Exploring quantitative dimensions of the economic impact of nanotechnology: food & food packaging

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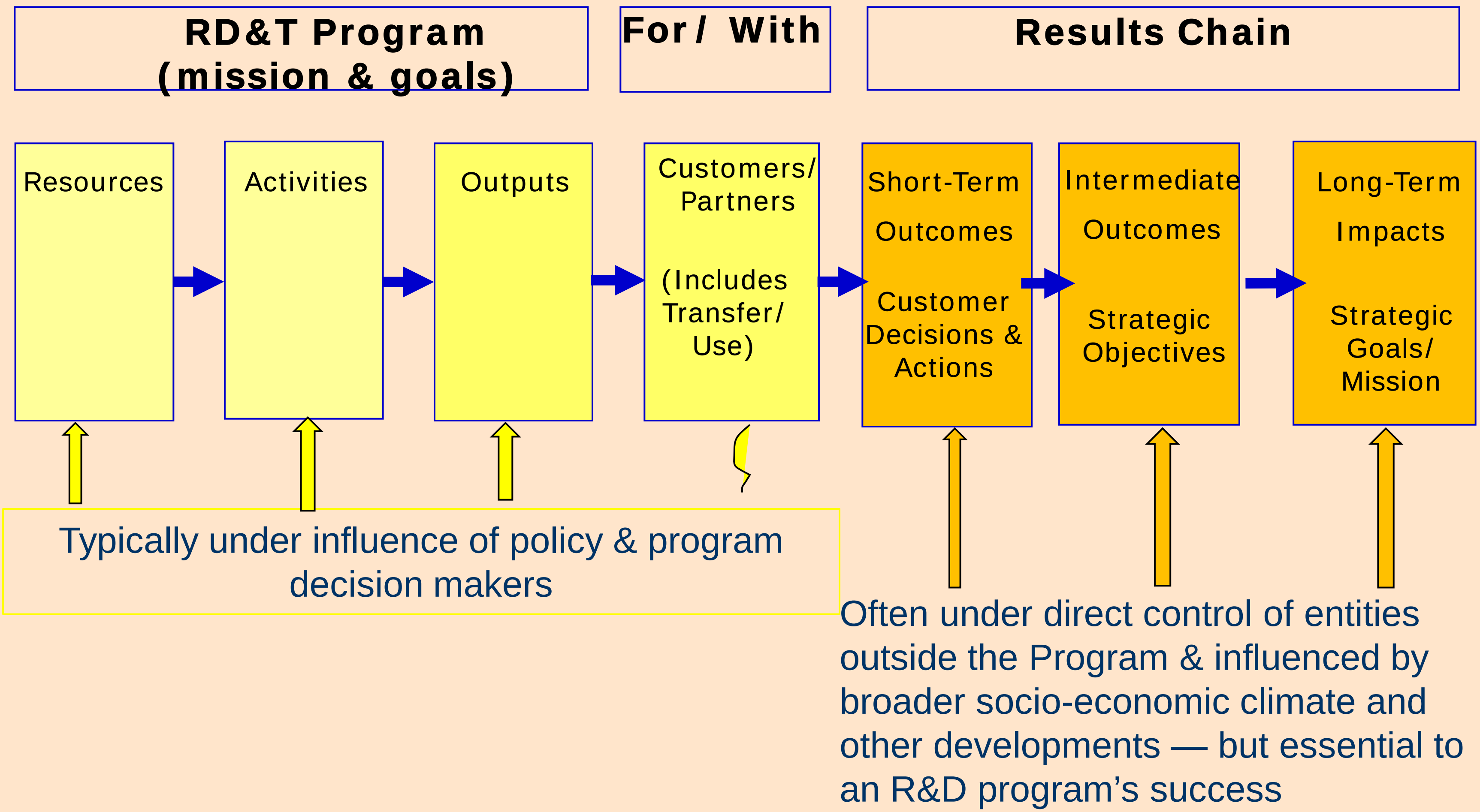
Evaluation purposes

- To learn how a program works & how to improve it
- To provide feedback on performance
- To meet requirements for accountability
- To develop policy insights

Logic Modeling reveals the what, why, & when of evaluation



Source: Ruegg & Jordan, 2007

Assessing outputs & early tech transfer

Sample Questions	Methods/Measures
What technologies were successfully developed as laboratory prototypes?	Counts/descriptions of lab prototypes
What technologies have moved into commercial use?	Interview
How many publications resulted?	Publications counts
How many patents were filed and how many were issued?	Patent counts
What efforts have been made to transfer knowledge directly; to what client bases?	Numbers/attendance/ratings of presentations, meetings, visits to on-line sites, etc.
Is knowledge transfer underway through publication and patent citations?	Bibliometric citation analysis
What barriers are slowing tech transfer and early adoption?	Survey; interview, case study

Assessing short-term outcomes

Sample Questions	Methods/Measures (examples)
What industries are using the technologies developed?	Survey; patent citation analysis
What are the advantages/disadvantages of implementing the technology?	Interview; case study; survey
What are indications that a portfolio of projects is on track to deliver desired performance?	Performance rating scheme
How has the community of researchers changed	Social network analysis
Are program changes needed?	Process evaluation using interview, survey, case study, and other methods
What returns have been realized to date; what is projected	Benefit-cost analysis – retrospective and prospective

Assessing long-term outcomes/impacts

Sample Questions	Methods/Measures (examples)
Percentage of potential users who have adopted the technology?	Market survey/statistical analysis
Growth in users geographically?	Survey (repeated); visualization tools
Comparative influence of organizations on knowledge advances and downstream innovations?	Comparisons of patent & publication citation data across organizations
Development of an industry/supply chain based on a new technology	Comprehensive assessment across the innovation chain
Impact on productivity in food provision Impact on food safety?	Econometric analysis Safety & medical cost impact evaluation
Impact on the economy?	Benefit-cost analysis; econometric analysis

Exploring the quantitative dimensions of the economic impact of nanotechnology

There are multiple methods that can be used to provide quantitative assessment of nanotechnology used in food & food packaging, e.g.,

- Econometrics and statistical analysis
- Survey and associated statistics
- Market assessments
- Social network analysis
- Performance rating schemes
- Patent and other bibliometric analyses
- Benefit-cost analysis

As well as supporting quantitative techniques, e.g., probability analysis, simulation analysis, visualization tools, use of a data enclave to provide researcher access to confidential data (Lane & Shipp, 2007), and database analytical tools, etc.

Overview of two quantitative methods with promising applicability to nanotechnology

1. Patent analysis extended

- Advantages
- Trends and comparisons
- Forward tracing to see downstream influences
- Backward tracing to see if particular innovations were influenced by given R&D
- Identifications of most influential patents
- Limitations

2. Benefit-cost analysis extended

- Advantages and limitations
- Extension from project to cluster scope
- Extension of categories of benefits
- Consistent approaches across studies facilitates aggregation across cluster studies
- Illustrations
- Limitations

Why these?

- Experience with these methods in other technology fields have produced useful results.
- They are generally practical to undertake
- They can be used independently or in combination with synergistic value.
- Their use can help answer evaluation questions in both the near-term and long-term.
- Recent advances have made these methods more useful.

Method #1: Patent analysis extended

Advantages:

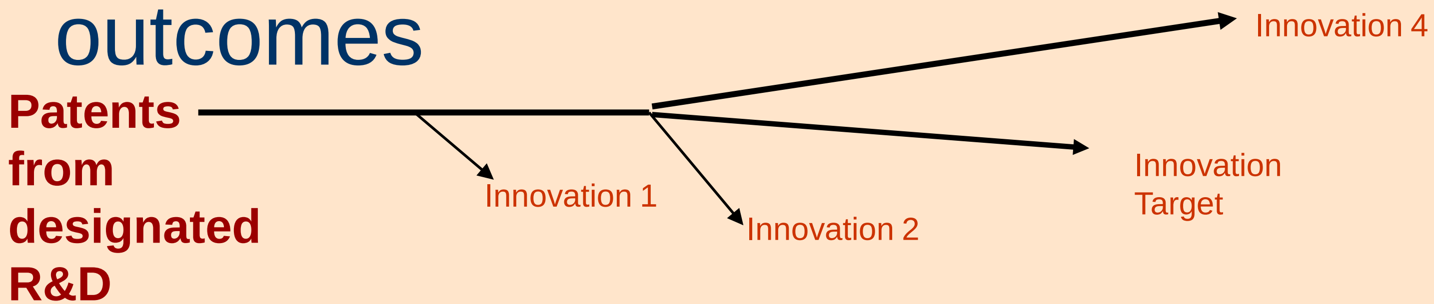
- Objective, quantitative measures
- Non-intrusive approach
- Can be used to answer a variety of evaluation questions
- Data usually exists and can be assembled

Patent analysis can address multiple evaluation questions

- How many patents did a given program produce? (output metric)
- What was the average cost per patent? (output efficiency metric)
- Did patent outputs of a program reach downstream producers positioned to apply the innovation in commercial development? (effective tech transfer)
- How does the influence of a given program's patents compare with those of others? (program effectiveness)
- Which patents have had a particularly notable influence on innovation? (understanding where impact has occurred)
- Does an important innovation trace back to R&D of a given program? (long-term impact)

Tracing patents forward and backward

Forward tracing from R&D to downstream outcomes



Backward tracing from a selected outcome to upstream R&D

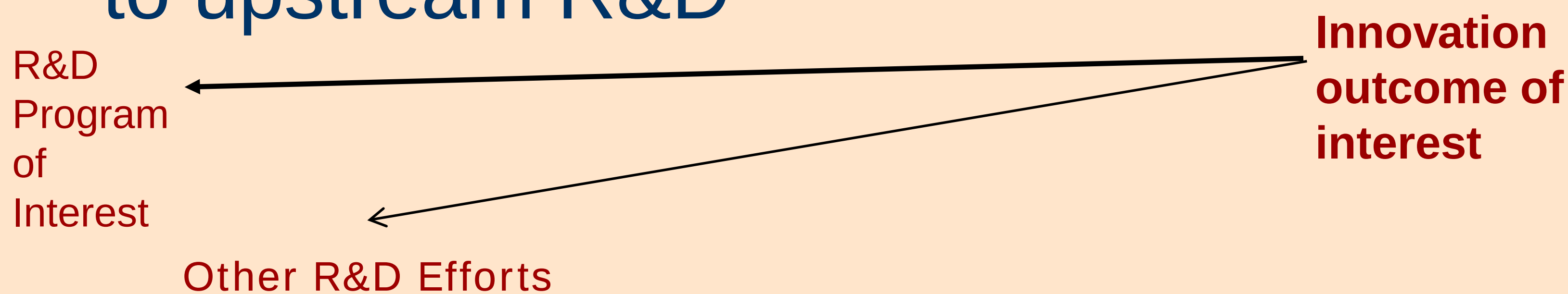


Illustration of patent analysis to:

- Document paths linking R&D with downstream products and processes.
- Show the often complex, evolutionary paths by which R&D may lead to innovation.
- Show a linkage from a demonstrably valuable innovation back to a specific R&D program.
- Compare influence of different R&D investments
- Identify particularly influential patents.

[Drawn from recent work by Ruegg and Thomas]

Constructing patent databases for use in analyses

For example,

- Nanotechnology patent set attributed to a given R&D effort
- Earlier patents cited by the above set of patents
- Nanotechnology patent set(s) attributed to other organizations and their citation links
- Downstream important innovations, innovators, their patents, and their citation links
- Highly cited nanotechnology, related patents, & assignees

Illustration: Patents linked to DOE-attributed combustion patents grouped by their International Patent Classifications (IPCs)

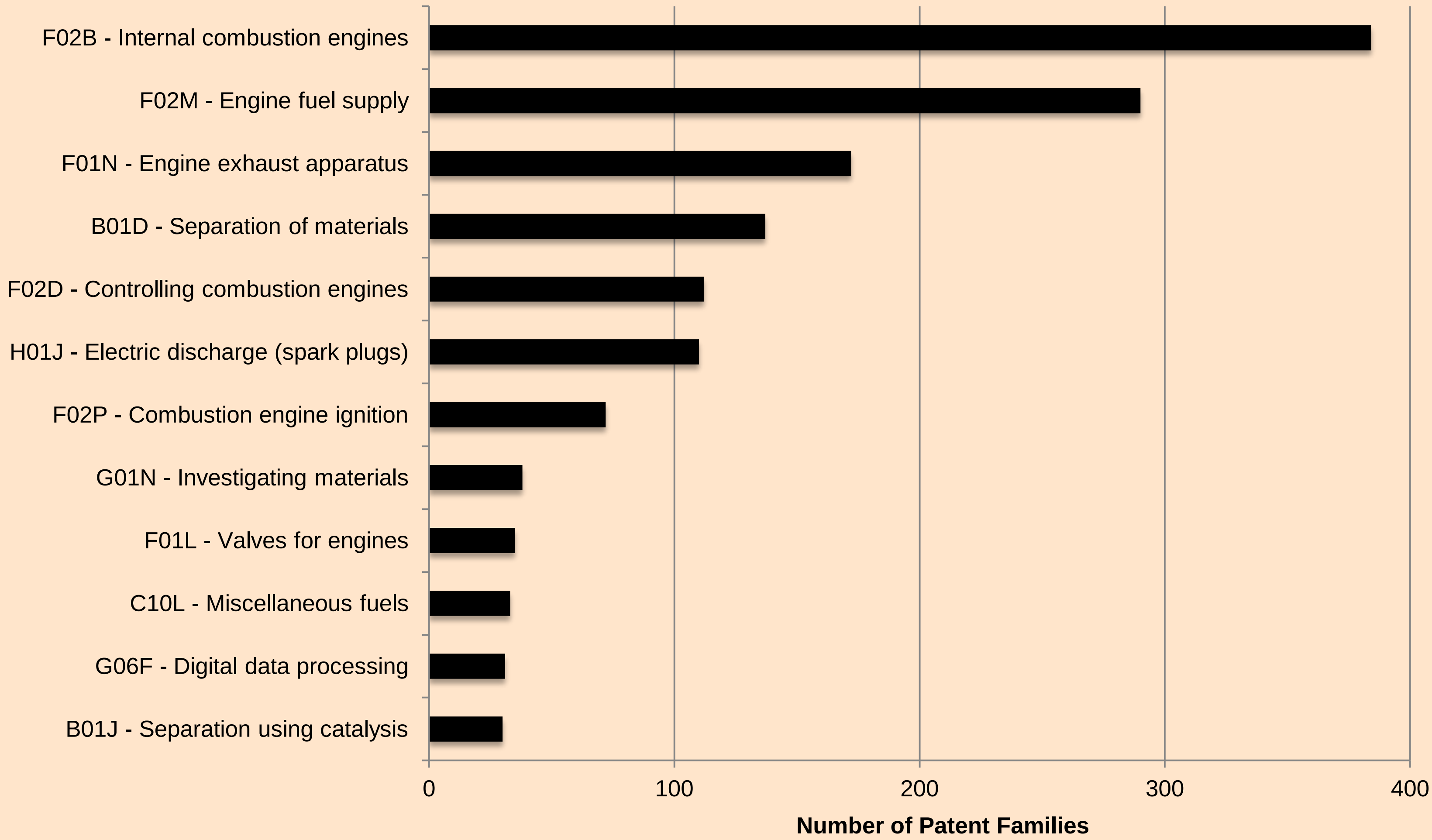


Illustration: DOE-attributed advanced combustion patents are most linked to subsequent patents assigned to the listed organizations (forward patent tracing)

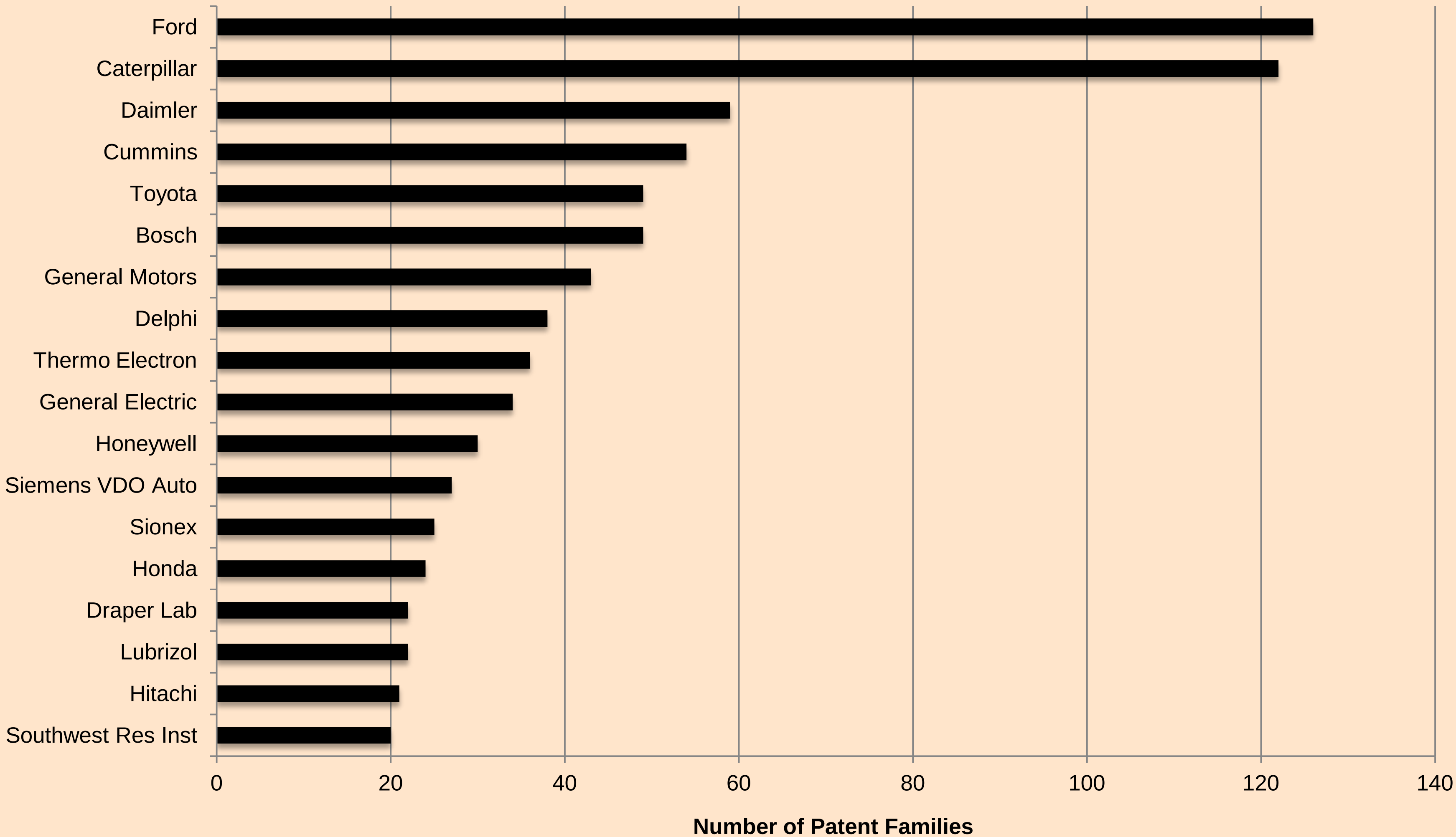
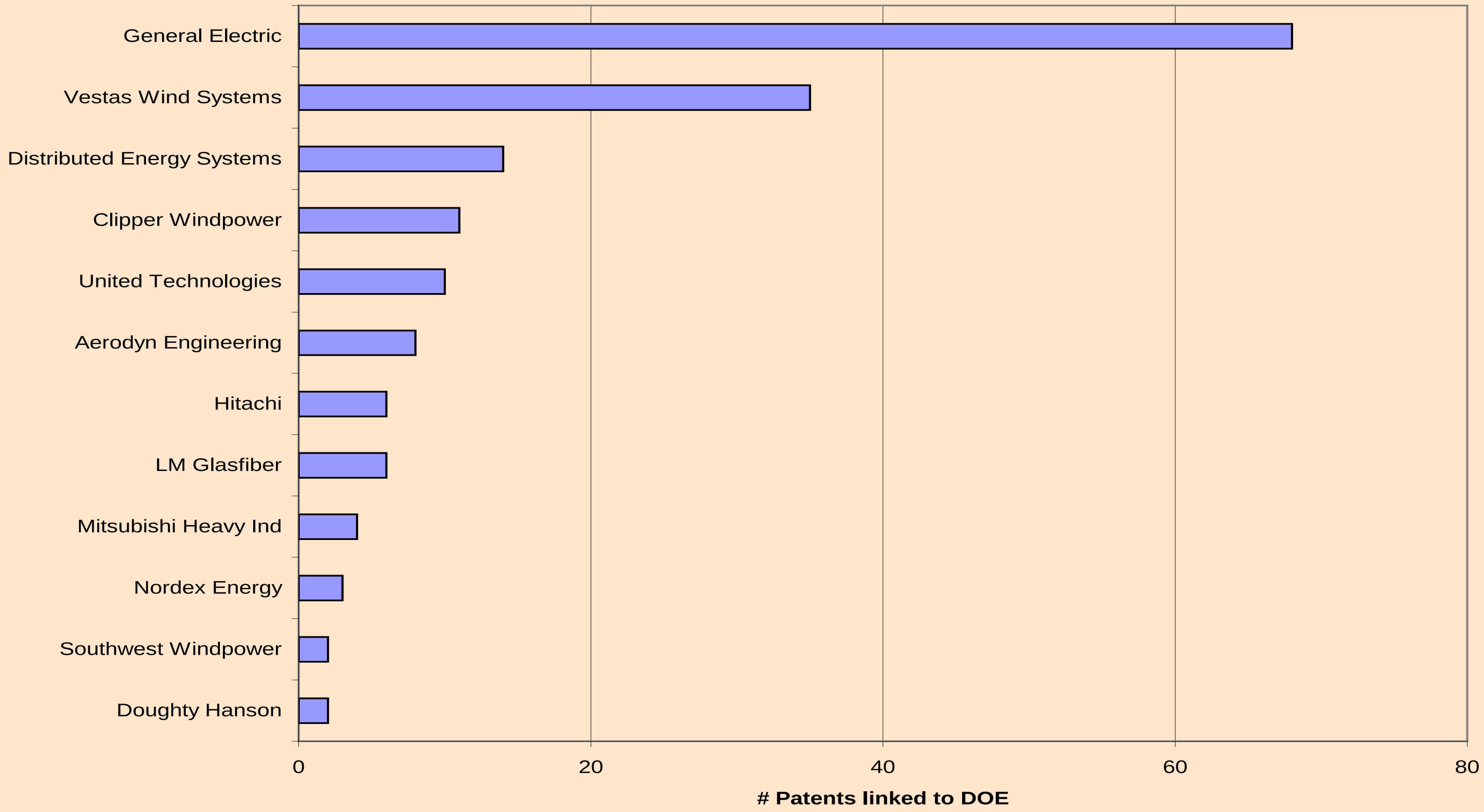


Illustration: patents of leading innovative wind energy companies are linked to earlier DOE-supported wind energy patents (backward patent analysis)



Ruegg & Thomas, 2009

Highly cited wind patents of leading innovative companies linked to earlier DOE wind patents, e.g.,

Company	Technology	Citation Index	Links to DOE
Clipper WindPower	Retractable rotor blades	6.90	8
GE Wind	Variable speed generator	6.16	10
United Technologies	Speed Avoidance Log	3.10	6
Vestas Wind Systems	Variable speed turbine/ matrix converter	12.18	13

Limitations of patent analysis

- Not all knowledge outputs of significance are embodied in patents; thus patent analysis tends to capture only a part of a program's output.
- A patent’s influence may occur through IP licensing, which may be held confidential, and not be fully revealed by analysis of citation linkages.
- Not all patents are equal.
- Not all citations are equal.
- Not all citations mean that a patent or publication was actually used.
- A citation does not reveal the economic value of the patent in use.
- The inability to identify with certainty patents attributable to an evaluated program, or to construct the necessary starting databases, may also weaken the analysis in practice.

For these reasons, patent analysis is often used in combination with other methods to provide a more comprehensive coverage of a program's effects.

[See Ruegg and Thomas, “Patent Analysis,” in *Handbook on the Theory and Practice of Program Evaluation*, ed. Link & Vornortas, forthcoming.]

Method #2: Benefit-cost analysis extended

B-C method was traditionally applied at the project level, but has been extended by ATP and DOE:

- Extended to evaluate technology clusters.
- Extended to address multiple categories of benefits for technology programs and subprograms.
- Extended through use of a unifying framework (Ruegg & Jordan, 2011) and database analytics (Ruegg, Cox, & Loftin, 2012) to enable aggregation across cluster studies.

Benefit-cost analysis description

Features of Traditional B-C Analysis:

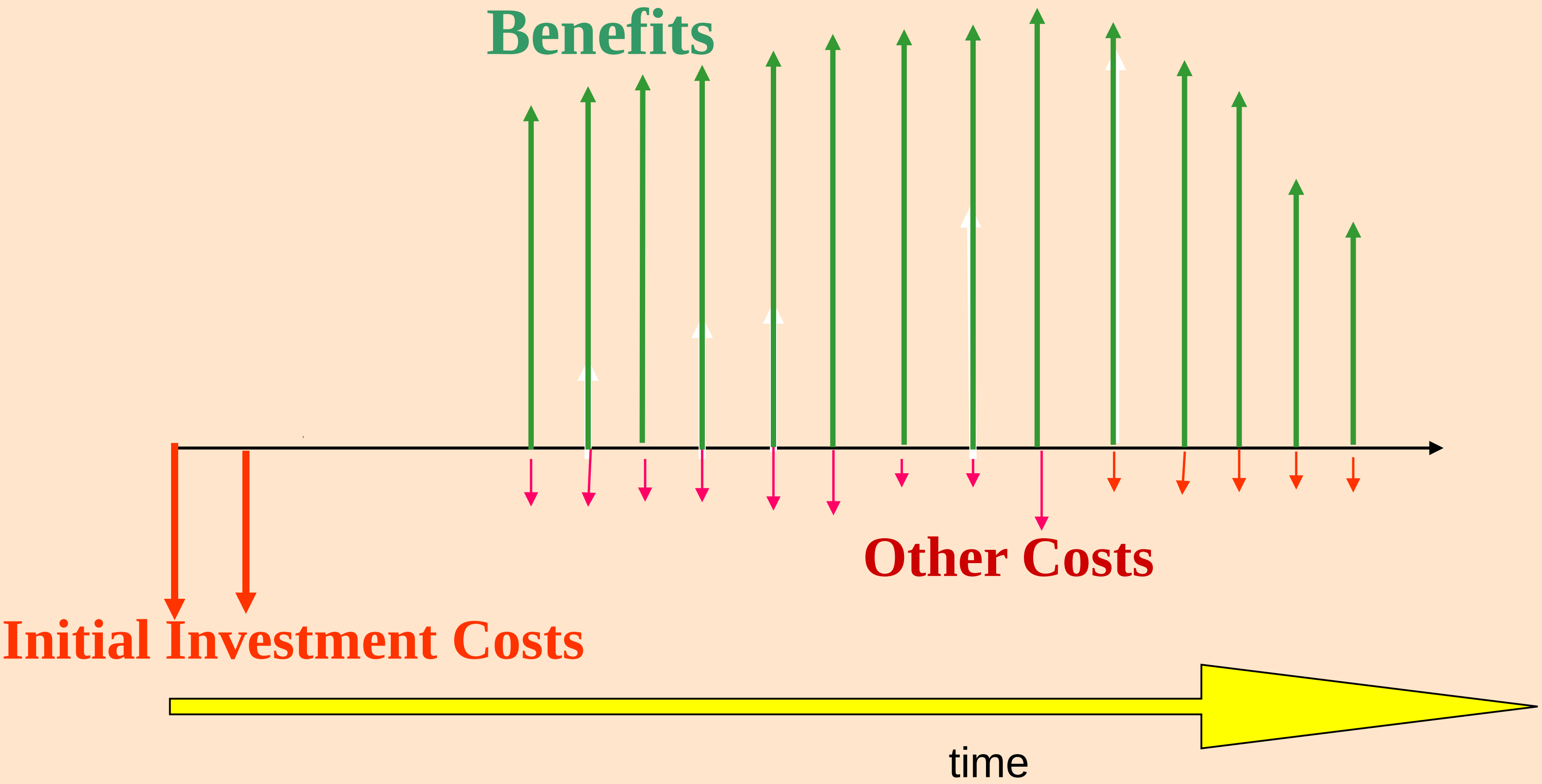
- Quantification of positive and negative effects of a project (or program or portfolio)
- Expressed in money terms where possible
- Timing of cash flows taken into account & appropriate discount rate applied
- Computation of resulting economic performance measures, e.g.,

  - Net Present Value Benefits (NPV), - Benefit-to-Cost Ratio (B/C), &
  -Internal Rate of Return on Investment (IRR)
- Qualitative treatment of other effects

Principal Use:

- To demonstrate that a project (or program) was or was not economically worthwhile

Benefit-Cost Analysis: Working with Cash Flows



Benefit-Cost Analysis Extended from a Single Project to a "Cluster" or Portfolio by ATP

Extension of the analysis from application to a single **applied** research project to a **cluster** of technologies or portfolio of projects has the advantage of providing a more useful, scaled-up measure without a similar scale-up in evaluation costs.

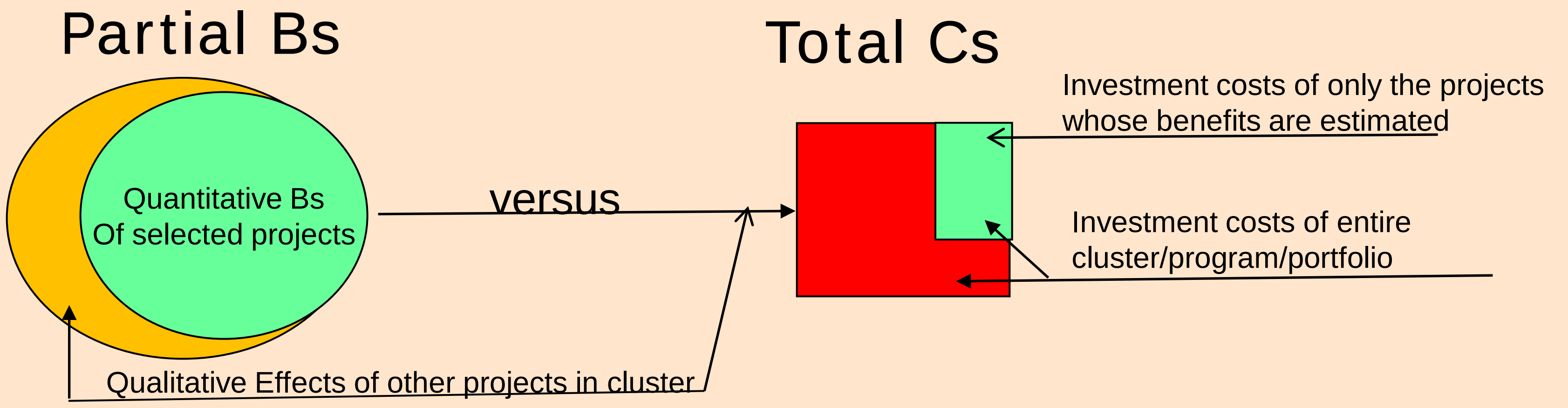


Illustration: benefit-cost study results

Final Outcomes	Units	Total Measure	Attributed to DOE
Economic benefits	Million $		Accelerated R&D
Rate of return on investment	IRR		
Total public cost	Million $		% share of impact
Net economic benefits	Million $		
Health benefits	Million $		
avoided mortality	Deaths		
etc. Emission reductions	Cases		
CO2 etc. Energy security benefits	Tons BOE		
etc/ Knowledge benefits	Import % Patents		
	Publications R&D networks		

Limitations of benefit-cost analysis

- Even in its extended form, important effects are often missed.
- It tends to be costly to perform.
- It is data-intensive.
- It requires considerable skill (and cleverness) on the part of the evaluator to determine cost-effective ways to arrive at benefit estimation.

Achieving synergy between patent analysis & benefit-cost analysis

Possible synergies:

- Knowledge is a benefit of nanotech R&D worthy of measurement.
- Establishing linkages between program R&D and downstream innovations, such as through patent citation analysis, helps to demonstrate program attribution.

Approaches to achieve synergies:

- Conduct the two types of analysis jointly and in collaboration.
- Integrate the results of the patent analysis with that of the benefit-cost analysis.

Quantitative assessments: promising methods for applications in nanotechnology

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Summary steps in conducting evaluation

- Map evaluation needs to program logic model.
- Establish databases in support of evaluation.
- Identify current evaluation needs and intended audiences.
- Conceptualize/formulate questions/hypotheses of interest.
- Develop an evaluation plan with identification of approach, general study design, method(s), & analysts.
- Develop detailed evaluation plan, with methodology, data collection plan, and deliverables.
- Conduct the analysis.
- Interpret and communicate results to diverse audiences.
- Provide feedback to program staff.
- Preserve data and evaluation study report.
- Identify next evaluation need & repeat steps.