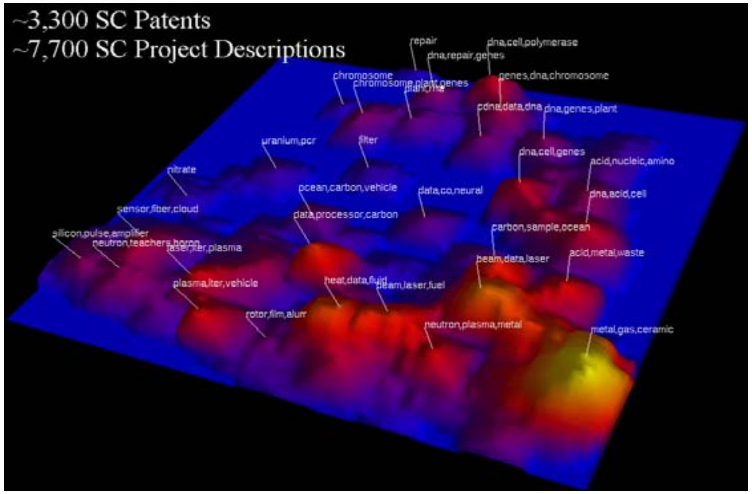
*The 2002 edition of the **State of the Future** addresses in a coherent and forward-looking way many of the issues that impact on the evolution of our planet and the people living on it. At a time of accelerating globalization and an increasing need to organize our societies accordingly, it is essential for policy-makers at all levels to be able to rely on such solid analysis of global trends. The study is a good example of building collective intelligence based on a large network across the world.*

Philippe Busquin, Commissionner for Science & Technology
The European Commission



Data Mining (Patent Analysis Shown Below)



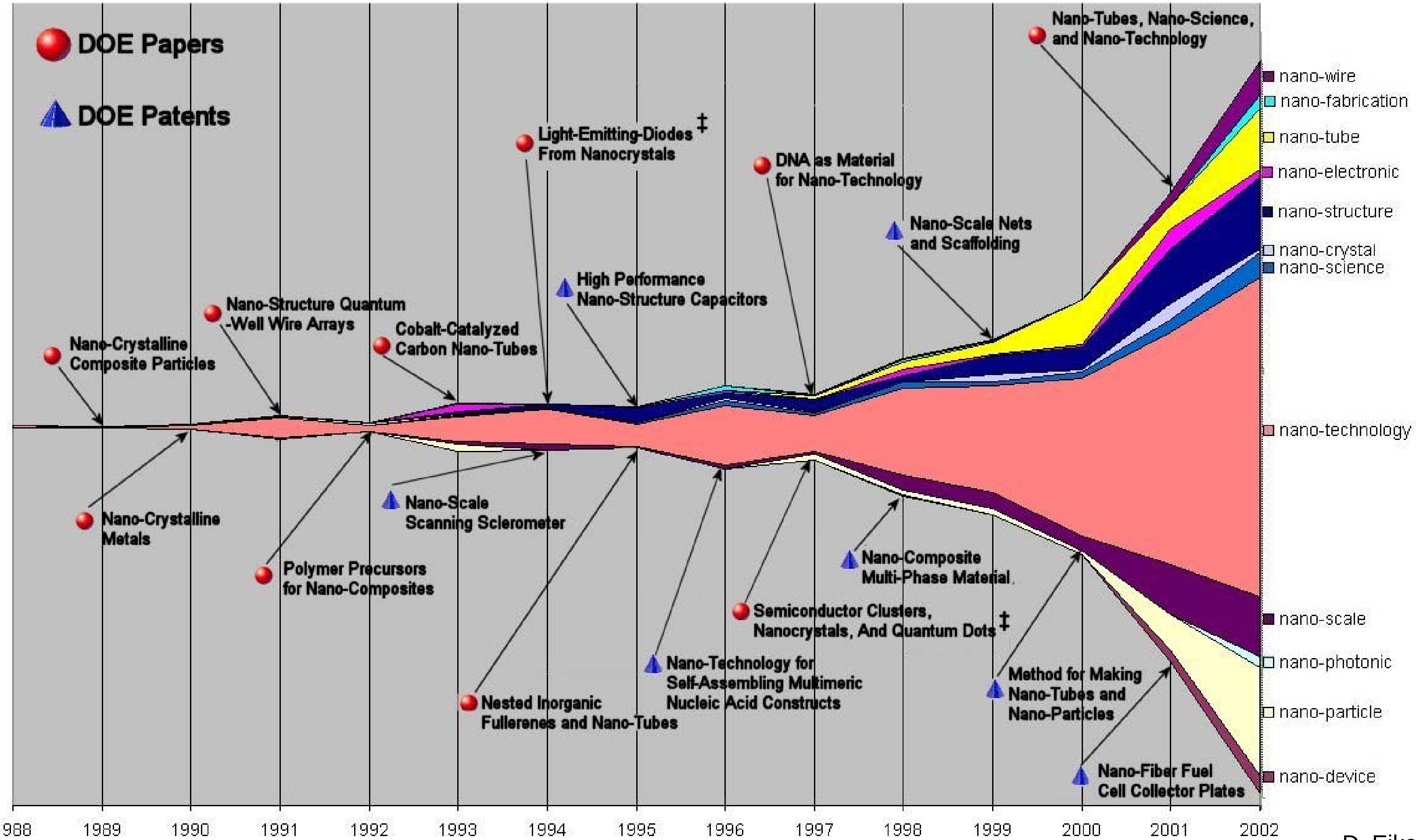


D. Eike, et.al

Research Supported by DOE: B. Valdez

Citation & Bibliometric Analyses

Emergence of the Term "Nano" in the Open Literature and Growth/Decline of Specialty Terms as One Possible Indicator of Maturity Levels or Transformation*



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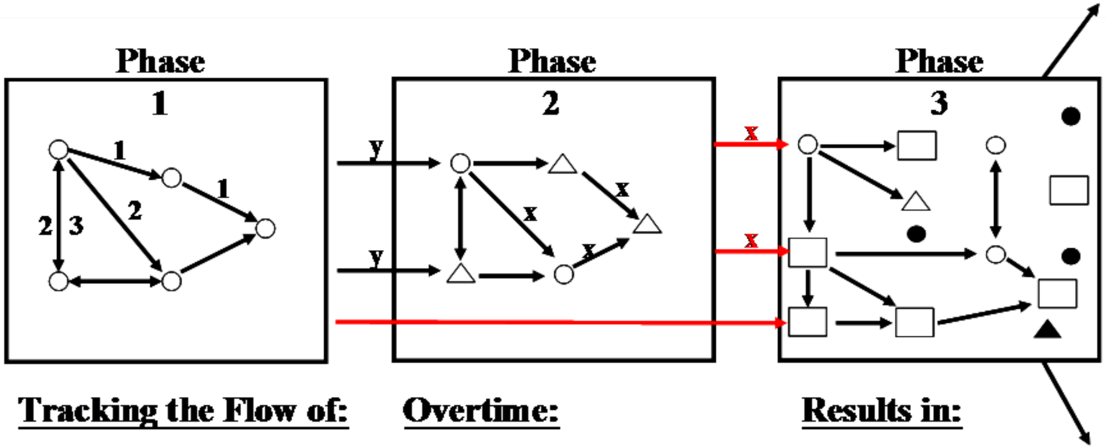
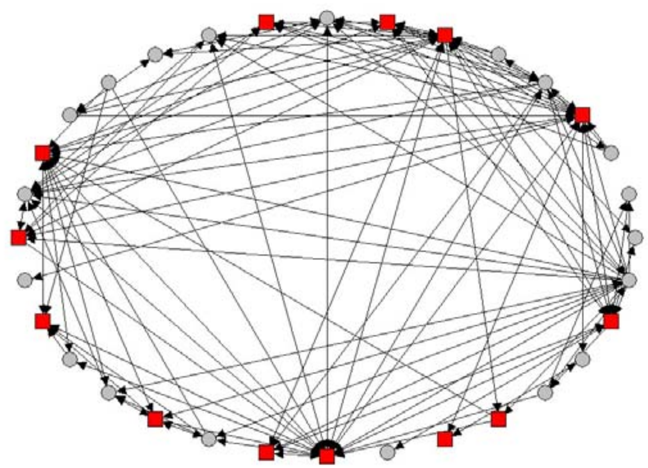
Knowledge Diffusion Networks



Tracking the Flow of:	Overtime:	Results in:
People	Linkages Grow	New Networks
Funding	Networks Expand	New Ideas
Discipline	Disciplines Evolve	New Products
Project	Knowledge Grows	New Disciplines
Application		
Projects		

Example: Knowledge diffusion network analysis as a potential predictor of impact (Collaboration MICS – Phase 3)
Red squares = MICS funding;
Gray Circles= no MICS



Implications for IA

- Analysis of the past and present has value in projecting innovation trends.
- Are these methods predictive of the future – NO!
- Can these and other analytic methods inform IAM's? Conceivably.
- Are they better than straightforward expert elicitation techniques? Time will tell. Perhaps better used as inputs into expert processes.
- NO SILVER BULLET for predicting paradigm shifts.

Summary

- IAMs are useful tools for R&D priority setting
  - DOE has adjusted its applied technology portfolio based on insights gained from IAMs
- Need to explore how IAMs can be informed by and reflect deeper insights about the potential for transformational changes
  - Input parameters, innovation interdependencies, cross-sectoral and/or resource issues (e.g., material flows, water resources, etc.), evaluation of complementary tools.
- Might be informative to conduct one or more case studies using IAMs and supplemental information/evaluations
  - For example, a highly solar/electrified economy. How do the models behave? What are the implications for the grid, other aspects of the energy system. Vulnerabilities and/or surprises?

BACKUPS

Managing Innovation as a Continuum… While Recognizing it is Non-Linear

Grand Challenge Research	Discovery Research	Use-Inspired Basic Research	Applied Research	Technology Maturation & Deployment
▪ Basic research to address fundamental limitations of current theories and descriptions of matter in the energy range important to everyday life – typically energies up to those required to break chemical bonds.	▪ Basic research for fundamental new understanding on materials or systems that may revolutionize or transform today's energy technologies	▪ Basic research for fundamental new understanding, usually with the goal of addressing showstoppers on real-world applications in the energy technologies	▪ Research with the goal of meeting ***technical milestones***, with emphasis on the development, performance, cost reduction, and durability of materials and components or on efficient processes ▪ Proof of technology concepts	▪ Scale-up research ▪ At-scale demonstration ▪ Cost reduction ▪ Prototyping ▪ Manufacturing R&D ▪ Deployment support

Goal: new knowledge / understanding
Focus: phenomena
Metric: knowledge generation

Goal: practical targets
Focus: performance
Metric: milestone achievement