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National Research Council Studies: Measuring Retrospective and Prospective Benefits of Energy Research at DOE

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Benefits Assessment at the NRC:

- In 2000, the NRC was asked by congress to evaluate the benefits of DOE research in Fossil Energy (FE) and Energy Efficiency (EE) from 1978-2000
- The NRC committee considered 39 case studies:
  - The 22 FE case studies represented almost all of the DOE R&D expenditures in FE: $11 billion out of $15 billion budget.
  - The 17 EE case studies represented a small sample of a large pool of small projects in EE: $1.6 billion out of $7.3 billion budget.
- In 2003, the NRC was asked by DOE to evaluate *prospective benefits* of DOE energy programs
  - Phase I (2005) developed a methodology
  - Phase II (2007) reported on experience applying the methodology to 6 projects

The retrospective methodology was built around the benefits matrix

	Realized Benefits and Costs	Options Benefits and Costs	Knowledge Benefits and Costs
Economic benefits and costs			
Environmental benefits and costs			
Security benefits and costs			

Understanding the classes of benefits represented by the rows of the matrix

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 five year 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 columns reflect different degrees of uncertainty about the benefit

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*

Broad summary of conclusions

	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	

Benefits matrix for the Flue Gas Desulfurization Program

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.

Benefits matrix for the Improved Indirect Liquefaction Program

TABLE F-8 Benefits Matrix for the Improved Indirect Liquefaction Program[a]

	Realized Benefits/Costs	Options Benefits/Costs	Knowledge Benefits/Costs
Economic benefits/costs	DOE RD&D costs: $320 million[b] Industry cost share: $164 million[c] No realized economic benefits	Improved state-of-the-art technology could be deployed when economics are favorable and the price of oil increases sufficiently[d] Plant integration to coproduce fuels and electricity improves economics Liquid Phase Methanol Process demonstrated[e]	Enhanced knowledge of novel catalysts and reactor designs Advances in gas separations, Fischer-Tropsch synthesis, carbon sequestration technology, and reductions in process contingencies Advances relating to petroleum hydroprocessing
Environmental benefits/costs	No benefits	If CO_2 is sequestered, total fuel cycle emissions are less than for petroleum, and there are potential significant carbon savings compared with other conventional coal and gas options[f] Can produce gasoline and diesel fuels that exceed proposed EPA tier 2 sulfur specifications	Development of knowledge base to produce clean fuels from coal in an environmentally acceptable manner
Security benefits/costs	No benefits	Fuels from coal would displace oil use	None

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

[b]Total includes $224 million in R&D funds and $96 million for the Liquid-Phase Methanol Clean Coal Demonstration Project.

[c]Total includes $38 million in R&D funds (17 percent cost share) and $126 million for the Liquid-Phase Methanol Clean Coal Demonstration Project (57 percent cost share).

[d]FE estimates that, assuming successful integration of all process components at the commercial scale, coproduction plants producing electric power and ultraclean fuels may be competitive at a world oil price of about $33/bbl, and that, with appropriate technical advances, coproduction with CO_2 sequestration may be competitive at a world oil price of about $25/bbl. However, knowledgeable experts question whether the technology would be competitive with oil at that price.

[e]A demonstration project has been successfully operating at the Eastman Chemical manufacturing complex in Kingsport, Tennessee, since 1997 and is scheduled to be completed in 2003.

[f]FE gives these numbers but provides no documentation or sources for them.

Benefit Matrix for the Fluorescent Lamp Electronic Ballast Program

	Realized Benefits/Costs	Options Benefits/Costs	Knowledge Benefits/Costs
Economic benefits/costs	DOE R&D costs: $6 million[b] Benefits are substantial: $15 billion[c] Electronic ballasts had captured about 25% of the $1 billion ballast market by 1998 Improved lighting quality (less flicker and hum)	Benefits may be substantial: Nearly all ballasts will be required to be of the electronic type by 2010, and by 2015, electronic ballasts are expected to capture 75% of the market[d] Enabling application of dimming and other lighting controls[e] Future electronic ballasts may incorporate Internet addressable features coupled with wireless control	Development of advanced control systems incorporating advanced ballast technologies, chips, wireless control, integrated daylight and occupancy sensing, etc. Facilitate subsequent development of electronic ballasts for high-intensity-discharge lamps Contributed to broadening of lighting R&D through development of commercial lighting roadmap
Environmental benefits/costs	These ballasts save about 25% of the energy required by conventional magnetic ballasts, reducing energy requirements and the resulting environmental impacts Substantial reduced emissions of carbon, NO_x, and SO_2[f] Avoided emission of suspended particulates from reduced coal emissions	Benefits may be substantial: Lighting consumes 4.8 quads, about 14% of the energy used in buildings. Increased lighting efficiency will decrease energy requirements and pollutant emissions of carbon, NO_x, and SO_2[g] May reduce the number and severity of nonattainment incidents, resulting in improved health Provides increased flexibility in responding to future environmental and energy regulations	Benefits may be substantial if technologies are widely disseminated and diffused
Security benefits/costs	Improved electric system reliability during a period in which electricity infrastructure is expected to be strained	Increased demand-side flexibility to reduce peak loads on congested T&D systems[h]	Provided technical basis for additional research into controllable ballasts

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

[b]Cost-sharing data are not available. However, EE notes that "The successful deployment of the technology in the marketplace required substantial outlays by ballast manufacturers."

[c]EE estimates that reduced net energy bills from sales of electronic ballasts through 2005 will result in savings of $21.9 billion, $13 billion of which is due to a 5-year acceleration of market adoption. This assumes that 20 W is saved by replacing a magnetic ballast with an electronic ballast that has an annual 3200 hr of ballast operation in a lifetime of 45,000 hr.

[d]EE estimates that the ballast efficiency standard adopted on September 19, 2000, will save approximately 2 quads of energy by 2030, resulting in savings to U.S. industry with a net present value of about $2 billion. However, since the ballasts are required by DOE minimum energy efficiency standards, all of the benefits cannot be attributed to R&D.

[e]Especially when used with design software, these save energy by increasing opportunities for day lighting and task-specific lighting, and they also could increase occupant satisfaction with the indoor environment.

[f]Assuming a 5-year acceleration of market penetration and the 1999 marginal fuel mix for electricity, EE estimates that the ballasts have avoided 44.7 million tons of carbon, 410,000 tons of NO_x, and 720,000 tons of SO_2.

[g]Based on the efficiency standard, EE estimates that for 2005 to 2030, the ballasts will avoid 15 million tons of carbon and reduce NO_x emissions by 50,000 tons.

[h]During periods of peak demand (around 4:00 p.m.), electronic ballasts reduce energy demand directly and also indirectly, by reducing cooling loads which are highest on peak.

Benefits Matrix for the Stirling Engine Heat Pump Program

	Realized Benefits/Costs	Options Benefits/Costs	Knowledge Benefits/Costs
Economic benefits/costs	DOE R&D costs: \$30.2 million Industry costs: >\$14 million[b] No realized economic benefits	Minimal benefits, but the technology can be resurrected for further development. One company may be interested.[c] Niche applications[d] Potential to save energy and reduce electricity peak loads[e]	Advances in the technology[f] Development of three different mechanical design concepts Thermal performance goals achieved[g] Basic knowledge with various applications[h] Technical potential demonstrated Understanding of key technical issues and R&D needs
Environmental benefits/costs	None	Minimal[i] Some applications of FPS engine technology[j]	Combustion effluents well understood for natural gas Use of environmentally benign working fluid (hydrogen) has been proven
Security benefits/costs	None	Minimal	Minimal

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

[b]This is the total of industry cost-sharing contributions for 1984 to 1992, the only years for which the data are available. Thus, the total industry cost share for the total program is probably higher.

[c]Natural gas heat pumps can save 40 percent of the energy used by today's best gas and oil heating systems and can reduce summer electric peak loads by providing an alternative energy source for air conditioning. However, other gas heat pump approaches investigated in the DOE program have better potential.

[d]Stirling-driven generators and compressors have a variety of niche applications, and CHP for residential applications of Stirling-engine-driven generators will probably be commercialized in Europe.

[e]Natural gas heat pumps can save 40 percent of the energy used by today's best gas and oil heating systems and can reduce summer electric peak loads by providing an alternative energy source for air conditioning.

[f]There is no doubt that the DOE and GRI investments in Stirling-driven heat pumps advanced the technology, and it is much farther along today than when the program was terminated in 1993.

[g]This concept met the thermal performance goals of the project, demonstrating that such systems could attain the projected efficiency levels and save significant energy.

[h]For example, the knowledge gained during the program about magnetic coupling across hermetic seals is currently being applied to an artificial heart pump by Foster Miller.

[i]Gas heat pumps can reduce energy and electricity use during peak summer cooling periods and have the potential for reducing heat island effects and nonattainment incidents.

[j]Basic FPS engine technology could facilitate the development of solar thermal power generation systems and remote power systems using agricultural waste fuels in developing countries.

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

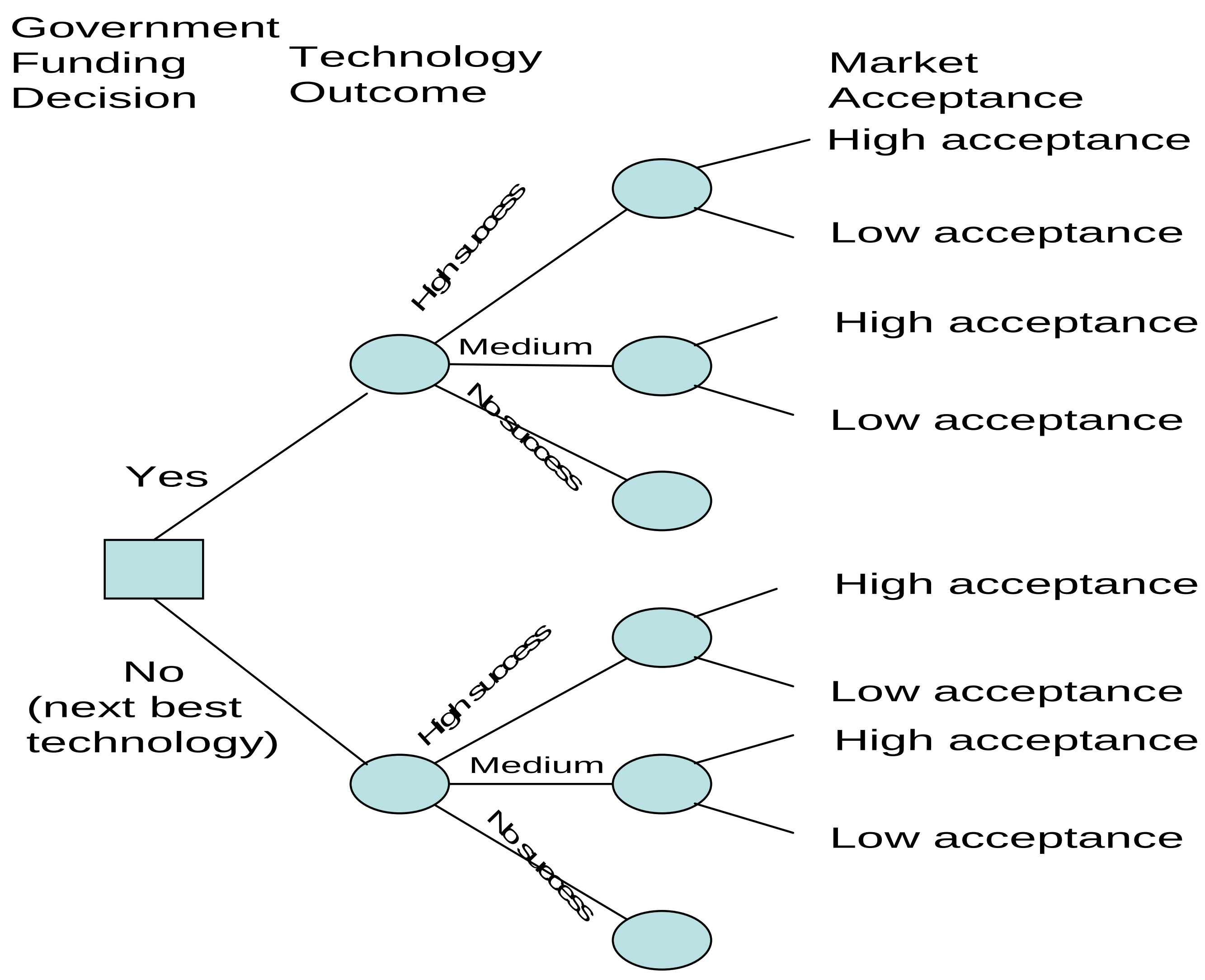
Prospective Benefits Matrix

		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			

- Three scenarios describe possible future states of the world:
  - **Reference Scenario**: A "base case" scenario like the EIA reference case
  - **High Oil and Gas Price Scenario**: US oil and gas prices are persistently higher than current projections
  - **Carbon-sensitive Scenario**: Limiting carbon emissions becomes a regulatory priority
- The risk categories are qualitatively different
  - Scenarios – policy choices; wide range of beliefs
  - Technical risk – scientific, management issues within the program/agency
  - Market risk – activities and technologies external to DOE

Decision Tree Approach to Prospective Benefits Analysis

- 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 investmens).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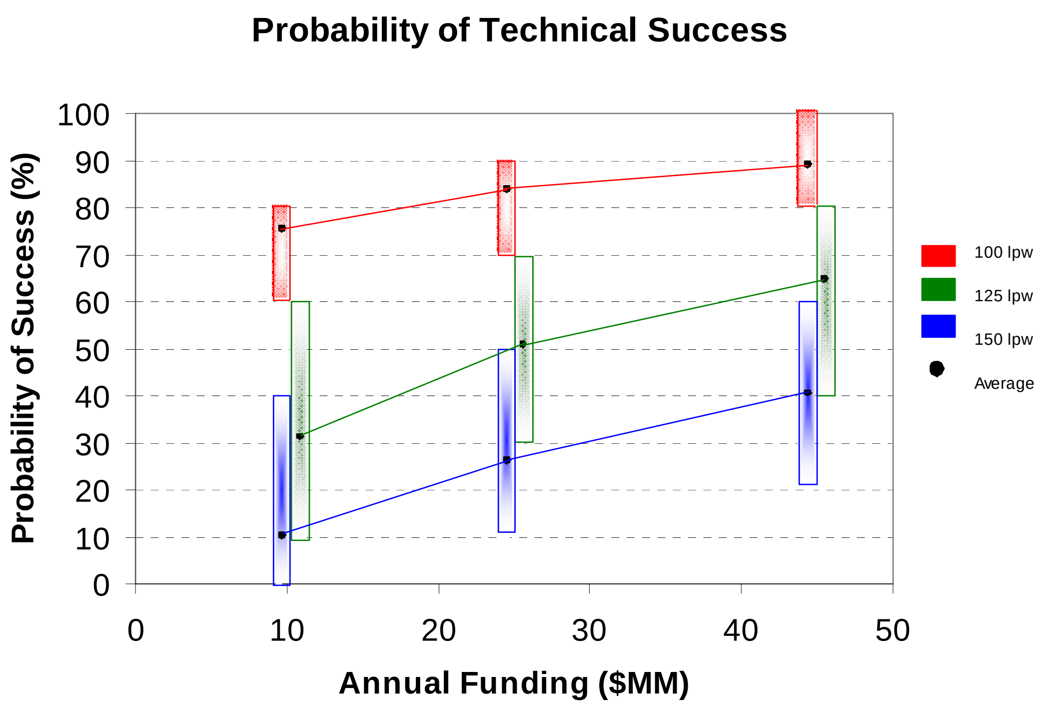
Lighting Panel Estimates



	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**	

Lessons Learned

- Common to Retrospective and Prospective Studies
- Retrospective Study
- Prospective Study

Lessons Learned: Common to Retrospective and Prospective Studies

- 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 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
- Priorities depend on policies and judgments, not just mechanical application of cost-benefit analysis.

Lessons learned from retrospective and prospective analyses, cont.

- Consistent use of the framework enables understanding and evaluation of FE and EE R&D
  - Allows an evaluation of the portfolio of projects in the DOE programs
- Tree/Matrix clarifies the sources of risks, highlights critical components of program success.
- Evaluation exercise forces interaction between FE and EE programs.
- Use of outside experts provides credibility and objectivity
  - In assessing probabilities and defining benefits
  - Allocating credit to the DOE

Lessons Learned: The Retrospective Analysis

- No feasible methodology can evaluate the outputs of all programs
- RD&D programs for near-term deployment technologies need parallel market incentives
  - Standards can be an important mechanism to pull new technologies
  - Industry collaboration is essential for introducing new technology;
- Evaluation requires consistent record of budgets and cost sharing.
- Expect project failure
  - “failures” generate knowledge
  - Know when to terminate a project

Lessons Learned: The Prospective Analysis

- Consistent application improves quality and comparability at the program level
- The NEMS model is not well-suited for evaluating RD&D at the Department of Energy (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
- Adequate resources are needed to apply the methodology including use of consultant to work with all panels.