Retrospective and Prospective Reviews of Department of Energy Applied R&D Programs by the Board on Energy and Environmental Systems of the The National Academies and the National Research Council

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Background

- Three Reports Evaluating Benefits of Applied R&D

\# 1. 20-Year Retrospective Evaluation of Applied DOE R&D (EE & FE) (2001)

   » Have the Benefits of the Programs Justified the Expenditure of Public Funds Since DOE's Formation in 1977?

\# 2. Prospective Evaluation of Future Benefits of Ongoing DOE Applied R&D, Phase One (2005)

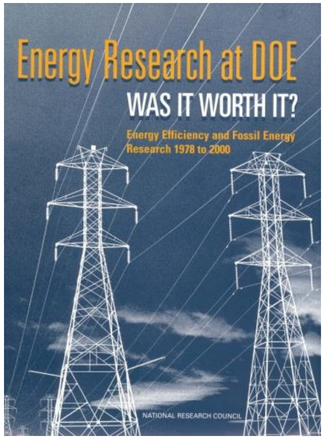
   » Adapting the Retrospective Methodology to a Prospective Construct

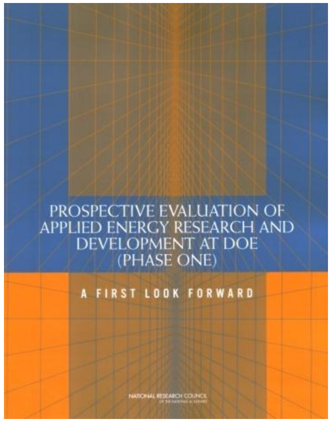
\# 3. Prospective Evaluation of DOE Applied R&D, Phase Two (2007)

   » Refines Methodology from Phase One

   » Conducts Six Case Studies of DOE Programs

Report #1





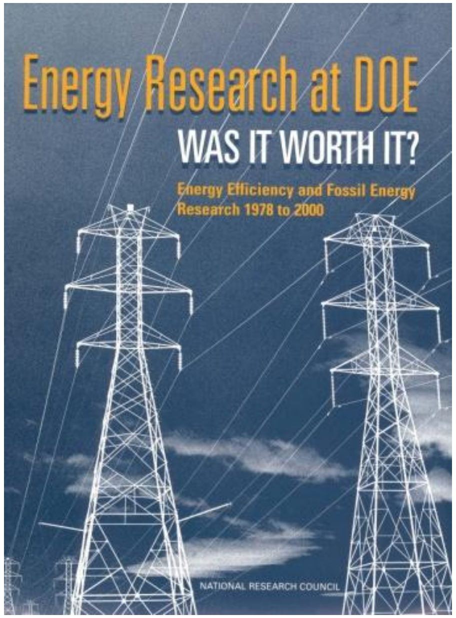
Report #2

Report #3

Report #1 – Retrospective R&D Evaluation

- **Scope:**
  - Examine DOE's Energy Efficiency and Fossil Energy Programs
  - Examine Research Funded 1978-2000

- **Tasks:**
  - Assess the Benefits and Costs of Energy R&D
  - Develop an Analytic Framework for Conducting Such Assessments
  - Evaluate 39 Randomly Selected Case Studies
    - » 22 FE R&D Programs
      - $11B out of $15B budget
    - » 17 EE R&D Programs
      - $1.6B out of $7.3B budget



Public Benefits Related to DOE Mission

Economic benefits and costs	***Change in total value of goods and services in the U.S. economy (under "normal" conditions) made possible by the technological advances stemming from the R&D program. (The 2005 rule!!)****
Environmental benefits and costs	***Change in the quality of the environment made possible by the new technology***
Security benefits and costs	***Change in the probability or severity of adverse abnormal events made possible by the new technology***

*__The 2005 Rule__: Realized economic benefits should include the results of the life-cycle operation of all capital stock utilizing the Technology that has been installed through the year 2000 and that is projected to be installed through 2005

Evaluating Benefits for Technological, Policy and Economic Uncertainty

Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Benefits are almost certain; technology has been developed and conditions are favorable for deployment	*Technology has been developed; conditions are not currently favorable for deployment, but may be later*	*All other potential benefits*

Study Methodology

- Case Study Approach Used:
  - 22 Fossil Energy Programs
    - » Comprised 73% of FE Budget
  - 17 Energy Efficiency Programs
    - » Comprised 20% of EE Budget
  - Examined "Representative" Programs

Note: The Committee's study was retrospective and should not be viewed as necessarily providing judgment on ongoing DOE energy R&D programs

Scope of Retrospective Study

Fossil Energy Technologies

1. Coal Preparation
2. Direct Coal Liquefaction
3. Fluidized-bed Combustion
4. Gas-to-Liquids Technology
5. Improved Indirect Liquefaction
6. Integrated Gasification Combined Cycle
7. Flue Gas Desulfurization
8. NOx Emissions Control
9. Mercury and Air Toxics
10. Waste Management/Utilization Technologies
11. Advanced Turbine Systems
12. Stationary Fuel Cell Program
13. Magnetohydrodynamics
14. Coal-bed Methane
15. Drilling, Completion, and Stimulation Program
16. Downstream Fundamentals Research Program
17. Eastern Gas Shales Program
18. Enhanced Oil Recovery
19. Field Demonstration Program
20. Oil Shale
21. Seismic Technology
22. Western Gas Sands Program

Energy Efficiency Technologies

1. Advanced Refrigeration
2. Compact Fluorescent Lamps
3. DOE-2 Energy Analysis Program
4. Electronic Ballasts
5. Free-piston Stirling Engine Heat Pump (Gas-Fired)
6. Indoor Air Quality, Infiltration, and Ventilation
7. Low-emission (Low-e) Windows
8. Lost Foam Technology
9. Advanced Turbine Systems Program
10. Black Liquor Gasification
11. Industries of the Future Program
12. Oxygen-fueled Glass Furnace
13. Advanced Batteries for Electric Vehicles
14. Catalytic Conversion of Exhaust Emissions
15. Partnership for a New Generation of Vehicles
16. Stirling Automotive Engine Program
17. PEM Fuel Cell Power Systems for Transportation

The Benefits Matrix

20 – Year Evaluation (1978 – 2000)	Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Economic Benefits and Costs			
Environmental Benefits and Costs			
Security Benefits and Costs			

Example Benefits Matrix – Flue Gas Desulfurization

TABLE F-10 Benefits Matrix for the Improvement of the Flue Gas Desulfurization (FGD) Program[a]

	Realized Benefits/Costs	Options Benefits/Costs	Knowledge Benefits/Costs
Economic benefits/costs	DOE R&D costs: $107 million[b] DOE Clean Coal Technology Demonstration costs: $117 million Private industry R&D costs: $37 million+[c] Private industry Clean Coal Technology Demonstration costs: $264 million[d] Estimated benefits: $1 billion[e]	DOE has demonstrated higher removal efficiency than first-generation technology; advanced multipollutant emission control technologies at lower capital cost than the first-generation FGD system	Research conducted in chemistry, thermodynamics, reaction kinetics, sorbent structural properties, and process control instrumentation
Environmental benefits/costs	Technology improvements result in 2-million-ton reduction in SO_2[f]	Second-generation FGD technology has been demonstrated and is ready for full-scale deployment Advanced FGD technology is available for retrofit, and new plants with 90+% removal efficiency for full range of U.S. coals, as well as some trace toxic species such as selenium, cadmium, and organic compounds[g]	Developed advanced technologies for multipollutant emission control at >90% efficiency
Security benefits/costs	None	None	None

[a]Unless otherwise noted, all dollar estimates are given in constant 1999 dollars through 2000.

[b]In addition, EPA sponsored approximately $100 million in FGD RD&D from the 1970s through the mid-1980s.

[c]Including the EPRI high-sulfur test center.

[d]This is the current dollar total, exclusive of site-sharing expenses.

[e]FE contends that the cumulative life-cycle economic benefits resulting from reduced FGD capital and operating costs for coal-fired plants that currently use FGD total $4.8 billion.

[f]FE contends that the cumulative life-cycle value of excess SO_2 removal is $841 million (based on the Cantor Fitzgerald SO_2 allowance value of $128/ton), that the cumulative emission benefits for the life cycle of FDG installations is 7.1 million tons of SO_2, and that the health-based life cycle SO_2 benefits (based on a health value of $7255/ton of SO_2 removed) total $47.6 billion.

[g]In addition, some of the advanced technologies yield valuable by-products that do not have to be landfilled. Both elemental sulfur and sulfuric acid by-products can be produced, and optimized integration into the power plant cycle may reduce ancillary power requirements and further reduce production of pollutants, as well as CO_2.

Realized Benefits and Costs (Economic)

- **ENERGY EFFICIENCY:**
  - **1978 to 2000 Net Realized Economic Benefits of $30B vs. Costs of $7B**

- **FOSSIL ENERGY:**
  - **1978 to 1986 (with Alternate Fuels Projects): Benefits of $3B vs. Costs $6B**
  - **1986 to 2000: Benefits of $7.4B vs. Costs $4.5B**
  - **1978 to 2000 Net Realized Economic Benefits of $11B vs. Costs of $11B.**

Note: Benefits are calculated only from case studies. Costs are total R&D for all of EE and FE including projects not examined as part of case studies.

Realized Benefits and Costs (Environmental)*

TECHNOLOGY:	SO_2 (million metric tonnes)	NO_x (million metric tonnes)	Carbon (million metric tonnes)
Energy Efficiency:			
Advanced Refrigeration	**0.4**	**0.2**	**20**
Electronic Ballasts	**0.7**	**0.4**	**40**
Low-E glass	**0.3**	**0.2**	**20**
Advanced Lost Foam Casting	**0.01**	**0.006**	**0.5**
Oxygen-fueled glass furnace		**0.02**	**1**
Advanced Turbines		**0.02**	**1**
Fossil Energy:			
Flue Gas Desulfurization	**1.81**		
NO_x Control		**23.6**	

*** As of Year 2000**

Realized Benefits and Costs (Security)*

- National Security has been Enhanced by a Number of the Programs:
  - Mostly benefits from Fossil Energy programs to increase domestic oil production of reserves.
  - Benefits from Energy Efficiency programs have potential to reduce oil consumption and enhance electricity reliability
  - But research programs to reduce dependence on oil for transportation sector have been disappointing so far in realized benefits.

* As of Year 2000

Summary of Conclusions

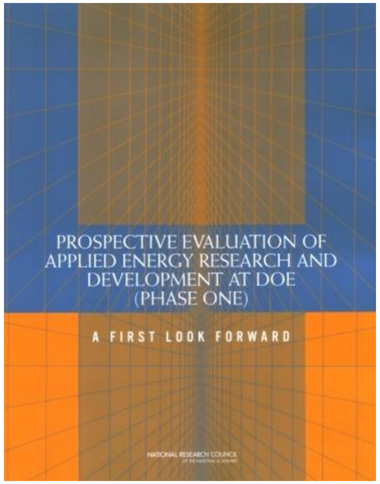
20 – Year Assessment 1978 - 2000	Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Economic benefits and costs (1999 $)	EE: benefits- $30B; costs - $7B FE: benefits - $11B; costs - $11B	Waiting technologies with promise: ATS, IGCC, PNGV, IOF	All the technologies funded by DOE.
Environmental benefits and costs	Substantial: $60B - $90B	(ditto, econ option benefits)	add to stock of knowledge in varying degrees
Security benefits and costs	Very modest increases in petroleum supply.	Possible impact from PNGV	

NAS Report Commentary on Evaluating Benefits and Costs

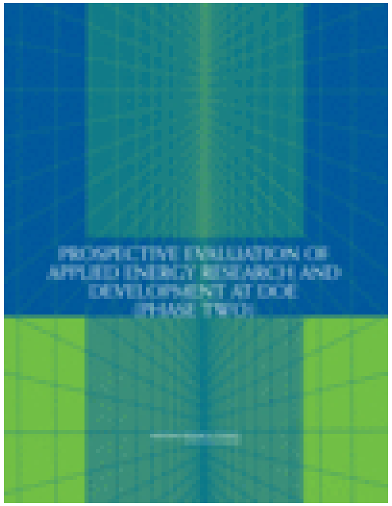
- **Present system of evaluation lacks clear rules, consistency and transparency**
- **Framework adopted for this study provides necessary rigor, and should be adopted as uniform method for reporting outcomes of R&D**
- **The analytic framework developed for this study provides a simple but effective means for assessing DOE program goals and progress**
- **Committee's experience builds confidence that the approach works, but also indicates need for further refinement to make it as useful as possible**

Reports 2 & 3 -- Prospective Evaluation of R&D

- Report # 2 – Refined Methodology (Phase One)
  - » Focused on Adapting the Retrospective Methodology to a Prospective Construct



- Report # 3 – Eval. of Selected R&D (Phase Two)
  - » Refines the Methodology From Phase One
  - » Conducts Six Case Studies of DOE Programs
    - IGCC Technology Program
    - Carbon Sequestration Program
    - Natural Gas Exploration and Production R&D Program
    - Distributed Energy Resources Program
    - Light-Duty Vehicle Hybrid Technology
    - Chemical Industrial Technologies Program



- As a "Prospective" Study, Evaluation Focuses on "Expected" vice "Realized" Benefits

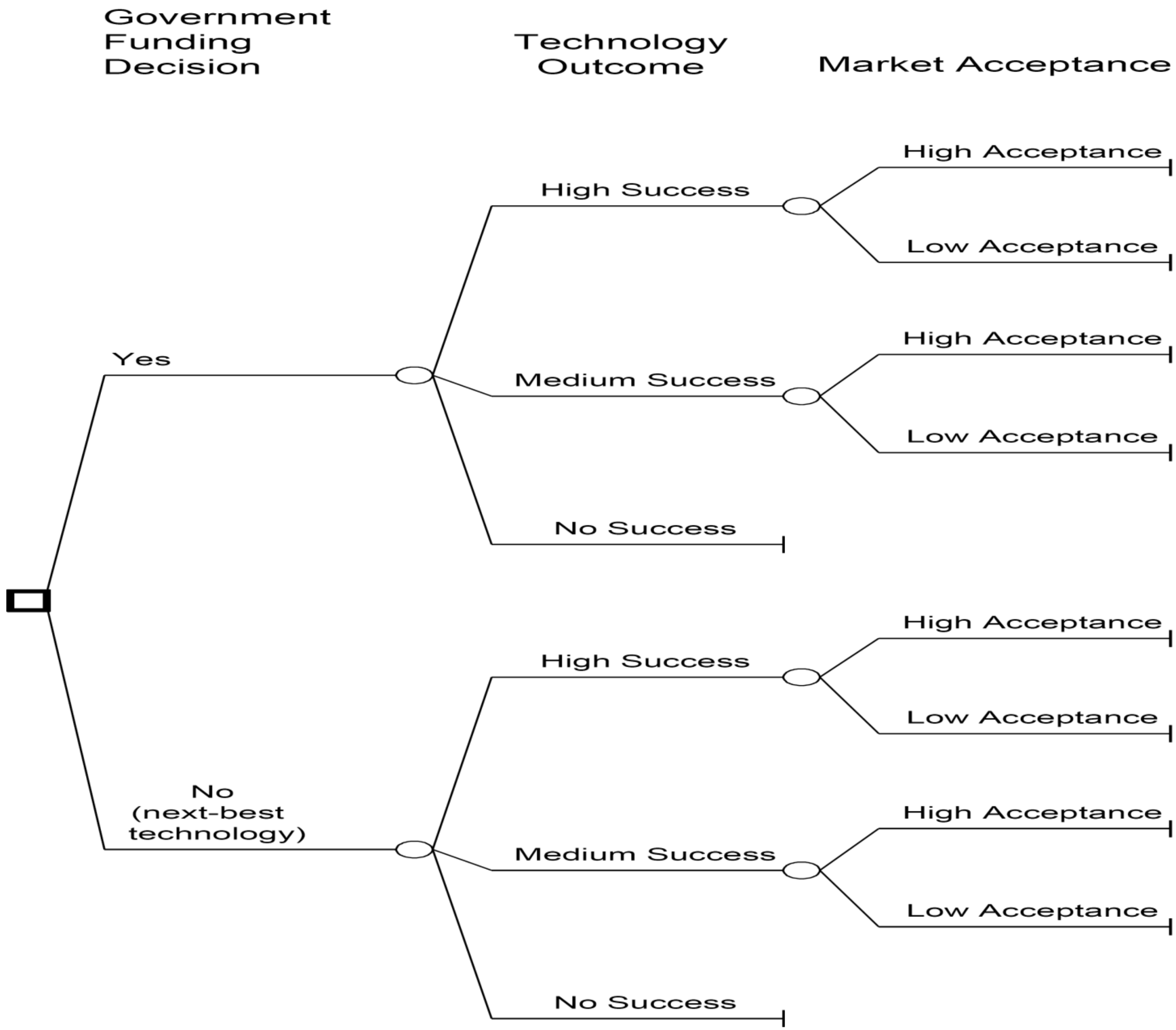
Refined Methodology (Phase 1 & 2)

- **Accounts for Technical and Market Risks**
- **Attributes Benefits to Program Investments**
  - **Expert Panels Estimate Benefits With and Without DOE's R&D Investments and Take the Difference**
- **Quantifies Expected Economic Benefits**
  - **Simple Spreadsheet Models are Used Where Possible, Calibrated to NEMS Outputs**
  - **Monetization of Reduction in air Emissions Based on Permit-Trading Prices; Express Other Pollutant and CO2 Reductions as Tons**
- **Quantifies Expected Security Benefits**
  - **Expresses Decrease in oil and gas Consumption as Physical Volume or Btu; Describes State of oil Market in Which Benefits Occur**

Decision Tree Approach

- **Benefits Conditional on Multiple Events, Each Subject to Probabilistic Outcome**
- **Multiple Potential Program Technological Outcomes**
  - **DOE Programs Often Have "Stretch Goals," but Even When These are not Achieved, Some Technological Improvements may Result from the Program**
- **Multiple Potential Outcomes in Competing Technologies**
  - **The Market Success Depends on *Both* What Happens in the Government Program and What Happens Outside it: a Mediocre Government Result may be Economically Successful if the "Next-Best-Alternative" is also Unattractive.**
- **Technology may Develop With or Without Government Program**
  - **Calculating Program Benefit Requires That it be Compared to What Would Happen in its Absence Rather Than Simply Evaluating the Rate of Return (the Standard for Private Sector Investments).**

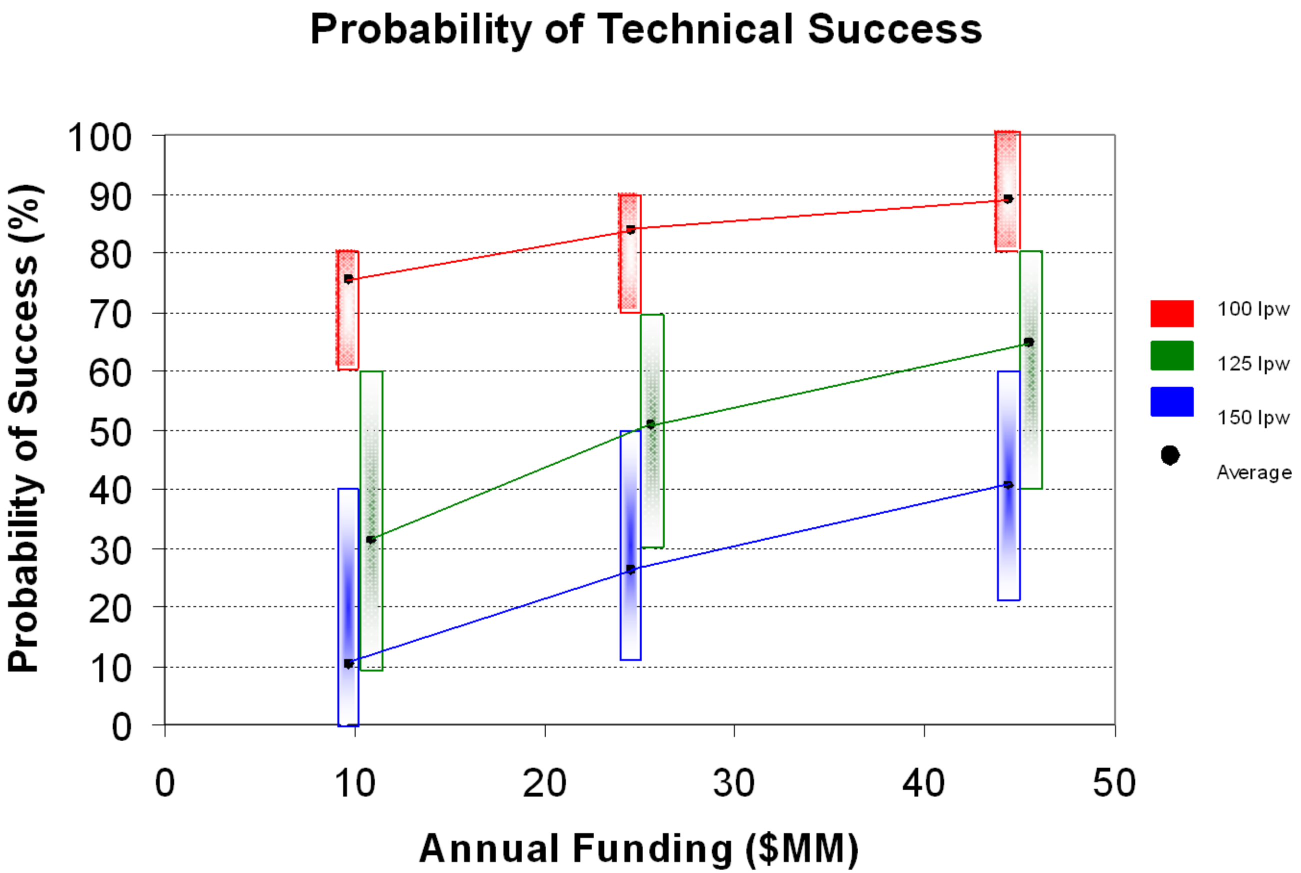
Decision Tree



Benefits are Calculated in Three or More Scenarios

- **For Consistency, all Programs Were Evaluated Under Each of Three Standard Scenarios:**
  - **Reference Case – The AEO "Base Case"**
  - **High Oil and Gas Prices**
  - **Carbon Constrained**
- **Panels Encouraged to Explore Whether Technologies Might be Valuable Under a Specialized Fourth Scenario, as Defined by the Panel**
  - **Evaluate Benefits Under the Three Standard *and* any Optional Scenario and Include in Summary Matrix**
- **Both the Risks and Benefits of a Program may Differ Under the Different Scenarios**
- **Consultant Helped with Decision Tree Approach**

Accounting for Technical Risks – Lighting Panel Estimates



Lighting Program Tree, at R&D Budget of $10M/year

	DOE Program Investment	DOE/US Industry Success Level	Asian Success Level	Probability	Benefits	Contribution to Expected Benefits
			150 Lumens/Watt	0.005	$4,803,077,819.0	$24,015,389
		150 Lumens/Watt	125 Lumens/Watt	0.05	$4,926,233,661	$246,311,683
			No Change	0.045	$4,926,233,661	$221,680,515
Expected Cost Reductions			150 Lumens/Watt	0.02	$4,679,921,978	$93,598,440
$2,965,592,664	Yes	125 Lumens/Watt	125 Lumens/Watt	0.2	$3,602,308,364.3	$720,461,673
			No Change	0.18	$3,694,675,245	$665,041,544
			150 Lumens/Watt	0.025	$4,679,921,978	$116,998,049
		No Change	125 Lumens/Watt	0.25	$3,509,941,483	$877,485,371
			No Change	0.225	0	$0
			150 Lumens/Watt	0	$4,803,077,819.0	$0
		150 Lumens/Watt	125 Lumens/Watt	0	$4,926,233,661	$0
			No Change	0	$4,926,233,661	$0
Expected Cost Reductions			150 Lumens/Watt	0	$4,679,921,978	$0
$2,323,027,061	No	125 Lumens/Watt	125 Lumens/Watt	0.15	$3,602,308,364.3	$540,346,255
			No Change	0.15	$3,694,675,245	$554,201,287
			150 Lumens/Watt	0	$4,679,921,978	$0
		No Change	125 Lumens/Watt	0.35	$3,509,941,483	$1,228,479,519
			No Change	0.35	0	$0
Expected Value of Gain From DOE Program (Millions of Dollars):					**$643**	

Lighting Program Tree, at R&D Budget of $40M/year

	DOE Program Investment	DOE/US Industry Success Level	Asian Success Level	Probability	Benefits	Contribution to Expected Benefits
			150 Lumens/Watt	0.02	$4,803,077,819.0	$96,061,556
		150 Lumens/Watt	125 Lumens/Watt	0.2	$4,926,233,661	$985,246,732
			No Change	0.18	$4,926,233,661	$886,722,059
Expected Cost Reductions			150 Lumens/Watt	0.02	$4,679,921,978	$93,598,440
$3,844,925,372	Yes	125 Lumens/Watt	125 Lumens/Watt	0.2	$3,602,308,364.3	$720,461,673
			No Change	0.18	$3,694,675,245	$665,041,544
			150 Lumens/Watt	0.01	$4,679,921,978	$46,799,220
		No Change	125 Lumens/Watt	0.1	$3,509,941,483	$350,994,148
			No Change	0.09	0	$0
			150 Lumens/Watt	0	$4,803,077,819.0	$0
		150 Lumens/Watt	125 Lumens/Watt	0	$4,926,233,661	$0
			No Change	0	$4,926,233,661	$0
Expected Cost Reductions			150 Lumens/Watt	0	$4,679,921,978	$0
$2,323,027,061	No	125 Lumens/Watt	125 Lumens/Watt	0.15	$3,602,308,364.3	$540,346,255
			No Change	0.15	$3,694,675,245	$554,201,287
			150 Lumens/Watt	0	$4,679,921,978	$0
		No Change	125 Lumens/Watt	0.35	$3,509,941,483	$1,228,479,519
			No Change	0.35	0	$0
Expected Value of Gain From DOE Program (Millions of Dollars):					**$1,522**	

Refined Benefits Matrix for Prospective Evaluation

		Global Scenarios		
		Reference Case	High Oil/Gas Prices	Carbon Constrained
Program Risks	Technical Risk			
	Market Risks			
Expected Program Benefits	Economic Benefits			
	Environmental Benefits			
	Security Benefits			

Sample Results: Energy Efficiency

Technology (program completion cost)	Expected Benefits		
	Economic (NPV at 3% disc)	Environmental (reduced emissions-tonnes)	Security (reduced consumption)
Chemical IOF ($75M to 2015)	$534M (R) $950M (H) $550M (C)	24,700 CO (all scenarios) 15,000 SO2 22,600 NOx 280 PM 540 VOC 2.87M C equiv	Natural gas: 89 Bcf Petroleum: 1.3 million bbls
Distributed energy resources ($205M to 2015)	$57M (R) $46M (H) $64M (C) $83M ($4^{th}$)	Unknown	primary energy: 10 TBtu (R) 8 TBtu (H) 11 TBtu (C) 15 TBtu (4^{th})
Hybrid vehicles ($567M to 2012)	$5.9B to 7.2B (R) $27.5 to 28.2B (H) $7.3B to 8.5B (C)	28M C equiv (R) 51M C equiv (H) 32M C equiv (C)	million bbls gasoline: 219 (R) 398 (H) 248 (C)

R=reference scenario; H=high oil & gas prices; C=carbon constrained; 4^{th}=electricity constrained

Sample Results: Fossil Energy

Technology (program completion cost)	Expected Benefits		
	Economic (NPV at 3% disc)	Environmental (reduced emissions-tonnes)	Security (reduced consumption)
Natural gas E&P ($140M to 2015)	$220M (R) $590M (H) $300M (C)	Not quantified—reduction in disturbed land area	1.2 Tcf (R) .6 Tcf (H) 1.2 Tcf (C)
IGCC ($750M to 2020)	$6.4B to 7.8B (R) $7B to 47B (H)	-90M to 30M C equiv (R) 34M to 36M C equiv (H)	4.5 Tcf natural gas (R) 3.6 Tcf natural gas (H) (if NGCC displaced)
Sequestration ($875M to 2020)	$3.5B ($100/tC) $3.9B ($300/tC)	zero—next best technology also zero-carbon emission	zero

R=reference scenario; H=high oil & gas prices; C=carbon constrained

Challenges for Prospective Benefits Study

- **Capturing and Measuring the Wide Variety of Benefits and Risks**
  - **Complex Technologies – Uncertainty About Technical Success**
  - **Dynamic Marketplace – Uncertainty About Market Success**
  - **Changing Society – Uncertainty About Future Constraints, "State of World"**
- **Determining the Proportion of the Benefits Attributable to DOE Support**
  - **Prorating Benefits When Costs are Shared or When Multiple Components are Required for Success**
  - **Guessing at What Would Have Happened Without DOE Support**

Lessons Learned

- Keep it Simple, Rigorous, and Transparent
- Create a Methodology Applicable to a Broad Range of RD&D Programs
- Methods to Evaluate Benefits Must Apply to Non-Economic Benefits as Well as Economic Benefits
- Data Need to be Available, Accurate and Consistent
- The NEMS Model* is not Well-Suited for Evaluating RD&D at DOE (Although it may Play a Role in the Evaluation).
  - Much Simpler Models Allow Consideration of Different Potential Outcomes, Allow the Evaluation to Focus on Features Important to the Success of the Programs, and are all That can be Justified Given the Quality of the Data and the Extent of Uncertainty
- The Methodology Needs to Force a Comparison Between the Program Outcome or Goal and the Next Best Technology
- Evaluation is Incorporated Into Budget Requests – Need for Clear Measurable Goals and Milestones

National Energy Modeling System (NEMS) of the Energy Information Administration, U.S. DOE.

Lessons Learned (Continued)

- Priorities Depend on Policies and Judgments, not Just Mechanical Application of Cost-Benefit Analysis.
- Consistent Application Improves Quality and Comparability at the Program Level
- Tree/Matrix Clarifies the Sources of Risks, Highlights Critical Components of Program Success.
- Evaluation Exercise Forces Useful Dialogue at High Levels.
- Use of Outside Experts Provides Credibility and Objectivity
  - In Assessing Probabilities and Defining Benefits
  - Allocating Credit to the DOE
- Adequate Resources are Needed to Apply the Methodology Including use of Consultants to Work With all Panels.

Conclusions

- Methodology
  - Committee Endorses Decision Tree Approach With Consultant to Facilitate
  - Global Scenarios Continue to be Valuable
  - Judgments About Success or Failure of Competing and Complementary Technologies Affect Outcome of Assessments
- Process
  - Panels Successfully Applied Methodology
  - DOE Must Support by Providing Needed Info
  - Quality Control Function Important
- Full Implementation
  - 40 Expert Panels/Triennial Rotation (13 Panels/Year)