Quadrennial Technology Review-2015

Chapter 12: Integrated Analysis

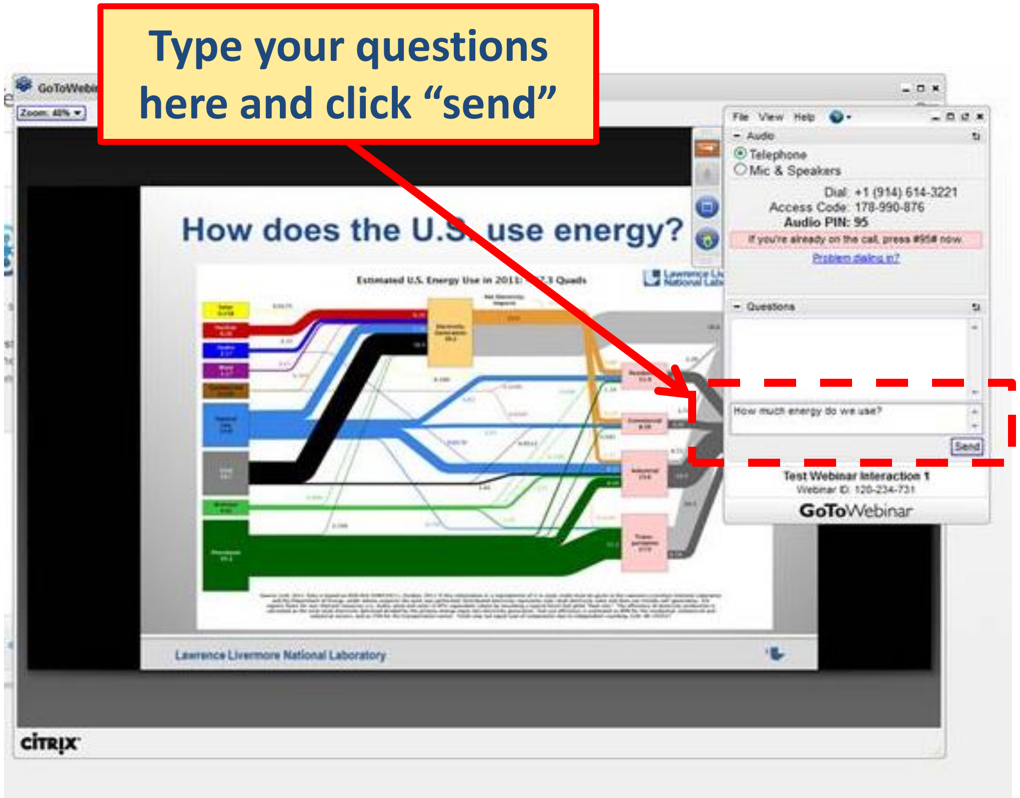
Public Webinar

Chapter Leads:
Sam Baldwin
Corrie Clark
Jae Edmonds
Paul Friley
Jeff Greenblatt
Thomas Jenkin

2015-03-04

Webinar Logistics

- Due to the large number of expected participants, the audio and video portions of this webinar will be a “one way” broadcast. Only the organizers and QTR authors will be allowed to speak.
- Submit clarifying questions using the GoToWebinar control panel. Moderators will respond to as many questions as time allows. Substantial input regarding chapter content should be submitted by email to: DOE-QTR2015@hq.doe.gov


Type your questions here and click “send”

● Telephone
○ Mic & Speakers

Dial: +1 (914) 614-3221
Access Code: 178-990-876
Audio PIN: 95
If you're already on the call, press #95# now.

How much energy do we use?

Test Webinar Interaction 1
Webinar ID: 120-234-731

QTR 2015 Chapter Outline

Introduction

1. Energy Challenges
2. What has changed since QTR 2011
3. Energy Systems and Strategies

Assessments

4. Advancing Systems and Technologies to Produce Cleaner Fuels
5. Enabling Modernization of Electric Power Systems
6. Advancing Clean Electric Power Technologies
7. Increasing Efficiency of Buildings Systems and Technologies
8. Increasing Efficiency and Effectiveness of Industry and Manufacturing
9. Advancing Clean Transportation and Vehicle Systems and Technologies
10. Enabling Capabilities for Science and Energy

Integrated Analysis

11. U.S. Competitiveness
12. **Integrated Analysis**
13. Accelerating Science and Energy RDD&D
14. Action Agenda and Conclusions; Web-Appendices
    Web Appendices

Chapter Overview

- This chapter presents metrics, tools, and methodologies to evaluate the RD3 portfolio.
    - *How should DOE best allocate funding and prioritize its RD3 portfolio?*
- This chapter presents a framework for decision making but does not present prioritization decisions.
- For DOE, identifying the right portfolio involves two interrelated steps:
    - Estimating technological improvements for any RD3 activity or portfolio
    - Estimating future system-based benefits of RD3 portfolio

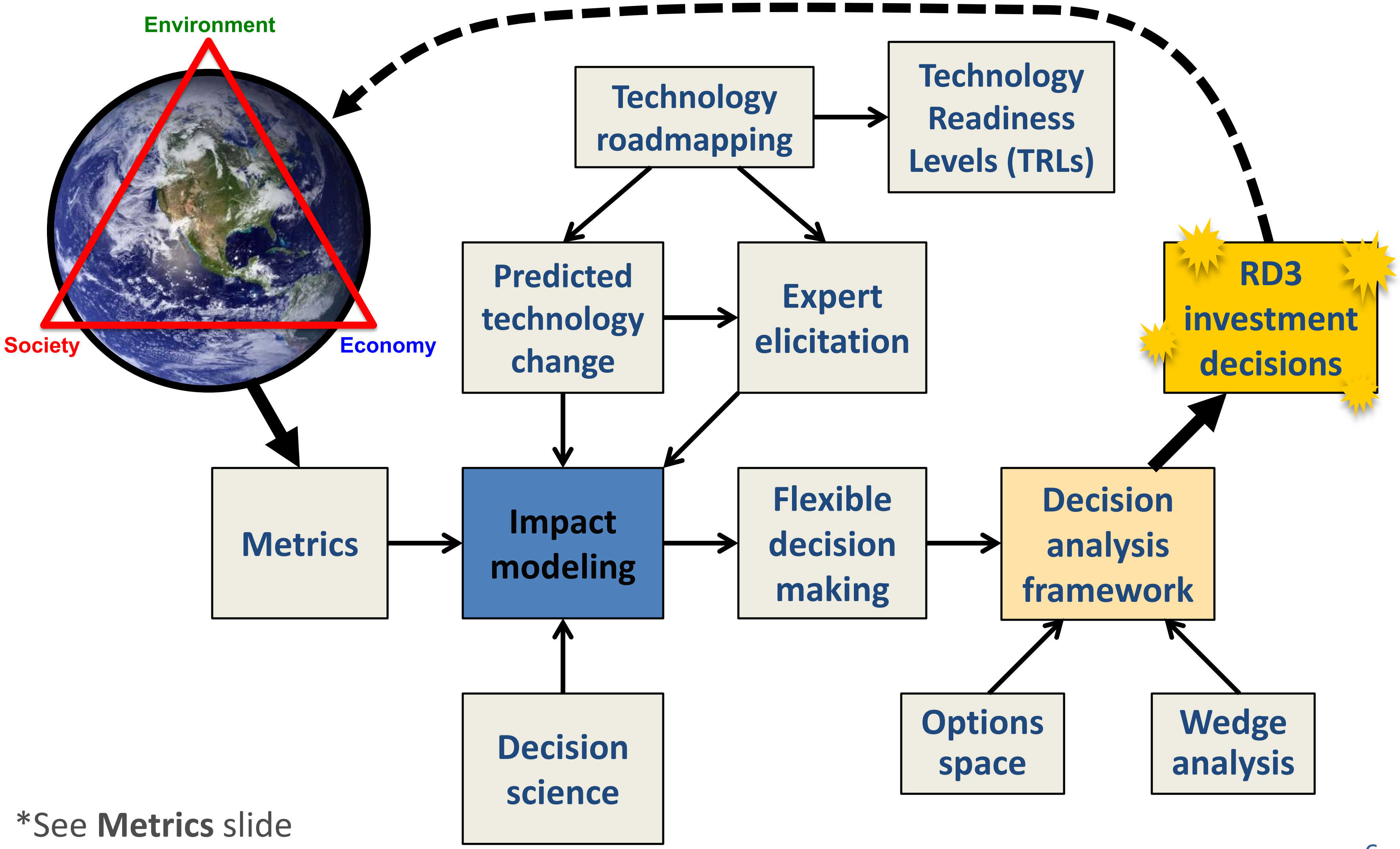
Chapter Outline

1. Introduction
2. Quantitative Assessment Tools
   1. Metrics
   2. Integrated Assessment & Other Models
   3. Risk and Uncertainty
   4. Flexible Decision Making: Real Options Valuation
   5. Predicting Technological Progress
3. Other Assessment Tools
   1. Technology Roadmapping
   2. Technology Readiness Levels (TRLs)
   3. Expert Elicitation
   4. Option Space
   5. Wedge Analysis
   6. Decision Science
4. Prioritization & Decision Making
   1. Conceptualization Framework: Goals and Needs
   2. Examples of Methods in Use
   3. Toward Improved Methods of RD3 Prioritization
5. Chapter Summary – RD3 Needs

Appendix: additional information not included in chapter text

1 Introduction

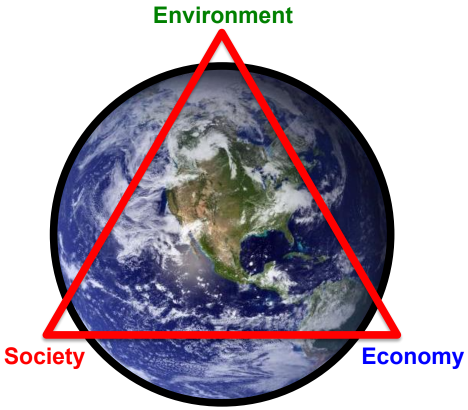
- Better prioritization of RD3 resources is needed to maximize impact of technologies in multiple dimensions:*

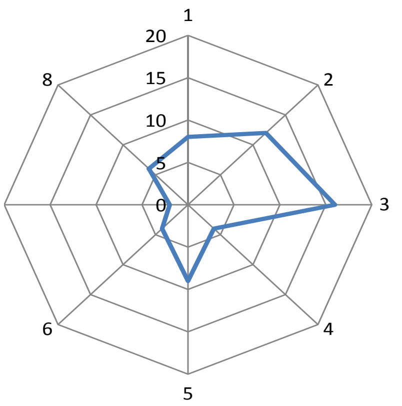


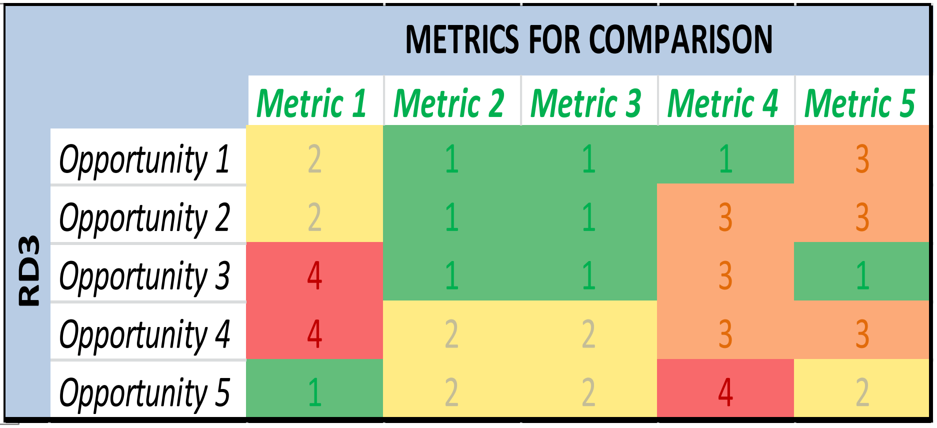
*See **Metrics** slide

2.1 Metrics

- Metrics enable the comparison of different technologies or projects.
- Relevant metrics for DOE's energy portfolio include those in the following categories:
  - Economic (e.g., levelized cost of energy)
  - Environment (e.g., greenhouse gas emissions, water use)
  - Societal (e.g., human health, national security)
- Many of these metrics can be evaluated over the lifecycle of a technology or project via life cycle assessment (LCA).
- Multiple metrics need to be considered in RD3 evaluation.







		METRICS FOR COMPARISON				
		Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
RD3	Opportunity 1	2	1	1	1	3
	Opportunity 2	2	1	1	3	3
	Opportunity 3	4	1	1	3	1
	Opportunity 4	4	2	2	3	3
	Opportunity 5	1	2	2	4	2

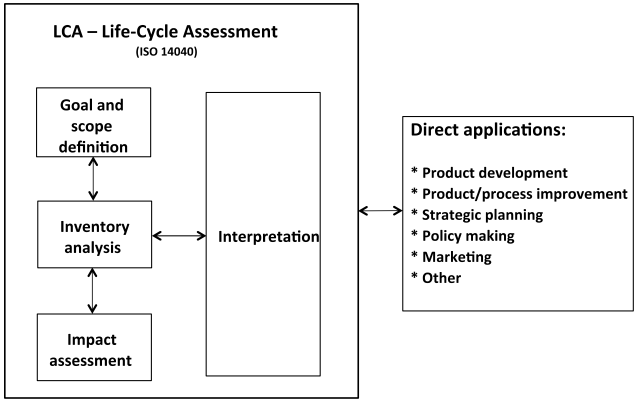
2.1 Metrics (Continued)

Covered in metrics section:

- Life cycle assessment (LCA) framework
- Levelized cost of energy (LCOE)
- Energy return on (energy) invested (EROI)
- Climate change impacts: Greenhouse gas (GHG) emissions and Social Cost of Carbon (SCC)
- Toxic pollutants
- Human health impacts
- Water use and consumption
- Land use
- Materials use and criticality
- Security and other diversity-related benefits

$$\text{EROI} = \frac{\text{Energy gained}}{\text{Energy required to obtain that energy}}$$

Year	Discount Rate			
	5%	3%	2.5%	3%
	Average	Average	Average	95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221



LCA – Life-Cycle Assessment
(ISO 14040)

Goal and scope definition

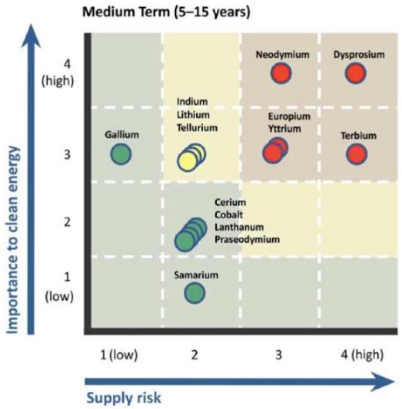
Inventory analysis

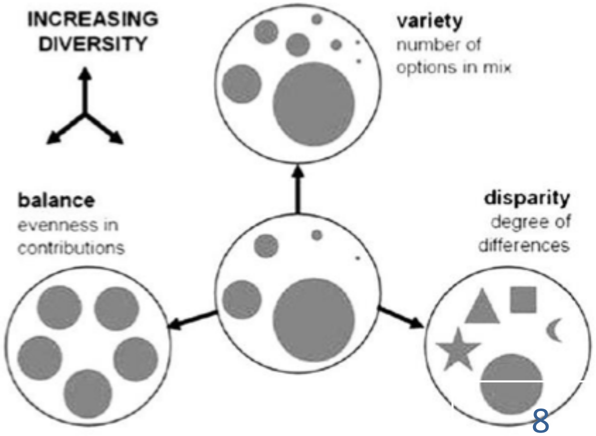
Impact assessment

Interpretation

Direct applications:

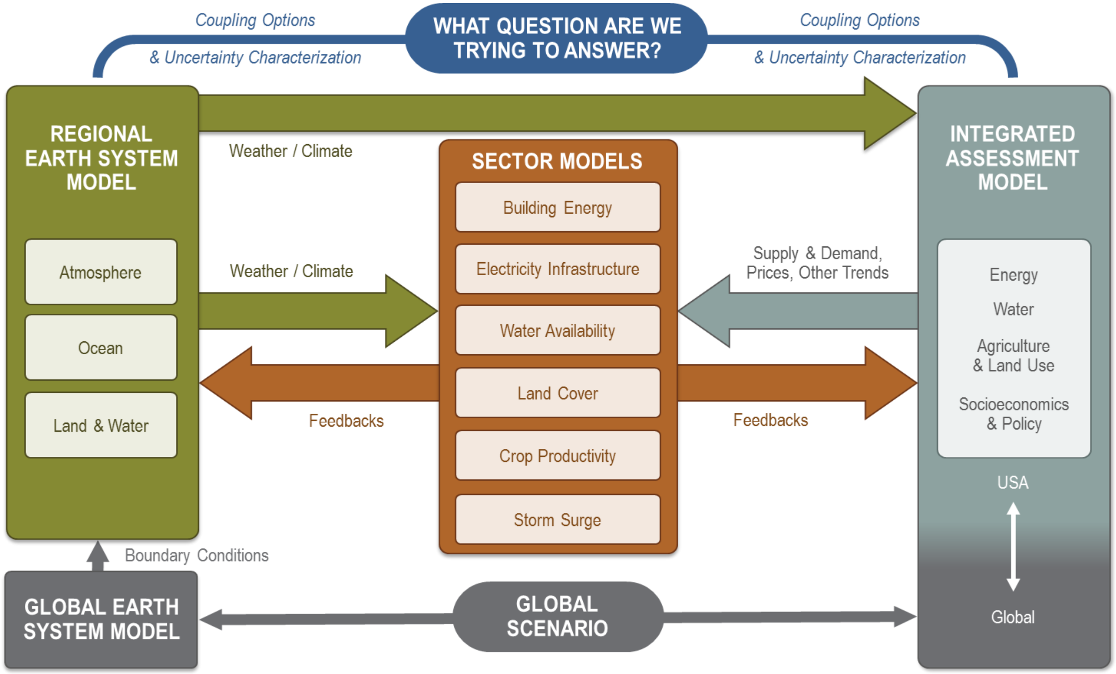
- * Product development
- * Product/process improvement
- * Strategic planning
- * Policy making
- * Marketing
- * Other





2.2 Integrated Assessment & Other Models

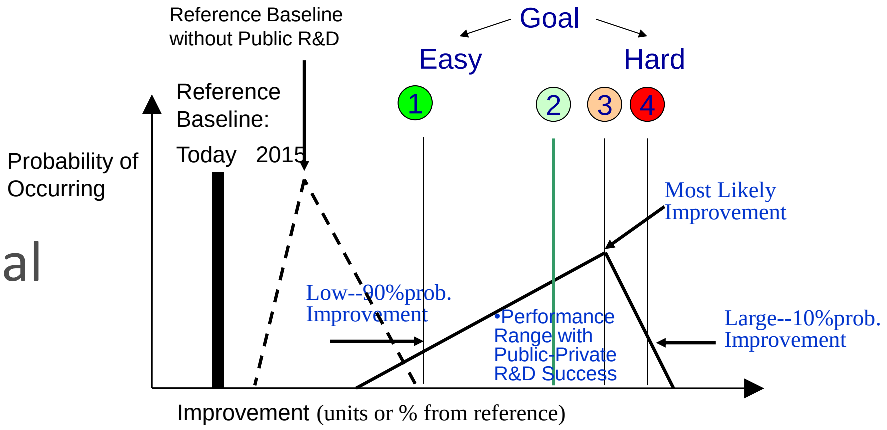
- Integrated assessment models (IAMs) provide three primary services:
  - Provide drivers for climate science experiments
  - Bring together major elements of physical and human Earth systems to provide new scientific insights
  - Provide science-based decision support tools



Model interactions in the PRIMA model

2.3 Risk & Uncertainty

- Risk is inherent in any RD3 activity. Yet not all risks are identical:
  - **Technical risk**: Can technology meet performance, cost goals?
  - **Market risk**: Do economics assure technology success in market?
- Other possible risks?
  - Schedule/Budget/Economic
  - Managerial/Organizational
  - Safety/Regulatory/Environmental
  - Political/Strategic

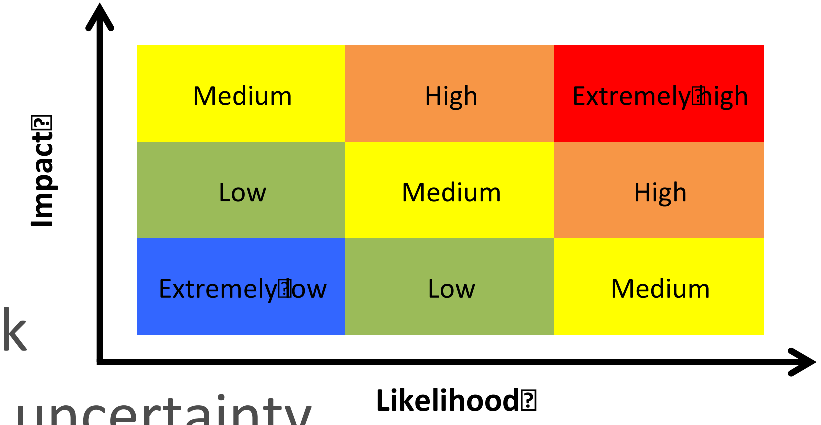


- Risk definition:

$$R = P \bullet I$$

Risk　　Probability (or Likelihood)　　Impact

- Higher uncertainty = higher risk
- Goal of RD3 is to reduce risk & uncertainty



Impact

Medium	High	Extremely high
Low	Medium	High
Extremely low	Low	Medium

Likelihood

2.4 Flexible Decision Making

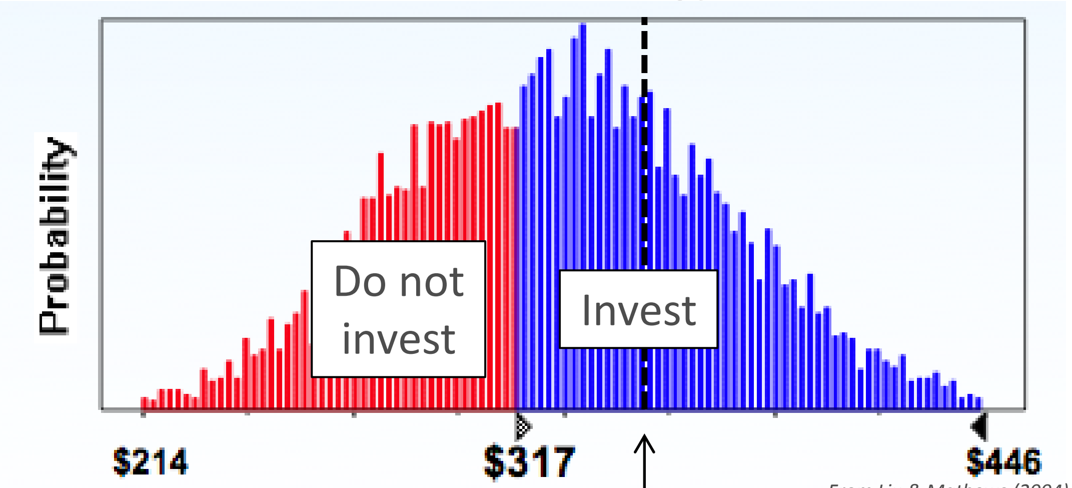
- Real options valuation (a version of decision tree analysis)
- Popularized by Amram and Kulatilaka (1999)
- Options = contingent decisions to invest depending on events
- Conventional valuation may undervalue investments with large uncertainty
- Holding options is not free, but reduces total cost & project risk
- DOE and other decision makers already do this (staged investment decisions), but real options valuation formalizes the process

RD3 investment risk = P • I

↗ Probability of success

↖ Average payoff

Future value of technology after RD3



From Liu & Mathews (2004)

↑ Average payoff

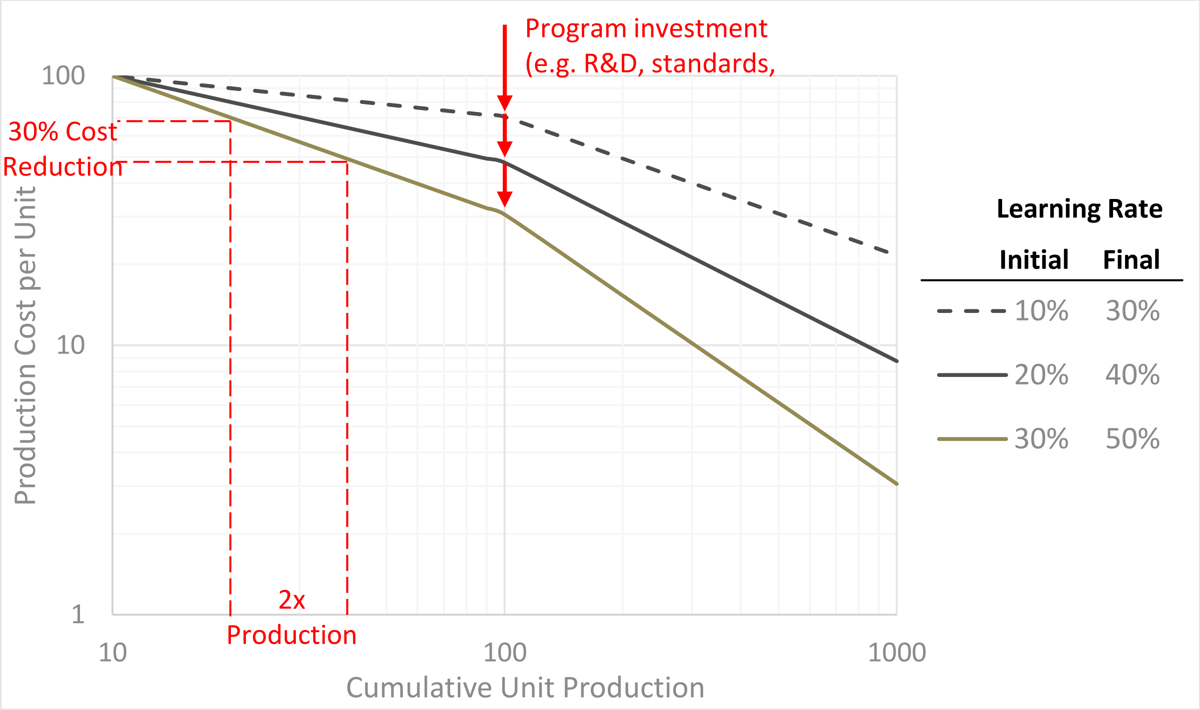
↑ Scale-up investment cost

Amram, M., N. Kulatilaka, 1999. *Real Options: Managing Strategic Investment in an Uncertain World,* Financial Management Association Survey and Synthesis Series, Boston: Harvard Business School Press, ISBN 0-87584-845-1

Liu, S., S. Mathews, 2004. “My First Real Options Model Applying the Datar-Mathews Method,” Computational Finance and Stochastic Modeling, Phantom Works, Boeing Co.

2.5 Predicting Technological Progress

- Technology “learning” or “experience” curve analysis
- Observed relationship between cost and cumulative production
- Curves can sometimes bend downward with program investment
- Changes may also depend on learning-by-searching, economies of scale, passage of time, spill-over, etc.
- Area for research investment?



3.1 Technology Roadmapping

- Commonly used by technology offices at DOE to craft RD3 investment strategies that address complex barriers
- Important tool for successful and flexible research portfolio
- Began in U.S. automotive industry in 1970s, later adopted by consumer electronics industry
- May identify critical technologies and gaps that can be leveraged by RD3 investment
- Useful when default technology, timing is unclear, or coordination of multiple technologies needed?

Technology roadmapping stages *(Garcia and Bray, 1997)*

Phase I. Preliminary activity

- Satisfy essential conditions.
- Provide leadership/sponsorship.
- Define the scope and boundaries for the technology roadmap.

Phase II. Development of the Technology Roadmap

- Identify the "product" that will be the focus of the roadmap.
- Identify the critical system requirements and their targets.
- Specify the major technology areas.
- Specify the technology drivers and their targets.
- Identify technology alternatives and their time lines.
- Recommend the technology alternatives that should be pursued.
- Create the technology roadmap report.

Phase III. Follow-up activity

- Critique and validate the roadmap.
- Develop an implementation plan.
- Review and update.

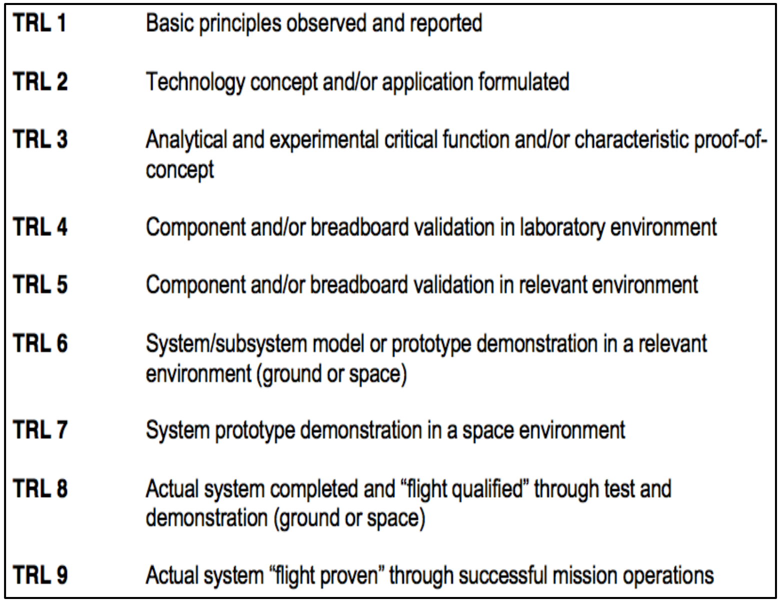
Garcia, M. L., O. H. Bray, 1997. Fundamentals of Technology Roadmapping, Sandia NL, SAND97-0665, April. http://prod.sandia.gov/techlib/access-control.cgi/1997/970665.pdf

Phaal, R., C. J. P. Farrukh, D. R. Probert, 2004. "Technology roadmapping—A planning framework for evolution and revolution," Technological Forecasting & Social Change, 71, 5 – 26. doi:10.1016/S0040-1625(03)00072-6. http://www.carlosmello.unifei.edu.br/Disciplinas/Mestrado/PQM-21/Textos%20para%20leitura/Texto_2_TRM_Phaal_Probert_2004.pdf

Ziagos, J., B. R. Phillips, L. Boyd, A. Jelacic, G. Stillman, E. Hass, 2013. "A technology roadmap for strategic development of enhanced geothermal systems," Thirty-Eighth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, SGP-TR-198. http://www1.eere.energy.gov/geothermal/pdfs/stanford_egs_technical_roadmap2013.pdf

3.2 Technology Readiness Levels (TRLs)

- Conceived by Stan Sadin in 1974 at NASA; formalized in 1989
- Subsequently adopted by DOD, DOE, others
- 9 levels (originally 7), spanning basic research to deployment:



TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 9	Actual system "flight proven" through successful mission operations

Mankins, J. C., 1995. *Technology Readiness Levels: A White Paper*, Advanced Concepts Office, Office of Space Access and Technology, National Aeronautics and Space Administration (NASA), 6 April. http://www.hq.nasa.gov/office/codeq/trl/trl.pdf

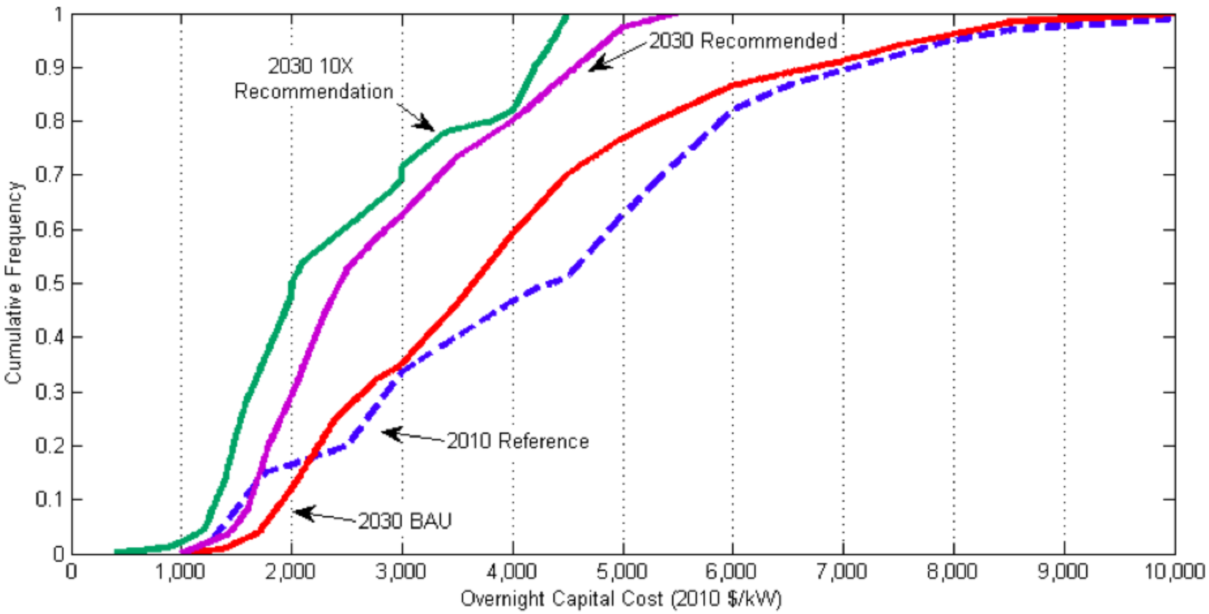
Possible critiques:

- Scale anchored to qualitative characteristics; valuation may vary with user, technology, time frame, etc.?
- Multiple technologies: Single TRL encompasses many subsystems. Should TRL be pinned to least developed subsystem?
- Cross-technology comparison: TRLs not readily compared across technologies or timeframes?

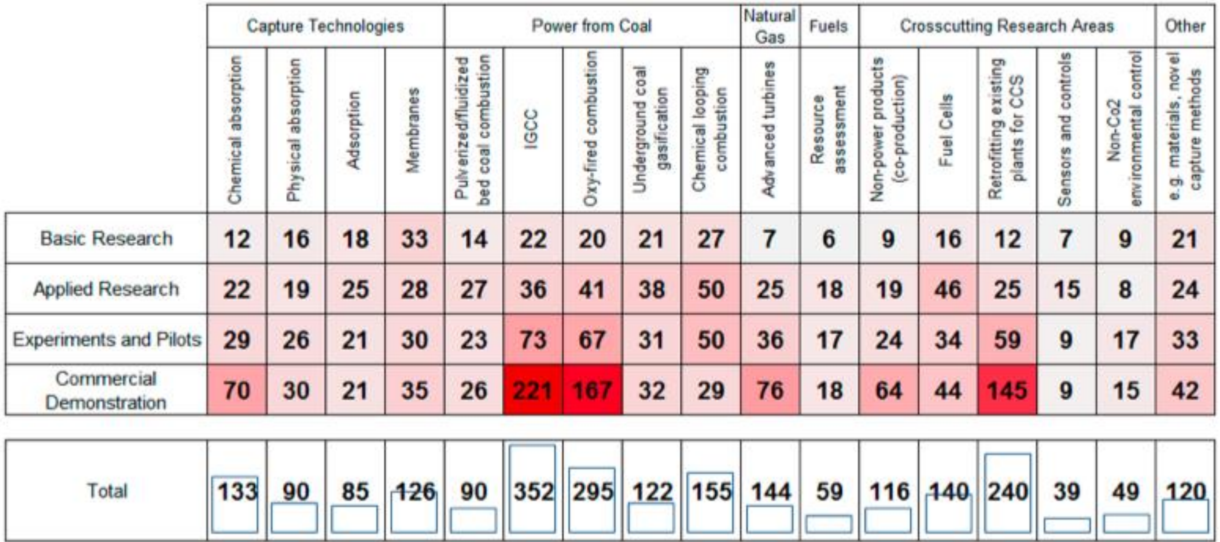
- Benefits analysis: Quantitative risk assessment not supported?
- Portfolio analysis: Little actionable information for decisions?
- Early-stage research: Not adequately characterized?

3.3 Expert Elicitation

- Can be used to forecast uncertain future technologies, using experts to supply recent knowledge about possible breakthroughs
- Does not rely on consensus (Delphi method) so preserves diversity of opinions
- Can fall prey to biases; good design can mostly overcome these?
- Expensive, time-consuming and imperfect; **further improvements needed**



Chan et al. (2011)

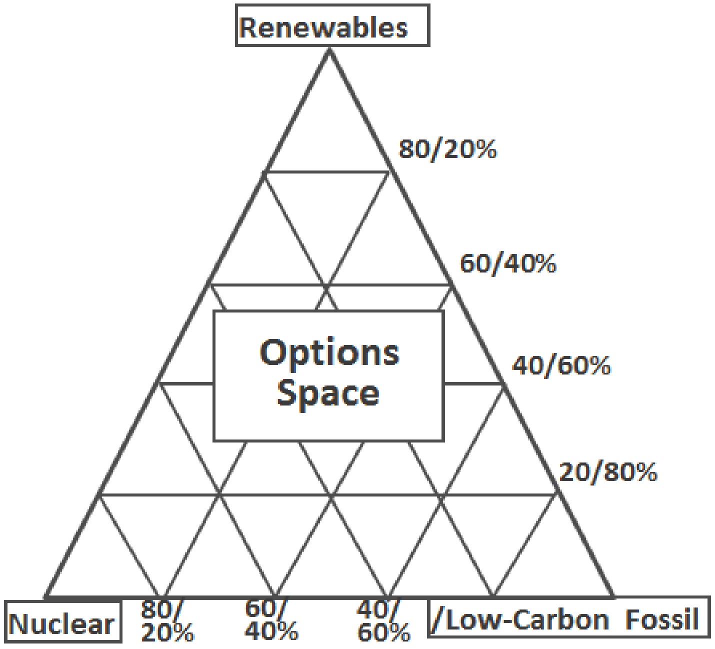


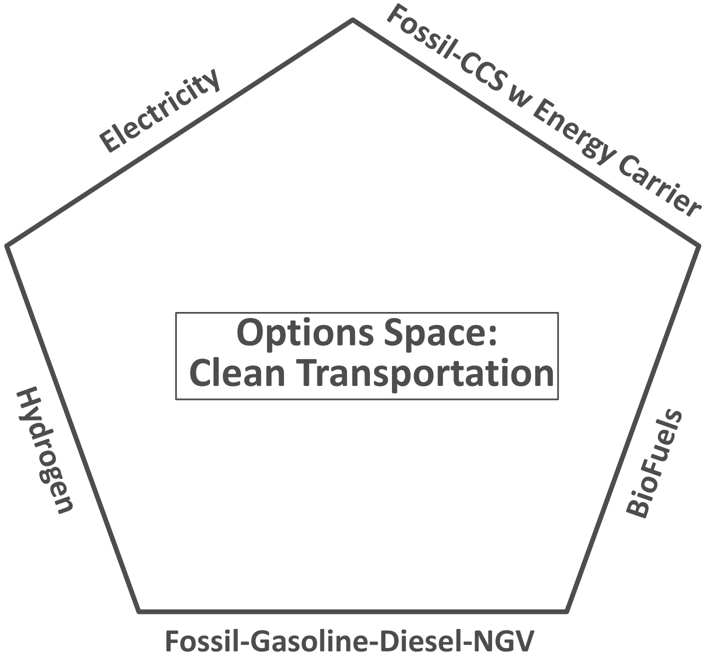
	Capture Technologies				Power from Coal					Natural Gas	Fuels	Crosscutting Research Areas					Other
	Chemical absorption	Physical absorption	Adsorption	Membranes	Pulverized/fluidized bed coal combustion	IGCC	Oxy-fired combustion	Underground coal gasification	Chemical looping combustion	Advanced turbines	Resource assessment	Non-power products (co-production)	Fuel Cells	Retrofitting existing plants for CCS	Sensors and controls	Non-Co2 environmental control	e.g. materials, novel capture methods
Basic Research	12	16	18	33	14	22	20	21	27	7	6	9	16	12	7	9	21
Applied Research	22	19	25	28	27	36	41	38	50	25	18	19	46	25	15	8	24
Experiments and Pilots	29	26	21	30	23	73	67	31	50	36	17	24	34	59	9	17	33
Commercial Demonstration	70	30	21	35	26	221	167	32	29	76	18	64	44	145	9	15	42
Total	133	90	85	126	90	352	295	122	155	144	59	116	140	240	39	49	120

Chan, G., L. D. Anadon, M. Chan and A. Lee, 2011. "Expert elicitation of cost, performance, and RD&D budgets for coal power with CCS," *Energy Procedia, 4*, 2685–2692. DOI: 10.1016/j.egypro.2011.02.169. http://www.sciencedirect.com/science/article/pii/S1876610211003663.

3.4 Option Space

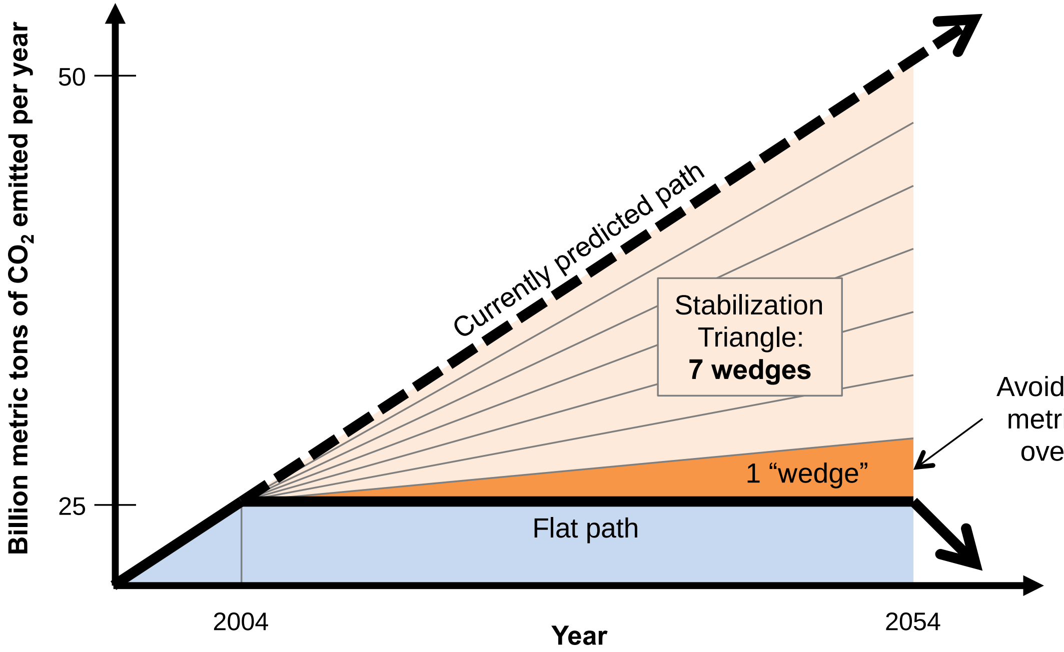
- Need to invest in multiple technologies/pathways
- Option Space = set of technologies that could contribute to a particular desired service (usually sector-specific)
- Examples of electricity generation and transportation:



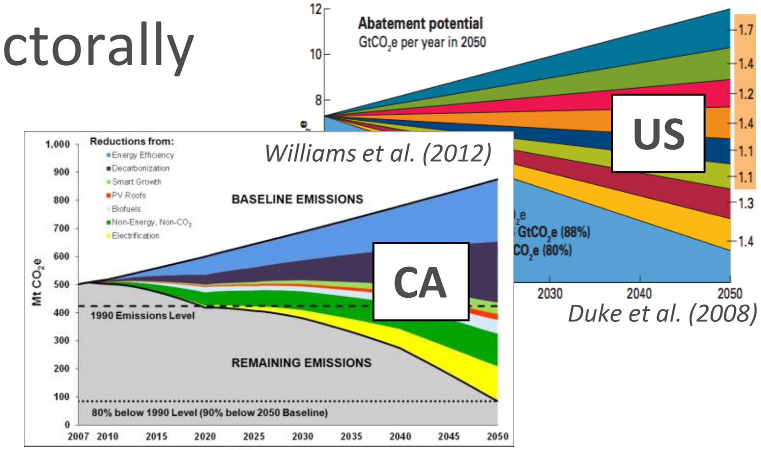


3.5 Wedge Analysis

- Conceived by Pacala and Socolow in 2004
- Useful way to compare disparate GHG mitigation options
- Emphasizes scale of impact (>1 GtC/yr or ~4 $GtCO_2$/yr), long time horizon (50 years) and need for steady ramp-up
- Can be applied globally, regionally, sectorally

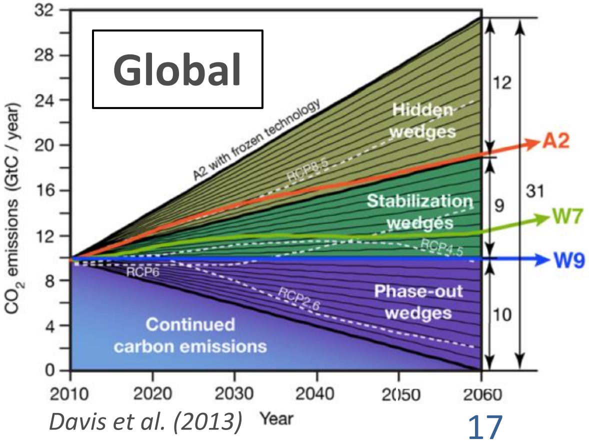


Avoids ~92 billion metric tons CO_2 over 50 years



Williams et al. (2012)

Duke et al. (2008)



Davis et al. (2013)

Pacala, S., R. Socolow, “Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies,” *Science*, 305 (5686) 968-972 (2004). DOI: 10.1126/science.1100103. Available via http://cmi.princeton.edu/wedges/articles.php.

Duke, R., D. Lashof, B. Dornbos, D. Bryk, N. Greene, R. Hwang, D. Lovaas, Y. Mugica, T. Spencer, J .Steelman, L. Tonachel, P. Lehner. The New Energy Economy: Putting America on the Path to Solving Global Warming, Natural Resources Defense Council Issue Paper (June 2008). http://www.nrdc.org/globalWarming/energy/eeconomy.pdf.

Williams, J. H., A. DeBenedictis, R. Ghanadan, A. Mahone, J. Moore, W. R. Morrow III, S. Price, M. S. Torn, 2012. “The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity,” Science, 335, 53-59. Doi: 10.1126/science.1208365.

Davis, S. J., L. Cao, K. Caldeira, M. I. Hoffert, “Rethinking wedges,” Environmental Research Letters, 8 (2013) 011001 (8pp). DOI:10.1088/1748-9326/8/1/011001. http://iopscience.iop.org/1748-9326/8/1/011001/pdf/1748-9326_8_1_011001.pdf.

3.6 Decision Science

- RD3 should address not only the technologies themselves, but also their design, adoption, and use?

  > "No matter how efficient the light bulb standard is, people still need to get to the hardware store, select the right bulb, take it home, install it, and use it properly before the benefits can be realized."—ACEEE (2013)

- Use evidence-based science to develop principles impacting design, selection, and use of energy technologies? Examples:
  1. Going beyond information
  2. Understanding context
  3. Leveraging technology
  4. Understanding human dynamics
  5. Using strategic rewards
  6. Raising the profile of energy
- Sectors affected: buildings, transport, power, manufacturing?

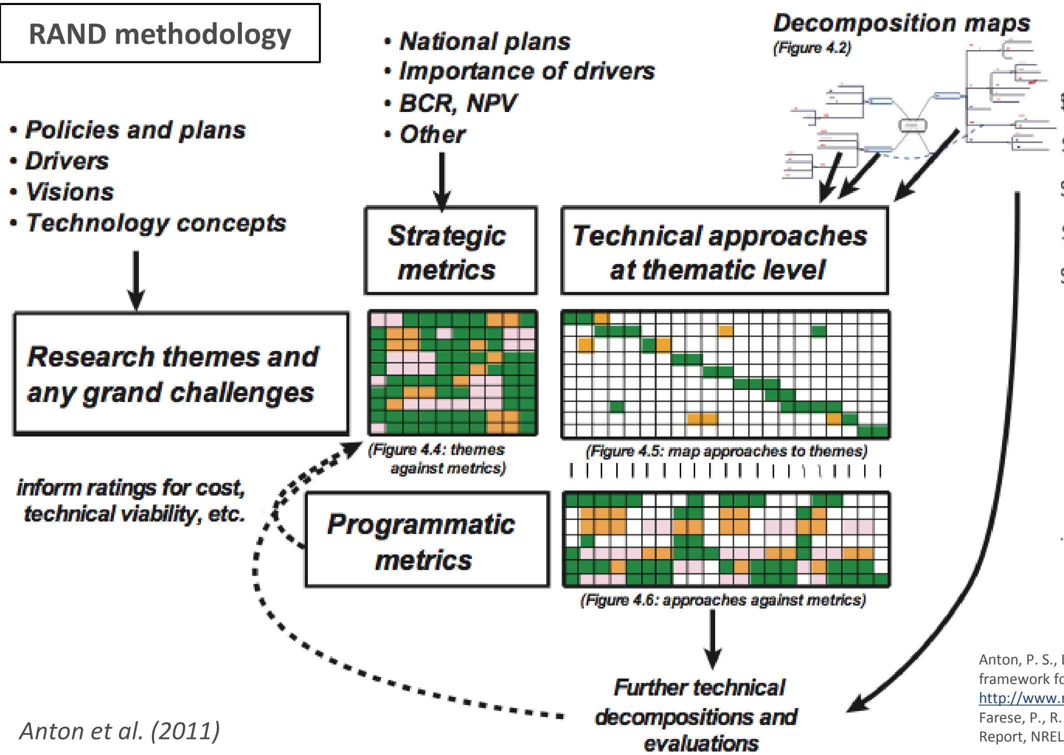
4.1 Conceptual Framework: Goals and Needs

- Provide key data and analysis for senior DOE leadership as they make decisions on the RD3 portfolio?
- Challenges include data/tool limitations, “unknown unknowns,” balancing incremental improvement against effort required?
- Ingredients of a strong portfolio?
  - Defining benefits
  - Balance and diversity
  - Strategic alignment
  - Resilience and flexibility

- Key steps in identifying the right portfolio?
  - Estimating technological improvements
  - Estimating the future system-based benefits
- All steps to incorporate uncertainty?

4.2 Examples of Methods in Use

- General Electric Research
- Electric Power Research Institute
- Massachusetts Institute of Technology Energy Initiative Seed Fund
- RAND report to the National Aeronautics and Space Administration
- DOE Building Technology prioritization tool



RAND methodology

- *Policies and plans*
- *Drivers*
- *Visions*
- *Technology concepts*

Research themes and any grand challenges

- *National plans*
- *Importance of drivers*
- *BCR, NPV*
- *Other*

Strategic metrics

(Figure 4.4: themes against metrics)

Decomposition maps *(Figure 4.2)*

Technical approaches at thematic level

(Figure 4.5: map approaches to themes)

Programmatic metrics

(Figure 4.6: approaches against metrics)

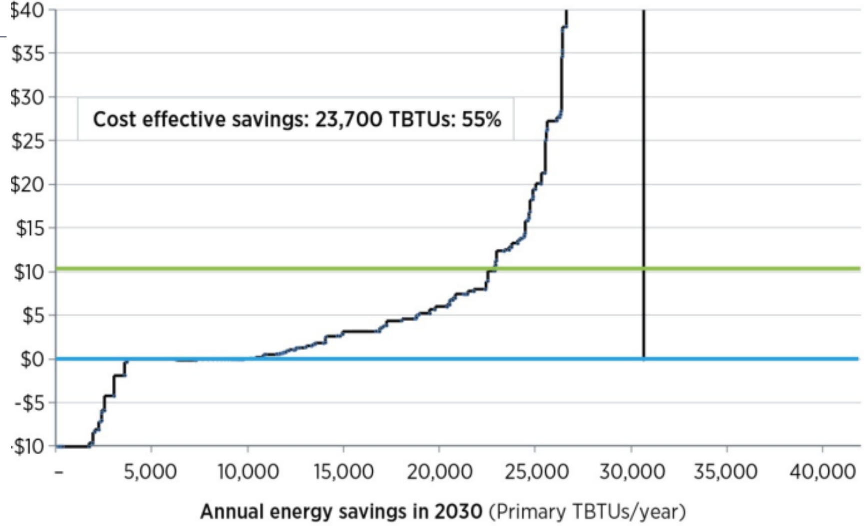
inform ratings for cost, technical viability, etc.

Further technical decompositions and evaluations

Anton et al. (2011)

DOE BT Prioritization Tool

Farese et al. (2012)

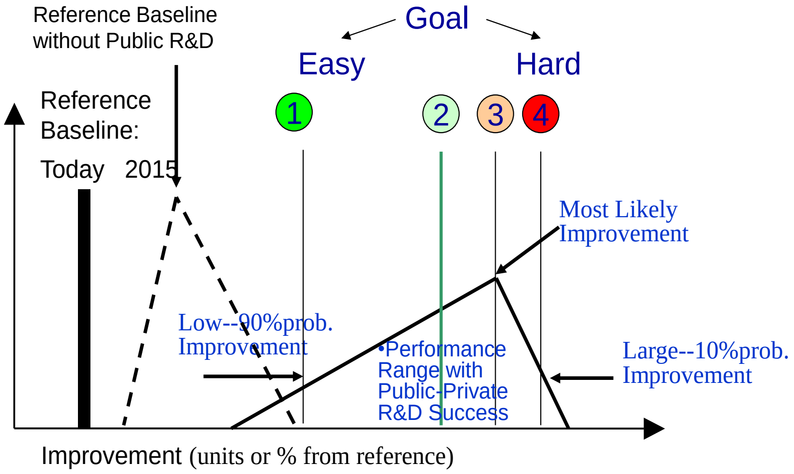


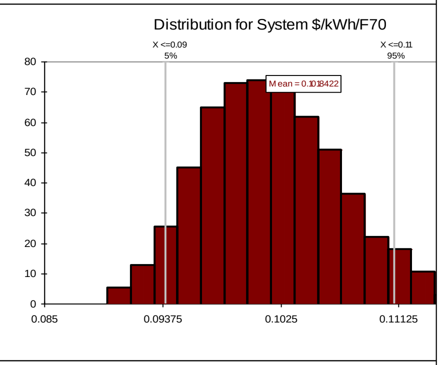
Anton, P. S., L. Ecola, J. G. Kallimani, T. Light, C. J. R. Ohlandt, J. Osburg, R. Raman, C. A. Grammich, 2011. Advancing aeronautics : a decision framework for selecting research agendas, RAND Corporation, ISBN 978-0-8330-5019-9. http://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG997.pdf.

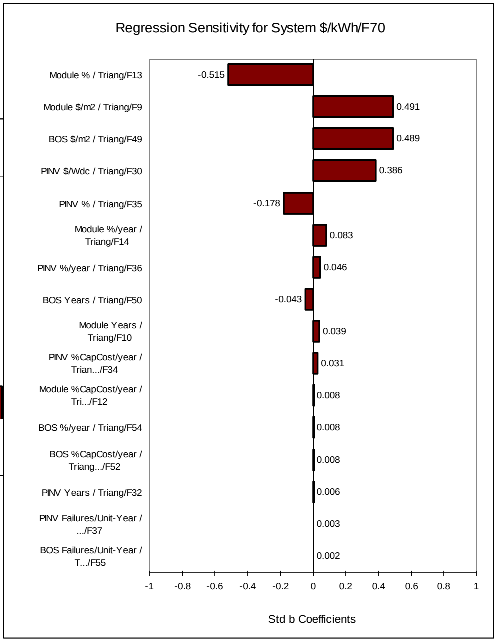
Farese, P., R. Gelman, R. Hendron, 2012. A Tool to Prioritize Energy Efficiency Investments, National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-54799, August. http://www.nrel.gov/docs/fy12osti/54799.pdf (accessed 4 February 2015).

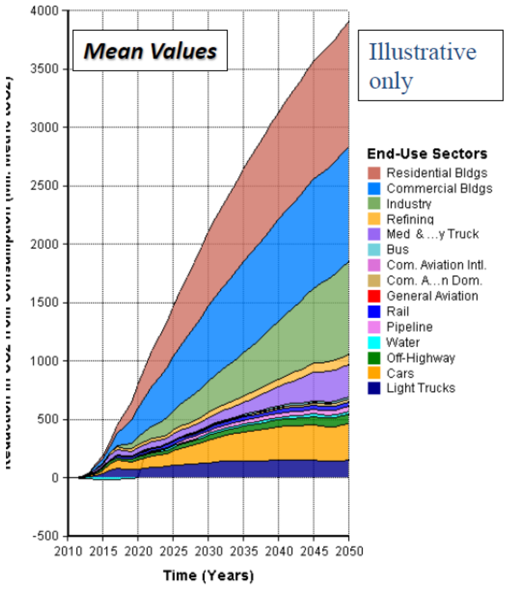
4.3 Toward Improved Methods of RD3 Prioritization

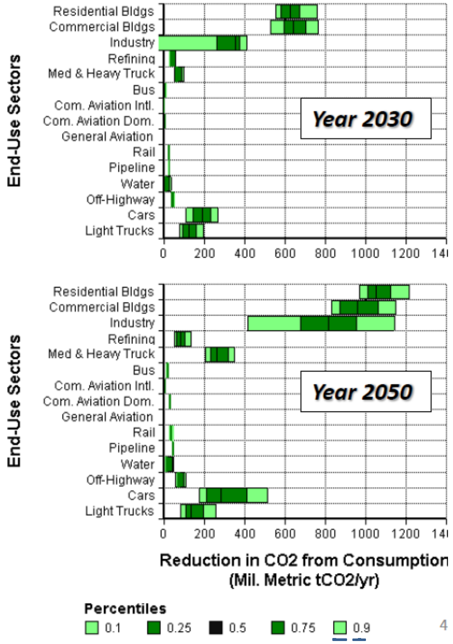
- Review of current approaches
- Goals for future DOE RD3 analysis?
  - Evaluate potential improvement under RD3 with full uncertainty
  - Rank-order investments by impact
  - Perform for multiple metrics
- Review of challenges











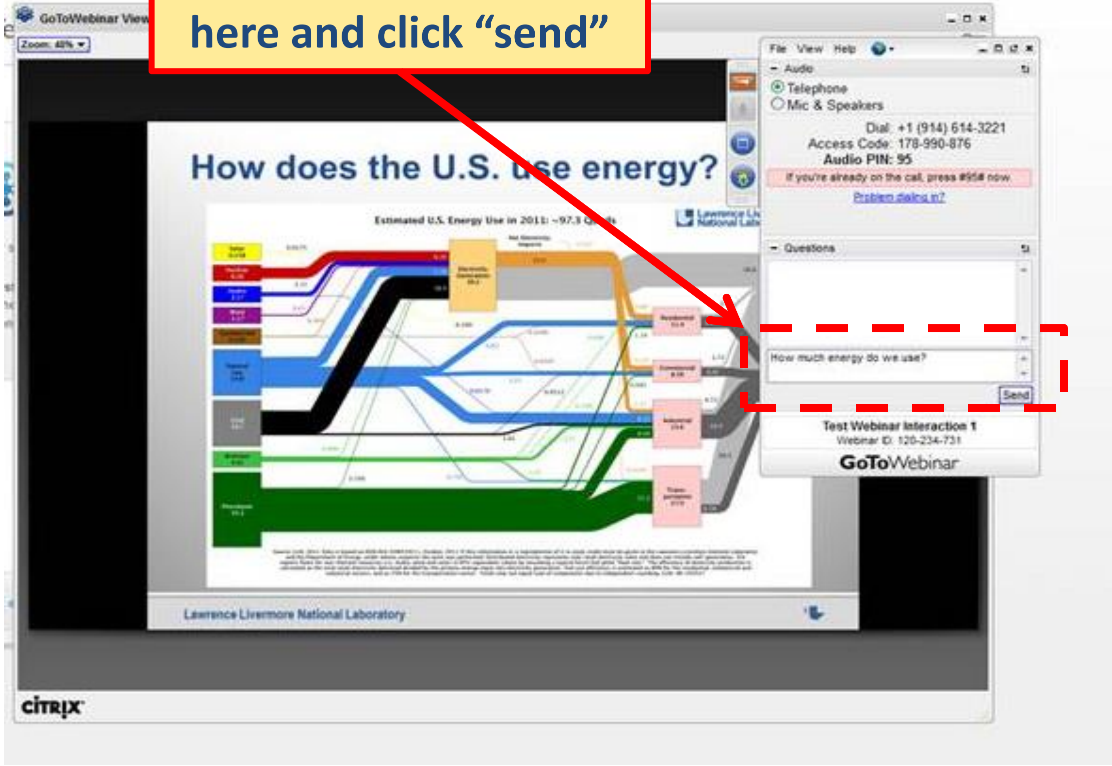
Summary – RD3 Needs

- Metrics
    - Better SCC estimates?
    - More work needed to address critical materials?
    - Other needs?
- IAMs
    - Develop databases for consistency across models?
    - Better characterize uncertainty and risk?
- Technological progress: Better understanding of drivers?
- Expert elicitation: More work needed to improve process?
- Decision science: More research needed to understand human impacts on technology implementation?
- Prioritization and decision making:
    - Refine, test and deploy methods outlined?
    - Iterate to find what works best for DOE?

Public Input

- You are encouraged to submit questions using GoToWebinar's "Questions" functionality. The moderators will respond, via audio broadcast, to as many appropriate questions as time allows.

Type your questions here and click "send"



How does the U.S. use energy?

Estimated U.S. Energy Use in 2011: ~97.3 Quads

Lawrence Livermore National Laboratory

● Telephone
○ Mic & Speakers

Dial: +1 (914) 614-3221
Access Code: 178-990-876
Audio PIN: 95
If you're already on the call, press #95# now.
Problem dialing in?

How much energy do we use?

Test Webinar Interaction 1
Webinar ID: 120-234-731

- If you have questions or comments that cannot be addressed during the webinar, email them to DOE-QTR2015@hq.doe.gov

DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

Quadrennial Technology Review-2015

Public Webinar